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Remote smart monitoring system for off-grid PV power generation

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Abstract

The demand for energy and growing concerns for the environment have led to the advancement of sustainable practices such as solar energy generation. Improvements in solar cell technology have led to an increase in photovoltaic (PV) generation, especially in remote regions. In order for PV grid systems to operate successfully, there must be a way to monitor and manage the data that is produced. This paper proposes a smart, remote monitoring system that will allow for an operator to monitor, store, and manage grid data in real-time. The smart monitoring system includes the use of an eGauge Pro smart meter at its heart, sensors, and interconnections with other grid electronics. The eGauge is a smart meter, data logger, and has a built-in web server, that allows it to communicate with the systems sensors, that connect grid devices such as the solar inverters, battery storage system, and solar arrays. An operator can connect the meter into a live grid system and begin capturing sensor data. Once the meter has all of the physical connections necessary, the operator is able to configure the meter through the web server. From the server, all of the sensors are registered, labeled, and available for display numerically and graphically, both locally and remotely. These capabilities provide the ability for grid data to be monitored remotely, anywhere there is network connectivity and customized for in-house or commercial use, packaged in a low-cost system. Thus, unique alerts and notifications are designed to better facilitate grid maintenance and protection.

Keywords: Intelligent Monitoring; Smart Monitoring; Smart Meter; Remote Monitoring

1. Introduction

The evolution of society has increased the demand for reliable energy in order to meet the needs of modernization [1]. Power is a critical component of modern life and it supports systems throughout society's infrastructure [2]. Even though power is a necessary commodity, there are concerns that traditional generation will cause irreparable damage to the surrounding ecosystems. It is because of these concerns that renewable energy generation has gained popularity. The power demand can be met while reducing the environmental impact caused by power generation. The renewable energy method discussed here is solar energy generation by the means of photovoltaic cells.

A PV off-grid power generation station is utilized to generate electric energy by harnessing renewable solar radiation [3]. The PV station is not connected to a utility service provider; therefore, it is considered to be off-grid. The PV cells capture the solar irradiance and convert it to electrical current, which is managed by the hybrid inverter. The hybrid inverter contains the charge controller, the Maximum Power Point Tracking (MPPT), routes energy to the battery storage system, and routes energy to the electrical loads. Throughout this process, the inverter may be monitored to observe the overall migration of energy, though it does not provide specifics. This is where the eGauge smart meter implementation can fill that role.

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The eGauge Pro meter is a smart meter that may be installed within a live grid system to capture sensor data and other specific data values during operation [eGauge Systems LLC, https://www.egauge.net/, Last accessed on 03/30/2025]. Real-time data collection is achieved by installing sensors throughout the off-grid system; such as cell temperature sensors, irradiance sensors, ambient temperature sensors, current transformer (CTs), and other sensors that may be necessary for grid monitoring [4]. The smart meter also allows for voltage measurements in single-phase or three-phase configured in either delta or wye (grid should be disconnected for voltage meter wiring) [5]. Once the smart meter is wired and installed with all of the desired components for monitoring, the operator may then access the meter's web server to complete configuration.

The meter's web server is the centralized location where an operator is able to configure system general settings, setup grid registers, view real-time data, design custom alerts, set notification preferences, and manage access controls. Within the server, the operator will identify all of the grid system registers; implementing formulas to produce additional monitoring values such as the power that are not represented as a default register. All of the data is stored locally on the device, may be viewed from the physical device, and may be exported at the operator's discretion. The presence of the web server promotes the ability for the grid to support remote monitoring and management, which is a key aspect of the architecture.

2. Materials and methods

2.1. Monitoring System Installation

The eGauge Pro meter is the main component of the intelligent monitoring system for remote grids. The meter will serve the role of a traditional electric meter, but with the added, embedded capabilities of data logging and exportation to a web server. The smart meter is the hub for all of the sensors that are connected throughout the grid system. This includes sensors that monitor the PV cells, inverter, battery storage, and loads; which allows the meter to monitor data across each component of their grid system. In order to accomplish this, the meter should be installed within an enclosure, on-site where wiring exist, or where it may be integrated alongside new wiring. This way, the phase voltages and sensor cabling may all be wired directly into the meter for data collection. To ensure that the meter operates as intended, it must be supplied with a DC Voltage adaptor. For this reason, the meter's enclosure should include access to power as well as network connectivity for the web server. The enclosure should also be manufactured to route all of the cables that will connect the sensors to the meter. All connections for the meter are managed through the web server to authorized operators.

2.1.1. Access Controls

Access controls are vital to the management and protection of the grid system. They ensure that the monitoring software is only accessible to authorized personnel. The operator receives the initial login information with their meter and once they have successfully gained access, they may change the credentials. The operator is also able to create new logins for other authorized users and determine the level of access for them. This includes granting full access, read only access, location specific access, and device control access. Afterwards, each individual user would be responsible for their login credentials and operating under their given access. Access to change settings within the web server are required to complete the meter installation process.

2.1.2. Sensors

Sensors are a necessary element of the intelligent monitoring system; their presence is essential to the functionality of the smart meter and the system as a whole. The sensors are a collection of various different electronic devices that are designed to measure and transmit the data for specific quantities within the grid system. The different types of sensors that are utilized (may vary based on grid configuration) are ambient temperature sensors, internal temperature sensors, cell temperature sensors, irradiance sensors, wind speed sensors, and current transformers (CTs). Ambient temperature sensors are utilized to capture the environment temperature surrounding grid components, internal temperature sensors measure the temperature within specific equipment, the cell temperature sensors will measure the temperature of the PV cells, the irradiance sensors are placed near the cells to measure the intensity of the solar energy that contact the panel, wind speed sensors are mounted high in an open area to capture wind data, and CTs are sensors that measure the current within a circuit by being latched around a current carrying conductor.

