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A Case Study: Validating a LabVIEW simulation models presentation of fundamental principles in emerging renewable energy systems

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Abstract— **LabVIEW has the advantage of being able to customize a graphical user interface to produce visual results at different stages, performing signal acquisition and processing of several stages simultaneously. It has become an integral part of many laboratories as academics seek new ways to help fuse theory and practice. The purpose of this paper is to validate the results obtained from a developed LabVIEW simulation model by comparing its results of a specific case study to those obtained from HOMER. HOMER software was developed by the National Renewable Energy Laboratory to assist engineers in the design of micro-power systems and makes extensive use of environmental parameters specific to a given location. The LabVIEW simulation model was developed to demonstrate fundamental principles of an energy generation system, with specific reference to a standalone PV system, where energy flow, efficiency and storage are demonstrated. Correlating the results between the LabVIEW simulation model and HOMER reveals that both simulation packages propose a minimum array size of 10 kW for a specific case study. The LabVIEW simulation module can thus be used with confidence.**

Index Terms—**learning styles, energy flow, PV systems**

I. INTRODUCTION

"Computers themselves, and software yet to be developed, will revolutionize the way we learn." These words, by Steve Jobs [1], are certainly true in the context of computer based simulations (CBS) that have been extensively used in demonstrating fundamental electrical engineering principles. These principles include energy flow, efficiency of components in a system, storage of energy, the effect of optimisation and the usage of energy.

CBS are valuable tools for product and process understanding, design, optimisation and control [2]. CBS can provide an interactive environment in which participants can manipulate a designed system while receiving instant feedback, being able to reflect on what can be improved through trial and error. This improvement of the system is once again achieved through some or other control mechanism, where engineers can almost instantaneously visually observe the effects of their decisions.

CBS are used by engineers when it is difficult or impossible to manipulate real life scenarios or equipment in the design stage [3]. However, simulations are not ideal and it is therefore important for the engineer to understand the limitations of this technology. Advantages of CBS can include the fact that it allows the engineer to freely vary specific parameters and observe the related effects, explore theoretical principles or systems under extreme conditions, allow for a detailed analysis of systems and be easily reproducible [4]. Some disadvantages of using CBS in engineering are that they can be expensive and time consuming to develop.

In this study, a LabVIEW simulation model (LSM) of a standalone PV system was developed at the Central University of Technology (CUT) to help engineers to test their designs before they implement the systems. This LSM enables engineers to manipulate parameters via a user interface, and observe the influence thereof on the performance of the designed system. However, it is equally important that the results of this LSM be validated against a scientifically accepted simulation package, like HOMER. This is to ensure that the system's results are in line with real world situations and that the results of the LSM are reliable and valid.

The purpose of this paper is therefore to validate the results obtained from a specific developed LSM by comparing the results of a case study to those obtained from HOMER. The paper firstly discusses the importance of simulation packages in the renewable energy field. The context of the study is then presented along with a brief overview of the LSM. The methodology follows with the results.

II. THE IMPORT OF SIMULATION PACKAGES IN THE RENEWABLE ENERGY FIELD

In a study by Connolly et al. in 2010, the researchers considered a total of 68 different computer tools for analysing the integration of renewable energy into various energy systems

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[5]. The sheer number of computer tools suggests that many, if not all, renewable energy systems are usually first analysed mathematically in terms of performance, before physically installing them. It further highlights that many different options are available for the design and simulation of renewable energy systems.

HOMER was developed in 1992 by the National Renewable Energy Laboratory in the USA. The simulation package simulates stand-alone and grid-connected systems with any combination of wind turbines, PV arrays, hydro power, biomass power, internal combustion engine generators, micro-turbines, fuel cells, batteries and hydrogen storage[5].

Some of the applications where HOMER was used include a hybrid renewable energy system in Iran [6], wind diesel power plants in Canada [7], a wind-solar-diesel system in Ecuador [8] and a grid connected PV system in South Korea [9]. In fact if the search word HOMER is used in Google Scholar it returns a total of 790 000 hits, suggesting that it is a valid and reliable simulation package that is widely used in the scientific community.

