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Modeling and Simulation of Renewables for Telelabs

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Abstract.

Increased growth in population and development activities result in increased energy consumption. Environment friendly renewable energy technologies should be promoted to meet this rising energy demand. On the background of this knowledge, research in the field of renewable Hybrid Power System (HPS) is significant. Along with simulation, familiarity with operation and control of physical HPS is equally important. The automation lab of Soest university currently works on a laboratory model of HPS consisting of photovoltaic (PV) panel, wind turbine, battery storage and inverter. In this paper, the concept of Telelab is used to demonstrate modeling of PV panel using Matlab software. Use of HOMER software for modeling and optimization is discussed. The results will be analysed and subsequently conclusion would be discussed. In this paper, the idea of Telelab/Remote lab and its role in knowledge and technology transfer at affordable costs would be discussed at the end.

The author would discuss the idea of resource sharing (software and hardware) through the concept of Telelab. The basic architecture of Telelab through which remote authorized users would be able to share the simulation environment and the lab experiment would be described.

Key words

Hybrid, Modeling, Simulation, Telelab, Remote lab

1. Introduction

Renewable sources of energy are environment friendly and available in abundance. Different possibilities are explored to tap this clean energy efficiently keeping in mind its intermittent nature. The idea to combine different renewable energy technologies and storage alternatives to provide an efficient HPS gains significance. Distributed generation is an important aspect of renewable technologies. A HPS can be developed close to the consumers saving energy transmission costs which otherwise would occur in a centralized distribution system.

Realising the importance of HPS based on renewable technologies in today's world, the author finds it significant to present a platform through which users across the globe could easily connect to a renewable research laboratory and perform simulation and real physical experiment control. In the section below, the difference between simulation and real time experimentation is described.

Simulation Vs Real Time Experimentation

Advancements of internet technology and its increasing popularity facilitated new alternatives for learning and teaching in different engineering disciplines. This technology has made the process of education more interactive since different tools can be effectively used for illustration, demonstration, simulation, experimentation, operation, communication and so on[5]. A typical challenge in this field is to be able to access the traditional laboratory environment over internet. In a research laboratory, especially in an engineering discipline, it is important to provide facilities which will assist users to experiment with simulation and real time environments. Simulation labs or virtual labs are based on simulation softwares like Matlab/Simulink, LabView, Java Applets and several others which help the user to simulate physical behaviour of equipment and perform experiments with the developed simulated version. It is seen that the behaviour of simulated equipment is as close as possible to the real equipment. However, it is not possible to develop a simulation which will satisfy all the constraints of a real physical experimentation. Simulation experiments are preferred when the equipments are costly or the operation of such equipments occurs in hazardous environments. Trial and error work can be executed using the simulation environment followed by real time implementation. User can analyse system behaviour without any fear of damage to life and property. Obviously, many experiments could be satisfactory performed with the simulation environment.

Remote lab or Telelab is the lab which involves physical equipments and components. User connected to such a lab over internet can access, monitor and control all equipments from a remote location. User can perform experiments and analyse the system behaviour in real time. As this lab involves physical equipments and not simulated ones, safety and security of people working in the lab and surrounding environment is considered to be of high priority. The cost involved to develop such a lab is high and hence the idea is to provide benefits of this lab to maximum users. This is possible by using the internet technology. Experiments can be identified and designed which can be conducted in simulation environment or real physical environment. Accordingly users could be directed to perform the experiment. Investments in buying softwares, periodically updating these softwares and protecting them from virus attacks by investing in anti-virus softwares could be reduced significantly. Investments made for buying costly hardware can be justified since the experiments along with local users could be used by large number of authorized users across the globe.

2. PV Panel modeling using Telelab

A PV panel from Kyocera KD140GH-2PU was considered for modeling using Matlab/Simulink environment in the remote research lab of the university of Soest. This model was selected since the above mentioned PV panel is part of HPS with real physical components available in the lab. The purpose of this experiment was to introduce the possibility of modeling a PV panel using internet from remote location. Audio and video streaming using network camera was available during the assignment. Some of the computers were allocated for remote users while some others for local users. It was ensured that all the discussions between the local users and the lab engineer could be easily followed by the remote user. Technical discussions among the users while performing the assignment could be followed by the remote user. This environment provides the user to get a real lab experience.
Remote user could also participate in the discussion using communication software like Skype. To save the internet bandwidth, remote user was visible only when the user participated in the discussion or in case if the user had some questions. The lab engineer ensured that the progress made by remote user was monitored and necessary help as required by the user was provided.

