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Research paper

Internet of Things (IoT) Scheme in Blank Spot Area for PV Smart Grid System

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Abstract

Application of the IoT (Internet of Things) for energy management systems has been implemented in a wide area. The wireless monitoring on the PV smart grid system commonly is encountered in the urban area which GSM covered area. In this paper, a blank spot area without the GSM signal for data transmitting via internet information is selected to characterized for optimizing the energy monitoring system due to the deployment of this system is in an out of reach area. In practice, this condition occurs in a forest, beach or outermost coverage areas. This monitoring technique of electric power based on the client-server internet of things is designed with the experimental verification using a combination of RF Lora communication for a blank spot area and Wi-Fi module for the coverage sector. In this study, the method used in the monitoring mechanism was using wireless communication via internet Wi-Fi module which can be accessed through a website. This system was conducted in monitoring the current and voltage on the load by using current and voltage sensors, then the data is converted into the power. This system is also capable of performing monitoring via an online system based on the web server and ubiquitous access. This scheme has the capability of reading up to 40A current changes and the change in voltage up to 24V. The data processing on the microcontroller will be stored on the memory card for being data loggers and sent to the web server for the real-time monitoring system wirelessly. This system can be used for the control mechanisms of future smart grid networks based on the IoT (Internet of Things) for the blank spot area without GSM or Wi-Fi connection directly.

Keywords: *IoT (Internet of Things), Lora Communication; Blank Spot area; monitoring system, Smart Grid.*

1. Introduction

Deployment of a pervasive smart grid in the various energy management systems has attractive attention for the industries, researchers or practitioners [1]. The application of the supporting technology based on the smart system was also developed in a wide area and different sectors [2]. The smart grid is a distributed generation system which uses the multiple sources of the energy as a source of the electrical energy including renewable energy sources, micro-grid that can work connected to the distribution network or work independently and monitored remotely [7-10]. The real-time monitoring system of the power system components in a smart grid, along with the connection and in large geographic areas, helps the operators to understand and optimize the behavior and performance of the smart grid system components [5]. The customized renewable energy resources can be developed by using a smart grid technology model to provide the renewable energy utilizing solar energy that is converted into electrical energy to improve the efficiency of electricity use and build a micro-scale generator system [3].

The consumption of the electrical energy in the local area in every year continues to increase, this increase can be caused by the utilization of electrical energy and the use of inefficient electrical equipment. The energy demands of electrical energy in Indonesia have been rise increasingly and becoming an integral part of people's daily needs. This is in line with the rapid development of technology, industry, and information. However, the implementation of electricity supply by electricity industry, as the official body appointed by the government to manage the electricity problems in Indonesia, up to now the fulfill society requirement of electric energy as a whole. The potential of solar energy in Indonesia is very large, it is about 4.8 kWh/m2/day or equivalent to 112,000 GWp, but it has been utilized about 10 MWp only. Currently, the government has issued a roadmap for the solar energy utilization that targets solar power capacity installed until 2025 amounted to 0.87 GW or approximately 50 MW/year. In addition to using solar cells, to build micro-scale systems can also utilize wind turbines. The electrical monitoring systems generally consist of several components designed to identify the conditions of electrical power systems and work on information obtained from such systems such as currents, voltages or power [6]. This paper motivation is to propose the experimental approach of a PV grid monitoring system using an online system. Measured data from PV are logged and transmitted to the server with the internet connection to obtain access information wirelessly. The energy distribution is shown in Figure 1.

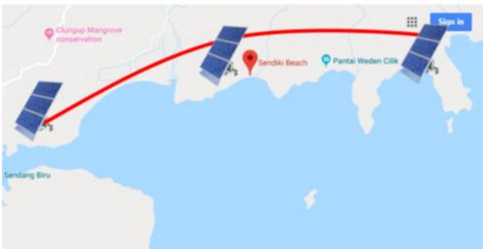

Fig. 1: Distributed energy resource with PV enabling

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2. Fundamental Concept

The fundamental theory to support this experiment comprises smart grid technology, light conversion on photovoltaic, spectral response, temperature dependence and parasitic resistance on the solar cell and PV setup on a smart grid.

