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Parameterization of Stand-Alone Solar PV System Performance – An IoT Solution

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Abstract

Stand-alone solar PV systems have many specific applications in real-time. The efficiency of these systems is highly depended on energy generated and its utilization. Due to intermittent nature of energy output, the load management is required to maximize its performance. In order to obtain improved results, it is required to monitor the performance of system regularly. The measurement of various parameter like panel voltage, current, and battery bank charging state etc., is difficult to due to isolated location frequently. Hence it is worthwhile to address this issue with Internet-of-Things (IoT) solution. This paper explains the application of IoT concept for stand-alone solar system at the premises of Faculty of Engineering, Christ University. The suppleness with IoT solution for load management according to system energy output is quite interesting and encouraging in addressing more social needs in future times.

Keywords: *Solar energy, stand-alone solar PV system, peak power operation, IoT*

1. Introduction

Around the world, the energy utilization is increasing drastically and various load balancing programs have been initiated by the system operators to ensure efficient demand – supply pattern. The interdependency on grid for energy requirements can be minimized by the integration of renewable energy systems and correspondingly the demand on grid, need of new non-renewable energy systems installations and so CO_2 emission can possible to minimize significantly. Demand response, load shifting, or load management *etc.*, are the various programs developed and followed by providing economic incentives to the consumers towards peak demand reduction on the grid. Apart from this, the integration of renewable energy sources becomes an alternative and attractive solution for sustainability across the world for sustainability. The ambitious solar expansion programme seeks to enhance the capacity to 100 GW by 2022 [1]. To accomplish this target, the Government of India has been encouraging roof-top solar system installations with subsidy under Jawaharlal Nehru National Solar Mission (JNNSM) [2]. The techno- economic difficulty involved in transmission/distribution system connectivity with network, the stand-alone solar/wind/hybrid energy systems have got special attention in various remote applications. In India, the integration of roof-top solar PV systems are also increasing tremendously. Since the energy from RES is mainly dependent on geographical and environmental factor, it is worthwhile to forecast for better planning and preventive as well as corrective actions in grid operation [3, 4]. In addition, the Demand Side Management (DSM) program is becoming an alternative solution for balancing supply and demand as well as investment towards new generation capacity. To be a successful consumer in DSM program, it can also become an essential thing to know probable energy output from the installed solar roof-top system and

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accordingly to plan his load profile for achieving better benefits. The forecast of power output, particularly the short-term forecast (say one-day ahead), is a challenging task for PV power system as the power output varies largely with the external conditions like sunshine, temperature, *etc.*, [5].

Basically, stand-alone solar system consists of PV panels, charge controller, battery bank and power electronic interface like inverter [3]. Currently, the power electronic interfaces are having in-built charge controller with multiple inputs for solar, wind, grid and other DG sources and multiple outputs for AC and DC applications. In general, the Stand-Alone PV System (SPV) is designed for a specific load requirement in the best possible manner. At design stage, all the meteorological conditions like solar radiation, latitude and longitudes, wind speed *etc.*, and various system components like panels and batteries, their specifications, number, inverter, charge controller, type of load and its nature like critical/non-critical, reliability, cost etc. should be taken in to consideration and hence we have various configurations come across in solar energy sector. These configurations can be very simple or complex based on type of control, monitoring requirements [6].

The generic configuration of SPV system is given in Figure 1. In this configuration, it has two DC sources *i.e.*, PV array and battery storage. The basic energy source in the system is PV array and its output power dependent on time and environmental aspects. Coming to secondary energy source in the system is battery bank and its output interdependent on PV output and load demand. In order to optimize the performance of SPV system, it is required to understand the energy flow between various components under different operating scenarios. The following energy flow scenarios can observe in the SPV system, (a) PV System to (Battery + Load), (b) (PV System + Battery) to Load and (c) Battery to Load.

