Stand Alone 1-MW Microgrid for Remote locations of Armed Forces with PV-Battery-Diesel Generator

CPS Pasricha, Rajeev Gupta, Rahul Walawalkar

Abstract—Many times, Armed Forces are deployed in bases in remote areas on the borders or Islands, which are far flung areas away from mainland. In many such cases, these areas do not have their power requirements through the main grid supply and entire power requirement of the deployment is supplied by diesel generators. These diesel generators have high environmental impact due to emission of greenhouse gases and are highly uneconomical as logistic sustenance of remote bases for supply of fuel is very challenging, Fossil fuel has to be supplied by vehicles, helicopters, boats or manually carried to hill tops. This increases the overall cost of deploying armed forces in remote areas. In recent years with the advancements in power electronic components and renewable energy, development in Microgrids (MGs) have shown a way to reduce dependency on main power grids. Hence, with the help of MGs, renewable energy can be used to fulfill power requirements of the armed forces deployed in remote places. In this work, a MG with capacity of 1MW has been designed keeping the special needs of armed forces as a major consideration. Solar power has been used as a primary renewable energy source in the proposed design. In order to mitigate the adverse effects of meteorological and extreme conditions on the solar power generation capacity, energy storage system in the form of batteries has also been provided. Batteries store power when excess power is generated from the photo voltaic (PV) system and discharge the power when power demand is higher than the PV generated power. Diesel generator sets have also been used to run critical loads, provide reliability and as backup to critical operations catering for outages, night time needs and un-expected meteorological conditions. MATLAB has been used to design and simulate the proposed MG. Working of the MG has also been demonstrated for varying meteorological and varying load conditions as well. The proposed design works satisfactory in all cases.

Keywords—Solar energy, battery, MG, diesel generator, voltage source inverter, PWM.

I. INTRODUCTION

MG includes small voltage supply systems along with distributed renewable energy resources, like photovoltaic as well as wind turbines power systems along with energy storage devices. The power systems are interconnected to the medium voltage distribution network, but they can also be operated isolated from the main grid. From the users point of view, MGs provide both thermal and electricity needs and in addition enhance local reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips and potentially lower the costs of energy supply. From the utility point of view, application of distributed energy sources can potentially reduce the demand for distribution and transmission facilities. Clearly, distributed generation located close to loads will reduce flows in transmission and distribution circuits with two important effects: loss reduction and ability to potentially take on additional loads in remote areas. Bases of armed forces are commonly located at the end of transmission feeders. This leaves them particularly vulnerable to service disruptions from natural causes such as downed power lines. In addition, electric grid have been targets of concerted attacks from insurgents on isolated transmission towers which could disable portions of the grid for extended periods. MGs can provide network support in times of stress by relieving congestions and aiding restoration after faults. The development of MGs can contribute to the reduction of emissions and the mitigation of climate changes. This is because available and currently developing technologies for distributed generation units are based on renewable sources and micro sources that are characterized by very low emissions. Technical challenges associated with the operation and control of MGs are immense. Ensuring stable operation during network disturbances or outages, maintaining stability and power quality in the islanding mode of operation requires the development of sophisticated control strategies for MG inverters in order to provide stable frequency and voltage specially in remote bases for critical loads like communication equipment, sensors, control and data centres. This paper's objectives is to demonstrate the transients of a MG in remote bases due to intentional islanding process and to illustrate the maintenance of stability of the MG in standalone mode of operation for varying loads and climate conditions. In 2001 A. Dimeas et.al implemented multi-agent methodology to accomplish the design process of MG. Small and integrated power generating systems are interconnected to form a MG and transmit low voltage to the consumer. The MG can be coupled with main grid network or operate autonomously. The local distributed generators perform several tasks except providing power to the grid, like back up during critical condition, maintaining the voltage level at a prescribed level or deliver heat for local level installation [1]. Oyarzabal et.al designed an agent based MG comprising of small and modular generation, storage and load power system, which are interconnected and supplemented by information communication technology to permit control activities. The efficacy of the architecture was verified in laboratory [2].

Revised Manuscript Received on October 20, 2020.
* Correspondence Author
CPS Pasricha*, Department of Electrical Engineering, University of Petroleum and Energy Studies, Dehradun, India E-mail. cps_pasricha@hotmail.com
Dr Rajeev Gupta, Department of Physics, University of Petroleum and Energy Studies, Dehradun, India E-mail. rajeev@upes.ddn.ac.in
Dr. Rahul Walawalkar, Executive Director, IESA & President & MD, Customized Energy Solutions Pune, India. E-mail. rwalawalkar@ces-ltd.com

In 2005, fast control approaches have been implemented to regulate the defined voltage and frequency without help of communication technologies [3]. An Artificial Neural Network is incorporated to estimate and predict the security index of an unplanned changeover to islanded mode due to turbulences in the upstream voltage network [4]. In 2009, SISO (single input and single output) d-q variables current controlled based voltage source converter is connected to the impedance. The phase locked loop blocks and Notch filters are employed to regulate the input current of the VSC [5]. Pipattanasomporn et.al demonstrated application of multi-agent power system to regulate a MG in a simulated atmosphere. The simulation response indicated that the projected multi-agent power system can simplify the transmission from grid coupled to an island stage during oscillation [6]. In 2010 Hak-Man Kim implemented a multi-agent system for grid-interconnected stage in MG operation which was tested on three different operating situations to verify the viability of the recommended multi-agent system [7]. This research paper shows an innovative protection system by employing digital relaying and progressive information communication technology. The setting of protection relay has been done centrally with respect to the operational conditions of the MG [8]. This research study analyses the state-of-the-art problems and reasonable solutions linked with the arrangement of MG technologies in India. The role of empowering technologies, computerization and communication technology for sustainable growth of MGs are also highlighted in this article [9]. Researchers designed, developed and implemented a multi-agent based system (MAS) that delivers intelligent and allows real-time supervision of a smart grid located at a distribution level [10]. Researchers have given description of MGs and the few decade's efforts in the direction of the standardization of AC & DC MGs including classification of controls resulting from ISA-95 and electrical dispatching standards giving smartness and flexibility to MGs [11]. Murali Krishna Kouluri et.al. proposed the idea of an intelligent control to regulate the power system network variables. The methodology of intelligent agent-based control would assist the power system to maintain optimal power equilibrium under dynamic conditions like load and power changes[12]. The power system frequency restoration and precise reactive power sharing (RPS) method in a stand alone MGs are introduced by researchers for improved power – frequency droop control. Initially, virtual impedance technique is employed to reduce the impact of line resistance on power coupling and RPS. To remove errors in RPS produced by voltages difference, the line voltage drop is employed to make up for the the voltage droop features [13]. Hossein Shayeghi et.al implemented methodologies for energy management system including non-renewable, ESS, hybrid systems and demand-side management (DSM) [14]. Research study along with the effect of communication technologies over a typical AC MG during islanded mode is introduced and the combination of stochastic delay procedures that can prevent oscillations caused by the delays thereby improving the power quality to some extent has been highlighted [15]. Research investigation of current applications of multi-agent-based decision support systems application in MGs is elaborated. They have suggested systems to monitor and process control and operations of MGs in order to meet the complexity of MGs. [16]. In [17], authors are implemented energy management system for renewable energy sources based hybrid system for grid connected system. From the literature survey, it is clear that MGs are becoming more and more important in today's world. From the armed forces perspective it can be said the MG will enhance reliability, reduce logistic requirements, cost of energy and carbon footprint during deployment in a remote area. Hence, in this work a MG system with a total capacity of 1 MW has been designed and simulated with the help of MATLB SIMULINK considering the special and critical needs of armed forces deployed in remote areas. The proposed design consists of renewable energy source like photo voltaic (PV) system and battery based energy storage system (BESS). In order to avoid the collapse or blackouts due the unpredictable meteorological conditions a diesel generator set running at standby mode with fixed critical loads was also the part of the design. PV system provides output in the form of a variable DC voltage depending upon the meteorological conditions. In order to remove these variations, proportional-integral (PI) controllers were used in the energy storage system which have the task to stabilize the dc-link voltage by controlling the charging and discharging current of the batteries. Hence, it can be said that BESS has to task, (i) to maintain the dc-link voltage at desired values and (ii) to supply the energy in case PV system does not provide enough power due to meteorological conditions. Further, three arm, six pulses voltage source inverter (VSI) was used to convert the dc voltage into 3-phase AC signal across the load. In order to control the output voltage, a PI controller was used to maintain the desired phase to phase peak voltage across the load. Diesel generator set was controlled with the help of control scheme based on the state of charge (SOC) of battery system. The proposed MG design has also been tested under varying meteorological and varying load demand conditions. It has been observed that all systems work satisfactory under these situations. Total harmonic distortion (THD) remains well within the range of less than 5% during complete simulated conditions. Further, detailed description of the entire system has been provided in the subsequent sections. Rest of the work is organised as follows: Section II presents the proposed MG design in detail along with the specifications of several subsystems, Section III presents the results and Section IV concludes the paper with possible directions of future work. PV modelling and BESS specifications have been provided in the APPENDIX.