The experiment was divided into different sections-

- Theory and background of the assignment
- Theory and equations of PV panel modeling
- Analyse the data sheet of the PV panel
- Introduction to Matlab/Simulink environment
- Analysis of results and conclusion

Theory and background of the assignment

In this section, a short introduction to the HPS that is under development in the lab was provided. The purpose and significance of the assignment was explained. Aims and objectives were clearly stated and at the end, the assessment criteria for a successful assignment completion were described. Theory and physics behind photovoltaic cells and their operation was explained. The experiment was described in a self explanatory way. However, if something was not clear to the local or remote users then they could communicate with the lab engineer easily. Doubts of the users were addressed. Simultaneously, lab engineer was directed to note down the doubts every time and modify the explanation part of the experiment accordingly. This was helpful to make the experiment as clear and simple as possible. Due to this feedback procedure, it was observed that in every passing week, doubts were significantly reduced and users could begin the experiment without hurdles.

Theory and equations of PV panel modeling

In this section, equivalent circuit of solar cell as current source in parallel with a diode was explained.

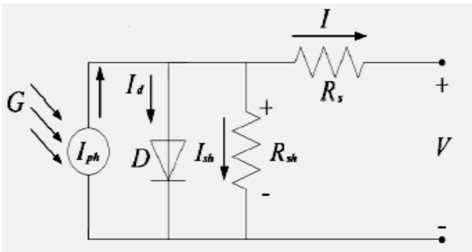

Fig 1: Circuit Diagram of PV Cell [4]

Parameters such as $\boldsymbol{I_s}$ which is reverse saturation current of diode and its temperature dependence, $\boldsymbol{I_{ph}}$: photo current of diode, series resistance ($\boldsymbol{R_s}$), diode current ($\boldsymbol{I_d}$), irradiance (G) and shunt resistance ($\boldsymbol{R_{sh}}$) were explained.

All the equations which defined modeling of PV panel were described with corresponding constants and parameters. Some of the main equations to be implemented are [7],[8] –

Equation for open circuit voltage ($\boldsymbol{V_{oc}}$):

$$\boldsymbol{V_{oc} = V_t ln\,(I_{ph}\,/I_s)} \quad (1)$$

$\boldsymbol{V_t}$ = Thermal Voltage, V (2)

Shunt current equation:

$$\boldsymbol{I_{sh}} = (V+I\boldsymbol{R_s})/\,(\boldsymbol{R_p}) \quad (3)$$

Current equation:

$$I = \boldsymbol{I_{ph}} * \boldsymbol{N_p} - \boldsymbol{I_d} - \boldsymbol{I_{sh}} \quad (4)$$

Current Voltage (IV) characteristic curve for a PV cell was explained. Fundamental parameters with respect to IV curve like short circuit current, open circuit voltage, maximum power point (operating point where power dissipated in resistive load is maximum), maximum efficiency which is ratio of maximum power and incident solar energy were defined.

Analyse the data sheet of PV panel

Data sheet of PV panel which consisted of the characteristics and specifications table was provided.

Table 1: PV Panel Specifications

Characteristics	Specifications (1000 W/m^2)
PV Module Type	KD140GH-2PU
Maximum Power (W)	140
Maximum System Voltage(V)	1000
Maximum Power Voltage(V)	17.7
Maximum Power Current(A)	7.91
Open Circuit Voltage(V_{oc})	22.1
Short Circuit Current(I_{sc})	8.68
Efficiency (%)	13.9

Users were expected to analyse the data sheet and understand the maximum and minimum values of different parameters with respect to the IV curve.

Introduction to Matlab/Simulink and implementation of program

It is expected that the user has some basic knowledge to work with the software. This section explains the user to with a systematic procedure to analyse the Simulink components which are required from the Simulink library to implement the expected program. User learns the process to select and use source models, sink models, tagging of these models, arithmetic models and display models. Hints to follow standard programming practices are provided.