2.1. Light Conversion

Silicone solar cells are diodes used with p-type (usually doped boron) and n-type silicon (usually phosphorous). The illuminating light is able to behave in various ways as illustrated in Figure-1. Use the generated power, solar cells must be designed according to replace. The electric field of j at a p-n junction, the electron moves to *n* side and hole to the *p* side. In addition, the ideal flow in the short circuit occurs at the connection with several electron-holes (e-h). In general, the generation of e-h at the p-n connection will accumulate the best. Collected carriers are limited strength only V = 0. The change in a collection is very good if the e-h pair is raised in the area along the diffusion from the other junction. For current I0 is the current without a light on the cell, where cell illumination only adds to the dark current diode city diodes to be (1)

$$I = I_0 \left[\exp(\frac{qV}{nkT}) - 1 \right] - I_L \quad (1)$$

where I_L is the current produced by the light. The light has an effect of shifting the I-V curve to the fourth quadrant where power could be extracted from the diode. The I-V curve characterizes cell characteristics with the same power output as the rectangular area in the lower right quadrant with the output curve in the first quadrant that can be represented as shown in equation (2).

$$I = I_L - I_0 \left[\exp(\frac{qV}{nkT}) - 1 \right] \quad (2)$$

The two limiting parameters are used to characterize the solar cells output for given radiation, working temperature and extent:

a) The short-circuit current (I_{sc}), the maximum current at the zero voltage. Ideally for this case, if V = 0 and I_{sc} = IL. It needs to be concerned that the I_{sc} is directly proportional to the available sunlight.
b) The open circuit voltage (V_{oc}), a maximum voltage at zero current. The V_{oc} values increase logarithmically with increased sunlight. So that, this parameter can be formulated as (3)

$$V_{oc} = \frac{nkT}{q} \ln\left(\frac{I_L}{I_o} + 1 \right) \quad (3)$$

Each point existed on the I-V curve, the results of the current and voltage represent the output of power for the operating conditions. The solar cells could also be characterized by a maximum power point when producing a $V_{mp} \times I_{mp}$ at their maximum value. This maximum output power of the cell is graphically obtained by the largest rectangle which it can be matched under the I-V curve. While $d(IV)/dV$=0, the voltage V_{mp} can be derived to be (4).

$$V_{mp} = V_{oc} - \frac{nkT}{q} \ln\left(\frac{V_{mp}}{(nkT/q)} + 1 \right) \quad (4)$$

2.2. Spectral Response

The solar cell responds to the photons from a light that comes in a way to absorb it to produce electron-hole pairs, provided that the energy of the photon (E_{ph}) is greater than the bandgap energy (E_g). The photon energy that exceeds E_g energy is quickly dissipated as the heat. The solar cell quantum efficiency (QE) is defined as the electrons moving number from the valence band to the conduction band for each photon that deals with the solar cell. The longest wavelength, in this case, is limited by the band gap. The maximum use can only be made from the incoming sunlight if the band gap is in the range of 1.0-1.6 eV. So that, this effect works to limit the maximum efficiency that the solar cell can achieve up to 44%. The silicone bandgap at 1.1 eV is almost optimal, whereas gallium arsenide at 1.4 eV is even better. the dependence of the ideal quantum efficiency on the band gap. The solar cell spectral response is given by the current produced per watt from the light that hits it. Ideally, this increases with the wavelength. Nevertheless, at short wavelengths, cells cannot use all of the energy present in the photons while at the long wavelengths, the absorption of weak light means that the most of the photons are absorbed away from the connection and the limited length of diffusion in the cell material limits the response cell. The responsiveness spectrum (SR) can be formulated as (5),

$$SR = \frac{I_{SC}}{P_{in}(\lambda)} = \frac{q \cdot n_e}{\left(\frac{hc}{\lambda} \right) n_{ph}} = \frac{q\lambda}{hc} \quad (5)$$

