Comprehensive Review on Real Time Monitoring of PV Solar Cells

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Abstract: These days, the globe is paying more attention to renewable energy due to rising energy needs, unstable energy supplies, and gas emissions. As a result, everyone in the globe is focused on renewable energy sources right now. Photovoltaic (PV) systems have become increasingly common in power generation systems all over the world, and This advancement in solar cell technology and certain requirements for the integration of PV power generating systems into the current generation systems have occurred at the same time. Monitoring PV generation systems will be one of these requirements. Additionally, thanks to advancements in software technology, we can now track data from any system in real time. The most effective technique to continually track how the solar power system is functioning is to monitor solar panel output. Solar monitoring software provides real-time information in addition to displaying how much power the solar panels are producing. It is possible to preserve the observed data for further study. This project will provide usable power for tracking solar energy at the solar plant on a continuous basis.

Keywords: Review, Real Time Data, Monitoring, PV Solar Cell

INTRODUCTION

India is the seventh-largest country in the world, with 3.287 million km2 of land. Additionally, it is a country that is both quite wealthy and expanding quickly, receiving more than 7 hours of direct sunlight every day of the year. Additionally, no harmful pollutants are produced that might harm our atmosphere. [1] One of the most popular non-conventional energy sources nowadays is solar energy. There has been a significant increase in the construction of solar power facilities in recent years, with a 35% annual growth rate worldwide. The total energy output and plant performance depend on how effectively this varied arrangement is maintained over time. Since solar plants are often installed in distant areas, they are challenging to regularly monitor. Therefore, an intelligent real-time monitoring and maintenance system that can combine external context information and identify the device malfunctioning, therefore decreasing the plant downtime, is needed to analyse the operation of the plant and discover inefficiencies in a timely way.[2] Solar energy is the most popular today. It is a clean, sustainable source of power. It plays a significant part in lowering gas emissions, air pollution, and other environmental problems. PV cells are now producing more energy globally than in the previous several years. When diagnosing degradation in PV cells of modules and strings, it is common practice to use the Current-Voltage characteristics as well as metrics derived from them, such as fill factor, maximum power, open-circuit voltage, and short-circuit current. The I-V characteristics, on the other hand, may be used to compare and analyse the actual power produced by modules under real-world working conditions. [3]. However, we may utilize LabVIEW, a program from National Instruments, to monitor the data for real-time applications.[4] A fresh approach to resolving these issues is provided by PV Solar Cell Real-Time Data Monitoring Using LabVIEW. The monitoring of real-time data. It enhances efficiency, accuracy, and economic benefit by enabling remote sensing and control of items via the current network infrastructure [4].

LITERATURE REVIEW

Yussef rehouma et al. (2022) Real time Data Acquisition of Solar Panel. The outcomes of the testing will be presented. The following presents the various results and their scientific explanation. The curve at the start of the day was 26° at 7:00 AM, equating to 232w/m2, the temperature reached a maximum value of 14:48 57°, and the light intensity likewise reached 963W/m2 at 13:00 s. We see that the temperature and radiation are similar. Weather changes have an impact on the solar panel's power as well as the results of the stability of temperature radiation at 13:00. As the battery charges, we see that the voltage rises from 12 to 13.8 volts. the battery's proper charging voltage is set by the Soler Charge Controller, As the load bulb is increased, we observe that the PV current rises from 0.37A at 7:00 to 1.6A at 12:00, after which it nearly stabilizes. The 48W bulb was on from 13:40 to 14:55. The battery's current has decreased to a negative 2.74A since it is draining, while the PV current has increased to 1.18A. The PV power curve matches the currents, as can be seen. It was 5W at 7:00 and stabilized around 30W between 12:00 and 19:00.[4]

Gokay Bayrak et al. (2013) Monitoring a PV power generation system that is connected to the grid using LabVIEW. The electrical and electronic engineering department at Frat University installed a grid-connected 1.2 kWp PV system as the initial step in this application research. Then, an explanation of the LabVIEW-developed monitoring system for grid-connected PV systems was given. With a specially created LabVIEW application, it was also recorded how much electricity was moving between the mains and the load. The prototype system's findings are also included in the report. The findings show numerous characteristics related to the grid-connected PV system, including current, voltage, active and reactive power, phase angles, and power flow, on each side of the PV inverter, load, and grid. The results show that the real-time monitoring system built on LabVIEW is dependable, efficient, and adaptable to PV systems that are linked to the grid.[5]