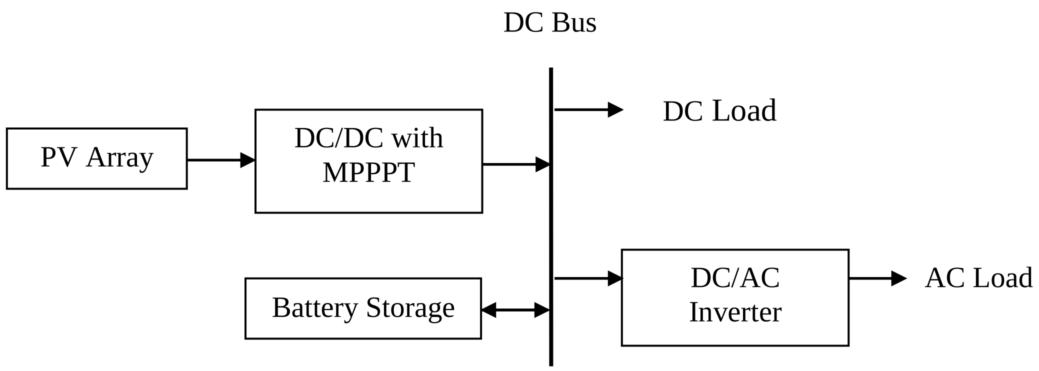

Figure 1. The Generic SPV System Configuration

In Scenario (a), the energy generated from PV system is alone sufficient to meet the load requirement and also the surplus can transfer to the battery storage. This can happen only when the load demand is less than PV output power and battery will be in charging mode. In addition, the PV panels have enough incident radiation to produce energy up to its rated efficiency. In Scenario (b), the energy generated from PV system is alone not sufficient to meet the load requirement and the deficit should be able supply from the battery storage. Under this scenario, the battery will be in discharging mode and the rate of discharge is dependent on initial SOC of battery and load demand. In Scenario (c), the energy generated form PV system is zero and the load is able to get supply by only batter system. Under this situation also the batteries are in discharging state but the rate of discharge is more compared to scenario (b). In order to meet load requirement, the battery bank requires to design with autonomy.

By observing all the above scenarios, the energy flow is primarily happing on load demand and not only on PV system output. To improve SPV system efficiency, the load balance is the key factor and one of the specific objectives of this paper. On the other side, peak-power operation of the system is also play a vital role for improving the overall efficiency. According to ideal I-V and P-V curves of any electrical source, the current will increase whereas voltage will decrease for a step increment in load demand. Up to maximum power point, the rate of current increment is greater than the rate of voltage decrease and consequently, the power will increase. Beyond maximum power, it is vice versa and so causes to power decrement. Hence there is a need to balance the load according to power output of the PV system for better stable operation.

The energy flow in the SPV system has to regulate for more optimized system output energy. In addition to the electrical load demand on system, the battery storage can also be a load to the PV system during charging period. During this situation, it is required to control electrical load demand and hence the battery bank can store more energy. As battery charging level increasing, the electrical load can increase accordingly with solar PV system output.

2. Peak-Power Operation SPV System

On the other side, peak-power operation of the system is also play a vital role for improving the overall efficiency. According to ideal I-V and P-V curves of any electrical source, the current will increase where as voltage will decrease for a step increment in load demand. Up to maximum power point, the rate of current increment is greater than the rate of voltage decrease and consequently, the power will increase. Beyond maximum power, it is vice versa and so causes to power decrement. Hence there is a need to balance the load according to power output of the PV system for better stable operation.