The smart meter allows for sensors to be plugged directly into it to begin recording sensor data. Up to 30 sensors may be plugged into the meter at once by direct connection to the meter's sensor ports. In order to plug a sensor directly into the smart meter, it must contain the 2-pin terminal plug that the eGauge manufactured sensors have, the plug may be outfitted to sensors that do not have it, or the operator may utilize a Sensor Hub from eGauge that will accept different sensor types and is compatible with the smart meter.

2.1.3. Voltage

To measure the voltage of the grid system using the smart meter, the operator must connect the voltage lines. The eGauge meter is configured for a 5-pin terminal Power Plug connection that an operator may insert existing wires into, or they could also utilize the branded Power Whip that comes with the 5-pin terminal and includes National Electric Code (NEC)/National Fire Protection Association (NFPA) 70 certified colored wires. The meter has illustration on it to identify the wire placement for both delta and wye configured systems, as well as acceptable voltages rating. It is capable of operating up to three-phase 277/480 Vac at 6900 A, Line-to Neutral less than or equal to 277 Vrms, and Delta-to-Delta less than or equal to 208 Vrms.

2.1.4. Web Installation

Web server installation is conducted once the operator has hardwired all of the desired connections for the smart meter. The installation settings for the meter are located under the setup menu option. Web server installation may still be done even after initial setup, and even whilst the system is live and recording. The operator should note that some changes to meter installation settings may require a server reboot and result in a pause in live readings. Within the web server, the operator will specify all of the sensors that are connected to the system as registers. When connected properly, the meter should automatically identify the sensors protocol and type. In the case that it the meter is unable to recognize a sensor type, it may be inputted manually.

Each of the register requires a record value type; whereas this system utilizes P, L, and S (Power, Voltage, and Sensor Current). L and S are selected from prepopulated options that are a result of the voltage and sensor connections established during installation. The operator may utilize the menus to select the appropriate register label for a sensor if it did not automatically select the proper one. In these settings the operator would also give the registers a proper title that indicates the function of the sensor, and select the measurement constraint. The measurement constraint may be a normal value (AC), a DC only value (mean), or a frequency value. For other registers such as the power (P), the operator must specify a formula to be used to calculate that register. Regarding the power, the formula would consist of the product of existing L and S registers.

2.2. Smart Monitoring Configuration

2.2.1. Register Configuration

The operator must ensure that the sensors that are placed throughout the system are operating correctly and that each is identified. It would be appropriate to include descriptive labels for each sensor in the web server and even provide physical labels on equipment that corresponds to the digital labels. This is also were the operator should confirm that the register value is set to the correct setting.

When configuring the meter's registers, the operator must define the parameters for special registers. Generally, in grid applications, one of the most common special registers would be power. The power register must be defined by utilizing existing registers and a formula. The register formula for power is the same theoretically as defined by the electrical power formula; current multiplied by voltage as shown in Equation 1. The product of the voltage (V) and the current (I) is the general power equation and it corresponds to how the meter interprets the formula; which is the product of the register voltage (L) and the register current (S) as described in Equation 2. It is important to note that when considering electrical power in a multi-phase system, the power factor (pf) needs to be included; though within the web server there is no option to incorporate the pf, but it can be concluded from measurements and calculations that the function is performed automatically based on Equation 3.

$$P = V * I \quad \text{......} (1)$$

$$P = L * S \quad \text{......} (2)$$

$$P = V * I * Pf \quad \text{......} (3)$$

2.2.2. Display Configuration

In order for the configured registers to be displayed, the display for the smart meter must also be configured. The operator may utilize the Liquid Crystal Display (LCD) settings option to identify which registers will be available to display. Each register that has been created will have a check box next to it for the operator to decide if they want to display the instantaneous value or the cumulative value. If both boxes are left unchecked, then that register will not be displayed. The two displays options consist of the physical display on the meter, and a remote display on the web server.

The physical display is viewed through the LCD screen on the smart meter as displayed in Figure 1. The enabled registers will appear in rotation on the screen but without the backlight. When the operator interacts with the toggle on the front of the meter, it will activate the backlight, and the operate will be able to navigate through the enabled registers. The toggle also provides access to the physical settings on the smart meter when pushed in. On the LCD screen, it will indicate the health of the device as well as the connection to an Internet network. When the meter is successfully connected to the Internet, it will allow for remote communication to the web server.

Within the web server, the operator may monitor the enabled registers remotely. There are a number of options that may be selected for the display of the desired registers. The operator may utilize the chart view, a classical view, a dashboard view, and a waveform view. There is also the channel checker view in the "Tools" menu that supplies the real-time register numerical values. These values may be used to determine billing data or usage data when applicable; though they are instrumental in the creation of alerts.

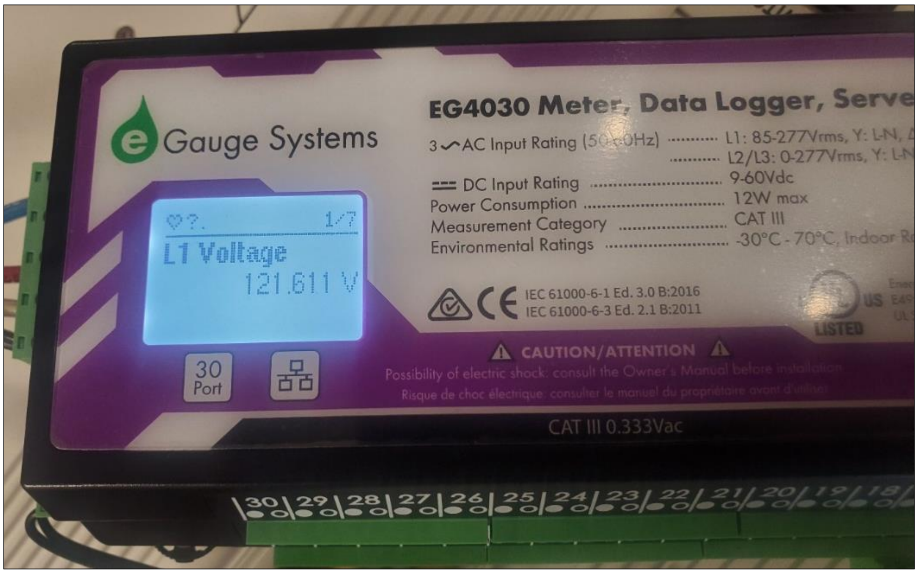

Figure 1 Smart Meter LCD Screen with L1 Voltage

2.2.3. Alerts

The meter has system alerts that are preloaded and may be activated to inform operators whenever there is an issue that affects the meter. This includes when the device is operational, when it is rebooted, connection status, remote connectivity, date and time, and temperature thresholds. Though, the operator also has the ability to design custom alerts to best suit their grid system.