Dinesh Kumar Sahu et al. (2021) Solar Monitoring System using LABVIEW.The system's goal is to measure the system's power by utilizing the Arduino to sense current and voltage values. This system aids in the implementation of solar technology for effective use. Solar energy is the name given to the electricity produced by harnessing solar energy, which is utilized for both domestic and commercial purposes. When photons strike solar cells, atoms lose their electrons. The more solar panels we deploy, the more power they produce since solar panels are constructed of many panels that are linked together. The semiconductors that resemble silicon are utilized to create PV photovoltaic solar panels. The solar panels create direct current.The majority of electrical appliances use AC power since it is less costly to transport AC across large distances. Solar, one of the most profitable and energy-efficient forms of renewable power on the market, is one of the renewable energy sources that many energy firms are growing to offer.[6]

Mohd Sajid Khan et al. (2019) Real-time energy monitoring for solar power systems with IoT support. In this study, we compared the output findings from the locally linked PV array simulator with those received remotely via the IoT cloud called Things talk. It can be seen from the comparison that both findings are identical. The data tracked online from IoT clouds throughout the world is subject to tolerance mistake. Calculating the minor, related error discrepancies is also done. Therefore, we may conclude that online monitoring approaches are quite beneficial for monitoring PV panels in industrial applications.[7]

Mayuri Ejgar et al. (2017) Real-time data analysis for intelligent solar plant monitoring and maintenance. In this paper, we presented various filters for detecting malfunctioning solar plant devices using real-time data. These filters included (1) Using a comparison at the group level to find abnormalities at the string level, (2) Historical trends in relation to different context filters to spot faulty inverters, and (3) Clustering methods for locating inverters that aren't working properly. Our research findings, which were based on real-time solar plant data, demonstrate that the suggested filters can identify a number of faulty equipment in the actual world. When faulty strings and inverters are discovered, real-time warnings are sent to the appropriate site engineers for proactive repair that boosts the overall solar energy output.[8]

Shruti Tiwari et al. (2015) Solar power plant real-time monitoring and automatic load balancing. In this study, an advanced solar power management system (ASPMS) is developed to dynamically scale renewable energy powered loads to match the time-varying power generated by solar PV plants. The suggested approach includes features including priority-based switching, enhanced remote metering, and automated load switching. By putting the aforementioned goals into practice, we can increase our reliance on solar power during times of need and greatly improve (up to 50%) the efficiency of solar power consumption. [9]

Ye Jihua et al. (2014) TinyOS-based Solar Photovoltaic Power Generation Monitoring System: Research and Design.In order to accomplish remote intelligent monitoring for solar power generating systems, we looked into how the Internet of Things may be used to photovoltaic monitoring systems. In order to collect data, we built a prototype system. By validating the data's correctness and instantaneity, we were able to confirm the design's viability and lay the groundwork for further monitoring. To enable broad remote monitoring of photovoltaic power generation in the future, cloud servers may be deployed. This will provide a means of managing and maintaining the PV power generation system. [10]

Gokay Bayrak et al. (2014) Real-Time Power Flow Monitoring in a PV Distributed Generation System Based on PLL Inverters. A grid-connected PV-based DG system was installed in the lab for this application research. The created monitoring system for Then, a LabVIEW-based grid-connected PV-based DG system was explained. The software that is being developed also keeps track of between the load and the mains in terms of power flow. The publication also includes the prototype system's findings that were attained. The findings show numerous characteristics pertaining to each PV inverter, load, and grid side of the grid-connected PV system, includes the system's power flow, phase angles, active and reactive powers, current, and voltage.The results show that the real-time power flow monitoring system created in LabVIEW is reliable and efficient. It can also be simply installed and tailored to operate with grid-connected PV-based DG systems. [11]

Ali Hosein Arianfar et al. (2009) design and modelling of a solar power plant's remote monitoring system. This study described various techniques for transporting data from faraway systems through a computer network. Then, based on QoS factors, the Internet dynamic associated to Tele operating system over the Internet was examined. Except for latency, there were clever and practical strategies for removing the corresponding impacts of QoS factors in systems over the Internet. based on distant area research Due to the fluctuating latency on via the internet, the wavevariable approach was chosen as the optimum monitoring strategy for solar power plants. The design and modelling of a system for monitoring solar power plants through the Internet. solar-powered transmission and monitoring of fluid temperature and flow signals. [12]

Chedly B. Yahya et al. (2008)Using reference cells to monitor the performance of solar photovoltaic systems. For PV systems, a straightforward technique for performance monitoring based on reference cells has been suggested. The accuracy and correlation of using a reference cell to calculate module power were investigated through experiments. The findings demonstrated accurate output power estimate and high module-reference cell correlation. There were suggested two possible technique implementations. Future research will make use of smaller cells and look at where they should be placed in relation to the module. The proposed implementations will be used to test the approach.[13]