The energy flow in the SPV system has to regulate for more optimized system output energy. In addition to the electrical load demand on system, the battery storage can also be a load to the PV system under not fully charged conditions. During this situation, it is required to control electrical load demand and hence the battery bank can store more energy. As battery charging level increasing, the electrical load can increase accordingly with solar PV system output. With this aim, an Evolutionary Programming has been proposed to adjust electrical load demand. This is similar to load shedding concept in smart grid environment in which the electrical load on distribution network will adjust as per available grid power by prioritizing the feeders and their associated load [7]. The load pattern to the system is classified in to following categories.

a) Primary and non-interruptible load during sunny period *i.e.*, battery bank under not fully charged condition, DC load with highest priority.
b) Primary and interruptible load during sunny period *i.e.*, battery bank under fully charged condition and AC load with lowest priority.
c) Secondary and non-interruptible load during sunny period *i.e.*, AC load with highest priority other than DC load.
d) Secondary and interruptible load during sunny period *i.e.*, AC load with lowest priority other than DC load.
e) Primary and non-interruptible load during non-sunny period *i.e.*, DC load with highest priority.
f) Primary and interruptible load during non-sunny period *i.e.*, DC load with lowest priority.
g) Secondary and non-interruptible load during non-sunny period *i.e.*, AC load with highest priority.
h) Secondary and interruptible load during non-sunny period *i.e.*, AC load with lowest priority.

From all these, the first 4 load patterns can maximize the SPV system output during sunny period and the later 4 load patterns can improve the battery storage back-up time during non-sunny period. In all the patterns, there is a need to estimate solar system output with forecasted meteorological conditions and available battery energy. With these estimations, the load pattern has to adjust on the system.

3. Description of Real-Time Solar PV System

3.1. System Design

A 1 kW roof-top solar PV system with 4 panels is integrated on roof-top. The system has four standard modules TP250 series of TATA Power Solar. A hybrid inverter of 1.2 kVA capacity is taken. This inverter has an inbuilt MPPT charge controller, DC-AC converter for AC output and DC-DC converter for DC output. It also has AC-DC converter for charging the battery from main grid during off-sun period. In this way, the whole system can convert as grid-tied system.

The system is designed to meet the lighting load distributed on the roof-top of hostel building (of 5 floors) during off-sun period automatically. It is required to operate the load continuously from the time of no sun-shine to around 10 pm each day (5hr, approximately). A 100W LED cool white flood lights are installed at the four corners of the building. Since the battery discharging can mainly dependent on load connected to the system, and we have a total load of 400W and in around 100W power loss in distribution. On an average 5hours daily running period, we need 500W × 5h = 2.5 kWh battery storage. In order to keep one day autonomy, 2 × 200 Ah × 12 V = 4.8 kWh battery storage capacity has been considered in design stage.

Since the PV system as well as load is situated on the roof top of 5 stairs building and system monitoring and load control is a typical task to the security persons every day. It is also difficult to monitor light intensity every day in the evening time and according to switch ON the load and to switch OFF, it is required to go on to the roof-top around 10:00 pm. So there is a need to monitor and control by making the system automation. In this process, the load controller is equipped with '*day/ night sensor load controller*' which will turn ON the load automatically in the absence of sun-light. Since the sensor will again turn OFF the load automatically again only with the presence of light and that may happen in the next day morning hours. But it is required to switch OFF forcefully around 10:00 pm in the night itself; hence there is a need for man-machine-interference again. To overcome this problem, a 5W LED lamp is kept near to the sensor and it will ON automatically at 10 pm by using '*timer based load controller switch*' and will turn OFF again in the next day morning at 05:00 am. During this period, the '*day/ night sensor load controller*' will be under the condition of light present, so the load will be under shut-down condition. Again at 05:00am, the 5W LED light gets OFF and the main load will turn ON due to the absence of sun-light at that that time and it will remains ON up to sun-shine presence. In this way, the load control made fully automation.

3.2. IoT Solution

The next important aspect of this pilot project is to monitor the performance without reaching the premises of actual solar system. This can be done by data logger through direct wire connectivity from the logger to monitoring PC/computer. In order to avoid external wiring run around the system – monitoring room, the data logger is integrated with mobile with internet and that's how this system become an IoT device innovatively. Basically IoT can define as "A network of physical objects or 'things' that can interact with each other to share information and take action" or "The Internet of Things (IoT) is the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure" [8]. Currently, IoT revolution has influenced all the sectors around world and has become bigger than industrial revolution. Eventually, adoption of this technology has turned towards essential part in current smart grid environment. The smartness involved with IoT implementation, the operation and control of any device become effortless and so enhancing our lives.