Definition of constants and their tags

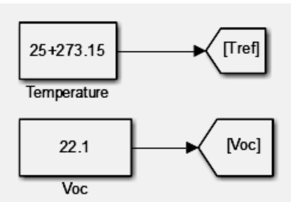

Fig 2: Constants and tags

A source block parameter is defined as constant and is identified as temperature block. The output of this block will be sent to T_{ref} which is goto tag. Visibility of this block can be defined as local, scoped or global. This tag will be further referred in the program for this temperature value.
Similarly, thermal voltage equation could be implemented as below –

$$V_t = (k * T_{op})/q; \quad (5)$$

k = Boltzmann's constant, $1.38e^{-23}$
T_{op} = Operating temperature of solar cell
q = Electron charge constant; $1.6e^{-19}$C

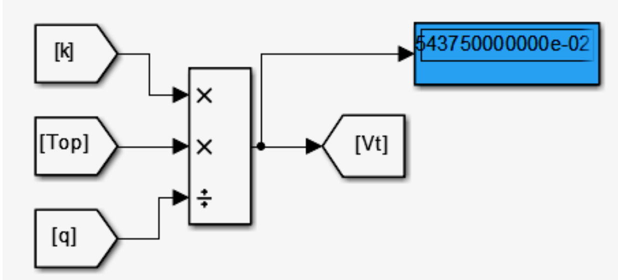

Fig 3: Thermal voltage equation

The display block helps us to observe the calculated value of V_t.

With the help of examples and description, users are assisted to learn the environment and implementation of equations in Simulink in short time.

Analysis of results and conclusions

In this section, users are expected to analyse and describe the results and write conclusions to the performed assignment. For instance, IV curves for different values of irradiance (G) as in Fig 4, Fig 5 below, R_s, R_p and T_{op} are analysed and the ideal condition to obtain maximum power output is determined.

IV curve for irradiance =1000 W/m^2

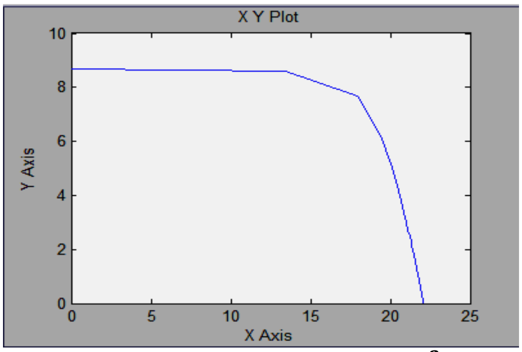

Fig 4: IV curve irradiance = 1000 W/m^2

IV Curve for irradiance =800 W/m^2

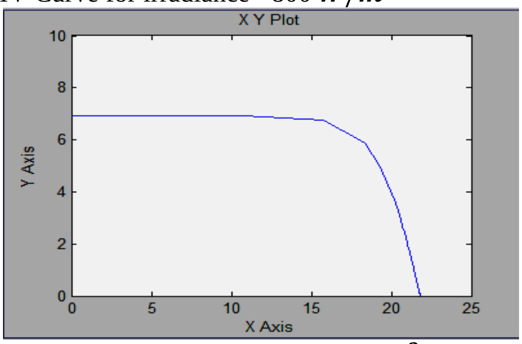

Fig 5: IV curve irradiance = 800W/m^2

The curves obtained at different irradiance levels were evaluated with PV panel datasheets.

3. Modeling with HOMER using Telelab

Another software which was demonstrated in the remote lab as part of resource sharing experiment of Telelab is HOMER which stands for Hybrid Optimization Model for Energy Resources. It is a micropower optimization model. It helps user to evaluate different power system design combinations. It assists user in deciding the components to be added to the system, size of components, available technology options, costs and energy resources. It performs optimization and sensitivity analysis. Optimization is to sort a list of possible system combination based on net present cost. Sensitivity analysis is the analysis where sensitive parameter like solar power output is considered to decide the optimum system combination.