PROPOSED GRID CONNECTED PV SYSTEM

Each component of the system is represented independently in Simulink to construct the simulation testbed. The PV module design requirements are organized in accordance with a solar cell analytical model. According to the second curve, The buck model is used in the construction of the DC-DC converter, which reduces the produced voltage to 160 V. The first curve of the same image shows the solar array voltage after it has been set by the MPPT controller to 160V, while the second curve shows the inverter voltage. According to European Grid regulations, the inverter's line voltage is transformed into a sinusoidal waveform and raised to 220V/50Hz.[14]

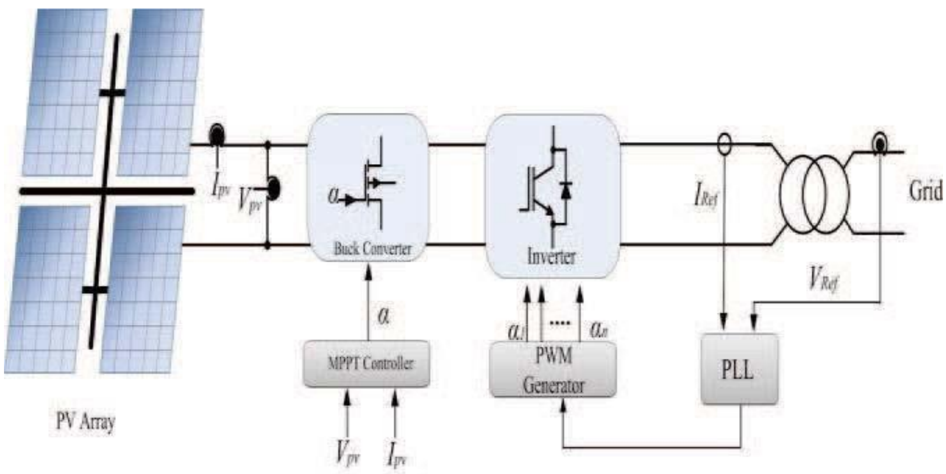

Figure1.An illustration of the proposed grid-connected PV system in block form. [14]

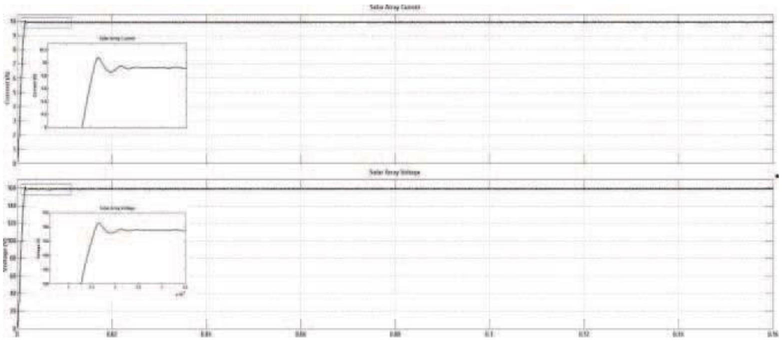

Figure2.Currentandvoltageofsolararray. [14]

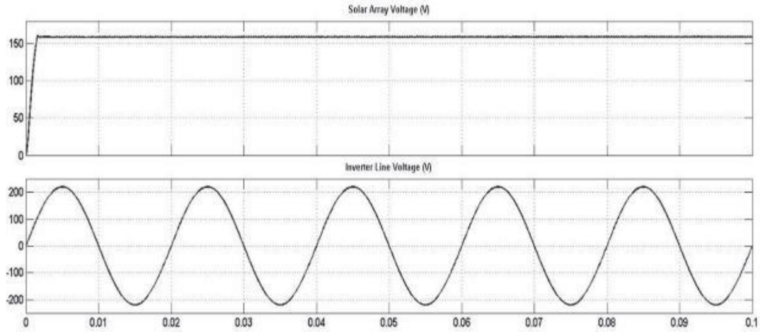

Figure3.solar array voltage and inverter line voltage. [14]

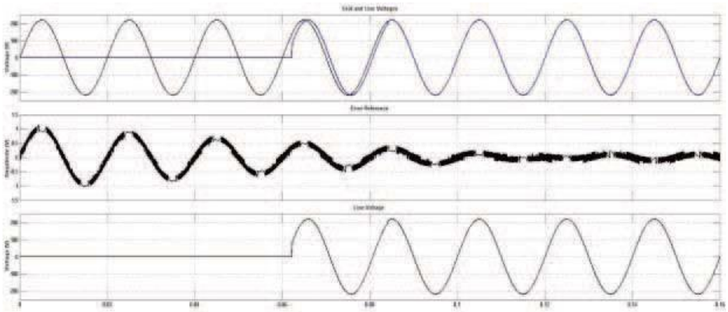

Figure4.PV system voltages on the grid and lines. [14]