II. SYSTEM DESCRIPTION

Figure 1 shows the complete block diagram of the proposed standalone 1-MW MG system for a remote base of the armed forces with its critical loads. It has several sub-systems like PV, Battery and inverter. Description of each sub-system has been provided in this section.

A. System Specifications

In this work, authors have proposed a 1-MW MG system in standalone mode for a base of the armed forces in a remote location.

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-10 Issue-1, October 2020

The system is designed to have an output phase-phase AC voltage at 400V rms. In order to keep the output AC voltage at 400V rms, dc link voltage at the input of inverter must be around 665V (after including the voltage drop across output LC filter). In this work, authors have adopted the control structure to maintain the dc-link voltage at 665V by charging and discharging of battery system with the help of dc-dc bidirectional converter. Description of the same is given in subsequent subsections.

B. PV System

In the proposed standalone MG, solar power is the main power source with total rating of 1 MW. The same has been represented by PV system block in Fig. 1. PV system consists of the series and parallel combinations of the PV panels in order to achieve the desired PV system specifications. PV system is created in such a manner that it removes the requirement of a separate converter and controller for maximum power point tracking (MPPT).

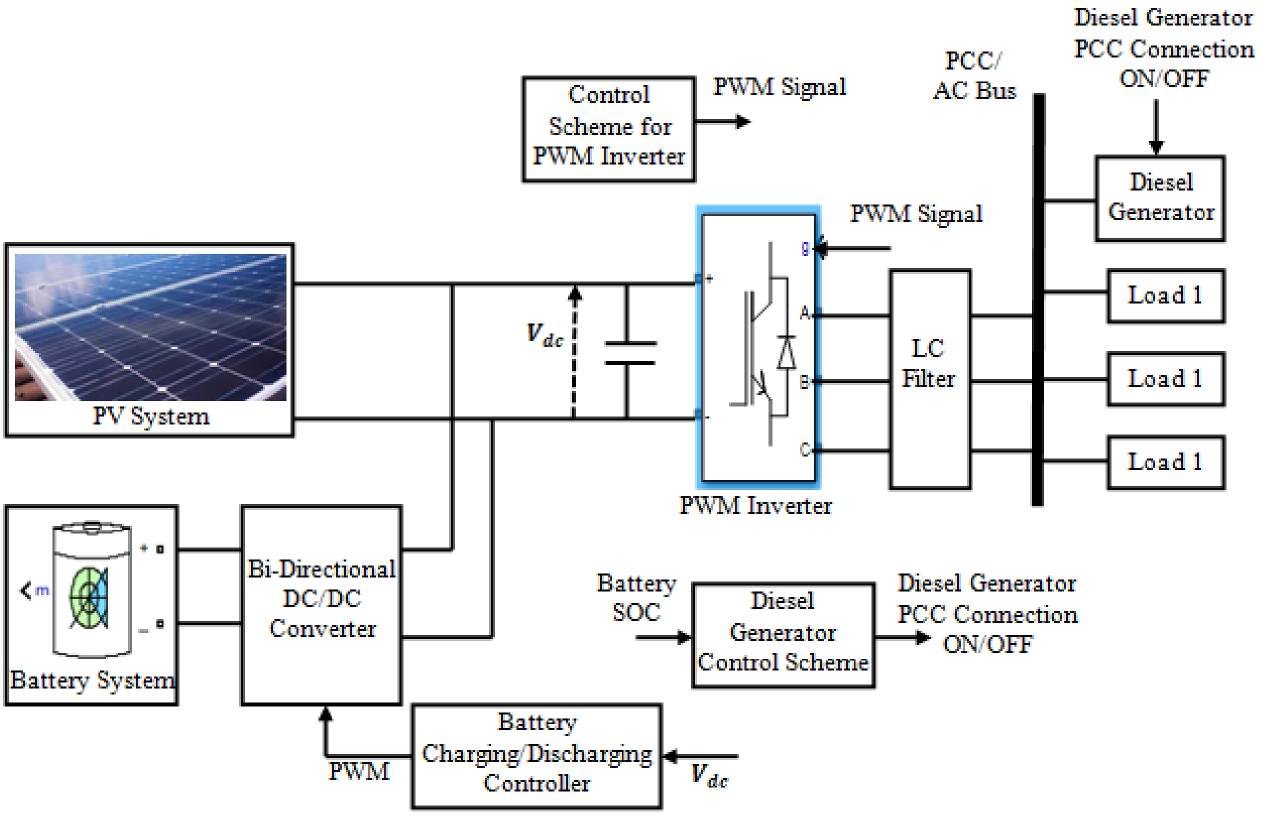


Fig. 1: Block diagram of the proposed 1-MW MG

In the proposed MG design, *1Soltech 15TH-215-P* solar panel module has been used. One such solar panel has maximum power of 213.15 W and open circuit voltage of 29V at maximum power point (MPP). In order to remove the requirement of separate controller and converter for MPPT, 23 solar panel modules are connected in series. This makes the open circuit maximum power point voltage at 667V which is nearly equal to the required dc link voltage for output phase-phase voltage of 400 V rms. Further, this dc link voltage is maintained by the battery dc-dc bidirectional converter and effectively eliminate the requirement of separate MPPT controller for the PV system. Hence, it can be said that battery controller makes sure that PV panel operates at MPP voltage.