III. STUDY CONTEXT

The Department of Electrical, Electronic and Computer Engineering at CUT undertakes research in electrical and computer engineering. One of the research fields that they are involved in is renewable energy with specific reference to solar systems. The LSM was developed with this emerging renewable energy system in mind.

The developed LSM enables the user to grasp the operation of an energy generation system, with specific reference to a standalone PV system, where energy flow, efficiency and storage are demonstrated. A simple analysis of the energy flow in a system is important in order to gain insights into the conversion process [10]. Maintaining a good energy efficiency is furthermore important for battery longevity [11], which is where the generated energy is stored.

The flow of electrical energy refers to the movement of electrons from the generating source to the storage device and associated loads. The user must be able to observe the input and output powers associated with each section of the energy system, thereby keeping track of the electrical energy flow. The main input power from the sun to the generating source (being the PV module in this case) is indicated in Watts/square meter (W/m^2) while the energy that is stored in the batteries (storage device) is indicated in Ampere hours (Ah). During direct sunlight hours, electrical energy will flow from the source to the storage device and then to the loads. During non-direct sunlight hours, students must be able to observe how the storage device is depleted, as it alone supplies energy to the load.

However, engineers tend to better understand complex processes, like the flow of energy in energy generation systems when they actively participate in the simulation of these systems [12, 13]. This helps them to visualize the operation of the different sections within the system, thereby moving away from purely abstract thinking. Abstract thinking is difficult, as it takes a great deal of time to become familiar with theory at any level of depth [14]. However, the use of active experimentation [15] in CBS enables the engineer to engage with the theory, eventually resulting in abstract conceptualization. The importance of helping engineers grasp these different energy generation principles is mandated by the logarithmic growth in the installation of these renewable energy systems, including the construction of many solar farms.

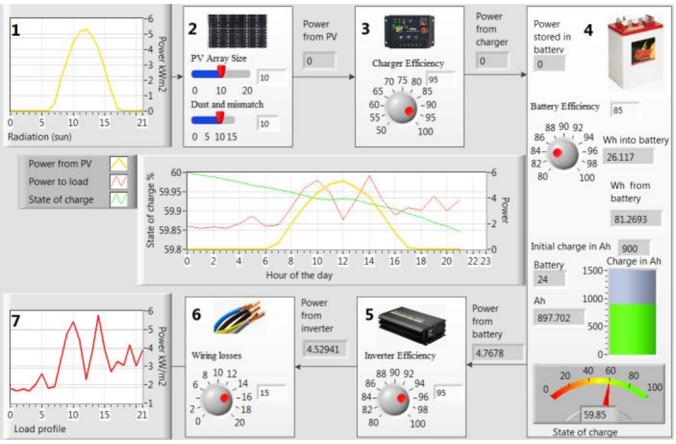
South Africa has some of the best solar radiation resources in the world, where the average daily solar radiation varies between 4.5 and 7 kWh/m^2 [16]. In the heart of South Africa lies the Free State province with Bloemfontein as the provincial capital. The main campus of CUT is located in Bloemfontein where the Faculty of Engineering and Information Technology resides. The co-ordinates of CUT's main campus is 29°07'17.24" S (Latitude) and 26°12'56.51" E (Longitude), and serves as the research site for this study. Bloemfontein is a semi-arid region (82% of South Africa is classified as such a region [17]) with a daily average global horizontal radiation of 5.15 kWh/m^2/day [16].

Annual rainfall in Bloemfontein is around 550 mm [18] with the majority of rains falling in the summer months and water restrictions being imposed during the winter season. Localized dust storms often occur in late winter due to open pan surfaces and large agricultural lands [19]. These conditions are typical of arid and semi-arid regions, which are often characterized by water scarcity, hot dry weather, large areas of poor soils [20] and dust storms [21]. These environmental conditions exert a strong influence on the optimal performance of PV systems, which are classified under the renewable energy field. These conditions are generally included in many renewable energy simulation software packages, such as HOMER which was used to validate the developed LSM.