PV REFERENCE MODULE

The best modelling and design of the PV system are connected to the effective conversion of photovoltaic energy and its early defect identification. Additionally, it's critical to analyse the behaviour of PV panels and create a model that can be used for a variety of PV panels. Therefore, a straightforward, precise, affordable, and quick evolutionary model is described in this part to enable system for monitoring heterogeneous PV (HPV) panels and predicting their power production. [15]

4.1 THE HPV ANN REFERENCE MODULE

An adaptable system with several structures is a neural network. A specific network architecture should be determined based on the kind of information that has to be transmitted via the network. Previous work highlighted the feedforward back propagation approach as an efficient way of associated modelling and prediction among the different ANN topologies. For air prediction in Milan, Corani used a feedforward neural network (FFNN).

The definition of a feedforward neural network is an MLP network type where information flow is in the forward direction. It is made up of a large number of linked processing units, or neurons. The suggested FFNN's structure is seen in Fig. 5. The produced power is roughly modeled using a neural network to simulate a heterogeneous PV panel output power.[15]

It has three layers: input, hidden, and output. Three nodes make up the input layer: the PV cell's characteristic as well as the cell temperature (Tc), solar radiation (G), and Voc (at a temperature of 25 °C and a power density of 1 kW/m2). Five nodes that utilize the sigmoid transfer activation function of the hyperbolic tangent make up the hidden layer. The output layer is made up of one node, which also produces the PV power output. An activation function that is linear is used by the output node. [15]

a multiple layer network with a linear output layer and a sigmoid hidden layer allows for the arbitrary training of nearly any function. The network outputs, however, are constrained to a narrow range if the output layer contains sigmoid neurons. After the FFNN model has been created, the input data are gathered and provided. The connection between the input and output parameters is then trained into the network.[15]

4.2 CALCULATING SERIES RESISTANCE IN REAL-TIME

To perform RTSR, two pieces of data are obtained. The operational dataset consists of the device's current and voltage under working load, as well as Temperature and irradiance of the module. Additionally, a low-irradiance Voc For example, a dataset is obtained for irradiances below 200 W/m^2. The points in this low irradiance set are (Vo oc, Eo, and To). Each operational point also has to include an estimate for Isc. This can be estimated using the temperature coefficient and the rated Isc, or it can be based on Isc calibration readings.[16]

The method for determining a particular operating point's series resistance, (Vo, Io, Eo, To) is as follows:

1. Calculate E0target from Eo, Io, and Isc, o (the estimated Isc for the operating conditions)
2. 2. List the subset of (Vo oc, Eo, To) points that were measured within d of E0target during the previous time interval of length l. (In this investigation, we utilized d of 10% and l of one week.)
3. Conduct a linear regression on the subset of (Vo oc, Eo, To) determined in Step 2 to determine V0oc vs. T0.
4. To determine the predicted value of Vo oc at temperature To, abbreviated Vo oc(To), use the regression's value at To.
5. In relation to the operating point (Vo, Io, Eo, To), the series resistance

THEORETICAL MODEL OF A PHOTOVOLTAIC PANEL

The electrical performance of a solar panel is predicted using a model that represents an electrical circuit with one diode as an equivalent. The "TRNSYS PV" model is another name for the model. The model was created by Duffie and was originally used by Eckstein (1990) as a part of the TRNSYS simulation program. According to Ulleberg (2000), whether the short-circuit IV slope is adjusted to zero or a positive value, this model uses the Eckstein model for crystalline PV modules. Equations for an empirical equivalent circuit model are used in the Energy Plus PV model to calculate the current-voltage characteristics of a single module. This circuit consists of a diode, a DC current source, and either one or two resistors. Solar radiation affects the current source's power, while temperature affects the diode's IV properties. The performance of a multimodule array is extrapolated from the findings for a single module comparable circuit.[17]

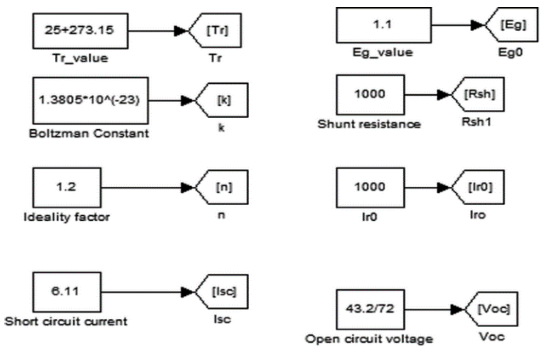

Figure5. Mathematical model of photovoltaic panel. [17]

