MONITORING OF PHOTOVOLTAIC PANEL IN A SOLAR-POWERED LAB-SCALE SMART IRRIGATION SYSTEM

[1]Ogidan O. K., [2]Amusan A. A., [1]Nkanga I. E.

[1] Department of Electrical and Electronics Engineering,
Elizade University, Ilara Mokin, Ondo State, Nigeria
olugbengaogidan@gmail.com +234 803 582 5897

[2]Department of Electrical and Electronics Engineering,
University of Lagos, Lagos State, Nigeria
aamusan@unilag.edu.ng

ABSTRACT

The solar photovoltaic (PV) or solar panel is an active transducer whose function in the provision of solar energy cannot be overemphasised. Many solar energy systems perform poorly or fail when the properties of the PV and conditions under which they are implemented are not taken into consideration during system design. Others fail due to environmental conditions such as temperature which might degrade the power generated by the solar PV. As a way of ensuring longevity and healthy operation of the PV, there is the need to do a constant monitoring of it properties and generated power. In this work, parameters such as current, voltage, and ambient temperature of 200 W solar panel are measured in real-time and obtained values used in design of solar power for a lab-scale smart irrigation system. The PV power was determined from the measured current and voltage values using appropriate sensors which are connected to an Arduino-based microcontroller. The PV under a load-OFF test was exposed to the sun from 5:30 am to 7:10 pm. The measured solar power confirms the peak sun hour of 4.5 to 5 hours for Ilara Mokin, Ondo State, Nigeria. Load-ON implementation with a lab-scale smart irrigation testbed reveals that irrigation pumps 2 and 3 maintaining an equal distance each from the water source absorb less power compared with pump 1 at a distance more than double of pumps 2 and 3 from the water source. Thus, the distance of the irrigation pumps and sprinklers from the water source is found to play vital role in the pattern of power consumption by the irrigation system. The maximum power thresholds of irrigation pumps under various load-ON conditions were determined. The power thresholds obtained would be useful parameters for configuring the lab-scale smart irrigation controller for effective performance while the peak sun hour obtained is a useful design parameter for this work and implementation of effective solar system in Ilara Mokin and its environs.

Keywords: Photovoltaic, microcontroller, smart irrigation, current sensor, voltage sensor

Introduction

A smart irrigation is a system whereby water is supplied to the crops automatically based on pre-defined conditions such as water availability, weather condition, crop water requirement, soil moisture contents amongst others. Rather than supplying water continuously to the crops in traditional irrigation system, a smart system detects the water needs and delivers appropriate amount of water to the crop. A lab-scale smart irrigation system had previously been developed in Ogidan et al., (2019).This is a low cost device that could be used in a lab setting for teaching systems automation or demonstrating a smart irrigation process in an attempt to marry the theory taught in the class with hands-on experience. The device incorporates irrigation facilities in a farm setting such as water reservoir, soil moisture content sensor, water level sensor, water pipes, irrigation control unit, pumps, sprinklers, three farms, a farm house and a feedback pump for water recycling back to the main reservoir. In developing countries with deficit power infrastructure, integration of a solar power source is very necessary to ensure uninterrupted use of the device especially in places where there is inadequate or no electricity from the grid. The solar photovoltaic systems make use of solar panels to convert the light energy from the sun to electricity. In the last two decades, solar photovoltaic (PV) system has evolved into mature technology becoming part of the mainstream source of electricity (Lund, (2016)). Thus, a stand-alone PV system can effectively be used as a power source for smart irrigation system especially in rural areas which lack grid-connection.

In order to develop a reliable solar system for the lab-scale smart irrigation, it is imperative to investigate the performance of the panel and other solar components under different conditions and make allowance for these in the design of the solar energy system. Furthermore, as solar photovoltaic system has emerged as the most promising technology to meet the demand for electricity growth, condition monitoring of PV system is essential to allow users to maintain and observe the PV system especially when installed in remote locations (Ranjit and Abbod, (2018)). In remote locations, there is often lack of technical manpower to perform operation check and maintenance on the solar PV system. Thus, it is essential to design a system that can continuously monitor the condition of the solar panel. This would assist in carrying out the preventive maintenance on the PV system when it is necessary (Ranjit and Abbod, (2018)). Several parameters of the PV system such as current, voltage, power and ambient temperature can be measured using their sensors and stored in real-time by microcontrollers to monitor the condition of the panels, as well as, use the data for other control purpose.

Review of Related Work

Over the years significant number of research work have been carried out related to monitoring of PV systems. Singh et al., (2019) developed a low cost wireless monitoring system for a single solar panel. The system continuously measures current, voltage and temperature of the solar panel. All the required sensors (voltage and current sensor, as well as, thermocouple) were arranged together with Raspberry pi zero in a modular box and externally wired to the solar panel. The acquired data (voltage, current and temperature) was sent to a Raspberry pi zero which transfers the data into a cloud server database via wireless link, in which users can monitor the acquired data via a webpage (Singh et al., (2019)).

Furthermore, a cost-effective, Internet of Things (IoT) – based health monitoring system was proposed for solar PV plant, where sensors were embedded in solar PV system and were linked to the Internet through wireless networks, using the Internet Protocol, Message Queuing Telemetry Transport (MQTT) (Badave et al., (2018)). The system comprised of PV array, storage battery banks, operational control unit of battery and an electrical load. The system could monitor current, voltage, temperature and humidity values using their respective sensors. The system was controlled by CC3200 microcontroller with ARM Cortex-M4 as core. On board Wi-Fi, wireless communication enhances the system performance with reduced area and facilitates monitoring of system parameters after every 30 s. An open source Internet of Things (IoT) application programming interface (API) (ThingSpeak) was used to store and retrieve data from sensors (Badave et al., (2018)).

