

GUI Based Online Monitoring of Performance Parameters of Solar Panel

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Abstract

This paper focuses on monitoring and assessment of the characteristics and the performance parameters involved with the solar panel are implemented using GUI. The characteristics curve and performance parameters are documented on the webpage and accessed online through the internet using the browser. The proposed method is verified with a 5KW solar panel which is used by an educational institution located in Madurai. The current-voltage (I-V), power-voltage (P-V) characteristics and the performance factors related to the solar panel are monitored and analyzed. The results show that there is a good agreement between the measured and simulation results values at the acceptable working condition of the panel. GUI is the Graphical User Interface that uses graphical icons for performing functionalities and visual indicators for interacting with users through input and output. Laboratory Virtual Instrument Engineering Workbench (LabVIEW) environment is used as GUI. LabVIEW is a graphical programming language used to acquire, present and analyze the electrical parameters. This application software integrates measuring instruments into a single system that able to display data from the solar panel on the webpage. This is used as potential pedagogical tool in teaching and learning process. The comparative results of the power generated from the solar panels in winter and summer are analyzed.

Keywords: Browser, GUI, LabVIEW, Online, Web page

1. Introduction

The electricity tariff for power consumption rises abruptly as the power utilization increases. For commercial industries, the tariff is varying based on the slab of power usage. To reduce the cost of the electricity bill, the industries generate electrical energy of their own by using renewable sources. The educational institute running at day time generates power with the help of renewable sources and cut down the EB bill. Moreover, renewable energy is clean, green and free energy. India receives more than 7 hours of direct sunlight each day throughout the year. The sunlight is converted to electrical energy with the help of the solar cell [1-5]. However, the performance solar panel plays a major role in power generation. A real-time monitoring system is needed to evaluate important parameters such as irradiance, output voltage, current, power, panel temperature and ambient temperature for appropriate utilization of solar panel. LabVIEW package is used to display, analyze and store the collected data. In this paper, all necessary data from the solar panel is acquired, parameters involved with the PV modules is calculated and evaluated, and webpage is created for online monitoring of data and the behavior of the dynamic system in real time at a remote location is studied and also it is used as pedagogy

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to teach the students in the classroom about the performance and characteristics of solar panels.

2. Description of Solar panel

This GUI based system is used to monitor and analyze a solar panel used in an educational institution, Madurai. The geographical location of the experimental setup is the latitude of 9.67° N and longitude of 77.97° E. This experimental setup consists of 250W of 20 solar panels connected in a series configuration, temperature and irradiance measuring sensors and an interface unit. The experimental set-up of the solar panel used for verification as shown in Figure 1. The used panel has following specifications.

Maximum Power, $P_{max} = 250$ W, Maximum Voltage (V_{max}) = 30.72 V, Maximum Current (I_{max}) = 8.14 A, Open Circuit Voltage (V_{oc}) = 37.8 V, Short Circuit Current (I_{sh}) = 8.63 A, cell size is 156 mm and multi crystalline type. The temperature coefficient of the open circuit voltage is -0.32% / $^{\circ}\text{C}$. These values are given by the manufacturer and taken under standard testing conditions of temperature 25°C and irradiance of 1000 W/m^2 . The exposed panel area to the solar irradiation is 1.965 m^2 . The weight of the solar panels is 21 kg and uses 3 bypass diodes of 15A [29].



Figure 1. Experimental setup of SVL 0250P

The solar panels are connected in series to produce power of 5 kW. The solar cell per module is 60 (10×6 matrix). The array of 14 solar panels is connected in series with 6 solar panels to generate 5 kW. The panel temperature, ambient temperature and irradiation were measured continuously. The proposed method of monitoring and performance analysis of PV systems is done by LabVIEW software and parameters are accessed through the internet. A schematic diagram of power generation using solar energy as shown in Figure 2. The solar panel (SVL 0250P) is used to generate DC power of 5 kW is converted to AC with the help of inverter (Solivia 5.0) and AC power is connected to the AC main panel through which electrical loads are supplied.

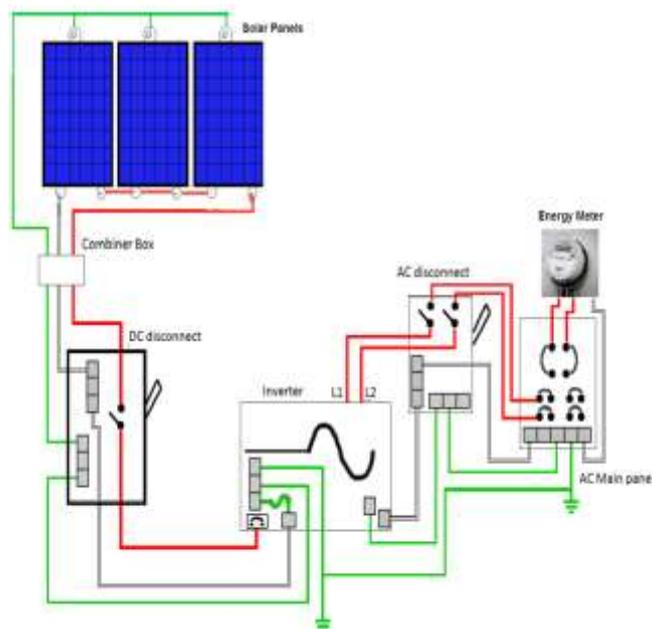


Figure 2. Schematic diagram of power generation using solar panel

The wall mounted inverter of Solivia 5.0, which converts direct current from the solar cells into alternating current. It gives the reading as shown in Figure 3. This enables to feed the electricity produced from solar energy into the grid. This facilitates with MPP tracking, maximum capacity utilization of the solar energy, integrated data display and communication with the external device. PV modules are connected in series to reduce the photovoltaic system's cabling requirements. The data interface enables to access the data and assures the continuous recording of operating data.



Figure 3. Inverter Model- Solivia 5.0

3. Performance Model for Solar panel

Four parameters to be considered in modeling of the solar cell are a current source, a diode, a series resistance and a parallel resistance. The current source represents

the photocurrent I_L , generated by the solar cell. It depends on the solar irradiation intensity falling on it. A diode represents the electrical behavior of the p-n junction, series resistance represents the electrical losses and shunt resistance corresponds to the leakage current [5-8]. The diode is connected in anti parallel with the photocurrent source represents the theoretical model of the ideal solar cell. The series and shunt resistances denoted by R_S and R_{SH} respectively. In an ideal case, R_S is zero and R_{SH} is infinite.

The well-known single-diode electrical equivalent circuit for a solar panel is shown in Figure 4.