Further, in order to generate 1MW of solar power while operating under the irradiance of 1000W/m^2, 204 rows of such series connected PV modules are connected in parallel. Graphical representation of this configuration has been shown in Fig. 2. Figure 3 shows the current v/s voltage and power v/s voltage curve of the entire PV system.

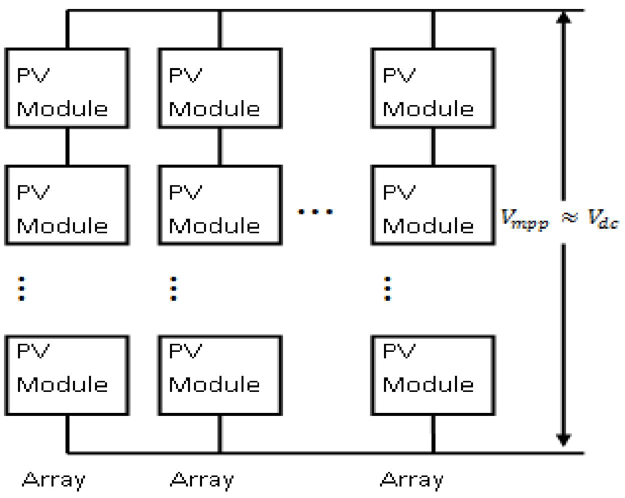


Fig. 2: Series and parallel combinations of the PV module to get the required solar power.

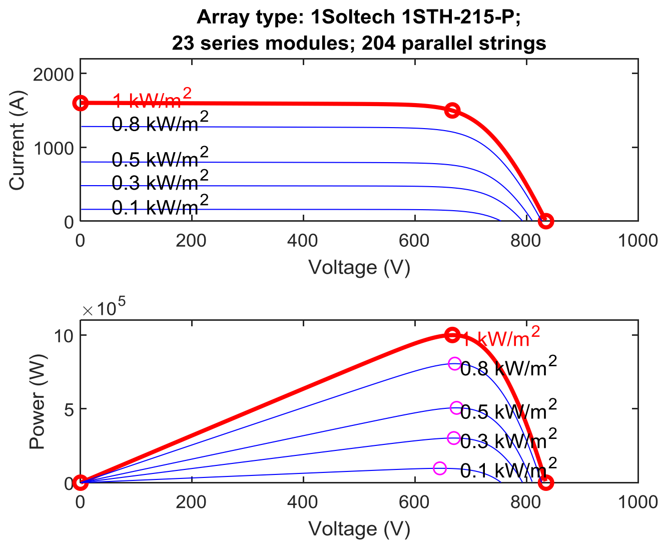


Fig. 3: Current v/s voltage and power v/s voltage curve of the PV system for different amount of irradiances.

C. Battery System and Charging/Discharging Controller

In this work, dc-link voltage is regulated by charging and discharging of battery with the help of dc-dc bidirectional control scheme. Fig. 4 shows the battery system discharging profile. Control scheme should be such that, if there is excess power from the PV system, then battery should start charging itself in order to maintain the dc-link voltage and if PV system produces less power due to meteorological conditions then battery should start providing additional power to maintain the dc-link voltage. Hence in this work, a control scheme is developed similar to the one shown in Fig. 5. Two proportional integral (PI) controllers have been used to control the operation of dc-dc bidirectional converter. First PI controller takes the error between reference dc-link voltage and generates the required battery current to be drawn or supplied by the battery unit.

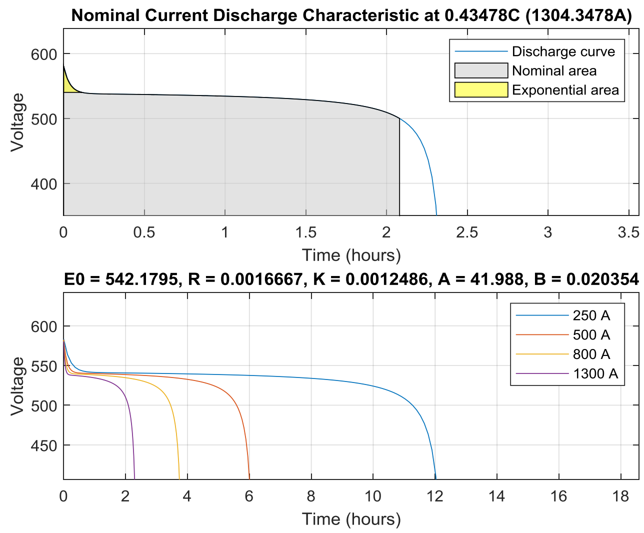


Fig. 4: Discharge characteristics of the battery system under nominal conditions.

Second PI controller takes the error between reference battery current and actual battery current being supplied and tries to reduce the error between two currents by changing the duty cycle of the PWM signal. These PWM pulses are applied to the switches of the bidirectional converter which ultimately controls the flow of current to and from the battery. In order to make sure that required current does not go beyond the battery current specifications, constraint limit is applied at the output of the first PI controller. Further, battery design specifications have been provided in the Appendix. Battery starts discharging within its current limitations whenever there is a demand for more power and PV system is not producing enough power due to meteorological conditions. Similarly, if load demand is low and PV system is generating excess power then battery with start charging itself with in the current specifications.

D. Control of Voltage Source Inverter (VSI)

Battery system and PV system were responsible to maintain the dc-link voltage at the required voltage of 665V for 400V rms phase-phase voltage across the load. VSI is primarily responsible to convert the dc-link voltage into high frequency three phase multilevel pulsed signal with varying duty cycle in accordance with the carrier sinusoidal signal with a fundamental frequency of 50Hz. In other terms, VSI generates multilevel PWM signal. This high frequency signal is passed through the LC filter. LC filter is designed in such a manner that it removes the high frequency components from the input PWM signal and converts it into 3-phase sinusoidal signal with a fundamental frequency of 50Hz. Figure 6 shows the block diagram for the control scheme of VSI. In this technique, PI controller is designed and tuned so that the peak voltage at load follows the reference peak voltage. In the proposed design reference phase-phase peak voltage is 565 V $(V_{rms}\sqrt{2})$. Load peak voltage is computed with the help of abc-dq transformation as shown in the Fig. 6. Three phase sinusoidal carrier signal with a frequency of 50Hz is generated and multiplied with the output of the tuned PI controller. This generates the reference value of PWM generation. In this work 3 arm 6 pulses bridge was selected as a VSI.