Custom alerts consist of the operator designing a specific formula to monitor register values. Typically, the formulas consist of a mathematical comparison between registers and a numerical value. Such as if the operator wanted to set threshold alerts for certain registers, they would set a less than, equal to, or greater than formula to alert whenever the condition is met. These alerts are important for the protection of the grid system, especially in cases where the grid does not have sophisticated self-healing. With timely alerts, appropriate maintenance may be performed to avoid critical damages or failures.

Figure 2 shows the window utilized for custom alert creation. In the "Name" field, the operator gives the alert an identifier which serves as the short message for the alert. Next, the "Priority" field is where the alert priority is set to determine what alerts will take precedent over the others. After, the "Check Frequency" is set to determine how often the meter will check the condition to determine if an alert should be prompted. The condition is set in the section with the "Left formula" and the "Right Formula." The operator dictates the condition for the alert to go live by inputting a mathematical comparison between registers and numerical values. Finally, the "Message" field is where the operator would include a detailed description of the alert to provide more information in the notification. For example, Equation

4 demonstrates how an alert condition formula is constructed. Whenever the Power reaches below 20W, it will trigger an alert and inform the operator so that the appropriate action may be take.

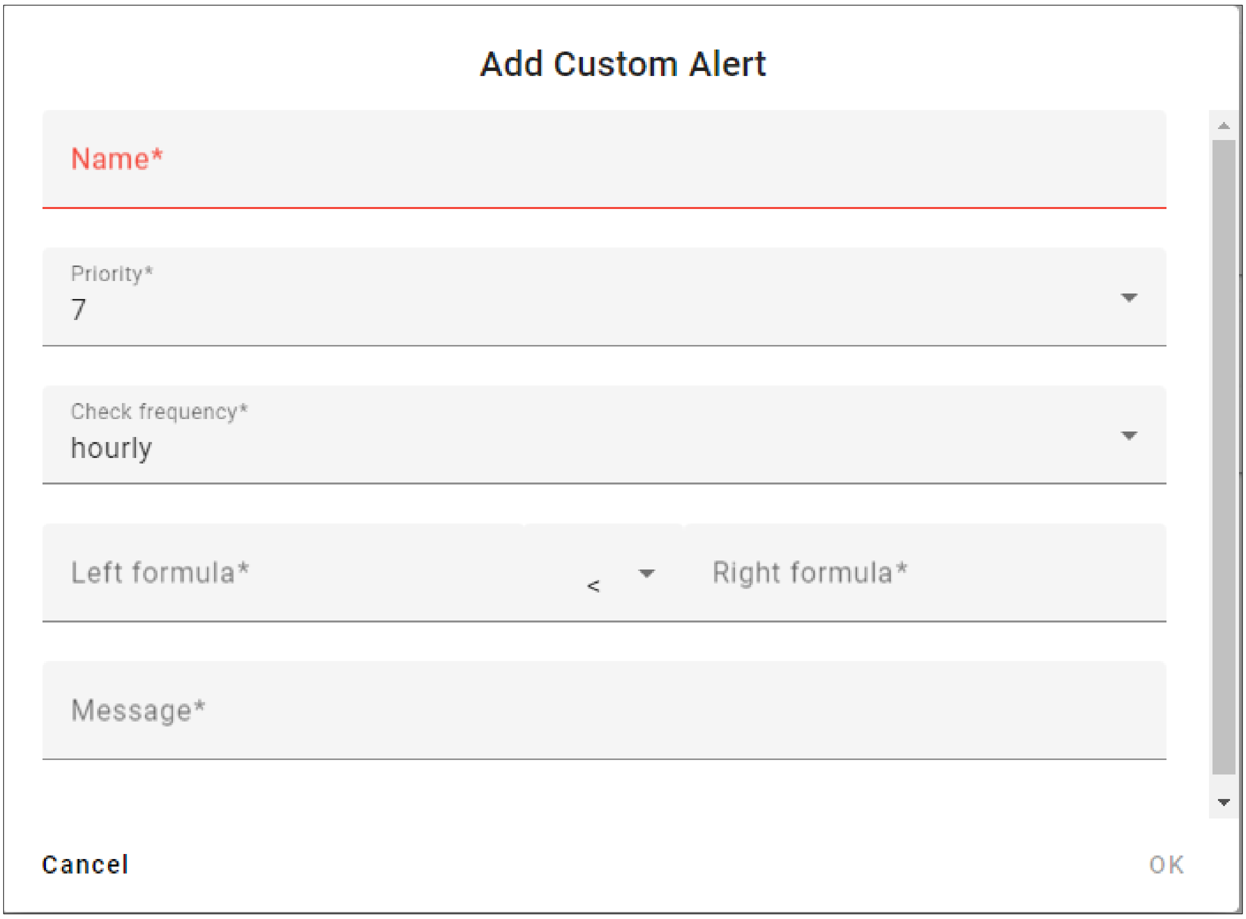

Figure 2 Custom Alert Creation Window

$$\$\text{"Power"} < 15 \quad \text{..................} \quad (4)$$

2.2.4. Notifications

Notifications are a crucial component of the smart monitoring architecture and are necessary to the visibility of alerts. When an alert function is enacted, the notifications are to key to how that information is disseminated. When setting up notifications, the operator may select the media in which the notification is received. These options include: notifications within the web server, a separate website server, email, text message, or push notification on a mobile device. The operator has the capability to create specific notification messages to pair with the alerts. A short message can be included to provide a synopsis of the alert notification for quick response, as well as a longer description that provides more details whenever the alert notification is selected. The notifications will be delivered based on the alert priority value that is assigned during the alert creation process.