This experiment was divided into different steps-

- Introduction to HOMER software
- Build a schematic:

Students were asked to define the system combination by selecting load, PV panel, converter and battery.

- Enter load details
- PV panel configuration in HOMER:

PV panel can be configured in HOMER by entering cost parameters like size (kW), capital ($), replacement, operation and maintenance costs. User can define properties like output current, panel lifetime (years), derating factor (%) and slope (degrees).

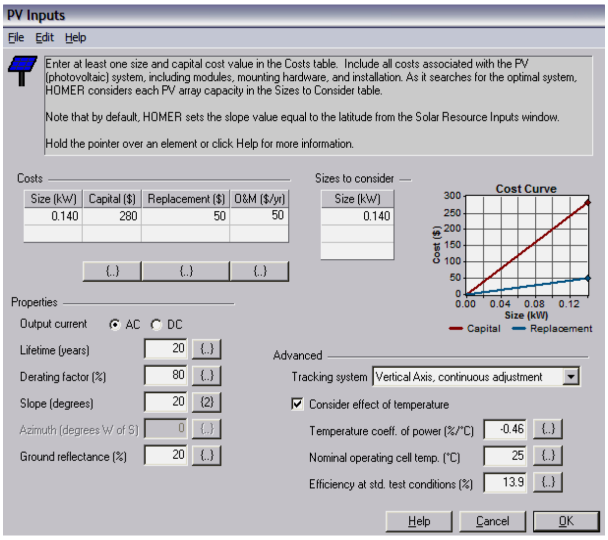

Fig 6: PV panel input

User can decide if the temperature effects should be considered. User can specify temperature coefficient of power, nominal operating cell temperature and efficiency at standard test conditions by referring the data sheet.

Enter details of all other selected components like battery, wind turbine, inverter and so on.

Examine optimization and sensitivity analysis

Analyse results and write conclusion of the assignment

4. Comparative analysis of Matlab and HOMER environment

The two experiments were evaluated by both local and remote users and their feedback was analysed on the basis of certain defined parameters.

Ease of learning and performing the experiment

The experiment conducted with Matlab/Simulink environment was found to be relatively difficult to perform in comparison with the HOMER software experiment. Users found it easy to learn HOMER software since almost no programming was involved and mostly the models were computer generated. Results were easily and quickly produced by HOMER.

System control

Matlab/Simulink environment offered better control of the system because every system component should be modelled by the user. On the other hand, HOMER offers relatively limited control of the system.

Prior experience with software

Matlab requires prior experience with software and it takes relatively more time to learn the software. HOMER does not necessarily require prior knowledge of software and can be learned quickly.

Detailed sensitivity analysis

Matlab/Simulink offers detailed sensitivity analysis of the system under evaluation compared to HOMER.

5. Structure of Telelab

In the sections above, two assignments were described which could be performed with Matlab/Simulink and HOMER software using the concept of Telelab. The purpose of conducting the assignments was to evaluate feasibility of performing experiments from remote location. Another purpose was to make users familiar with the components of physical HPS of the lab which could be monitored and controlled using Telelab. This promotes the idea of resource sharing that benefits users and institutes which are financially weak and geographically isolated and hence cannot afford costly lab infrastructure. The author believes that the significance of simulation and real time experimentation varies depending on the experiment to be performed. However, both of them have their own importance. It was discussed till now how the resource sharing feature of Telelab can be used to simulate a real lab environment and perform simulated experiments. Now, the Telelab structure will be discussed which along with simulation can also offer real time experiment control.

As mentioned before, laboratory of Soest hosts a HPS that includes a PV panel, a wind turbine, battery bank, solar charger and inverter. Similar to modeling of PV panel, users can model other components.