E. Diesel Generator Set ON/OFF Control

Generally, during night time PV system does not generate power and in that case power transfer to the load mainly happens through the battery system. Further, during unpredictable meteorological conditions, PV system may not be able to generate enough power during the day time, due to which battery system will not be charged and entire MG system will collapse. In order to avoid such a situation, an additional diesel generator set is planned in the MG design. Apart from such situation, diesel generator set is also used to provide continuous power for critical load like communication equipment, sensors and control centres in the remote bases. As diesel generator set runs on fossil fuel and contribute to pollution, its application is limited in the MG and used during special conditions. Figure 7 shows the logical flow chart to control the operation of diesel generator set. In the proposed diesel generator set control scheme, if battery system SOC falls below 25% during the discharging cycle, VSI gets disconnected from the load and diesel generator set starts supplying power to the load. During this time dc-link also gets disconnected from the VSI input in order to avoid high voltage at the output of the VSI. Further, during this period battery starts charging up with the available power from PV system.

Diesel generator set remain connected to the load till the SOC of battery system reaches upto 30% during the charging cycle. After that diesel generator set gets disconnected from the load and VSI starts providing power to the load. Through this scheme, usage of diesel generator set is minimized in order to have minimum environmental impact of the proposed MG system. In order to make diesel generator set capable of taking the entire load, generator set with the ratings of 1MW was used in this design.

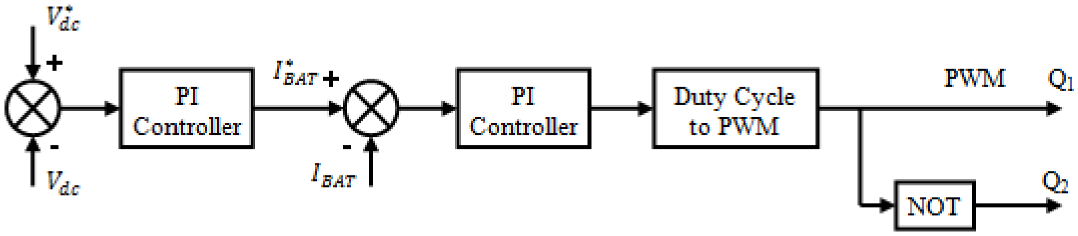


Fig. 5: Battery charging/discharging controller for bidirectional dc-dc converter.

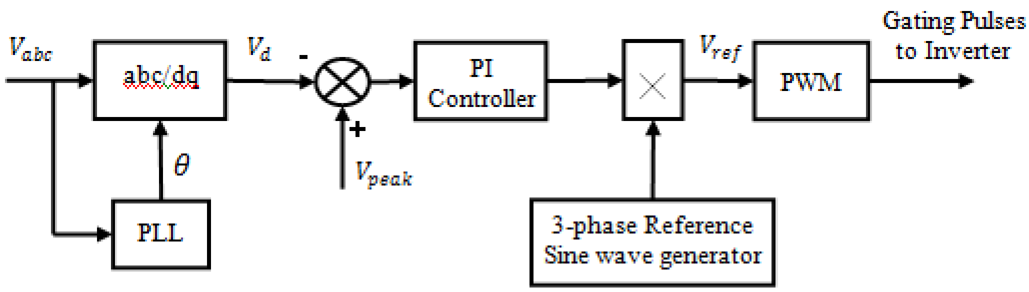


Fig. 6: Control scheme for PWM inverter.

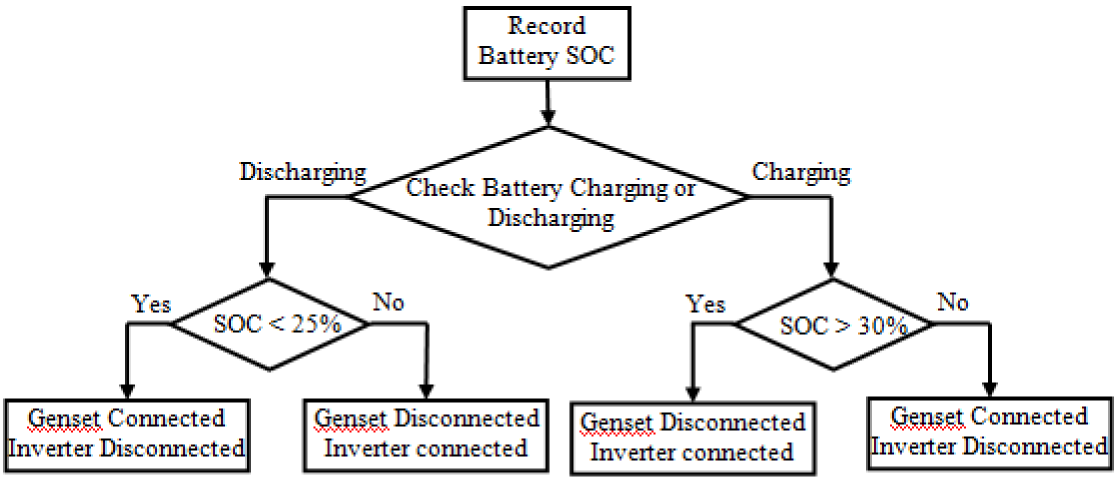


Fig. 7: Generator set ON/OFF control scheme.

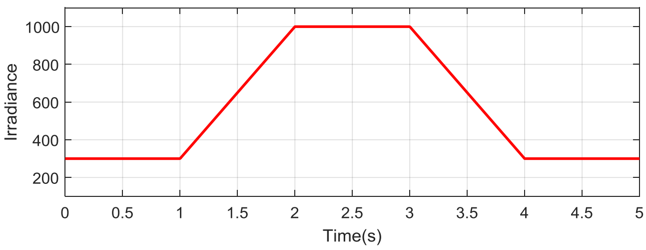
III. RESULTS

The proposed MG design has been simulated under different scenarios which include, (i) varying meteorological conditions and (ii) varying load demand conditions. This section shows the different parameters of the MG during the simulated conditions.

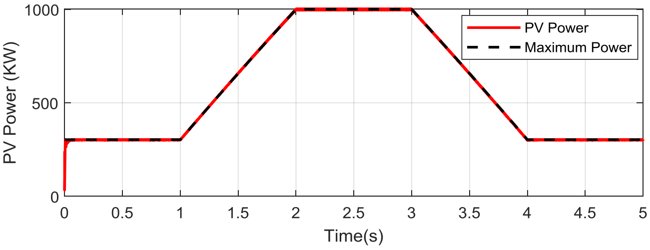
A. Case 1: Varying Meteorological Condition

One of the challenge for PV system is varying meteorological conditions which limits the power output from solar panels. In this case the study has been done to show the performance of the proposed MG under time varying meteorological conditions. For this simulation study, load demand was kept constant at 800 KW. Meteorological conditions was simulated with the help of time varying irradiance profile applied to the solar panels. Under standard conditions, solar panels generate highest power under full illumination of 1000W/m^2. Solar panels were illuminated with the irradiance profile as shown in the Fig. 8(a). Solar panels were illuminated with Irradiance of 300W/m^2 for one sec, thereafter irradiance is increased to 1000W/m^2 for one sec and kept at 1000W/m^2 for next one sec duration. After that irradiance was again decreased to 300W/m^2 in one sec and kept at the level of 300W/m^2.