An electronic system which monitored all the environmental parameters of the solar PV panel was designed and implemented in Amhani and Attia, (2017). The developed system could monitor the levels of light intensity on the panel, dust density in the air, temperature, humidity, as well as, the power delivered by the panel. Arduino-based microcontroller was used to acquire the sensor values and recorded on the computer (Amhani and Attia, (2017)).

In addition, an IoT – based system that remotely monitors the performance of PV system was implemented in Adhya et al., (2016). The proposed data acquisition system was capable of acquiring the values for battery voltage, battery current, PV voltage, PV current, grid voltage, grid current, solar insolation and ambient temperature. The brain of the data logging unit was the PIC18F46K22 microcontroller which is an extremely low power advanced reduced instruction set computer (RISC) microcontroller. The acquired data was sent to the web server via the Internet using a Global System for Mobile Communications (GSM) / General Packet Radio Service (GPRS) communication link. Stand-alone web hosting service running on the target personal computer (PC) with an Internet connection gave capability to monitor the live data from anywhere in the world (Adhya et al., (2016)). Similar system was developed in reference Kekre and Gawre, (2017) in which the data from the current and voltage sensors was sent to Arduino Uno microcontroller linked to the Internet via GSM/GPRS module. The acquired data was then sent to a dedicated server (Kekre and Gawre, (2017)).

The authors in Samara and Natsheh, (2019) developed an intelligent real-time monitoring system utilizing a small but efficient Artificial Neural Network (ANN) that is adequate to run on a low-cost system. It is usually not trivial to identify whether a solar panel is faulty or operating normally since the output also depend on current environmental condition. Therefore, an artificial neural network reference model was developed and used to predict the output of normal operational photovoltaic panel and then compared with real-time measured output under a set of changing environmental conditions. An alert is sent to a mobile terminal if the error margin between the predicted and measured solar output is too large (Samara and Natsheh, (2019)). The solar output data (current and voltage) and environmental data (temperature and irradiance) were acquired using their sensors. The ACS712 was used for current sensing while a voltage divider circuitry was used to measure voltage. Ambient temperature was measured using Analog Devices ADT7420 sensor while irradiance measurement was taken by Apogee SP-212-SS sensor. ATMega 2560 microcontroller was used for data acquisition and control. The developed PV monitoring system could intelligently identify whether the photovoltaic panel exhibits degradation due to fault conditions.

The authors in Márquez and Ramírez, (2019) proposed a novel condition monitoring system using radiometric and thermographic sensors embedded in an unmanned aerial vehicle to detect dust on PV panels. Dirt on PV panels can cause significant loss of energy produced in PV panels (from 5% up to 15 % annual loss without rain). Thermography takes the image of the surface temperature by capturing variations of infrared radiation. The radiated energy is measured by a thermographic camera and converted into temperature values with detectors or thermal sensors that compare measured radiation with fixed values and assign colour palettes to each temperature value depending on the camera type. Radiometry is used to obtain the measurement of electromagnetic radiation. Invisible radiation to the human eye is measured quantitatively using sensors and/or detectors that convert part of the radiation into electrical signals. These sensors capture the infrared energy emitted by objects through a detector, and it is transformed into an electrical signal to obtain the temperature value using a thermocouple or photodiode. The radiometric sensor measured the infrared signal, and an Arduino board transformed it into a suitable thermal value by electronic circuits, which was then transferred to a wireless platform where the data was analyzed. Generally, a clean surface gave higher temperature than a completely dirty surface (Márquez and Ramírez, (2019)).

In López-Vargas et al., (2019), the authors developed a low-cost data logger intended for stand-alone photovoltaic (PV) systems in developing countries employing open source software and hardware. The low-cost data logger was capable of measuring electrical and meteorological parameters meeting the accuracy requirements established by the International Electro-technical Commission (IEC) standard for PV monitoring systems. In addition, it measured the Stand-Alone PV (SAPV) system parameters such as PV module and battery temperatures, PV generator output voltage, battery voltage and load voltage, PV generator output current, battery current and load current (López-Vargas et al., (2019)).

A cost effective data acquisition system (DAQ) based on Lab Virtual Instrument Engineering Workbench (Lab-VIEW) was developed in Rezk et al., (2017). The proposed monitoring system was employed for continuously collecting and displaying the electrical output parameters of a stand-alone PV system. The system required a proprietary data acquisition and electronics circuit card from National Instrument (DAQ card NI USB-6009 8 inputs) which was used to measure the PV current and voltage. A computer running Lab-VIEW software was connected to the DAQ card using universal serial bus (USB) interface cable which displays the measured PV current and voltage. In addition, the solar irradiance can be estimated directly via measuring PV panel short circuit current instead of using costly commercial instruments (Rezk et al., (2017)).

In all the literatures discussed, several work were done on PV monitoring using different controllers and processors such as Rasbery Pi (Singh et al, (2019)), computer running Lab-VIEW software (Rezk et al., (2017)), ATMega 2560 (Samara and Natsheh, (2019)), PIC18F46K22 (Adhya et al., (2016)); none of the PVs monitored were applied to a smart irrigation system. At the same time, several works have been done on smart irrigation system (Masaba et. al. (2016), Parameswaran and Sivaprasath, (2016), Tyagi et al., (2017), Ogidan et al., (2019)). Many of the authors proposed the use of solar power source for a smart irrigation system (Shinde and Wandre (2015), Baladi and Shah, (2018)), yet they did not addressed real-time condition monitoring of the solar panel used in a lab-scale smart irrigation system. This work therefore focuses on monitoring of a solar photovoltaic (PV) in a lab-scale smart irrigation system. The purpose is to use the findings in the design of a reliable solar energy system to effectively power the irrigation system for reliable use especially in places with power infrastructural deficit.

The rest of the paper is arranged as follows. Section 3 describes the methodology, section 4 presents the results, and section 5 focuses on the discussion of results while section 6 is the conclusion.