3. Results and Discussion

A reliable monitoring system is important to the overall functionality and protection of a grid system. Efficient monitoring ensures that a grid's operations experience the lowest number of disruptions and the shortest amount of downtime with real-time data collection and alert notifications. One method for real-time data collection is through the "Channel Checker," as shown in Table 1. The Channel Checker is a web server tool that allows the operator to view real-time data for all of the sensors that are connected to their smart meter. The channel column displays the register's identifier in ascending order. This tool will display the AC+DC rms value, the AC rms value, the DC mean value, and the frequency for that register. Due to this tool operating in real-time, the values are variable and will experience changes over time.

Table 1 Channel Checker Tool

Channel	AC+DC (RMS)	AC (RMS)	DC (Mean)	Frequency
L1	119.480 V	119.480 V	-0.193 V	60.02 Hz
L2	120.330 V	120.329 V	-0.588 V	60.02 Hz
L3	121.810 V	121.810 V	-0.276 V	60.02 Hz
S1	0.045 A	0.033 A	-0.031 A	118.77 Hz
S2	0.053 A	0.041 A	-0.033 A	178.45 Hz
S3	0.092 A	0.030 A	-0.087 A	0.00 Hz

When monitoring PV generation systems, the irradiance captured by the solar arrays is a key component to track. The irradiance is an indicator of the potential power generation of the grid system. There is an expected correlation between irradiance measured and power generated; the greater the measured irradiance, the greater the power generated and vice versa. Through the storage and analysis of irradiance data, it will allow the operator to predict power generation levels and anticipate when battery storage or other supplemental systems are necessary. Table 2 displays the average irradiance measured for a week across three solar arrays in the PV grid system. The table of average irradiance is an indicator of roughly the amount of solar energy captured on a day-to-day basis when the conditions are consistent. The “Dates” column displays the date from midnight to midnight (24-hour scale) and the irradiance columns display the measured kilowatts per meter squared.

Table 2 Weekly Average Solar Array Irradiance

Dates		Irradiance [kW/m^2]	Irradiance 2 [kW/m^2]	Irradiance 3 [kW/m^2]
8/5/2024 0:00	8/6/2024 0:00	.3740334	.3440095	.2600675
8/6/2024 0:00	8/7/2024 0:00	.386685	.3572239	.2715806
8/7/2024 0:00	8/8/2024 0:00	.3822638	.3522387	.2750802
8/8/2024 0:00	8/9/2024 0:00	.3687043	.3395834	.2564156
8/9/2024 0:00	8/10/2024 0:00	.3537289	.3344012	.2708083
8/10/2024 0:00	8/11/2024 0:00	.3770109	.3527276	.2741564
8/11/2024 0:00	8/12/2024 0:00	.373166	.3492534	.2843241

Another data point that may be collected is the accrued irradiance. Table 3 displays the accrued irradiance for a week in kilowatt hour per meter squared. This data represents the total accrued irradiance for each day within a week. Similarly, to the average irradiance, the accrued irradiance should be stored and analyzed to gain a better understanding of how much solar energy is captured so that it may be cross referenced to the total amount of weekly power. This will provide a baseline for the expected power generation from the PV system.

Table 3 Weekly Accrued Solar Array Irradiance

Date	Irradiance [kWh/m^2]	Irradiance 2 [kWh/m^2]	Irradiance 3 [kWh/m^2]
8/5/2024	8.976801	8.256228	6.24162
8/6/2024	18.25724	16.8296	12.75955
8/7/2024	27.43157	25.28333	19.36148
8/8/2024	36.28048	33.43333	25.51546
8/9/2024	44.76997	41.45896	32.01485
8/10/2024	53.81823	49.92442	38.59461
8/11/2024	62.77422	58.3065	45.41839

Table 4 displays the irradiance for all three of the solar arrays. This table provides the measured solar energy on an hourly basis (24-hour scale) for one day out of the week. From the irradiance data collected here, the operator may draw conclusions regarding the daily performance of the PV system. Based on the analysis from the table, between the hours of 21:00 (9:00PM) and 6:00 (6:00AM) the numerical value from the irradiance sensors measures 0. This corresponds with the period of the day after the sun has set and is yet to rise. In some cases, artificial lighting around the solar arrays may still generate energy, though the sensors are unable to capture significant amounts for measurement. During these periods it should be expected that the solar arrays will not produce significant power and that supplementary options may need to be utilized. Analysis from the table indicates that midday and into the early evenings tend to produce the highest irradiance levels which would contribute to greater power generation. Oscillations in the data points may be attributed to shading from cloud cover, which results in decreases in the measured irradiance.