Terminology

- I_L = Photocurrent from the solar panel in Ampere
- I_D = Diode current in Ampere
- I_{SH} = Current through shunt resistance R_{SH} in Ampere
- I_o = Reverse saturation current in Ampere
- n = Diode ideality factor
- V = Output voltage of a cell in Volt
- I = Output current of cell in Amperes
- R_S = Series Resistance in Ohm
- R_{SH} = Shunt Resistance in Ohm
- T = Temperature in Kelvin
- k = Boltzmann's constant, = 1.3805×10^{-23} J/K

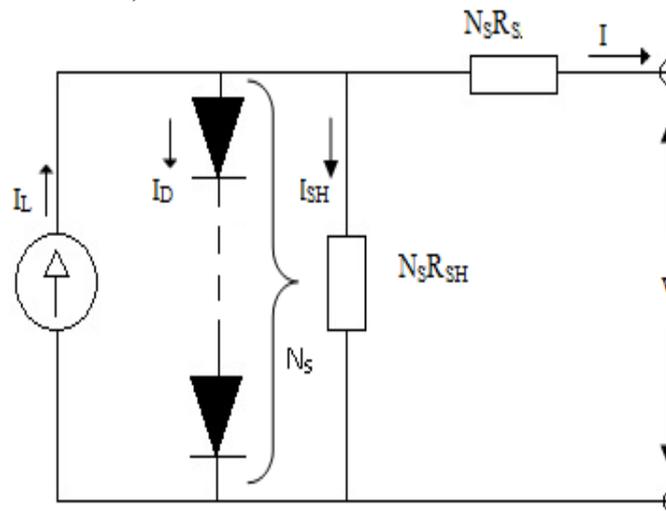


Figure 4. The electrical equivalent circuit for a solar panel

The Output current from the solar panel is written as

$$I = I_L - I_o \left[\exp \left(\frac{q * ((V \div N_s) + (I * R_s))}{k * T * n} \right) - 1 \right] - \left(\frac{(V \div N_s) + (I * R_s)}{R_{SH}} \right) \tag{1}$$

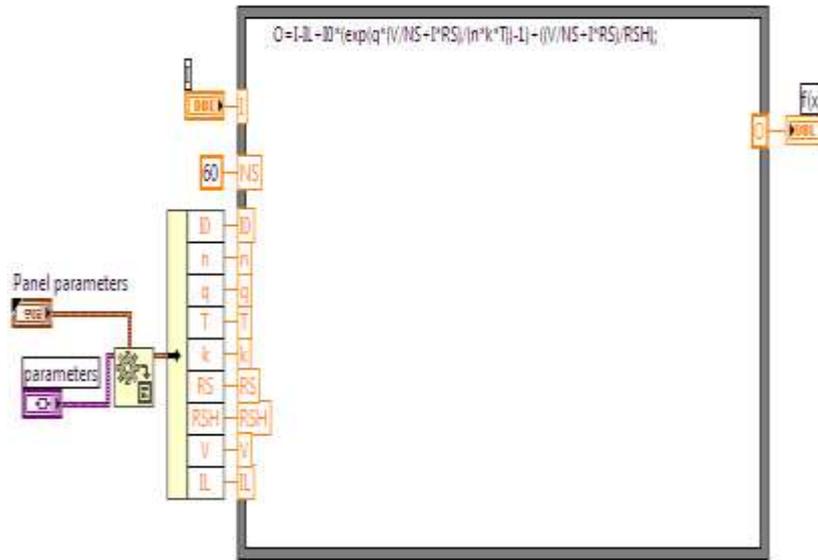


Figure 5. Estimation of output current using Formula Node

LabVIEW is a graphical programming language that consists of the front panel and block diagram [30]. The front panel is intended for the user interface. User interface elements of Controls and Indicators are accessible from the Controls Palette. The users feed the input data through controls. Indicators facilitate the user with display data, graphics, annotation and dialogs. The Block Diagram consists of applications program. Functional icons are accessible in the Function Palette. The parameters are defined in the cluster and it is given as input to build the solar model with the help of formula node as represented in Figure 5. The equation is defined in the formula node with inputs and outputs are declared in the left and right side of the frame of formula node respectively. The output current flowing out of the solar panel is calculated using this function. This output current is used to design the performance model of the solar panel [14]. The short circuit current, open circuit voltage, maximum power, maximum current, maximum voltage, fill factor and efficiency of the solar panel is modeled in the block diagram window using functional icons in LabVIEW software. In the front panel of the LabVIEW platform, output parameters and I-V, P-V curves are displayed.

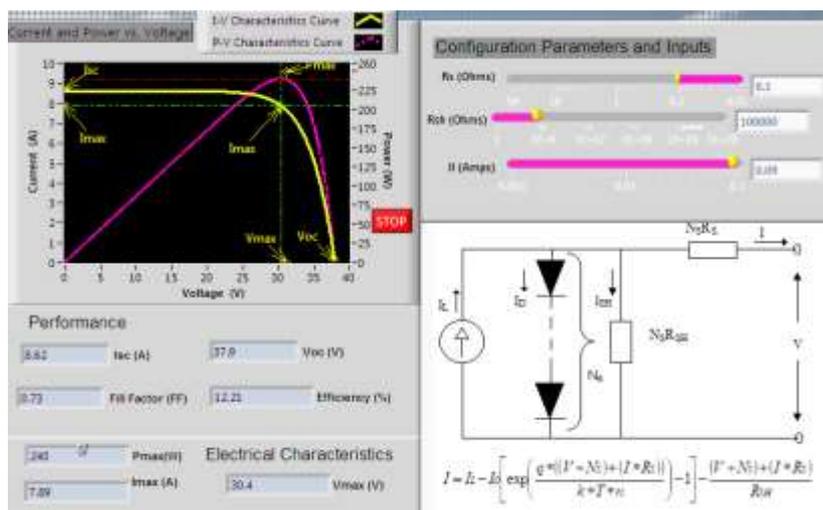


Figure 6. The performance model of solar panel

The performance model of solar panels with I-V and P-V characteristics curve is plotted as shown in Figure 6. The following parameters are obtained from this model

- i. Short Circuit Current (I_{sc})
The short circuit current I_{sc} related to the short circuit condition with impedance is low and it is calculated when the voltage equals zero.
 I (at $V=0$) = I_{sc} = 8.64 A.
- ii. Open Circuit Voltage (V_{oc})
The open circuit voltage (V_{oc}) occurs when there is no current passing through the panel.
 V (at $I=0$) = V_{oc} = 37.9 V
- iii. Maximum Power (P_{max}) = 239.4W
- iv. Current at P_{max} (I_{max}) = 7.91 A
- v. Voltage at P_{max} (V_{max}) = 30.26V
- vi. Fill Factor = .073
- vii. Efficiency = 12.1%