3.0 Methodology

The steps involved in this work are as shown in Figure 1, which include the choice of the PV, incorporation of the current and voltage sensors in the solar system, measurement of current, voltages and temperature of the PV and battery under the load-OFF and load-ON conditions, computation of the power thresholds under varying number of irrigation pumps and using the computed power thresholds as a basis for programming the microcontroller for irrigation.

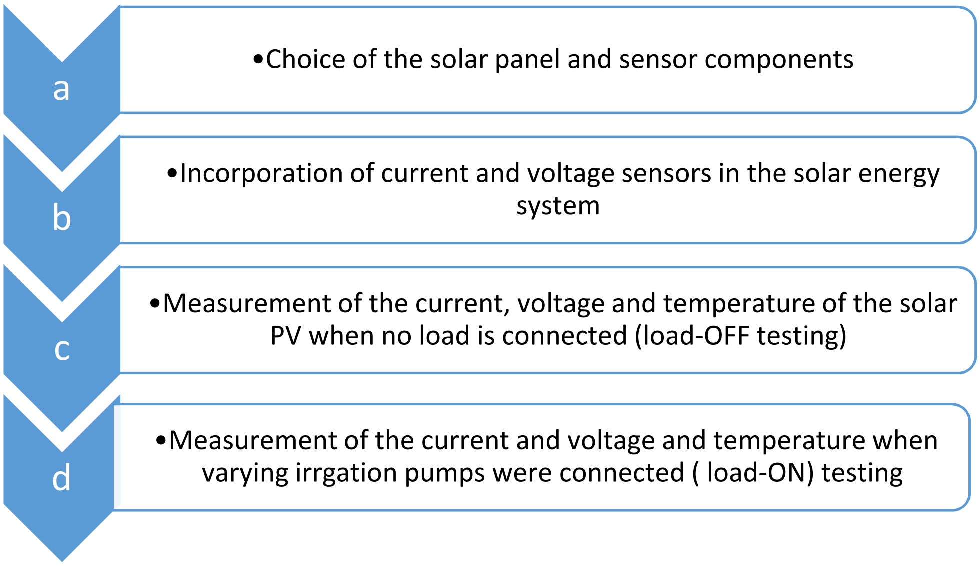


Figure 1: A step by step description of the methodology

a.) Choice of the solar PV

In this research, the choice of the 200 W solar panel was arrived at based on the following details:

Load assessment of all components to be powered by solar energy was100.5 W, calculated power demand was 117VA while the energy demand for a period of 5 hours per day without grid power was 585 Watt-hour.

Total Watt-hours/day to be supplied by solar panels = 585×1.3 = 760.5 Watt-hour (1)

With the location of Ilara Mokin, the sun peak hour of 5 hours was assumed.

Watt peak rating of the solar panel is then $\frac{760.5\ (\text{Watt}-\text{hour})}{5\ \text{hour}} = 152.1\ \text{W}$ (2)

Number of 100 W panels required = $\frac{152.1\ \text{W}}{100\ \text{W}} = 1.521 \approx 2 \text{ x } 100 \text{ Watts PV}$ (3)

Battery size (Ah) = $\frac{585 (\text{Watt.hour})}{0.85 \times 0.6 \times 12\text{V}} \times 1 = 95.5\ \text{Ah}$

Number of 100Ah batteries, 12 V required will be = $\frac{95.5\ \text{Ah}}{100\ \text{Ah}} = 0.95 \approx 1 \text{ battery}$ (4)

b.) Incorporation of current and voltage sensors in the solar energy system

In an attempt to monitor the solar PV and battery power, two current sensors and two voltage sensors were used. A current and voltage sensor was placed at the PV output as well as the battery and these are connected to an ATMega 328 microcontroller on an Arduino board as shown in Figure 2. The current sensor used in this research is ACS712 current sensors. The sensor is able to detect alternating current (AC) or direct current (DC) up to the maximum of 30A with an input voltage of 5 V from the microcontroller. The output for both the solar current and the battery current are connected to the analogue input pins A4 and A6 respectively of the microcontroller as shown in Figure 2. In order to measure the voltages at the PV and battery outputs, two voltage divider circuits were used. The detail of the connections of the current and voltage sensors is found in Figure 3. The equation for the voltage divider circuitry is given as:

$$V_{outPV} = \frac{R_2}{R_1 + R_2} V_{inPV} \quad (5)$$

$$V_{outB} = \frac{R_2}{R_1 + R_2} V_{inB} \quad (6)$$

V_{in} is the voltage coming from the PV or battery while V_{out} is the output voltage going into the analogue input pins of the microcontroller. The input voltage from the battery is labelled as V_{inB} while the output voltage going into the analogue input pins of the microcontroller is labelled as V_{outB}. In case of the PV, the input voltage is given as V_{inPV} while the output voltage is V_{outPV}. The solar power P_{pv} and battery power P_B are computed in equations 7 and 8 using the measured currents and voltages.

It should be noted that two 100 W solar panels were combined in series to obtain a total power 200 W. Each of the 100 W panel has open circuit voltage of 22 V which gave net open circuit voltage of 44 V for two 100 panels when connected in series. In addition, the battery output voltage is 12 V. Hence, the resistance R_1 and R_2 in voltage divider circuitry is selected based on voltage divider relationship such that the output voltage V_{out} is 4.4 V at the microcontroller analogue input pins. Therefore, from equations 5 and 6, the value of R_1 was selected to be 10 kΩ while the value of R_2 was selected to be 1Ω. At the software level, the data is calibrated back to equivalent measured value (V_{in}) at the input of the voltage divider.

From equation 7 and 8, one would observe that the power output of the PV and battery at any instant can be computed from the product of the acquired current and voltages values.