Table 4 Hourly Solar Array Irradiance

Date & Time	Irradiance [W/mÂ²]	Irradiance 2 [W/mÂ²]	Irradiance 3 [W/mÂ²]
8/5/2024 0:00	0	0	0
8/5/2024 1:00	0	0	0
8/5/2024 2:00	0	0	0
8/5/2024 3:00	0	0	0
8/5/2024 4:00	0	0	0
8/5/2024 5:00	0	0	0
8/5/2024 6:00	2.760833	2.4158333	2.5766667
8/5/2024 7:00	215.1578	43.291111	49.399444
8/5/2024 8:00	674.1814	534.42889	213.66639
8/5/2024 9:00	856.1956	809.69639	443.18778
8/5/2024 10:00	935.63	919.15361	658.94583
8/5/2024 11:00	847.6894	829.01333	729.69639
8/5/2024 12:00	441.5611	420.70333	424.55861
8/5/2024 13:00	651.5297	621.86278	648.99167
8/5/2024 14:00	969.2369	945.22722	941.08278
8/5/2024 15:00	881.9631	870.04361	761.47889
8/5/2024 16:00	941.1636	934.87139	675.54361
8/5/2024 17:00	821.5078	804.2975	449.86639
8/5/2024 18:00	572.7975	479.88972	195.34917
8/5/2024 19:00	162.0139	38.810833	44.574722
8/5/2024 20:00	3.411944	2.5219444	2.7013889
8/5/2024 21:00	0	0	0
8/5/2024 22:00	0	0	0
8/5/2024 23:00	0	0	0

The data points collected from the tables contribute to the graphical representations in Figure 3, Figure 4, and Figure 5 for each of the solar arrays. The graphs plot the irradiance in Watts per meter squared vs the time and date. Below each graph are numerical values in kilowatts per meter squared for the average, minimum, maximum, and accrued irradiance. The average value represents the total average for the entire week, the minimum values represents the lowest measured irradiance for the week, the maximum value represents the highest measured irradiance for the week, and the accrued value represents the total accrued irradiance measured for the week.

