MODELLING AND SIMULATION OF STANDALONE PV SYSTEM WITH BATTERY SUPERCAPACITOR HYBRID ENERGY STORAGE SYSTEM

[1]Mufti Mashood, [2]Navnidhi Sharma
[1]Research Scholar, Department of Electrical Engineering, E-Max Group of Institutions, Gola, Ambala
[2]Assist. Professor, Department of Electrical Engineering, E-Max Group of Institutions, Gola, Ambala
Ambala, Haryana

Abstract: ***The use of photovoltaic (PV) systems for electricity generation started in the seventies of the 20th century and is currently growing rapidly worldwide. In fact, many organizations expect a bright future for these systems. As the output power of a solar PV system fluctuates with time-varying parameters such as solar irradiance. Therefore, considerable PV research focuses on the effect of these transient variables on the PV system. Now-a-days, computer models are employed to estimate the effects of these transient parameters on a PV system. The accuracy of these models is usually dependent on the location where accurate meteorological data is available. This work presented a comprehensive overview of the current status of grid-connected PV systems while highlighting the research activities in different areas related to this field. Moreover, the work highlighted the importance of studying the impacts of large centralized PV systems on distribution networks. This is because current trends show that sizes and locations of installation of these systems are expected to highly impact these networks. The work also show the need to develop a new method to analyze the impacts of installing large PV systems on the operation of the electric network, especially due to power fluctuations generated from these systems. This is mainly due to the fact that existing methods used to study the impacts of PV systems either do not include the temporal information of the data in the analysis, and thus, fail to provide any details about power fluctuations, or are difficult to apply in cases where long historical time series data with high resolution is used. Clustering based method proposed in this research is a novel method that overcomes the drawbacks of existing methods used to evaluate the performance of PV systems. The method utilizes the available data in an efficient and intelligent manner, and thus, generates comprehensive results that can help.***

Index Terms- Super-capacitor, PV system, DC link.

(I) INTRODUCTION

The importance of Renewable Energy sources has been growing at a fast pace for the two primary reasons, one being the ever unavoidable quest for inexhaustible sources of energy and the other being the reduction of the environmental effects. When compared to the traditional non-renewable resources like gasoline, natural gas and coal which have many restrictions like geographical abundance, business transactions, import regulations and price fluctuations, the renewable energy sources are independent of the above factors mentioned. Also, the main drawback of the non-renewable sources is being exhaustive in nature. Hence extensive emphasis is placed on the energy utilization through renewable energy sources, the recent examples being the new brand of hybrid cars launched into the market and the increased percentage of energy generation through renewable energy sources such as solar, wind etc. Consequently, the current researchers are faced with the evolving challenges regarding issues of efficient renewable energy conversion and intermittency in availability of renewable energy resources.

Therefore, in recent years both academic institutions and electric utilities have focused their research attention on studying the possible impacts of distributed power systems - PV systems on the electrical grid network. Most of this research focuses on dynamic responses and PV system performance when interfaced with a power grid; viz. sudden grid voltage changes, system faults - both on AC and DC sides, power fluctuations due to solar irradiation changes etc. In order to detect faults and protect devices/systems, various control schemes have been developed.

The output power of a solar PV system fluctuates with time-varying parameters such as solar irradiance. Therefore, considerable PV research focuses on the effect of these transient variables on the PV system. Now-a-days, computer models are employed to estimate the effects of these transient parameters on a PV system. The accuracy of these models is usually dependent on the location where accurate meteorological data is available.

1.1. Intermittency Problem

PV power output mainly depends on the time of day and the weather conditions such as clouds. Since the variations of solar irradiance occur in the minute-to-minute time frame, PV power systems are called intermittent energy sources. The passage of clouds will cause considerable fluctuations in PV power output both in “standalone” as well as “grid connected” systems. Instantaneous output changes have considerable impact on system voltage and also operating reserve requirements. At the time of power output fluctuations or due to failure of generation due to bad weather conditions, the backup generators should act instantaneously to compensate for the loss of energy.Fig1.1 shows a typical cloud transient that was recorded locally over a 100 minute period. Note that changes can occur slowly at times and rapidly at other times. This thesis to explore the problems associated with MPPT algorithms and determines how the MPPT interacts with intermittency.

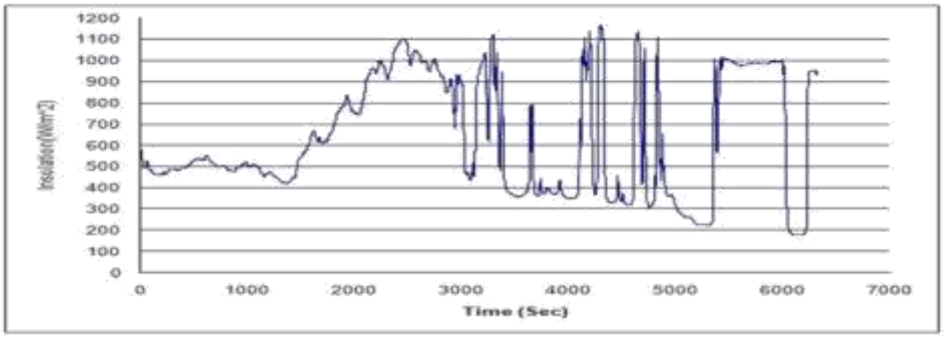


Fig 1.1Typical variation of solar irradiance on a cloudy day

1.2 PV inverters and smart grid

Photovoltaic (PV) power supplied to the utility grid is gaining more and more visibility, while the world's power demand is increasing. Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid. Integration of PV power generation systems in the grid plays an important role in securing the electric power supply in an environmentally-friendly manner. Grid-connected PV System comprises of PV panel, a DC/AC converter that capably connected to the grid. This system is used for power generation in places or sites accessed by the electric utility grid. If the PV system AC power is greater than the owner's needs, the inverter sends the surplus to the utility grid for use by others.

The utility provides AC power to the owner at night and during times when the owner's requirements exceed the capability of the PV system. Depending on the application and requirements PV system can either be a standalone or hybrid system.

1.3 Photovoltaic system overview and inverter sizing

Generally the PV system comprises of PV generator which is a set of series-parallel electrically interconnected solar panels. PV panels are delivered by the manufacturers and are given in terms of the nominal peak power of the panel at standard test conditions (STC). PV generator gives the total installed power which is the sum of nominal peak power of each solar panel present in the PV installation. This PV generator is connected to an inverter which connected to an AC/DC load and/or grid. The grid-connected inverter must be designed for the peak power and must obey conditions that deal with issues like power quality, detection of islanding operation, grounding; MPPT and long-life. Inverter maximum power is exactly referred to the total installed power of the PV generator and has to optimize the energy injected to grid. Since the expected irradiance in the physical location of the PV installation is lower than the nominal or standard one, a current practice is to select the inverter maximum power than the nominal peak power of the PV generator. This practice is what is known as under sizing of the Inverter.

1.4 Photovoltaic characteristics

Voltage and Current outputs of the PV modules is affected by temperature and irradiance. Power electronics components of a photovoltaic system, such as grid-direct inverters have maximum and minimum voltage inputs. During rating of power electronics equipment, these variations should be taken into account especially for the MPPT range of inverters.

1.4.1 Open Circuit Voltage and Temperature

A PV module's voltage output is actually a variable value that is primarily affected by temperature. The relationship between module voltage and temperature is actually an inverse one. As elaborated in Fig.1.1 the module's temperature increases, the voltage value decreases and vice versa. It is important to put into consideration the cold and hot temperatures during PV design as shown in PV calculations. If the temperature of the module is less than the STC value of 25°C, the module's open circuited voltage, Voc value will actually be greater than the value listed on the module's listing label.

1.4.2 Module Current and Irradiance

The amount of current produced by a PV module is directly proportional to how bright the sun is. Higher levels of irradiance will cause more electrons to flow off the PV cells to the load attached. However the amount of voltage produced by the PV module is affected by the irradiance value, but the effect is very small.

As demonstrated in Fig. 1.2 the PV module's voltage changes very little with varying levels of irradiance. In the modules used in the NTNU façade system, the BP solar module has coefficient of current of +0.0025 A/ ^{o}C

(II) CONCEPT & THEORY OF PROBLEM

2.1 Components of Grid-Connected PV Systems

The building blocks of a grid-connected photovoltaic system are shown in Fig 3.1. The system is mainly composed of a matrix of PV arrays, which converts the sunlight to DC power, and a power conditioning unit that converts the DC power to AC power. The generated AC power is injected into the grid and/or utilized by the local loads. In some cases, storage devices are used to improve the availability of the power generated by the PV system. In the following sub-sections, more details about different components of the PV system are presented and the recent related research activities are discussed.