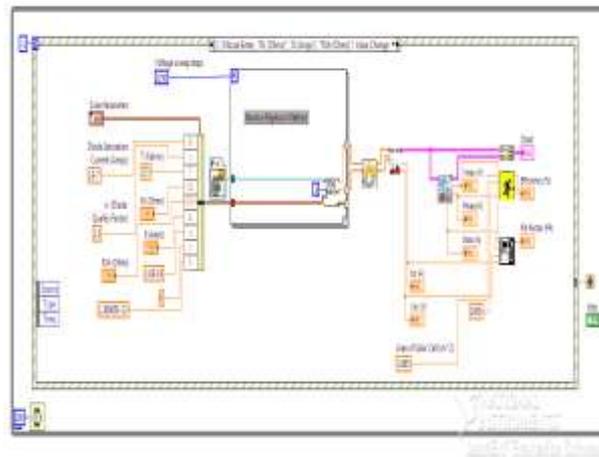


Figure 7. Design of Performance model of solar panel

The design of the performance model of solar panel is depicted in Figure 7. It uses the Newton Raphson method to extract the solar panel parameters. Sub VI is created to calculate the parameters involved in the solar panel.

4. I-V and P-V characteristics of SOLAR PANEL

From an I-V plot, the user able to comprehend the power output as well as the maximum panel voltage [11]. The measured voltage and current values are used to plot the I-V curve starting from the short-circuit current (I_{sc}) at zero volts, to zero current at the open circuit voltage (V_{oc}).

Table 1. Parameters calculated from the I-V and P-V curve

Parameters	Symbol	Results
Short Circuit Current	I_{sc}	8.62 A
Open Circuit Voltage	V_{oc}	37.7 V
Maximum Power	P_{max}	249.7 W
Current at P_{max}	I_{max}	8.12 A
Voltage at P_{max}	V_{max}	30.8V

The data are collected in an array and then manipulated to calculate the maximum power, voltage at maximum power, current at maximum power, I_{sc} and V_{oc} are presented in Table 1. Using build array and bundling options, the I-V curve and P-V curve are displayed on the waveform chart. The power produced by the Solar panel in Watts is calculated along the I-V curve using equation 2.

$$P_{dc} = V_{dc} \times I_{dc} \quad (2)$$

With the PV cell open-circuited, the current is zero and the voltage across the cell is at its maximum called the open circuit voltage V_{oc} . When the PV cell is short circuited, the voltage across the cell is at its zero but the current flowing through the cell is maximum called the short circuit current, I_{sc} . The I-V and P-V characteristics of the Solar Panel are presented in Figure 8. This I-V characteristics curve ranges from the I_{sc} at zero output volts, to zero current at the V_{oc} . The maximum power will occur at the V_{max} and I_{max} . The estimation of the maximum power point is essential and has to be found from I-V and P-V plots [15]-[18], [23].

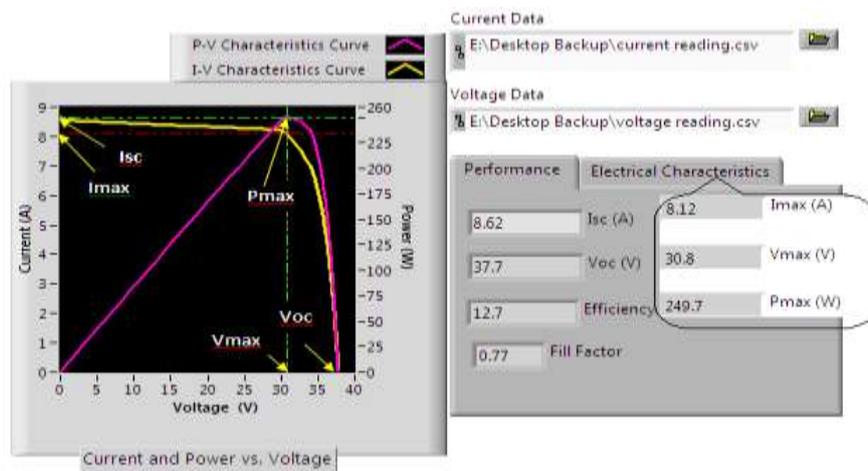


Figure 8. The front panel of I-V and P-V characteristics of the Solar Panel

The appropriate module is devised to obtain I-V and its corresponding P-V plots when required data is given as input. Figure 8 shows I-V curves (yellow color) and their corresponding P-V curves (pink color). These curves are superimposed on the same plot for analysis, performance evaluation and determination of maximum power points. The functional icons are used to calculate the electrical characteristics and subVI is created and used to determine the performance characteristics. The subVI is the program modularity of VI which can be called within the VI. It is similar to the subroutine like text-based programming languages. The block diagram for the design of the front panel of I-V and P-V characteristics of the solar Panel are presented in Figure 9.

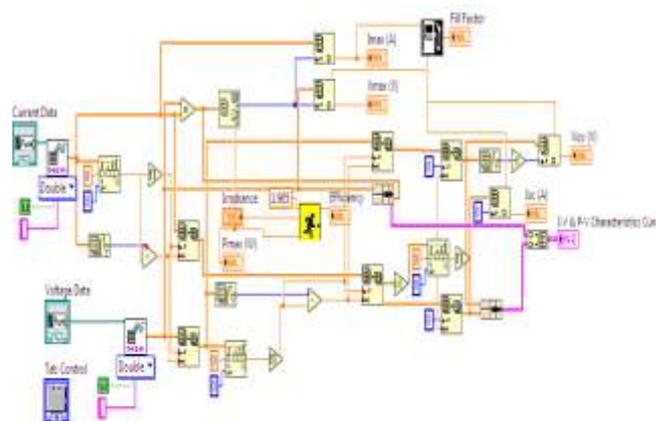


Figure 9. Block diagram of I-V and P-V characteristics of Solar Panel

The parameters are extracted from the solar panel model which is designed using the LabVIEW environment utilizing the mathematical equations of solar cells. The SVL 0250P module electrical parameters from the specification sheet given by the manufacturer are validated with a simulation model. Model is designed and it is simulated at STC conditions and parameters of I_{max} , V_{max} , P_{max} , I_{sc} , V_{oc} , fill factor and efficiency are calculated. From the measured values of current and voltage, the above parameters are extracted using virtual instrument modules. All the electrical parameters are presented in Table 2.