In this work, the important point is that the load control became as automatic using day/night light sensor switch in association with the combination of timer switch irrespective of battery SOC level. At present, the IoT technology is implemented to monitor the system performance only from off-site. But it is required to switch ON the load automatically as per the sun light intensity in the evening time and at morning at 05:00 am. Similarly, the load should turn OFF automatically from 10:00 pm to 05:00 am. In addition, as per battery discharging level, each light should switch OFF sequentially according to priority set. The switching OFF of the next light depends on battery level. The complete lay out of the designed system is illustrated in Figure 1.

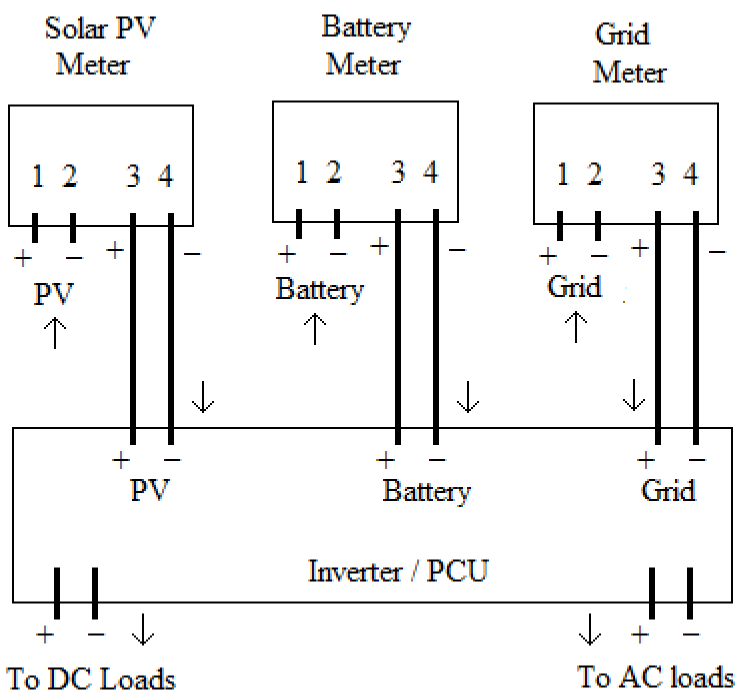

Figure 1. Energy Meters Integration for IoT Solution

The test system integrated with DC multi-data meter to measure solar array parameters (voltage and current) as well as battery voltage and charging current, AC multi function meter to measure import/export energy from/to grid through inverter. In order to get data from energy meters, E-Senz remote monitoring device is integrated with system. In this way, using IoT technology, the stand-alone system performance monitoring and control can be done further smooth.

4. Results and Discussions

Using IoT solution, the parameters of all the equipments in test system are continuously measured and can be observable in www.esenz.com website in customer portal [9]. For a particular instant/login time, the system performance is illustrated in the Figure 2 for day-time and in Figure 3 for night-time. The total energy generated from the solar array can visualize hours/days/month/year time span. We can also able to understand easily the percentage of power generating at that particular instant. It is actually calculated as the ration of power generating at that instant to total installed plant capacity.

Similarly, the inverter is integrated with grid to maintain proper charging level in battery during non-sunny days. Since the inverter is stand-alone mode, we can take only draw power from the grid to charge the battery and we cannot export excessive power from the system to grid. Hence we can visualize the power imported from the grid in hours/days/month/year time span.

