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USING PERFORMANCE RATIO AND MICROCONTROLLER SYSTEM TO MONITOR THE OUTPUT OF A SMALL SCALE PV ELECTRICITY GENERATION SYSTEM

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Abstract

Malaysia has ramped up the integration of photovoltaics (PV) on a utility scale to meet the power demands of the nation. The reasoning behind this decision is to decrease the reliance on non-renewable sources of energy such as natural gas, which resulted in the government introducing schemes and policies to improve the usage of solar energy in the domestic as well the utility sector. Detailed in this paper is the development of a microcontroller-based PV performance monitoring system. Then, the variables which affect PV output were identified via literature review, which led to the selection of performance ratio (PR) as a measuring metric. A prototype was then designed with the appropriate sensors which allows PR to provide an accurate reading of the PV performance. The system works but more work can be done to improve the monitoring system.

***Keywords*: Photovoltaics; Performance; Ratio; Monitoring; Microcontroller**

1. Introduction

An energy source that can be naturally replenished is known as a renewable energy source. A prime example of a renewable energy source is wind, water and the sun. Renewable energy sources such as the wind and sun are also known to have little to no emissions when they are used to generate electricity, unlike its non-renewable equivalents. This makes them a clean and sustainable source of energy as they do not discharge any harmful pollutants into the environment. Additionally, the utilization of renewable energy sources will eventually allow the reduction of society's reliance on fossil fuels, which plays a significant role in greenhouse gas emissions as well as climate change. By reducing the usage of fossil fuels and increasing the usage of renewable sources, societies can reduce their carbon footprint and contribute to a cleaner and healthier environment. [F. Bilgili et al., 2016]. Malaysia, with its close proximity to the Earth's equator which then allows the nation to receive high levels of solar radiation, making it an ideal location for PV systems to be utilized. The Malaysian government recognizes the potential of PV and executed different initiatives to boost the utilization of PV to meet the nation's energy demands. In 2018, PV systems generated 282-megawatt (MW) of power and in 2020 the government started constructing several utility scale PV farms which will contribute up to 1 gigawatt (GW) through the Large-Scale Solar (LSS) scheme. The government also devised a scheme that aims to expand the role of PV electricity generation systems to meet power requirements on a domestic scale, which is known as the Net Metering (NEM) scheme. However, a major issue that plagues PV systems is that the power generated by a PV system depends on the availability of solar radiation, which is intermittent in nature. It fluctuates throughout the day, with its daily peak radiation being dependent on various factors such as geographic location and weather conditions. While it is possible to predict the range of expected solar radiation as well as the output of a PV panel using various techniques and technologies, it is critical for PV systems to have a monitoring system that would provide an accurate measure of its performance. Systems like supervisory control and data acquisition (SCADA) are being utilized for utility scale PV farms but are not suitable for domestic usage. Therefore, a prototype was developed that uses performance ratio (PR) to monitor the performance of a small-scale PV system.

2. Literature Review

2.1. *Variables that affect the performance of photovoltaic panels*

Detailed in this section are the variables that affect the output of a PV panel. The performance of a PV panel is mainly dependent on four variables. These variables are the silicon composition of the PV panels, the magnitude of solar irradiance received by the panels, PV panel orientation and PV panels surface temperature.

Most commercially available PV panels are either manufactured using monocrystalline silicon compound or polycrystalline silicon compound. A monocrystalline compound is a type of silicon with only a single crystal silicon. Polycrystalline compounds are essentially a type of silicon that is a blend of multiple types of crystal silicones and are often cheaper than monocrystalline compounds. However, PV panels with monocrystalline silicon have a bigger efficiency magnitude, which is approximately twenty percent, and polycrystalline silicon panel efficiency is lower, with it being at approximately fifteen. percent

Moving on, the magnitude of solar irradiance that is received by a PV panel will directly impact its output [Chaichan & Kazem, 2016]. During favorable meteorological conditions such as a sunny day with minimum clouds, the PV system will be able to generate its maximum power, especially during solar noon. However, if the meteorological conditions are unfavorable such as presence of large volume of clouds or rain, the output of PV panels will be significantly lower, and its maximum power generated for that day might not occur during solar noon. There are also other factors that will affect the radiation received by the PV panels which are shading and soiling. Shading occurs when an object such as trees or buildings blocks a PV panel either entirely or partially from receiving adequate sunlight while soiling is a phenomenon that occurs when dirt, leaves, snow, and animal droppings cover the PV panels, preventing the panels from receiving maximum solar radiation. Unlike the weather conditions, shading and soiling can be controlled and prevented via selection of appropriate installation location and regular cleaning respectively.