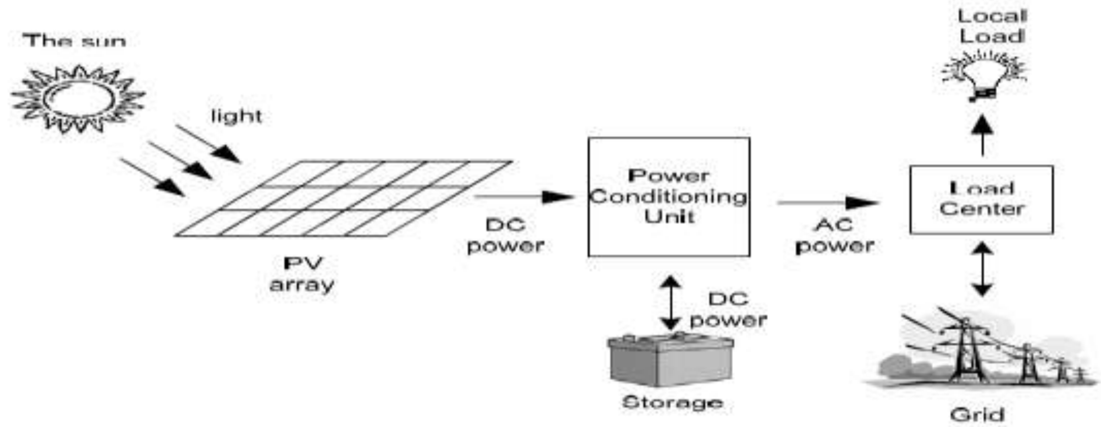


Fig 2.1 Main components of grid-connected photovoltaic system.

2.2 The Light From The Sun

Irradiance or insolation is the instantaneous solar power received on a unit surface area and is normally given in W/m^2. The *global irradiance*, G_g that reaches a horizontal surface on the earth is the sum of two components: 1) *direct (beam) irradiance*, G_b, that directly reaches the horizontal surface without being scattered by the atmosphere and; 2) *diffuse irradiance*, G_d, that reaches the horizontal surface after being scattered by clouds. Weather stations usually measure the global horizontal irradiance by a Pyranometer placed horizontally at the required location. On the other hand, a Pyrheliometer is used to measure the direct normal irradiance, which is the irradiance received by a surface that is perpendicular to the sun rays. Accordingly, the direct irradiance on the horizontal surface can be calculated. To measure the diffuse irradiance, a shading ball or ring can be used to permanently shade the Pyranometer. Fig2.2 shows pictures of the three devices used to measure different irradiance components.

Fig 2.2 Pyranometer (left top), Two- axis tracked Pyrheliometer (left bottom), Pyranometer with shading ball (right)

PV arrays are usually tilted to maximize the energy production of the system by maximizing the direct irradiance that can be received. Usually the optimum tilt angle with respect to the horizontal surface of the earth is calculated for each specific site; however, it can be roughly set within $\pm 15^o$ of the site latitude. Thus, the irradiance components received by the tilted surface of the PV array are different from those provided by the weather stations. Accordingly, different models must be used to estimate the different irradiance components on the surface of the PV array from those provided by the weather stations. The accuracy of these models is mainly dependent calculating the different components of irradiance on the surface of the PV array .

Currently, one of the main research activities in this area focuses on analyzing the short-term fluctuations of irradiance due to passage of clouds. Some of these studies use frequency domain analysis to investigate the smoothing effect of extended area of the PV system on the fluctuation of irradiance. Other studies use frequency domain analysis to analyze the amplitude, and persistence of these fluctuations.

Another research activity related to this field focuses on developing models for the different irradiance components at a certain location by using either cloud observations obtained from weather stations or images obtained from satellites. These models are important for predicting the output energy produced from PV systems installed at these locations. Short-term prediction of solar irradiance from historical time-series data is very important for short-term planning related to the operation of electric networks in the presence of PV systems, especially in the case of large systems. Different methods, such as ARMA models and neural networks have been used for this purpose. However, the research in this field still needs more work to become as mature and well-established as wind speed prediction. In fact, predicting the solar irradiance is a complicated task as it is affected by many factors such as types of clouds, cloud heights, wind speed, and wind direction.

(III) PRESENT WORK

The DC link Super capacitor sometimes called power decoupling is normally achieved by means of electrolytic capacitor. For years design engineers have chosen electrolytic capacitor technology for use as the bus link capacitor on power grid connection. Electrolytic capacitors have been the workhorse technology for hard switched inverter bus link capacitors for many years. Electrolytic capacitor technology has also remained virtually unchanged over the years. The main attraction has always been the low cost per farad associated with electrolytic capacitors. The DC link capacitor is very important in the life time of the converter, and it should be kept as small as possible and preferably substituted with film capacitors. A lot of work has been invested into reducing the DC-link capacitance of inverters in order to replace electrolytic capacitors with the more reliable, but also more expensive and larger film capacitors. The comparison of electrolytic capacitor and film capacitor has been explained earlier. Temperature has been the effect to electrolytic capacitor to its life time. Film capacitors are a clear the alternative given their long life expectancy and wide operating temperature range. Unfortunately, film capacitors are far more expensive than the electrolytic ones in term of cost per farad and hence the size of the capacitance has to be smaller to keep the price of the capacitor acceptable.

The second factor, which can be referred to as the AC fluctuation of the DC-link voltage is caused by the double-line frequency ripple power generated from the grid side. This double line frequency ripple component can couple through the DC voltage control loop to cause a significant amount of distortion on the current reference signal.

As indicated from the flow chart of Proposed Work, super capacitor is used as power bank. After checking minimum voltage power charging & discharging of capacitor continues. If charging voltage is above the threshold voltage, then stop the capacitor charging.

In this flow chart it is indicated that super capacitor used as power source. After checking threshold voltage use battery to power Starter in Conjunction with Capacitor. If there is no power requirement, disconnect capacitor and battery from starter. Then again check all the connections with maximum voltage.

The bus link capacitor is used in DC to AC inverters to decouple the effects of the inductance from the DC voltage source to the power bridge. The bus link capacitor also plays a role in reducing the leakage inductance of the power grid.

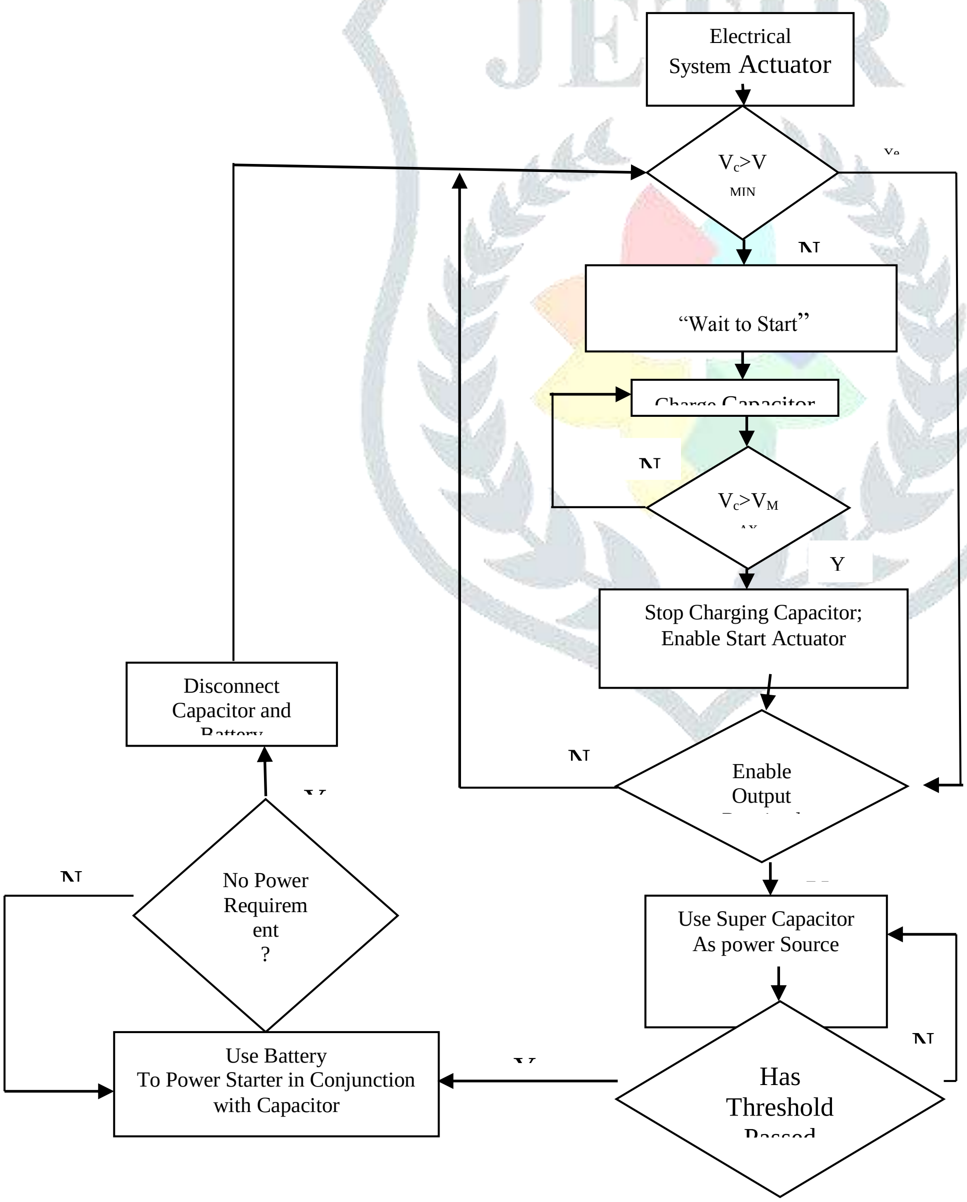


Fig 3.1 Flowchart of proposed model

(IV) SIMULATION TOOL AND RESULTS

4.1Simulink Model

PV system with super capacitor model is designed as below in Fig 4.1 In this model; grid is connected to super capacitor. A universal bridge is provide to connect input source & super capacitor.

