TeleLab for Decentralized Hybrid Power System with renewables

(An innovative TeleLab concept for future power systems with renewable)

DOCTOR OF PHILOSOPHY

The thesis is submitted in partial fulfillment of the requirements of University of Bolton, UK in collaboration with South Westphalia University of Applied Sciences, Soest, Germany.

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Abstract

Training, education and research on renewable based power systems and automation is the topic of discourse among scientific and academic community. Renewable energy generation technologies are viewed as one of the solution that could significantly contribute to solve the problems associated with global warming and environment destruction. They are clean, available in abundance and distributed in nature. This means, on one side, there are huge solar or wind parks generating energy for large number of households connected over grid and on the other side, there are stand-alone systems capable of satisfying energy requirements of a single household. For efficient operation and control of these systems, trained and educated power system engineers are required. In order to increase acceptability of these systems among common people, awareness regarding the system and its operation is significant. Theoretical and simulation based platforms are useful but not sufficient to deliver power systems education. There is requirement of a platform which would offer opportunity of learning through interaction with real system hardware. It should be affordable, easy to access and familiar to most of the users. The concept should extend further to include a defined learning methodology which could offer the best education value from the experiment.

In this thesis, methodology to use the idea of TeleLab (also known as remote lab or web lab) for Hybrid Power System (HPS) with renewables is proposed, implemented and evaluated on the basis of its purpose to offer high educational value to the users and its ability to promote knowledge and technology transfer between users and institutions all over the world. The purpose of this PhD work is to take advantage of remote communication technology like internet to access labs or research facilities/infrastructure to promote power systems education.

This work is aimed at developing a TeleLab with focus on renewable based HPS. The knowledge of information technology, automation technology and power systems engineering is used to describe best practice to perform renewable energy experiments from remote location. The remote experiment platform would be cost effective and could be used for technology and knowledge transfer among users located in remotely accessible areas, those with physical disabilities, those representing educational and research institutions and including those who represent professional firms. Resources could be shared between different institutions along with promoting collaborative learning and research activities focused on power engineering education. Development of this remote platform to perform real experiments offer several economic advantages to the users like saving in travel time and costs, saving in infrastructure investments, saving in lab personnel costs, possibility to use the experiment environment with greater flexibility and for longer time. Social advantages offered by this approach to the user are in terms of possibility to establish good work-life balance. Significant benefits are offered for users from developing or poor countries where possibilities of investments in costly lab infrastructure are rare.

The thesis discusses scientific contribution to knowledge like design, development and implementation of the hardware structure of HPS consisting of renewable energy technologies like solar and wind supported by battery system. Programmable Logic Controller (PLC) is used to automate the HPS which functions as a “smart system” contributing to the idea of smart grid. It performs operations like reading and recording system parameters, monitoring and control of system components, management of system load and management of battery
charging mechanism. This follows by design, development and implementation of TeleLab to monitor and control the system from remote location over internet. This involves the task of development and implementation of safety and security measures related to the proposed system. It was aimed to develop a remote lab which offers high educational value to the user. This was achieved by proposing innovative thinking in designing and development of learning activities on MOODLE learning management system. To facilitate efficient solving of issues related to the lab and to encourage participation of users in the experiment design and development process, a feedback mechanism was proposed. Methodology to analyze, evaluate and assess system as well as user performance assisted by possibility to provide suggestions or guidance for improvement was proposed. The thesis concludes by presenting results about the performance of the HPS using TeleLab platform and its impact over user performance with respect to knowledge and technology transfer. This analysis is performed by evaluating and assessing user performance in comparison to hands-on lab and TeleLab. Economic impact of remote experimentation for users and institutions is discussed in this thesis. At the end, possible future aspects of this concept are discussed.

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<tr>
<td>CD</td>
<td>Communication Processor</td>
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<tr>
<td>CS</td>
<td>Current Sensor</td>
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<tr>
<td>EJSApp</td>
<td>Easy Java Simulation App</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HOMER</td>
<td>Hybrid Optimization Model for Electric Renewables</td>
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<td>HPS</td>
<td>Hybrid Power System</td>
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<tr>
<td>HTML</td>
<td>Hypertext Markup Language</td>
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<td>I/O</td>
<td>Input/Output</td>
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<td>ILOs</td>
<td>Intended Learning Outcomes</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
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<td>MATLAB</td>
<td>Matrix Laboratory</td>
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<td>MOODLE</td>
<td>Modular Object Oriented Dynamic Learning Environment</td>
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<td>MSC</td>
<td>Main Switch Cabinet</td>
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<tr>
<td>OSSD</td>
<td>Output Signal Switching Device</td>
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<td>PC</td>
<td>Personal Computer</td>
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<tr>
<td>PID</td>
<td>Proportional Integral Derivative</td>
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<td>PLC</td>
<td>Programmable Logic Controller</td>
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<td>PROFIBUS</td>
<td>Process Field Bus</td>
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<td>RCL</td>
<td>Remote Control Laboratory</td>
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<td>RO</td>
<td>Reverse Osmosis</td>
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<tr>
<td>Rpm</td>
<td>Revolutions per minute</td>
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<td>SCC</td>
<td>Solar Charge Controller</td>
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<td>SET</td>
<td>System Engineering Test</td>
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<td>SOC</td>
<td>State of Charge</td>
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<td>TIA</td>
<td>Total Integrated Automation</td>
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<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
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<tr>
<td>UPS</td>
<td>Uninterrupted Power Supply</td>
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<td>UTS</td>
<td>University of Technology, Sydney</td>
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<td>VPN</td>
<td>Virtual Private Network</td>
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<td>VRML</td>
<td>Virtual Reality Modeling Language</td>
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<td>WDU</td>
<td>Water Desalination Unit</td>
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1. **Introduction**

1.1 **Motivation and problem statement**

In the field of engineering, practical training experience is very significant. Theoretical knowledge should be assisted with practical implementation skills. Engineering institutes or companies aim to provide hands-on experience to the participants which may be either students or company personnel. However it comes with a price. The investment in infrastructure depends upon the experiment or on the training requirements of the technical concept to be experimented. In the field of renewable energies, these infrastructure costs could be significantly high. Users from poor or developing countries with low investment possibilities on infrastructure development for labs/training institutes usually are devoid of much necessary practical experience of performing experiments. The other problem is inability of users to travel and visit the experiment sites due to different reasons like lack of accessibility of training facilities due to geographically remote locations or physical disability of user or unavailability of sufficient time/sufficient financial means to periodically travel and visit such institutes. Engineering companies have to think about loss of work of the employee if he has to spent large number of hours to travel for training purposes or for maintenance and diagnosis purposes. Traditional labs offer less flexibility as they have defined and fixed timings to perform the experiments. The users who have to work during lab hours to earn their living cannot attend such training institutes to gain practical experience.

Renewable energy experiments are many times organized based on weather conditions suitable for those technologies in particular areas. These locations could be remote or difficult to access. For example, setting up and analyzing a wind turbine performance located at the top of a remote hill. Companies suffer heavy losses in case of faults in production systems which might take hours to eliminate since the expert engineer has to travel long distance to visit the production site. All these issues have motivated engineers to use and develop internet medium so that it can be used for training and educational purpose. Virtual labs or simulation labs were developed so that users could remotely attend lectures, educational seminars and even perform simulation experiments. Simulation experiments provided better understanding as compared to textual or theoretical knowledge. User can perform the experiment without caring for the mistakes as no real hardware is involved during simulation. The cost involved in developing these experiments is reasonable. However, they fell short of providing a real lab experience. Users realized that they are not working with real experiments but a software version. There were restrictions regarding simulation of dynamic behavior of different systems. This further motivated engineers to use internet for remote monitoring and control of real physical devices. The lab which dealt with interaction of real hardware devices from remote location is termed as remote lab or TeleLab. It provides remote access to staff and students to laboratory equipment in cost effective manner using internet [17].

Figure 1.1 below shows the client server architecture of TeleLab or remote lab. Client or user at the right side of the figure shown as user 1, user 2 up to n users, make use of a computer with internet connection and web browser. A user can access web server over internet where authorization is verified by the user database or user identification system. Experiment PC can be accessed by the user when the authentication of login data is completed. This PC is connected to Programmable Logic Controller (PLC) over Ethernet connection. In other cases, in place of PLC a microcontroller could be preferred. Ethernet connections are preferred for the communication between PC and PLC. Through the analog/Digital inputs and outputs of
PLC, corresponding communication signals with the equipment could be established, data could be read and written and thus monitoring and control is possible. A real time view of the experiment is made available to the user through network camera. It could be zoomed, tilted or focused as per the requirement through remote camera control interface. The camera is visible on the local network (LAN) through its IP address. User can make observations and monitor developments occurring at the experiment site using the camera.

Fig. 1.1 Idea of TeleLab or remote lab

The concept of TeleLab was used to remotely control a particular device like a robot to better understand its functionality, to remotely monitor a production process, to monitor a device in hazardous environment or to remotely diagnose system fault and eliminate it. Application of this concept to provide practical experience on renewable technologies to users and further systematic development of a lab structure that could provide power engineering education was the motivation behind this work. The author of this work, got an opportunity to participate in a renewable research project entitled “Sunwater” primarily implemented in Egypt to produce fresh water from saline sea water using solar technology. Experience obtained by working on this project further motivated the author to think of TeleLab as a platform to offer power engineering education. The idea of infrastructure sharing between different institutes and between institutes and companies motivated the author to use TeleLab for educational and experimental purposes.

1.2 Research aims and objectives

The aim of this research is to develop and implement TeleLab for Hybrid Power System (HPS) based on mix of renewable to provide users across the globe opportunity to perform hands on experiments with no additional costs. Learning management system like MOODLE is used to provide power engineering education and research to users. The objectives can be listed as follows-

- To design, develop and implement a Hybrid Power System (HPS) lab based on renewable technologies with purpose to promote power engineering education
To offer real lab experience to the lab participants through the combination of real and virtual experimentation. Simulation activities are defined as part of user preparation for the lab. Audio/Video platforms and virtual or augmented reality ideas could be thought to promote real lab experience for remote users.

To develop and implement infrastructure of TeleLab/Remote lab for HPS so that user can access the experiment hardware (not simulation) to perform real experiments from remote location (remote mode). Internet is used for this purpose to communicate with the devices like PLC and Lab PC in a secure way. Security through login mechanism and secure firewall protection would be implemented. Internal security setting of lab devices would be effectively used. Safety devices like safety light curtain and internal PLC timer would be used to ensure safety of lab during experimentation. Access to network camera would be made available to the user for real time monitoring of the experiment. Basic knowledge would be provided to the user through design of preparation activities before performing the lab so that general experiment failures could be avoided. This would ensure that the user interacts with real experiment hardware in a secure way with minimum investment.

To promote technology and knowledge transfer through development of lab website and by effective use of features offered by LMS – MOODLE. To define methodology so that user performance could be analyzed, evaluated and assessed to deliver high value education experience.

1.3 Scientific and research contribution

This work is a unique effort to combine the features of information technology, automation technology and renewable power engineering to promote knowledge and technology transfer in the field of power systems engineering education.

What is the significance of this discourse?

The ever increasing demand of energy and the search for clean/green alternatives to produce energy without damaging the environment (global warming issues) is the debate followed by researchers across the globe. In Germany, the decision to close nuclear power generation plants and promote use of renewable power resources to satisfy energy requirements has motivated researchers to focus on this area. In comparison to carbon emissions in the year 1990, Germany aims to achieve 50% reduction till 2050. Hence, topic of research, education and training in the field of renewable power systems achieve significance. As per study discussed in [61], the number of research publications in the field of virtual and remote laboratories were more than 450 in the year 2012 -13, 400 in 2014 and 250 in 2015. These large number of publications indicates the interest of researchers to study the usefulness of remote lab concept as power engineering platform. Along with development of new technologies, it is equally important to train and educate power system engineers to work with these technologies efficiently. This work would contribute to the discourse of developing new methods or new approaches to solve the issues of renewable power systems training and education at affordable costs.
Contribution to action science for innovative power systems education

Best methodology or best practice is proposed to use innovative TeleLab concept as a platform for renewable power systems education. The proposed mechanism includes use of surveys, experimentation, discussion forums to share observations with a purpose to collect empirical data. This data which is based on observation, experimentation, testing and evaluation is used to demonstrate the feasibility and utility of the proposed concept. The proposed methodology supports the idea of user participation to develop and update the experiment and define learning strategies to achieve the learning targets efficiently. Successful implementation of this method is evaluated and tested with respect to parameters like educational value, real lab experience offered, safe and secure experimentation and ease of performing experiment.

Addition of value to education

In terms of addition of value to education, it can be understood that the idea of TeleLab provides an education platform with a possibility to interact and share knowledge with international users or it provides opportunity to share good pedagogical practices with researchers across the globe. The user along with education benefits by the process of exchange of ideas and thoughts with international community. TeleLab proves to be economical by facilitating the practice of experiment sharing and promotes reuse of experiment hardware and software. User benefits by saving time and costs which otherwise would be spent to travel to the lab. A comparative analysis of educational value offered and reduction in costs determines the addition of value to education through this concept.

Contribution to knowledge of smart grid operation

In this work, smart grid operations like load management or battery energy management based on the amount of energy generated and stored. Load management algorithm for the 4x24 V loads and energy management algorithm to facilitate efficient energy transfer between the 24 V and 12 V batteries are implemented. The demonstration experiment thus promotes the knowledge of smart grids and provides a platform to learn these activities through real experimentation. The work further contributes to the knowledge of managing safety and security of a real experiment lab and its personnel over internet from remote location.

Self-regulation to enhance the learning outcome of the experiment

Learning management system MOODLE is used to design and develop learning methodology with focus on developing cognitive skills of the users. Cognitive skills mainly refer to efficient learning techniques, problem solving skills and critical thinking skills of the user. Different teaching and learning strategies in the form of tutorials, presentations, graphs, video-demonstrations are implemented which offer great flexibility to the user to regulate the learning environment by himself (self-regulation). The user develops the knowledge and skills to apply learning strategies to derive best learning experience. He can plan, monitor and self-evaluate the learning process. Communication and transmission of information between the tutor and the user through features in MOODLE like emails, discussion or chat forums, reports, audio-video platforms or virtual notice boards are used to provide feedback to the user about his learning progress and also to motivate user to perform the tasks assigned.
Proposed methodology to analyze, evaluate and assess user performance

This work proposes innovative methodology which involves designing and implementation of learning activities on MOODLE. The user participation in completing these activities is used as part of evaluation of his performance. Real time monitoring of user activities while performing the experiment is another proposed method to evaluate the performance. A personal interaction between the lab tutor and the user through chat forums and through one-to-one meeting over internet is suggested as part of performance evaluation. A grading system is defined which assigns points to the user after evaluation at different stages. The outcome of this practice is evaluated on the basis of comparative analysis with outcome from hands-on only lab. The author believes that this discussion would contribute significantly to the discourse of developing best lab practice in the field of power systems engineering.

Compatibility of proposed experimentation framework with future mobile technologies

The work discussed here involves use of web based technology as a platform to promote power systems education. Though the work started with using desktop computer and internet platform as the resources to perform the experiment, it could be easily extended to be used with latest and future mobile technologies like IPhones, IPads and Tablets. Under the concept of “Appification”, apps could be used as user-interface between the mobile system and the experiment. These mobile systems which are usually used for the purpose of communication could now be extensively used for the purpose of engineering experimentation. This would further increase the participation of users to use this platform as they are already comfortable using the mobile systems as their day to day communication medium.

Laboratory experimentation contributes to engineering and scientific knowledge

The proposed framework can be used in collaboration with modeling and simulation platforms like Hybrid Optimization Model for Energy Resources (HOMER), MATLAB or LabVIEW to educate and train users. As part of preparation for TeleLab, user can use the same TeleLab framework to access the web server. MATLAB for example is installed on the web server which can be used to perform modelling of solar panel used in the experiment. Before performing the real physical experiment, the user prepares himself through virtual experimentation. This combination of virtual and real experiment methodology works efficiently as compared to virtual-only or real-only approach.

1.4 Structure of the Dissertation

Chapter 1: Introduction, motivation and problem statement

It presents the introduction of research area, problem statement and motivation, research aims and scientific contribution to knowledge by this work. The structure of dissertation is stated in this chapter.

Chapter 2: State of the art and literature review

This chapter presents the state of art of TeleLab. It covers the research and development occurred in the area of remote experimentation in the past years. It explains significant difference between virtual lab and TeleLab and provides architecture overview. It elaborates remote lab examples with focus on engineering education. Examples of remote experiments implemented in different application areas are stated.
Chapter 3: Development and implementation of HPS demonstration experiment

This chapter discusses overall structure and functionality of demonstration plant. It covers in detail all the hardware and software components required to implement the Hybrid Power System (HPS) in the lab. Hardware and software specifications, configurations and features are explained in detail. The last part of this chapter covers the implementation of demonstration plant. In this section, Hardware installation and wiring of the system is discussed. Use of Step 7 software for PLC programming and WinCC software for visualization purposes is discussed.

Chapter 4: Development and implementation of TeleLab

The chapter discusses the structure of the proposed TeleLab. Topics such as Client-Server architecture, use of MOODLE learning management system for booking an appointment with the HPS experiment, unique method of designing set of questions in the form of multiple option questions, quizzes or feedback questions to enhance user knowledge about the experiment, procedure to connect to the experiment computer through smart access software and development of user-friendly websites so that user can access the experiment with the use of internet browser are explained.

Chapter 5: Execution of HPS experiment with TeleLab

In this chapter, procedure to perform the HPS experiment is classified and described as preparation phase, planning phase and execution phase. An overall idea about different tasks to be performed during the experiment is explained. These tasks include reading and display of measurement parameters, control of hardware components like switches and motor, control logic for load management and control logic for battery management.

Chapter 6: Evaluation and analysis of TeleLab performance

This chapter starts with discussion of using MOODLE learning platform as part of preparation phase of the Lab. Different methods of evaluating and analyzing the performance of the user are discussed in this chapter. They include use of tests before and after the experiment in the form of questions to receive user feedback, design of a feedback mechanism to identify and eliminate system issues, allocation of grades to the users and use it as method for evaluation, evaluation is based on lab reports submitted by the user. The chapter discusses use of remote monitoring facility to monitor and to evaluate the performance of the user during the lab.

Chapter 7: Discussions and results

This chapter is focused on discussing the results of the overall work. The discussions are classified as results of technical performance of the system, results of the feedback mechanism and results based on contribution of this concept on economic area for the user. The technical part of results is aimed at discussing the performance with respect to measurements of experiment parameters, storing of values for analysis, control action of relays, safety and security parameters of the experiment. Discussion of results based on feedback mechanism is aimed at analyzing the results with respect to the reference parameters like educational value, real lab experience, clarity of experiment description, ease of performance and some other parameters. Economic results are aimed at discussing the advantages offered by the concept of TeleLab with respect to the overall costs saved in
infrastructure, costs saved in travelling, costs in terms of time saved due to travel and economic advantage due to flexibility in work management.

Chapter 8: Future prospects and summary

In this chapter, expected development of the concept of TeleLab in future is discussed. Applications and the factors which might affect the development of remote labs in future are presented. The chapter and the thesis work concludes by writing the summary of the work completed in the field of hybrid power systems and remote labs at the University of Soest in Germany.
2. State of the art and literature review

Remote access laboratories using internet communications are discussed since the mid 1990's from Goldberg 1999, Taylor and Trevelyan 1995, Henry 2003 [18]. The path of development of TeleLab over time is discussed in the following part of the work. Analysis of the trend of development of different remote laboratories, lab architectures, integration of educational and learning environments and lessons learnt from experiences would be significant to understand the amount of work completed in this area (research stand) and to define the course of work for this thesis.

2.1 Development of TeleLab: an overview

References to the development of remote control of an equipment could be traced back to a Tele-robot which was controlled over internet using a web browser along with the required protection mechanism from accidental damage around year 1994. The user was able to share the task of operating this robot with other users over internet. The users were able to collaborate with each other to perform monitoring and control of robot from remote location.

Table 2.1: Development of TeleLab over past years

<table>
<thead>
<tr>
<th>Period</th>
<th>Trend of developments and focus of research</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994-96</td>
<td>Web controlled tele-robots</td>
</tr>
<tr>
<td></td>
<td>Control engineering</td>
</tr>
<tr>
<td></td>
<td>Distance learning platforms</td>
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<tr>
<td></td>
<td>Internet communication technologies</td>
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<tr>
<td></td>
<td>Web based techniques</td>
</tr>
<tr>
<td>1997-00</td>
<td>Laboratory teaching</td>
</tr>
<tr>
<td></td>
<td>Physics labs, real-time control labs</td>
</tr>
<tr>
<td></td>
<td>Teacher education</td>
</tr>
<tr>
<td></td>
<td>Remote labs for dynamic systems</td>
</tr>
<tr>
<td></td>
<td>Information technology for remote labs</td>
</tr>
<tr>
<td>2001-04</td>
<td>Cost effectiveness of labs</td>
</tr>
<tr>
<td></td>
<td>Collaborative aspects</td>
</tr>
<tr>
<td></td>
<td>Engineering education; Learning management systems</td>
</tr>
<tr>
<td></td>
<td>Standard framework for remote labs</td>
</tr>
<tr>
<td></td>
<td>Use of virtual reality environment for remote labs</td>
</tr>
<tr>
<td>2005-10</td>
<td>Effective learning techniques over remote platforms</td>
</tr>
<tr>
<td></td>
<td>Comparative experimental evaluation – virtual and remote labs</td>
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<tr>
<td></td>
<td>Effects on learning outcomes</td>
</tr>
<tr>
<td></td>
<td>Framework for set of remote labs</td>
</tr>
<tr>
<td></td>
<td>Power electronics, PLC based labs, Electrical engineering, Electrical machines</td>
</tr>
<tr>
<td>2011-till date</td>
<td>Cloud computing platform and remote labs</td>
</tr>
<tr>
<td></td>
<td>Development of low cost solutions</td>
</tr>
<tr>
<td></td>
<td>Remote labs over cyber physical systems (IPhones, IPads, smart phones)</td>
</tr>
<tr>
<td></td>
<td>Industry 4.0</td>
</tr>
<tr>
<td></td>
<td>Renewable energy/hybrid energy labs (renewables) remote labs</td>
</tr>
</tbody>
</table>

The information collected by the author based on attendance of various international conferences and based on the literature review is displayed in Table 2.1 for quick review of the path/trend of developments in the area of TeleLab or remote lab. The table shows the areas which were focus of researchers across the globe during specific time period. For
instance, research publications during 1994-96 discussed about robots which could be remotely controlled over web or control engineering application based on web or internet communication technologies and so on.

A remote control platform to monitor and control a chemical process could be found in [19] during 1998. During 1998-2000, as could be found in [20] [21], remote labs over internet were developed with focus on areas like laboratory teaching, laboratories dedicated to physics courses and labs focused on teacher education and information technology. Dalton in 2001 made some useful observations about communication protocols like TCP/IP and UDP/IP. He found TCP/IP connections more reliable to be used by remote clients as compared to UDP/IP. Regarding use of server configuration, his work recommends to make use of Message Oriented Middleware (MOM) server configuration which displays better reliability. In case of complex remote clients, it was suggested not to use java applets running in web browsers since they failed to provide reliable platform and required specific browser versions to be downloaded. A laboratory with focus on control technology experiment was developed which could be accessed through internet with reference found in [44]. Mention of real time control engineering laboratory (internet based) or automatic control remote lab or TeleLab for control of dynamic systems focused on the control engineering field could be found in [16][45].

A distance learning application was developed in Java programming language at Oregon State University which allowed a remotely located user to perform control engineering experiments. Institutes like Swiss Federal Institute of Technology, Massachusetts Institute of Technology (MIT), British Open University and couple of German universities focused on developing remote laboratories framework during the period 2000-04. The purpose was to prepare a platform which would offer possibilities to develop distributed internet applications, support wide range of hardware interfaces and use of single software license for all the users rather than separate licenses for individual users. LabVIEW software was used by the researchers at Swiss Federal Institute of Technology to develop real time control application for distance learning. The software offered better internet connectivity features, wide range of industrial hardware support, multiplatform support and license cost independent of number of users. At MIT, applications for remote labs were developed based on software like Java and .Net. British Open University worked under the project called “PERL – Practical Experimentation for Accessible Remote Learning” to develop a generic remote lab architecture for live experiments around the year 2000-01. The focus was to develop a flexible system which would work over the internet and enable users to perform remote experiments. The purpose of “PERL” was also to research the pedagogical impact of this approach on higher education. The work in German universities was aimed at development of self-directed learning and tutorial assistance in a remote lab. The paper presented in [18] mentions the experience of development of remote lab framework with focus on development of server client technologies with features like monitoring of routine student actions, appropriate access control level for work in the University environment, facility of queueing for the users to access the experiment hardware, development of task dependent user interfaces, possibility to perform shared control of the experiment for group learning, built in archiving of experiment data, possibility to recover from lost connections and easy management of experiment schedules (time tables).

Engineering education using remote lab concept was focused as area of research during the year 2003. Development of effective learning techniques to promote engineering education by synchronizing lectures and tutorials with remote lab experiments was discussed. The aim was
to make the facility of remote labs available to users so that they could spend more time with the equipment which would result in contributing towards skill development. One of the suggestion which came out of research performed at University of Western Australia was to use remote labs as supplement to normal lab classes. This means observations could be made during local lab classes and detail dynamic behavior of the experiment could be analyzed over internet remotely. Other suggestion was to split the remote labs into several short exercises of about 15-30 min. which could be synchronized with tutorials on week basis. The complexity of these exercises would increase in step by step manner as they are performed every week. One of the research carried out by Lindsay [22] over impact on learning outcomes, found that there is no difference in the learning outcomes achieved by traditional or remote labs. In addition, it was concluded that remote labs offered longer practice time and better skill development for the users.

During the period 2005-2009, the author could find references to development of a web based remote power electronics lab, development of a photonics lab using remote control web technologies, development of platforms which can be remotely operated to perform multi robot experiments and development of platform to perform experiments in the field of electrical machines. Reference work with focus on education was found with a purpose to analyze the effects of laboratory access modes on learning outcomes. An educational platform to perform remote experiments for electrical engineering courses is mentioned in [38]. Remote Controlled Laboratories (RCL) with focus on development of Physics laboratory experiments was the project implemented by University of Munich in Germany along with other partners like Intel education, Gesamtmetal and Eberhard von Kuenheim Stiftung which would be discussed under the section “TeleLab experience in Germany” in later part of this thesis. A remote lab with focus on flexible manufacturing cell as part of PLC course was developed and is presented in [39]. Due to introduction of the concept of cloud computing an idea to use the concept of remote lab using cloud computing features was proposed in [43]. The paper proposes the concept of “Lab@Home” under which user can make use of the cloud computing feature “Software as service” to access software tools from the cloud to perform remote experiments as individual user or in collaboration with other users. This idea suggests that if the users have their own measurement or display devices which can be used for performing the lab then they can be shared with other users over internet. Equipment which is light weight, compact, portable and less expensive could be located at different user sites and can be shared with other users to perform tests and analyze results. For instance, five users are participating in a remote lab and every user has one device that can be used for the experiment. Then, users could make their devices visible by sharing their web cameras and the results obtained with other users. A software platform “BigBlueButton” developed by the researchers was introduced to the readers which enabled participants to share their own resources like applications, white board, chat rooms and audio-video platforms as part of the remote lab.
According to a remote lab survey \[61\] about number of publications in the field of virtual and remote labs from 1993-2015, it can be noticed that significant number of publications and citations were published in this field of technology. This indicates the acknowledgement about usefulness of TeleLab as education platform by the research community across the globe. The initial publications could be figured out in the year 1993-94 and subsequent increase in publications through time. The peak could be observed during years 2011, 2012 and 2013 during which around 400-450 papers were published every year. Latest, in year 2015, 250 papers and around 1200 citations could be noted.