Table 2. Comparison of SVL 0250P model values, simulation model values at STC and Practical values

Parameter	Specifications SVL 0250P	Simulated Results	Measured Value
Open circuit voltage (V)	37.8	37.9	37.7
Short circuit current (A)	8.63	8.62	8.62
Maximum power voltage (V)	30.72	30.4	30.8
Maximum power current (A)	8.14	7.89	8.12
Maximum power rating (W)	250	240	249.7
Fill factor	N/A	0.73	0.77
Efficiency (%)	N/A	12.21	12.7

There is acceptable concurrence between specifications of manufacturer datasheet, simulated result and measured value are presented in Table 3. The maximum relative error is 4.17% and the minimum relative error is 0%.

Table 3. Summary of relative error of electrical parameters of solar panel

Parameter / Relative Error %	Specifications vs Simulated Results	Specifications vs Measured Results	Simulated Results vs Measured Results
Open circuit voltage (V)	0.26	0.27	0.53

Short circuit current (A)	0.12	0.12	0.00
Maximum power voltage (V)	1.05	0.26	1.30
Maximum power current (A)	3.17	0.25	2.83
Maximum power rating (W)	4.17	0.12	3.88

The relative errors of the electrical parameters of the solar panel with the specifications, simulated results and measured value are plotted in Figure 10. From the plot, the relative error between the specifications and the measured value is lower when compared to others. There is a conformance between the specifications of the manufacturer and the measured values.

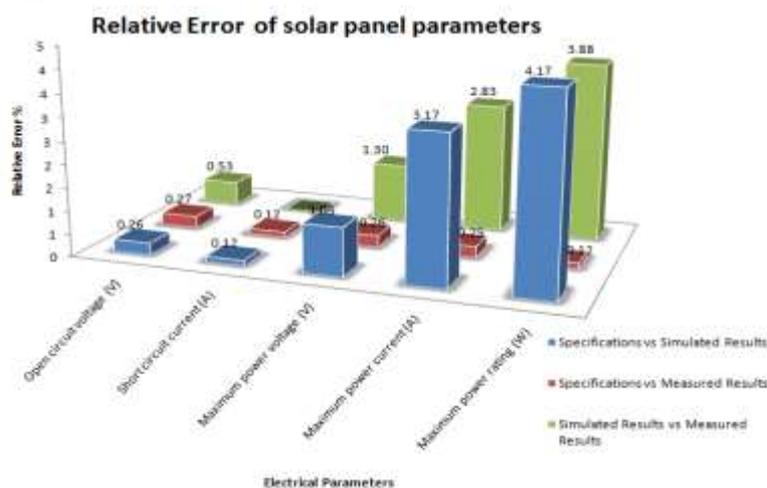


Figure 10. The relative error of solar panel parameters

5. Monitoring of solar panel system

The system employed to monitor and analyze the performance of solar panels is presented in Figure 11 and it is used for power generation in an educational institute as a supplementary power unit.

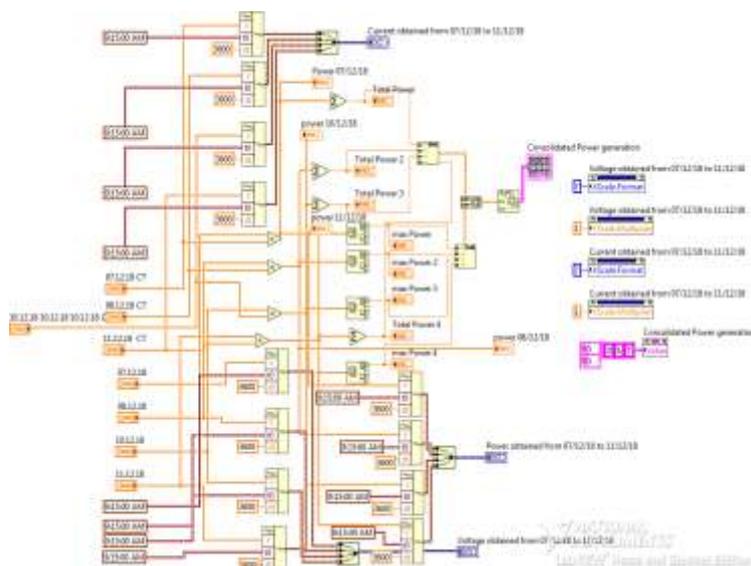


Figure 11. Design of VI for monitoring the current, voltage and power obtained from solar panel

This experimental setup is made of solar panels, sensors and an Interfacing unit. Temperature, irradiance, DC voltage and Direct current are measured with the help of respective sensors. The outputs are conditioned and it is stored in an array. The measured data are shown in a graph. The data received from the solar panels are built as an array and it is displayed graphically from time to time for four days. The power is calculated using Equation 2. Maximum power, minimum power and the total power generated in a day are tabulated for monitoring purposes. The maximum and minimum power is calculated using the LabVIEW functional icons. The outputs are displayed in graphical form using a waveform chart. Built waveform functions are used to construct the waveform and merge signal function is used to combine four days current, voltage and power waveforms and show it on a single chart. The design of displaying the current and voltage data are collected in the month of December from the solar panels are kept in the array and the output power of solar panel is calculated and presented as a waveform is presented in Figure 11. The measured values are also displayed on the webpage for remote monitoring. The front panel display of VI designed for monitoring DC current, voltage and power obtained from the solar panels as shown in Figure 12. The DC current, DC Voltage and DC power generated from the solar panel during the working hours of the educational institute from 09.15 A.M to 05.15 P.M for four days. The multiple plots are used to display the electrical parameter such as current, voltage and power for four days. The White color plots show the variation in current, voltage and power from 09.15 A.M to 05.15 P.M on 07/12/18. Red, Green and Blue color plots show the measured value of current, voltage and power from 09.15 A.M to 05.15 P.M on 08/12/18, 10/12/18 and 11/12/18 respectively. As an average, the current is gradually increasing as time increases till peak time and gradually decreases as time increases. The voltage is varying nonlinearly with respect to time.