IV. LABVIEW SIMULATION

Fig. 1 shows the LabVIEW user interface of a stand-alone PV system that was developed to be the control panel of the simulation model. The first section represents the energy source, namely the sun. In this section data is obtained from a text file that represents a 24 hour cycle of energy from the sun. The values are in kWh/m^2 and are derived from monthly average radiation data from NASA's surface solar energy data set [22]. The engineer has no control over the energy from the sun and the simulation reflects the normal daily radiation available from the sun, peaking at around 1 kW/m^2.

The second section represents the PV array. This is where the engineer can change the array size from 0 to 20 kW. If, for example, a 100 W module is selected and the input from the sun is set at the Standard Test Condition (STC) of 1 kW/m^2, then the output of the module will be 100 W. The output of each section is shown in Watts to enable the engineer to observe energy efficiency principles. The dust and mismatch factor of the PV array is also included where typical values are set around 15% [23]. Engineers may manipulate this value to visually observe the negative effects that dust and mismatches exert on the energy flow and performance of the overall system.



PV Array Size 10

Dust and mismatch 10

Power from PV 0

Charger Efficiency 95

Power from charger 0

Power stored in batterv 0

Battery Efficiency 85

Wh into battery 26.117

Wh from battery 81.2693

Initial charge in Ah 900

Battery 24

Ah 897.702

59.85

Wiring losses 15

Power from inverter 4.52941

Inverter Efficiency 95

Power from battery 4.7678

Figure 1: Developed LSM user interface

The third section illustrates the charge controller that serves to charge and protect the batteries. Modern charge controllers have typical efficiencies of 97% [24]. The user may control the efficiency of the charger by varying it between 50 and 100%, again being able to visually observe its effect on subsequent sections.

The fourth section is the battery bank (storage device). The efficiency of the battery may also be altered between 80 and 100%, which is in line with current technology providing battery efficiencies of around 85%. It must be noted, though, that battery efficiencies are highly dependent on charging and discharging regimes as well as on the depth of discharge [25]. The battery's voltage, charge and state of charge (SOC) are also indicated in this section, playing a major role in the sustainability of the system.

The fifth section is the inverter where the user may once again set its efficiency between 80% and 100%. Current technology allow for inverter efficiency's in the order of 97% [26]. However, it must be noted that inverter efficiency is dependent on the AC load and may vary greatly over the operating range of the inverter [27]. Fundamental engineering principles of energy conversion between DC and AC are demonstrated in this section.

The sixth section shows the losses in the wiring which can be controlled between 0% and 20%. Wiring losses include losses in electrical connections in the system as well as resistive losses that are affected by the length and diameter of the wires that are used [28]. In this section, fundamental engineering principles relates to resistance losses of different cables that are required to connect the various components of the system together.

In the seventh section, the load profile is presented which is obtained from a text file. In experimenting with the LSM, the user can modify the load profile in order for it to represent specific case studies. The load is presented in one hour intervals, and the flow of energy from the battery to the load can be observed in the simulation. The load profile is an integral part of any renewable energy system and needs to be accurate [29] in order for the design to be sustainable. Engineering principles relating to a dynamic and varying load over a prescribed time period is conveyed in this section. The next section covers the research methodology that was followed in this study.

V. RESEARCH METHODOLOGY

The aim of this study is to validate the simulation results of a simple PV stand-alone simulation system that was developed in LabVIEW, by comparing the simulation results with HOMER, a widely used and accepted simulation package. Both the simulation packages require data inputs which include solar radiation data, a 24 hour load profile and component specifications. Solar radiation data that was used is explained in subsection A, that follows, and was obtained from NASA [22]. A load profile of a typical middle income household was used and is explained in more detail in sub section *B* that follows. Component specifications that relates to the efficiency of the charge controller, batteries and inverter as well as wiring, dust and mismatch losses are explained in subsection *C* that follows. The same data inputs were used for both simulations and the simulation results were compared in terms of the recommended PV array size for a specific load profile. The PV array size is the key simulation variable that is dependent on all the selected components as well as the available solar energy at the research site. If the array size that is recommended by HOMER correlates well to the array size that is used in the LSM, then it would indicate validity and reliability of the LSM.