where n_e is the electron flux per unit time, which flows in the external circuit in a short circuit connected condition, and I_{sc} is a short circuit current, n_{ph} is the photon flux for the wavelength λ coming on the cell per unit time, P_{in} is the incoming light power and $EQE=(1-R)$. The IQE is an external efficiency, which differs from the internal quantum efficiency (IQE), R is a light reflected from the upper surface. The SR to be 0 due to λ=0. This phenomenon occurs with several photons in each power of incoming light. The wavelengths have a strong influence on the responsiveness, thus making cell performance is very dependent on the contents of the solar spectrum. In addition, the optical loss and recombination loss mean that in reality the cell can only be approached with ideal.

2.3. Temperature Dependence

The solar cells working temperature is assigned by the temperature of the characteristics of the encapsulated module, the surrounding air, the intensity of sunlight falling on the module, and the other variables such as wind speed. The dark saturation current I_0 increases with the temperature according to the equation (6).

$$I_0 = BT^{\chi} \exp\left(\frac{E_{g0}}{kT} \right) \quad (6)$$

where B does not depend on the temperature, E_{g0} is the zero extrapolated linear bandgap of a semiconductor that composes the cell and the γ includes the temperature dependence of the remaining parameters which determine I_0. The short circuit current (I_{sc}) increases with the temperature, because the band gap energy (E_g) decreases and more photons have sufficient energy to make the *e-h* pair. Nevertheless, this is a small effect, for silicon can be formulated as (7)

$$\frac{I}{I_{sc}} \frac{dI_{sc}}{dT} \approx +0.0006°C^{-1} \quad (7)$$

The temperature increasing main effects for the silicon solar cells are the *Voc* reduction, the fill factor, and it also affects the output of the cell. The higher of the *Voc* value, the smaller the expected temperature dependence. The temperature dependence of *Voc* and FF for silicon is estimated by the following equation (8)

$$\frac{dV_{oc}}{dT} = \frac{-\left[V_{go} - V_{oc} + (kT/q)\right]}{T} \approx -2mV/°C \tag{8}$$

2.4. Parasitic Resistance

The main contributors to series resistance (R_s) are resistances that are mostly from semiconductor materials, metal connections and interconnects, transport of carriers through the top of the diffused layer, and contact resistance between metal and semiconductor contacts. Shunt resistance (R_{sh}) is caused by a non-ideal pn connection and impurity near the junction, which causes the connection to be shortened from a junction, especially near the edge of the cell. Because the fill factor (*FF*) assigns the cell's power output, the maximum output power, and the current associated with the series resistance, can be estimated approximatively through the following equation (9) and (10).

$$P_m = P_{mp}\left[1 - \frac{I_{sc}}{V_{oc}} R_s\right] \tag{9}$$

$$I = I_L - I_0\left[\exp\left(\frac{V + IR_s}{nkT/q}\right) - 1\right] - \frac{V + IR_s}{R_{sh}} \tag{10}$$

3. Experimental Method

The method of this research is experimentally conducted by hardware and software design. The system design constructed with PV measurement node, internet connection with web server and client as typical access user. The systems were also measured and validated with experimental verification on data logger and web service application.

3.1. System Design

The system block diagram for this design is shown in Figure 2. Generally, the system block diagram is consisting of more than one node. For each node consists of the PV set, electrical load, solar charge control, energy storage, data monitoring, and wireless sensor module. The controlled mechanism and system coordination contained in a node is monitored via internet connection. Basic online monitoring client-server web service is shown in Figure 3. Each node sends the data from measurement with structure of time, date, voltage, current, power, temperature and humidity from node client to the server. The web server was constructed using PHP web-based programming and MySQL database to accommodate the request and response from client and server.