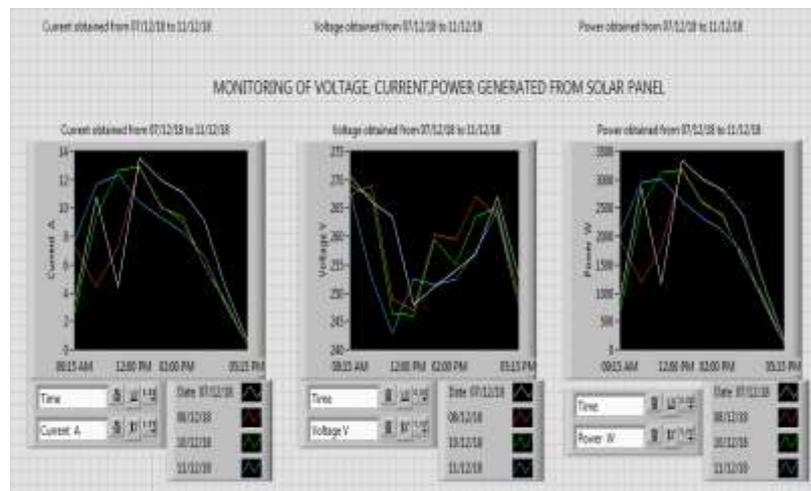


Figure 12. Front panel display of DC current, voltage and power obtained from solar panel

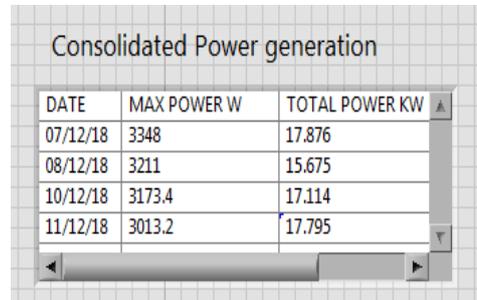
From the above results, it is authenticated that the power generation is favorable during the period of 12 noon to 3.00 P.M and the power generation is low from the period of 04.15 P.M. The maximum power and the total power generated during the working hours of the institute on a day is calculated and tabulated.

This Graphical User Interface program enables the user to interact with the computer through graphical representations of measured variables. A GUI displays the

data that communicate information and indicate actions that could be accomplished by the user. This also tabulates the maximum power generated by the solar panels in a day.

From Table 4, it is listed that the maximum power generated in W, minimum power in W and the total power generated in kW and an average of 17.115 kW power is generated per day.

Table 4. Consolidated Power generation Report



DATE	MAX POWER W	TOTAL POWER KW
07/12/18	3348	17.876
08/12/18	3211	15.675
10/12/18	3173.4	17.114
11/12/18	3013.2	17.795

5. Description of online monitoring

These parameters are made available from a remote location through the internet by creating a webpage for this VI program. The Virtual Instruments (VIs) created as web documents can be sited on a web-server and accessed by the users at remote locations. The created VIs for monitoring the performance or parameters involved in the solar panel can be made available and executed by user/ Plant Engineer at on and off campus. Designed VI program is first created to HTML files and operated by the user in various locations on/off campus.

5.1 The steps to build HTML file are as below

- Step 1: Select the Web Publishing Tool from the Tools menu located in the Menu bar.
- Step 2: Select VI program that has to be accessed over the web and then select the viewing options either Embedded/Snapshot or Monitor in the web publishing tool window.
- Step 3 (Optional): Selecting title, header, and footer for the HTML files to be generated. Here, the creator is provided with a chance to preview the HTML file before publishing it.
- Step 4: Select the destination directory and file name to be associated with the “VP” file already selected in step 2. URL address of the created HTML file will be displayed at the bottom of the dialog box. Then click “Save to disk” and the “OK” buttons in the next appeared dialog box consecutively for completing the process. This VI program is created as the webpage and can be accessed by clicking this weblink below.

<http://a4eie22.kc.vnr:8000/Monitoring%20of%20solar%20panel.html>

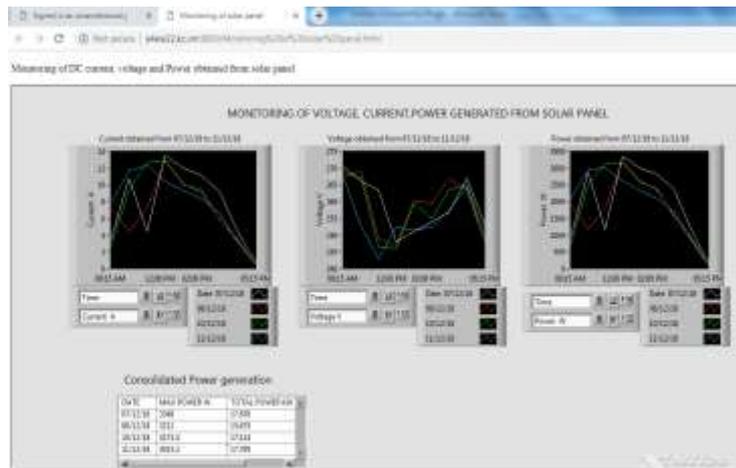


Figure 13. Remote monitoring of DC current, voltage and power obtained from solar panel

The webpage is created and accessed by entering the dedicated URL in the browser is described as shown in Figure 13. This enables the user to monitor the performance of the solar panel from the remote location. For teaching learning purposes to execute the blended learning, the course instructor may teach the real time performance of the solar panel at the classroom using this web link to the students and used this as a pedagogical tool for teaching the performance of the solar panel.

6. Performance analysis of solar panel on winter

The power generation from solar panels is assessed by parameters such as maximum power, fill factor, efficiency [12], [20]. Data used for the calculation of performance parameters are obtained from the measurement taken in the month of December 2018. Solar panel efficiency is the ratio of the power obtained from the solar panel to the incident radiation over the area of the solar panel.

$$E = (P_m \div (R * A)) * 100 \quad (3)$$

The efficiency of the solar panel quantifies the ability of the solar panel to convert sunlight into usable power.

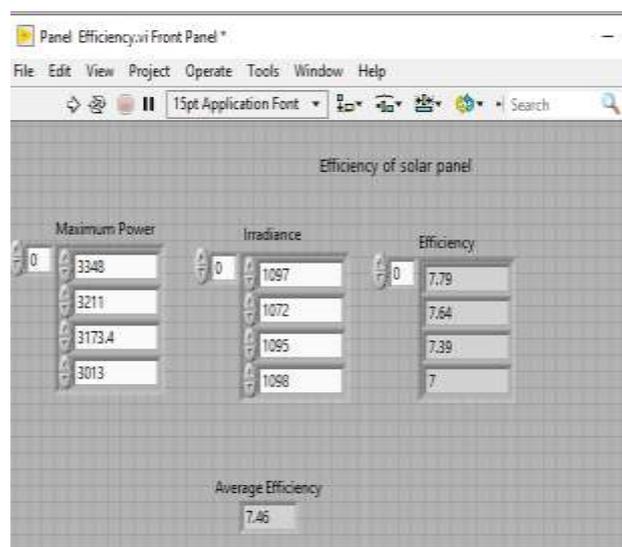


Figure 14. Front panel display of efficiency of solar panel

The design of the front panel for calculating the efficiency of solar panels is presented in the Figure 14. The solar panel used here is capable of converting sunlight into usable electrical power in the range of 7 to 7.79%. From the calculation, it is observed that average efficiency is around 7.46%.