The solar power P_{pv} and the battery power P_B are given as:

$$P_{pv} = I_{pv} \times V_{pv} \quad (7)$$

$$P_B = I_B \times V_B \quad (8)$$

Where: I_{pv} = Solar PV current, V_{pv} = Solar PV voltage, P_{pv}= Solar PV power, I_B = Battery, current, V_B = Battery voltage and P_B = Battery power

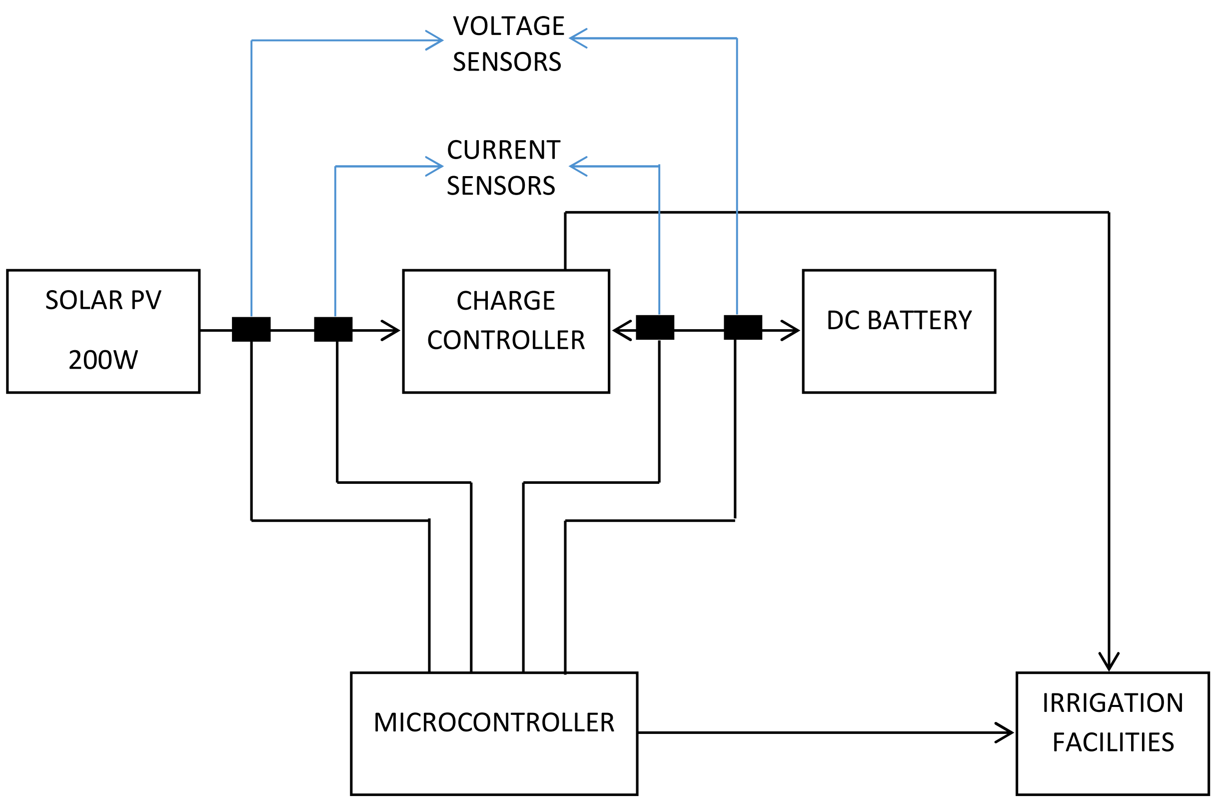


Figure 2: Block diagram of current and voltage sensors connection with solar PV, battery microcontroller and irrigation system

c.) Load-OFF testing of the PV

The first investigation performed on the PV was to measure its power delivery in relation to temperature changes when it is not connected to any load. To do this, the PV was connected to other solar energy components such as the charge controller and battery while two current and voltage sensors are connected to it at the PV and battery outputs as shown in figure 3. The sensors are interfaced with ATMega 328 microcontroller on Arduino prototyping board. The generated power shown in equations 7 and 8 takes place in the microcontroller and displayed in real-time through the serial monitor of a computer. The experiment was performed from 5:30am till 7:10pm while the acquired data (PV and battery current and voltages as well as the environmental temperature) was recorded every 10 minutes. The temperature was acquired by the inbuilt thermistor sensor of the Maximum Power Point Tracking (MPPT) charge controller used. The acquired data is shown in Table 1. It should be noted that during this load-off period, the PV is connected to the solar components and the control unit of a smart irrigation testbed as shown in figure 4 but all irrigation pumps are set to OFF position.