The battery bank is the basic key component in stand-alone system and it is required to monitor continuously charging level. The energy meter equipped to measure import and export power for every instant. The percentage of SoC is calculated as follows:

$$\% \text{ SoC} = \frac{(\text{Watt-hour measured as import - Watt-hour measured as export})}{(\text{Battery Voltage} \times \text{ Total Ah Capacity})} \times 100\%$$

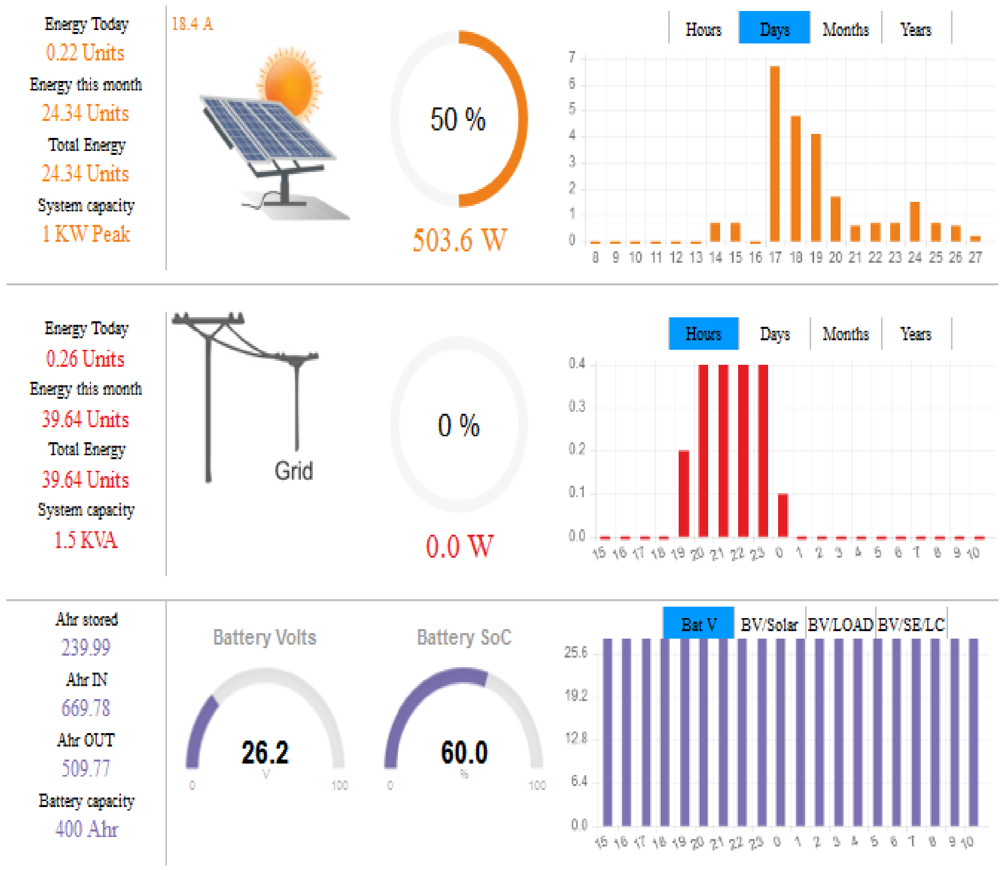

Figure 2. Visualization of System Performance during Day-Time

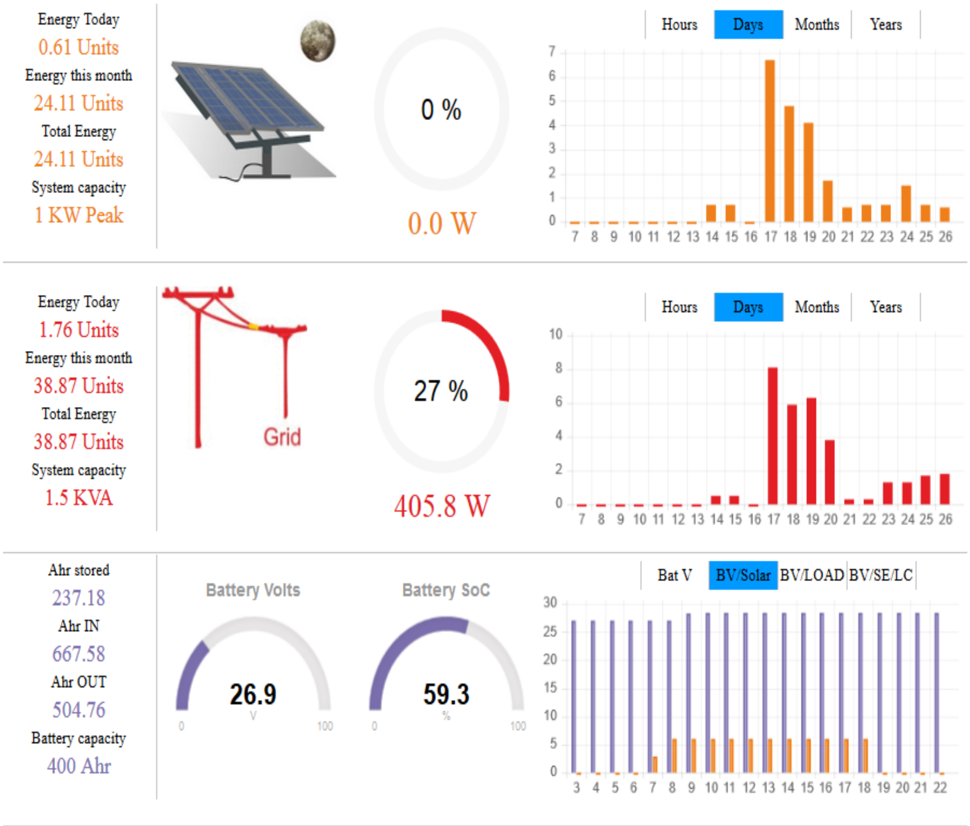

Figure 3. Visualization of System Performance during Night-Time

5. Conclusion

This paper explained the application of IoT concept for stand-alone solar system at the premises of Faculty of Engineering, Christ University, Bangaluru. Using this facility, it is also possible to import raw data of the system to work space. This data can be used to understand each equipment performance and its associated parameters. By using this facility, the solar system performance curves like I-V, P-V curves, battery charging, discharging phenomena and its SoC level can easily measure. In addition, the power flow pattern among various components in the system can easily explain to the students from off-site itself like an e-teaching facility.

Since the system integration is done only in the month of January, 2017, the Demand Side Management (DSM) scheme as explained in section 2 is yet to be implemented to maximize system performance and it will be the subject for future work.

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References