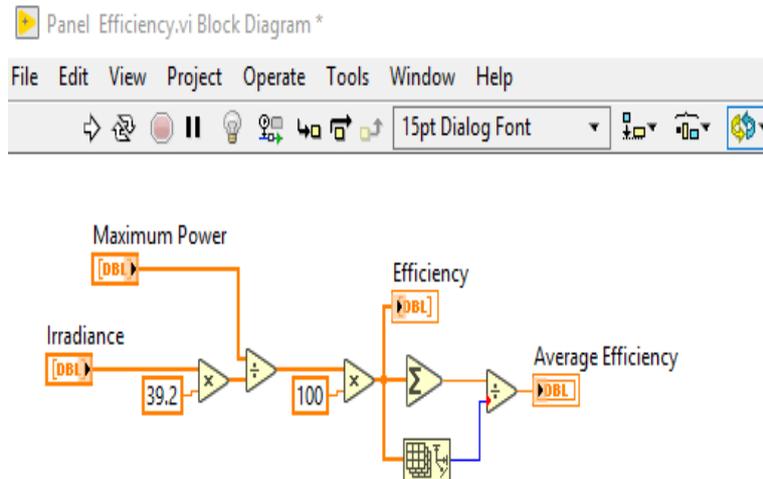


Figure 15. Design of VI for calculating the efficiency of the solar panel for power generation

The design of a block diagram for calculating the efficiency of the solar panels according to equation (3) is presented in Figure 15. Fill factor is the ratio of maximum power obtained to the product of open circuit voltage and short circuit current.

$$ff = (E * R * A) \div (V_{oc} \times I_{sc}) \quad (4)$$

The fill factor is calculated to assess the solar panels in terms of the quantity of power conversion. Higher the fill factor indicates higher the power conversion and lower the value represents lower the power conversion.

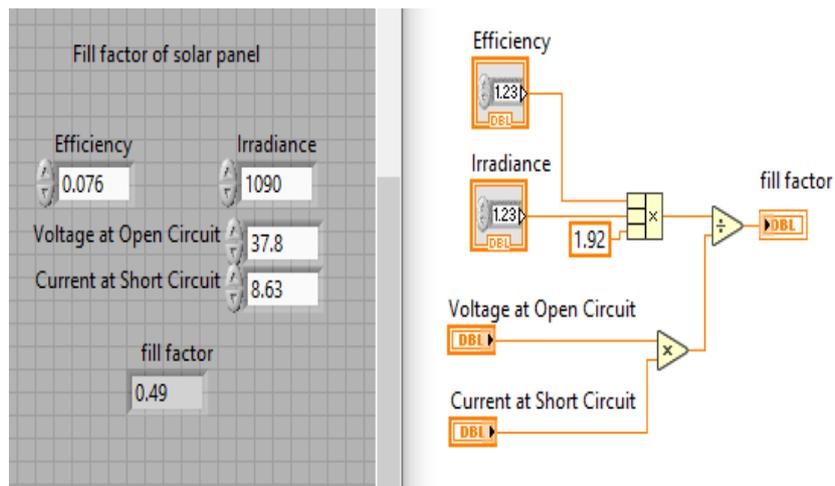


Figure 16. VI for the calculation of fill factor of solar panel

VI for the calculation of the fill factor of the solar panel according to equation (4) is presented in the Figure 16. This VI consists of both the front panel and block diagram to calculate the fill factor of the solar panel. The efficiency, irradiance, V_{oc} and I_{sc} are the measured data which is given as input in the respective controls for calculating the fill factor. The corresponding output is indicated in the front panel.

7. Comparison of performance - Winter vs Summer

The Average solar irradiation in this region is about $6.6 \text{ kWh/m}^2/\text{day}$ the month of March whereas it is about $4.9 \text{ kWh/m}^2/\text{day}$ in the month of December. The average collected energy by irradiance in winter is about 25% less when compared to summer. Solar panels generally producing the power in the month of December are about 60-75% of the power generated in the month of March. This means that solar power generation is significantly less during the winter than summer [9]. The factors responsible for this variation are listed below:

Shorter days - Winter days are appreciably shorter than Summer days. The availability of solar irradiation is comparatively lesser time and the amount of irradiance energy in the winter was observed to be up to 61% less than in the summer [24]. Consequently, it produces less average power, according to the day.

Angle of the sun – The impact of the shorter days is the fact that the angle of the sun changes significantly in the winter. The sun, even at noon, is much lower in the sky during the winter months. This means that the direct sun insolation falling on the solar panels is lesser than during the summer months and influences the power production.

Atmospheric conditions – Winter days are subjected to the cloudy weather, and so solar panels will generate less amount of solar energy. However, the same radiation exposed during summer is made to fall on the solar panels, it could generate more power

Here the temperature data are collected for every one hour starting from 08.30 a.m to 05.30 p.m for four days in the month of December 2018 and March 2019. In the meantime, maximum temperature, minimum temperature and the average temperature are also recorded and presented in the chart. The temperature in the solar panel site is measured in the month of December 7 -12, 2018 and in the month of March 4 – 7, 2019 as plotted in Figure 17.

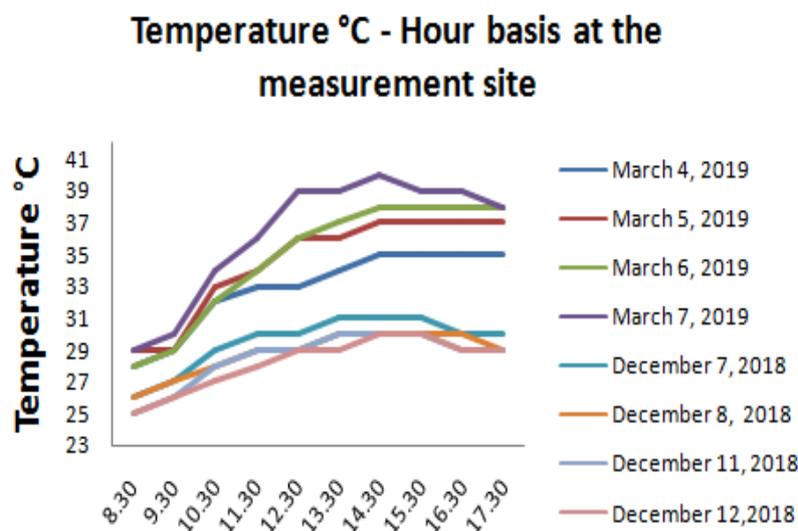


Figure 17. Time to time temperature at the measurement site

The average maximum temperature in the winter was observed that it is 22% less than summer.