Next, the factor that impacts the electricity generated by a PV panel is its positioning of PV panels [Hartner et al., 2015]. PV panels must be positioned accurately according to their geographic location for the panels to receive the maximum amount of sunlight that is available in that region. A standard practice is to orient the PV panels at 45^{o}, facing either north if the panels are in the southern hemisphere and vice versa. However, a more accurate orientation can be achieved by setting the tilt angle of the panel according to the geographical latitude of where the PV is installed. To add to the accuracy, a calculation method can be used during the summer and winter months. During winter, add 15^{o} to the latitude and during the summer months subtract 15^{o} from the latitude. It should also be noted that the photovoltaic panels should be arranged on the path of the sun, which travels from the East to West for maximum exposure to solar radiation.

The final factor that impacts the output of a PV panel is the temperature of the PV panel. The ideal temperature for a PV panel to operate is 25 degrees Celsius. However, since the PV panel will be exposed to sunlight throughout the day for it to generate electricity, the temperature of the PV panels will naturally increase. This increase of temperature will affect the output of the PV panel, particularly the voltage. During a sunny day without clouds and wind, panel temperatures can reach up to 70 degrees Celsius, which is almost 50 degrees Celsius more than its optimal operating point. According to [Tresna Dewi et al.,2019], when the temperature of a PV panel the output of the PV panel will be affected, and its efficiency will reduce.

2.2. *Performance ratio*

Once the identification of the variables that impact the output of photovoltaic panels has been completed the subsequent action is to determine a metric that would allow for the performance of the PV panel to be measured and monitored. Based on the list variables, the magnitude of solar irradiance and the surface temperature of photovoltaic panels are quantitative by nature and can be measured using various tools like solarimeter, infrared thermometer and sensors that can be integrated into a multipurpose microcontroller board. Based on research via literature review, performance ratio (PR) was identified as a suitable method to keep track of a PV panel, [Daliento et al., 2017].

Performance ratio is essentially a mathematical model that is utilized to provide an assessment of the performance of a PV panel. It is a ratio of instantaneous power that is produced by a PV panel over the theoretical maximum output power that is generated by the PV panels at a specific magnitude of solar irradiance. When the ratio is 1, this means that the PV panel is operating at maximum efficiency and there is no loss in power. However, in real life conditions, the ratio is usually between 0.7 until 0.9. The PR equation is as below:

$$PR(t) = \frac{Instantaneous\ Power\ from\ PV\ panels\ x\ 1000\ W/m^2}{Instantaneous\ Solar\ Radiation\ x\ (\ Maximum\ output\ power\ of\ PV\ panels\ x\ \gamma\ x\ \Delta T)} \quad (1)$$

The equation takes into account the quantifiable variables that impact the output power generated by photovoltaic panels, that being solar radiation and panel temperature. Performance ratio, theoretically, can also take into account external factors that impact the output power generated by PV panels, such as soiling, improper orientation and shading. The equation can also help the consumer identify if the PV panel is generating adequate power during varying meteorological conditions such as cloudy days and rain.

3. Methodology and Research Activities

3.1. *Manually collected the data of the performance of a PV system.*

A 60-Watt PV electricity generation system was assembled with the purpose of investigating if PR was a suitable method to measure the performance of a PV system. An ammeter and voltmeter were used to measure the current and voltage that is generated by the photovoltaic panels while an infrared thermometer was used to measure the temperature of the PV panels. As for the solar irradiance, a solarimeter was used. The data was collected hourly between 8 am and 7 pm. The collected data would then be tabulated in excel and calculated using the PR equation, where the data would be analyzed. These steps are repeated the next day but with an additional step. When the data is collected, the panels will be randomly shaded to simulate a condition where the power generated by the photovoltaic panels are disrupted via external condition. Data would then be analyzed to provide evidence that PR is suitable to be utilized for PV performance monitoring. The purpose of the manual measurement is to verify the suitability of the PR equation as well as to understand how the mathematical model will behave during relatively ideal conditions and during conditions where the PV panels are not performing optimally.