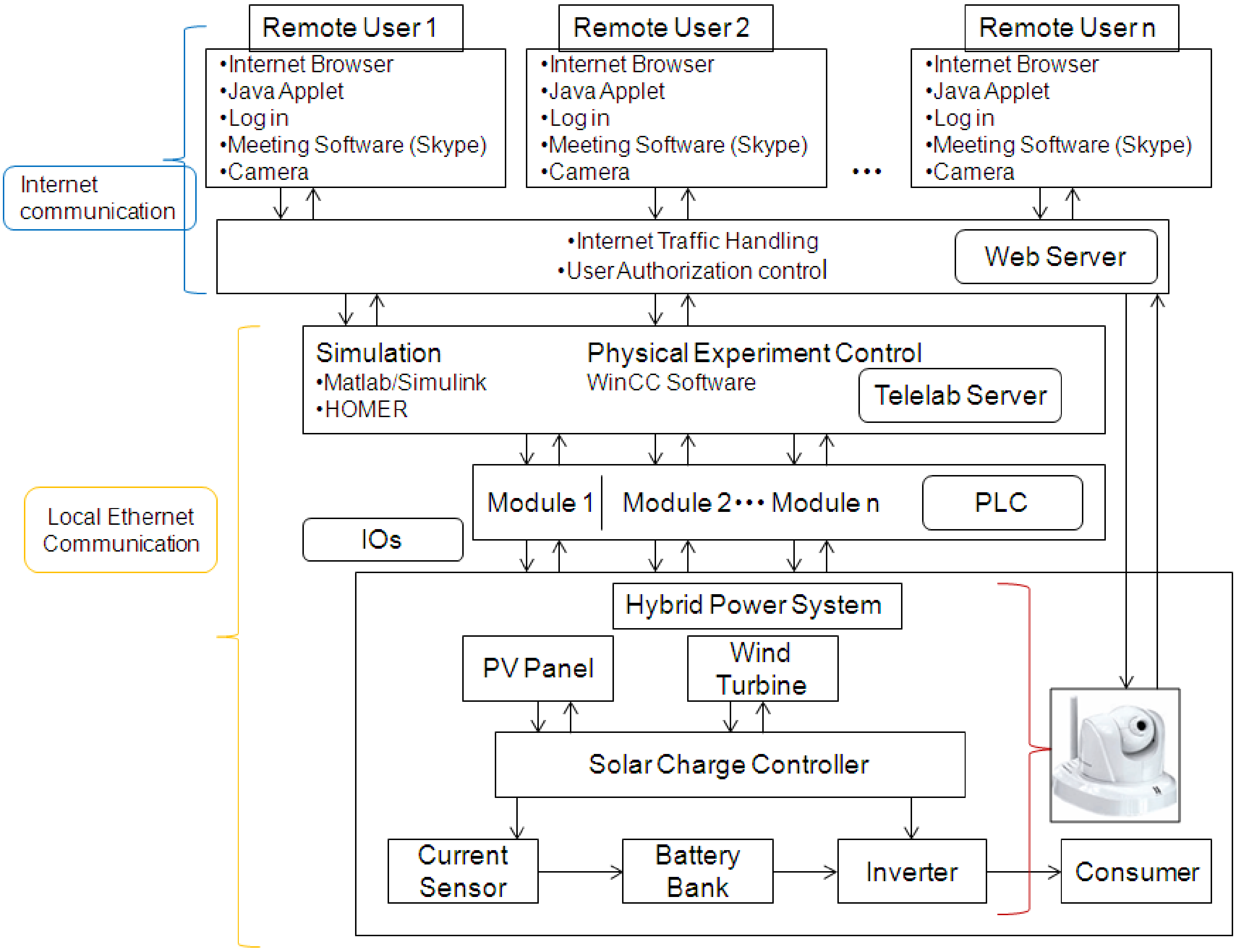

Fig 7: Telelab structure

The structure of Telelab is visible in Fig 7 above. Every user is expected to have a computer with internet browser and java applet which is freely available and no additional investment is necessary. However, experiments which require audio and video streaming expect the user to install the necessary communication software and camera. Remote users can connect to the web server from any part of the world over internet. Internet traffic and user authorization process is managed by web server. Users are requested for basic information like name, organization or institute they work for, location and email address. Users are asked to mention their preferred time to conduct the lab as per the lab schedule. Labs which can be performed individually have more flexible timing as those to be performed in groups. Based on user inputs, username and password is generated and emailed to the user. Timeslot to perform the experiment is defined for every user. User is allowed access to the experiment set up in the allocated timeslot when correct login data is provided. User is directed to the Telelab server where the user can perform simulated experiment followed by real time experiment with physical set up. The idea as mentioned before is to increase the familiarity and understanding of user with the experiment before the user begins working with the hardware. This ensures that the errors performed with the live experiment set up are minimized.