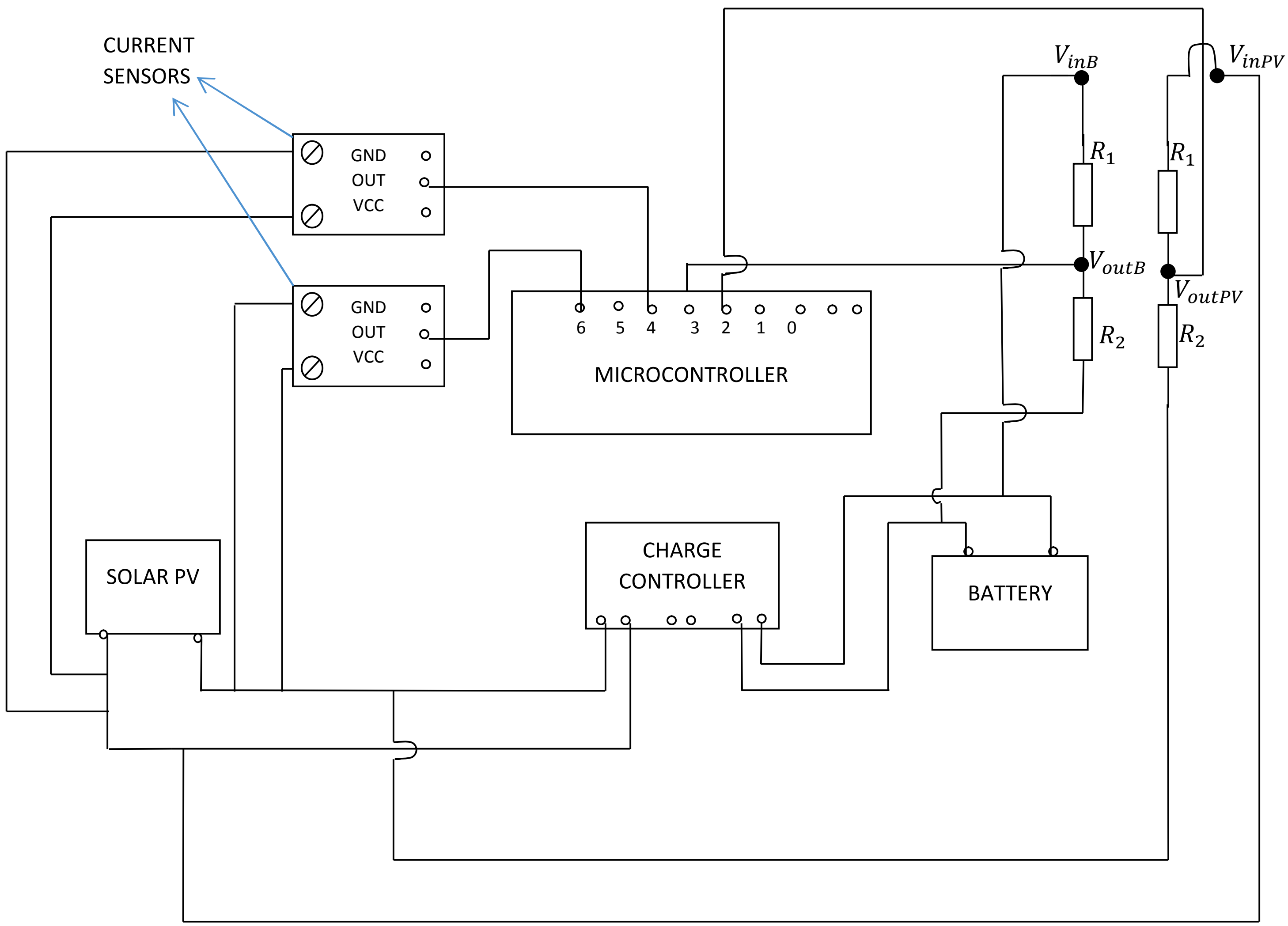
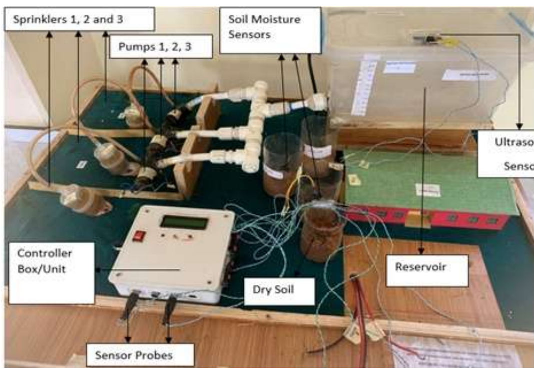


Figure 3: Schematic diagram of the power sensors connection with solar PV and Arduino-based microcontroller

d.) Load-ON testing of the PV with irrigation pumps

In this case, the smart irrigation pumps (loads) were connected one after the other and used to draw water from the reservoir of the lab-scale irrigation testbed for a few minutes two minutes in each case, until it stabilises and readings of the PV and battery voltages and currents were recorded. This exercise was carried out about three times after which the average current and voltage were obtained. The essence of the test is to see how the PV and battery will behave at different power levels to aid us in programming the irrigation systems for optimal power usage that would prevent the solar system from overload and possible failure. This implementation was carried out using a lab-scale smart irrigation testbed (Ogidan et al., 2019) developed in Elizade University, Nigeria as shown in Figures 4a and 4b. Figure 4b shows the solar components including a Maximum Power Point Tracking (MPPT) charge controller, Gel deep cycle battery, Arduino Uno microcontroller and the power sensors. Also contained in lab-scale smart irrigation testbed are Toyota pumps which act as actuators through which water is drawn to the three sprinklers representing different farm sections. Ambient temperature is measured using the sensors in the Maximum Power Point Tracking (MPPT) charge controller.



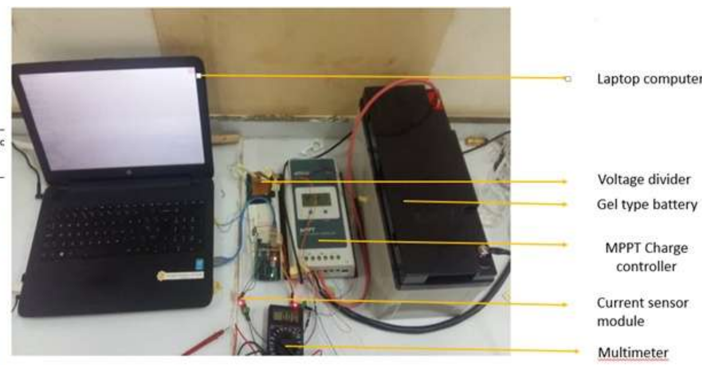


Figure 4: a.) Lab-scale smart irrigation testbed Ogidan et al., (2019)
b.) Solar system used to power the lab-scale smart irrigation system