3.2. *Selection of sensors*

If the analysis of the data provides a favorable result, then the next step would be to select the appropriate sensors that will be used alongside the microcontroller. For the microcontroller, the Arduino Mega 2560 prototyping board was selected. The open access nature of Arduino and its board design makes it easier for prototyping purposes. A voltage sensor was used to measure the voltage of the PV system while a Hall Effect current sensor was used to measure the output current. As for the temperature of the PV panels, an LM35 temperature sensor was selected, and a high current low voltage PV panel was used as a reference cell to measure the solar radiation. All the sensors are then integrated into the Arduino. The data from the sensor is printed and can be viewed via serial monitor, which can be accessed by the Arduino IDE. The data collected by the sensors will be used to calculate the PR, which will be coded into the Arduino and will be displayed in the Arduino Serial monitor. The Arduino will be connected to a Window's based microcomputer where the data can be view and extracted. The setup is as in Figure 1.

3.3. *Data collection and analysis*

The integrated sensor circuit will be connected to the 60 W PV electricity generation system. The current sensors will be connected in series with the PV system while the voltage sensor will be connected parallelly. The temperature sensor is installed on the PV panels and the radiation sensor is positioned near the photovoltaic panels. Just like how it was executed during the manual measurement, the integrated sensor circuit will collect data for 2 days. The first day is just to measure the PR throughout the day while the second day the PV panel will be randomly shaded to emulate external interference on PV performance. The system collects data for 11 hours, which is between 8 am till 7pm and data will be recorded down hourly for the two days. The data will then be tabulated and analyzed based on the results collected via manual measurement.

Fig. 1. The prototype collecting data

4. Results and Discussion

4.1. *Manually collected the data of the output of a PV system.*

Figure 2 contains the graph of the PR collected on Day 1 and Day 2 of manual measurement. One the first day of data collection, the magnitude of PR had minimum fluctuations. It stayed consistent throughout the day despite the output power varying. The lowest PR value was 0.7419 at 8.00 am and the highest was 0.8351 at 1.00 pm, with the overall average PR being 0.80335. The slight fluctuations in PR can be attributed to various factors including human error during measurement, random error present in the measuring equipment and power loss due to voltage drop across the wires. However, it should be noted that these fluctuations are within acceptable bounds as the lowest PR magnitude and highest PR magnitude vary approximately 7.649% and 3.952% from the average. Hence it can be inferred that during ideal conditions, PR can provide an accurate assessment of the performance of PV panels.

On the second day of data collection, the PV panels experience partial shading at random intervals. From the graph, it can be observed that whenever the panels are covered there is a notable decrease in the magnitude of the PR. The magnitude of PR can drop as low 0.3128 as when the output of the PV panel is affected due to shading**.** However, in the most efficient state of operation where no shading occurs, the PR is close to the average that was obtained during ideal conditions.

From the data collected on both days, it proves that PR can provide an accurate reading of the PV panel performance and it has a potential to be integrated into an automated system where it will be capable of providing an accurate analysis of the performance of the PV system.

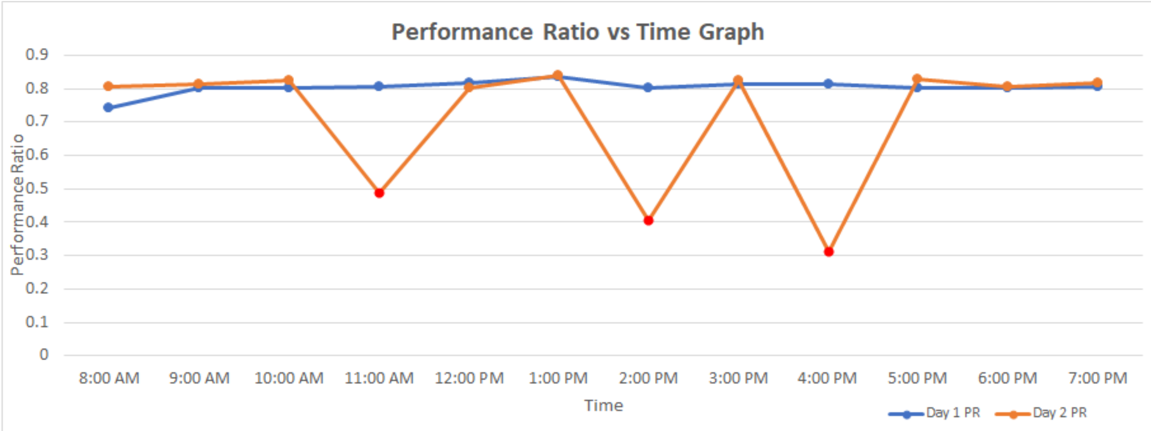

Fig. 2. The graph comparing the PR magnitude when the PV system during ideal conditions (Day 1) and during partial shading (Day 2)