A. Solar radiation data

Solar radiation data for Bloemfontein was obtained from NASA's surface solar energy data set that provides monthly average solar radiation data for specific locations on earth [22]. The complete set of monthly average solar radiation values were used as input to the HOMER simulation (see Fig. 2). From Fig. 2 it can be seen that radiation for summer months is considerably higher than those for winter months. The average daily radiation for December is 7.76 kWh/m^2, where in June it is only 3.49 kWh/m^2. The annual average solar radiation for Bloemfontein is 5.69 kWh/m^2/day [22].

Since the LSM requires only one radiation curve for a specific day, the average of the daily profiles for December and July were used. HOMER has the ability to extract by means of mathematical calculation the average daily radiation profile per month from the irradiation data that is obtained from the NASA database. The data that is presented in Fig. 3 was obtained from HOMER where December refers to midsummer and July to midwinter at the research site. From Fig. 3 the deference between the July (winter) and December (summer) radiation profile can be observed, where the July profile starts later in the morning and ends sooner in the afternoon. It can also be seen that the peak July radiation is lower than the peak December radiation.

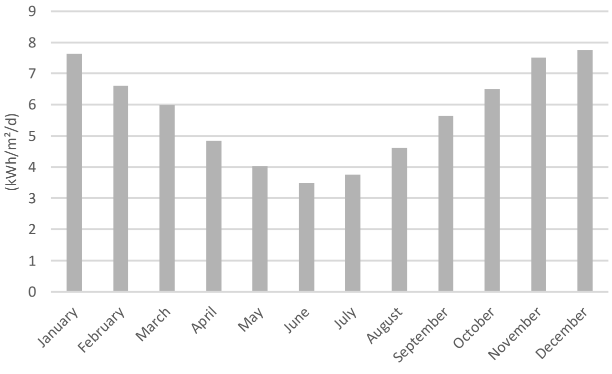


Figure 2: Average daily radiation per month for Bloemfontein [22]

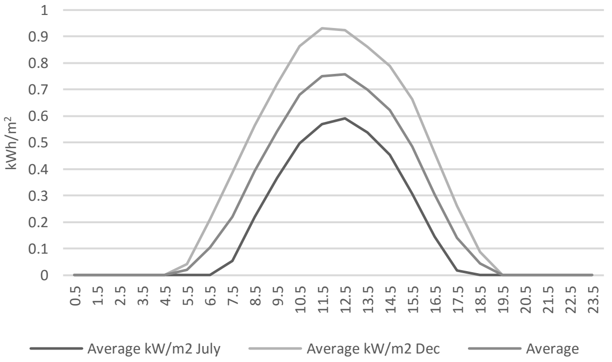


Figure 3: Average radiation per day for December and July in Bloemfontein [22]

B. Load profile

A critical input for both simulation packages is the load profile. Any 24 hour load profile with one hour intervals can be used. A typical load profile was derived from research that was done by Fritz and Kallis at Cape Peninsula University of Technology, in Cape Town [30]. The load profile is indicated in Fig. 4 and represents the energy usage by a single middle class domestic home in November. This data may be imported into the developed LSM from a generic text file, while it must be entered manually into HOMER. Fig. 5 represents the HOMER interface where the hourly load data is entered.

C. Component specifications

The components of the standalone PV system that are used in the simulations include the PV module size, the charge controller rating, the battery size and the inverter rating. The parameters that must be specified relate to the efficiencies of the different components. The inverter and the charge controller's efficiencies were selected as 95%. The in-out efficiencies of the batteries were 85%. The battery that was chosen in HOMER is a 200 Ah deep cycle battery (6FM200D) that is manufactured by Vision Batteries. Two 12 V batteries were used to match the 24V DC bus of the LSM. The LSM has an input for dust and mismatch in the PV array as well as losses in the wiring of the system. These losses are automatically taken into account with HOMER. In the LSM, dust and mismatch in the array were taken as 10% and wiring losses as 15%.