5.2 USING WAVE VARIABLES IN CONTROLLING SOLAR POWER PLANT

The control signal (input) is oil flow (g), and the output signal (output temperature level, T) is that signal. in solar power plants that are monitored. Using the wave variable technique, the power plant's best linear model, Gp (z), sends and receives control signals. This block contains the flow control signals gm from a remote operator, gs for applying to a power plant model, and Ts for the system's reaction to the flow input (gs). Finally, Tm is the operator's output temperature as seen in response.[9]

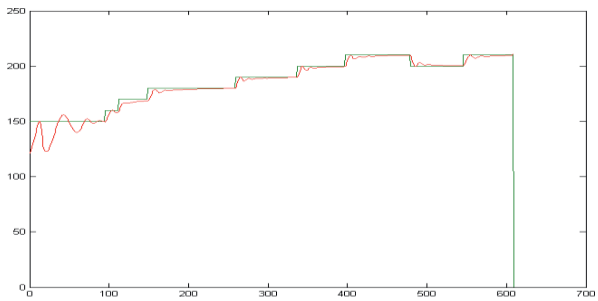

Figure 6.-modelingresults(Temperature) [9]

5.3 MODELING OF PHOTOVOLTAIC CELLS USING MATHEMATICS

For improved outcomes, raise the performance of the photovoltaic (PV) module. By simulating a single diode identical circuit, the conduct of PV cell I-V and P-V characteristics are investigated. Due to its simplicity and accuracy in mathematical computation, one diode model has been used to describe PV panels. Np stands for parallel PV cells, Rs() for series resistance, Rsh() for shunt resistance, and Vt(V) for diode thermal voltage. [18]

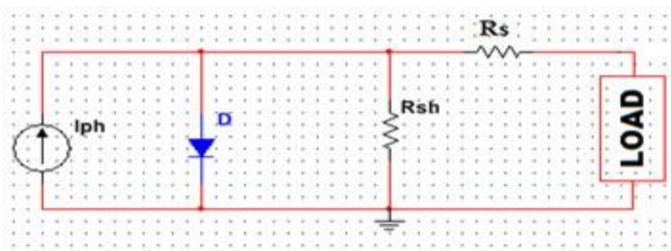

Figure 7-Singlediodeidenticalillustrativeforphotovoltaiccell.

5.4 PERFORMANCE MONITORING METHOD

Based on the reference cells, the module's maximum power output may be determined. on the initial measurements displayed in table II, where FF is the computed fill factor. dividing the area of the inner rectangle (IMPPVMPP) by the size of the outer rectangle (ISCVOC). At 14:00, the reference cell's power is Pr=0.514W. assuming that the element and reference cells have a typical value of FF=0.75. Pr may be multiplied by the product of the scalar (11.54*2.10=24.2) to get the estimated module power, which is 12.46W. With a 1% inaccuracy, this compares quite favourably to the predicted module power (17.28*0.95*0.75=12.31W) based on the observed data.[19]

PARAMETRIC ANALYSIS AND VALIDATION

Simulated variables included various south-facing surface slopes, PV ratings, size to cost ratios, load profiles, and utility tariff rates. There were 0 to 90 slopes on the PV surface. or from horizontal to vertical. To maintain a consistent inverter operating voltage, by adding more parallel modules, the PV rating was altered. while maintaining a constant number of series modules. the lack of losses caused by cables, tracking the highest power point, and I-V curve mismatch or shade was assumed. By adjusting the inverter's rated input capacity while keeping the size of the PV constant, sizing ratios between 0.6 and 2.2 were taken into consideration. Cost ratio was adjusted by altering inverter price while keeping PV price constant.We took into account the two contrasting load profiles shown, where load profile 1 was based on assumptions and Measurements under stress profile 2. Regarding load profile 1, the peak load time coincides with the peak PV generating period, and electricity consumption is concentrated during the day. A typical household's load profile 2 shows moderate consumption in the middle of peak loads during the day and at 7-8 a.m. and 7-8 p.m. Regarding load profiles 1 and 2, the daily average load consumption is 40 kWh and 33 kWh, respectively [20].