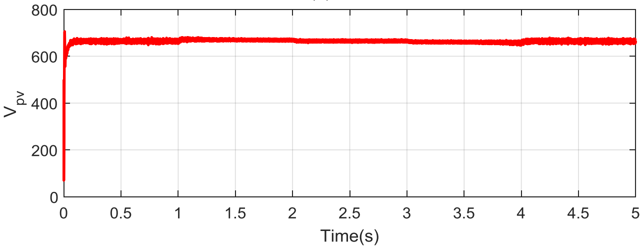
As stated earlier that dc-link voltage across solar panels in PV system remain at 665V, which is also the MPP for solar panels. During this entire time of varying irradiance profile, maximum power is draws from the solar panels with an efficiency nearly equal to 100%. The same is shown in Fig. 8(b) which displays the power drawn from PV system and theoretical maximum power is available from the PV system.



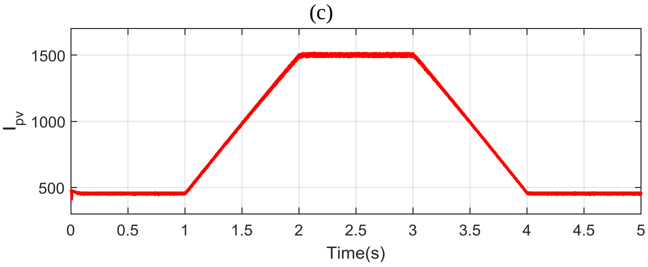
(a)



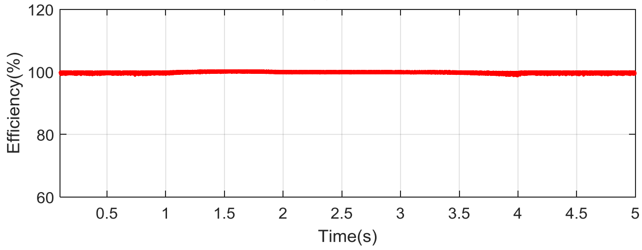
(b)



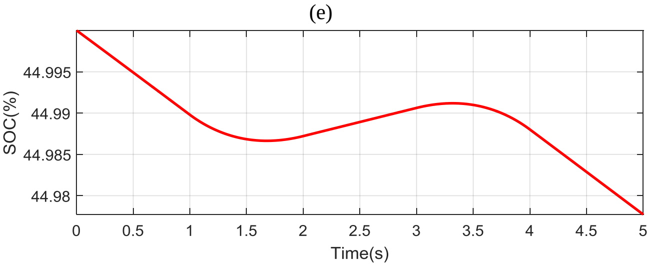
(c)



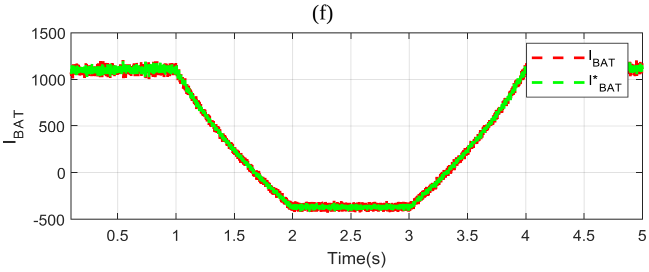
(d)



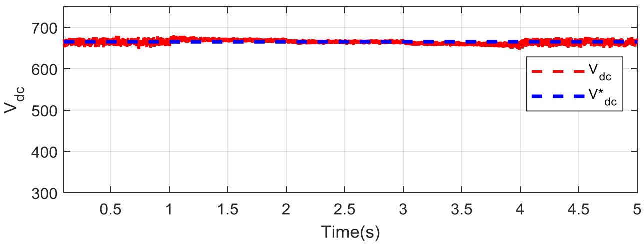
(e)



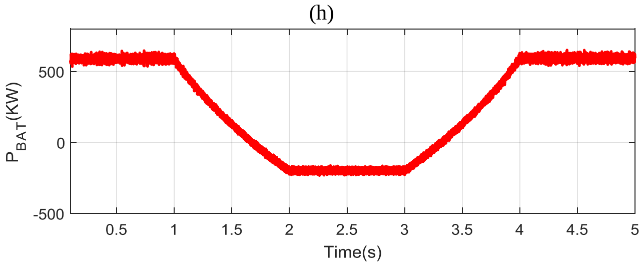
(f)



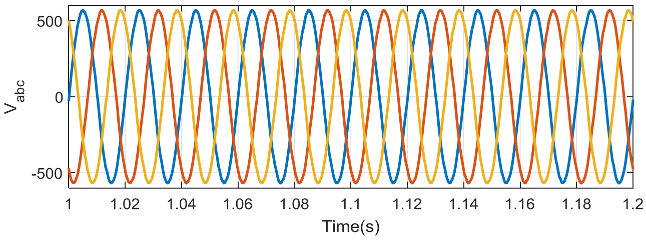
(g)



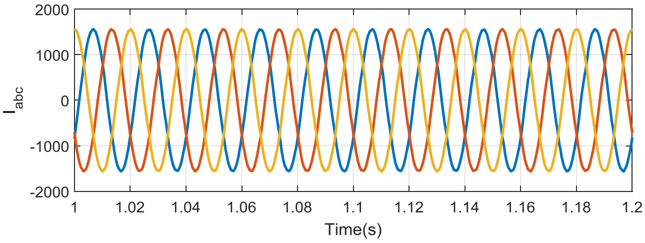
(h)



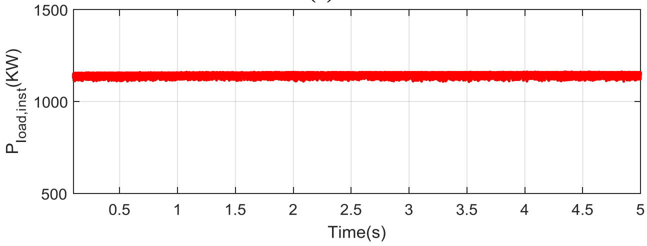
(i)



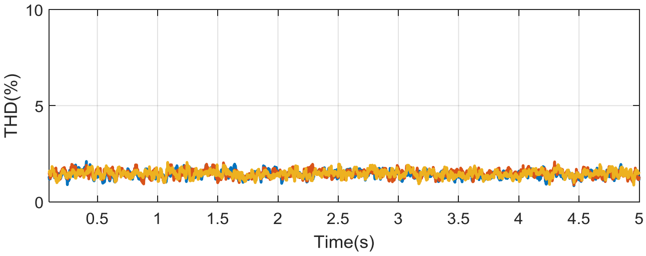
(j)



(k)



(l)



(m)

Fig. 8: (a) Variation in irradiance profile, (b) Generated PV power and theoretical maximum power, (c) Voltage across PV system, (d) Variation in current from PV system, (e) Power efficiency of the PV system, (f) Battery bank SOC (%) representing charging and discharging state of battery bank, (g) Variation in current from the battery bank, (h) DC-Link voltage, (i) Power flow profile from battery bank, (j) Three phase voltage across load, (k) Current flowing through load, (l) Total instantaneous power to load, (m) THD in output three phase voltage across load.