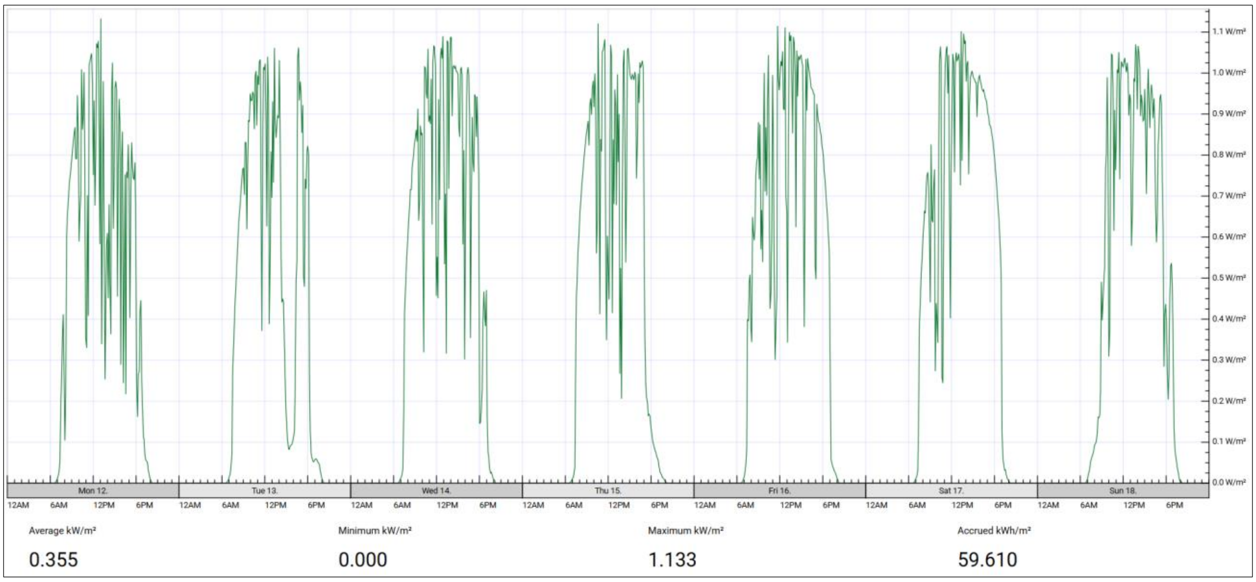

Figure 3 Weekly Irradiance Measured for Solar Array 1

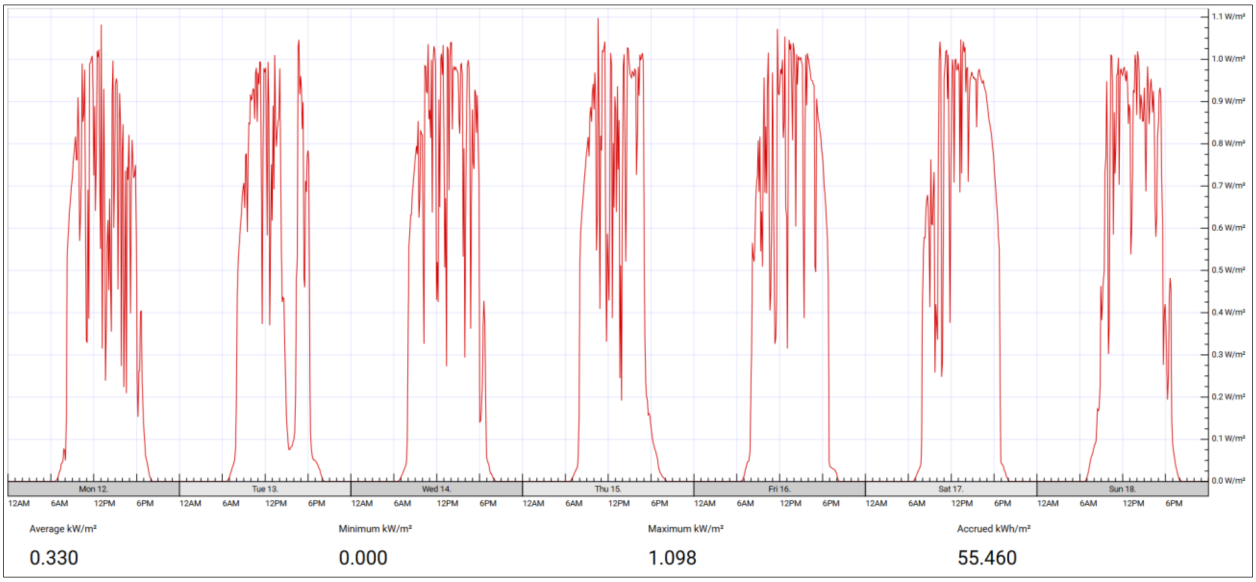

Figure 4 Weekly Irradiance Measured for Solar Array 2

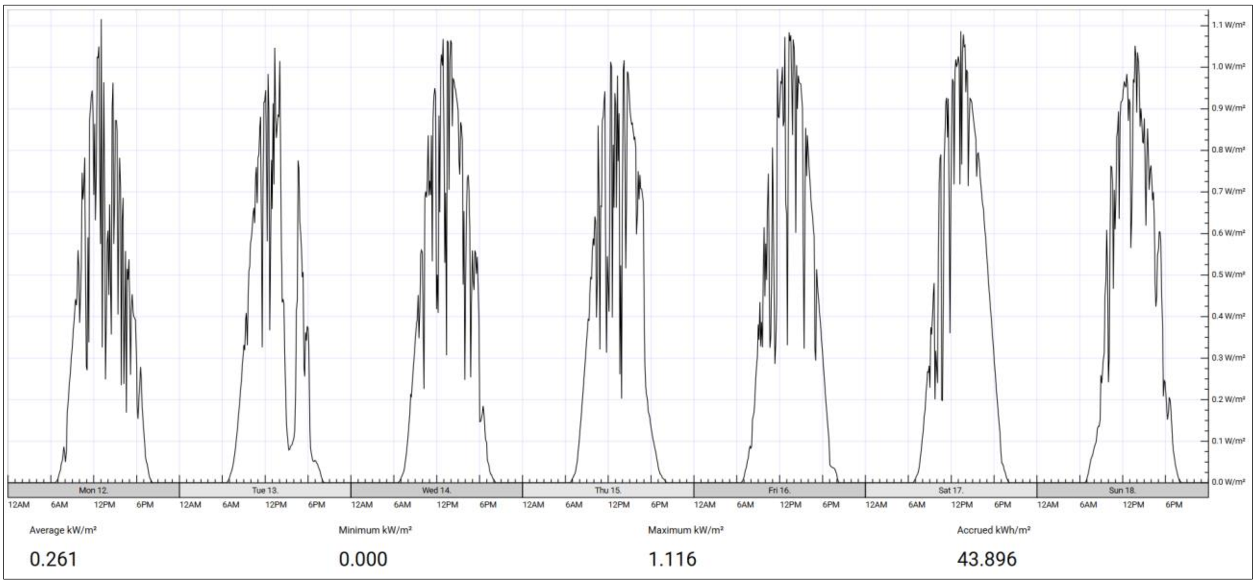

Figure 5 Weekly Irradiance Measured for Solar Array 3

The irradiance is essential to the power generation for the PV system, as it relates to both the current and power measured from the inverter. Table 5 displays the daily inverter current in amperes vs the daily power calculated in kilowatts. As discussed before, the power register is not native to the smart meter so it is necessary for it to be calculated from the existing registers. Therefore, by inputting the power formula that is the product of the inverter current (S) and the PV voltage (L), the new register will produce the desired power. Through analysis, it may be inferred that the current and power trend in a similar matter to the irradiance. The current and power do not reach absolute zero due supplemental systems that maintain functionality when the solar energy is low, allowing the solar inverter to continue operations. At relatively the same hours of the day when the irradiance measured experiences it's peaks, the current and power will also measure greater values.

Table 5 Hourly Inverter Current v. Power

Date & Time	Currently [A]	Power [kW]
8/12/2024 0:00	1.220865614	0.035563056
8/12/2024 1:00	1.187441949	0.030251667
8/12/2024 2:00	1.171896701	0.029878611
8/12/2024 3:00	1.164153103	0.026291944
8/12/2024 4:00	1.185289171	0.021768056
8/12/2024 5:00	1.186680094	0.022108333
8/12/2024 6:00	1.207862278	0.024642222
8/12/2024 7:00	1.232191976	0.030721111
8/12/2024 8:00	1.607762587	0.086886111
8/12/2024 9:00	3.665390354	0.352430556
8/12/2024 10:00	3.717741699	0.354310278
8/12/2024 11:00	3.439825846	0.317142222
8/12/2024 12:00	4.912966037	0.451844167
8/12/2024 13:00	3.871163194	0.367826111
8/12/2024 14:00	4.360646973	0.406536389

8/12/2024 15:00	5.028900282	0.459525556
8/12/2024 16:00	4.914148763	0.4518625
8/12/2024 17:00	4.930784505	0.452189444
8/12/2024 18:00	4.360842828	0.408990556
8/12/2024 19:00	1.945293376	0.120655833
8/12/2024 20:00	1.228496229	0.043426389
8/12/2024 21:00	1.283409831	0.054030833
8/12/2024 22:00	1.265351969	0.050814444
8/12/2024 23:00	1.21916843	0.044475556

The graph shown in Figure 6 illustrates the weekly current measured from the solar inverter. Much like with the irradiance, when instances of shading occur, they contribute to the oscillations in the measured values. These measurements are completed by placing the current transformer across the current-carrying conductor that runs from the inverter to the load. The average current, minimum current, and maximum current captured are expressed in Amperes below the graph. Then the total accrued current in Amperes is shown below the graph in ampere-hours.