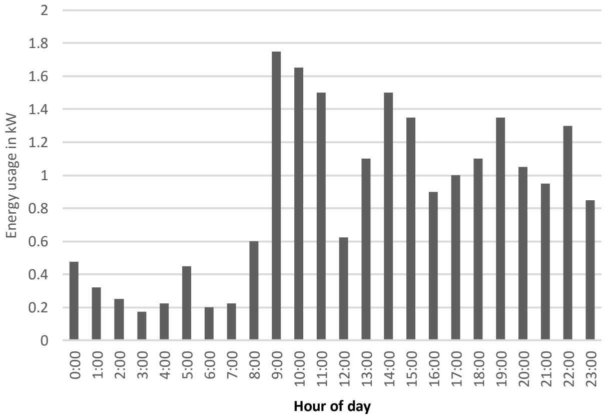
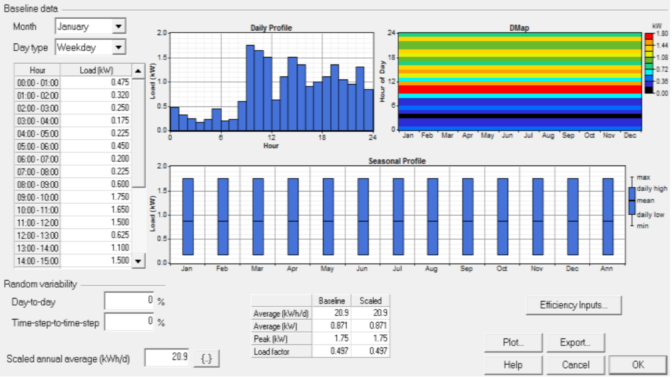


Figure 4: Load profile of domestic house



Month: January

Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	0.475
01:00 - 02:00	0.320
02:00 - 03:00	0.250
03:00 - 04:00	0.175
04:00 - 05:00	0.225
05:00 - 06:00	0.450
06:00 - 07:00	0.200
07:00 - 08:00	0.225
08:00 - 09:00	0.600
09:00 - 10:00	1.750
10:00 - 11:00	1.650
11:00 - 12:00	1.500
12:00 - 13:00	0.625
13:00 - 14:00	1.100
14:00 - 15:00	1.500

Day-to-day: 0 %

Time-step-to-time-step: 0 %

Scaled annual average (kWh/d): 20.9

	Baseline	Scaled
Average (kWh/d)	20.9	20.9
Average (kW)	0.871	0.871
Peak (kW)	1.75	1.75
Load factor	0.497	0.497

Figure 5: HOMER user interface for load profile

VI. RESULTS AND DISCUSSION

By using the abovementioned method and parameters, two simulations were done in the LSM and in HOMER. The HOMER simulation package considers all input data and recommends a system based on its ability to deliver the amount of energy required by the load that is represented in the load profile. The system that HOMER suggests for the given load profile for the research site (CUT environmental data obtained from NASA) is a 10 kW PV array with a 1441 Ah battery bank. In the LSM, the use of a 10 kW PV array resulted in an increase from 60% to 60.05% in SOC of the 1500 Ah battery bank (see Fig. 6). The slight increase in the SOC indicated that the system was able to supply the load and maintain its SOC under the given radiation conditions. The load and radiation profile is shown in Fig. 6.

In order to investigate the influence of smaller PV array sizes on the sustainability of the system during reduced radiation periods in winter months, the average winter radiation curve was used in the LSM (see Fig. 7). Please note that the SOC started at 60 % for each of the simulation days.

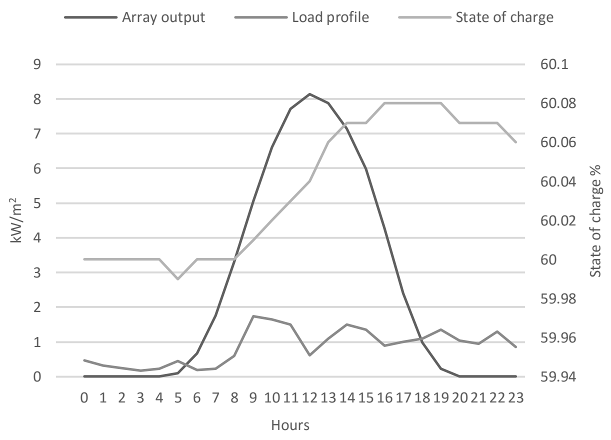


Figure 6: Simulation results of energy flow from the LSM (average radiation profile)