After considering the revolutionary increase in use of internet and introduction of technologically advanced mobile communication systems (smart phones), it is expected that the trend of publications and the interest of researchers would continue to increase in future.

Overall analysis presented by the authors in \[48\] regarding technology and approaches used by researchers in implementing remote labs shows that HTML with Active X along with Java and Java applets finds wide use including this PhD work. Use of remote lab environments like LabVIEW and MATLAB/Simulink on equally large scale could be understood from the fact that these two software are widely used for modeling, simulation and analysis purposes in different educational institutions and universities across the globe. Virtual Reality Modeling Language (VRML) has found its use increasingly in remote labs especially to improve the concept of collaboration among remote users.
2.2 Traditional labs, virtual labs and TeleLabs

The method of performing experiments by physically being present in the lab is known to everyone. This is the traditional way to perform experiments and hence such labs where physical presence of user is important are called as traditional labs. Advent of internet technology and its wide spread use among common people, provided a platform to perform experiments from remote location without physically being present at the experiment site. These remote experiments could be classified based on their environment as virtual remote experiments or real remote experiments. Different simulation and visualization software like MATLAB, WinCC and LabVIEW to mention a few are used to simulate an experiment. This simulated experiment can be performed by the user from remote location. The user gets access to the experiment PC where such experiments are developed. The advantage of these experiments is that the cost involved is low as no real hardware or physical devices are involved in the experiment. Possibility of accidents due to loss of control over remote devices is almost zero and the most important thing is that the user can learn by doing mistakes. Even if mistakes are done while doing an experiment, it will not damage or harm anyone in the surrounding. Learning by doing without worrying about safety and security of the experiments can be effectively achieved by virtual experiments. This method of performing experiments is better than theoretical study as the user gets better understanding of the concept. The user can change different experiment parameters or he can implement programs to analyze the behavior of different systems. Simple introductory experiments can be easily simulated and preferred for better understanding.

![Fig. 2.3 Overview of traditional, virtual and remote labs](image)

However, the experiment is not real. Certain complicated dynamics or behavior cannot be effectively simulated and hence the experience of user is restricted to simulated version of the experiment. For higher level of experiment analysis and understanding, it is crucial that the user gets access to real experiment set up. This task though involves implementation of safety and security measures to ensure that no accidents or mishaps occur, is worth doing. This idea of monitoring and controlling real hardware devices from remote location developed the concept of TeleLab. Strict authorization and authentication methods, safety and security measures make it possible to implement TeleLab so that users all over the world can access the experiment and perform it to get a real time experience. The point of arguments for some
users in favor of traditional labs is that the physical presence for performing the experiments is the best and it cannot be replaced by virtual presence. Interaction with lab colleagues and lab engineer is direct and not over chat forums, social forums or audio-video software as in case of remote labs. On the other side, users in favor of remote labs, argue that because of wide spread use of chat platforms and remote communication devices like mobile phones or Skype, direct communication with lab colleagues or lab engineer can be effectively carried remotely. They further argue that the advantages offered by remote labs are so practical that even though physical presence is the best it can be compromised by remote presence and some shortcomings can be ignored.

It is mentioned in [18] that a comparative study between traditional and remote labs showed that for an experiment of three hours, traditional labs offered around 20 min. for every student to control the experiment and the overall user participation was observed to be 50%. The statistics changed for same group when they performed the experiment over internet under remote lab concept. Every student could spend around four hours with the experiment with overall participation of the users noticed to be 96% in favor of remote labs. During one of the remote control experiment on tuning of PID controller, it was found that efficient combination of simulation lab and TeleLab enables faster design of a PID controller. The controller which was designed with simulation could be used for real experiment with minor tuning changes.

2.3 TeleLab experience in Germany

TeleLab save large infrastructure investments as the lab equipment could be shared with different institutions or companies, it reduces travel time and travel costs and is seemed as the technology of future. In Germany, different institutions are working on developing remote labs and the infrastructure associated with it. Some of the examples are illustrated below. TeleLab developed by different institutions can be analyzed for various characteristics like performance, educational value, simplicity of use, clarity in description, security features to prevent unauthorized users and several other to understand the exact development phase of these labs.

2.3.1 Collaborative remote experimentation – University of Hagen, Germany

This research paper presents the work carried out at University of Hagen in Germany to perform remote experiments in collaboration with multiple users who are geographically separated but connected together over network [46]. The purpose of this work is to provide a platform for remote user to perform experiments collaborating with each other similar to the one that is observed in traditional labs. Internet is used as communication platform and web browser with no additional software is used as user interface. The communication structure that enables transfer of information between the user and the experiment is discussed. It is based on client server architecture developed in Java language. Virtual reality 3D chat environment and avatars (graphical representation) are used to represent movement of users which could be shared with other users on the network.
The communication of remote user with the experiment control server and the real experiment takes place through web browser. Three Java applets are included in the webpage as visible in figure 2.4. One applet is used to receive the audio-video information from the lab, second applet is used to control the experiment while the third one is used to implement the virtual reality 3D chat. “User 1” is able to exchange information with the experiment control server, media server and the 3D chat server. All the required Java applets are loaded on the client side by the web server. A separate PC hardware with real time operating system is used for real time control of the experiment. Access management mechanism takes care of the tasks like creating and deleting user accounts, set up of time-quotas, defining time slots and analysis of logging messages. Remote users are able to modify the gestures of their avatars like “raising the hand” or “point to” gestures. The information for collaboration between the remote users is managed by Media server and 3D chat server. The remote users can collaborate with each other in the same way like in traditional lab, take decision after discussing issues and then the user 1 who is connected to the experiment control server would take the required control action or implement changes which could be observed and followed by all other remote users.

2.3.2 Remote control physics laboratories – University of Munich, Germany

This is another project based on the concept of remote laboratories that was implemented by University of Munich along with other partners like Eberhard von Kuenheim Stiftung, GESAMTMETALL, Think Ino, and Intel Education. The information could be found at http://rcl-munich.informatik.unibw-muenchen.de. The purpose behind this project was to build a network of RCLs with schools, universities all over the world to have variety of experiments to support teaching in the field of physics. The first RCL project was developed in year 2001 by Dr. Daniel Roth. Projects focused on the field of Physics like deflection of electrons, optical computer tomography, experiment for speed of light, world pendulum,
oscilloscope, photo effect, wind channel, optical Fourier transform, deflection and interference and some other experiments were developed.

Fig. 2.5 RCL project focused on physics experiments

Teaching courses were developed as part of this remote control lab project. The RCL Portal provides information about the project like the idea of TeleLab/remote control lab and explains that the focus of the project is to develop experiments and make them available to users. These users might be interested to realize their own remote control project in the school. The experiments should be designed so that they are directly applicable for teaching purposes. Activities like tutorial to understand the RCL technique, Teaching course activities, references and websites associated with this project are mentioned on the webpage under the tab “RCL-Projekt”. The image shown in figure 2.5 shows the RCL server, interface device and the experiment. Programming languages like C++, Visual basic and graphic oriented programming language LLWin was used. As per the technical specifications of the system valid in year 2011 following information could be noted:

- Operating System: Microsoft XP Professional with Service Pack 3, Microsoft Hyperterminal
- Webserver and PHP: Apache Friends (XAMPP 1.7.4 for Windows), PHP 5.3.1
- Videoserver: Moonware Studios (WebcamXP 5 Free/Private)
- RCL Software: Technical University of Kaiserslautern, RCL-folder htdocs
- Remote Maintenance and Desktop sharing: TeamViewer 6 (full version)
- Virus scanner: Avira
- Web editor: Notepad++ 5.9; Adobe, Dreamweaver CS5.5
- Microcontroller: AT mega 16: ATMEL, AVRstudio 4.18; WinAVR, BASCOM-AVR
  Full version, Demo version, Micro pascal Pro for AVR

The project offered possibility to control the experiment from local and remote environments.

2.3.3 MARVEL project

Marvel (Mechatronics Training in Real and Virtual Environments) – A Leonardo da Vinci pilot project was implemented by University of Bremen with other partners like Higher Technical Institute (HTI), Nicosia, Cyprus, FESTO Didactic GmbH &co. KG, Germany, University of Porto, Portugal, other vocational colleges and training enterprises. According to the report published in 2005 [47], concepts practices and recommendations were discussed under the MARVEL project. This project involved vocational colleges, training enterprises and universities which worked together to develop novel concepts to use internet for
accessing costly lab equipment from remote location. The project was focused on using remote lab technology to access mechatronics equipment and machinery in virtual learning environments. During the course of this project, various assigned tasks like implementation of solar heating plant, solar energy lab, robot training lab and an electro pneumatic workshop and electronics workbench were completed. Real and Virtual environments like laboratories, simulators, remote laboratories and workshops are analyzed as part of this project to evaluate their usefulness for mechatronics training.

The tasks assigned to different project partners were:

- Mixed reality web service for Mechatronics – artecLab, University of Bremen, Germany
- Robot training workshop for remote tutoring, Zenon SA Athens, Greece
- Remote accessible pilot solar Lab, Higher technical institute, Nicosia, Cyprus
- Remote Mechatronics, Haute Ecole Valaisanne, Sion Switzerland
- Remote workbench for Electronics, University of Porto, Portugal
- Remote accessible full scale solar plant, Delmenhorst, Germany
- Remote workshop for Robotics and Automation, West Lothian College, Scotland

Fig. 2.6 Distributed real and virtual learning environment [47]

The tasks completed by project partners were worth understanding in order to improve the knowledge of design, implementation and evaluation of remote labs. The real and virtual learning environment could be understood from figure 2.6. It shows example of a full scale solar plant task where PLC was used for monitoring and control purposes. The lab facility of Full scale solar plant at Delmenhorst, Germany could be analyzed as an example where Programmable Logic Controller (PLC) was used to continuously control the solar plant consisting of solar heating system. Almost 40 sensors were used to monitor different process parameters like temperature, volume flow etc. The PLC was connected to these sensors and also to actuators like valves, pumps and servomotors via a Field bus. It was possible to remotely access the solar heating process over internet using the Ethernet I/O module of the PLC. A server was used to store the process data to be analyzed at later stage. Web based learning material like virtual books were stored in the server and made available for remote
user for access and study. WinCC visualization software was used to build the process interface so that the process parameters could be accessed, read or modified.

2.3.4 Remote control automation lab – University of Dusseldorf, Germany

TeleLab developed by University of Applied Sciences (FH) Dusseldorf is studied as an example with respect to above mentioned characteristics with a purpose to give an overall perspective of general features of lab.

It was observed that the website verifies authorized users by asking for valid username and password. A new user can obtain valid log in parameters by writing a mail to the lab coordinator. In case if someone is only interested to have a look at the experiment rather than live interaction with it then it is also possible to have access to the set up as observer.

The site also offers the option of selecting the instructions of operation in German or in English. Thus, both the type of users can access the experiment and thus it reaches to large number of students. The requirements of PC configuration and software essential to perform the experiment are also specified. Thus, user can verify whether his computer set up is capable enough to perform the experiment. The software required to perform the experiment is freely available and therefore user does not have to invest in additional software. The experiment is described properly and all the instructions for registration are clearly explained.

The striking feature of this website is the live experiment image. The camera shows a live image of the experiment set up. Visitor can identify whether the experiment set up is available for use or not. Due to any reason if the experiment set up is not reachable then it displays a message specifying that the experiment is unavailable. Camera provides interactive feedback. All the changes made by the user can be viewed by the camera. Manual and automatic cameras make live access to the experiment easy. Thus, overall equipment control is effective.

The site however suffers certain disadvantages like poor image quality. Transfer rates are poor and can extend up to 10 sec. Due to low camera resolution, image enlargement is not possible. Changes in process can be observed only using camera or certain on/off bits. No visualization software or method is used to give an overall view of the experiment.
Educational value of the experiment is relatively low because the user is asked to follow the instructions, press certain defined buttons and observe changes using camera and certain bits. This means that the user cannot program or make any major experiment modifications. Moreover, the experiment is same every time and resets to its original state once the user logs out.

Overall analysis suggests that the website is nicely developed as it provides secure user log in features, well defined instructions which make use of the site easier, time slots for using the experiment set up for users are managed effectively, system and software requirements are freely available and the site information clarity is good. With regard to experiment, instructions and assistance is good. However, the educational value of the experiment can be further improved. Introduction of visualization of process can improve the interaction between the experiment and the user. Camera resolution and image quality can be improved. Significant changes were undertaken to improve the value of the lab in last few years under the guidance of Prof. Dr. Langmann. A web platform is developed and the operation of this lab is monitored by the Competence Center Automation Düsseldorf (CCAD). Several PLC exercises based on Industry 4.0 platform like Cloud based industrial control system or web oriented automation system are developed for the department of automation at the University.

2.3.5 Remote control lab – University of Potsdam, Germany

Second example of TeleLab developed in Germany is the distributed control lab from University of Potsdam. This lab is developed to manage different remote experiments and also to protect them from unauthorized user access. The name of this lab is DISCOURSE.

Fig. 2.8 Distributed Control Lab [5]

Four different universities such as Freie Universität, Technische Universität, Humboldt Universität and Hasso-Plattner-Institut are involved in this project. The purpose is to use Microsoft .Net technology to prepare a test bed for research. The figure above shows the central elements of DCL architecture. It is based on SOAP communication protocol which stands for Simple Object Access Protocol. It is platform independent and is used as a format for sending and receiving messages based on XML. The user can test his code and analyze the
results. However, before sending the code to the experiment, user data and availability of experiment is verified in the beginning. When user login data is correct and the corresponding experiment is available then the code can be sent to the Experiment management to ensure that it is safe and will not damage the experiment set up. When the code is verified for safety of the equipment then it is compiled and installed on the real experiment. After the experiment is completed, the results are sent to the result manager and back to the user. The figure 2.8 shows different experiments like Foucault’s pendulum, Lego robots and High striker real-time and Windows CE are managed by the experiment manager.

Lab safety and safety from malicious code is ensured by safety controller using dynamic reconfiguration. Whenever malicious code is detected, it is replaced by the code from safety controller avoiding damage to the equipment. “.Net code access security” is used to implement secure run time environment. Source code analysis techniques or experiment specific programming languages to forbid use of pointers and recursions are used to ensure safety [5].

2.4 TeleLab applications in various engineering disciplines

There are several other application areas like remote lab for control of robots. Costly but interesting robots can be controlled by school going students using TeleLab. This is bound to increase their interest in the field of engineering and research. Remote labs offer employees a chance to learn throughout their life. A technician for example can keep himself updated about the latest technological developments in his field and receive the much required training [6]. The application of remote lab for international companies with offices across the globe is significant. There can be difference found between training received by employees of the same company since they are trained at different locations. TeleLab offers the opportunity for such companies to train their employees on similar training platform following uniform training structure so that the difference between the training standards could be reduced. In addition, the company does not have to develop and maintain training infrastructure at different office locations. A single training system can be accessed by the company’s employees from different offices. In the area of fault diagnosis and maintenance in production plants, TeleLab offers the possibility to identify faults from remote locations by accessing the plant and eliminate the fault. This saves traveling time and money for the employee and the non-productive time of the plant is reduced too. Another application area where TeleLab can be effectively used is the applications in hazardous environments which are either dangerous to human beings or not easily accessible [7].

Renewable energy education is the focus area of this thesis work. One example to be discussed here is the Energy cube from FESTO. This example is shown in figure 2.9 (a). It contains a solar panel, wind turbine, battery storage, an inverter and settings for control and safety. In addition, there are sensors which can obtain data like wind speed or solar irradiance. This systems is easy to transport and can be implemented without much efforts. Wind speed and solar irradiance at different places can be analyzed and compared. From the point of education, the availability of sensors makes it realizable to implement remote monitoring and control with configured computer and operating system. Students or users can study different operating conditions and control methodologies of this energy supply and storage system. The energy produced with this system can be used to integrate it in a system. This can satisfy load requirements of an experiment. Current topics of research for electrical engineers like
decentralized energy system, intelligent load consumption or integration of electric mobility could be researched with the help of such a system.

Industry 4.0 refers to the technological evolution from embedded systems to cyber-physical systems. It represents the coming fourth industrial revolution on the way to an internet of Things, Data and Services. This concept aims to connect different working stations located at different places and make them work in coordination with each other to achieve better efficiency. Users can experiment to understand such complex system with the help of MPS 500-FMSb system from FESTO didactic as visible in figure 2.9 (b). A manufacturing model with six stations is defined. These stations are connected with each other with a transport system. When the work piece enters in to the system through the entry station then it is operated and automatically drilled. At the end, a camera system checks the quality of the work piece. After that an industry robot assembles the work piece and arranges it in a store. At the outlet, the products will be sorted for delivery. For the field of automation, it is interesting to control the transport system or the store with Programmable Logic Controller (PLC). The camera system can be used to obtain measurements and implement structure/shape identification strategy. Fieldbus communication, Frequency converter or AC motors used for the transport system are interesting in the field of industrial communication. It is possible to get a software packet which will enable the visualization and presentation of system data on internet. The Ethernet interface and the possibility of representing sensor data on web makes it possible to use this example for TeleLab application.

Hazardous environment application is significant to demonstrate the use of TeleLab. One such application example is robot “Octopus” which will help the Fukushima Atomic area cleanup process. In such areas of nuclear disaster, it is difficult for human beings to work. Only a remotely monitored and controlled robot can work and cleanup the area where hazardous atomic radiations exist. The robot is designed so that it can work with the radioactive material and with the help of a remote control station shown in figure below, can be efficiently used. An application area could be the situation where people have to be saved in the event of fire [8].

Fig. 2.9 Energy Cube (a) and MPS 500-FMS system (b) from FESTO [6]
2.5 Security issues related to TeleLab

TeleLab operates with real physical system hardware. When a system is monitored and controlled from remote location by a remote user in the absence of lab engineer at the experiment site then the safety and security aspects become significant. Lapses in implementation of safety and security of the equipment can result in damage to lab personnel and lab infrastructure. Figure 2.11 presents a view of safety and security concept of TeleLab.

Fig. 2.11 Security of TeleLab
Safety refers to safe operation of the experiment and safety of life of lab personnel. Security refers to protection from malicious attacks from hackers and security issues caused due to user faults or infrastructure faults. User faults could be in terms of wrong commands or wrong programming logic. Infrastructure faults could be faults due to internet delays or faults due to faulty sensor readings and actuator signals [49].

2.5.1 Information security

As discussed in [49], security could be classified as information security and operational security. Information security is caused by hackers by introducing malicious contents and the
probable targets in a TeleLab system could be the experiment server and the booking system. Operational security would be discussed in the consequent section. Information security can be implemented by controlling the login information of the user and by controlling the experiment booking system. The user authorization is important to ensure that user’s accountability is verified before he gets access to the experiment. The user is able to access documents related to the experiment, software and hardware and also has rights to implement his own program for testing and analysis purposes. Before giving all these rights to the user, it is important to assign the user with authorized login data. This login data consisting of username and password is generated by the administrator of the lab. The user has to send an email to request for authorized login information to the administrator. In his email, he has to provide information about his background like whether he is a student or an employee and the purpose of doing the experiment. If necessary, the administrator can also make some quick internet search about the user or his institution to which he is attached.

- Time limited use of login data
  The password generated by the administrator will be of use only for one time. After using it once, it will be automatically deactivated and the user cannot login with same password again. This step ensures that the same password cannot be used by unauthorized user to access the experiment. Once the user is able to login, he is asked to reserve date and time for his experiment. During this time and date is the user allowed to perform the experiment.

Fig. 2.12 Safety and security of TeleLab

- Use of VMs, VPN and VNC
  Virtual Machine (VM), Virtual Private Network (VPN) and Virtual Network Computing (VNC) protocol of a VNC-server could be used to ensure effective safety and avoid damage to the equipment. Virtual Machines reset the PC configurations to the original after the experiment is completed by the user. Thus, any errors from the user will not be transmitted to the experiment server. Additional access rights if required by the user could be assigned to the VM. VNC enables encoded data transfer between the client and the server [9][10].

- Remote monitoring of the user during experimentation
  If required the administrator can monitor the user remotely while he is doing the experiment. If it is found that the user is involved in bad practices that may cause damage to the experiment then the administrator with higher priority can get control of the experiment and deactivate the user’s access in real time. This is usually done for those users who are performing the experiment for first time or who are representing certain institutions unknown
to the administrator. Passwords could be defined for devices separately. For example, network camera used for live images can be password protected. The user should know the password to use this camera after login. The experiment PC with all the required software installed can be secured with separate password.

- Regulation of user priority access
  Priority access of the user could be defined to ensure secure operation. The user could be given guest access which allows the user to view and monitor the experiment but he cannot make any changes or cannot implement a new program into the system. A user can be given higher access rights where he can change certain experiment parameters to learn the experiment behavior but cannot make programming changes.

- Limited access to the experiment equipment
  It is possible to secure the experiment from simultaneous access from other users. It is also possible to provide user access to limited programs installed in the PC. It is possible to design a questionnaire or a test which the user should attend before performing the experiment. This test will ensure that the user receives all the required basic knowledge like “dos and don’ts” during the experiment, parameter settings, parameter limits or technical specifications to perform the experiment securely.

- Periodic software maintenance
  Safety of the equipment could be ensured by maintaining the software periodically. The lab administration ensures that the software versions are periodically updated and the antivirus software has the latest version to protect the experiment PC from virus attacks.

2.5.2 Operational security

Operational security refers to protecting the equipment from faults caused by user due to wrong commands or wrong programming. Since the user can prepare his own program and implement it in the PLC, care should be taken to ensure that the wrong commands could be filtered out automatically or wrong programming could be verified by defining internal program checks. For example, when the infrared light protection system from company “Pilz” gives an output signal due to interception of the beams, the signal sent to the motor should be off. If the user program sends signal “on” despite the active signal from protection system then it should be avoided by program checks. Operational security also refers to faults or insecurity introduced due to faulty infrastructure. This might be due to internet delay or internet disconnection. A local mechanism to monitor the inactive state of screen of experiment PC should be implemented to bring the experiment in safe mode in the event there is loss of internet connection. Faulty sensors or actuators could be another reason to introduce operational insecurity into the system. In this case, a sensor actuator diagnosis information could be used to ensure that there are no logical conflicts with the sensor-actuator signals and the functionality of the system. Maximum and minimum limits on the system parameters which the user can enter should be implemented. Fire alarms and emergency switches should be implemented to ensure immediate handling of insecure environment.

2.6 Experience of TeleLab projects at Soest University

2.6.1 “Sunwater”: An innovative water desalination project

The author got an opportunity to work on an innovative project entitled “Sunwater” in collaboration with other partners such as Helwan University of Egypt, a German company
known as Terra Water and some other partners. It is worth to mention some details about this project and the kind of experience it gave to the author. Under this project, the author was part of the SWU research team which was responsible for designing a solar water heating system which would supply hot water to the water desalination unit to produce fresh water from saline sea water. It can be observed from Fig. 2.13 cold water is pumped into the solar thermal roof with the help of a solar pump. Hot water as output from solar thermal roof is stored in the two cylinders and later with a heat transfer pump is pumped towards WDU. Based on the concept of evaporation, WDU operated and fresh water was produced. Hotel “Sunrise” in Hurghada was another partner in this project which offered a building site close to red sea to implement the demonstration plant.

A Reverse Osmosis (RO) system was located at this site. Sea water from reverse osmosis system could be used to generate freshwater with the WDU. The remaining brine water with higher salinity can be depolluted with the existing system. This reduced the costs effectively since neither salt water supply system nor brine disposal system had to be installed [2]. High solar radiation at this site was another reason to select it for implementation of the project. The existing piping system which supplied water to the hotel guests was used to supply fresh water produced by the demonstration plant. The demonstration plant was planned as a backup supply of fresh water in case the existing RO system faulted or for some reason failed to produce the required amount of water required for the hotel premises. This project was used as a feasibility study to show that fresh water could be produced using renewable energy. More than 90% of the design of this project was done by the SWU team in Soest, Germany.

The author was responsible for developing a monitoring and control system for the demonstration plant. To control the solar thermal part of the demonstration plant a controller from Trend (IQ3XCITE/96/100-240) with three add-on modules was installed at the building site in Egypt. For the purpose of programming software from Trend called as System Engineering Tool (SET) was used. System visualization was implemented with software

![Diagram](image-url)
known as “963 supervisor v3.2”. For the purpose of this project, three day training was attended by the author in Offenbach, Germany. During this training, the author learnt different tasks like setting the input/output parameter configurations of the controller, working with individual configuration module, parameterization and testing different control strategies, application specific control strategies, use of SET software, implementation and testing of strategies together with SET and set up of communication between hardware, SET and 963 visualization software. The author got opportunity to travel from Germany to the building site in Egypt, as shown in Fig. 2.14 to perform tasks which can be classified as – hardware installation, controller configuration, set up of connection between Trend controller and Beckhoff controller, set up of 963 software along with visualization and data recording system, functionality test for remote monitoring and control and analysis of errors, interlocks and system operation.

![Main Switch Panel Diagram]

**Fig. 2.14 Project site connections [7]**

The author developed programming and control strategies for solar pump, desalination pump, solar radiation driver, three way valves and logic for communication between the two controllers. The building site in Hurghada includes the desalination unit, solar collectors and other devices as shown in Figure 2.14. Sunwater project is integrated inside conventional RO plant where the raw water and brine water are the same for both plants. The building site consists of four locations. The Main Switch Cabinet (MSC) is located inside the building. It includes the Trend controller and its analog & digital modules. There are 64 different points to be connected to the controller. Some of these points were cancelled after the final design of the project. The Trend controller can be accessed through the LAN connection or by using the touch screen in the front of the MSC. For further development of the control system, a 48 plug was used to switch all sensors and pumps signals from the Trend controller to any external controller. Remote access to MSC is based on a GSM router which has two main ports for Beckhoff controller (WDU controller) and Trend. The first location is "A" which is located on the roof of the building site. It includes two temperature sensors for solar in/out temperatures, 16 units of horizontally oriented vacuum solar collectors and the weather tower. The weather
tower consists of solar radiation, air temp, humidity, air pressure, wind direction and wind speed sensors. The third location is called "B" which is located in the left hand side of the building site. It includes two storage tanks of five \( \text{m}^3 \) capacity of salt-free water to be fed through the solar collectors. Two pumps for solar and WDU with their inverters are located beside storage tanks to prevent the cavitations problem. Flow meters are inserted for solar and WDU pumps. The third location is called "C" which is located inside the building beside the RO machines. The desalination unit locates at "C" and its handshaking signals to/from Trend accomplished through two cables and control box [7]. For details, the internal project report [6] on installation, programming, monitoring and control strategies could be referred.