After completing the simulation experiment successfully, user knowledge can be tested with a simple set of questions. The questions are designed in a way that the user also understands the dos and don’ts with the hardware set up. Advices are provided as and when necessary to the user. Now, when the user is ready to work with the physical set up, access to the WinCC software is provided which further connects the user to PLC. PLC with its i/o modules communicate with HPS. Solar charge controller is the central element which monitors the charging and discharging state of battery with the help of current sensor. It receives the power generation data of PV panel and wind turbine. The battery state is informed by the current sensor. Based upon this information, it is decided whether to send the charge to the battery or to the inverter which further sends it to the household consumer.

With this set up, user can gain experience of working with a physical hybrid system from a remote location. Significant to note is that the user requires only a computer and internet connection to perform this experiment. A local camera at the experiment site gives user the live working images. This is a network camera which has zoom features and 360 degree rotation. User can observe the hardware movements with the help of this camera and also ensure that the data visible in the visualization software matches with the site data. Range of measurement parameters is predefined. Thus user is prevented from entering a parameter range out of limit. Internet disconnections are monitored by the web server. In such situation, results of experiment are emailed to the user. If the connection is broken for short time then state of work is saved by the web server and user can continue his work at later stage without disturbance.

6. Results and Conclusions

Comparative analysis of simulation experiments with Matlab/Simulink software and HOMER software, as mentioned before, were designed to evaluate the two softwares and check the feasibility of performing simulation assignments over internet with Telelab. The feedback from users were analysed and it was noted that certain positive and negative views were provided. The idea to note down the problems faced by users in understanding the description or procedure and updating the contents accordingly produced positive results. As the number of labs conducted increased, the updated description after every lab became simple and easy to understand. Users, to large extent, were able to perform the lab without any guidance from lab engineer which was the ultimate goal of this process. Audio and video streaming gave the users opportunity to actively participate in discussions and express their views. This was considered as a positive aspect. It was concluded that Matlab/Simulink assignment involved component level modeling and programming and hence presented better system control as compared to HOMER. However, with respect to ease of use, economic modeling and getting quick results, HOMER was preferred over Matlab.

Users who favoured flexibility of time as an important aspect assessed the lab positively. Internet offered them a chance to perform the lab without need to travel to the actual location. This offered them convenience to schedule the lab as per their own timings. It was considered a positive solution by institutes and users who could not afford investing money in buying software licences and updating these softwares regularly. User need not worry about the safety of computers and softwares from virus since the maintenance work was managed by the lab. In the situation when internet was disconnected, the work state was either saved so that the user can continue his work later or in some cases the results were emailed to the user which was seen positive. The work progress of remote user was monitored and if certain task was taking longer time then suggestions were given. This made the work interactive. Live camera images combined with interactive discussions gave the remote user a real life experience. The idea of performing simulation experiment followed by real physical experiment made the later task easy to execute.

Despite of several advantages offered by Telelab, some users could not feel the real lab environment and preferred to perform the experiment real time and not over internet. Delay in internet showed difference in hardware reading (visible from camera images) and readings noted by the software. This along with audio and video disturbances caused due to internet bandwidth restrictions annoyed some of the users. Problems occurred due to internet disconnection demotivated some of the users. In the situation where certain assignment areas were not clear, local students got most of the times, preference to ask questions and get their doubts solved while the remote students had to wait for their turn.

However overall analysis of advantages and disadvantages and feedback received from different users, it was concluded that the advantages offered were more as compared to disadvantages. In future, advancement in sensor technology like sensors accessible over internet will make it easy to remotely access data from these field sensors. This will make the task of implementing such labs more feasible. Research in the field of internet technology to offer stable bandwidth is another positive area in support of Telelabs. Research in the field of internet safety and security from hackers would provide new alternatives to use internet and such labs. Strong anti-virus softwares are evolving and they would keep the system safe from virus attacks in future. Increasing fuel prices, in future would motivate users to search for learning platforms that would avoid travel-costs and travel-time.

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