6.1 DAQ CARD INTERFACING FOR LABVIEW

1. To access the system, first download the Measurement and Automation Explorer (MAX) and NIDAQmX driver software.
2. Go to 'Devices and Interfaces' now, then click to enlarge it.
3. Create a task by using a right click on the NIDAQmX devices.
4. By doing a right click on the NIDAQmX devices, you may create a task.
5. There will be a list of several settings visible. Depending on your needs, choose one or more.
6. Selecting a USB device now will reveal a list of available channels.
7. Select a channel from ai0 to ai7 according to how they are connected.
8. There will be a page with many setups. Make the necessary adjustments. You can finish by clicking the "Ok" button. [4]

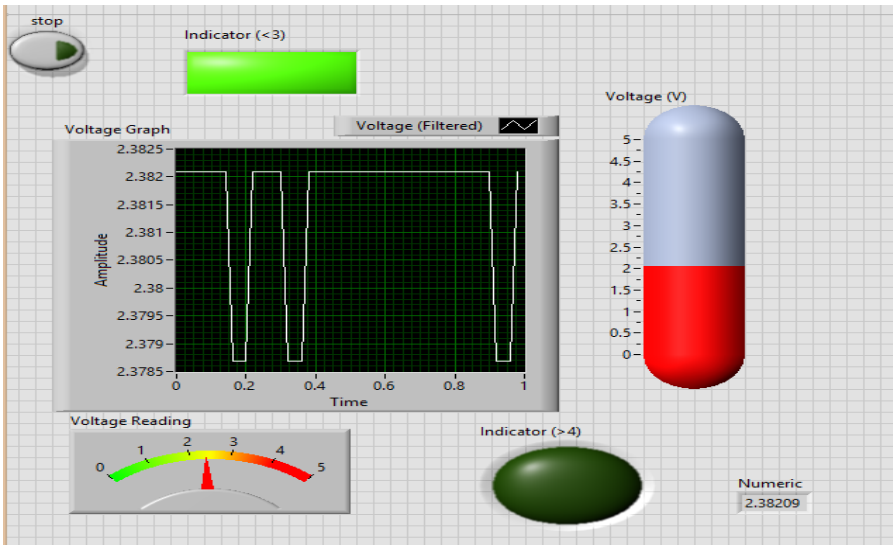

Figure8:FrontPanelforTemperaturemeasurement [4]

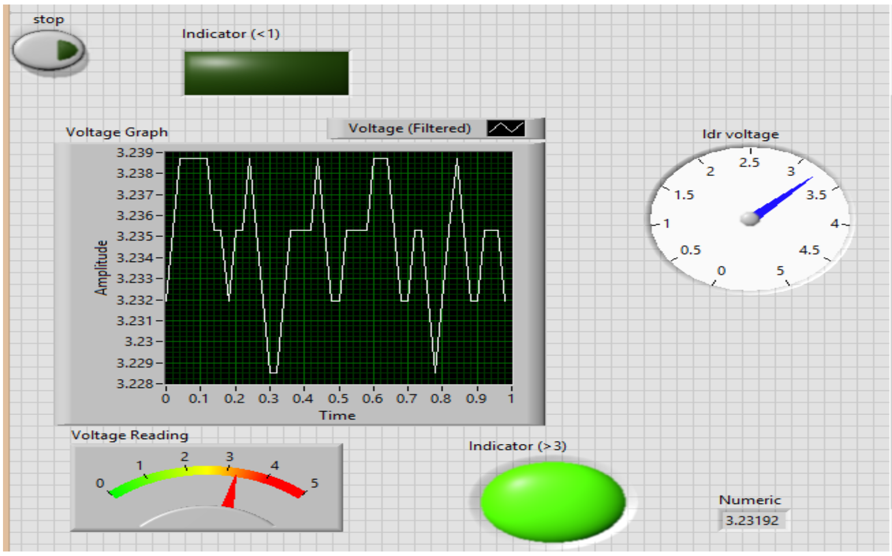

Figure9:FrontPanelforLightIntensity [4]

ADVANCED PV SYSTEM GRID CONNECTED

The grid-connected prototype system developed in the lab was thoroughly explained. A mature grid-connected PV system typically has four basic components. These include the electrical load, DC-DC converter, PV inverter, and PV panels and array. Basic design of the developed grid-connected solar power system and the recommended monitoring setup. In an experimental investigation, a 1.2 kWp PV array was produced using A series connection is made up of seven 160 Wp PV panel components. The PV system was then linked to the PV inverter, bi-directional electric meter, sensor box for measuring webbox for delivering system data to distant units, module temperature, solar irradiation, and [8].