Development of remote monitoring and control set up of the project was the task assigned to SWU, Soest, Germany. The focus of this work was to set up communication between SWU, Germany and the building site in Hurghada, Egypt to monitor and control the desalination system and to collect data for research and analysis. This assignment was successfully completed which motivated the author to undertake the task of developing remote lab or TeleLab for renewable with focus on power engineering education.

As it could be observed in the figure above, on the left side is the campus of University of Soest in Germany presented. The remote user establishes a VPN network between campus Soest and the router provided by “Terrawater” – one of the project partners which is located at the project site. This router provides access to the local PC in Egypt which has monitoring and programming software like 963 visualization software and SET V5 programming software from Trend. The author through a secure communication channel, accesses the experiment PC, loads the required program in the controller through which measurement of weather parameters like temperature, pressure, wind speed was possible. All these weather sensors were commissioned by the author during his one of the visits to Egypt. Measurement of parameters like hot water level, flow rate of the water flowing through the solar vacuum tube collectors was achieved using the controller. The output channels of the controller were used to initiate control actions like opening or closing of valves, inverters or other output devices.

Fig. 2.15 TeleLab concept for desalination project
based on the incoming sensor measurements. Two controllers were used for this project. One is the trend controller and the other was the controller from Beckhoff used for measurements of the water desalination unit. A digital signal was defined to initiate communication between the two controllers. When the measurement parameters were optimum enough to begin the desalination process then the digital signal was sent from trend controller to the Beckhoff controller for initiating the desalination process. It was possible to access all the measurements in Soest, analyze and use them for further processing.

2.6.2 TeleLab project with University of Cape town, South Africa

The author was involved in the project entitled “Wind Turbine, Micro turbine and Solid Oxide Fuel Cell (SOFC) based hybrid power system” funded by National Research Fund (NRF) south Africa and DLR Germany. The electrical department of University of Cape Town, South Africa (UCT) represented by Prof. Dr. Chowdhury with expertise in the field of modeling and simulation of hybrid power systems with focus on wind turbine, micro turbine and solid oxide fuel cell was involved in this project. The automation department of Soest was assigned the task of setting up remote facilities to monitor and control this project. Part of this PhD work is supported from this collaboration. The author used this opportunity to explore some useful literature resources at the UCT and to carry out significant discussions with the UCT team of researchers. As part of this project, number of seminars, workshops and conferences were attended both in Germany and South Africa. The project could be seen as beginning part of this PhD work. The focus of this project was:

- Implementation of hybrid power systems by carrying out operation, control and energy management studies of an experimental wind turbine, Micro turbine and Solid oxide fuel cell (SOFC) to promote distribution generation
- Technical difficulties of integrating distributed energy resources with each other and the grid
- Optimal operation of distributed energy resources
- Development of communication standards and protocols
- Development of safety and protection guidelines
- Legislation and regulations for integration of distributed energy resources

At the end of the literature review, author concluded that:

- Significant research work is in progress in the direction of development of TeleLab architecture. The areas of focus of research for researchers were automation and information technology
- Educational experiments were developed in the areas of electronics and robotics
- Integration of learning management systems and TeleLabs for education purposes were discussed
- However, no significant contribution to develop TeleLab for the field of renewable energy technology as the focus of experimental research and education was done by researchers at the time of beginning of this work. The author further found out that though different controllers were used for monitoring and controlling purposes, use of PLC for monitoring and controlling purposes under TeleLab infrastructure was limited to certain applications. Power engineering education was not really the target area of research and hence the author decided to use the knowledge of information technology, automation technology and power engineering field to define the focus of his work in the direction of using TeleLab to promote renewable energy education.
3. Development and implementation of HPS demonstration experiment

3.1 Theoretical background

Renewable energy technologies are researched as the demand is increasing for clean energy to save the environment from polluted exhausts released by electricity generation stations. High energy demand and depleting natural energy resources have inspired the world to search for possibilities of increasing the contribution of regenerative energy resources or green energy resources. Hybrid energy system indicates an energy system with combination of different regenerative energy resources like solar, wind, geothermal, biomass and several others. Training and research on renewable power systems or hybrid power systems with renewable attain high significance with this background. HPS consists of combination of photovoltaic system, wind energy system and battery storage system. The energy generated by photovoltaic and wind energy system can be used to charge the battery storage system. The user can either feed this energy into energy supply net or can use it for personal use.

Automation, control and monitoring of above mentioned HPS will be interesting and helpful for detail understanding of this concept. Data interfaces for different elements of the system provide important information for monitoring and analysis. For example, data interfaces for battery system helps us to know the amount of energy available in the battery and also charge that can be further stored inside the battery.

The cost to develop such systems and to make them available for education and training purposes to institutions across the globe is financially challenging task. Simulated HPS systems are helpful to get basic knowledge about operation and functionality, however they cannot replace real systems. With an aim to make a renewable HPS available to users and institutions so that the required training and experience could be obtained, this work involves developing a HPS demonstration experiment.

3.1.1 Proposed concept of system development

The proposed idea of HPS consisted of solar panel and wind turbine as the renewable power system components is shown in figure 3.1. A battery storage system is proposed which would be a 24 V and 12 V battery systems. A solar charge controller that has terminals to connect solar panel, battery system and load was proposed. 24 V relays along with outlets to connect 24 V loads which would be supplied from the 24 V battery were proposed. The sources of energy were halogen lamps to illuminate solar panels and motor with integrated frequency converter to rotate the wind turbine. An inverter to convert the energy from 12 V battery into 230V ac to the customers was proposed. A DC/DC converter to facilitate exchange of energy between 24 V and 12 V batteries was planned as part of the system.
3.2 System analysis and definition

HPS consists of solar panel system operated with 24 V supply and wind turbine System operated at 12 V supply. Depending upon the requirements, exchange of energy between the two stations take place through buck down DC/DC converter.

Overview of the system components

The overview of the hardware components of HPS could be seen in the Fig. 3.2. It consists of solar panel, wind turbine, 12 V batteries, motor with integrated frequency converter and current sensor for measurement of current of solar panel, batteries and the load.
It further consists of sinewave inverter which converts 12 V output of wind turbine into 230 VAC output to be fed directly to the consumers. Solar charge controller is the central component and is used for overall monitoring of the system. 24 V relays are controlled by PLC and are used to control the loads. A remote control of the lights used for illuminating solar panels is possible with the help of 24 V-230 VAC contactor. It could be controlled with digital signal output of PLC. The user can switch on/off the solar lights from remote location to analyze the behavior of the panel. 24 V-12 V DC/DC converter is step-down converter which transfers energy from 24 V system to 12 V system in the event of deficiency. Main switch is used to switch on/off the complete system.

3.2.1 Working principle of the system

3.2.1.1 Solar panel system or 24 V system (Station A)

The system consists of monitoring and control elements. Solar panel operating with 24 V generates energy and is illuminated by artificial lamps. Current sensors P1, P2, P3 and P4 as shown in figure 3.3 are used to measure system parameters like solar panel current, load current, battery current and current to DC-DC converter. These parameters are displayed by PLC on the experiment computer. The terminals of solar panel are connected to the corresponding terminals of the solar charge controller (SCC). These terminals on SCC are indicated with solar panel symbol. SCC is the central control element of this system. It monitors total energy flow into the system and is responsible for charging and monitoring of the battery storage system.
Fig. 3.3 Solar panel system (24 V system)

Two 12 V batteries (Sonnenschein S12/41) are connected in series to build the 24 V battery system. Battery terminals are connected to the terminals of SCC shown with battery symbol. Load is connected to the remaining terminals of the SCC shown with 12 V/24 V symbol. This means a load of either 12 V or 24 V can be connected to the SCC. Four load terminals of 24 V, 20 A are provided which can be controlled with “Distrelec” contactor relay 24 VDC. This relay can be controlled by a PLC program. A buck down DC/DC converter is connected between the battery system of 24 V and 12 V. The converter is required to transfer energy between the two systems via the two batteries operating at different supply voltages. Measurement data can be obtained and displayed on the experiment computer which contains programming software Step 7 and visualization software WinCC from Siemens.

3.2.1.2 Wind Turbine System (WTS) or 12 V system (Station B)

The WTS consists of wind turbine (AIR 40) of 160W@12.5 m/s wind speed operating at 12 V supply voltage. Since it is a lab demonstration experiment, wind is not available to rotate the wind turbine. It is rotated with the help of VLT drive FCM 305 AC motor with integrated frequency converter. Frequency control can be used to control the motor speed. The motor system has a PROFIBUS connection. This connection can be used to connect motor directly to the PROFIBUS terminal of the PLC.
The output energy from 24V system which is converted into 12V by DC-DC converter is measured with the help of sensor P5. Battery of 12V is protected with the help of circuit breaker and the battery current is measured with sensor P6 as shown in figure 3.4. Wind turbine charges the battery as the output of 12V can be fed to it. Sensor P7 measures the output energy from wind turbine. The battery charge of 12V can be converted to 230VAC with an inverter. The output of inverter can be made available to meet the consumer load requirements.

3.2.2 Advanced mechanical construction of WTS

For the purpose of lab demonstrator, the wind turbine model is attached with additional mechanical constructions so that it can be connected to the motor. A circular metal plate with cylindrical extension as visible in Fig. 3.5 is attached to the hub of wind turbine. The extended part of this circular plate was used to fit one black coloured metal plate with a possibility to attach the rubber belt drive. Other similar metal plate was placed on the motor at the other end. The metal plates had grooves through which passes the rubber belt drive connecting the motor and the wind turbine. A wooden base plate or board platform is prepared for the motor and the wind turbine for better stability.
Fig. 3.5 Mechanical extended parts of wind turbine system

Two steel sliders below the motor are used to offer flexibility for adjustment of distance between the wind turbine and the motor. Two steel rods at the back provide stability to the wind turbine when it is in operation. The base part of wind turbine is made of ceramic material with upper part round in shape and lower part squared. This construction was required depending upon the shapes of the metal rod that supports the turbine.

3.2.3 Smart energy management of HPS

As explained above, the two systems are operating with different rated supply voltages of 24 V and 12 V. Hence, to exchange energy between the two systems, a 24 V DC to 12 V DC/DC converter is used. The monitoring system monitors different system parameters like panel current, battery current, load current, motor speed, motor power, wind turbine speed, wind turbine output and the charge status of 24 V and 12 V batteries. The charge status of battery depends on factors like load consumed, no. of hours of consumption and battery safety factor. There are two methods of monitoring and controlling the exchange of energy between the two batteries. They are “Charge control method” and “Voltage control method”.

Charge control method: This method determines the charge of the two batteries in percentage like 30%, 50%, 70% and so on. Drop of battery charge below 30% would switch off all the connected loads to avoid deep discharge. PLC periodically monitors the battery charge of both the stations. Whenever, the charge of one of the 12 V battery falls below certain level (for example below 40%) and the other battery has sufficient charge (>70%) then energy transfer from 24 V to 12 V battery occurs. A PLC program is implemented which sends a digital signal to the 24 V switch (normally open). This switch is supplied from 24 V battery and transfers the output signal to DC/DC converter. When the converter is switched on, energy flow occurs.

Voltage control method: The implementation for this experiment is based on this method. The technical specification manual for solar charge controller was used to determine the
relationship between battery charge and corresponding voltage values. Measured voltage was used to develop the control program for energy exchange between 24 V battery and 12 V battery.

3.2.4 Smart load management of HPS

Four loads are available which are supplied from the 24 V battery. 24 V switches as shown in figure 3.6 are used to control the loads. This is an important figure as it provides the user quick and easy information about the switches, local control buttons and the loads.

Fig. 3.6 Load management

Four 24 V loads could be connected to the 20 A load connection outlets. These loads could be remotely switched on/off through PLC. The digital outputs of PLC are connected to the 24 V switches. Based on voltage control method, an algorithm is defined below. It helps to determine the number of loads which could be supplied depending upon the charging status of the batteries.

Fig. 3.7 Algorithm defined for 24 V load management
A current sensor is used to measure the voltage of 24 V battery. The algorithm, shown in figure 3.7 defines charge of battery corresponding to voltage values. When the battery voltage is less than 22.2 V (30% battery charge) then no loads would be supplied. If the charge is greater than 30% but less than 50% (25V) then only 1 load would be supplied. If the charge is between 50% and 70% (25.4) then 2 loads would be supplied. Finally, if the charge is greater than 70% then all the loads would be supplied with charge.

### 3.3 System mounting (connection) platform

The system connection box consists of the system hardware mounted on a single platform. The experimental set up could be understood after studying the mounting platform. It consists of current sensors for measurement of solar panel current, battery current, load current, wind turbine output current. Main on/off switch and fuses by the side of it offer the require protection to the system. Switches, local switch buttons and loads are connected as visible in the figure 3.8 below.

![System mounting box](image)

Fig. 3.8 System mounting box

Solar charge controller at the top is visible which is described in detail in the Appendix section. The inverter which converts 12 VDC to 230 VAC is mounted at the bottom right.

### 3.4 Security system for lab personnel

During the experiment, if a person in the lab comes in contact with equipment that might cause injury then it could have serious consequences for life and property. For this purpose, security system offered by company “Pilz” is used. They are known as safety light curtains with infrared beams. This security system available in the automation lab of Soest could be used to ensure safety of lab personnel from wind turbine which rotates at relatively high speed. The blades of wind turbine are sharp and can cause injury to the person during operation. The safety light curtains PSEN 4B/1 are multibeam optoelectronic protection
devices. They are preferred to be used for devices or machines like robots or automatic machine plants which can cause physical injury to the person at work place.

This system consists of an emitter (TX) and a receiver (RX). Aluminum profiles are used to house the emitter and the receiver. The control logic is located in these two units. The units are synchronized optically. That means no direct connection is required. A microprocessor is used to monitor and control the infrared beams. LED indicators are used to inform the user about the operating status of the safety light curtains. When an opaque object, in our case, a person in the lab interrupts the infrared beams send from emitter to receiver then the outputs (Output Signal Switching Device (OSSD)) are opened and the machine (wind turbine in our case) is stopped. When the lab person moves away then the interruption of infrared beams end and the machine is restarted. The placement of safety light curtains should be done in such a way that there should not be any possibility of lab person to enter the danger area (area where injury could be caused) without interrupting the infrared beams. The location of wind turbine in the lab is selected such that there is a table on the left side of wind turbine assembly and the other experiment hardware on the right side. At the back side is the wall. Hence, there is no possibility for any person to enter the danger area from back or left or right side of wind turbine. The only possibility is from the front side. Since the rotating blades are on the sides, the person even in normal conditions without the security system will not come in contact with the blades. The transmitter and receiver are placed in front of the wind turbine and the person, if by mistake enters the danger area then has to enter through the infrared beams exchanged between the emitter and the receiver.

The infrared beams are transmitted from emitter to receiver. This assembly is placed in front of the wind turbine from which the lab person should be protected for physical injury. The minimum safety distance between the protective field and the wind turbine should be determined for effective operation. During calculation, factors like the speed at which the object which requires protection is approaching the danger zone, reaction time of safety light curtains in seconds, machines overrun time in seconds, resolution of the safety light curtain and a factor which depends upon the resolution selected should be considered. PLC should be configured to receive the status signal from OSSDs. Based on the signal received, PLC would turn on/off the motor which would turn on/off the wind turbine. When the lab person interrupts the infrared beam or the safety light curtain then the OSSDs become open. This is detected by the PLC in the form of a digital signal. The digital signal is used to turn off the motor and the wind turbine. When the person or the object is removed from the protection area then the uninterrupted infrared beams would close the OSSDs which would switch off the digital signal sent to the PLC. The PLC turns the motor on and this results in the resumed operation of wind turbine.
4. Development and implementation of TeleLab

The difference between traditional lab, virtual lab and remote lab/TeleLab is discussed in the beginning chapters of this thesis. It is explained that TeleLab functions with real physical devices and the experiment set up consists of real hardware which can be accessed, monitored and controlled from any remote location by authorized user provided who has a PC with internet connection and java software version that can be downloaded free of cost from internet. In this chapter, development and implementation of remote lab for HPS would be discussed.

Different terms are used in the context of remote lab like web-lab, virtual lab, TeleLab, collaborative or online lab and other synonymous terms. The table below explains the difference between these terms. It is prepared on the basis of two factors

- Nature of lab equipment (real equipment or virtual)
- Mode of user access to perform a task (local or distant access) [11]

<table>
<thead>
<tr>
<th>Nature of equipment</th>
<th>User access (local)</th>
<th>User access (distant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical (real)</td>
<td>Hands on lab (traditional lab)</td>
<td>Remote lab (TeleLab)</td>
</tr>
<tr>
<td>Virtual (modeled)</td>
<td>Virtual lab</td>
<td>Distributed virtual Lab</td>
</tr>
</tbody>
</table>

A study was conducted to test the effectiveness of web lab (remote lab) in comparison with no lab condition, virtual lab and local lab as in figure 4.1. One experiment was agreed upon by different universities of different countries to be conducted with learning performance as outcome from different lab models. The learning performance of different lab models was analyzed as shown in figure below.

![Fig. 4.1 comparative study of different lab models [12]](image)

It can be observed from the above figure that even though the local lab performance with respect to learning is best, after several training sessions, the web lab performance could become equally good or even better [12]. In the absence of any lab, the performance was found to be poor.
4.1 Remote lab architectures: UTS lab and iLab

Remote lab architectures are developed depending upon the mode of communication between the client and the web server or the experiment computer. The mode of interaction between the experiment and the client i.e. online or offline interaction is important in deciding the remote lab architecture.

![UTS remote lab architecture](image1)

Fig 4.2 UTS remote lab architecture [14]

University of Technology, Sydney (UTS) remote lab architecture as visible in the figure 4.2 contains a web server and an arbitrator. The remote user with authorized login data accesses the web server and requests for an equipment to perform the experiment. Arbitrator allocates one of the unused equipment to the user and sometimes the allocation requests are queued up as required. As can be seen in the diagram, audio video devices are connected to the web server to which user receives access. Virtual machine is booted by the arbitrator which runs on the master server. Through this virtual machine user can connect to the remote GUI and to the hardware equipment. Tasks like creating a remote desktop on this virtual machine, running the control equipment and controlling it are performed by the user. The virtual machine could be reset after the experiment is performed. This means, modifications done by the user will have no effect on the master server.

![iLabs remote lab architecture](image2)

Fig. 4.3 iLabs remote lab architecture [14]
ILabs architecture involves an iLab service broker as shown in figure 4.3. The access request is sent by the user from remote location to the iLab service broker. This service broker will authenticate and verify the user login information and provide user access to the lab servers. This is distributed architecture used for the MIT iLabs. The distribution of tasks of equipment management and user management occurs between lab servers and iLab service broker. Two forms of experiments could be implemented. Interactive and non-interactive or batch experiments. Interactive experiments provide user with scheduling feature to communicate directly with the experiment server. Through the experiment server the remote user can monitor and control the lab equipment. A modified Interactive Service Broker (ISB) accomplished the task of establishing communication between the user client and the experiment server. Under batch experiment, direct interaction between the user and the equipment is not allowed. The user communication with the experiment happens through the service broker. The experiment parameters are configured and sent to the service broker by the user which are further passed on to experiment server by the service broker. When the experiment is completed then the results are sent back to the user through the broker.

The architecture implemented in the development of TeleLab of the University of Soest is based on interactive iLab architecture.

4.2 Soest remote lab architecture

The architecture of TeleLab at automation department of University of Soest is shown in figure 4.4 below. Learning management system MOODLE is integrated to enhance the educational value of the experiment performed by remote user.

Fig. 4.4 TeleLab architecture at University of Soest
Different steps performed by the remote user starting from login from remote location and getting access to the equipment are discussed in table 4.2 below:

<table>
<thead>
<tr>
<th>Steps</th>
<th>User Task</th>
<th>Administrator Task</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Remote user log in: MOODLE environment</td>
<td>Login data issued on user request</td>
<td>User should send email to administrator with background information and request for login data</td>
</tr>
<tr>
<td>2</td>
<td>Remote user time slot reservation and login: web server</td>
<td>Login data issued based upon exercise completion on MOODLE</td>
<td>User completes the MOODLE exercise; it is verified by administrator; user data with defined access/authorization rights is generated</td>
</tr>
<tr>
<td>3</td>
<td>Remote user: camera server access</td>
<td>Login data issued by administrator along with step 2</td>
<td>No extra request is required from user; login data is provided along with data from step 2</td>
</tr>
<tr>
<td>4</td>
<td>Remote user: network camera control access</td>
<td>No need of login data</td>
<td>Access to camera server provides access to camera live images</td>
</tr>
<tr>
<td>5</td>
<td>Remote user: access to experiment PC</td>
<td>VNC authorization</td>
<td>Login data generated with other remote PC configurations</td>
</tr>
<tr>
<td>6</td>
<td>Remote user: PLC access</td>
<td>No password required</td>
<td>PLC has its own IP address and can be accessed over LAN</td>
</tr>
<tr>
<td>7</td>
<td>Remote user: access to equipment</td>
<td>No additional authorization required</td>
<td>Through PLC, remote user can access and perform the experiment</td>
</tr>
</tbody>
</table>

4.2.1 Remote user access: MOODLE environment

Remote user with authorized login data access the MOODLE environment. This learning management system is managed and maintained by the IT department of University of Soest. All the students who are enrolled at the University can login with their student login information. Those users who are not registered as students at the University should request the IT department to provide the login data. A separate enrolment key is assigned to every experiment oriented module. The user can get access only to that experiment module whose enrolment key is available to him. For the enrolment key, he should contact the experiment tutor. At this stage, user is expected to get familiar with the MOODLE environment and different features that it has to offer. User is expected to learn the use of social forums, chat platform, experiment related literature, presentations and media that is available under this experiment section. The user is asked to attempt a pre-experiment-knowledge-analysis questionnaire to enhance his knowledge about the experiment and the concept of TeleLab. The questions are designed in the form of multiple choice questions or in the form of quiz so that the user does not have to read long experiment descriptions as it is usually the procedure. Through this method, the user gets informed about the dos and don’ts of the experiment. Technical information about the equipment is provided to the user through this exercise. He does not have to schedule a time slot for this exercise on MOODLE. Once the user has completed the exercise on MOODLE, he can make use of EJSApp feature which provides a java script based booking system as shown in figure 4.5, to schedule a time slot and control
the access to the physical equipment of the remote lab. It can be accessed by one user at a time [14].

Fig. 4.5 MOODLE booking system [11]

It is possible for the administrator to select users and provide them access rights to book an appointment with the equipment. This means, the administrator can decide that certain users do not get over-access to the equipment by not providing them right to book the experiment for a defined duration. Once the user has successfully booked his time slot to perform the experiment then he receives login data to web server. This login data is activated for defined time slot. After this time slot, the login data is deactivated and cannot be reused by the user.

4.2.2 Web and remote server configuration

The access to web server is provided by the administrator to the user based upon analysis of his task completed in MOODLE. The administrator has access to the MOODLE exercise performed by the user. If all the tasks are performed by the user satisfactorily then he is provided with a username and password to log into the web server. This step ensures that the user is well prepared to perform the experiment. The user gets password for the camera server so that he can access the live images of the network camera.

In this section, configuration of web server and remote server is discussed. Security measures should be taken before providing the user access to servers. Different security features offered by WinCC software should be understood and effectively configured to provide high level of security for remote use. It might be argued that this discussion could be better presented as part of experiment manual as attachment to this report. However, the author feels that it should be discussed here in detail since it forms an important part of the security arrangement for automation based remote labs.

The setting of password for the web server can be accomplished by going to Control panel>WinCC Internet Settings>web server>User Administration. After clicking on User Administration following window “UserDatabase-Edit” will appear.
Fig. 4.6 WinCC flexible overview window and user administration window [15]

Under the “User Manager” tab, it is possible to create new user data by clicking on “New” button. The administrator can define the username and password. This information will be later forwarded to the user to access the web server. As seen in the figure 4.6 “Email” tab can be used to configure the SMTP server and email addresses of users who will receive messages in the event something at the experiment site goes wrong. For example, alarms can be configured with respect to certain critical parameters. Due to some reason if these alarms are activated then messages can be delivered to the experiment management to ensure safety and security. The “Proxy” tab helps to configure entries and settings for the proxy server based on HTTP protocol [15]. Web authorizations can be assigned under the “Web Server” tab. The last tab “Remote” is used to configure the start and stop settings of the Sm@rtserver. Settings for connection, session management and security could be accessed by “change settings” button under “Remote” tab.

“Description” tab enables to describe user information and the “Authorizations” tab enable the administrator to assign the user with different authorizations. For example, read and write access to file browser is possible to a particular user only if he is authorized as “FileBrowserAdministrator”. Some other authorizations are “RuntimeAccess” which authorizes user to start and stop the runtime platform or “SoapUser” to read and write access via web service (SOAP). Web server can be configured to enable or disable remote transfer of project files. It is suggested to disable this option so that the user will not be allowed to transfer files from remote location to web server. Though it is possible to start and close the web server explicitly, it is suggested to select the start the web server automatically after the booting of HMI device and close the web server along with runtime by enabling the corresponding option.

“Remote tab” can be used to change the user properties like passwords, authorizations, screen update mechanism and the behavior in the event of disconnection.
It is possible to define remote user access rights by clicking on the “view only” option as could be seen in figure 4.7. This will provide user with remote monitoring rights or guest rights but no modifications could be done by the remote user. From the above diagram, user with password 1 has remote monitoring and control rights but user with password 2 has no control rights. Port numbers could be defined as 5900 and 5800 and corresponding modifications should be done in the java configuration file. In the event of client sessions, local input could be blocked. In the event of disconnection the suggested method is to either lock or logoff work station. Remove desktop wallpaper option removes screen background on the experiment PC which saves transmission effort. Enable network packets queuing enables data splitting into multiple data packets which are sent separately over the network. When multiple clients are connected then this option is helpful. In case of low internet bandwidth, under the “Display” tab it is possible to set screen scale. “1” indicates no reduction and “3” indicates 33% reduction in height and width of the screens. Option 3 should be selected for reducing the amount of data transferred in the event of low bandwidth. Update handling option enables to define the updating of server screen which further manages the bandwidth problem. “Query” tab configures the settings which govern acceptance of incoming connections.
Query timeout can be specified as in figure 4.8 above. In the event of incoming query to connect after defined time the connection will be automatically refused or accepted depending upon the selected option. Priority of connections could be defined such as disconnect existing connections which means in the event of new connection, existing connection will be disconnected or automatic shared sessions which gives access to new user along with the existing user or the connection could be refused automatically. Download applet option should be selected so that the user connecting for the first time will have automatic download of java applet on his PC which is free of cost and is required to perform the experiment and to access several java features. Several other administration security settings are provided which can be used to enhance the security of the system.

The configuration of web server and remote server discussed enhances the security of the lab, equipment and personnel through password protections, user access right protections, authorization protections, protection in the event of internet disconnections and certain features can be efficiently used to handle the low internet bandwidth problem.