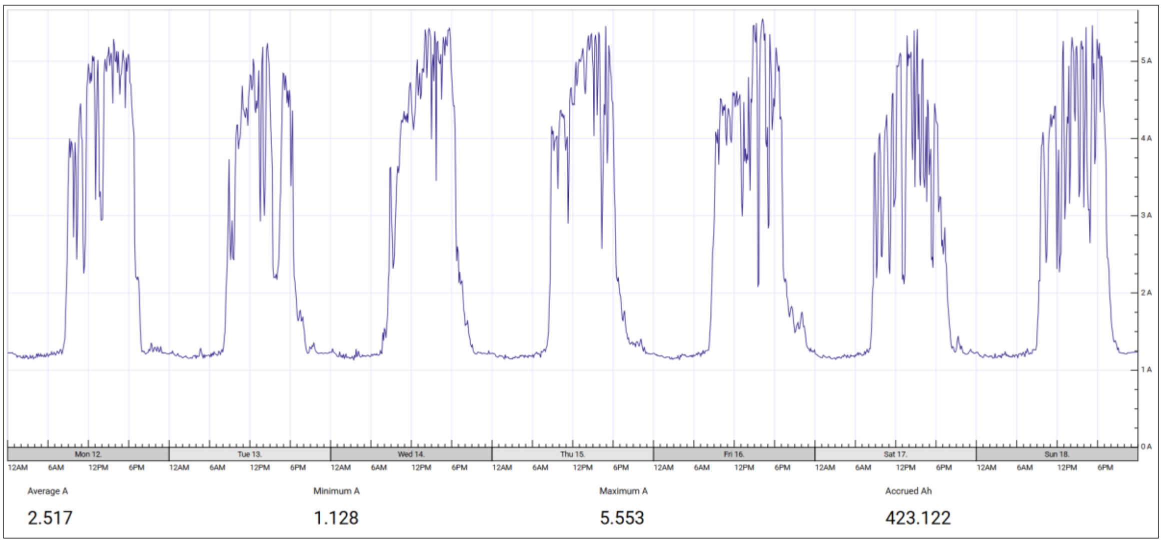

Figure 6 Weekly Inverter Measured Current

Figure 7 displays the weekly solar inverter calculated power based on the operator defined formula. The graph is the date and time vs the power measured in Watts. There are different power values that may be measured, it is the operator's responsibility to include the appropriate registers for the power that they desire to calculate. This power identifies the energy carried from the inverter to the load. From the graph in Figure 7, the average power, minimum power, and maximum power are shown below the graph in Watts. There is also the total accrued power that is shown below the graph in kilowatt hours.

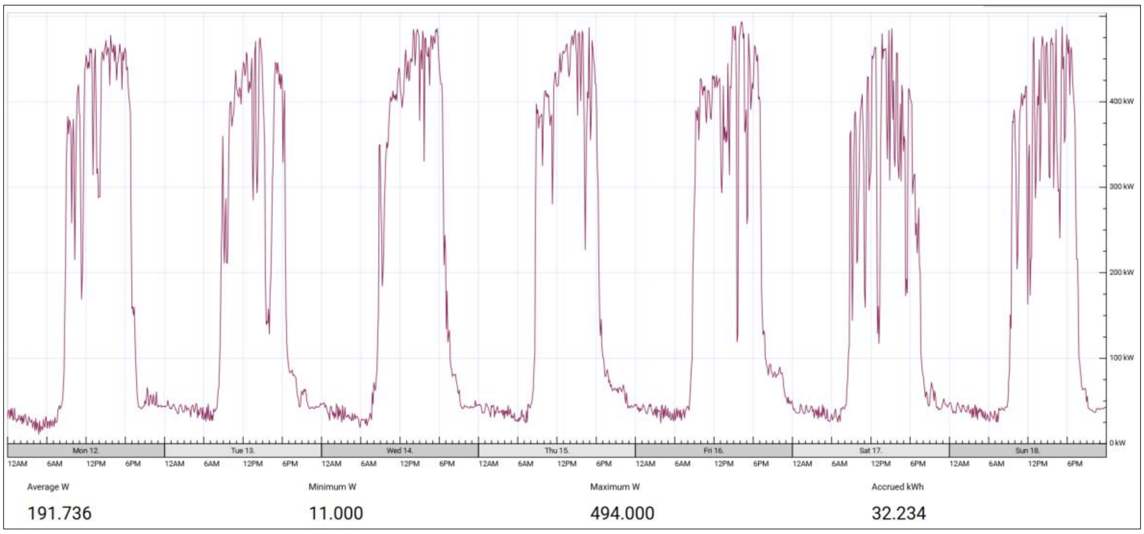

Figure 7 Weekly Inverter Calculated Power

Collectively, this data is captured by the smart meter and accessible remotely through the web server. The operator may manually analyze or develop programs to analyze the data for alert notifications. It must be determined which values should be utilized as threshold values. In terms of the power, this would be an evaluation of which values should be a cause for a trigger condition. Whenever the power is below a certain wattage, the PV generation may no longer be able to sustain the amount of power necessary to supply the load. Once this occurs, supplemental systems such as battery storage must make up for the discrepancies. Based on the data, the minimum wattage measured is 11 W; combined with data from the solar inverter, the battery storage system begins to take over for the PV generation at roughly 15 W. Due to this data, the alert is designed to trigger whenever the measured power falls below a threshold value of 15 W. This may not be an indication of a critical failure, though it will alert the operator that the PV generation has fallen too low.

Figure 8 shows the alert setup where the operator has an overview of the alert. From this window, the operator may adjust the priority from 0 – 7, where 7 represents the highest priority. The highest priority should be assigned to critical alerts so that their notifications are visible over lower priority alerts. Within the setup window the operator may also make changes to the check frequency to determine how often a condition needs to be checked.