[1] India's Intended Nationally Determined Contribution: Working towards Climate Justice, Sep. 25, 2015. Available at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf.
[2] Jawaharlal Nehru National Solar Mission Towards Building SOLAR INDIA, Available at: http://www.mnre.gov.in/file-manager/UserFiles/mission_document_JNNSM.pdf.
[3] W. T. Jewell and T. D. Unruh, "Limits on cloud-induced fluctuation in photovoltaic generation", IEEE Trans. on Energy Conversion. vol. 5, **(1990)**, pp. 8-14.
[4] E. Lorenz, J. Hurka, D. Heinemann and H. G. Beyer, "Irradiance Forecasting for the Power Prediction of Grid-Connected Photovoltaic Systems", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 2, **(2009)**, pp. 2-10.
[5] C. Tao, D. Shanxu and C. Changsong, "Forecasting Power Output for Grid-connected Photovoltaic Power System without using Solar Radiation Measurement", Proceedings of 2nd IEEE International Symposium on Power Electronics for Distributed Generation Systems, **(2010)**, pp. 773-777.
[6] C. Singh Solanki, "Solar Photovoltaics: Fundamentals, Technologies and Applications", PHI Learning Pvt. Ltd., 09 May **(2015)**.
[7] A. K. Sinha and N. Kumar, "Demand response management of smart grids using dynamic pricing", 2016 International Conference on Inventive Computation Technologies (ICICT), Coimbatore, India, **(2016)**, pp. 1-4.
[8] J. Gubbi, "Internet of Things (IoT): A vision, architectural elements, and future directions", Future generation computer systems, vol. 29, no. 7, **(2013)**, pp. 1645-1660.
[9] www.esenz.com.