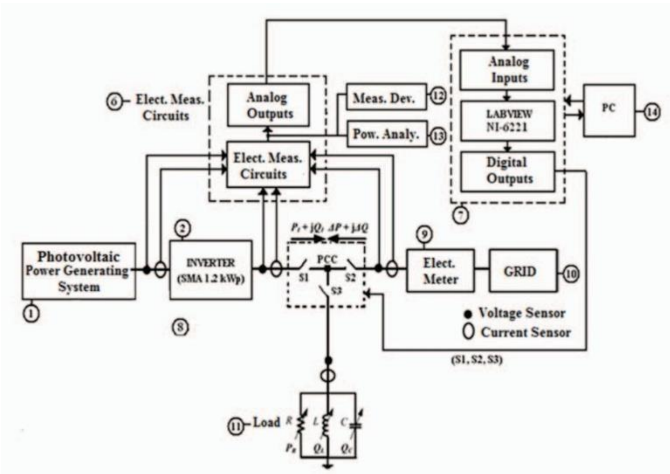

Figure 10. basic design of the created grid-connected PV system and suggested monitoring system. [8]

7.1 REAL-TIME DATA-BASED PERFORMANCE ANALYSIS OF A LARGE-SCALE BUILDING

The advantages of renewable energy technologies over conventional ones include unbounded and widespread resources, low environmental impact, and a tendency toward decreasing costs Since 2015, yearly capacity addition for renewable energy has outpaced the percentage of all non-renewable technologies, and the gap is fast growing. In contrast to the total addition of 60 GW made by all fossil fuels in 2020, 260 GW of additional capacity was added by renewable sources (IRENA, 2021a). Solar photovoltaic (PV) technology is one of the most well-known types of renewable energy. Solar PV has been successful in both wealthy and developing nations with to qualities including simple installation, versatility in size, and the trend toward lower costs. The current advances in battery technology are also addressing the intermittent problem. One of the main industries where solar PV is used is the construction industry. [21]

7.2 ELECTRICITY POWER AND PRODUCTION

We estimate the maximum power (D) and yearly production (Q) of the PV home are used to describe its electricity output. A PV home with a higher D value would produce more power in a given amount of time. Then, as increased energy generation may worldwide lower CO2 output, the environmental performance of the PV home should be considered to be improved [17].

7.3 IMPACT OF THE PV/INVERTER SIZE RATIO ON THE PERFORMANCE OF THE CONVERTER

Due to the fact that the inverter utilizes some of the input energy for MPP finding, grid monitoring, and auto test operations at the beginning of operation, inverter efficiency declines at low partial load operation [35]. When an inverter's input power exceeds its rated capacity, its efficiency decreases. As a result of the maximum power point tracking algorithm, the inverter is pulled away from the maximum power point.sorestricting the input power at the rated nominal power, and the degree of input overload scenario consequently affects inverter efficiency. the relationship between the inverter's efficiency and the input power to nominal DC power ratio. the inverter is operating at 40% of nominal power, it performs at its most efficient level. Due to its operation at nominal power, a severely undersized inverter runs mostly under overload circumstances, increasing the inverter operating temperature. High operating temperatures render an inverter incapable of sustained operation [35]. Prolonged overload operation shortens an inverter's lifespan [22]. To solve this issue, the operating voltage of the PV array is often changed from its maximum power point to open circuit circumstances [22]. This limits the inverter's temperature [23].

CONCULUSIONS

Depending on different data processing units and transport techniques, the evaluation presented a thorough investigation of several solar PV monitoring technologies. Accordingly, the evaluation provided a summary of the monitoring system, its categorization, a thorough explanation, and its limitations. The monitoring platform, structure, requirements, deficiencies, and contributions are provided together with a thorough analysis for solar PV monitoring systems, different data processing modules. The different data transmission modules have been examined as a second contribution, with an emphasis on the kinds, power consumption, setup, data transfer rate, sampling rate, strength, and weakness. An emphasis was placed on data processing, while discussing the current issues and limits of the various technologies for solar PV applications, we will also cover security, signal interference, energy efficiency, transmission range, environmental effect, and efficiency. The development of a better monitoring system that would result in sustainable operations and management in solar PV applications has been suggested as a fourth contribution. Despite the fact that renewable energy sources have higher costs than non-renewable ones, these technologies are continually improving as a result of the increasing demand for renewable energy caused by global warming. In addition, traditional resources are becoming more expensive and less plentiful day by day. So, more and more individuals are installing solar panels on their rooftops. Therefore, to guarantee accurate device operation and reduce energy losses, it is crucial to determine the output of the PV panels. We have collected data from the solar module in the system that has been constructed. Therefore, we may collect data from any solar power plant and send it for additional study. When it comes to data capture and ongoing measurement, this technology is incredibly accurate and dependable. In the future, we want to transport data that has been collected from one location to another remote region while attaching a stepper motor to maximize efficiency.