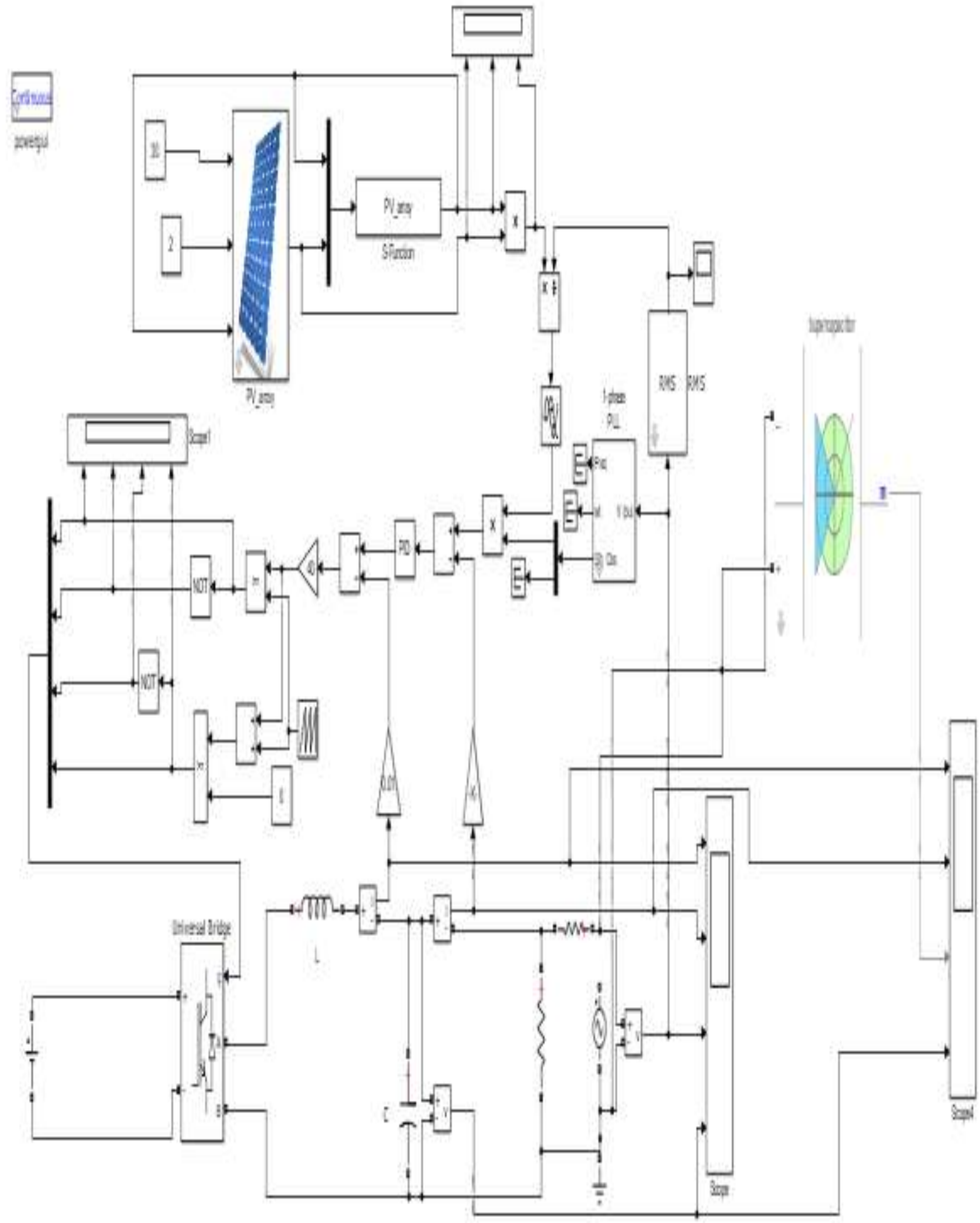


Fig 4.1 Model of PV System

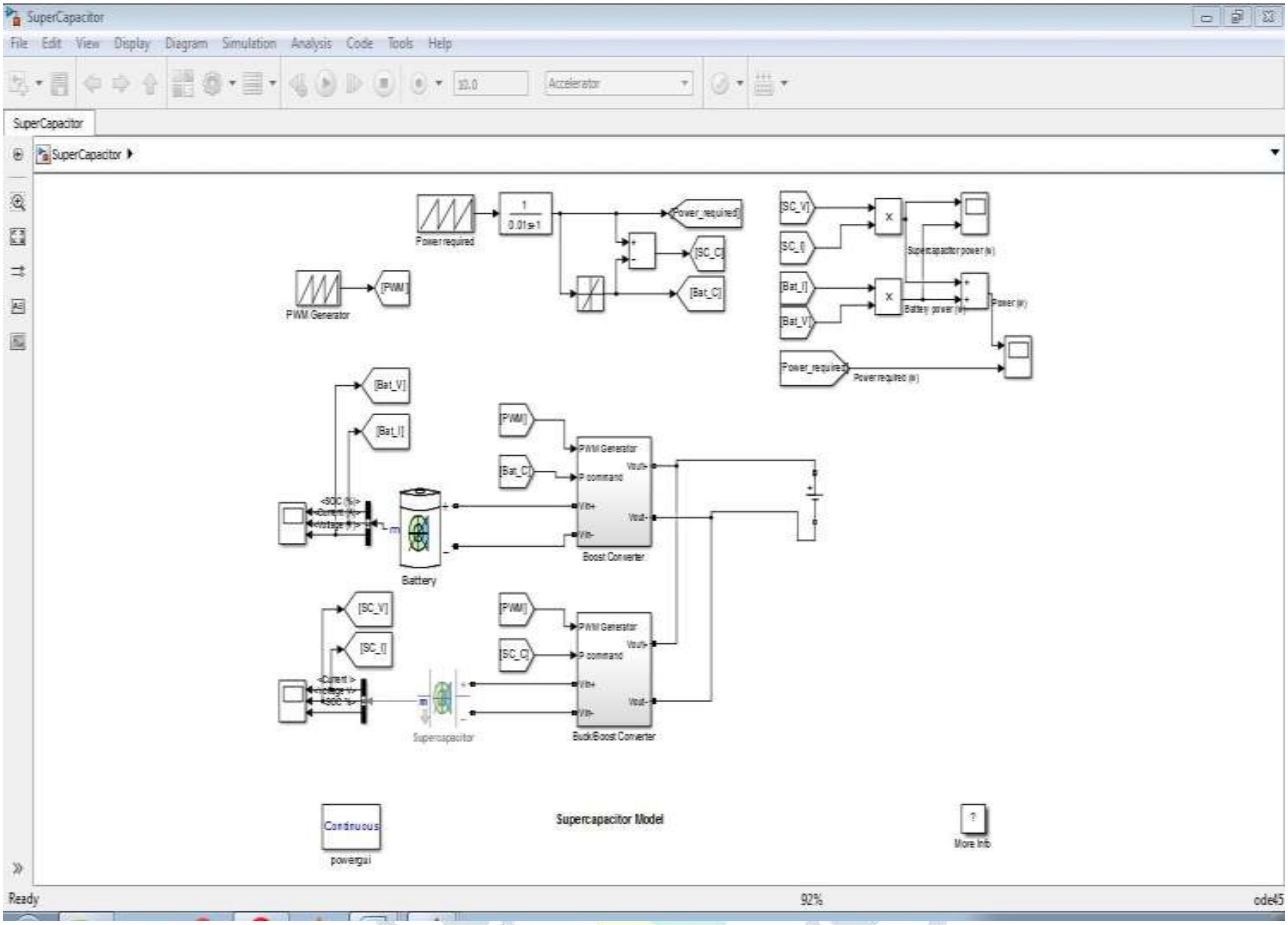


Fig 4.2 Super-capacitor Model gives internal model of Super capacitor which contains controllable circuit.