4.3 Website for TeleLab: HTML access of the experiment

After the web server login is successful, the user gets access to experiment PC through an IP address which opens the TeleLab website of University of Soest. This website is developed with using Dreamweaver software. The purpose behind development of the website is to make use of web browser like Internet Explorer, Firefox or Google Chrome as user interface to the experiment set up. If the user has any of these browsers then he can access the experiment. The recommended web browser is Firefox.

![Image of the TeleLab website]

Fig. 4.9 Homepage of TeleLab website

The idea behind developing the website was to provide user quick access to experiment images, description, TeleLab concept, training material, presentations, audio-video examples and research material related to renewable energy labs to enhance the educational value of the experiment. The home page, as visible in figure 4.9, contains periodically changing images of
the experiment which includes overview of the experiment set up and close view of different hardware components. Information about TeleLab concept and hardware details with images are presented for quick access by the user. A video tutorial explaining concepts related to renewable and hybrid power systems is added. All the material required for performing the experiment along with some useful research material such as recent conference papers on remote labs or on renewable energy technologies, hybrid technologies is present under the “Material section” of the website. User not only benefits from performing the experiment but also gets access to latest research material to keep himself updated about the research stand in this field. Under “Training section”, user can get access to different audio-video tutorials and tutorial material to understand the expected learning outcomes after performing the experiment. He is informed about standard procedures to be followed while performing remote experiments and the things which he should avoid doing to prohibit common experiment mistakes. User can define use of learning strategies to develop his cognitive skills. Information about problems faced by previous users at different stages of the experiment while performing it is updated to serve as guidelines for subsequent users. As part of preparation, user can access this information in “view only” mode, so that there will be no time restrictions and he can read or download the required information.

4.3.1 Network camera configuration

“HPS Experiment” tab opens the experiment webpage which is divided into three parts- part 1 shows the controls of the camera, part 2 shows the network camera live image and part 3 is reserved for the experiment PC control – WinCC screen.

Fig. 4.10 Remote user view
The above window in figure 4.10 shows the screen which the remote user will see on his computer. The left side of the screen displays camera control window shown in blue color. At the top of this window, a small circle shows possibility to move the camera in four directions, right, left, up and down by pressing the arrows. Camera can be tilted with the buttons at the top of this window. Camera parameters like zoom or focus could be adjusted with other controls displayed on the screen. It is possible to select the resolution of the camera depending upon the requirement and bandwidth available. 8 positions of the camera can be saved focusing on different hardware devices. This saves user time in adjusting the camera while performing the experiment.

In our experiment the camera positions defined are as follows:
1= experiment overview, 2= solar charge controller, 3= PLC, 4 = switch; 5 = Measurement device; 6= Experiment PC; 7 = Wind Turbine; 8= Motor

This means during the experiment if the user wants to observe the readings on solar charge controller (SCC) then he has to press button “2” and the camera will immediately get focused on the corresponding device. In the diagram above, the camera is focused on SCC and hence it is possible to observe the SCC readings showing the state of charge of the 24 V battery.

The IP address to access the camera is “http://172.19.10.7/” which can be configured in the html page of the website. It should be ensured that the camera is switched on and connected to the network. Camera is protected with security password which should be entered to display the live camera images. The second window is allocated for the camera view.

Experiment PC can be accessed and displayed in the third window to the extreme right of the webpage. The IP addressed allocated for experiment computer is http://172.19.10.249:5800/ where 5800 indicates the port number.

4.3.2 Design of TeleLab website

In this section, the design and structure of website developed for TeleLab at Soest University is discussed.

![Fig. 4.11 Structure of TeleLab](image)
The structure of website as in figure 4.11 is kept simple and easy to navigate. The main page is the introductory page to the user which provides the user quick idea about the concept of hybrid power system and TeleLab. At the top of this page, rotational view of the experiment images is visible. It contains live camera image and video explaining TeleLab functionality. The next tab found at the top of this page is “Training Tab”. After getting introduced to the concept of the experiment, the user can click on this tab which opens up the training page. This page contains information about how to get connected to the experiment, certain instructions to be followed while performing the lab, a detail explanation of the lab in the form of “Lab Manual” and short description of different tasks to be performed by the user during the lab. The user can click on “Task 1” to begin with the experiment. The page structure for all the tasks is kept same. The page begins with description of aim and learning outcomes of the task. Procedure to perform the task is described in the form of a flow chart diagram. Task deliverables inform the user about the documents and the contents which should be included at the end of the task to be delivered to the lab administration.

There is a provision to inform the lab administration about problems faced during the experiment. The user can also provide suggestions for improvement. The problems could be informed by clicking in the problem notification box. A pop down menu appears with list of #hashtags that define the probable experiment issues. For example, if the user comes across a problem concerned with panel current measurement through PLC then the available hashtag is:

#Technical/PLC/Panel_Current_Measurement

This approach was developed so that the information exchange between the lab management and the user about issues during the lab is made easy and clear to understand. Every task page contains a simple diagram which explains the aim and learning outcomes of the task in the form of a diagram. Based on frequently asked questions from the users about the task, tips are developed and periodically updated informing the user about steps to perform the experiment easily. The user can click the “next task” button to navigate to “Task 2” in this case.

HPS experiment is the third tab on the main page which is opened when the user wants to start performing the experiment. Opening of this page automatically connects the user to the network camera and the experiment PC. Java software required for the VNC connection to the experiment PC is downloaded from the internet automatically. The user might have to make certain modifications in the security settings of the Java software installed on his PC. Ports 5800 and 5900 should be allowed to communicate. The VNC window asks for login data which if entered correctly provides access to the experiment PC. Now the user can see the camera control panel, live camera image and the experiment PC screen simultaneously on the same page.

“Study material” tab opens the page where all the resource material to improve the educational value of the user is made available. This includes videos, research publications, examples of TeleLab implementing across the globe and different internet resources are available for the user to study and prepare himself for the lab or later to improve his knowledge about remote labs with renewables and hybrid power concept.

4.4 Java configuration settings

The user is asked permission to automatically run a Java software required to connect to the experiment PC.
This software should be run on the user computer to be able to use java features as in figure 4.12. It is important to ensure that the latest Java version is installed on the computer. This version installation check can be done under “Java Config” window. As can be seen in figure 4.13 the latest Java version 1.8 is installed. In case if more than one versions are available, it is suggested to use the latest version available.

It is necessary to include the IP address of the experiment PC along with port numbers 5800 and 5900 in the java.policy file. The process to include the IP address is as follows:

```java
permission java.net.SocketPermission "172.19.10.247:5800", "connect, resolve";
permission java.net.SocketPermission "172.19.10.247:5900", "connect, resolve";
```

This ensures that java allows connection to this specific IP address and port numbers. Otherwise socket connection error will be displayed on the screen.
After the configuration of java is completed, a VNC authentication screen as in figure 4.14 appears where the user has to enter the password of experiment PC. This password is set by the administrator and can be changed periodically. The figure below shows the screen shot of this window. At the top of this window there are options like disconnect, record, send cntrl+alt+Del and refresh. All these features can be used to disconnect or refresh or record the established connection with the experiment PC.

Fig. 4.14 VNC authentication window

After successfully entering the login information, the user through secure VNC platform gets remote access to the experiment PC which is connected to the experiment hardware through PLC. Depending upon the configuration of remote server, the user may get monitoring access or both monitoring and control access. If the user has monitoring access only then he will observe a WinCC visualization of the experiment. The user can read different experiment parameters and can write some defined parameters to understand the behavior of the system. However his access rights will be restricted which means he cannot make any modifications in the system or in the software programs. All he can access on remote PC is the visualization screen. Users with access to control the experiment can switch between WinCC and Step 7 programming screens and are allowed to make programming changes.

4.5 Real lab experience with Deutsche Forschungsnetz (DFN)

TeleLab is performed from remote location by monitoring and controlling the experiment with the help of PLC. One of the arguments made by users is the ability of TeleLab to provide real lab experience similar to that offered by hands-on labs or traditional labs. The user is not physically connected to the experiment set up but he is accessing the experiment remotely. This might give him a feeling that the experiment which he is performing is unreal or simulated version. That is the reason why network cameras are added as part of the experiment set up. User can control the network camera and use its features to remotely view the changes taking place at the experiment site. In addition to network camera, audio-video devices, remote conference software developed by Deutsche Forschungsnetz (DFN) and smart boards are integrated into TeleLab at University of Soest to give user real lab experience.
4.5.1 Deutsches Forschungsnetz (DFN) overview

Deutsches Forschungsnetz (DFN) is developed by German national research and education network for academic and research purposes. It is managed by scientific community which was founded by universities, non-university research institutions and research oriented companies to stimulate computerized communication in Germany.

University of Soest is a member institute which has got authorized login information to use this application for educational purposes. This software visible in figure 4.15 enables user to share audio-video information with other users. The administrator can view the camera image of the user performing the experiment which will enhance the security aspect of the experiment. A discussion window provides possibility to initiate discussion topics where other users/remote lab engineer can participate and provide required suggestions. A chat window enables user to chat with concerned person in the event of lack of clarity of the lab content or other similar issues. There is also possibility to frame multiple choice questions which the user can answer to enhance his experiment knowledge. Different features available under this software are meeting management, layout management, PODS, task windows management and audio-video management. Meeting management enables user to define roles of other participants like moderator, event creator, guest or participant. It is possible to restrict new participants from participating in the meeting or restrict their roles to guests. The user can make his screen accessible to other participant if he needs their assistance. Different task windows like free streaming, question-answer task, chat, sharing of data or web links, video telephony, camera and voice settings, work-groups management window can be set up under the POD features.

4.5.2 DFN whiteboard

In traditional labs, users have the possibility to note down the measurements or write down notes or some important points to be developed at later stage which could be added in their
final experiment report. The user can scribble down some spontaneous doubt to be asked at later stage to the lab engineer or to the Professor.

Fig. 4.16 DFN whiteboard

This platform shown in figure 4.16 to scribble on an electronic whiteboard can give user similar experience of working in traditional labs.
5. Execution of HPS experiment with TeleLab

In the previous chapter, steps to access the Soest-remote-lab were discussed. Pre-experiment-knowledge-analysis and post-experiment-feedback-analysis tasks are planned under the MOODLE environment. In this chapter, experiment execution process would be discussed. As part of experiment design, lab information like syllabus and Intended Learning Outcomes (ILO), self-study, pre-test, planning, experimental activity, assessment and user feedback online survey should be provided [34]. The remote lab at Soest University was designed keeping these criteria in mind. The phases involved in conducting the experiment are discussed below.

![Remote experiment execution phases](image)

**Fig. 5.1 Remote experiment execution phases**

The outline for defined lab structure is explained in figure 5.1. Definition of syllabus and learning outcomes to the user is the initial part of designing a remote laboratory experiment. Contents like clear description of the experiment, recorded presentations explaining the experiment and procedures, literature sources and descriptive figures are used as knowledge resources.

Learning outcomes should be defined so that the user knows precisely the value addition by the experiment and the kind of education and skills that are expected to be developed after the completion of the lab. Lecture notes or lab notes, pictures and videos could be made available to the user so that he prepares himself adequately to perform the experiment. A website for example could be developed where user gets access to all the relevant lab material and sources required for preparation of the experiment. A preparation-test in the form of multiple choice questions, short/long answer questions or feedback questions would provide the user with information system information. Several learning management software or training software platforms offer the possibility to design and develop informative tests as part of learning activities to enhance the experiment knowledge of the user. Learning activities performed by the user could be assigned with grades which could be defined as criteria to allow the user to perform the lab.

Planning phase includes the tasks user must focus on to get access to the experiment. After the grades are achieved and the user becomes ready to perform the experiment, he should get the necessary security information from the administrator. Time slot for the experiment should be reserved by the user.
PC requirements are mentioned on the experiment webpage. The user has to ensure that his computer is equipped with the necessary resources like audio/video devices, internet connection and other free downloadable software to perform the experiment. A view of the screen visible to user from remote location is shown in figure 5.2. The camera control interface helps user to position the camera whose live image is visible on the screen. The screen of experiment PC could be accessed by the user for monitoring and controlling purposes. Java software would be automatically installed on the user PC in case if the latest software version is missing. A user can perform the experiment as per the description of tasks mentioned in the experiment manual. He can perform measurements, note his observations, collect required data from different experiment devices, perform data analysis, derive conclusions and note the results. Experiment report could be prepared and it could be ensured that all the ILOs are fulfilled. The report could be sent for evaluation and the post experiment tests could be answered.

5.1 HPS experiment procedure

The procedure to be followed for performing the experiment at TeleLab in Soest is discussed in this section in detail.

5.1.1 Preparation phase

This preparation phase shown in figure 5.3 is explained in the form of flowchart for a speedy reference for the user. It expects the user to make himself familiar with the aim and intended learning outcomes of the experiment. The user has to complete the registration process and request for login information into MOODLE platform and course enrolment key from the lab administrator. He should provide his email address to the administrator so that the required information could be delivered to him. At the University, all registered students are entitled to receive login information from the IT department which can be used throughout their study period to have access to different IT resources of the University. Enrolment key for the lab course could be obtained from the lab administrator. User is expected to make himself familiar with features of MOODLE learning platform and the features/contents of HTML website developed for the HPS experiment. Seminar/Training on MOODLE platform is offered periodically for the students by the University.
Successful login provides the user access to MOODLE features that include different forums, audio-video file download feature, access to presentation files, diagrams, latest research material corresponding to the field of renewable energy and TeleLab, chat forums, social forums and grade evaluation procedures. The user is expected to appear for the pre-experiment-knowledge-analysis questionnaire which is available on the MOODLE platform in the form of multiple choice questions, quiz questions, short/long answer questions and true/false questions. The answers would be evaluated by the course developer and grades are assigned for different learning activities. A user is expected to achieve grade>80%. The criteria to set this grade requirement are based on the experience of automation department regarding evaluating and accessing labs since years. After achieving the required grade, the user is provided with access to perform the experiment. All the users who fail to achieve the required grades are expected to prepare further for the experiment till they fulfill the criteria. This ensures that the users become familiar with the basic knowledge to use the experiment setup before they are provided access to the devices.

Mathematical modeling of solar PV module – Kyocera KD135GH-PU panel with MATLAB/Simulink

The purpose of this activity is to provide experience of remote experimentation to the user based on the concept of distributed virtual lab. It means a virtual lab performed over internet from a remote location. This exercise is simulation based and does not involve interaction with real physical hardware. However, it provides user with knowledge and experience about environment similar to the TeleLab environment. The advantages of virtual lab are offered to the user through this experiment before he performs the experiment with real physical hardware. The user is expected to understand the theoretical background to perform the mathematical modeling of solar PV module. The necessary literature sources are provided to the user. Lab recommends to use [72] as reference to implement the PV module equations.
Single diode model of a solar cell in figure 5.4 is used to define the I-V equation as solar cell is the building block of a solar panel.

![Diode model of a solar cell](image)

**Fig. 5.4 I-V characteristic equation of solar cell [72]**

\[ I = I_L - I_o \left( \exp \left[ \frac{q(V + I_{RS})}{A k T_c} \right] - 1 \right) - \frac{V + I_{RS}}{R_{sh}} \]  \hspace{1cm} (1)

The IV characteristic equation of solar cell is given as [73]:

- \( I_L \) = photo current
- \( I_o \) = saturation current
- \( R_s \) = series resistance
- \( A \) = diode ideality factor
- \( k = 1.38 \times 10^{-23} \text{W m}^2 \text{K}^{-1} \) = Boltzmann’s constant
- \( q = 1.6 \times 10^{-19} \text{C} \) = magnitude of charge on an electron
- \( T_c \) = working cell temperature

Photo current or light generated current is calculated as:

\[ I_L = G[I_{SC} + K_I(T_C - T_{ref})] \]  \hspace{1cm} (2)

- \( G \) = solar insulation in \( \text{KW/m}^2 \)
- \( I_{SC} \) = short circuit current at 25°C, 1 KW/m²
- \( K_I \) = short circuit current temperature coefficient
- \( T_{ref} \) = reference temperature

Saturation current is described as:

\[ I_O = I_{RS} \left( \frac{T_C}{T_{ref}} \right)^3 \exp \left[ \frac{q E_G (1/T_{ref} - 1/T_C)}{k A} \right] \]  \hspace{1cm} (3)

- \( I_{RS} \) = reverse saturation current at reference temperature and solar radiation
- \( E_G \) = band gap energy of the semiconductor used in the cell

Combination of IV curves of all solar cells in a solar module gives the IV equation for solar module:

\[ V_{mo} = -I_{mo} R_{Smo} + K_{mo} \log \left( \frac{I_{Lmo} - I_{mo} + I_{Omo}}{I_{Omo}} \right) \]  \hspace{1cm} (4)
\[ V_{mo} = \text{voltage of solar PV module} \]
\[ I_{mo} = \text{current of solar PV module} \]
\[ R_{Smo} = \text{series resistance of the module} \]
\[ K_{mo} = \frac{AKT}{q} = \text{constant for the module} \]

If the solar module consists of \( N_s \) number of cells connected in series then the series resistance would be the combined series resistance of all the cells while the current flowing through cells connected in series would remain same.

\[
V_{mo} = -I_{mo}N_sR_S + N_sK\log\left(\frac{I_L - I_{mo} + I_O}{I_O}\right) \tag{5}
\]

I-V equation for PV module considering the number of cells connected in series:

\[ N_s = \text{number of cells connected in series} \]

\[
V_{mo} = -I_{mo}\frac{R_S}{N_p} + K\log\left(\frac{N_pI_L - I_{mo} + N_pI_O}{N_pI_O}\right) \tag{6}
\]

For resistances connected in parallel, the above equation would be:

\[ N_p = \text{number of cells connected in parallel} \]

The user is expected to implement the above equations in MATLAB/Simulink. Reference guidelines to implement the mathematical equations are provided to the user.

An implementation-example of solar panel model in MATLAB is shown below. However, users are given flexibility to implement it provided the results are correct.

![Solar Panel model](image)

**Fig. 5.5 Modeling of solar PV module (part A)**

The figure 5.5 above shows different input variables defined for the solar panel module as per the datasheet for the PV module Kyocera KD135GH-PU.
Table 5.1: Input parameters to PV module

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Temperature (°C)</td>
<td>25</td>
</tr>
<tr>
<td>02</td>
<td>Irradiance (W/m²)</td>
<td>200-1000</td>
</tr>
<tr>
<td>03</td>
<td>Series resistance (Ω)</td>
<td>0.18</td>
</tr>
<tr>
<td>04</td>
<td>Parallel resistance (Ω)</td>
<td>340</td>
</tr>
<tr>
<td>05</td>
<td>Diode ideality factor</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Fig. 5.6 Modeling of solar PV module (part B)

An example Simulink program to calculate and display the values of current, voltage, and power is shown in the figure 5.6 above.

The simulation results obtained are shown in the table below.

The first part in figure 5.7 displays results when the irradiance is constant at 1000 W/m² while the operating temperature varies. The reference temperature is set at 25°C.

Table 5.2: IV values for varying temperature

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Temperature (°C)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>25</td>
<td>8.6</td>
<td>22.09</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>8.72</td>
<td>21.76</td>
</tr>
<tr>
<td>03</td>
<td>75</td>
<td>8.78</td>
<td>21.42</td>
</tr>
</tbody>
</table>
Fig. 5.7 IV graph of solar PV module, $T=25^\circ C$ and irradiance $= 1000 \ \text{W/m}^2$

The figures 5.8 and 5.9 shows the results when the temperature is constant at $25^\circ C$ while the values of irradiance vary.

Table 5.3: IV values for varying irradiance

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Irradiance (W/m$^2$)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>800</td>
<td>6.9</td>
<td>21.8</td>
</tr>
<tr>
<td>02</td>
<td>600</td>
<td>5.2</td>
<td>21.4</td>
</tr>
<tr>
<td>03</td>
<td>400</td>
<td>3.5</td>
<td>20.9</td>
</tr>
<tr>
<td>04</td>
<td>200</td>
<td>1.7</td>
<td>20.1</td>
</tr>
</tbody>
</table>

Fig. 5.8 IV graph of solar PV module, $T=25^\circ C$ and irradiance $= 600 \ \text{W/m}^2$
Fig. 5.9 IV graph of solar PV module, T=25°C and irradiance = 400 W/m²

5.1.2 Planning phase

If the user succeeds in getting the required grades then he is considered to be prepared to perform the experiment. This method is structured and explained in figure 5.10. It ensures that the user is updated with the required basic information to perform the experiment. Planning phase includes that user plans and reserves the timeslot to perform the lab. MOODLE booking system is used for this purpose. As shown in figure 4.5 in previous sections, the booking system enables user to select the day and time during which he wants to perform the experiment. The user can see in the booking system if a particular day and timeslot is available. The user clicks on a particular day to get the details of timeslots available on this day. By clicking in the small box next to the timeslot, user can reserve that particular timeslot. The available timeslot is shown with green colour.
The user when required can check his bookings by opening the booking system. In order to avoid the same user making multiple bookings, the administrator can restrict number of bookings for a single user. For example, a user cannot reserve more than one timeslot on the same day or if the requirement is high then one user can be restricted from booking more than one slot during the period of one week. As the session ends, settings in WinCC would terminate the session automatically. The user can login as guest (monitoring mode only) before performing the experiment to study the experiment in detail. He has access to all the experiment material like manuals or descriptions so that he can prepare himself effectively. Login data required for experiment PC, HTML website, camera server and network camera access could be obtained by the user during this phase from the lab administrator. User when attempts to connect to the experiment PC through VNC channel then the required java software will be automatically downloaded. As instructed, user has to make some changes in the java security settings to get connected through ports 5800 and 5900. User might sometime have questions regarding these settings which might be asked to the lab administrator as required. The necessary settings will be explained in the user manual too. Due to some reason, if there are issues with login data then user has to contact the administrator using chat forum/email or telephone to solve the problem. The lab administrator ensures that he remains online and ready to help the user at the beginning of every timeslot.

5.1.3 Experiment activity Phase

This phase begins after the user successfully accesses all the resources to perform the experiment. A step by step guide (manual) to perform the experiment should be used by the user. In case the user has issues in understanding the description or the task or the procedure to perform the task then he can make use of chat forums on MOODLE platform or the DFN framework to communicate with lab tutor. Discussions on social forum can be useful. The user is expected to use the camera to focus it on different hardware devices to understand and make observations regarding their functionalities. Measurements visible on WinCC screens could be verified by observing measurements on local measurement devices. For example, the value of solar panel current or battery current can be observed on the multimeter connected to
the system and it would be displayed on the experiment PC simultaneously. Use of hash-tag method is described in the table below.

Table 5.4: Classification of issues

<table>
<thead>
<tr>
<th>Technical Issues</th>
<th>Administrative Issues</th>
<th>Manual/Description Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Issues related to experiment PC</strong></td>
<td><strong>Issues related to MOODLE</strong></td>
<td><strong>Issues related to Theoretical description</strong></td>
</tr>
<tr>
<td>- Speed of PC is slow (PC_Speed_Slow)</td>
<td>- MOODLE login failure (Login_Failure)</td>
<td>- Description of task is unclear/confusing</td>
</tr>
<tr>
<td>- Software is outdated (software)</td>
<td>- Features access issues like inaccessibility of chat forums, social forums, tests, quizzes, feedback questions</td>
<td>- Description of experiment has mistakes/conflicts</td>
</tr>
<tr>
<td>- Antivirus software installation (Software_Antivirus)</td>
<td>- Screen resolution problems (Screen_resolution)</td>
<td>- Text does not show literature citing’s</td>
</tr>
<tr>
<td>- Screen resolution problems (Screen_resolution)</td>
<td>- Picture quality problems (Picture_Quality)</td>
<td>- Diagrams are unclear or misleading</td>
</tr>
<tr>
<td>- Picture quality problems (Picture_Quality)</td>
<td>- Network address problems (Network_Address)</td>
<td></td>
</tr>
<tr>
<td>Hashtag: #Technical/PC/issue_name</td>
<td>Hash tag: #Admin/MOODLE/issue_name</td>
<td>Hash tag: #Manual/issue_name For example: #Manual/diagrams: Description</td>
</tr>
<tr>
<td>For example: #Technical/PC/Picture_Quality: Description</td>
<td>For example: #Admin/MOODLE/chat_forum_failure: Description</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PLC related issues</th>
<th>Camera and camera server issues</th>
<th>Issues related to description of tasks to be performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Configuration of hardware problems</td>
<td>- Login issues</td>
<td>Hash tag: #Manual/Task_number For example: #Manual/Task_1: Description</td>
</tr>
<tr>
<td>- PLC network address issues</td>
<td>- Feature access issues</td>
<td></td>
</tr>
<tr>
<td>- Step 7/TIA portal/ WinCC software platform issues</td>
<td>Hashtag: #Admin/Camera/issue_name</td>
<td></td>
</tr>
<tr>
<td>- Input/ Output measurement issues</td>
<td>For example: #Admin/Camera/Login_failure: Description</td>
<td></td>
</tr>
<tr>
<td>Hashtag: #Technical/PLC/issue_name : Description</td>
<td>For example: #Admin/Camera/Login_failure: Description</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hardware issues</th>
<th>Experiment PC issues</th>
<th>Issues concerned with understanding of ILOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurements or functionalities of hardware like motor, wind turbine, solar panel, battery, current sensors, inverter, converter, switches, camera etc.</td>
<td>- Login issues</td>
<td>Hashtag: Manual/ILO: Description</td>
</tr>
<tr>
<td>Hashtag: #Technical/Hardware/device_name/issue_name: Description</td>
<td>- Java software issues</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hashtag: #Admin/PC/issue_name</td>
<td>Hashtag: Manual/Submission: Description</td>
</tr>
<tr>
<td></td>
<td>For example: #Admin/PC/Java_failure: Description</td>
<td></td>
</tr>
</tbody>
</table>

Graphical displays could be analyzed; data could be collected and analyzed by the user based on which he should prepare the results and conclusions. As and when instructed, user should make screen shots to display the step by step progress of the lab. During the lab, the user is asked to inform the lab management, problems or issues as technical issues, administrative issues or description issues under the section “Problem notification”. This feature is made
available to the user on every webpage of the corresponding task. Concept of hashtag is used by the user to inform the management about the issue in a defined manner. It helps the management to direct the issue to the correct lab person who takes care of solving it without delay. User can also mention the issues in his report. With the help of the table above, user can use the problem notification feature to inform the lab management problems that he came across while performing the experiment.

5.2 HPS experiment description

Lab manual with detail description of the HPS TeleLab experiment is should be referred by the user to perform the experiment. The experiment is divided into different tasks which are discussed here.

5.2.1 Task 1: Read and display system parameters

The initial step as described in figure 5.11 under this task is configuration of PLC which includes configuration of Step 7 programming software, WinCC graphical visualization software and configuration of hardware devices connected to the PLC. A flowchart method of describing procedures is followed to ease the understanding process for the user. The figure below shows the diagram of configuration of PLC which when completed, enables user to prepare the logic for development of program in Step 7 to read measurement parameters from different hardware devices.