4.0 Results

From Figure 5 and Table 1, it could be observed that the power output of the PV increased from less than 60W at around 12 noon to maximum of 400 W at around 1:10 pm which remained relatively constant at the peak power until 4:20 pm. It could be noted that although two 100 W (200 W) solar panels were used, yet the maximum power delivered by the panels during peak sun hours was up to 400 W.As shown in Figure 6, the power generated had a normal distribution reaching the peak power at about 1:00pm and falling as from 4:30 pm in the evening as the temperature rose from 23ºC reaching the peak of 31ºC at 12:50 pm and falling back to 25ºC at 5:50 pm. It could be observed from Figures 7 and 8 that pump 1 absorbed the highest PV power (44.55 W) when compared with pump 2 (28.48 W) and pump 3 (32.33 W). This phenomenon is consistent with the battery power where the power absorbed by pump 1 (28.80 W) was also the highest compared with pump 2 (18.29 W) and pump 3 (11.89 W). Experimental results furthermore reveal that at the PV, the system under pumps 1 and 2 were found to absorb more power (51.40 W) than pumps 1, 2 and 3 (36.18 W). This phenomenon was similar to the battery side where the system experienced highest power (67.69 W) with pumps 1 and 3 compared with combined pumps 1, 2 and 3 (32.41 W).

5.0 Discussion of results

In Figure 5 and Table 1, the period of 4 hours, 20 minutes or approximately 5 hours (1:00 pm to 4:30 pm) when the power generated increased significantly confirms the peak sun hour for Ilara Mokin (Powerlarc, 2019). This is the period when the energy from the sun is most beneficial to the solar PV system. This parameter is consistent with our design of estimated average peak sun hour of 5 hours for Ilara Mokin. Comparing the power generated with temperature in Figure 6 and Table 1, it has been reported that solar PV works best between temperatures of 25 to 35 degree Celsius (Verma and Singhal, 2015), the normal distribution of power and in this work could be due to the fact that the highest temperature recorded in this work (31 ºC) is still within the normal range for solar PV.

In Figures 7 and 8 where pump 1 absorbed the highest power both at the PV and battery sections in comparison to pumps 2 and 3; this could be due to the fact that pumps 2 and 3 maintain an equal distance of 2 inches each from the reservoir and as such they are closer to the water source than pump 1 which is at a distance of 4.5 inches (more than double the distance of pumps 2 and 3) from the water source as shown in Figure 4a. This distance could have effect on flow pressure resulting in less water supplied to pump 1. The resultant effect is that due to less availability of water to pump 1, the pump would generate more heat and as such a lot of power meant for pumping of the water could have been lost through heat and so more power was dissipated by pump 1. The implication is distance of irrigation pumps from the water source could increase or decrease the power needed to operate such pumps and this has to be accounted for in designing of a smart irrigation system. In the case where 2 pumps absorb more energy compared to three pumps at the PV and battery sections as shown in Figure 7 and 8, this sounds abnormal because one would expect that two or three pumps should normally absorb more power than two pumps. This could be that at that time when the three pumps were engaged, the PV system might not be generating enough power to effectively power them. The power thresholds obtained from the load-ON tests of the solar PV and battery will be useful for programming the microcontroller to optimise the available solar power for a lab-scale smart irrigation testbed.

Table 1: Load-off measurement of the solar system

Time (hour)	Solar Voltage (V)	Solar current (A)	Solar power (W)	Temperature (°C)
5:30am	0	1.2	0.00	23
5:40	0	1.2	0.00	23
5:50	0.16	1.2	0.19	24
6:00	0.18	1.2	0.22	23
6:10	1.2	1.2	1.44	23
6:20	1.87	1.22	2.28	25
6:30	5.44	-21.36	-116.20	23
6:40	12.75	-15.29	-194.95	23
6:50	12.85	-17.59	-226.03	23
7:00	12.91	-16.55	-213.66	23
7:10	21.6	-8.18	-176.69	23
7:20	14.08	-14.92	-210.07	23
7:30	16.09	-12.07	-194.21	23
7:40	14.24	-15.7	-223.57	23
7:50	14.08	-1.44	-20.28	23
8:00	14.24	-2.55	-36.31	23
8:10	14.29	-12.03	-171.91	23
8:20	14.45	-11.89	-171.81	24
8:30	14.45	-14.63	-211.40	24
8:40	14.77	-14.55	-214.90	25
8:50	14.72	-0.4	-5.89	25
9:00	14.88	-2.33	-34.67	25
9:10	15.09	-2.7	-40.74	26
9:20	15.2	-1.3	-19.76	26
9:30	16.37	-1.37	-22.43	26

9:40	39.04	-0.56	-21.86	26
9:50	43.15	-1.67	-72.06	26
10:00	36.48	-2.63	-95.94	27
10:10	39.57	-1.81	-71.62	27
10:20	35.79	-2.04	-73.01	26
10:30	15.73	0.19	2.99	26
10:40	38.72	-0.78	-30.20	26
10:50	43.31	0.41	17.76	29
11:00	27.31	-0.93	-25.40	28
11:10	41.07	0.26	10.68	28
11:20	40.53	0.19	7.70	27
11:30	15.95	0.19	3.03	28
11:40	41.55	-0.11	-4.57	28
11:50	40	-0.19	-7.60	29
12:00	38.72	0.19	7.36	28
12:10	40.8	-0.19	-7.75	30
12:20	40.43	-0.04	-1.62	30
12:30	35.41	-0.11	-3.90	30
12:40	41.76	-0.11	-4.59	30
12:50	40.48	0.26	10.52	31
1:00	41.71	0.26	10.84	31
1:10	41.55	10.63	441.68	31
1:20	41.17	9.74	401.00	32
1:30	41.01	9.29	380.98	31
1:40	41.55	9.59	398.46	31
1:50	40.96	9.15	374.78	30
2:00	39.79	8.18	325.48	30
2:10	40.37	8.71	351.62	30
2:20	40.59	8.7	353.13	30
2:30	40.85	8.92	364.38	30
2:40	40.11	8.41	337.33	30
2:50	40.16	8.55	343.37	31
3:00	39.25	7.59	297.91	31
3:10	38.4	7.29	279.94	31
3:20	39.59	8.29	328.20	31
3:30	39.57	8.63	341.49	30
3:40	39.41	9.22	363.36	30
3:50	40.16	7.15	287.14	29
4:00	38.35	5.52	211.69	29
4:10	39.52	6.55	258.86	29
4:20	38.72	5.81	224.96	29