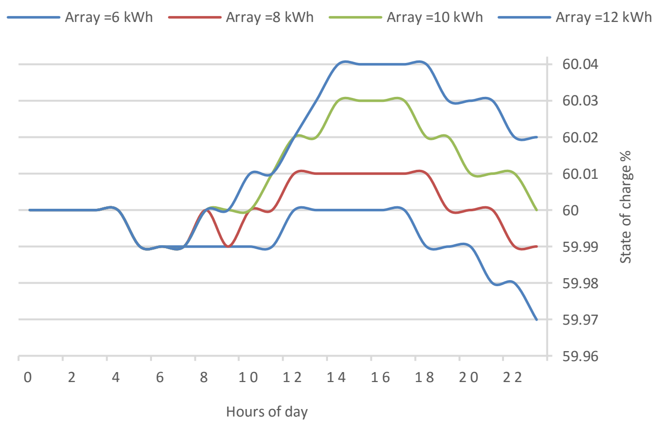


Figure 7: SOC over a 24 hour simulation period for different PV array sizes in the LSM

It is clearly shown in Fig. 7 that if the array size were to be reduced below 10 kW, then the SOC at the end of the 24 hour cycle would also be lower than at the start. This will cause the system to eventually collapse, as it is no longer sustainable. This is in line with the recommendation from HOMER that requires an array size of 10 kW to meet the load profile within the given environmental conditions and component specifications of the experimental system. Please also note that if a smaller battery bank is selected, then the percentage in drop or rise of the SOC would be more.

Fig. 8 presents the average SOC of the battery bank derived from the HOMER simulation package. It indicates that the SOC will never drop below 80% for a 10 kW system over a 12 month period for the given load profile, battery bank and environmental conditions of the research site. It can also be noted that the SOC will rise to more than 88% in the summer months. The life expectancy of the battery bank (6FM200D) under these conditions according to the HOMER simulation package is 4.17 years. This 10 kW system proposed by HOMER and validated by the LSM will thus prove sustainable for at least 4 years with possible battery change after that.

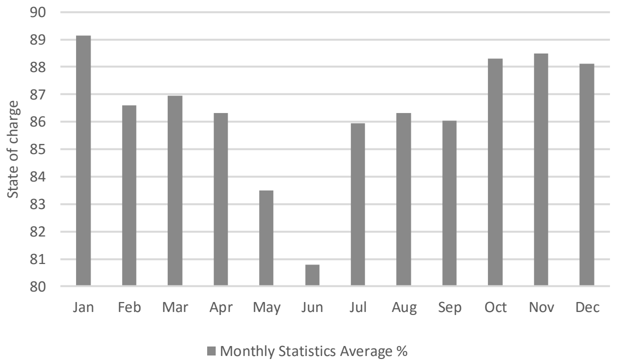


Figure 8: Monthly average SOC for battery bank (6FM200D) with 10 kW array (HOMER)

VII. CONCLUSIONS

The purpose of this paper was to validate the results obtained from a developed LSM by comparing its results of a specific case study to those obtained from HOMER, a distinguished renewable energy simulation package. Key limitations of the study may include that the comparison in simulation results were done with solar radiation data from one site and with a load profile for one typical residential home. Using additional load profiles with different research sites will strengthen the results.

However, simulation results obtained from HOMER, with specific component specifications and radiation data, suggested that a minimum 10 kW PV array would suffice to ensure the sustainability of a given system with a specific load profile. Using the same radiation data, component specifications and load profile, the 10 kW PV array was validated in the developed LSM. It would indeed be able to sustain the system under less favourable (winter) radiation conditions as the SOC actually increased from its starting point (see Fig. 7). The developed LSM can thus be used with confidence in validating the proposed systems of engineers of standalone PV systems.

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