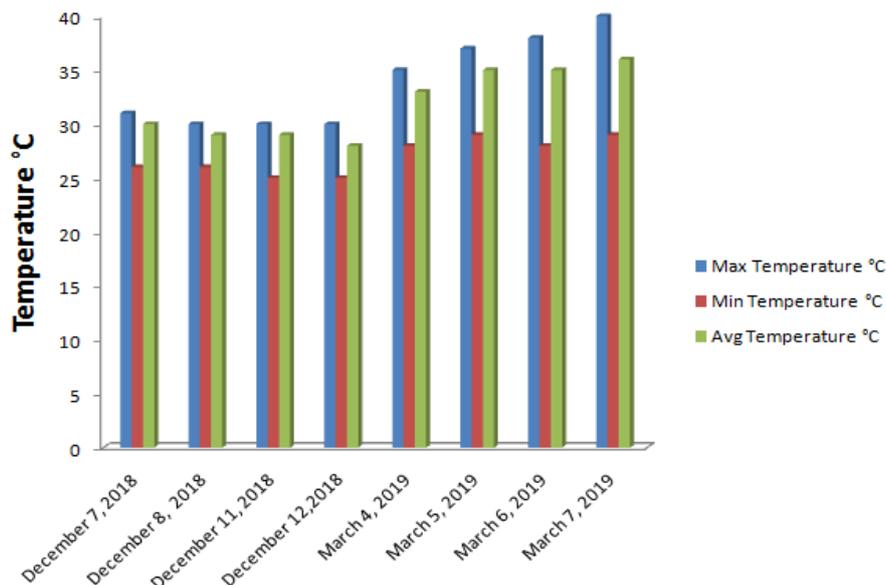


Figure 18. Outline of temperature in winter and summer

The average temperature in winter on those days varies from 28-30°C whereas it varies 33-36°C in the summer on the observed days is shown in Figure 18.

Winter vs Summer

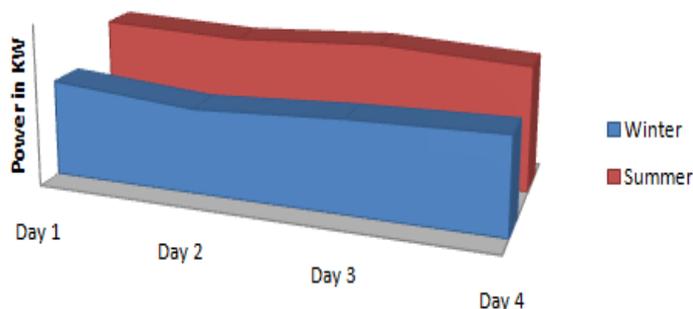


Figure 19. Power generation from solar panel

The power generated from the solar panel site on the observed days of December and March is recorded and presented as shown in Figure 19. The power production in the winter is low when compared to summer [24], [25]. The average power generation in the winter is 72% of the average power generated in summer. It is observed that power generation in winter is 28% lesser compared to summer.

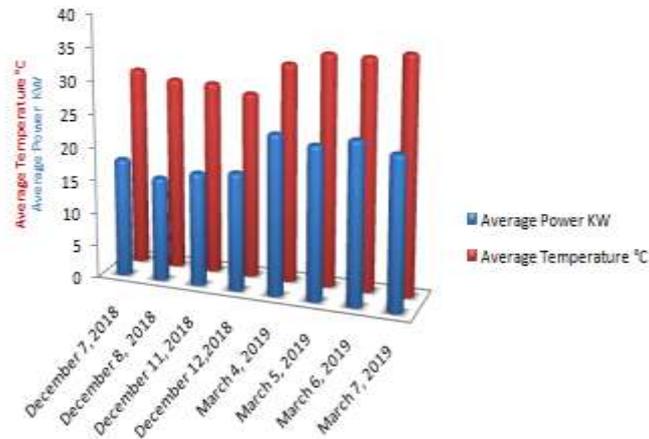


Figure 20. Comparison of temperature and power generated by the solar panels at the measurement site

The average power generation by the solar panels and temperature on those 4 days of December 2018 is compared and analyzed with the power generation by the solar panels and temperature of 4 days in the month of March 2019 and it is represented in Figure 20. The power generated by the solar panels is following the temperature. It reveals that in the month of March, 5kW solar panel is capable of producing maximum power.

8. Simulation of controller

The supplementary power generation system consists of sensors, controller and final control element. Figure 21 shows that simple process control. It uses the sensor to measure the process variable and error detector to generate the error signal by comparing the process variable with desired value. According to the error signal, the controller generates the controller output which will actuate the system through the final control element.

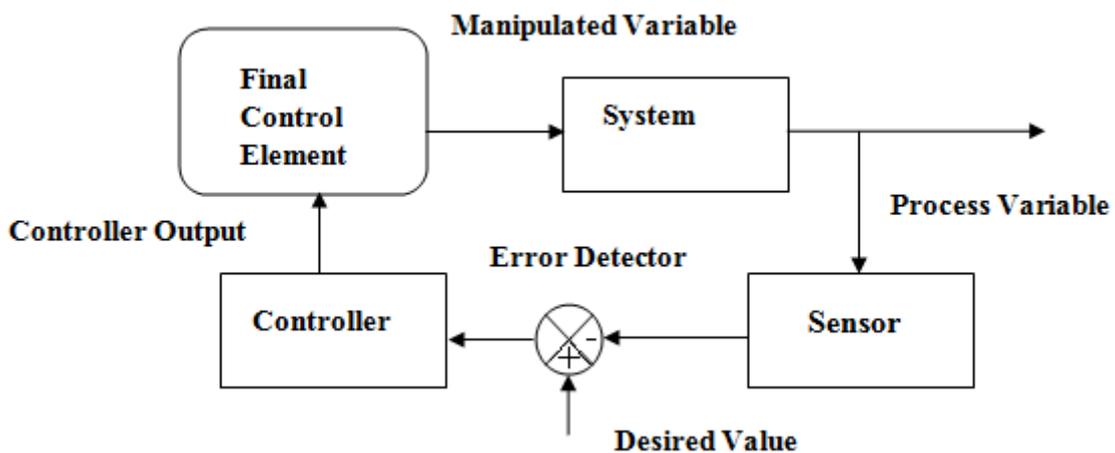


Figure 21. Simple Process control system

The power generated by the solar panel is measured with the help of sensors and it is compared with the set point. The error signal is generated and based on error signal, On Off controller produces the output which is used for switching either on or off the power drawn from the battery. The hysteresis is integrated to the error detector, to improve the performance of an on/off controller. This is called differential band gap controller.