Fig. 5.11 PLC configuration

Measurement parameters like solar panel current, battery current, load current could be measured using current sensors whose output is in the form of voltage that can be read by the Step 7 program developed by the user.
As described in figure 5.12 followed by PLC configuration, a program should be developed using Step 7 programming software to read the measurement parameters. WinCC software can be used to graphically display the parameters. Different graphical tools like buttons, graphical displays, symbols or graphs could be configured along with configuration of tags in WinCC. If the variables and tags are defined and configured properly then readings should be displayed on WinCC screen. The user has possibility to observe the readings on actual measurement devices connected in the lab. For example, a multimeter can be used to display current sensor values. These values could be verified with values displayed on solar charge controller (SCC). SCC can display parameters like solar panel current/voltage, battery current/voltage, state of battery charge and several other parameters. Similar readings should be displayed on the WinCC screen. A parameter like solar panel current could be observed on multimeter, SCC and WinCC screen developed for this purpose. In case if there is mismatch then the user should inform the lab administration with a message showing appropriate hashtag (refer Table 5.4) indicating the exact problem. However, if the readings are verified then the user can take a screen shot of the WinCC screen and a picture of the measurement device with network camera which should be documented as part of the lab report. The screen shot and the picture taken at the end of every task will inform the lab management the time taken by the user to complete this task. In case, the user has taken more time as compared to what was expected by the administration then the reason would be determined by the recorded lab session or during personal dialog session with the user. The flow of data is from hardware devices to PLC and then to the experiment PC.

5.2.2 Task 2: Control of system hardware

In this task shown in figure 5.13, user is expected to write or send signals from PLC to hardware devices to initiate device communication from remote location. User has to implement PLC program and develop WinCC screen to perform tasks like switching of loads through switches (on/off) or to switch the motor on/off from remote location. The user is expected to understand the user manual of the AC motor with integrated frequency converter
to develop an interface to control the motor speed or to implement braking control for the
motor. The user is expected to test the functionality of infrared light system. The task of using
the switch control to turn on and off the DC/DC converter should be performed by the user in
this part of the experiment.

Fig. 5.13 Task 2: Control of system hardware

This task as visible from Fig. 5.13 aims at implementing PLC programs to read and write
parameters to the hardware components of the system. Hardware consists of four switches
(NC) operated with 24 V supply. User is expected to implement a program in Step 7 and
develop on/off control for all the four switches after referring to the I/O connection diagram
of the PLC and the switches. Four toggle buttons could be developed in WinCC that toggles
the state with mouse clicks. Subsequent task for the remote user could be to develop a
program and WinCC button to start/stop the motor from remote location. The user has to
understand the PROFIBUS connection configuration connecting the motor to the PLC. He
could read the speed of the motor or set new value. A white light output can be used to
indicate the toggle of “switch 1” which is connected to DC/DC converter. The purpose of
“switch 1” is to toggle state based upon the state of battery charge of 24 V and 12 V batteries
which would activate/deactivate the DC/DC converter. Active or inactive state of the
converter allows or blocks the flow of charge between the batteries.

5.2.3 Task 3: Experiment with wind turbine

Table 5.5 below shows the relationship between frequency, motor speed and wind turbine
speed. Tachometer is used to measure the speed of wind turbine at different speeds of the
motor. At speed >400 Rpm, the wind turbine starts generating output energy. This is indicated
by the LED located on the wind turbine. The LED glows when the output is generated. This
can be captured by the remote user through network camera. The output generated is indicated
on the WinCC screen. The user is expected to note the motor speed and the output of wind
turbine in the form of voltage. A current sensor is used for this purpose. The user can use the
electronic white board to note down the measurements. This is one more feature to give the user feeling of working in real lab. In traditional labs, users can write down the measurement readings on paper and to enter them in the lab report at later stage. The only difference is in traditional labs, instead of using electronic white board, user scribbles the readings on a piece of paper or in a notebook. The electronic white board gives similar live experience to the user.

Fig. 5.14 Task 3: Test wind turbine functionality

A reference table which contains the speed of motor and corresponding speed of wind turbine is provided to the remote user.

Table 5.5: Motor speed values

<table>
<thead>
<tr>
<th>Ideal speed (Rpm)</th>
<th>Actual motor speed (Rpm)</th>
<th>Wind turbine speed (Rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>656.25</td>
<td>550</td>
<td>544</td>
</tr>
<tr>
<td>562.5</td>
<td>505</td>
<td>485</td>
</tr>
<tr>
<td>500</td>
<td>450</td>
<td>443</td>
</tr>
<tr>
<td><strong>468.75</strong></td>
<td><strong>433</strong></td>
<td><strong>425</strong></td>
</tr>
<tr>
<td>375</td>
<td>371</td>
<td>359</td>
</tr>
<tr>
<td>281.25</td>
<td>163</td>
<td>156</td>
</tr>
<tr>
<td>243.75</td>
<td>136</td>
<td>132</td>
</tr>
<tr>
<td>187.5</td>
<td>107</td>
<td>104</td>
</tr>
<tr>
<td>93.75</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>37.5</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>28.125</td>
<td>2.25 (by observation)</td>
<td>2.25 (by observation)</td>
</tr>
<tr>
<td>18.75</td>
<td>0 (observable motion but can be neglected)</td>
<td>0 (observable motion but can be neglected)</td>
</tr>
</tbody>
</table>

The measurement values of wind turbine output are noted down by the user. It is followed by increasing the motor speed and noting down the corresponding values of the wind turbine output. Braking control of the motor should be tested as part of this task. The maximum speed
limit of the motor is informed to the user. Measurements should be performed till the maximum motor speed is achieved. For safe operation of the system, it is possible to lock the maximum motor speed limit. This ensures that even if the user increases the speed beyond safe limit, the internal motor settings will ignore it and allow user to work with the predefined maximum safe speed limits. At the end of this task, user is expected to take screen shots of WinCC screen and perform the documentation.

5.2.4 Task 4: Smart load management

The load management algorithm is defined in Fig. 3.8. The voltage control method is used to determine the charge of 24 V battery based on which the number of loads to be supplied are determined.

5.2.5 Task 5: Smart battery management

In this task described in figure 5.16, the user is expected to implement a PLC program which will read the state of charge (SOC) in the form of voltages from 24 V and 12 V battery. The program, based on the SOC values should decide whether to activate or deactivate the DC/DC converter. If the SOC of 12V battery drops below certain defined level and the SOC of 24 V Battery is above defined safe level then it indicates that 12 V battery should be charged. The PLC program will activate “switch 1” connected to DC/DC converter. This will activate the converter and initiate charge transfer from 24 V to 12 V battery. However, if the charge of 24 V battery is not above safe level, then despite the requirement of 12 V battery, no charge transfer should take place. In this case, 12 V battery should be charged from external power source. The program ensures safety of batteries from over and under discharge state. SOC_A indicates state of charge of 24 V battery and SOC_B indicates state of charge of 12 V battery.

Fig. 5.15 Energy management of batteries

In Fig. 5.15 safe and unsafe battery modes are defined. Unsafe mode is defined as SOC<40%. Safe mode is defined when SOC>=40%. This logic can be implemented in different ways. A reference example is shown here. If both the batteries are in safe mode then the program
should continue reading the SOC of both the batteries and no charge transfer takes place. When 12 V battery goes in unsafe mode and 24 V battery at that time is in safe mode, capable of providing charge to 12 V battery then the charge transfer between the two batteries is initiated. PLC sends signal “1” to the “switch 1” which gets closed and activates the DC/DC converter. The step down converter would transfer the charge from 24 V to 12 V. Transfer of charge continuous as long as 12 V battery is in unsafe mode. When it reaches safe mode, charge transfer stops. Charge transfer can also stop if during this time, 24 V battery goes into unsafe mode. In other situations where only battery A is in unsafe mode then no charge transfer occurs, the DC/DC converter remains off and the 24 V battery gets charged from the solar PV module. It could be possible that both the batteries are in unsafe mode. In this situation, charge transfer does not occur, DC/DC converter remains off and the batteries get charged from their respective renewable sources.
6. Evaluation and analysis of TeleLab performance

The performance of TeleLab could be evaluated on the basis of learning activities completed by the user on MOODLE, lab performance and communication between the lab tutor and the user. Analysis of feedback survey provides required information to the lab management regarding the changes or improvements to be made in the lab. The knowledge and experience of lab management is used to update or improve the lab. Factors like educational value offered by the lab, implemented safety and security measures, ease of performing the experiment, clarity of pictures/images and contents of the lab are considered for lab design and development. Failures which occur due to hardware, software, content of the lab or personal failures from the user are solved by the lab management by periodic monitoring and maintenance of the infrastructure. The user in addition, gets opportunity to inform the lab management about failures which he came across while performing the experiment. He can offer suggestions for improving the experiment. Accordingly the infrastructure could be updated or new content could be added to existing lab or new structure of the lab could be designed. Before discussing the parameters which would be considered to perform the evaluation and analysis of TeleLab performance, short information is provided about use and access of MOODLE platform at Soest University.

6.1 Use and access of MOODLE environment at Soest University

Responsibility of management and maintenance of MOODLE platform is executed by the IT department of Soest University. Secure login information to every registered student is allocated by the IT administration. The internet address used for this purpose is https://elearning.fh-swf.de/login/index.php. This web address directs user to the login page of MOODLE. Tutors or professors are assigned administration rights. It is possible to develop a new lab course or a new learning activity using the administration rights. Analysis of student performance, evaluation and feedback submission could be performed by the lab tutor. The name of the lab course developed is “TeleLab”. A new user after logging in the MOODLE website has to follow the following path to reach the main page of the lab-

My home>My courses>Fachbereiche>EET>Elektrotechnik>WiSe 15/16>TelLab

The user is asked the enrolment key which is set by the tutor of this lab. After entering the enrolment key, user is given access to the webpage. The lab tutor can view all the participants enrolled for the course. He can create and view message forums to discuss different lab related topics or he can create learning activity like “TeleLab preparation phase” which includes different documents related to lab along with activities like pre-experiment-knowledge-analysis and post-experiment-knowledge-analysis exercises.

As can be observed in figure 6.1 under “participants” tab, it is possible to see the details of activities performed by a particular participant. Details like date and time when the participant has logged in and performed the assigned tasks could be observed. It shows the name, email address and last time when the participant has accessed the lab. On the ride side, it displays the full profile of the participant and the activities performed by him. TeleLab Preparation activities include social forum where participants can express their opinions, post questions to clear their doubts or share latest information about the topic under discussion. The topic could be research oriented related to the lab topic or regarding any issue or any update related to the lab to be performed. TeleLab ppt includes the presentation slides on the topic of TeleLab or
on the experiment to be performed. In the form of pictures, diagrams, user can have quick look and understanding about the concept of the lab.

Fig. 6.1 Structure of lab assessment developed on MOODLE platform

Chat forums offer possibility to interact with lab engineer or other colleagues during the experiment to solve certain problem or to ask questions regarding certain issues. Spontaneous questioning by the user can be done using chat forums. Feedback survey is prepared to collect feedback about the contents of the MOODLE platform and ease of accessing and usefulness of these contents for preparation of the lab.

The parameters considered for evaluation and analysis of TeleLab performance are-

1. User feedback based evaluation and analysis
2. Grade based evaluation and analysis
3. Remote performance monitoring based evaluation and analysis
4. Report based evaluation and analysis

6.2 User feedback based evaluation and analysis

The feedback provided by the user during the pre and post experiment knowledge analysis activities is used to evaluate and understand the preparation of the user to perform the experiment. These two learning activities are designed so that the user is informed about the lab and that the administration gets information about educational background of the user.
6.2.1 Pre experiment knowledge analysis

The pre experiment knowledge analysis section contains set of questions which are expected to be answered by the user before performing the lab. The questions are informative in nature. He answers multiple choice questions or short/long answer questions to become familiar with TeleLab-experiment and to provide the lab administration information about his preparation for the lab. The pre experiment questions are divided under the titles-

- TeleLab experience
- Concept understanding
- Internet use
- Understanding TeleLab and simulation lab
- Geographical constraints
- Flexibility over real lab
- Educational value offered
- Effective use of audio-video chat interactions
- Possibility of spontaneous questioning
- Pre TeleLab survey

6.2.1.1 TeleLab experience and concept understanding

TeleLab experience asks the user if he has performed a remote lab experiment before. Three options are provided for the user.

- Yes, I have performed,
- No, I have not performed
- Can’t say.

Fig. 6.2 The question of TeleLab experience to the user and responses
User has to click one of the option and press the save my choice button. All the responses provided by different users could be observed by the administrator pressing the “view responses” button on the right side as visible in the figure 6.2. This feature can be used by the tutor to analyze the responses of the participants. It can be observed that out of 22 participants, 17 participants which mean 77% of the participants have never performed a remote lab before. 13% of the participants as in figure 6.3 performed a remote lab in the past or had the knowledge of performance of a remote monitoring system or a remote diagnosis system. The rest 10% of the participants were not sure about the idea/concept of TeleLab or whether they performed it in the past.

![Have you Performed Remote Lab before?](image)

Fig. 6.3 User preparation question 1

This analysis helps the administration to understand the participants and their knowledge and experience with TeleLab before they perform the lab. Based on the findings of the survey, the administration can expect the 13% users to perform the experiment with fewer issues compared to other users. It also informs the administrator about the familiarity of TeleLab concept among the target participants. Since a small percentage of participants (13%) have performed such a lab before indicates that at Soest University, remote lab concept is rarely used till today and if effectively presented, it could be accepted by many users as the platform to perform engineering labs. The question of concept understanding asks user whether he understands the idea of TeleLab or not and the question on internet use asks the user whether he finds the idea of performing real experiments over internet interesting. These questions according to author give more insight about the possible approach the user might develop towards the experiment.

6.2.1.2 Informative/self-explanatory framing of options

The next question asks user whether he knows the difference between simulation lab and TeleLab. This is one of the important question which the author wants the user to know before he begins the experiment. The author has participated in different conferences and has travelled around the world to know that this question is unclear to many researchers and users. Hence, the question is framed with informative options. The user has three options out of which the first option itself tells the answer to the user.

- **Option 1:** Yes, I know that simulation lab mainly works with simulated experiments and not real physical experiments
- **Option 2:** No, I have no idea about simulation lab or remote lab
- **Option 3:** Can’t Say
After reading the first option, the user understands the difference between simulation and TeleLab. For ignorant users, even if they are unaware about the difference, this informative option would inform them about the basic difference between the two labs. Such informative framing of questions ensures that the user knowledge is enhanced at the end of the survey.

6.2.1.3 Preference of TeleLab over traditional lab

Another question which is asked as part of this survey is to understand the readiness of user to prefer TeleLab over traditional lab. This question is asked with focus on the flexibility aspect offered by TeleLab. In this question, user is asked whether the advantages offered by TeleLab mainly that it saves travel time and travel costs and offers more flexibility to establish work-life balance are attractive enough to prefer it over traditional lab. The options provided here are as follows-

- **Option 1**: Yes, I would prefer remote lab even if there are some shortcomings in lab experience compared to traditional lab
- **Option 2**: No, I will not compromise with the Lab experience offered by traditional labs
- **Option 3**: Minor shortcomings can be ignored since the advantages are significant

After analyzing the responses to this question, it was observed in figure 6.4 that 37% of the users found that TeleLab is attractive to prefer it over traditional lab (option 1) while 37% users selected 3rd option which says that minor shortcomings like absence of real lab feeling can be ignored since the advantages offered by TeleLab are significant. However, it is important to note that 26% users said that they would not prefer to compromise with the lab experience offered by traditional labs. These students said that for them the feel of working with real hardware or real equipment is very important and that they would prefer to invest time and money to attend the lab personally rather than performing it over internet. The author interacted specifically with these students to know the environment in which they would prefer to use TeleLab and the feedback from these students was that in case if the lab is split into two parts: basic lab at local place and advanced lab over internet. This split lab approach would ensure that the user can construct the hardware

![Preference of Telelab over Traditional Lab](image)

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Fig. 6.4 User preparation question 2

This would ensure that those students who would not compromise with traditional lab experience can perform basic measurements, observations and some hardware interaction in the first part of the experiment with local presence while the second part of the experiment which would be advanced part involving programming modifications could be performed over internet. This split lab approach would ensure that the user can construct the hardware
and get the required feel of the experiment hardware locally. The tasks like detail experiment analysis, programming, data analysis could be done remotely.

6.2.1.4 Educational value offered by the activity

One of the goal of this lab is to increase the educational value of the experiment. Users were asked whether this exercise of participating in this activity to answer lab relevant basic questions as part of preparing for the lab in a better way, would result in increasing the educational value of the lab. They were provided with options like –

- Yes it would increase the educational value of the lab
- Yes, there is possibility that the value might increase
- No, such activity will have no impact on the educational value of the experiment.

![Educational Value offered by Telelab?](image)

Fig. 6.5 User preparation question 3

The analysis of responses to this question as shown in figure 6.5 suggest that 75% of the participants believe that this exercise would result in increase of education value of the experiment while 25% believe that there is possibility that it might increase. No participant believed that it would not increase the educational value of the experiment which the author found satisfactory.

6.2.1.5 Interaction process and spontaneous questioning process

Interaction with lab engineer or other lab colleagues during remote lab happens over chat forums or over audio-video software like Skype. The next question which was asked to the participants was whether they are comfortable with internet medium for communication or do they think that it would affect the interaction process and that they would prefer to have real physical interaction.

![Impact on Interaction process?](image)

Fig. 6.6 User preparation question 4
60% of the participants as visible in figure 6.6 believed that while performing experiment over remote lab, the interaction process with lab engineer or lab colleagues would get affected while 40% believed that though physical interaction is the best they are comfortable of interaction over internet medium since they extensively use this medium for communication in daily life. In traditional labs, since the lab engineer, colleagues and the user are physically present at the experiment site, any spontaneous doubt could be asked by the user during the experiment expecting quick response from the concerned person. In case of remote labs, the user can ask spontaneous question over chat but there might be a situation where he may not get reply promptly and that he may have to wait till the time the reply comes and this may affect his work flow or curiosity about the experiment. This question was asked to the participants and according to 75% participants, spontaneous questioning would get affected over TeleLab. The only solution which the author could think of to improve this situation is to prepare the lab engineer or the lab management to promptly reply to all the questions posed by the user during the experiment assisted by a list of FAQs (Frequently Asked Questions) which is periodically updated.

6.2.1.6 Prelab feedback survey

The second small sub part of this survey was in the form of short answers. The user in this case, has to write down his suggestions, understanding of the concept or his economical experience in the scenario when such a lab gets implemented. The focus of questions asked in this survey was:
1. List most important advantage and disadvantage of TeleLab (as per the participant).
2. A rough idea of travel time and travel cost which could be saved in case of the individual participant for every experiment performed remotely
3. Individual suggestions from the participants for the improvement of TeleLab to increase its acceptability and performance

Extract of responses to the first question as provided by the participants were-

The participants liked the following about TeleLab:

- Travel time and travel costs could be saved. This way, student can manage more time with the experiment and understand it better.
- Flexibility and ease of work
- More time with family and friends. A better work-life balance
- It is possible to perform experiments in inhuman conditions or inaccessible/dangerous environments like nuclear sites, explosion sites etc.
- Scientists, researchers can work together effectively as compared to before from all over the world
- Latest and cutting edge technology could be accessed by users located in remote places across the globe
- A platform for speedy transfer of scientific knowledge
- Reduction/elimination of instructor and infrastructure costs
- 24 hours/ 7 days availability of the lab infrastructure for the users

Worries/Concerns expressed by the participants:

- Absence of face to face communication
- Possibility of not receiving immediate answer if certain question is asked by the user
• More possibility of data getting vulnerable to theft or illegal attacks or damaged if not backed up properly and safely
• Possibilities of misunderstandings or miscommunication over internet communication is higher as compared to real communication
• Concerns over TeleLab working independently without any assistance and in case if assistance is required due to failure, it should be provided immediately
• Investment is involved to make existing labs available over internet. Might be additional technology or infrastructure is required
• Concerns over IT security and infrastructure. Misunderstandings or language miscommunications might occur while speaking to lab engineer over internet medium.
• The idea is innovative but in testing phase. Users are not very well informed/experienced about this concept which would take some time to settle down.
• The hardware cannot be built by the user on his own though he can work with the hardware and get the functional experience.
• Lab quality depends on speed and quality of internet available.
• Certain failures related to devices (instrumentation failures) could be solved only when the person is located at the lab site.

6.2.1.7 Economic significance of TeleLab

One of the important advantage of TeleLab is that it saves travel time and travel costs. The second question of this survey was asked to get an idea about how much costs or time could be saved by the participants if they decide to perform the experiment over internet. After analyzing the responses, it was noted that 2-5 hours per experiment could be the travel time which could be saved by the participants if the same experiment is performed remotely. 5-10 € per experiment could be saved as travel costs. Since most of the participants were either located close to the lab, the significance of cost saving appears less. Moreover the transport system of Germany is one of the standard system of world and hence the loss of time during travel for the participants is relatively limited. However, if analyzed on the backdrop of poor transport infrastructure in most of the developing countries, the time saving due to travel would become significant. Most of the participants were students with semester ticket to travel inside the state. This system of semester ticket in Germany enables students to travel at very low cost. That might be another reason why the travel cost saving was less significant. However, the author believes that participants from countries where no such semester ticket system for students exist and where the costs of travel are high would benefit significantly from the concept of remote labs.

Some of the participants who stay close to the experiment site informed that during harsh winter or bad weather conditions, they would prefer to perform the lab from home rather that coming to the lab. Some other participants responded that even though the savings in terms of travel costs and travel time may not be large, they would save energy by performing the experiment from home. Some of them replied that on particular days there are no lectures and that they have to travel to the University only to perform the lab. In such scenarios, they would prefer to perform the lab from home. On such days, the worth of performing experiments from home is more. Some of the participants feel that bigger advantage of TeleLab is the flexibility of work management that is offered. The user can plan his work to earn for his living with higher flexibility.
6.2.1.8 Suggestions to improve the educational value of the experiment

Educational value offered by the experiment was the topic behind framing this question. The lab management is committed to try in different ways to ensure that higher educational value is delivered. This question asked the users their opinions about developing the lab further to increase its educational value. The responses were analyzed and noted as below:

- To divide the experiment into three phases: simulation phase, system development phase and advanced experiment phase. Simulation phase could be completed from remote location. User can visit the lab and built the system. This would provide user the required hardware development experience. The third part to conduct advance understanding of the experiment could be performed from remote location.
- The user manual could be made informative. Lab structure could be designed so that at different stages of the lab, supportive basic literature or research oriented literature could be added.
- The experiment can be performed more number of times or more time could be spent with the experiment to increase the educational value.
- Lectures could be synchronized with small practical experiments. During the lecture, lab equipment could be accessed over internet from the lecture hall and the required concepts could be practically explained to the users to increase the educational value.
- Motivation and advantages of remote experimentation should be clearly explained to the users before performing the experiment.
- Introductory video guiding the users to build up educational approach about the experiment and explaining its worth in industry could be prepared.
- Lab focused manuals and literature contents would educate the user about the lab.
- A Powerpoint Presentation (PPT) showing graphically the functionality of TeleLab and presenting some of the TeleLab examples in operation.

6.2.1.9 Informative technical quiz for better system understanding

A technical quiz is developed to inform user about the technical data of the equipment which would be used during the lab. User is asked to answer the multiple answer quiz. Even if the user attempts wrong answer, he would be informed with the correct answer at the bottom of the page. This method of developing the quiz helps the tutor to transfer lab specific information to the user without asking him to go through long descriptive texts. An example question which could be asked in the quiz is the rated capacity of wind turbine in watts and the wind speed at which it is achieved.
Fig. 6.7 The technical quiz for assessment

It can be observed from figure 6.7 that even if the user has provided wrong answer, he is informed that his answer is wrong and at the bottom, the correct answer is displayed. At the top of the figure, day, date, time and grade information of the user could be noted. This provides information to the tutor about the user knowledge and preparation for the lab. The user is expected to repeat the quiz number of times as long as the required grades are achieved by him. The interactive nature of the activity ensures that the user shows readiness to perform the activity and as a result prepares himself better for the lab.

6.2.2 Post experiment knowledge analysis

This part of the preparation phase is prepared to collect feedback from the user about the performance of different factors of TeleLab. Some of the questions framed under this activity are-

- TeleLab performance
  - Feedback about performance of TeleLab whether the participant found it very good, good, satisfactory or unsatisfactory. This question is aimed at knowing general response about the complete lab from the user. The users with satisfactory or unsatisfactory responses could be followed up to know the reason behind their response. As could be observed in figure 6.8, out of the total participants, 55% responded with “very good” feedback while 45% responded with “good” feedback.

Fig. 6.8 User feedback question 1
There were no participants who were unsatisfied with the remote experiment concept. The idea of working in remote environment and the use of camera to perform live measurements were some of the reasons behind their positive responses.

- **Ease of user-interface for the experiment**
  - The aim of this question is to understand whether it was easy for the user to use the interface and whether it was user-friendly. A web browser from Firefox or internet explorer could be used as interface between the user and the experiment. The user response could help the tutor to determine if there is any issue with the use of this interface. 77% of the users shown in figure 6.9 found the interface user friendly and easy to use while rest 23% found it satisfactory.

![Ease of User-Interface?](image)

**Fig. 6.9 User preparation question 2**

Inconvenience explained by some users:
Concern informed by the users was the lack of possibility of viewing the complete experiment screen in a single window without using the slide bar. The view of the user interface shows the camera control on the left side, camera view in the middle and the large part of the screen on the right side for working on the experiment PC. The purpose behind such setting was to enable user to use the camera, view it and use the experiment PC without need to change the screen. However, these results in reduction of the size of window of experiment PC accessed and hence with the help of slide bar, the remaining view of experiment PC should be observed. This compromise however is important to have a complete view of the live camera and experiment PC next to each other.

- **Performance of the camera (picture quality, use of camera by the user, rotation, focus etc.)**
  - The response of user to this question would be analyzed with respect to the quality of image delivered by the camera in figure 6.10. The camera control enables user to adjust the focus of camera or to tilt the camera or to rotate it by 360°. It also offers the user to use the saved camera positions and focus it on the hardware of interest to the user. There are eight camera positions. Out of which, five positions are pre-defined by the lab tutor and three positions are left for the user to define them as per his requirement/convenience. The user can define his own camera positions for easy and fast access.
Problems discussed by users:
Instability of camera because of local users. The camera is mounted on a table to offer better flexibility. However, because of local users if the table is touched then the camera vibrates along with the table which disturbs the live image. The solution to this problem could be to mount it on a stable surface so that in the incident of vibrations of the table due to local users, the camera remains unaffected. Second problem that was discussed was improper light intensity. The light intensity on certain hardware components was less because of which they were not properly visible to the remote user. This could be solved by placing a new light focused on these particular devices. Placement of certain devices could be changed so that they could be captured properly by the camera. It could be thought of investing on one more camera and focus it on hardware components which are accessed improperly since the limited space does not allow too many changes in the device placements.