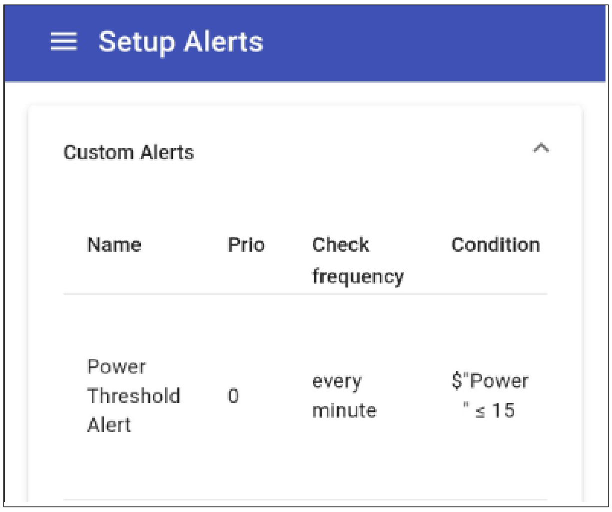

Figure 8 Alert Setup View

As observed in Figure 9, when the power drops below the set threshold value it will trigger an alert. Here it is sending the alert notification to a smart device. The notification contains the time that the event occurred, the name of the alert, and when expanded it will display the custom message. The operator may then click the mobile notification from the banner to be redirected to the Alert Viewer window.

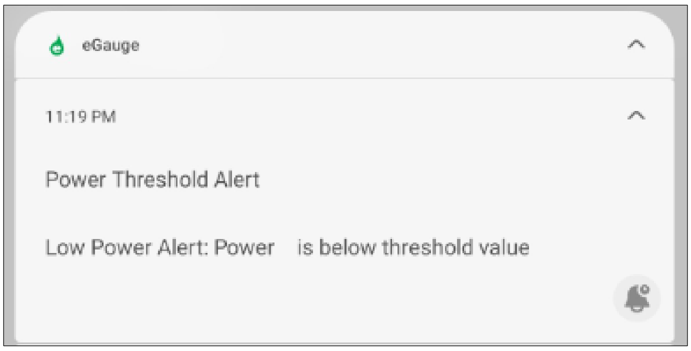

Figure 9 Power Threshold Alert Mobile Alert Notification

The Alert Viewer window as shown in Figure 10 will display additional details regarding the alert. This window contains the time and the date, the detailed custom alert message, the alert priority, and the number of occurrences. From this window the operator may view other alerts or delete alerts if they have been addressed.

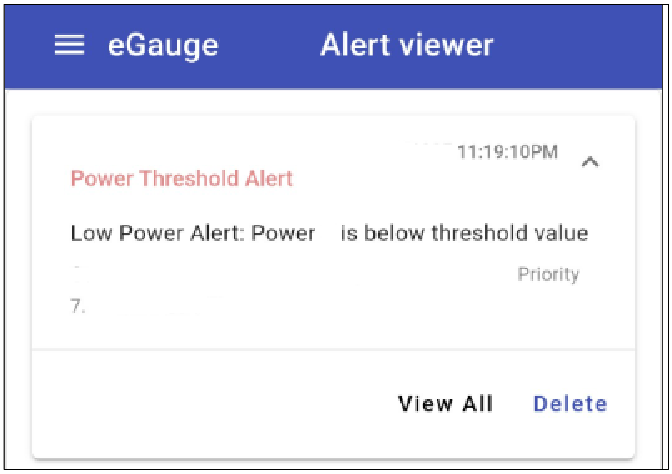

Figure 10 Alert Viewer Window

4. Conclusion

Off-grid PV systems and other types of remote or localized grids are becoming more prominent to address energy concerns. While addressing energy concerns, it has also been a focus to improve sustainability and decrease the lasting impact on the environment; this is where smart grids have filled those criteria. Smart grids are intelligent systems that rely on IoT devices and network connectivity to be reliable and efficient. An important component of intelligent systems is the ability to monitor and communicate remotely. The eGauge smart meter provides this functionality.

The smart meter is like a traditional electric meter, but it has the benefit of Internet connectivity. This allows smart meters to enable a host of remote functions that were not found in traditional meters. The eGauge smart meter records data, stores data, and provides remote access through a web server. Operators can view real-time data for their grid system, view archived data, and make live changes from remote locations on various network connected host devices. These functions minimize the need for 24-hour operators on-site, and reduces the need for physical visits to remote sites. With the real-time data, operators are able to determine when it may be necessary to be physically on-site to address any concerns or grid events. The smart meter is a critical to the smart monitoring architecture.

Collectively, the smart grid architecture is comprised of various intelligent devices that operate together to ensure reliable and efficient operations. Regarding off-grid PV generation systems, the smart meter is the heart of the architecture as it provides the operator with the capability to customize their monitoring system. This monitoring system with the eGauge meter is scalable, customizable, low cost, and may be injected into a live grid. These features minimize disruptions to power generation and help to eliminate downtime. The operator can connect sensors to desired conductors within the system and wire them into the smart meter to measure. Within the meter's web server, the operator may manipulate the settings to identify the sensors as specific registers and generate formulas to calculate values based off of their sensor connections. From the data collected from the registers, the operator may organize it and utilize the variety of native views for data analytics. Recorded data may also be exported for storage in separate databases or fed into external programs for analysis. The analysis of data is crucial to the secure operation of the grid system and the creation of alert notifications.

Alert notifications help to protect the grid and ensure its integrity. Operators determine what conditions are essential to their system and set them up in the alert system to trigger whenever the conditions are met. Power generation from solar energy is paramount to off-grid PV system and that is why it is an important alert. Whenever the power falls below an acceptable threshold for the system, it will supply a custom alert notification to the operator based on how the alert was designed. It could be delivered by email, text, push notification, and/or exported directly to a separate web page. The receipt of on time alerts is necessary for the smart monitoring system to be effective. It will allow the operator to promptly take the appropriate actions to ensure the safety, longevity, and continued operation of the grid.

Off-grid PV systems, much like any grid system, depend on reliable energy without minimal disruptions. Smart monitoring is deployed to improve the intelligence of a grid and to focus maintenance efforts. With intelligent monitoring systems, operators may determine when it is necessary to be on-site or to adjust remotely. Through the collection and analysis of grid data, off-grid systems can fortify themselves against critical events that threaten to compromise their efficient operation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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