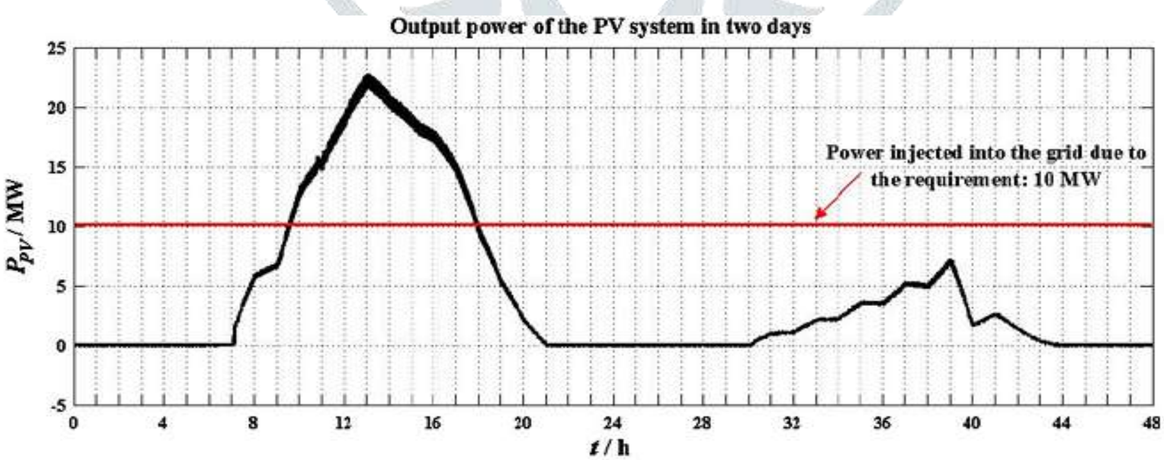


Fig 4.3 Output Power of PV System

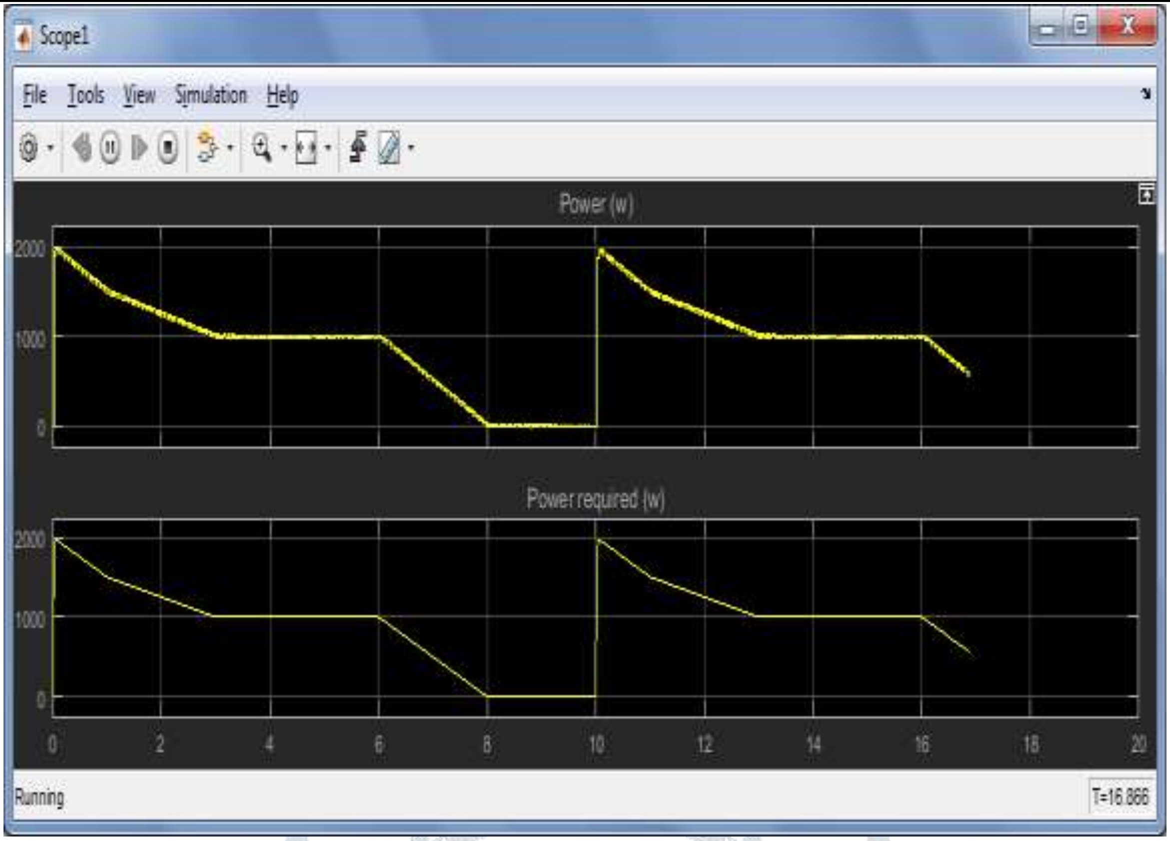


Fig 4.4 Input Output power of Supercapacitor with Proposed Model

It can be clearly noted that when we use Our Super capacitor Module Power Injected follows closely to Power Required. As in figure 6.3 (taken from base paper) it is clear that battery powered system is very bad at injecting power into grid when it is needed.