• Degree of isolation experienced by the user from the experiment
  o The experiment is performed over internet from remote location. There is possibility that the user might feel some isolation between himself and the experiment. The aim is to reduce this feeling of isolation. 88% of the users shown in figure 6.11 responded by saying that they felt degree of isolation between themselves and the experiment. This was expected since the degree of isolation is probably felt while performing remote experiments.

Problems discussed:
One of the possibilities could be slow internet speed or slow exchange of signal information between the experiment and the user. Another reason could be delayed images of the live camera. This means changes visible through the camera might occur in a delayed manner after the user had made changes remotely to the experiment set up. The solution to this problem is internet connection with high data transfer speed.
Another suggestion could be to avoid continuous sharing of live images through camera. The user can use the live camera intermittently so that more bandwidth would be available for data monitoring and control. However this might reduce the real lab experience of the user. But, a compromise has to be found out by the user in this situation. Another solution is to view the camera with lower resolution option. The user can decide the resolution of images displayed by the camera. Three resolution options are available. The user can switch between these resolutions as per his requirement.

- User experience of working with real experiment
  - The user is working with real equipment but he cannot touch the hardware or the measurement devices. Information is exchanged with different experiment devices through computer and PLC. In this process, user might lose the feel of working with real equipment. Noise of hardware devices in operation or noise of people speaking in background can provide the user, the feeling of working with real lab environment.

Presence of live camera played an important role to provide real lab experience. 79% of the participants shown in figure 6.12 responded positively saying that even the experiment was performed from remote location over internet, they felt that the work was done with real physical equipment. 21% of the participants noticed the remoteness strongly and felt that the feeling of working with real equipment is absent.
• Understanding of practical aspects
  o Is this lab designed and structured properly so that the power system concepts of the user are explained satisfactorily. Almost 90% of the users answered this question positively. They explained that the literature material available on MOODLE platform, the pre lab survey, different audio-video presentations helped them to get a good understanding about practical aspects. The fact that the equipment under operation is real helped them to test some programs and make certain observations to clear their understanding about functionality and operation of different devices and the experiment.

• Improvement in understanding
  o Does the user feels that his understanding of the experiment is improved? Since, the user has received more time to spent with the experiment as compared to the time he spent during traditional lab, has that improved his understanding? 100% of the participants responded positively to this question since they felt that the flexibility of scheduling the experiment as per their convenience enables them to select the time of the day to perform the experiment when their work efficiency is the best. More time spending with the experiment helps him to improve his understanding about it and about the renewable energy technologies. The structure of the lab and the methods used to provide required knowledge to the user play significant role in improving understanding. The availability of lab engineer over chat and the user participation in social forums enhance the possibility of understanding.

• Flexibility in managing the tasks
  o This response evaluates the flexibility offered by TeleLab to the user with respect to place, time and travel in comparison to traditional lab. The participants appeared unanimous over this question of flexibility. The flexibility offered not only saves travel time and costs but also help them to manage their other jobs effectively. The time spent in traveling could be used for other useful activities by the participant.

• Use of TeleLab for future
  o This response evaluates if the user was really satisfied with the performance of TeleLab and if he would suggest other users/colleagues or friends to use this concept to perform experiments. All the users were satisfied with the possibilities offered by remote labs. They were of the opinion that provided better response time, safety and security of the equipment is assured, they would use it and also suggest it to their friends for future use. Due to the advent of Industry 4.0 concept and extensive use of cyber physical systems like iPhone, iPad etc., participants believed that remote labs could be positively looked forward in coming future.

• Effectiveness of internet communication medium
  o The users have provision to discuss the issues of lab with lab tutor or lab colleagues over internet mediums like chat, audio-video calls. Was it effective and easy to use such mediums was the focus of this question. The participants suggested that they frequently make use of internet medium for communication like chats, audio-video platforms and hence the use of these mediums to interact and to perform the experiment was done without any inconvenience. However, most of them suggested that in the event of
availability of good internet bandwidth, they would use audio-video chats as compared to text chats for communication.

- Ease of writing lab report
  - As compared to traditional lab, user can document the measurements and note down the observations directly into word document and prepare the lab report easily. Did the user too found it easy to prepare the lab report? This question was answered positively by most of the users. The users felt that as they do not have to move all-round the experiment with notes/paper in hand to make observations and note them down, it becomes much easy to document the results and measurements. If the experiment is performed with other colleagues, collection of results to document them becomes much easier over internet. The user can start the process of report writing in parallel with performing the experiment. This otherwise could not have been possible with traditional labs.

6.2.3 Feedback system for evaluation and analysis

The evaluation, assessment and overall performance of the TeleLab is monitored, controlled and periodically improved using a feedback concept. It works similar to the idea of feedback loop in control systems.

Fig. 6.13 Feedback mechanism for TeleLab performance analysis

As is visible in Fig. 6.13 the feedback mechanism is defined with parameters which act as reference parameters for evaluation and analysis of the performance of the lab. The purpose of feedback mechanism is to ensure that the reference parameters satisfy the defined standards and as required modifications or improvements could be implemented. Educational value offered by the experiment, real lab experience, ease of performance, clarity of contents along with safety and security in performing the experiment where some of the parameters which were monitored, updated, tested and evaluated to ensure a high standard experimentation. These parameters are evaluated by the lab tutor/management and as required necessary updates or modifications are made in the experiment. After performing the experiment,
feedback is collected from the user which is analyzed by the lab tutor to provide suggestions for improvements of the experiment or to solve issues related to the experiment.

6.3 Grade based evaluation and analysis

In MOODLE, it is possible to define the lab completion settings. Different activities are created by the lab administration for the user to perform them before and after the experiment. These activities include technical quiz, hardware quiz, discussions through chat forums and social forums, pre and post experiment knowledge analysis questionnaires and some other useful activities. Depending upon the completion of these activities, the grade of the user could be finalized. It could be defined that the activity would be considered as complete if either some of the defined activities mentioned above are completed or all of the activities mentioned should be completed. If the user satisfies this condition then his activity is marked as complete. Failing to do so, would not qualify user to perform the experiment. Other factors like enrolment duration or condition that some other courses should be completed could be used to evaluate the user grades. One specific condition called as “Course grade” is available where the tutor can define the minimum grade that the user should achieve at the end of these activities. The minimum grade defined to be able to perform the experiment is 80%. Based on the structure of different learning activities and the experience of the tutor, this grade was defined. The user can perform the tasks as many number of times as he wishes but he has to attain the minimum grade defined before he is eligible to participate in the lab. The condition for the grades could be defined only by the tutor. For this purpose the administrator should access the section under “course administration>course completion”.

![User report](image)

Fig. 6.14 User grade report

As it is visible from the table above, the activities like technical knowledge of the experiment quiz, hardware quiz named as wind turbine specifications, pre and post experiment knowledge analysis and TeleLab preparation activity are listed in the column to the left. Grade, range and percentage are listed in the subsequent columns. The user name appears at the top. This user has secured an overall grade of 99, 69% which qualifies him to perform the experiment as visible in figure 6.14. Every user performance regarding the experiment activities could be analyzed in detail using the user report. This report also helps to understand the user participation under different activities and the educational value of the user upgraded after this exercise. Under the “grade report” section, comparative analysis of the performance of
participants could be done. This data could be exported in the form of OpenDocument spreadsheet or plain text file or as excel spreadsheet or as XML file. The data made easily available in excel file for example makes the work of analysis easier. There are course completion or activity completion sections which inform the administrator about the activities completed by the participants and the percentage of overall course completed by them. Under the “statistics” feature, the administrator can view graphically the overall activities performed during certain time period. This includes number of students, teachers and guests who logged into the lab course and performed the activities.

6.4 Evaluation and analysis based on remote performance monitoring of the user

It is possible for the lab engineer to remotely login to the experiment PC in “view only” mode and monitor the performance of the remote user. The lab engineer can monitor the systematic progress of the experiment by the user. He can monitor whether the user understands the description of the experiment on the web site/user manual and in case if the user has problems then what approach is followed by the user to solve the problems before referring them to lab engineer who remains available over chat or audio-video medium.

6.4.1 Time taken to complete tasks

The experiment is divided into five major tasks. Every WinCC visualization screen is developed with time parameter displayed on it. The standard time expected to be taken for completion of every task is internally defined by the lab tutor based on performance of different users and based on his own experience of testing the tasks. The delay occurred in completion of tasks by the user may depend on different factors like structure of the experiment, clarity of content, formulation of tasks and formulation of targets to be achieved by the user, complexity of performing the tasks, proficiency of language in which the experiment is described, understanding of the experiment by the user in advance through different activities and so on. All these factors would be monitored and the user performance would be evaluated by rating these parameters. If the time taken by the user to perform a particular task is more than the average time taken by users to complete that similar task, then the lab tutor would try to identify the reason and if possible correct it. The screen shots of WinCC screen showing the status of measurements and results at the end of every task, which the user is expected to take, informs the lab administration about the time taken by the user for every task. This can be further analyzed for performance evaluation.

6.4.2 Independent problem solving skills

This is the attribute of the user which the lab tutor would be keen to observe remotely when the user performs the experiment. The feedback mechanism of the lab management ensures that the problems faced by users are either eliminated or assisted as early as possible. Despite of that in case if the user faces certain problem then the method or approach followed by him to solve it and arrive at a solution before taking help from the remote lab tutor would be observed. Based on this observation, user performance could be evaluated. For example, in order to inform a technical problem or an administrative problem to the lab management, the user is expected to select the appropriate hash tag and send it to the management. Identification of the problem and sending it in correct form ensures that the problem gets attended and solved by the lab management in minimum time. Selection of incorrect hash tag prolongs the process of problem solving. The user is expected to identify the problem and the corresponding hash tag correctly. The use of information discussed on social forums or social blogs by other users to solve similar problem is considered for evaluation. Even if the user
decides to use chat platform to contact and discuss the problem with his colleagues, it is observed how effectively he is able to communicate the problem and get the solution.

6.4.3 Personal dialog with the User

This method is used to communicate with the user to understand his feedback about the experiment. The user is asked to explain the overall experiment and the steps he followed to ensure smooth completion of the experiment. His understanding of the experiment and the educational knowledge obtained after performing the experiment is evaluated. Areas where he noted the problems like experiment description or hardware/software configuration are noted. This feedback is used to make improvements in the experiment if required and to evaluate the user performance.

6.5 Evaluation and analysis based on submitted experiment report

The report submitted by the user is evaluated with respect to the submission tasks which were defined in the user manual. Some of the parameters to evaluate the report are mentioned in table 6.1. It is verified whether the user has tried to analyze the validity of results with respect to his theoretical understanding of the experiment concepts. In case of programming, has the user made use of innovative ways to implement the program in an efficient way? In case of deviations from expected results or disagreements with the obtained results, has the user identified the probable reasons and explained them in the report. The diagrams used by the user to describe the experiment are clear and understandable? The description and analysis of results presented in the report by the user is acceptable? These are some of the parameters on the basis of which the evaluation of the user is performed.

Table 6.1: Criteria for report evaluation

<table>
<thead>
<tr>
<th>Report evaluation parameters</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are all the tasks submitted?</td>
<td>If a particular task is incomplete then it should be mentioned. The reasons for not completing the task should be found out.</td>
</tr>
<tr>
<td>Arguments about validity of results presented?</td>
<td>This shows the user understanding about the expected results. Logically he should be able to analyze if the obtained results are correct.</td>
</tr>
<tr>
<td>PLC programs implemented and explained with clarity? Are the expected outputs achieved?</td>
<td>PLC programs should be checked for results. They should be checked for comments and logical flow of the tasks of program.</td>
</tr>
<tr>
<td>Are the diagrams/screen shots presented by the user clear and understandable?</td>
<td>As mentioned in the user manual, the diagrams/screen shots should be taken when asked for them. They should be used to support or validate the completion of task.</td>
</tr>
<tr>
<td>Is the description of report correct?</td>
<td>The report should be written in clear language without any mistakes.</td>
</tr>
</tbody>
</table>
7. Discussions and results

The results associated with the performance of the implemented Hybrid power system (HPS) and TeleLab with reference to operation and functionality would be discussed in this section. Different areas of the developed experiment and TeleLab could be focused for discussion. The results could be discussed based on system performances with respect to technical, administration, learning management system and feedback mechanism.

7.1 Discussion of system results focused on technical performance

The HPS consisting of renewable technologies and remote monitoring and control components would be discussed with respect to the performance of technical components. To perform measurements and observations of experiment parameters, visualization screens with the help of WinCC software are developed. Current sensors are used to read the system parameters and display them on the screen of experiment PC. WinCC panels with graphical windows are used to display the experiment results. Solar charge controller is another display device which is used for local observation of system measurements. Multimeter readings could be read by using network camera. 24 V relays are used to control the system load based on charge of 24 V battery. The change of position of these relays could be monitored on the WinCC screen, but could also be observed by focusing the network camera on these relays. Similarly, measurements and control actions for other system parameters would be discussed under this section. The user develops WinCC panels to display the measured system parameters and use them in combination with local hardware display devices to perform the experiment measurements. WinCC panels developed as part of the results of this work are discussed here.

7.1.1 Measurement of technical parameters of the HPS

The system parameters which the remote user is expected to measure and display on the WinCC screen are parameters related to solar panel like solar panel current, voltage and generated power. There are parameters related to the 24 V battery bank and 12 V battery like battery current, battery voltage and power. The load current depends on the relays in operation. As the number of relays in operation increases, the load current also increases. There are parameters with respect to motor, which is used to drive the lab wind turbine like motor speed, motor torque, power output and frequency of the motor. The remote on/off control switch for the motor operation could be checked for its performance. Graphs in WinCC could be developed to display the performance of these parameters over time. Archiving of parameters is displayed and used for analysis at later stage. The desired, actual speed of motor and wind turbine could be determined with the table/graph of measurements that shows wind turbine speed with respect to motor speed. The speed of wind turbine at which it produces output could be measured as part of results of this section.

Developed and tested functionality of WinCC panel for display of system parameters

WinCC panel was developed which displays four switches used for the experiment. The status of these switches is displayed by the buttons with green and red color as visible in figure 7.1. When pressed, the switches display as green and the released status is displayed with red color. As part of the experiment, users are asked to develop similar panel which would include display of measurement values like panel current, battery current and load current. Press/Release action of the relays should be performed with mouse click. Camera could be focused on the hardware to visualize that the relays have changed their status in addition to
change of color on the WinCC panel. Users are expected to verify the values of current displayed on WinCC panel with those displayed by local measurement device with the help of camera. Graphical window offers possibility to analyze the measurement parameters with respect to time. The values are archived in WinCC archive for analysis by the user in offline mode.

Fig. 7.1 WinCC panel for display of system components

These values could be exported to the user for analysis in the event of internet disconnection. These tasks are aimed to make the user learn the skills of developing WinCC panels and display the basic measurement values of system parameters.

Developed and tested WinCC panel for motor measurement parameters

Display of desired and actual speed of motor in Rpm

Additional WinCC panels were developed to display the motor speed in Rpm shown in figure 7.2. The desired speed of motor is the speed selected by the user. The actual speed delivered by the motor is displayed by the circular analog speed display in Rpm on the right side of the panel.

Fig. 7.2 WinCC panel for motor measurement parameters
As part of the lab, the user is expected to develop an on/off switch for the motor so that the motor can be started and stopped from remote location. Implementation of other tasks like development of graphical displays for desired and actual speed of motor or button to switch from one WinCC panel to another or a button to close the current WinCC panel should be completed by the user.

Graph showing ideal speed, measured motor speed and measured wind turbine speed

![Graph showing ideal speed, measured motor speed and measured wind turbine speed](image)

Fig. 7.3 Measurement of motor speed

The graph in figure 7.3 shows the relationship between desired speed, actual motor speed and actual wind turbine speed. A tachometer was used to measure the actual speed of motor and wind turbine. The remote user is expected to set the desired speed of the motor, note down the actual speed of the motor displayed on the WinCC panel and determine the wind turbine speed based on the table and graphs provided. It was observed that the wind turbine achieved speed of 425 Rpm (speed when the turbine produces output) when the motor speed was measured as 433 Rpm and the desired speed set was 468.7 Rpm. As it is asynchronous motor, the measured speed is not constant and small variations are observed. The parameters for the motor are defined in hexadecimal format (as per the technical specifications/requirements). 0-4000 Hex represents frequency range of 0-50 Hz for the motor. The range of speed is from 0-1500 Rpm.

Display of motor parameters like frequency, torque and output power

The user is expected to develop and test the functionality of other motor parameters as visible in the WinCC screen developed in figure 7.4.
Fig. 7.4 Measurement of motor parameters

The logic of PLC program to manage the system load based on charge available in the 24 V battery would be tested and the results of control action for the relays would be verified using the voltage control method.

Developed and tested functionality of WinCC panel features to display the load management task

WinCC panel displaying the concept of load management related to charging state of battery corresponding to voltage control method is visible in figure 7.5.

Fig. 7.5 WinCC panel for load management
Table used for “Voltage control method” is displayed. As can be observed, when the battery is 100% charged then it corresponds to voltage of 27.8V as specified in the user-manual. At this voltage value, all the 4 switches are on and the battery operates at full load. In the visible condition, the battery voltage is 25.1 V which is shown below the battery picture marked with red box. According to the table, this corresponds to charge (>50% <70%). Hence, x5 and x6 loads are off (red color) and the remaining loads x7 and x8 are on (indicated with green color). Two batteries each of 12 V is connected in series to form a 24 V battery bank as shown in the picture. Date and time of performing the task is indicated at the top of the panel. This gives idea about the time taken by the user to perform this particular task. It also serves the purpose of recording the date when the task is performed.

Developed and tested functionality of internet webpage for different tasks with feedback through user “problem notification” feature

The TeleLab experiment was divided into different tasks. A webpage was developed for every task. The aim, learning outcomes, deliverables were specified on this page related to the task.

**Fig. 7.6 Structure of task webpage**

All the technical documents which the user would need to complete the task were provided under the “support files” section. As could be observed in figure 7.6, “problem notification” section was defined. The probable issues related to the experiment were classified as technical, administrative and manual/description related issues. The user has the possibility to click on the arrow next to the main issue which results in a drop down menu. All the associated issues appear in the form of a list. The user can select the issue which he wants to inform to the experiment management team or to the tutor. Corresponding hashtag will appear in the box below. In case if the user wants to add some comments/description to the issue then he is free to do so. After pressing the “submit report” button, an email is sent to the tutor regarding the task and the associated issue. This will be followed and solved by the tutor. Systematic classification of probable issues and a method to inform it (as hashtag) to the tutor ensure efficient communication between the user and the tutor and ensures understanding and solving that issue in less time.
For example, the user has issues related to the Java plug in download required for the experiment. This is classified as administrative issue related to the experiment and mentioned as Java plug in. The hashtag for this issue which appears in the text box is:

#Administrative/Experiment/Java plug-in

After receiving the email by the lab management, the person responsible for solving the issue is immediately informed to take necessary corrective action. In this case, the java plug in download should start automatically once the user is logged in. However, if it fails to download then the user is expected to download the plug in manually. Even if that fails then the user is informed about the link on the website which could be clicked to download the required java plugin. This link downloads the plugin which is stored on the local PC.

The front page of the internet website is displayed in figure 7.7. It shows the navigation possibility for the user through homepage, training page where instructions to perform the experiment along with description of all the tasks are mentioned. The user can navigate to corresponding tasks through this webpage.

Fig. 7.7 Developed webpage for TeleLab

“Experiment” page is where the user performs the experiment which shows camera control, live camera image and the experiment PC screen. “Material” page contains all the lab relevant material or research material related to the area of remote labs. Images, diagrams and videos are displayed to inform the user about the concept and the lab to be performed.
7.1.2 Results of control action of relay for DC/DC converter

A relay is used to control the on/off action of the DC/DC converter. This relay operates based on the charge levels of the two batteries. When the transfer of charge is initiated due to drop in charge of 12 V battery below certain defined level then DC/DC converter is switched on. This is indicated by a LED bulb on the converter.

![Image of batteries and DC-DC converter]

Fig. 7.8 WinCC panel for smart battery energy management

The developed WinCC panel is visible in figure. The condition to initiate charge transfer from 24 V battery to 12 V battery is that the charge level of 24 V battery should be >40% and the charge of 12 V battery should be <30%. Since the voltage control method is used, >40% for 24V battery corresponds to >23.4 V and <30% for 12 V battery corresponds to <12 V. As a result, in the WinCC panel visible in the figure, DC/DC converter is switched on which is indicated by a green circle. This green circle in figure 7.8 shows the on/off status of the converter. If the converter is off then the off status is indicated by same circle. However, this time it would turn red in colour.

7.2 Discussion of system results focused on feedback mechanism performance

As discussed in the section above, reference parameters like educational value offered by the experiment, ease of doing the experiment, clarity in description of the lab, clarity in image/pictures used for the lab content or from camera, real lab experience offered by the remote lab, safety/security of the lab and error communication framework are defined. Monitoring and control of the system by the lab management personnel to ensure that these defined reference parameters meet the set requirement standards is the crucial task. The
performance of the feedback system with respect to these parameters would be discussed with the help of obtained results.

7.2.1 Educational value offered by the experiment

The educational value offered by the experiment is evaluated based on the activities performed by the user. The lab administrator/Engineer used the activity performance profile of the user as one of the criteria to evaluate the educational value offered by the experiment. It was decided that only when the user completes minimum 80% of the defined activities in MOODLE, then will he get the required login data and access permission to perform the experiment. As part of final evaluation based on the educational value offered to the user, the lab engineer is expected to go through the activity profile of the user to find out the activity performance details.

Developed MOODLE Website

This work as discussed in previous sections has used the features offered by MOODLE learning management system to enhance the lab performance. In the figure, the platform offered by the IT department at the University was developed according to the lab requirements.

Fig. 7.9 Developed MOODLE website for TeleLab education

As could be observed in figure 7.9, the page is divided into different sections from A-F. Section A refers to “TeleLab preparation section” where learning activities in the form of forums, descriptions and presentations are highlighted for the user to prepare himself for the lab. Section B refers to pre-lab questionnaire which are informative in nature and could be answered mostly as multiple choice questions designed to enhance the knowledge of the user before the experiment. Section C refers to lab reports, grades and outcomes which the user can access to view his progress. Section D informs the internet address to access the MOODLE website. Section E refers to additional learning activities such as forums, discussions and participant information. Section F refers to activities like chat, quizzes and additional activities offered by MOODLE defined as per the lab requirements.
The analysis of user activity profile on MOODLE platform or on the TeleLab website gives information about following points:

- Active participation of user in different social and chat forums
- Performance of user related to technical quizzes
- Performance of user related to independent problem solving questions
- Whether the uploaded literature like presentation about TeleLab/hybrid power system/renewables are followed by the user
- Whether the user has gone through the research papers section
- Whether the user has gone through the media such as videos

Rating of user activity profile is one of the method used to determine the educational value offered by the experiment to the user. Rating of lab report submitted by the user was another factor that contributed to the educational value. Personal online interview with the user was used as platform to ensure that the user has understood the experiment and associated educational content.

The results were evaluated based on combined performance of the user based on activities performed, lab report and answers to standard questions framed during personal online interviews. The author has good experience of evaluating users based on one-to-one communication as similar tasks were undertaken for traditional labs in the past. Some of the questions which were asked and rated were:

Questions related to theoretical understanding and understanding of the lab performed:
- Explain the concept of TeleLab and hybrid power system as per your understanding.
- Explain the aim and learning outcomes of the lab
- Explain the reasons why certain tasks (if incomplete) were incomplete.
- What difficulties did you face in understanding the experiment or during performing the experiment?

Questions based on activities performed by the user before the experiment:
- Which learning activities before the experiment were useful to make performing the experiment easy?
- Based on user activity (participation in social/chat forums): It appears from the discussion on social forum entitled “…” that you disagreed with the technical background of certain part of the experiment. What is your view about it? Are the doubts still unclear?
- Your chat conversation with the lab engineer indicates the problem with camera/PLC/wind turbine… was it solved satisfactorily? What was the reason for the problem? Ignorance of the user or discrepancies in the description or material provided?

Questions based on research associated with TeleLab, renewables, hybrid power systems:
- Which research papers uploaded on the websites (MOODLE and TeleLab website) could you study?
- What was the focus of research of these papers?
- What are your views about the proposed research ideas, their possibility of getting implemented and user’s suggestions/comments about those ideas?
- Any additional research resources, tutorial or relevant labs studied by the user to increase his knowledge?
- Suggestions to the user to refer research conferences, research material or relevant websites which suits to the topic of his interest regarding TeleLab for renewables.

The overall process of grade allocation was focused on preparation for the experiment (preparation phase), execution of the lab (execution phase), deliverables and report writing (lab report) and personal dialog as shown in table 7.1. A comparative analysis of the educational value offered by the experiment performed with traditional labs and remote labs was performed.

**Table 7.1: Grades allocation**

<table>
<thead>
<tr>
<th>Distribution of experiment phases</th>
<th>Grades allocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation phase</td>
<td>10</td>
</tr>
<tr>
<td>Execution phase</td>
<td>20</td>
</tr>
<tr>
<td>Deliverables and lab report</td>
<td>10</td>
</tr>
<tr>
<td>Personal dialog with the user</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
</tr>
</tbody>
</table>

The overall results of experiment were performed in two parts by 40 users. 20 users participated for the TeleLab experiment while 20 for the traditional lab experiment. The results cannot be compared directly per user since the users are different with different skills and abilities. However, they provide an overall analysis of the capability of both the labs to offer educational value to the users. It was ensured that the users had no prior knowledge of the experiment. The users who participated in the process were new to the experiment. The author felt that there should not be any background knowledge effect on the performance of the users. It has to be understood that while performing the experiment using traditional labs, the user is expected to prepare before he arrives in the lab but there is no method to evaluate his level of preparation except based on the way he performs during execution of the lab. The lab engineer allows students to perform the lab irrespective of their level of preparation for the lab. It depends upon individual users how they plan for preparation of the experiment. Experiments in traditional labs are performed in groups of two, three, four or sometimes five users. In certain universities, with large number of users, groups of 7-10 users is possible. Many a times, due to infrastructure issues, a certain group of users perform he lab and the rest of the users have to observe it. For this analysis, traditional labs with group of five users were considered. This means, five users formed a group and performed the experiment in which it was expected that the students would decide on task sharing among themselves. The results would be documented and later on added into the lab report. Time of one week was provided to assemble the results, prepare the report and submit it to the lab engineer. Users were asked for appointments to conduct personal interviews regarding the lab conducted by them. Under remote lab concept, experiment was performed individually by the user and not in group. Reports were written individually and users were asked to refer the “Material” section on the website to update themselves about the latest knowledge of hybrid power system and TeleLab in the form of research material, presentations and videos.