4:30	37.44	-0.85	-31.82	28
4:40	38.67	-0.7	-27.07	28
4:50	37.65	-0.56	-21.08	28
5:00	38.29	-0.56	-21.44	27
5:10	37.65	7.37	277.48	27
5:20	37.6	0.04	1.50	26
5:30	36.37	0.26	9.46	26
5:40	32.69	-0.41	-13.40	26
5:50	15.04	-0.41	-6.17	25
6:00	14.88	-0.33	-4.91	25
6:10	14.77	-0.33	-4.87	25
6:20	14.72	-0.26	-3.83	25
6:30	14.67	-0.41	-6.01	25
6:40	14.51	-0.26	-3.77	25
6:50	14.01	-0.26	-3.64	25
7:00	13.23	-0.7	-9.26	25
7:10	4.8	-0.85	-4.08	25

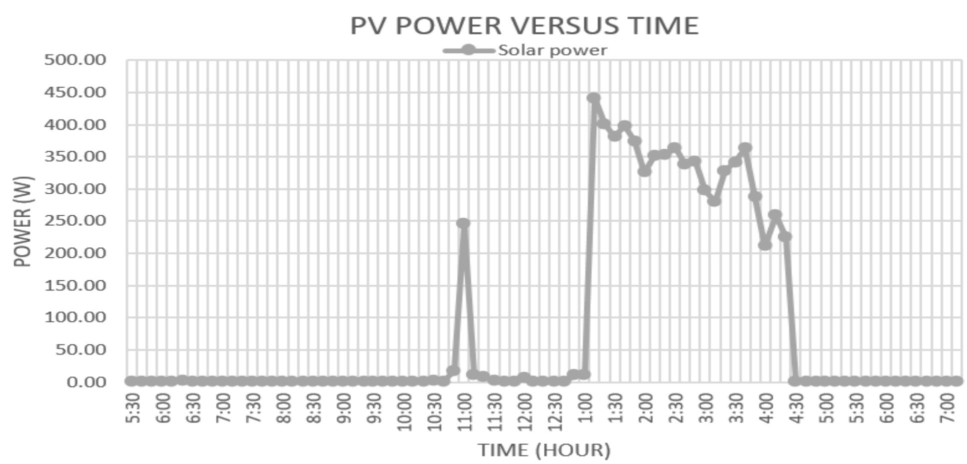


Figure 5: PV power distribution under load-OFF condition

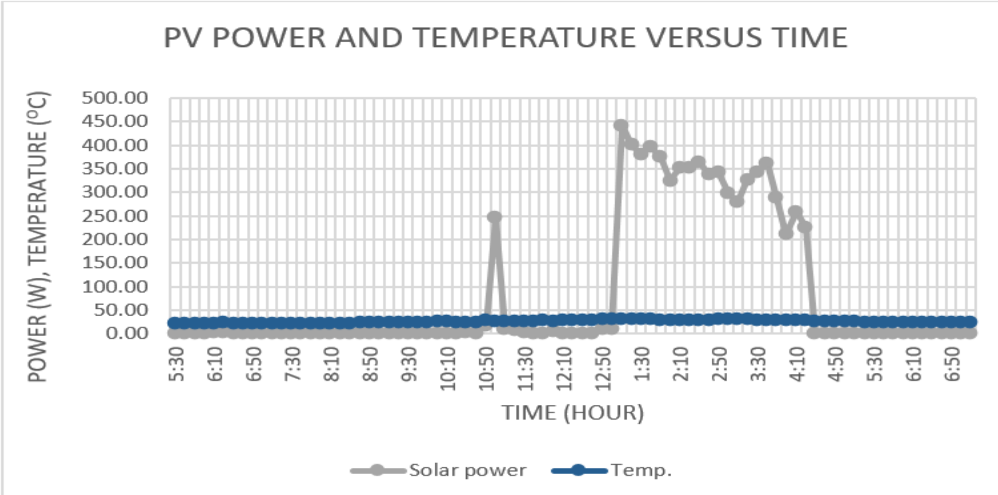


Figure 6: PV temperature and power under load-OFF condition

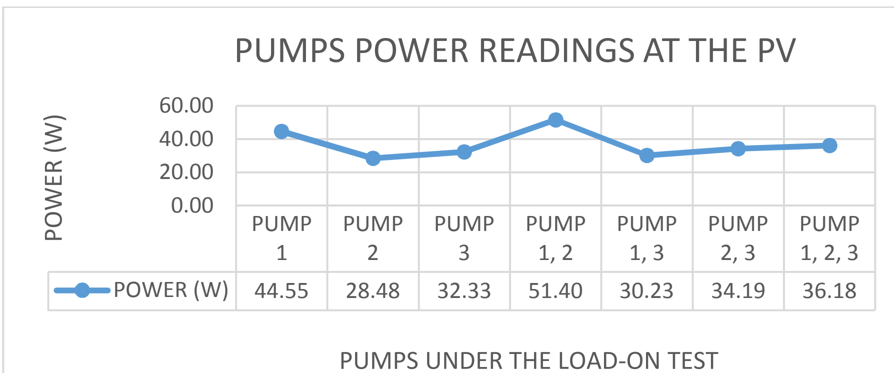


Figure 7: PV power when varying irrigation pumps were connected in load-on mode

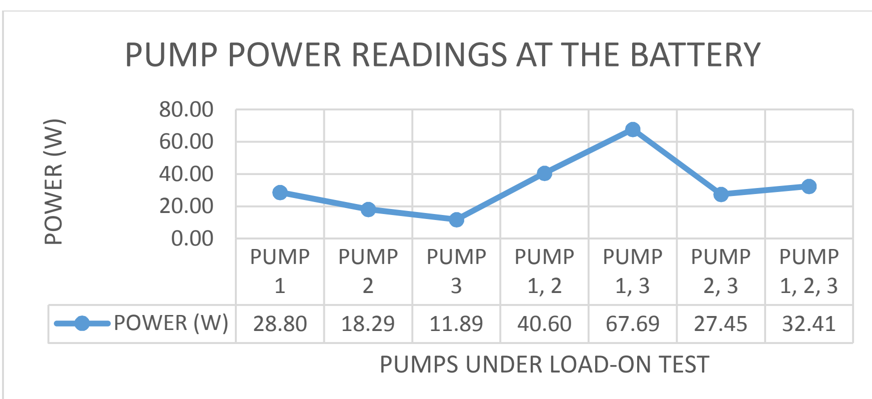


Figure 8: Battery power when varying irrigation pumps were connected in load-on mode

5.0 Conclusion

In this work, the performance of a solar PV system under a load-OFF and load-ON with a lab- scale smart irrigation testbed were evaluated. The load-off tests carried out on the solar PV confirms the peak sun hour of 4.5 to 5 hours for Ilara Mokin, Ondo State, Nigeria which agrees with previous findings (Powerlarc, 2019). Load-ON implementation with the lab-scale smart irrigation testbed revealed that the distance of the pumps to the water source plays significant role in determining amount of solar power absorbed by the smart irrigation system. The maximum power thresholds of irrigation pumps under various load-ON conditions were also determined. The power thresholds will be useful for configuration of the smart irrigation controller for optimal performance while the peak sun hour is useful for design and implementation of effective solar system in Ilara Mokin and the environs. Future work will include the incorporation of water optimisation with the developed power optimisation for the operation of a smart irrigation system.

References

Adhya, S., Saha, D., Das, A., Jana, J., & Saha, H. (2016, January). An IoT based smart solar photovoltaic remote monitoring and control unit. In 2016 2nd international conference on control, instrumentation, energy & communication (CIEC) (pp. 432-436). IEEE.

Amhani, A., & Attia, H. A. (2017, November). Online multi-parameters electronic monitoring system for solar photovoltaic panel applications. In 2017 International Conference on Electrical and Computing Technologies and Applications (ICECTA) (pp. 1-4). IEEE.

Badave, P. M., Karthikeyan, B., Badave, S. M., Mahajan, S. B., Sanjeevikumar, P., & Gill, G. S. (2018). Health monitoring system of solar photovoltaic panel: an internet of things application. In Advances in Smart Grid and Renewable Energy (pp. 347-355). Springer, Singapore.