REFERENCES

1. Vyas, Maulik, et al. "Real time data monitoring of PV solar cell using LabVIEW." *International Journal of Current Engineering and Technology* 6.6 (2016): 2218-2221.
2. Ejgar, Mayuri, Bashirahamad Momin, and Tanuja Ganu. "Intelligent monitoring and maintenance of solar plants using real-time data analysis." *2017 IEEE International Conference on Consumer Electronics-Asia (ICCE-Asia)*. IEEE, 2017.
3. Gupta, Abhishek Kumar, Narendra Singh Chauhan, and Ravi Saxena. "Real time IV and PV curve tracer using LabVIEW." *2016 International Conference on Innovation and Challenges in Cyber Security (ICICCS-INBUSH)*. IEEE, 2016.
4. Rehouma, Youssef, et al. "Real time Data Acquisition of Solar Panel." (2022).
5. Bayrak, Gökay, and Mehmet Cebeci. "Monitoring a grid connected PV power generation system with labview." *2013 International Conference on Renewable Energy Research and Applications (ICRERA)*. IEEE, 2013.
6. Sahu, D., and Anil Brahmin. "A Review on Solar Monitoring System." *International Research Journal of Engineering and Technology* 8 (2021).
7. Khan, Mohd Sajid, Himanshu Sharma, and Ahteshamul Haque. "IoT enabled real-time energy monitoring for photovoltaic systems." *2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon)*. IEEE, 2019.
8. Ejgar, Mayuri, Bashirahamad Momin, and Tanuja Ganu. "Intelligent monitoring and maintenance of solar plants using real-time data analysis." *2017 IEEE International Conference on Consumer Electronics-Asia (ICCE-Asia)*. IEEE, 2017.
9. Tiwari, Shruti, and R. N. Patel. "Real time monitoring of solar power plant and automatic load control." *2015 IEEE Students Conference on Engineering and Systems (SCES)*. IEEE, 2015.
10. Ye, Jihua, and Wen Wang. "Research and design of solar photovoltaic power generation monitoring system based on TinyOS." *2014 9th International Conference on Computer Science & Education*. IEEE, 2014.
11. Bayrak, Gökay, Ersan Kabalci, and Mehmet Cebecı. "Real time power flow monitoring in a PLL inverter-based PV distributed generation system." *2014 16th International Power Electronics and Motion Control Conference and Exposition*. IEEE, 2014.
12. Arianfar, Ali Hosein, et al. "Design and modeling remote monitoring system for a solar power plant." *2009 Second International Conference on Computer and Electrical Engineering*. Vol. 2. IEEE, 2009.
13. Yahya, Chedly B. "Performance monitoring of solar photovoltaic systems using reference cells." *2008 International Conference on Microelectronics*. IEEE, 2008.
14. Samara, Sufyan, and Emad Natsheh. "Intelligent real-time photovoltaic panel monitoring system using artificial neural networks." *IEEE Access* 7 (2019): 50287-50299.
15. Deceglie, Michael G., et al. "Real-time series resistance monitoring in PV systems without the need for I–V curves." *IEEE Journal of Photovoltaics* 5.6 (2015): 1706-1709.
16. Bojić, Milorad, and Mirko Blagojević. "Photovoltaic electricity production of a grid-connected urban house in Serbia." *Energy Policy* 34.17 (2006): 2941-2948.
17. Salim, Salim, and Jyoti Ohri. "Monitoring and Analysis of Solar PV based on GUI." *2020 First IEEE international conference on measurement, instrumentation, control and automation (ICMICA)*. IEEE, 2020.
18. Yahya, Chedly B. "Performance monitoring of solar photovoltaic systems using reference cells." *2008 International Conference on Microelectronics*. IEEE, 2008.
19. Mondol, Jayanta Deb, Yigzaw G. Yohanis, and Brian Norton. "Optimising the economic viability of grid-connected photovoltaic systems." *Applied Energy* 86.7-8 (2009): 985-999.

20. Alazazmeh, Ayman, et al. "Real-time data-based performance analysis of a large-scale building applied PV system." *Energy Reports* 8 (2022): 15408-15420.
21. Mondol, Jayanta Deb, Yigzaw G. Yohanis, and Brian Norton. "Optimising the economic viability of grid-connected photovoltaic systems." *Applied Energy* 86.7-8 (2009): 985-999.