The purpose of conducting a comparative analysis of traditional and TeleLab to assess user performance was qualitative and not quantitative in nature. Hence the number of participants who performed the experiment in traditional and TeleLab environments was small. The author designed different phases like preparation, execution, report writing and personal interview to understand different reasons, opinions and motivations of the participants towards TeleLab
and the remote lab experimentation environment. The purpose behind collecting this
descriptive data was to evaluate and assess user feedback to enhance the quality of knowledge
and education offered to the user. Platforms like Chat forums or social discussion forums or
the descriptive user feedback responses were designed so that the users can qualitatively
describe or express their experience regarding TeleLabs. The purpose of personal interview
phase with the participants was to carry open discussion to note the qualitative development
of the participant after the experiment. The survey activities were designed not to collect
quantitative data about the participants but to record their motivations and opinions and to
serve the purpose of education and knowledge transfer. Some of the questions asked to the
participants as part of surveys expected them to describe advantages/disadvantages of
TeleLab and to provide suggestions to improve the remote lab experience from their
perspective. This clearly indicates that the purpose was qualitative and not quantitative.
Report writing phase evaluates the understanding of the participant about the experiment.
Hence, even though the number of participants evaluated under both the labs is restricted in
number, the purpose of analyzing user performance as part of qualitative analysis is
satisfactorily achieved.

![Fig. 7.10 Overall grade based performance results (1-10 users)](image-url)
The results displayed by first group of 10 users under traditional and other group of 10 under remote labs could be observed in figure 7.10. The maximum grade achieved by student with remote labs is 42 and minimum is 35. The grades are shown by blue line at the top of the figure. The average grade was calculated to be 39. Traditional labs performed in groups of five were evaluated and the results show a maximum grade of 43 and minimum grade of 26. The average grade calculated was 34. Users under traditional labs who did not prepare for the lab or who participated inactively in the lab were graded poorly. With remote labs, since every student had to perform the lab individually and had to go through the preparation phase, they were well prepared. This brings the author to conclude that depending upon the quality of preparation activities designed, the educational value offered by the experiment would vary significantly. Another set of 10 users under each lab environment were asked to participate. The results could be observed in figure 7.11 which shows similar trend.

Fig. 7.11 Overall grade based performance results (11-20 users)
The maximum grade under remote labs was observed to be 42 and minimum of 30. The average grade for these 10 users was calculated to be 36. With traditional labs, maximum grade was observed to be 41 and minimum as 26. The average is 30.

Discussion of results of preparation phase of 10 users under remote lab and traditional lab

Results of preparation phase are noted as in figure 7.12 for the first set of 10 users each under both the labs.

![Comparative Chart: Preparation Phase](image1)

Fig. 7.12 Preparation phase grade based performance results

It can be observed in figure 7.12 that even under traditional labs, some of the users were prepared to perform the experiment like user one, five, eight and nine while users six, seven and ten were poorly prepared. This could be understood by evaluating the nature of questions posed by them to the lab engineer during the experiment, mistakes committed by them, level of interest and participation shown and based on the personal interview conducted with the lab engineer. Similarly, other phases could be discussed as visible below.

![Comparative Chart: Execution Phase](image2)

Fig. 7.13 Execution phase grade based performance results
The execution phase chart has shown in figure 7.13 evaluated users who could perform the experiment better as compared to other users who have to act as observers since they were performing in a group of five. The situation would become bad as the number of users in a group increases. Performance grades of traditional lab users were restricted to 15 or less in most of the cases which involved inactive users in a group. The remote location of users with remote labs also affected the execution performance to some extent. This task was evaluated on scale of 20 points. Parameters of the user like active participation, spontaneous questioning to the lab engineer, systematic analysis of the task, problem solving during the experiment were considered. Traditional labs offered users opportunity to work directly with the experiment but since the group of five users worked together, users six and seven, for example, did not get enough time to spend with the experiment or they were not actively involved to take initiatives to perform the tasks. They either preferred to observe their colleagues performing the experiment or did not take active participation in discussions. Hence, their grades were poor. Seven out of ten users of traditional lab had their grades were either 15 or less than that. On the contrary, users could spend more time with the experiment under remote labs and almost all of them touched the average required score of 15.

![Comparative Chart: Report Writing Phase](image)

**Fig. 7.14 Report writing phase grade based performance results**

The report writing task in figure 7.14 had a good overall evaluation by both traditional labs and remote labs. However, by remote labs, tasks like collection of results from colleagues was avoided since individual users had the results documented and ready to be inserted in the lab report by the end of the experiment. This saved time while preparing the report. Time required by users of remote labs to complete and submit the report was quiet less compared to traditional labs. Fewer mistakes were performed since the data was stored at single place. It was relatively easy to prepare the report for remote lab users. On the contrary, users of traditional lab submitted a single report for a group of five users. However, the evaluation and allocation of grades was carried out on the basis of quality of report, documentation and analysis of results and committed mistakes if any. The overall performance was satisfactory for both the users.
Normally, the process of personal dialog with the user was carried out to understand the knowledge gained by the user and also to direct user towards different resources to improve his overall experiment knowledge both from application and research perspective. The general trend as in figure 7.15 which was observed was that the users who were well prepared to perform the experiment also referred to additional material provided on the websites to increase their educational value. Traditional lab users depended on the instructions provided by the lab engineer to increase their knowledge and education about the experiment which were limited in sense. As a result, the performance of remote lab users was found to be better as compared to traditional lab users.

Based on the results discussed in the section, the author would conclude that the design of educational activities in the preparation phase, clear and simple formulation of tasks to execute during the experiment and a platform with rich source of resources for further study to the user are significant parameters which would define the educational value offered by TeleLab.

7.2.2 Quality and clarity of content results

This refers to the quality of contents uploaded on the websites which includes presentations, diagrams, pictures, videos and research material. The user can inform about problem regarding images or task description to the lab engineer. For this, after every task, he can use the hashtag defined message format. Some of the problems reported by users during the experiments performed were regarding inability to open documents under the material section of the website, lack of clarity about description of task 2 and deliverables associated with it. For this purpose messages used were-

#Manual/material: Link to document 4 not working
#Manual/description: Description of Task_2, section 2.3, point 2 unclear/difficult to understand
Both these problems could be removed by ensuring that the corresponding document link works and the description is simplified so that the user understands it correctly without confusion.

7.2.3 Real lab experience offered

The remote user is connected with the experiment through the web browser. Unlike traditional lab, the user cannot touch and feel the hardware, connect or disconnect a measurement device or adjust local displays. It is possible for the user only to access the local computer and the PLC. Further communication with different devices occurs through PLC. Even though the user works with real equipment, he might not get the feel of real lab experiment. To improve this experience of the user, network camera and possibility of audio-video communication is offered under the concept of TeleLab. The network camera shows live experiment images to the user. The user can control the camera movement using the camera control panel. This enables user to focus the camera or to zoom the camera and make measurements or observations from local measurement devices. The user for example can verify the functionality of local hardware devices by observing them through camera. The involvement of live camera images, interactive nature of camera and audio-video interactions with lab engineer or lab colleagues enhance the real lab experience of the user.

Usefulness and contribution of social/chat forums while performing the experiment, contribution of audio-video media like DFN to interact with lab engineer or with the colleagues during the experiment was considered with respect to technical performance of this sources as well as the user opinion.

Discussions:
Most of the users were satisfied with the camera performance and were also satisfied with the functionality of DFN platform to simultaneously communicate with multiple users or with lab personnel as required over multiple cameras. Efficient performance of these platform ensured that the user enjoyed real lab experience.

7.2.4 User problems feedback performance

As discussed in previous sections, process of fast error identification and elimination was thought. As part of this process, error hash tags were defined which would help the lab administration to identify and eliminate the error in short time. Users on every task page were provided with error notification option with a drop-down menu where all probable errors were listed. The user if comes across some problem during the experiment which he thinks should be eliminated or improved then he can select one of the error hashtag depending on the problem and press the sent button. The lab administration would be informed per email about the issue which would be eliminated as per the requirement.

Discussions:
The hashtag message method helped the lab administration to identify the problems at the earliest without going through long text describing a particular problem by the user. The possibility to select the corresponding error message through the drop down menu under the error notification section after every task, maintained the uniqueness of informing the problem to the administration. The overall experience was satisfactory.
7.2.5 Safety and security measures for the lab and personnel

The safety measures implemented to ensure information security of the equipment has worked well for the lab. User authorization methods, regulation of user access rights and user priorities, active monitoring of the user performing the experiment by lab management as required, periodic software maintenance and several measures discussed in section 2.5 of this work ensured that the information was secured. The operational safety was ensured by implementing different measures like to include the PLC programming as part of pre experiment test so that the user is informed in advance about correct and logical programming practices. TIA portal- the software platform for PLC programming takes care that the syntax errors are eliminated. Following table was implemented to ensure that in case of faulty sensor or actuator responses, damage to the equipment could be avoided.

Fault handling mechanism
As discussed in [49], probable faults which could occur due to faulty sensor readings or actuators or combined sensor-actuator responses are handled with the mechanism shown in figure 7.16.

Fig. 7.16 Mechanism to handle system faults

The performance of system components might get affected along with ageing which might affect the overall system performance. Sensor or actuators may affect the process of exchange of signals in improper manner which might produce wrong measurements or might affect system behavior. In this section, in case if it happens then the probable system interlocks would ensure that the effect would be cross checked. Different scenarios are discussed below:

Discussions: In the event of faulty readings by current sensors

A chart of standard readings from current sensors for different conditions is provided to the user. If the readings obtained by the remote user are deviating from the reference readings then the user is expected to use the camera to make use of local measurement devices to perform measurements. If the readings obtained by local measurement devices are agreeing with the reference readings then the fault lies with the current sensors which should be informed through the “problem notification” feature to the lab tutor. The implemented system
interlocks ensure that the negative impact of faulty sensor readings on other system components is nullified or minimized.

In the event of faulty motor on/off control

There is possibility that the PLC output signal to switch on/off the motor might not work because of some fault. This however is verified during task 2 where the user is expected to develop and test the functionality of motor switch through the WinCC screen controls. In case, this does not work then the user can inform the tutor about the probable fault. PLC being the monitoring and control unit, it is expected that system safety and security related functioning of it is regularly tested.

Fault in PLC output signal to the motor when the motor or wind turbine is working

This is a critical event when the motor and the wind turbine are in operation and due to some fault the PLC output signal to the motor is not delivered. In this case, the motor would continue running at the defined speed till it receives a stop signal from the PLC. The user is expected to inform the lab tutor who would take necessary action to stop the motor. The lab administrator if required might use communication medium other than internet like LAN or mobile telecommunication medium to reach the motor and switch it off. A mechanical construction assembly would be beneficial to avoid probable damage.

In the event of internet disconnection

Use of internal PLC timer ensures that the motor and the wind turbine remains in operation for defined time interval. After this time, the wind turbine will be automatically stopped as safety measure. Setting of this time depends on the average time taken by users to complete the task associated with wind turbine. In the event, when internet connection is lost and the user has no control over the wind turbine operation, the internal PLC timer would switch off the motor as per the time set.

In the event of faulty operation of the infrared light protection system

As discussed before, the positioning of the wind turbine and motor assembly ensures that no person in the lab could enter the danger area around the wind turbine. The functioning of the protection system is tested by the lab management regularly. This ensures the reliable working of the protection system. However, due to some faults if the protection system is not able to send safety signals to the PLC then the signal from infrared motion detector sensor would be used to send a motor on/off signal from PLC. If any of the signal from infrared light protection unit or infrared motion detection sensor is detected then the motor is switched off.

7.3 Discussion of results focused on economic costs

TeleLab offers economic benefits to the users, to the host institute and also to the institute which uses the lab by sharing it with the host institute. The results discussed in this section provides an overview about the investments required to be done in Germany to set up a local lab and a TeleLab with respect to personnel costs, maintenance costs and travel costs for users and lab management.
7.3.1 Personnel costs

The HPS Lab requires one lab engineer and one student assistant if the lab is to be performed in local environment. According to the salary rules in Germany, a lab engineer is paid 1000 €/week and student assistant is paid 100 €/week [50]. The time invested in design, development, monitoring and evaluation of the experiment by the lab engineer was calculated to be 16 weeks.

The student assistant assisted the lab engineer in all the activities of the lab from design to evaluation over a period of 16 weeks. The costs could be calculated as:

\[ 1000 \text{ €/week} \times 16 \text{ weeks} + 100 \text{ €/week} \times 16 \text{ weeks} = 17600 \text{ € /semester} \]

These costs should be paid as personnel costs in every University wherever this experiment should be executed as part of semester study program.

With the concept of TeleLab it is not required to hire a lab engineer to work for 16 weeks. The tasks of lab development could be distributed among lab engineer, lab developer, lab assistant and lab evaluator. A lab engineer works for 4 weeks, lab developer for 6 weeks, lab assistant for 10 weeks and lab evaluator for 10 weeks over a total duration of 16 weeks.

<table>
<thead>
<tr>
<th>Position</th>
<th>No. of weeks</th>
<th>Salary/week (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab engineer</td>
<td>04</td>
<td>1000</td>
</tr>
<tr>
<td>Lab developer</td>
<td>06</td>
<td>600</td>
</tr>
<tr>
<td>Lab assistant</td>
<td>10</td>
<td>400</td>
</tr>
<tr>
<td>Lab evaluator</td>
<td>10</td>
<td>200</td>
</tr>
</tbody>
</table>

\[ 1000 \text{ €/week} \times 04 \text{ weeks} + 600 \text{ €/week} \times 06 \text{ weeks} + 400 \text{ €/week} \times 10 \text{ weeks} + 200 \text{ €/week} \times 10 \text{ weeks} = 13600 \text{ € /semester} \]

The figures show that for one time development and execution of the HPS lab, the local environment costs 17600 € while the remote environment costs 13600 € /semester. In one semester, the savings could be around 4000 €. If for instance, 20 Universities want to develop similar lab then the total investment will come around 352,000 €. In comparison, one TeleLab could be shared among 20 Universities.

7.3.2 Infrastructure costs

The table 7.4 shows the costs of different components which are used in the HPS lab developed at University of Soest, Germany. These costs however are onetime costs during the development of the lab. Universities and institutes with good research budgets might afford investing such costs to develop a lab, however those institutes which cannot afford high investments especially from poor or developing countries would find it an advantage to make use of such labs over internet with minimum or no investment.
Naturally, they have to compromise in terms of not getting experience related to hardware setup but these labs would offer them significant learning experience in comparison to simulation labs or theoretical learning experience. If we consider the personnel costs (17600 €/semester), infrastructure costs (7985 €), lab maintenance costs which include electricity costs, equipment calibration and maintenance costs, Programming, visualization and antivirus Software license costs, safety and security expenses and rent of place for the experiment (if not available) around 10-20,000 €/semester then it would be calculated close to 50000 € per semester. In Germany, there are around 150 technical and applied technical Universities. Spending around 50000 € per semester for 150 universities would cost 150*50000 = 7.5 million €. Setting up of TeleLab facilities to share atleast 20% of the work load could bring down the expenses by 1-2 million €.

7.3.3 Travel costs for service engineer and students

This discussion could be significant for companies and training institutes along with educational institutions. A failure that occurs in the lab might require for instance someone to travel from a place like Munich to Soest to diagnose and eliminate the failure. Even if the failure is software or programming related, the same has to be done. The table below gives an idea about the costs which would be spent on an engineer before he performs any diagnosis.

Table 7.4: Infrastructure costs analysis

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Components</th>
<th>Source</th>
<th>Quantity</th>
<th>Total costs (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Steca SCC</td>
<td><a href="http://www.steca.com">www.steca.com</a></td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>02</td>
<td>Current sensors, resistances, other small components</td>
<td><a href="http://www.distrelec.com">www.distrelec.com</a></td>
<td>-</td>
<td>610</td>
</tr>
<tr>
<td>03</td>
<td>Studer AG 500-12 inewave inverter</td>
<td><a href="http://www.smart-powershop.com">www.smart-powershop.com</a></td>
<td>1</td>
<td>520</td>
</tr>
<tr>
<td>04</td>
<td>Solar panel KD-135W</td>
<td><a href="http://www.kyocera.de">www.kyocera.de</a></td>
<td>1</td>
<td>220</td>
</tr>
<tr>
<td>05</td>
<td>AIR 40 wind turbine</td>
<td><a href="http://www.conrad.com">www.conrad.com</a></td>
<td>1</td>
<td>770</td>
</tr>
<tr>
<td>06</td>
<td>Battery S12/41A</td>
<td><a href="http://www.voelkner.de">www.voelkner.de</a></td>
<td>02</td>
<td>350</td>
</tr>
<tr>
<td>07</td>
<td>Battery SBG 12-150</td>
<td><a href="http://www.autobatterienbilliger.de">www.autobatterienbilliger.de</a></td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>08</td>
<td>VLT drive motor FCM 305</td>
<td><a href="http://www.danfoss.com">www.danfoss.com</a></td>
<td>1</td>
<td>535</td>
</tr>
<tr>
<td>09</td>
<td>Mean well DC converter</td>
<td><a href="http://www.distrelec.com">www.distrelec.com</a></td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>PLC</td>
<td><a href="http://www.siemens.com">www.siemens.com</a> [51]</td>
<td>1</td>
<td>1700</td>
</tr>
<tr>
<td>11</td>
<td>PLC software (Step7+WinCC)</td>
<td><a href="http://www.siemens.com">www.siemens.com</a> [51]</td>
<td>1</td>
<td>2400</td>
</tr>
<tr>
<td>12</td>
<td>24 V contactor relays</td>
<td><a href="http://www.siemens.com">www.siemens.com</a></td>
<td>04</td>
<td>160</td>
</tr>
<tr>
<td>13</td>
<td>Solar lights</td>
<td>-</td>
<td>02</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>Mechanical construction on wind turbine</td>
<td>-</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>15</td>
<td>Motion detector</td>
<td><a href="http://www.steca.com">www.steca.com</a></td>
<td>01</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>Network camera</td>
<td>-</td>
<td>01</td>
<td>150</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>7,985€</strong></td>
</tr>
</tbody>
</table>
Table 7.5: Travel costs analysis

| Distance travelled from Munich to Soest | 580 km |
| Time travelled                     | 5.5 hrs. |
| Car rent                          | 100 €/day [52] |
| Petrol                            | 1.45/liter |
| Estimated costs (2 way)            | 240 € |
| Time lost in travel               | 11 hrs. |
| Salary of engineer in Germany      | 1000 €/week |
| Costs due to work loss during travel | 275 € |
| Total costs before diagnosis of failure | 515 € |

Table 7.5 shows that before the engineer performs any failure analysis of the system, his productive working hours are lost along with 515 € that the company should spent. The concept of TeleLab enables user to diagnose and remove a system failure related to software by observing and analyzing the failure from his work place in Munich. He can even direct a local person in Soest to make some changes in experiment hardware or can ask the local person to perform certain tests which could be monitored through camera from Munich. In case if the failure still exits only then the service engineer can travel to Soest. These costs could be much higher if the service engineer is located in a foreign country. For instance, if the service engineer has to travel from New York to Soest then the initial costs could be as high as 2600 €.

As in year 2013-14, 1670244 students were registered in 106 universities and 847233 students were registered in 212 Universities of Applied Sciences in Germany [53]. Out of this, it was found that 35% of the students have to travel 20-50 km every day to the University to perform their studies [54]. If the travel costs are calculated then every lab visit costs the student 12 € of fuel costs and half an hour to one hour of travel time. If 10 labs are scheduled in a semester which could be performed remotely then every student would manage to save 120 € fuel costs. Considering the number of students registered, the amount of money saved would be significant.

7.3.4 Longer operational hours for TeleLab

The time of experimentation possible for local labs could be restricted to eight hours/day. However, the concept of TeleLab offers experimentation time round the clock (24 hours/day). If we consider that on an average, one experiment is conducted for four hours then it means that in a local lab environment one experiment could be performed two times in a day by two different group of students. Every group containing four students, in a day, eight students can make use of the experiment to get trained. In a semester of around 75 working days, 75*2 = 150 labs could be conducted and 150*4 = 600 students could be trained. In comparison, with TeleLab, six labs could be conducted every day. In a semester, 75*6 = 450 labs could be conducted. Even if every single student is made to perform the experiment individually, 450 students would benefit from knowledge of the lab. It should be understood that during traditional labs, a group of four students is planned and hence not every student would get access to all the tasks of the lab. Sometimes students of a group might have to act as observer without actually performing the experiment. But with TeleLab every individual student get hands-on experiment knowledge and experience. The student can select the time to perform the lab as per his work schedule. This means, the student can establish good work-life balance with the concept of TeleLab.
8. Future prospects and summary

In this PhD work, the process of design, implementation of a HPS lab followed by development of TeleLab platform to make the lab available for remote users all over the world is explained. However progress in any field depends upon its development possibilities in future. This development is seen in perspective to technological developments in other related fields. For instance, innovation and research in internet technologies or in the field of web based automation would increase the usability of the concept of TeleLab. Similarly, development of sensors which could be monitored and controlled directly over internet through their IP addresses would strongly improve the application area of web based automation. In this chapter, development of those areas in future would be discussed which would affect the future of TeleLab application.

8.1 Collaboration

Performing a remote lab with single user as compared to performing it with group of users is less complicated due to lack of synchronous execution. However, traditional labs could be performed in groups and the advantages of working in a group should also be possible with remote labs. Hence, future development of TeleLab could focus on developing it so that more experiments could be executed in collaborative sessions with multiple users. The collaborative session application platform offered through EJS App in MOODLE might be one of the examples which offers simultaneous access to the experiment by multiple users located at different locations. The problems associated with executing a lab as collaborative session includes simultaneous activation of instances on the PC screen of every user, bandwidth requirements, and effective coordination between the users through audio-video platform along with safety and security issues. It would depend on how technological developments in future would address these problems associated with collaborative labs.

8.2 Cyber Physical System (CPS) based TeleLab

Industry 4.0 project was planned with a view to ensure development of production centers in Germany in the year 2012. The aim is to merge information processing systems with conventional industrial processes [57]. This results in cyber physical systems which aim at linking real objects with virtual objects using global interlinked information networks i.e. internet. This concept of networking offers high amount of data exchange and services which can be used to make the process of production flexible, efficient and cost effective. An automation pyramid displays a hierarchical structure of interaction between different stages of automation process. At the base of the pyramid is the process/system which could be understood as “level 0” where data is collected usually in binary form. The next level (level 1) is the input/output level where signals are exchanged in and out of the system. This exchange of signal happens with Programmable Logic Controller (PLC) which is placed as “level 2” in the pyramid. The task of PLC is to monitor and control the automation system. The next level is “level 3” of Supervisory Control and Data Acquisition system (SCADA). This level acquires and archives the data and provides management and supervisory control over the system. Operational level is the next level which is “level 4”. At this stage, operation planning, system data acquisition, material management and quality management tasks are executed. The topmost level is the company level (level 5) where order development or production planning at higher level is executed. The pyramid could be understood as movement of data from bottom to top and movement of planning from top to bottom. According to this structure tasks are distributed at different levels. Every level has its own
communication technology and the exchange of information between different levels is limited. As a result, change in production plan is inflexible and can be turn out to be costly. The solution is CPS where large amount of information exchange occurs between different parts of the overall processes and hence high flexibility is offered.

![CPS-based Automation System](image1)

**Fig. 8.1 CPS based remote lab**

In the figure 8.1, different colors indicate different levels of system or different services offered by TeleLabs. Every service would exchange information or would communicate with any other lab service without following any hierarchy. CPS based systems work like internet where easy data exchange occurs and services all over the world could be effectively used to achieve the end result. Every level of the system is connected to each other and to the internet. No hierarchy is followed. In future, TeleLabs could be developed based on the concept of CPS. A TeleLab which works in a hierarchy where the level 0 or ground level are the lab components which exchange signals with PLC which is monitored and controlled by the experiment PC which further is managed and administered by the web server (operational level) which is at the top managed and controlled by the lab administration. This hierarchy of development of TeleLab could imagine as the way CPS works. For this to function, it is required to use sensors/actuators and all the lab equipment compatible with industry 4.0 concept. The purpose is that the lab components which normally communicate only with PLC should be able to now communicate with all the levels up to the management level. All the components of the system such as sensors, actuators, PLC, experiment PC, web server and lab management should be able to exchange data with each other. If the lab equipment could be made available with own IP addresses then they would be accessible over internet and could be directly monitored and controlled. The same concept could be applicable for TeleLabs developed all over the world and offered as services for the purpose of experimentation. The scenario would be interesting to observe when TeleLab developed in Europe could deliver results which could be used as input to another TeleLab developed in Asia. The output results of Asian TeleLab could be analyzed, evaluated and archived by TeleLab in Australia. This means, connecting TeleLabs distributed all over the world with each other and performing experiments in collaboration with different TeleLabs.

### 8.3 Advancement of internet technology

Future of TeleLab depends on technological advancements in internet technology. The bandwidth as discussed in section 8.1 and speed requirements of internet are core factors which would decide acceptance and development of TeleLabs in coming future. Developments are expected in the area of internet architecture and infrastructure as visible in
Construction of fast optical core networks or optimized virtual networks would be useful in using TeleLab efficiently. Research in the field of internet architecture could introduce efficient methods to manage information exchange over internet and to manage overall capacity. Modeling, simulation and measurements related to internet could result in development of self-managed networks. These networks would monitor the use of internet with respect to transfer of data in the form of files, audio or video media during the operation of TeleLab and optimize the use accordingly. Development of communication protocols and uniform platforms to handle different TeleLab applications would play crucial role in defining future use of remote labs. These networks should be resilient so that it has good fault handling capability.

As number of remote labs would increase and many of the labs might function in collaboration with each other, a huge pool of resources in the form of TeleLabs would be formed. Development of internet algorithms and software which could perform the tasks of resource management, resource allocation and scheduling, database management, storage, update and retrieval of lab content would be significant. Progress of research in this field should be closely observed to define the future progress path of TeleLab applications. TeleLabs could be offered as services. This would make both the institute which offers TeleLab service along with the users as potential source of information. The sensors used in different experiments which are currently without IP addresses and are not connected to internet, in future they would possess their own IP addresses and could be accessible over internet. This means, thousands of devices would be connected to internet and these devices would periodically exchange information which should be updated, upgraded and managed remotely and with convenience. This might demand developments of new paradigms for routing, information search, data maintenance and data processing methods. To summarize, it could be discussed that research in the field of internet architecture, infrastructure, modeling,
simulation, algorithms, software, self-management of networks, management of large amount of data would define the future path of TeleLabs.

8.4 TeleLab with cloud computing

Cloud computing, as it is familiar, delivers different services to the user depending on application requirement. It provides hosted services over the internet [58]. Cloud computing is a paradigm shift based on a collection of many old and few new concepts in several domains such as Service-Oriented Architecture (SOA), distributed and grid computing as well as virtualization [59]. The services offered are defined as Infrastructure as a service (IaaS), Platform as a service (PaaS) and Software as a Service (SaaS). Pay-as-you-go is an important feature of cloud computing which gives user opportunity to use massive computation ability and scalability features. Many companies are using these features of cloud computing like software applications, programming platforms, data storage, computing infrastructure and hardware as service offered by various cloud computing providers.