Retrieval Number: 100.1/ijeat.A18681010120
DOI:10.35940/ijeat.A1868.1010120
Journal Website: www.ijeat.org

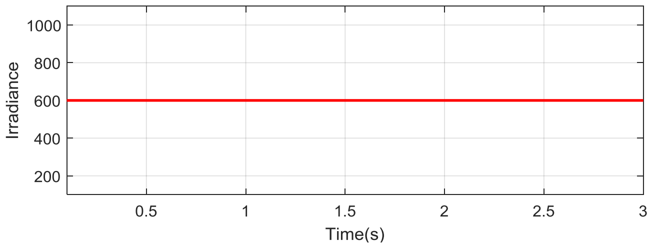
Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-10 Issue-1, October 2020

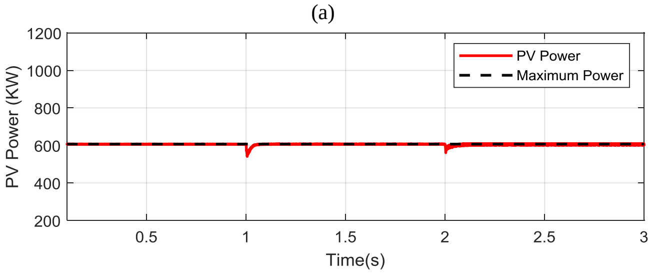
Figure 8(c) shows the voltage across PV system during this entire simulation time and it remains at 665V. Fig. 8(d) shows the current drawn from PV system and Fig. 8(e) shows the operating efficiency of the PV system during the entire simulation time. Fig. 8(f) shows the SOC of battery system and reflects proper working of battery charging/discharging controller. When irradiance is 300W/m^2, power from the PV system is not sufficient to run the loads and excess power is provided by the battery system. As a result of which the batteries start discharging and same is evident from the SOC curve, as SOC is decreasing during this time. During the transition period of irradiance from 300W/m^2 to 1000W/m^2 battery SOC starts bending from discharging to charging as PV system starts providing sufficient power to run the loads. When PV system is illuminated with irradiance of 1000W/m^2 there is excess power available from the PV system, as a result battery system starts charging up and same is displayed from the increasing values of the SOC. Fig. 8(g) shows the current being drawn from the battery system. Positive battery current indicates the discharging of battery system and negative current from battery indicates the charging of battery system. Fig. 8(h) displays the reference and dc-link voltage. Dc-link voltage remains at reference value during the entire simulation period indicating the effectiveness of battery controllers in maintaining the dc-link voltage. Fig. 8(i) shows the power flow to and from the battery system. Fig. 8(j) and 8(k) represents the small duration of voltage and current across the load. Fig. 8(l) shows the instantaneous power flow to the load and Fig. 8(m) shows the THD in the converted voltage across the load.

B. Case 2: Varying Load Conditions with 60% Irradiance

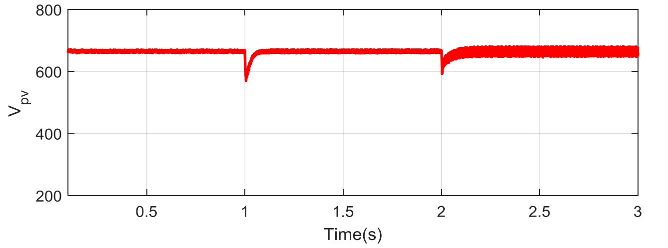
In the simulation study of designed MG, Case 2 has been taken with varying amount of load and 60% irradiance of maximum value for PV system. This case demonstrates the effectiveness of the proposed system to absorb the variation in loads effectively. In this simulation study, load across MG increases by 400 KW i.e. during the simulation time of 0-1 sec 400 KW load was connected to the MG. Another 400 KW load increases across MG at 1sec and 2 sec instants. Hence during 1-2 sec of simulation time total load across MG was 800 KW and from 2-3 sec of simulation time total load across MG was 1.2 MW.



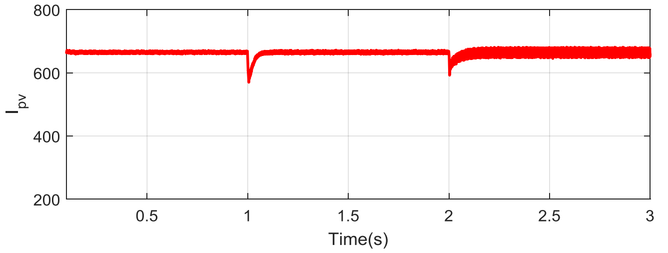
(a)



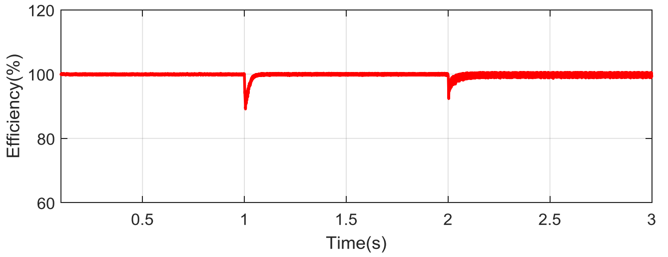
(b)



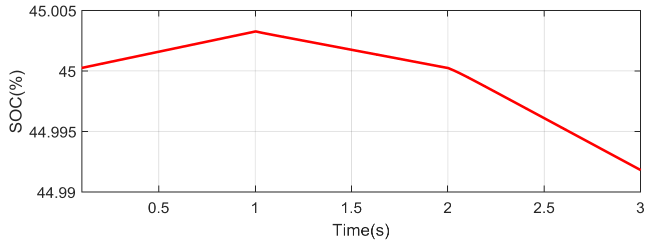
(c)



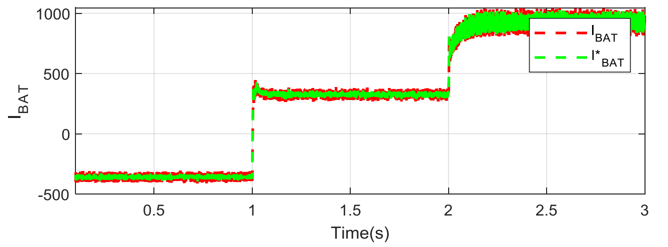
(d)