The controller output produces high output (1) when the power in battery is not sufficient power (desired value \pm hysteresis) to drive the load. The final control element is used for switching the power drawn from battery to grid and vice versa. The controller affects the system through the manipulated variable.

The figure 22. shows that design of front panel for the implementation of differential band gap controller. The desired value (battery power in watts) is set as 55 and proportional band is 5. The controller output is high when the process variable is below the 50 and the user is notified by the pop up message that the power is drawn from grid.

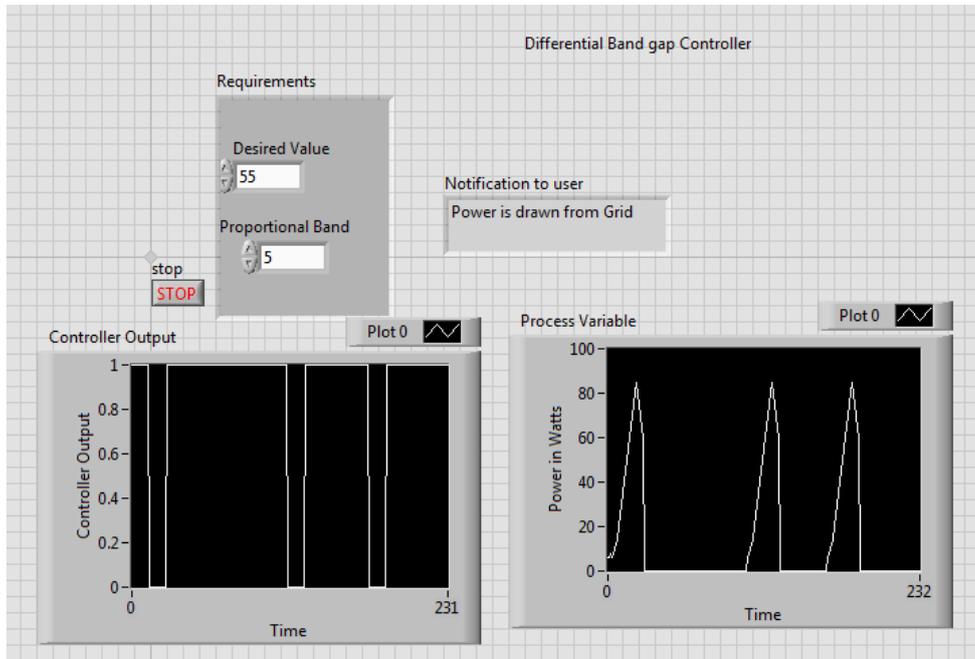


Figure 22. VI for implementation of Differential band gap controller

The figure 23. shows that design of block diagram for the implementation of differential band gap controller. The error signal is generated with the concern .of hysteresis and controller output is to be generated in the programmed in case structure.

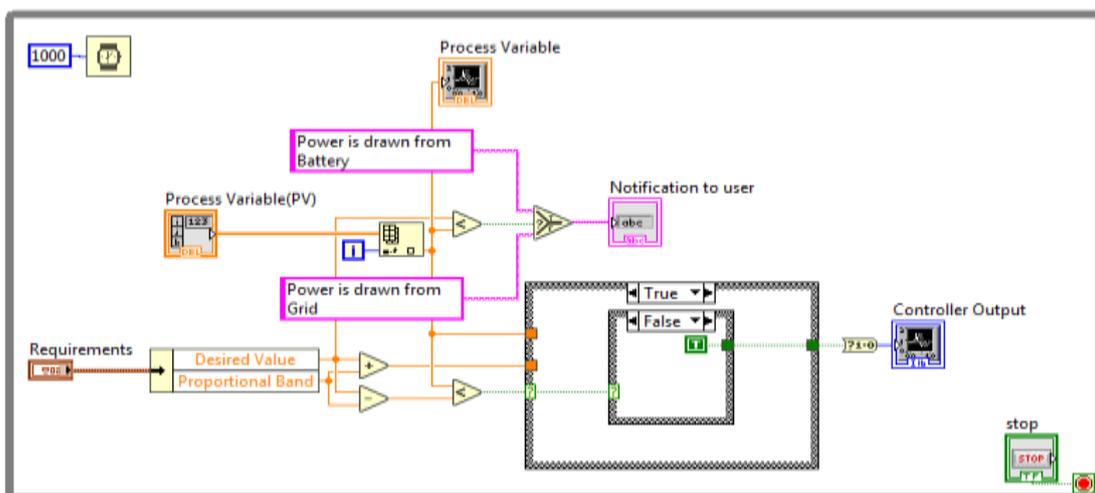


Figure 23. Design of VI for implementation of Differential band gap controller

This type of controller is chosen for the system which has adequate storage capacity to allow final control element to supply the load. It is suitable for process variable which consists of noise. The differential band gap controller does not respond for variations lying within the differential band gap.

9. Conclusion

The procedure for simulating a PV panel with G programming tools, icons based functions and Graphical user interface in the LabVIEW Software are described in this paper. With this package, the modeling of the PV module acknowledged with the measured data obtained from the site to estimate the key PV module parameters. This validates that simulation values compliance with measured values of the characteristic curve and performance of the PV solar module. This modeling procedure assists the researchers, manufacturers to comprehend the I–V and P–V operating curves of the PV module. Besides, it can be considered as a potent tool to calculate the performance parameters of solar PV arrays under varying environmental conditions (temperature, irradiation). The maximum relative error percentage is 4.17% which confirms the adequate concurrence between specifications, simulated values and measured values. The step by step procedure of the design of online monitoring of electrical parameters of the solar panel is discussed. The dedicated webpage is created and accessed by the user by entering the URL in the browser. This facilitates the user to monitor the performance of the solar panel from the remote location. Also, it is used as a pedagogical tool to teach the real time performance of the solar panel using the web link by the course instructor. The power generated by the solar panel during the winter and summer is compared. The Performance parameter of the PV solar module in the month of December data provides passable results. It is observed from the temperature plot in the experimented days of December and March that the average temperature in winter is 22% less than in summer and thereby power generation in summer is better compared to winter.

The findings from this work are the outcome of measurements with very short days, as the key purpose is to study the universal approach. Further study should be carried out for long days at least a year, to get more persuasive results.

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