A cloud computing platform can dynamically configure and reconfigure computation resources as per the application. The structure of cloud computing working in collaboration with TeleLab is shown in figure 8.3. These resources can be physical machines or virtual machines with scalable computation resources like CPU, storages, network equipment or other devices. This application of cloud computing resides on a large scale data center or power servers that host the web services and web applications. TeleLab can be provided as service using the concept of cloud computing. Resources required for development of TeleLab which could be in the form of software or hardware devices could be obtained from certain service provider. As per the resources used, the service provider could be paid. It is also possible to make use of another TeleLab offered by a service provider coupled with one’s own TeleLab to perform experimentation. Computation of huge amount of data and scalability are two main features which are required for TeleLab and are offered by the idea of...
cloud computing. Developments in the field of cloud computing could define the future development of TeleLab.

8.5 Summary of the PhD work

This work was focused on developing hybrid energy system based on renewable. Development of TeleLab or remote lab to make the system accessible for users over internet all over the world was another important aspect of this work. To propose a systematic methodology to enhance the educational value of the experiment was another significant part of this work. Use of learning management system like MOODLE to provide the user through different learning methods on internet was achieved by developing internet content on the MOODLE site provided by the IT department of the University. Website was developed specially for this experiment with relevant text, audio, video and research material to enhance the educational experience of the user in the field of power engineering. This scientific contribution of this work as explained in the beginning could be explained in the form of defining best methodology or best practice to provide power systems engineering education by making use of information and automation technology.

A systematic approach was defined considering the safety and security aspects of remote experimentation focused on renewable hybrid power system in terms of data security and hardware security. Users were directed through the experimentation process which started with the preparation phase followed by experimentation phase, report writing and personal interview phases. Parameters and methods were defined to evaluate user performance during all these phases. Remote monitoring of the user while performing the lab was suggested as required to assist the process of evaluation. Visualization software was used to present the user with the experience of experiment parameter visualization. Numerous references and work completed by researchers in this field was studied and analyzed to extract the required knowledge for this work. Performance of the user was analyzed in the form of results with respect to system performance, educational value offered, safety and security aspects and economic advantages. At the end, discussion was completed about the factors and areas which could affect the development of TeleLab in future.

In Chapter 1, the research methodology was discussed which focused on defining the problem at the beginning of this work. It was identified that along with development of renewable energy technology, its management and penetration was significant to solve the issues associated with global warming, uneconomical use of fossil fuels and as a result damage caused to environment. Technology and knowledge transfer of renewable power systems was defined as the focus of this work. Since, renewable energies are distributed in nature, the knowledge to use this technology should be effectively transferred which would also increase its acceptability among consumers. It was discussed that a platform which would be safe, secure, cost effective, easy to use and which would provide possibility to interact with real system hardware should be proposed. The expertise and experience of automation department of soest in the field of information technology and power systems motivated the author to take up the task of implementing a hybrid power system with renewable which could be accessed monitored and controlled from remote location. Aims and objectives of the work were broadly classified as development and implementation of HPS, development of infrastructure for TeleLab platform and use of internet website and MOODLE learning management system to enhance the educational value of the lab experiment. Effective use of virtual experimentation features to offer real lab experience was discussed as one of the objective of
this work. Contribution of this work to science/knowledge was discussed in terms of contribution to action science where knowledge is generated to solve practical problems through user activities on MOODLE, self regulation of learning techniques by the user and through conducting activities like modeling and simulation which contributes to the field of laboratory experimentation. Innovative aspects of this work were discussed in this chapter which includes defining the best approach to perform remote lab experiments with possibility to analyze, evaluate and assess user performance. An effective feedback mechanism between the lab tutor and the participants was aimed to be developed and tested for efficient knowledge sharing and sharing of issues during experimentation. Compatibility of this work with future mobile technology platforms was discussed as one of the new aspect. This was followed by brief definition of the structure of different chapters to be included in this thesis.

The study performed on state of art and literature review was covered in the second chapter. A table listed different areas in the field of engineering and science where TeleLab applications were experimented. Difference between traditional labs, virtual labs and TeleLabs was explained to give the reader a clear understanding about these platforms. Applications of remote labs and projects completed in Germany were discussed. Research work done at different German universities like University of Hagen, Munich, Düsseldorf and Potsdam was elaborated which provided user idea about the nature of work in this field in Germany. Experience of the automation lab of Soest in the field of remote labs, monitoring and control of remote experiments was discussed at the end of this chapter. This included description of international research project “Sunwater” focused on renewable energy for water desalination application. International cooperation project based on remote labs with Cape Town University was discussed with respect to its contribution to the knowledge and expertise in the remote lab domain.

Chapter 3 and chapter 4 explained the design, development, implementation, integration and functionality testing of the infrastructure for proposed HPS and TeleLab. Theoretical background of HPS was followed by describing the working principle of the proposed system. Solar panel system and wind turbine system were explained with their operational features. Algorithms developed for smart energy management between the two subsystems were discussed. Smart load management algorithm was elaborated to help user understand the mechanism implemented for the proposed HPS. Considering the importance of safety and security in the field of remote experimentation, different measures like safety light curtain for lab personnel safety, motion sensor, multiple stage password protection, implementation of PLC internal timer and effective use of WinCC security settings were discussed. Detailed description of all the system components was included as part of appendix for user reference. This was followed by chapter 4 in which popular remote lab architectures like UTS lab and iLAB architectures were discussed in the beginning. This was followed by describing the soest remote lab architecture in detail. A step by step description was provided about the functionality and execution of the proposed remote lab. Different features like development of MOODLE environment, development of website focused on lab activities, web and remote server configurations, use of network camera along with DFN platform for real lab experience were discussed in this chapter.

After the discussion of system and lab implementation, the next logical step was to explain the execution of proposed experiment in a systematic way. It was covered in chapter 5. The experiment was divided into preparation phase, planning phase and experiment activity phase. Preparation phase expected the user to perform different activities on MOODLE in the form
of quizzes, multiple choice questions or study of material in the form of presentations and videos so that he is well prepared for the lab. A minimum achievable grade was defined for the user which should be achieved in case if he wishes to perform the lab. Planning phase expected the user to ensure that his PC satisfies the configuration required to perform the lab. It also guided the user to understand the process of booking experiment slot using the EJSApp booking system. This was followed by experiment activity phase where user could get access to the experiment set up to perform the lab. The experiment was divided into five different tasks. The design of these tasks ensured that after conducting the experiment, the user should develop skills like writing simple PLC routines to read and write system parameters, to monitor and control system hardware and to implement energy exchange algorithms or load management algorithms into the system. After completing the experiment, evaluation and analysis of TeleLab performance was discussed in chapter 6. The significance of conducting surveys before and after the lab for qualitative analysis or the significance of feedback mechanism to promote effective interaction between the lab and the user was elaborated. The purpose of collecting feedback from the user was to understand his level of knowledge about remote labs and also to know his opinions and motivations about working in remote environment. To analyze the performance of the lab, user grade based performance evaluation method was proposed. Factors like run time monitoring of user while performing the lab or well structured interview of the user about the experiment were proposed to further evaluate and assess user performance. Report submitted by the user was evaluated as part of his performance evaluation process.

Results of the work were discussed in chapter 7. Technical performance based results were discussed. This included the performance of the implemented HPS and TeleLab with respect to its operation and functionality. WinCC screens developed by the user were evaluated to understand the skills and knowledge of the user. The values of system parameters displayed on WinCC screens were verified with local measurement devices for accuracy. Functionality of system components based on implemented algorithms was tested for logical correctness. The safety and security components of the system and the lab were tested for their operation. The results delivered by the developed lab with respect to educational value offered, real lab experience or solving of user issues through feedback platform was discussed in this chapter. Results were also evaluated on the basis of economic criteria. The costs in development of the experiment and the lab such as infrastructure costs, personnel costs or cost advantages with respect to travel and related to long operation hours of the lab were discussed in support of remote experimentation concept. The last chapter was written to provide user understanding about future prospects of TeleLab or expected future developments in the field of TeleLab. This included discussion about development of TeleLab platform in future such that it would strongly support the concept of collaborative remote experimentation. This might require effective use of concepts like virtual reality or augmented reality to facilitate collaboration among different users across the globe to perform an experiment at the same time. It was discussed that in future, the concept of hierarchical exchange of information between different experiments of different labs would disappear and that the information like in case of cyber physical systems could be exchanged between all the levels starting from plant level to management level. This would give rise to large amount of data acquisition and processing on internet. Hence, future path of advanced internet technology development was other field discussed that could define the future of TeleLabs. Developments in the area of cloud computing to solve issues like high data computation and scalability were discussed at the end of this chapter. The thesis is terminated in this section with summary of whole work.
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Appendix

8.6 Implementation concept: hardware and software components

8.6.1 Steca: Solar Charge Controller (SCC):

Complete flow of energy can be controlled using the solar charge controller. Solar Charge Controller is directly connected to the battery system. With the help of an integrated energy meter it is possible to measure the energy flow.

All the information regarding charging and discharging current from current sensor is transferred to the solar charge controller. Based upon this data, the controller responds to further changes. It also has integrated digital signal processors. These processors use the data available from current sensor to determine the state of battery system to manage energy critical conditions. It provides protection from overcharge and undercharge of battery system. Solar charge controller can be appropriately programmed with the help of operating unit or serial interface so that it gives optimal performance for a particular energy situation. It is also possible to integrate a wind sensor or radiation sensor or a data logger to work in a remote environment.

Display features of SCC

The display of SCC provides information in the form of graphic symbols. There are symbols as shown in figure 3.10 which display parameters like error messages, State of Charge (SOC), current direction, system status, load, seven segment display for text and numerals, battery and charge during day and night, SOC window, battery voltage window, solar module output current, battery charging current and battery charge. The Ah values displayed are since initial installation or since last reset. In addition, advance warning is displayed in the event of deep discharge protection. Symbols like battery, right arrow, load or bar display will flash when deep discharge protection is active.

Different functions of SCC

SOC calculation: this function calculates the state of charge of battery by monitoring various battery parameters like voltage and current. SOC represents the amount of energy available in the battery.
Charge control: Depending upon the behavior of the battery, different charging methods like normal charging, compensation charging or boost charging is used.

Deep discharge protection: When the battery charge drops below certain level then load is switched off from the battery to prevent further discharge.

Nightlight and daylight functions are some other functions of the SCC

Table 3.1: Solar charge controller specifications

<table>
<thead>
<tr>
<th>Electrical data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating voltage</td>
<td>12/24 V (automatic detection)</td>
</tr>
<tr>
<td>12 V voltage range</td>
<td>6.9 V – 17.2 V</td>
</tr>
<tr>
<td>24 V voltage range</td>
<td>17.3 V - 43 V</td>
</tr>
<tr>
<td>Own Consumption</td>
<td>12.5 mA</td>
</tr>
<tr>
<td>Maximum input voltage</td>
<td>&lt; 47 V</td>
</tr>
<tr>
<td>Minimum battery voltage</td>
<td>6.9 V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Currents</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. constant module current at 25 °C</td>
<td>10A</td>
</tr>
<tr>
<td>SOC&lt;40% or voltage&lt;11.7 V/23.4 V</td>
<td>Load disconnection advance warning</td>
</tr>
<tr>
<td>SOC&lt;30% or voltage&lt;11.1 V/22.2 V</td>
<td>Load disconnection</td>
</tr>
<tr>
<td>SOC&gt;50% or voltage&gt;12.5 V/25V</td>
<td>Load reconnection</td>
</tr>
</tbody>
</table>

8.6.2 LEM current sensor

In the absence of data logger, the current sensor measures DC, AC and pulse currents. Measurement of solar panel current, battery current and load current is possible with this current sensor. It converts input current into output voltage. This voltage measurements are read by the PLC and displayed on the experiment computer.

Principle of use

For voltage measurements, a current proportional to the measured voltage should be passed through resistance $R_1$ which is selected by the user and installed in series with the primary circuit of the transducer.

It is usually used in industrial domain and in applications like ac variable speed drives and servo motor drives, static converters for DC motor drives, battery supplied applications and UPS.

Table 3.2: Current sensor specifications

<table>
<thead>
<tr>
<th>Primary rated current</th>
<th>3 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>2.5 V(+/− 0.625 V)</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>+12…+15V</td>
</tr>
<tr>
<td>Measuring range</td>
<td>+/- 9A</td>
</tr>
<tr>
<td>Response time</td>
<td>3 μs</td>
</tr>
</tbody>
</table>

8.6.3 Studer AG 500-12 500 W sinewave 12 VDC inverter

A sinewave inverter with terminals for battery connection and output 230 VAC terminal though which load can be directly connected to the inverter. The basic knowledge of system concept informs us that sinewave inverter converts DC current to AC current with required voltage and frequency.
Any device designed for the public electrical network of 230 V, 50 Hz can be connected to it. The consumer devices are connected first to avoid any further contact once the 230 V voltage is present. They should be turned off before connecting the battery. A control switch on the inverter can be used to activate or deactivate the inverter. This function can be used to save energy of the batteries when not in use.

### Table 3.3: Inverter technical data

<table>
<thead>
<tr>
<th>Inverter model AJ 500-12</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal battery voltage</td>
<td>12 VDC</td>
</tr>
<tr>
<td>Input voltage range</td>
<td>10.5-16 VDC</td>
</tr>
<tr>
<td>Continuous power at 25°C</td>
<td>400 VA</td>
</tr>
<tr>
<td>Output voltage</td>
<td>sinewave 230 VAC</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Consumption – standby</td>
<td>0.4 W</td>
</tr>
<tr>
<td>Consumption – “ON” no load</td>
<td>4.6 W</td>
</tr>
</tbody>
</table>

**Inverter connections**

Connection of consumer devices should be done observing the colors as below

- Yellow-green = earth
- Brown = phase
- Blue = neutral

For battery connection: black = negative and red=positive

### Functioning indicator (green LED 1)

- Illuminated: 230 VAC output is present and the inverter is on
- Blink: no load (standby) or 230 V voltage is cut due to an alarm
- The other green LED is Battery Lifetime Optimizer (BLO) indicator when this function is activated

#### 8.6.4 Solar panel and halogen lamps

The solar panel used in the HPS is Kyocera 135GH-PU. Maximum power rating is 135 W at 1000 W/m² and 97 W at 800 W/m² irradiance.
Fig. 3.12 Solar panel characteristics

Current voltage characteristics of solar panel at different cell temperatures and different irradiance levels are shown in figure 3.12 above. Irradiance levels from 200 to 1000 W/m² can be observed.

Table 3.4: Solar panel specifications

<table>
<thead>
<tr>
<th>PV Module Type</th>
<th>KD135GH-2 PV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>At 1000 W/m²</strong></td>
<td></td>
</tr>
<tr>
<td>Standard test conditions</td>
<td></td>
</tr>
<tr>
<td>Max power</td>
<td>135 W</td>
</tr>
<tr>
<td>Max system voltage</td>
<td>1000 V</td>
</tr>
<tr>
<td>Max power voltage</td>
<td>17.7 V</td>
</tr>
<tr>
<td>Max power current</td>
<td>7.63 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>22.1</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>8.37 A</td>
</tr>
<tr>
<td><strong>At 800 W/m²</strong></td>
<td></td>
</tr>
<tr>
<td>Normal operation cell temperature</td>
<td></td>
</tr>
<tr>
<td>Max power</td>
<td>97 W</td>
</tr>
<tr>
<td>Max power voltage</td>
<td>16 V</td>
</tr>
<tr>
<td>Maximum power current</td>
<td>6.1 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>20.2 V</td>
</tr>
<tr>
<td>Open circuit current</td>
<td>6.78 A</td>
</tr>
</tbody>
</table>
Since this is a lab experiment setup, no natural sunlight is available. Hence, halogen lamps that could simulate the sunlight are used to illuminate the solar panels. The height of the lamps could be adjusted. Each setup consists of 2x500 W halogen lamps. They are powered with a normal 230 V power source.

8.6.5 Wind turbine AIR 40:

The wind turbine is developed by primus windpower. It has built in advanced microprocessor technology for superior performance and high wind protection without mechanical braking. It is usually paired with solar energy for redundant energy production. It produces 40 kWh of energy per month generating energy in wide range of wind speeds.

Table 3.5: Wind turbine specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>Air 40 Wind Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated capacity</td>
<td>160 watts at 28 mph (12.5 m/s)</td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>1.17 m</td>
</tr>
<tr>
<td>Weight</td>
<td>5.9 kg</td>
</tr>
<tr>
<td>Shipping dimensions</td>
<td>27x12.5x9 in</td>
</tr>
<tr>
<td>Startup wind speed</td>
<td>6 mph</td>
</tr>
<tr>
<td>Voltage</td>
<td>12 VDC</td>
</tr>
<tr>
<td>Controller</td>
<td>Microprocessor based smart internal regulator with peak power tracking</td>
</tr>
<tr>
<td>Kilowatt hour per month</td>
<td>38 kWh/month at 12 mph (5.4 m/s)</td>
</tr>
</tbody>
</table>
8.6.6 Battery system of 24 V

The battery S12/41A used for “solar panel system” is developed by Sonnenschein. It is suitable for use with solar panel applications.

Table 3.6: Battery specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>S12/41A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom. Voltage</td>
<td>12 V</td>
</tr>
<tr>
<td>Nom. Capacity</td>
<td>41 Ah</td>
</tr>
<tr>
<td>Weight</td>
<td>14.6 kg</td>
</tr>
<tr>
<td>Part number</td>
<td>NGSO120041HSOCA</td>
</tr>
</tbody>
</table>

Two such batteries of 12 V are connected in series to get an output voltage of 24 V for the solar panel system. The voltage gets added by connecting in series while the capacity remains same which is 41 Ah. If it is required to increase the capacity then the batteries should be connected in parallel.

In this case, however the output voltage remains constant which is 12 V.

Fig. 3.14 Battery system of 24 V (series combination)

8.6.7 Battery for wind turbine system

The battery SBG 12-150 used for wind turbine system is developed by company Banner. The rated voltage is 12 V

Table 3.7: Technical specifications of the battery

<table>
<thead>
<tr>
<th>Technical details</th>
<th>Technical specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage in V</td>
<td>12</td>
</tr>
<tr>
<td>Charge voltage Max. A</td>
<td>B</td>
</tr>
<tr>
<td>Capacity in Ah C 20 (1.8 V/Z)</td>
<td>150</td>
</tr>
<tr>
<td>Capacity in Ah C 10 (1.8 V/Z)</td>
<td>128</td>
</tr>
<tr>
<td>Capacity in Ah C 5 (1.75 V/Z)</td>
<td>115</td>
</tr>
<tr>
<td>Capacity in Ah C 1 (1.65 V/Z)</td>
<td>101.7</td>
</tr>
<tr>
<td>Length mm</td>
<td>482</td>
</tr>
<tr>
<td>Width mm</td>
<td>170</td>
</tr>
<tr>
<td>Height mm</td>
<td>242</td>
</tr>
<tr>
<td>$R_t$ mΩ</td>
<td>2.5</td>
</tr>
<tr>
<td>$I_k$ in A</td>
<td>4.2</td>
</tr>
<tr>
<td>Terminal no</td>
<td>2</td>
</tr>
</tbody>
</table>
Calculation of required battery capacity:

The required capacity of a battery is calculated depending upon load specifications and rated output voltage (V) of the battery. For example, a load of 100 W and 12 V battery if is required to supply charge from seven hours then the battery capacity is calculated as:

Capacity (Ah) = \((100/12) \times 7 \times \text{battery safety factor (1.7)}\) = 99.16 ~ 100 Ah

This means a 12 V battery if has to supply load of 100 w for 7 hours should have a capacity of 100 Ah.

24 V battery:

- Rated capacity = 41 Ah
- Rated output voltage (Series combination) = 24 V
- Load = 100 Watts
- Safety factor = 1.7
- Hours = \((41 \times 24) / (100 \times 1.7)\) = 5.78 hours ~ 5 hours

12 V battery:

- Rated capacity = 150 Ah
- Rated output voltage (Series combination) = 12 V
- Load = 100 Watts
- Safety factor = 1.7
- Hours = \((150 \times 12) / (100 \times 1.7)\) = 10.5 hours ~ 10 hours

Based on specifications, the 24 V battery system can supply a load of 100 W for five hours while fully charged 12 V battery with capacity of 150 Ah can supply the same load for 10 hours for the wind turbine system.

8.6.8 Danfoss motor with integrated frequency converter:

The VLT drive motor FCM 305 is a compact alternative to traditional solution with a VLT frequency converter.

It is user friendly product that saves commissioning time. Less space is required because the frequency converter assembly is mounted on the motor itself. There is possibility of setting up and controlling the motor through remote control panel or fieldbus communication. For HPS it is planned to use the PROFIBUS connection with PLC to set up and control the motor from remote location. The enclosure is robust and there is no power cable length limitation.
### Table 3.8: Motor specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor output [HP]/[kW]</td>
<td>0.75 /0.55</td>
</tr>
<tr>
<td>Motor torque 2-pole/4-pole [NM]</td>
<td>1.8/3.5</td>
</tr>
<tr>
<td>Frame size [mm]</td>
<td>80</td>
</tr>
<tr>
<td>Input current [A] 380 V 2-pole/4-pole</td>
<td>1.5/1.4</td>
</tr>
<tr>
<td>Efficiency at nom. Speed 2-pole/4-pole</td>
<td>61/66</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>3x380 V</td>
</tr>
<tr>
<td>Supply frequency</td>
<td>50/60 Hz</td>
</tr>
<tr>
<td>Frequency range</td>
<td>0-132 Hz</td>
</tr>
<tr>
<td>Overload torque</td>
<td>160% for 60 s.</td>
</tr>
<tr>
<td>System response time</td>
<td>30 ms +/- 10 ms</td>
</tr>
<tr>
<td>Speed accuracy</td>
<td>+/- 15 RPM</td>
</tr>
<tr>
<td>Programmable digital inputs</td>
<td>4</td>
</tr>
<tr>
<td>Voltage level</td>
<td>0-24 VDC</td>
</tr>
<tr>
<td>Analog inputs</td>
<td>2 (voltage and current)</td>
</tr>
<tr>
<td>Voltage/Current level</td>
<td>0-10 VDC</td>
</tr>
<tr>
<td>Programmable analog digital output</td>
<td>1</td>
</tr>
<tr>
<td>Programmable relay output</td>
<td>1</td>
</tr>
<tr>
<td>PROFIBUS DP</td>
<td>integrated</td>
</tr>
</tbody>
</table>

It can support applications with constant and variable torques. Due to construction of VLT motor control together with the motor, motor cables and EMC problems are eliminated.

8.6.9 Mean well DC/DC converter

This DC/DC converter SD-100B-12 is a step-down transformer which is used to transfer charge as per the requirement from a 24 V battery system to 12 V battery. The input voltage has large range, the output voltage can be regulated, and high isolation voltage between input and output are some of the features of this converter.

### Table 3.9: DC/DC converter specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>19…36 V DC</td>
</tr>
<tr>
<td>Output voltage</td>
<td>12 V DC</td>
</tr>
<tr>
<td>Output current</td>
<td>8.5 A</td>
</tr>
<tr>
<td>Power</td>
<td>100 W</td>
</tr>
<tr>
<td>Galvanic separation</td>
<td>Yes</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-10 → +60°C</td>
</tr>
<tr>
<td>Dimensions</td>
<td>199x98x38 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>600 g</td>
</tr>
</tbody>
</table>
8.6.10 Programmable Logic Controller (PLC)

The Programmable Logic controller (PLC) plays significant role acting as interface between the experiment PC and the HPS. The PLC along with Communication Processor (CP) comes with a PROFIBUS connection.

![Controller CPU 314-2DP](image)

Fig. 3.15 Controller CPU 314-2DP

This connection can be directly connected to the motor which drives the wind turbine. It has analog and digital input channels through which signals can be exchanged with hardware devices of HPS. The output values of current sensors in the form of voltages are read by the PLC and displayed on the experiment PC for the user. It also has an Ethernet connection with its own IP address. The experiment PC is connected to the PLC through this Ethernet connection. Initial PLC configuration can be completed through MPI port which establishes a direct communication channel between the PC and the PLC. A MPI cable is used for this purpose. Technical details are noted below.

<table>
<thead>
<tr>
<th>Table 3.10: PLC specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General information</strong></td>
</tr>
<tr>
<td>Product number</td>
</tr>
<tr>
<td>Hardware product version</td>
</tr>
<tr>
<td>Firmware version</td>
</tr>
<tr>
<td>Programming package</td>
</tr>
<tr>
<td>Supply voltage</td>
</tr>
<tr>
<td>24 V DC</td>
</tr>
<tr>
<td>Permissible range (lower limit) DC</td>
</tr>
<tr>
<td>Permissible range (upper limit) DC</td>
</tr>
<tr>
<td>Load voltage</td>
</tr>
<tr>
<td>Rated value (DC)</td>
</tr>
<tr>
<td>Digital inputs</td>
</tr>
<tr>
<td>Load voltage</td>
</tr>
<tr>
<td>Rated value (DC)</td>
</tr>
<tr>
<td>Reversed polarity protection</td>
</tr>
<tr>
<td>Digital outputs</td>
</tr>
<tr>
<td>Load voltage</td>
</tr>
<tr>
<td>Rated value (DC)</td>
</tr>
<tr>
<td>Reversed polarity protection</td>
</tr>
<tr>
<td>Memory</td>
</tr>
<tr>
<td>Integrated work memory</td>
</tr>
<tr>
<td>Expandable</td>
</tr>
</tbody>
</table>
8.6.10.1 Step 7 programming software

Totally Integrated Automation (TIA portal) version 13 engineering framework is used in the lab for PLC operations. It supports engineering, communication, diagnostics, safety, security and robustness. Windows 7 Home professional operating system is installed. Step 7 engineering software is used for programming. A processor – Core i5-3320M, 3.3 GHz is recommended for this platform. RAM of 8 GB and screen resolution of 1920x1080 pixels are the requirements. An overview of TIA Portal can be seen below.

Some of the features of this framework are:

- Newly developed program editors facilitate fast programming
- Integrated symbolic programming, block expansion during operation
- Remote maintenance with teleservice and integrated system diagnostics
- Scalable and effective motion functionality
- More security with security integrated – know how, copy protection, access protection and manipulation protection
- Shared configuration environment with HMI devices and drives in the TIA Portal engineering framework

Fig. 3.16 Totally Integrated Automation (TIA) Portal

8.6.10.2 WinCC visualization software

Some of the WinCC features are:

- Efficient graphic system facilitates graphical display of complex plants or systems with key system parameters
- Editors for alarm logging, tag logging, text library, user administrator, user archive for higher engineering efficiency
- Tags and optimized communication to the S7 PLCs
- Efficient engineering diagnostics
- Integrated user administration including simatic logon
8.6.10.3 Monitoring, control and visualization for this project work

- Acquisition and processing of system parameters
  PLC program to read and process HPS data such as solar panel current, 24 V battery current, 24 V load current, 12 V battery current, motor speed, motor current, motor voltage and several other parameters.

- Acquisition and processing of digital signals like switches and on/off controls
  There should be possibility to control switches through PLC which will manage 24 V loads. Switch on–off of the motor from remote location should be possible.

- Smart energy exchange between two stations
  A PLC program to monitor and regulate energy exchange between 24 V and 12 V batteries using step down DC/DC converter.

- Development of WinCC visualization for HPS which includes visualization of current, voltage, power, battery state of charge, energy exchange diagrams, motor and wind turbine parameters.