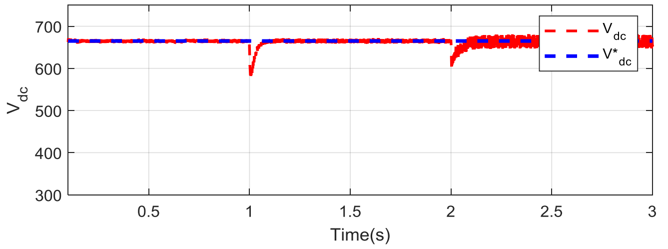
(e)



(f)



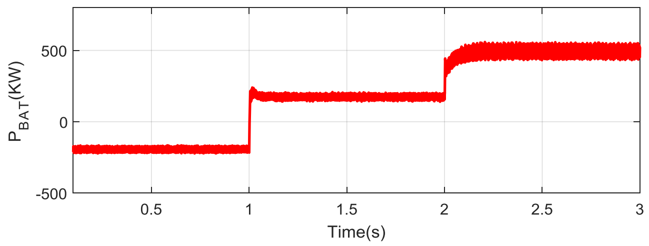
(g)



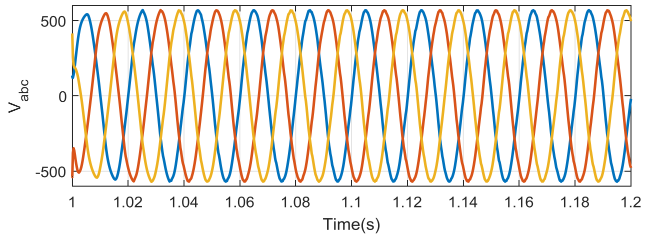
(h)

Retrieval Number: 100.1/ijeat.A18681010120
DOI:10.35940/ijeat.A1868.1010120
Journal Website: www.ijeat.org

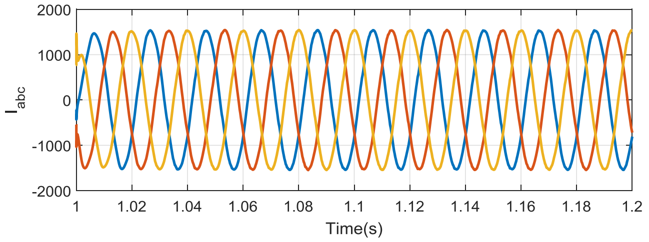
Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication



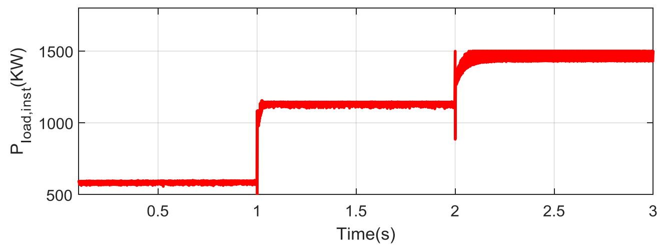
(i)



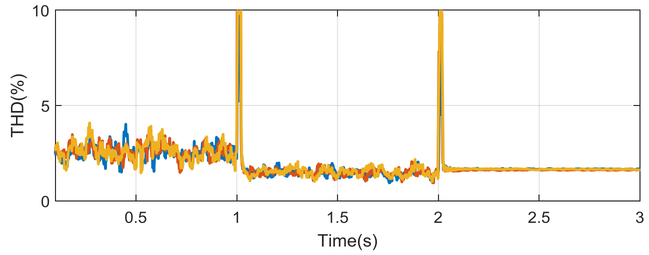
(j)



(k)



(l)



(m)

Fig. 9: (a) Constant irradiance across PV system, (b) Generated PV power and theoretical maximum power, (c) Voltage across PV system, (d) Variation in current from PV system, (e) Power efficiency of the PV system, (f) Battery bank SOC (%) representing charging and discharging state of battery bank, (g) Variation in current from the battery bank, (h) DC-Link voltage, (i) Power flow profile from battery bank, (j) Three phase voltage across load, (k) Current flowing through load, (l) Total instantaneous power to load, (m) THD in output three phase voltage across load.

Figure 9(a) shows the irradiance value during the simulation time of Case 2 and it remain constant at 600W/m^2. Maximum power drawn from the PV system and theoretical maximum power available from the PV system is shown in Fig. 9(b). Voltage across PV system equal to the dc-link voltage is shown in Fig. 9(c). Slight variation occurs in the voltage at the time when load increases suddenly at 1 sec and 2 sec instants. Dc-link voltage again reaches to its' reference value of 665V due the battery charging/discharging controller actions. Current drawn from the PV system remains constant as continuously max power is provided by the PV system. The same has been shown by Fig. 9(d). Efficiency of the PV system is shown by Fig. 9(e). Battery charging and dis-charging rate has been shown by Fig. 9(f) in the form of battery SOC. Current drawn from the battery system has been shown by Fig. 9(g) and Fig. 9(h) shows the dc-link voltage along with the reference voltage. Power drawn from the battery increases as the load across the system increases and the same has been demonstrated by Fig. 9(i). When load across system was less than the power delivered by the PV system, then excess power was delivered to the battery and it is shown by negative power during 0-1 sec of simulation. When load increases more than the power available from PV system, then the battery system starts delivering the extra required power to the loads and same has been demonstrated from Fig. 9(i) during 1-3 sec of simulation time. Fig. 9(j) and 9(k) shows the three phase voltage and current wave form across the load. Total instantaneous power across the load is shown with the help of Fig. 9(l) and overall THD during this entire simulation time has been shown by Fig. 9(m). THD remains less than 5% during the entire simulation of load variations.

IV. CONCLUSION

In this paper, a 1 MW MG system in stand-alone mode for a remote base of the armed forces has been designed and simulated. The proposed MG involves 1MW PV system as primary renewable energy source in order to minimize the environmental impact. Energy storage system has been designed in order to maintain the dc-link voltage at required reference value of 665V and to supply power to the load when enough power is not generated from PV system for critical loads and to cater for varying meteorological conditions. Effectiveness and working of the proposed MG has been verified with the help of two case study, (i) with varying meteorological conditions for PV system and (ii) with varying load applied to the MG. Simulation study shows that the proposed system works effectively in mitigating the effect of varying irradiance and meeting the load demand. Further, diesel generator was also designed to supply power to specified critical loads and as an alternative power source in order to avoid any blackouts in case of unexpected meteorological conditions or faults. Overall the system was able to maintain the dc-link voltage at predefined reference value and THD was also less than 5% during the entire simulation time.

APPENDIX

A. Modeling of PV Solar Panel

PV power generation is associated with several elements. Principally, the cells of PV generation may be connected in series and parallel to improve the panel output voltage and current to designed values respectively. The PV system comprises of bypass diodes within panels to avoid shaded or faulty cells which disturb the complete system rated power.