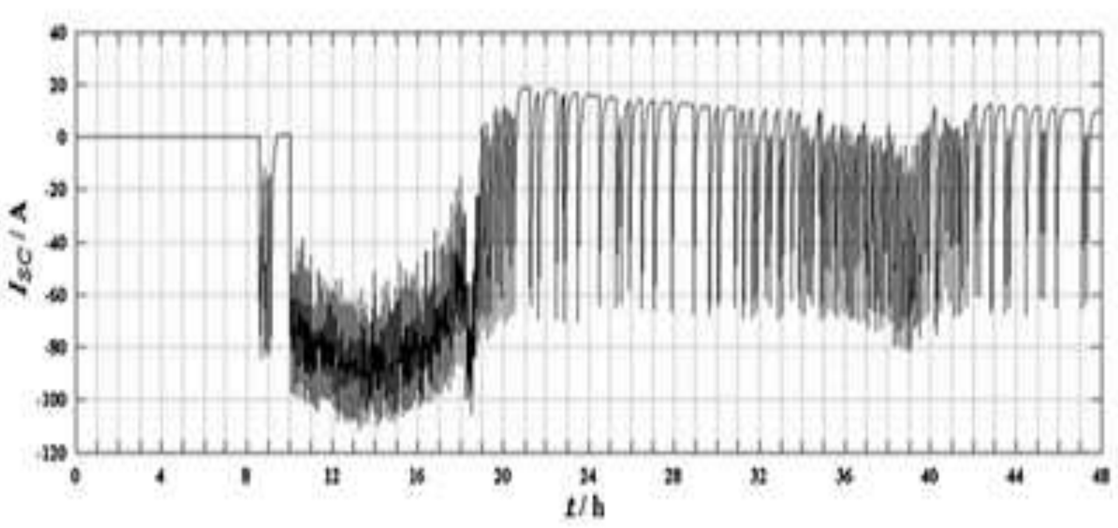


Fig 4.5 Current though Capacitor

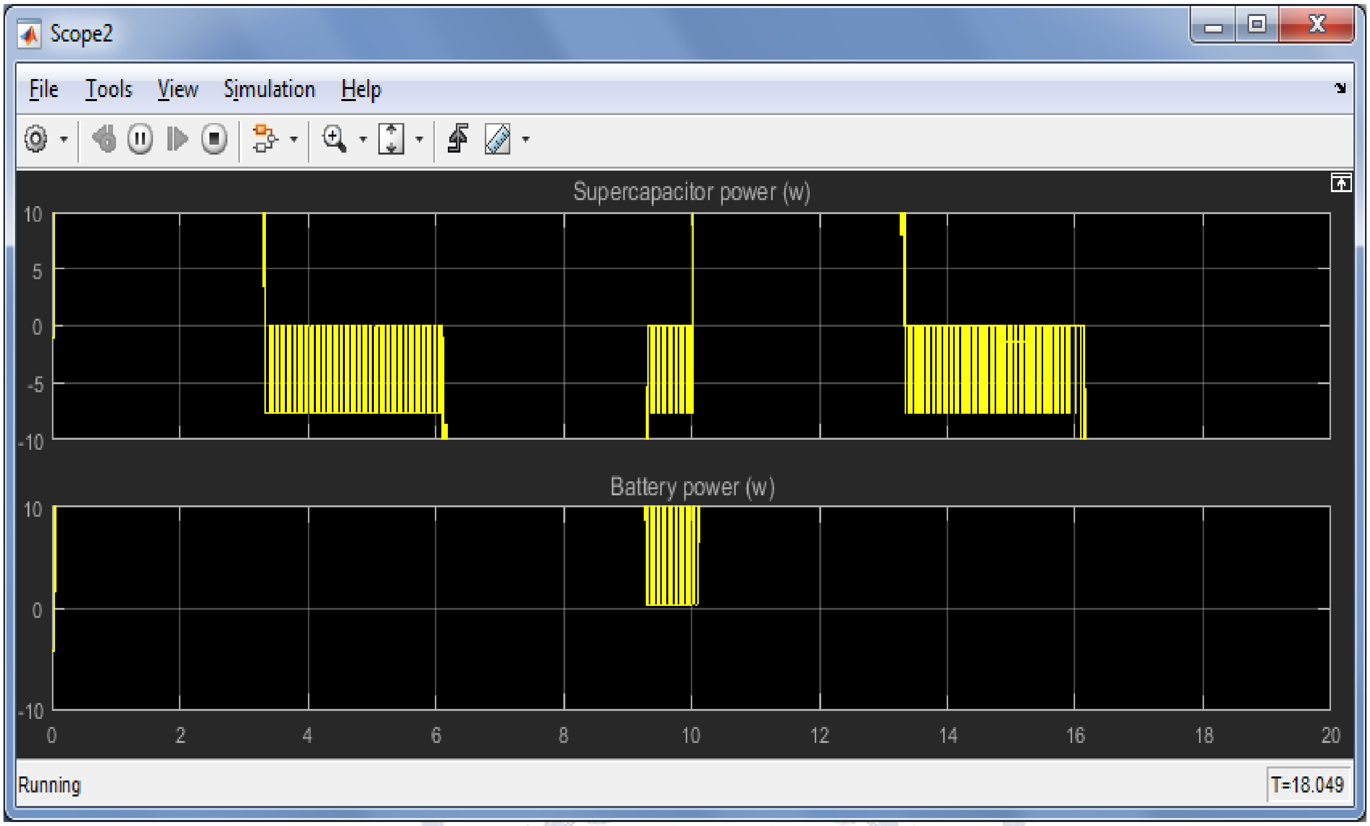


Fig 4.6 Current though Proposed Supercapacitor

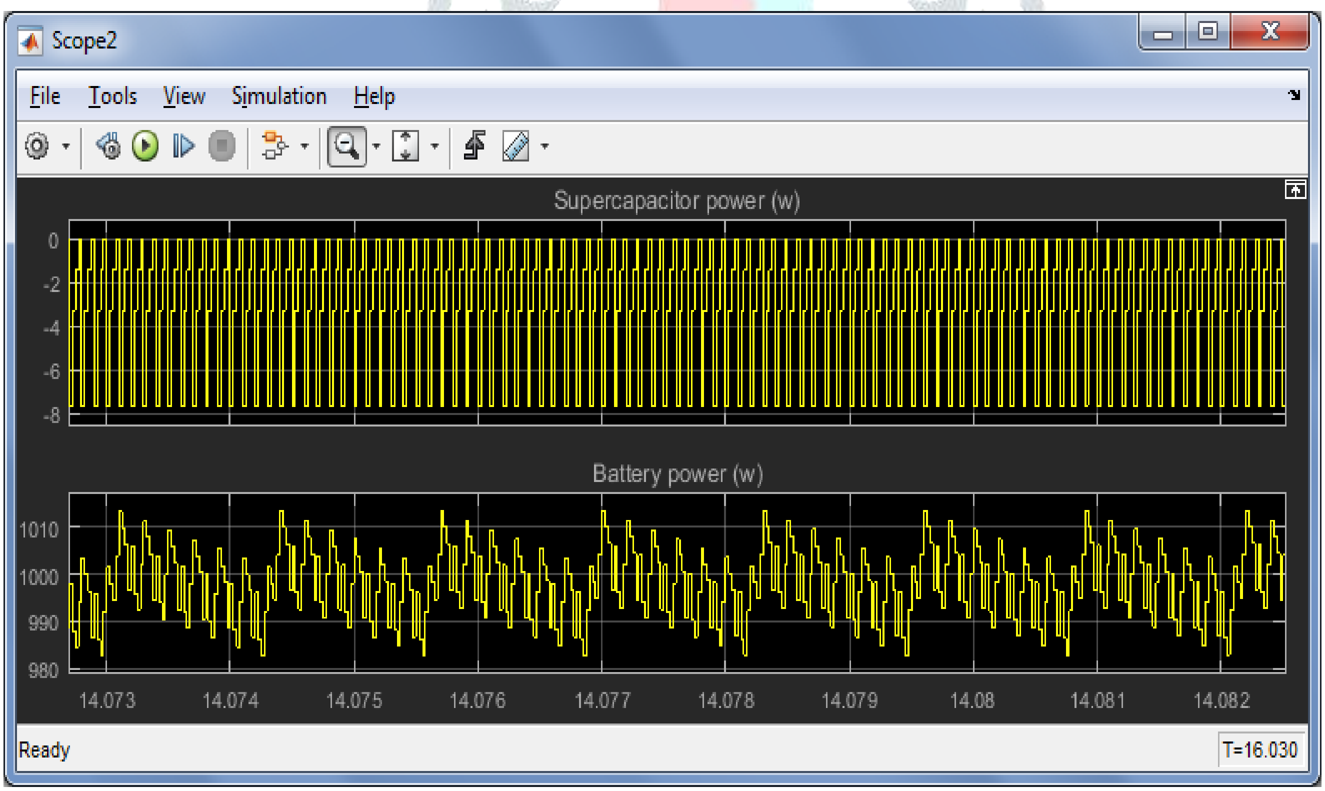


Fig 4.7 Current though Proposed Super capacitor when you zoom in

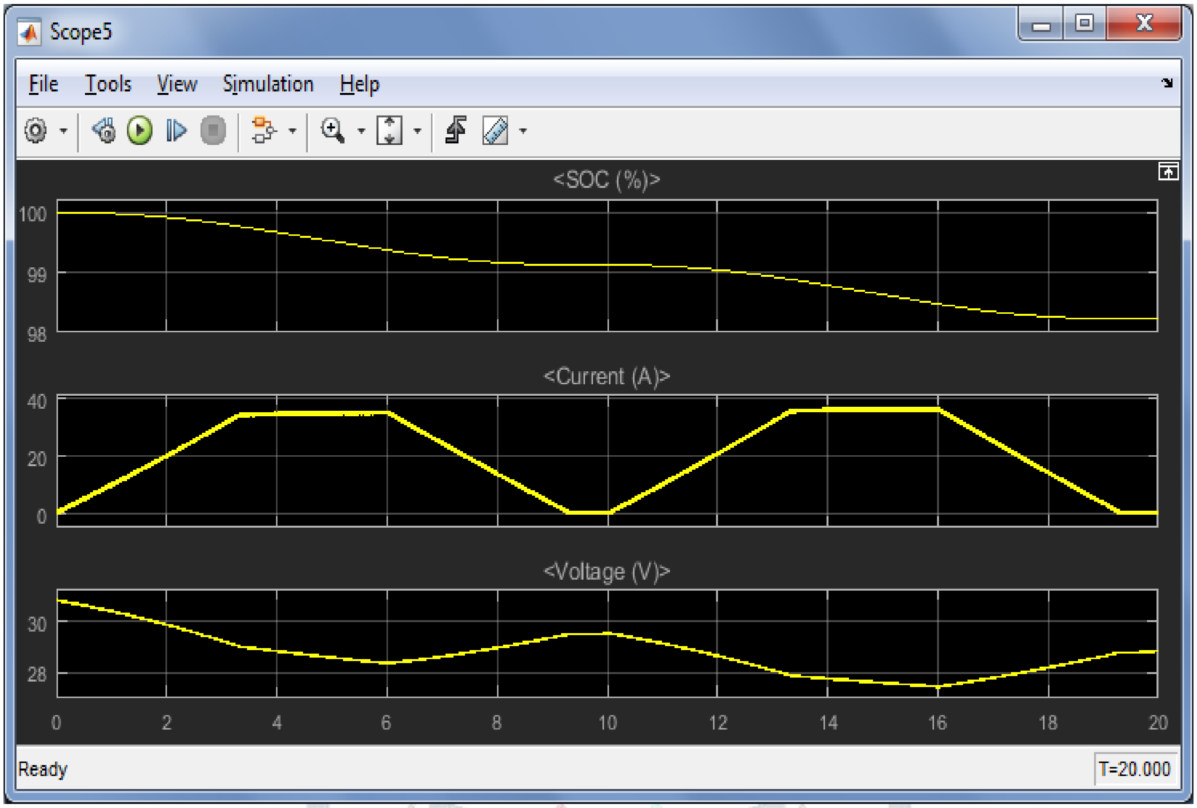


Fig 4.8 Battery State of Charge, Current and voltage of Proposed Super capacitor

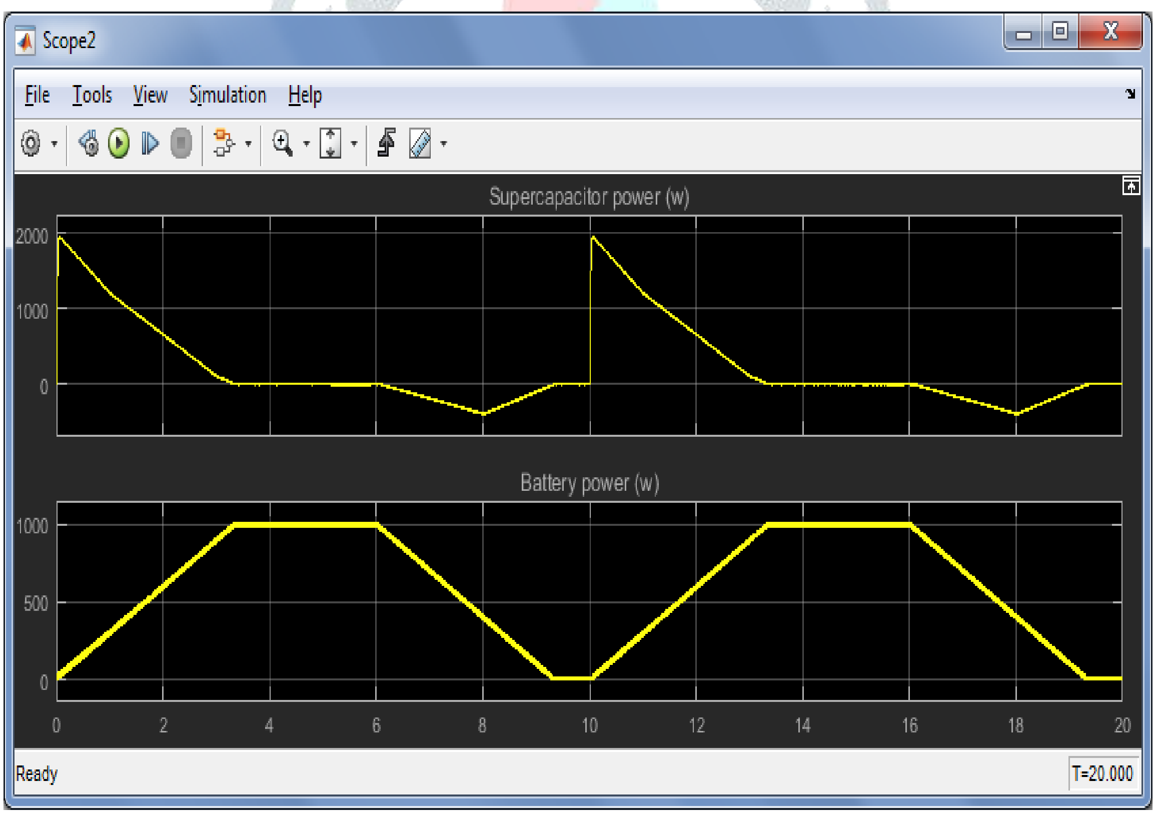
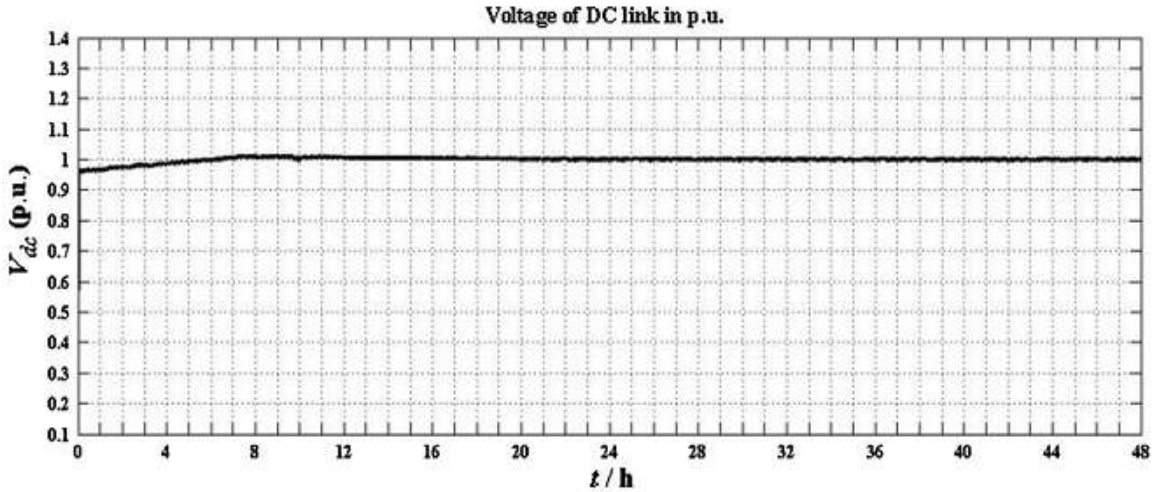


Fig 4.9 Battery power Vs Super capacitor Power.

Super Capacitor Provides Sharp Charge Storage and slow Discharge as contrast to battery, it is to be noted that the Super capacitor is charged only twice in this scenario at time T=0 and T=10 as opposed to continuous charging to battery

Due to the high power density and the low energy density, the discharging time of the super capacitor is very short and its response is very fast. The super capacitor plays the role of absorbing the high-frequency power fluctuations from the PV and maintaining the voltage of the DC link in a proper range.