4.2. *Data collected using the microcontroller-based integrated sensor circuit.*

The collected data is visualized in Figure 3. The data collected by the prototype is visualized in the figure below. The data is similar to the manual measurement. When the PV system experiences no interruption in electricity generation, its PR is relatively stable and has minimum fluctuations. While the average PR magnitude, which is 0.79923 is slightly lower than the manual measurement, the data overall is consistent. This proves that a microcontroller integrated sensor circuit with can be used measure the performance of a PV system accurately, despite some minor differences in the data collected. Even on the second day of data collection where performance issue was emulated, the microcontroller-based system was able to pick up the dips in PV system performance. Hence, it can be inferred that the system is capable of measuring PV performance accurately.

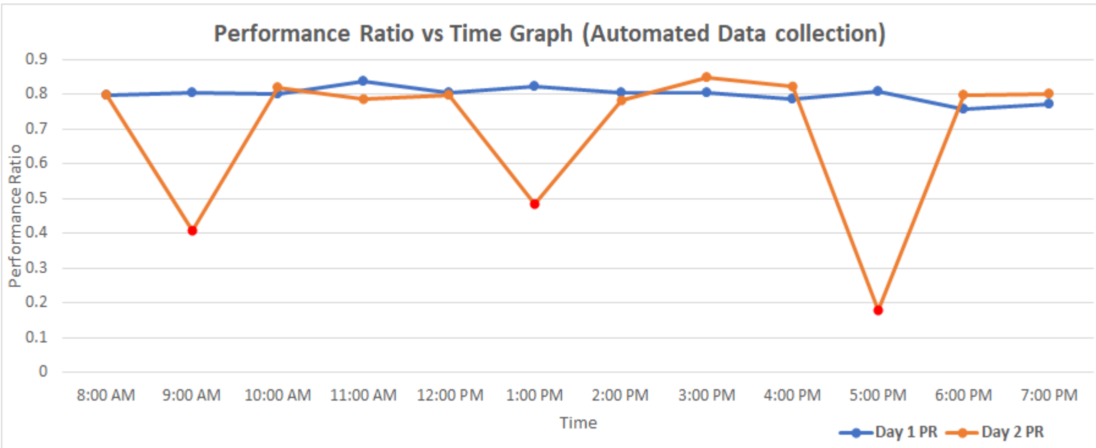

Fig. 3. The graph compares the PR magnitude when the PV system during ideal conditions (Day 1) and during partial shading (Day 2) via automated data collection.

4.3. *Discussion and future*

Based on the results of the experiment, it is evident that PR mathematical model can be used measure the performance of the PV system and it can also be used to detect if there are any issues with the PV panels such as the panels experiencing shading or soiling. However, there is a flaw with this method of measuring PV panel performance. The mathematical model cannot be used to detect faults if they occur. The model can only be used to alert the consumer whenever their PV panels are not performing at its optimal point, but not provide a diagnosis of the issue or faults. Despite that, it is possible to integrate the mathematical model with other methods of fault detection which can provide a more accurate diagnosis. Another weakness of this method of performance evaluation is that it is not suitable large scale PV performance monitoring due to the complexities that come with large scale PV systems. Instead, it has to be limited to systems within the kilowatt (kW) range. That being said, further investigation must be conducted by upscaling the microcontroller system so that it can be tested PV systems of kilowatt scale. Additionally, a software can be developed to act as the user interface for consumer when the want to access the data. Finally, it is recommended that the Arduino prototype board be switched to the more standard PIC (Programmable Interface Controllers) microcontrollers as they are much more suitable for real life applications, especially when considering to upscale the data collection system into the kilowatt range of PV electricity generation systems.

5. Conclusion

To conclude, as the utilization of PV systems is becoming more common, it is essential that each system is equipped with a performance monitoring system. In the system, the performance monitoring method will determine architecture of the device. The performance ratio mathematical model was used to monitor and evaluate the performance of PV panels. The data collected from the experiments indicate that PR can be used to monitor the performance of the PV panels as it provides an accurate evaluation of the performance and is able to detect when the PV panels performance is affected by shading. However, the PR equation does not provide an indication of the type of faults that causes the performance issue. The next step of this research is to develop a more robust prototype that can be used for PV systems that range in kilowatts and to integrate the PR mathematical model with other methods of fault detection.

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Conflicts of interest
The authors have no conflicts of interest to declare.

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