Moreover, the PV system is associated with many protection equipment and breakers. The foremost dissimilarity within a grid-coupled and an isolated photovoltaic system is autonomy. An isolated system should be oversized along with huge storage system. A charge controller along with batteries should be implemented to stop exceeding limits which may destroy them. More than one backup generators are utilized to increase the reliability of the system. But, in a grid-connected system, power can also be supplied from the grid during non-availability of power. To deliver power to the grid, it is essential to keep control on inverters since the output of PV system is direct current. A mathematical model of PV array including fundamental components of diode, current source, series resistor and parallel resistor is modeled in Simulink environment (http://mathwork.com). The modelling of PV array is mathematically shown in equations below and implemented from [18], which is derived from a cell's equivalent circuit where all cells are equal.

$$I_{pv} = I_{ph} - I_0\left[\exp\left(\frac{q\left(I_{pv} \times R_s + V_{pv}\right)}{AKT}\right) - 1\right] - \frac{V_{pv} + I_{pv} \times R_s}{R_{sh}}$$

Where,

$$I_{ph} = \left[I_{sc} + k\left(T - T_r\right)\right]\frac{G}{1000}, \; I_0 = I_{rr}\left[\frac{T}{T_r}\right]^2 \exp\left(\frac{qV_{oc}}{AK}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right)$$

B. Energy Storage System Specifications

In the proposed design, the energy storage system of batteries with nominal voltage of 500V and 3000AH current was considered. A single battery of 24V with 150AH is considered, 21 such batteries are connected in series and 20 such series connected batteries arrays are connected in parallel in order to achieve the desired battery system specification.

REFERENCES

1. Dimeas, A., & Hatziargyriou, N. (2004, May). A multi-agent system for MGs. In Hellenic Conference on Artificial Intelligence (pp. 447-455). Springer, Berlin, Heidelberg.
2. Oyarzabal, J. R. A. E. J., Jimeno, J., Ruela, J., Engler, A., & Hardt, C. (2005, November). Agent based micro grid management system. In 2005 International Conference on Future Power Systems (pp. 6-pp). IEEE.
3. Kanellos, F. D., Tsouchnikas, A. I., & Hatziargyriou, N. D. (2005, June). Micro-grid simulation during grid-connected and islanded modes of operation. In International Conference on Power Systems Transients (Vol. 6).
4. Moreira, C. L., & Lopes, J. P. (2007, May). MGs dynamic security assessment. In 2007 International Conference on Clean Electrical Power (pp. 26-32). Ieee.
5. Popov, M., Karimi, H., Nikkhajoei, H., & Terzija, V. (2009, June). Dynamic model and control of a MG with passive loads. In IPST Conference Proceedings.
6. Pipattanasomporn, M., Feroze, H., & Rahman, S. (2009, March). Multi-agent systems in a distributed smart grid: Design and implementation. In 2009 IEEE/PES Power Systems Conference and Exposition (pp. 1-8). IEEE.
7. Kim, H. M., & Kinoshita, T. (2010). A multiagent system for MG operation in the grid-interconnected mode. Journal of Electrical Engineering and Technology, 5(2), 246-254.
8. Oudalov, A., & Fidigatti, A. (2009). Adaptive network protection in MGs. International Journal of Distributed Energy Resources, 5(3), 201-226.
9. Balijepalli, V. M., Khaparde, S. A., & Dobariya, C. V. (2010). Deployment of MGs in India. IEEE PES General Meeting (pp. 1-7).
10. Khamphanchai, W., Pisanupoj, S., Ongsakul, W., & Pipattanasomporn, M. (2011, September). A multi-agent based power system restoration approach in distributed smart grid. In 2011 International Conference & Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia (ICUE) (pp. 1-7). IEEE.
11. Guerrero, J. M., Vasquez, J. C., Matas, J., De Vicuña, L. G., & Castilla, M. (2010). Hierarchical control of droop-controlled AC and DC MGs—A general approach toward standardization. IEEE Transactions on industrial electronics, 58(1), 158-172.
12. Kouluri, M. K., & Pandey, R. K. (2011, September). Intelligent agent based micro grid control. In 2011 2nd International Conference on Intelligent Agent & Multi-Agent Systems (pp. 62-66). IEEE.
13. Zhang, Z., Dou, C., Yue, D., Zhang, B., & Luo, W. (2018). A decentralized control method for frequency restoration and accurate reactive power sharing in islanded MGs. Journal of the Franklin Institute, 355(17), 8874-8890.
14. Shayeghi, H., Shahryari, E., Moradzadeh, M., & Siano, P. (2019). A survey on MG energy management considering flexible energy sources. Energies, 12(11), 2156.
15. Tavassoli, B., Fereidunian, A., & Mehdi, S. (2020). Communication system effects on the secondary control performance in MGs. IET Renewable Power Generation.
16. Salgueiro, Y., Rivera, M., & Nápoles, G. (2020). Multi-agent-Based Decision Support Systems in Smart MGs. In Intelligent Decision Technologies 2019 (pp. 123-132). Springer, Singapor.
17. Siva Ganesh Malla and Priyanka Malla, "TSFuzzy Controller based Grid Connected Hybrid Renewable Energy Sources", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 7, Issue. 7, pp. 1-13, July 2020
18. Siva Ganesh Malla, Priyanka Malla and Rajesh Koilada, "Solar Energy based Hybrid Electric Car: Part 1", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 6, Issue 6, pp. 11- 25, Dec. 2019

Biography:

CPS Pasricha has completed his B Tech from College of Military Engineering, Pune, M Tech from Indian Institute of Technology, Delhi in Power Systems Engineering and MSc (Defence Studies) from Defence Services Staff College, Wellington. A Member of the Institution of Engineers, he is presently pursuing PhD in Engineering in the field of Microgrids from University of Petroleum and Energy Studies, Dehradun. He has been Chief Engineer for infrastructure development in remote areas. His expertise is in the domain of energy system and Microgrids.

Dr Rajeev K Gupta is presently Sr.Associate Professor of Physics and former HOD in the Department of Physics, School Of Engineering, University of Petroleum and Energy Studies, Dehradun. His area of Specialization/Research and interests include Nanotechnology, Surface engineering and Energy conservation. He is a prolific writer and author of a number of research papers and books.

Dr. Rahul Walawalkar leads the Emerging Technologies & Markets team with focus on energy storage, renewables, demand response and smart grid technologies as well as international markets. He is an acclaimed energy expert. Rahul serves on the Board of Energy Storage Alliance and provides input to FERC & various state agencies. He has served on panels for US Department of Energy and in working groups for IEEE & NIST. Rahul holds a Ph.D. in Engineering and Public Policy from Carnegie Mellon University and Master's degree in Energy Management from NYIT, United States and B.E. from Walchand College of Engineering, India. He is the recipient of numerous awards and is a member of various professional organizations including AEE, IET, IEEE and IAEE.