Baladi, R. A., & Shah, M. A. (2018). Solar Powered Irrigation System for Agriculture based on Moisture Content in the Field and Saving Energy and Water with Optimum Designing. Asian Journal of Engineering, Sciences & Technology, 8(1).

Kekre, A., & Gawre, S. K. (2017, October). Solar photovoltaic remote monitoring system using IOT. In 2017 International Conference on Recent Innovations in Signal processing and Embedded Systems (RISE) (pp. 619-623). IEEE.

López-Vargas, A., Fuentes, M., García, M. V., & Muñoz-Rodríguez, F. J. (2019). Low-Cost Datalogger Intended for Remote Monitoring of Solar Photovoltaic Standalone Systems Based on Arduino™. IEEE Sensors Journal, 19(11), 4308-4320.

Lund, P. D. (2016). Clean energy systems as mainstream energy options. International Journal of Energy Research, 40(1), 4-12.

Márquez, F. P. G., & Ramírez, I. S. (2019). Condition monitoring system for solar power plants with radiometric and thermographic sensors embedded in unmanned aerial vehicles. Measurement, 139, 152-162.

Masaba, K., Ntakirutimana, A., & Ustun, T. S. (2016). Design and implementation of a smart irrigation system for improved water-energy efficiency.

Ogidan, O. K., Onile, A. E., & Adegboro, O. G. (2019). Smart Irrigation System: A Water Management Procedure. Agricultural Sciences, 10(01), 25.

Parameswaran, G., & Sivaprasath, K. (2016). Arduino based smart drip irrigation system using Internet of Things. Int. J. Eng. Sci, 5518.

Powerlarc, (2019). https://power.larc.nasa.gov/, accessed on 29th March. 2020.

Ranjit, S. S. S., & Abbod, M. (2018). Research and Integration of IoT based Solar Photovoltaic Panel Health Monitoring System. Indian Journal of Public Health Research & Development, 9(12), 1678-1684.

Rezk, H., Tyukhov, I., Al-Dhaifallah, M., & Tikhonov, A. (2017). Performance of data acquisition system for monitoring PV system parameters. Measurement, 104, 204-211.

Samara, S., & Natsheh, E. (2019). Intelligent Real-Time Photovoltaic Panel Monitoring System Using Artificial Neural Networks. IEEE Access, 7, 50287-50299.

Shinde, V. B., & Wandre, S. S. (2015). Solar photovoltaic water pumping system for irrigation: a review. African Journal of Agricultural Research, 10(22), 2267-2273.

Singh, R. S. S., Nurdin, M. I. B., &Chiew, W. Y. (2019) Raspberry Pi Zero Wireless Monitoring System for Analyzing Solar Photovoltaic Panel.

Tyagi, A., Gupta, N., Navani, J. P., Tiwari, M. R., & Gupta, M. A. (2017). Smart irrigation system.

International Journal for Innovative Research in Science & Technology, 3(10).

Verma, A., & Singhal, S. (2015). Solar PV performance parameter and recommendation for optimization of performance in large scale grid connected solar PV plant—case study. Journal of Energy Power Sources, 2(1), 40-53.