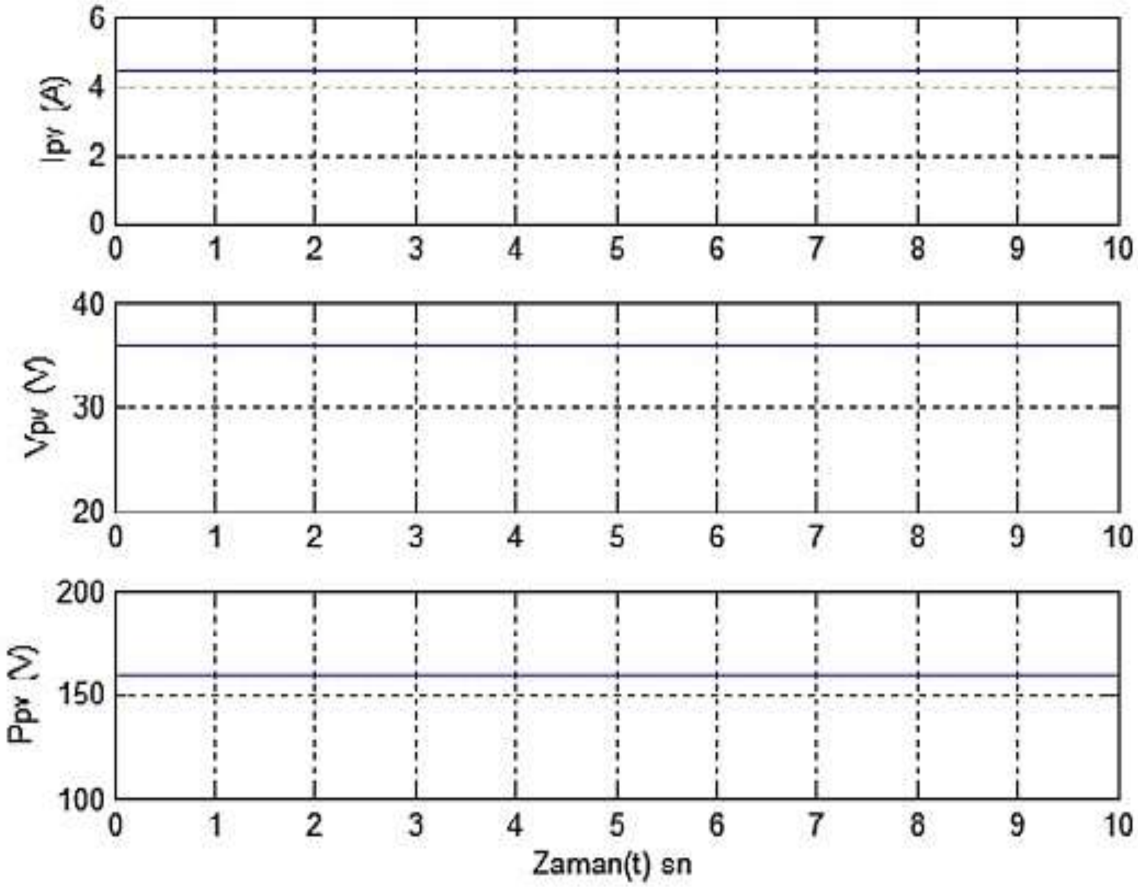


Fig 4.10 Current, Voltage & Power Graph of PV Grid

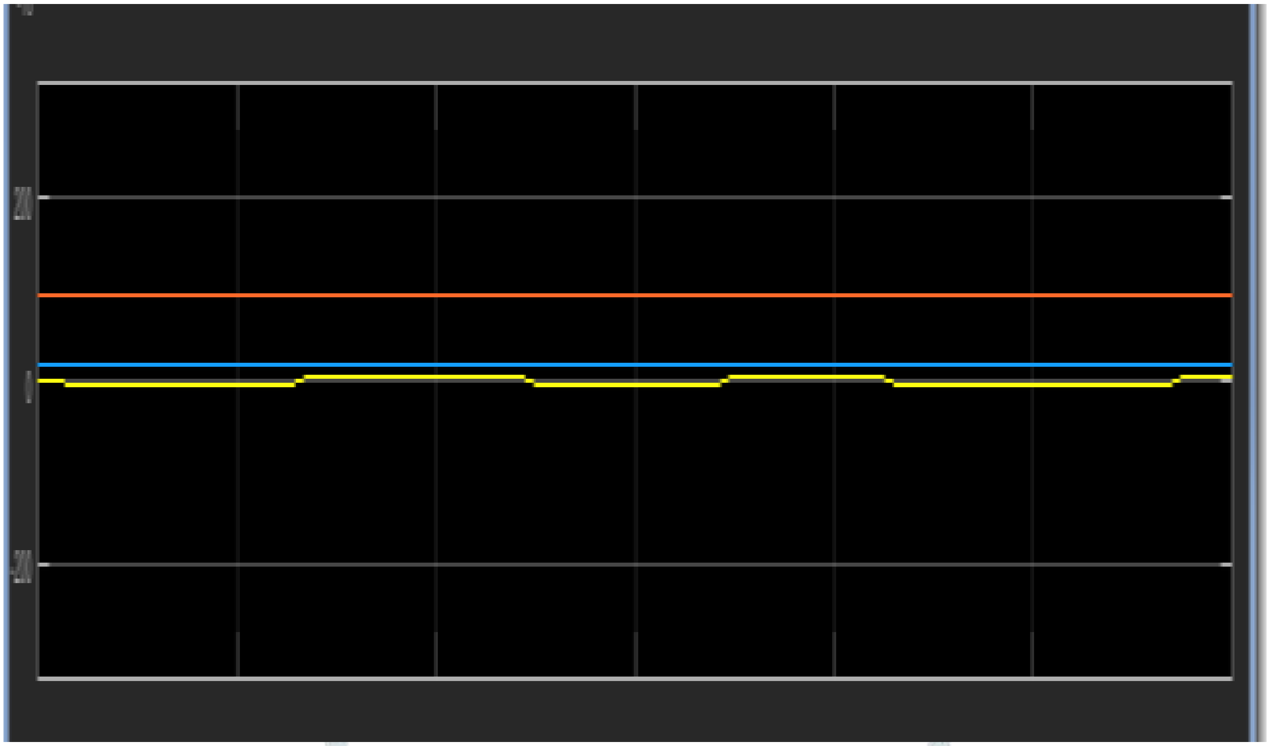
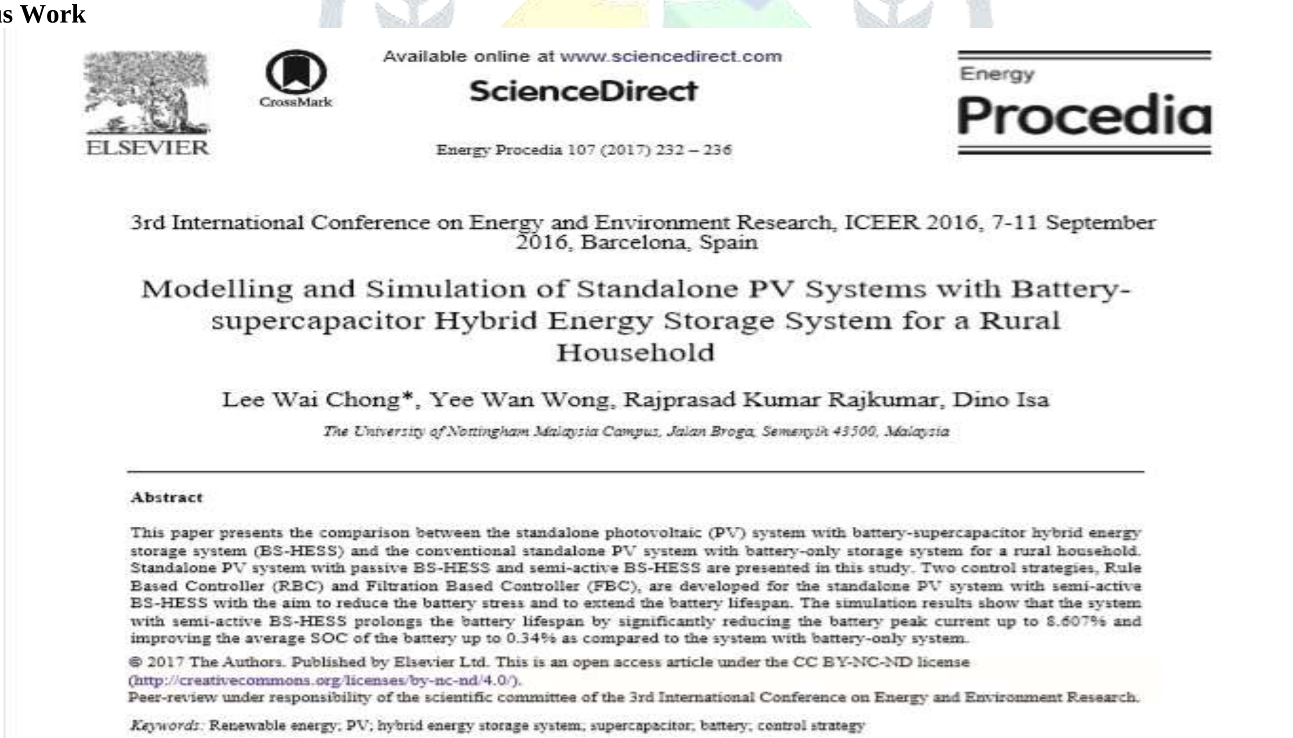


Fig 4.11 Current, Voltage & State of Charge of Proposed Super Capacitor.

The super capacitor always charges or discharges in a shorter time than the battery therefore the battery is protected from the high frequency fluctuations.

(V) COMPARISION, CONCLUSION & FUTURE SCOPE

5.1 Previous Work



Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 107 (2017) 232 – 236

Energy Procedia

3rd International Conference on Energy and Environment Research, ICEER 2016, 7-11 September 2016, Barcelona, Spain

Modelling and Simulation of Standalone PV Systems with Battery-supercapacitor Hybrid Energy Storage System for a Rural Household

Lee Wai Chong*, Yee Wan Wong, Rajprasad Kumar Rajkumar, Dino Isa

The University of Nottingham Malaysia Campus, Jalan Broga, Semenyih 43500, Malaysia

Abstract

This paper presents the comparison between the standalone photovoltaic (PV) system with battery-supercapacitor hybrid energy storage system (BS-HESS) and the conventional standalone PV system with battery-only storage system for a rural household. Standalone PV system with passive BS-HESS and semi-active BS-HESS are presented in this study. Two control strategies, Rule Based Controller (RBC) and Filtration Based Controller (FBC), are developed for the standalone PV system with semi-active BS-HESS with the aim to reduce the battery stress and to extend the battery lifespan. The simulation results show that the system with semi-active BS-HESS prolongs the battery lifespan by significantly reducing the battery peak current up to 8.607% and improving the average SOC of the battery up to 0.34% as compared to the system with battery-only system.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Energy and Environment Research.

Keywords: Renewable energy; PV; hybrid energy storage system; supercapacitor; battery; control strategy

5.2 Previous Results

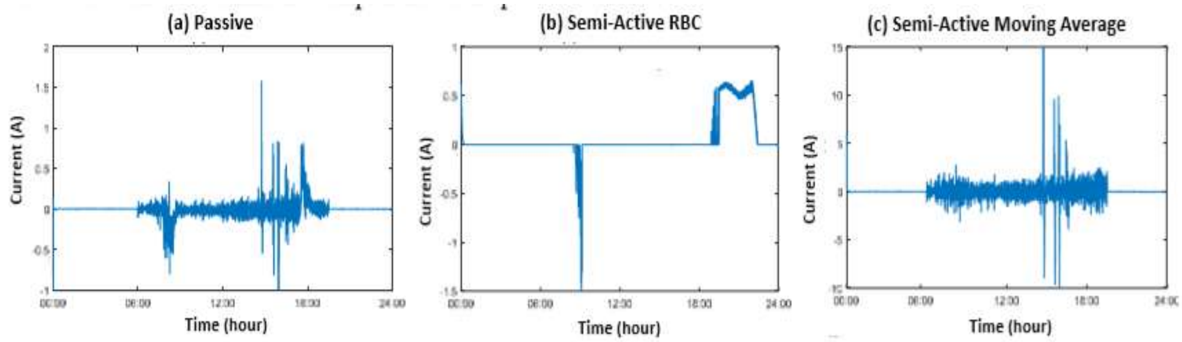


Fig. 5. Supercapacitor Current. (a) Passive BS-HESS. (b) Semi-active BS-HESS (RBC). (c) Semi-active BS-HESS (Moving Average).

Table 2. Performance of Battery in Simulation Test

		Batt-Only	Passive	Semi-Active Moving Average	Semi-Active RBC
Peak Current	**Current (A)**	6.664	6.655	6.622	6.090
	Reduction (%)	-	0.137	0.624	8.607
Final SOC	**SOC (%)**	76.702	76.693	76.746	77.00
	Improvement (%)	-	-0.011	0.058	0.390
Average SOC	**SOC (%)**	67.226	67.200	67.241	67.248
	Improvement (%)	-	-0.039	0.022	0.033

5.3 Comparison of my results with the Base Paper.

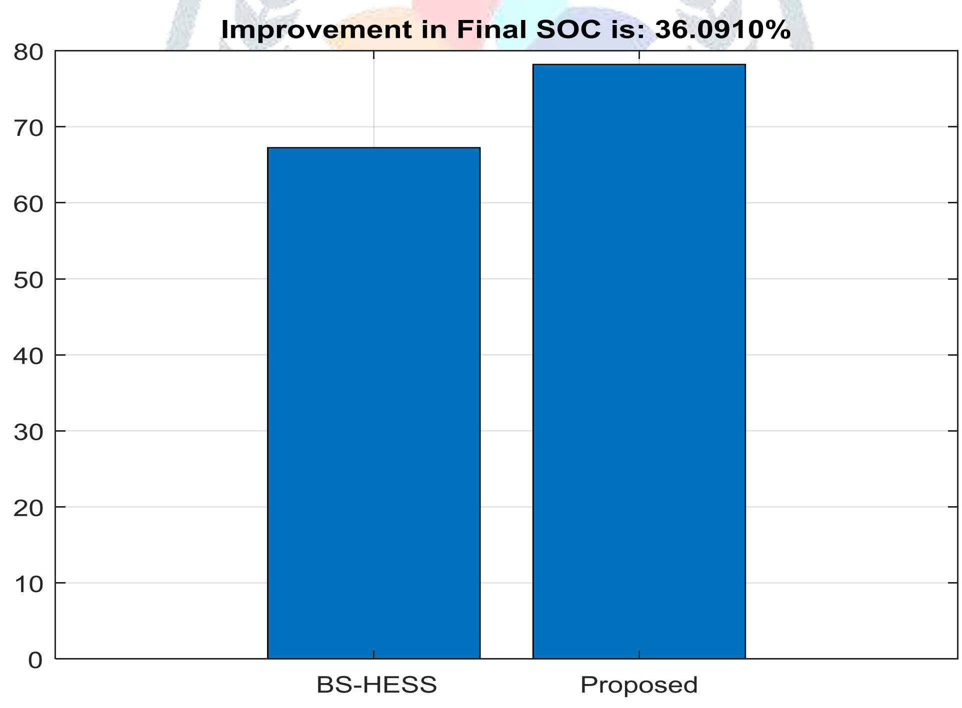


Figure showing Comparison of Average State of Charge % of the BS-HESS and Proposed Model.

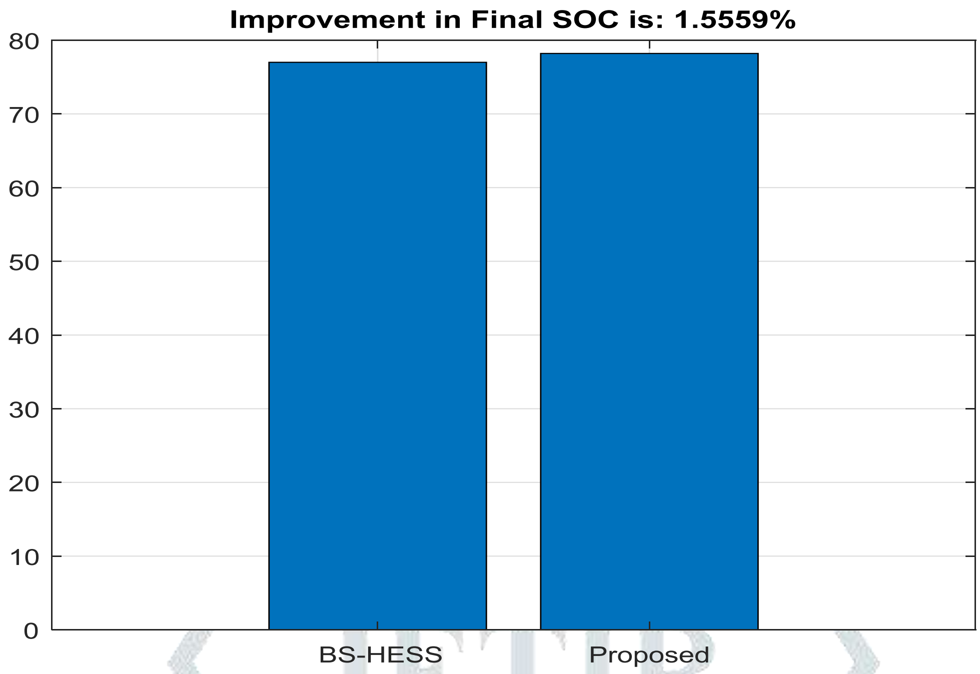


Figure Showing Comparison of Final State of Charge % of the BS-HESS and Proposed Model

5.3 Conclusion

This paper presented a comprehensive overview of the current status of grid-connected PV systems while highlighting the research activities in different areas related to this field. Moreover, the thesis highlighted the importance of studying the impacts of large centralized PV systems on distribution networks. This is because current trends show that sizes and locations of installation of these systems are expected to highly impact these networks. The thesis also showed the need to develop a new method to analyze the impacts of installing large PV systems on the operation of the electric network, especially due to power fluctuations generated from these systems. This is mainly due to the fact that existing methods used to study the impacts of PV systems either do not include the temporal information of the data in the analysis, and thus, fail to provide any details about power fluctuations, or are difficult to apply in cases where long historical time series data with high resolution is used.

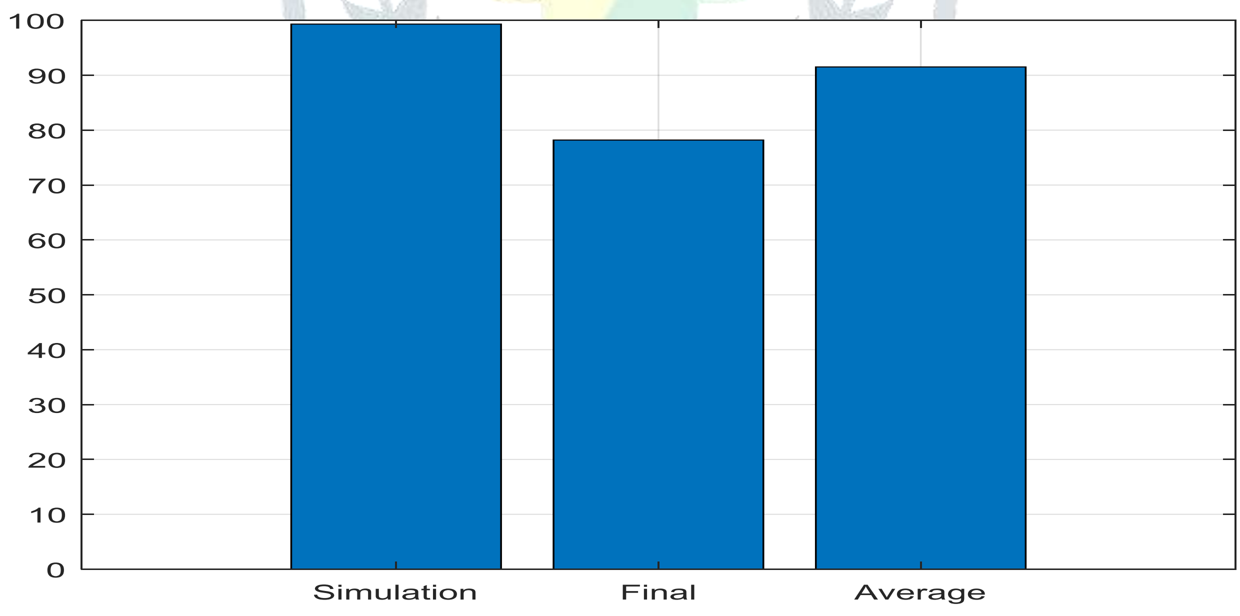


Fig Comparison of Simulated, Final and Average State of Charge % of the Proposed Model

5.4 Scope of Future Research

This thesis establishes a new direction for research related to PV systems and other intermittent renewable energy sources. Investigate the performance of the clustering-based method with different loading profiles of the network and with different network topologies. Examine the use of other sets of features and different grouping techniques in order to improve the accuracy of the results obtained from using the cluster representatives in the power flow analysis. Apply the clustering-based method in studies related to asset management such as those carried out to predict the lifetime of voltage regulators. Other studies that can also utilize the proposed method are those related to studying the impacts of very large PV systems on the scheduling of generating units.

REFERENCES

[1] "International Energy Outlook, 2008", Energy Information Administration, Available online:

[2] "Meeting Future Electricity Demand Will Increase Emissions of Some Harmful Substances", Report to Congressional Requesters prepared by the United States General Accounting Office, October 2002.

[3] Unleashing the Potential of On-Grid Photovoltaics in Canada. An Action Plan to make PV an Integral Component of Canada's Energy Future," Report prepared for Industry Canada by The Delphi Group, 2003.

[4] "Trends in Photovoltaic Applications. Survey report of selected IEA countries between 1992 and 2007.

[5] E. Vartiainen, "A new approach to estimating the diffuse irradiance on inclined surfaces," Renewable Energy, Vol. 20, 1999.

[6] Volker Quaschning "The Sun as an Energy Resouce, Technology Fundamentals" Renewable Energy World magazine, May 2003, pp. 90-93.

[7] S. Roy, "Optimal planning for utility generation by photovoltaic sources spread across multiple sites," IEEE Transactions on Energy Conversion,vol.21, no.1, pp. 181-186, March 2006.

[8] N. Kawasakia, T. Oozekia, K. Otania, K. Kurokawaa, "An evaluation method of the fluctuation characteristics of photovoltaic systems by using frequency analysis," Solar Energy Materials & Solar Cells Vol. 90, 2006.

[9] A. Woyte, R. Belmans, J. Nijs, "Fluctuations in instantaneous clearness index: Analysis and statistics," Solar Energy, Vol 81, 2007.

[10] J. Ehnberg, M. Bollen, "Simulation of global solar radiation based on cloud observations," Solar Energy, Vol 78, 2005.

[11] J. Polo, L.- Zarzalejo, L. Ramirez, B. E-spinar "Iterative filtering of ground data for qualifying statistical models for solar irradiance estimation from satellite data," Solar Energy, Vol. 80, 2006.

[12] F. Vignola, P. Harlan, R. Perez, M. Kmiecik, "Analysis of satellite derived beam and global solar radiation data," Solar Energy, Vol 81, 2007.

[13] A. Moreno-Munoz, J. de la Rosa, R. Posadillo, V. Pallares, "Short term forecasting of solar radiation," IEEE International Symposium on Industrial Electronics, 2008. ISIE 2008.

[14] E. Crispim, P. Ferreira, A. Ruano, "Solar radiation prediction using RBF Neural Networks and cloudiness indices," International Joint Conference on Neural Networks, 2006. IJCNN '06.

[15] A. Mellit, M. Menghanem, M. Bendekhis, "Artificial neural network model for prediction solar radiation data: application for sizing stand-alone photovoltaic power system," IEEE Power Engineering Society General Meeting, 2005.

[16] D. M. Chapin, C. S. Fuller, and G. L. Pearson, "A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power," Journal of Applied Physics, Vol. 25, Issue 5, May 1954.