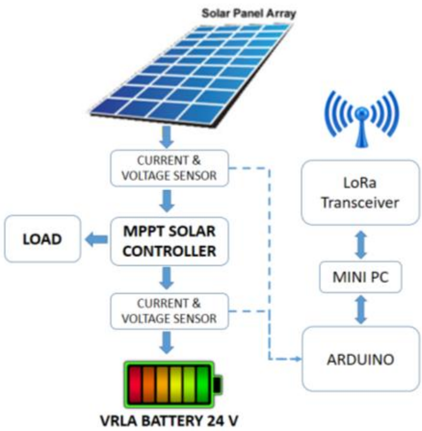

Fig. 2: Design of the online monitoring system

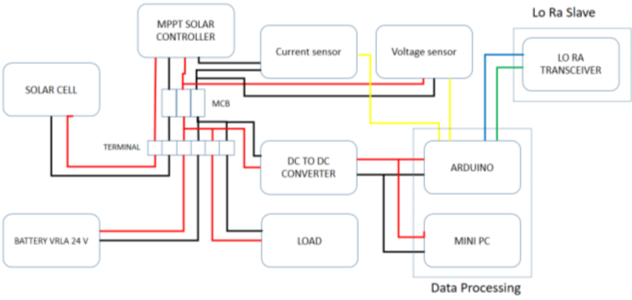

Fig. 3: Wiring diagram system

3.2. Measurement Setup

The measurement in this paper was conducted by testing of the current, voltage and power from the electrical energy toward the sensor data by the change voltage source under light solar illumination. The stored data in the SD card memory is achieved when the measurement process has been conducted and it is used to validate the result data that is provided by the web report. This measurement test is conducted using 200 Wp of PV panel and 100 Ah of sol gel VRLA battery, respectively. PV monitoring measurement device is shown in Figure 4 and Figure 5.

Fig. 4: Sensing and measurement device inside the box

Fig. 5: Measurement Setup of direct light PV conversion

4. Result

The result has shown the measured data from the voltage and current sensor installed in the smart grid system. The current sensor in this case is utilized to measure the current flowing from the PV panel, electrical load, and battery. The measurement itself is performed ten times with a supply voltage is derived from the provided source up to 30 A. The test of the current sensor circuit was used to measure the current flowing at the load in the resistive load form. The voltage sensor is applied to measure the voltage generated by the PV module and battery. The power voltage is limited to the voltage with a range of 0-30 volts and regarded as an input voltage of the voltage sensor circuit which is converted into the input voltage of the analog-to-digital converter (ADC) that can be processed by a microcontroller. Interval time for data processing varying from each minute, 5, 10 and 15 minutes during recorded in the internal memory of SD card and sending wirelessly to the server.

4.1. Online web monitoring

Web observation is prepared by reading the electrical parameters of PV through an internet connection with a bandwidth of 2-10 Mbps through the public domain. Measured data over internet wirelessly using chrome and safari web browser is shown in Figure 6. and Figure 7, respectively. Represented data from these table indicated electrical and physical phenomenon have been recorded. The parameter promises the voltage, current and power from PV, battery and electrical load, respectively. The temperature, relative humidity and PV tilt angle were also measured and monitored wirelessly. There is no different value between direct measurement and monitoring wirelessly through online system.

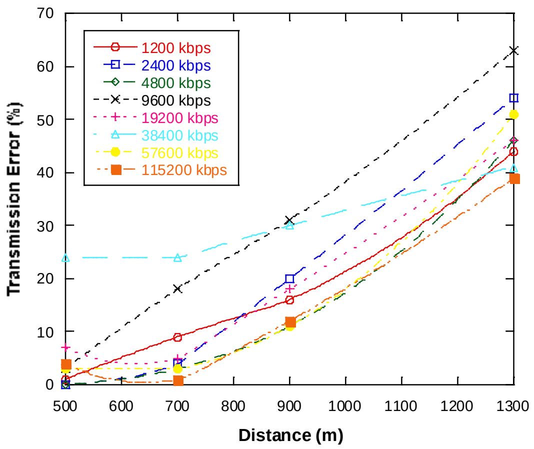

Fig. 6: Distance measurement toward transmission error

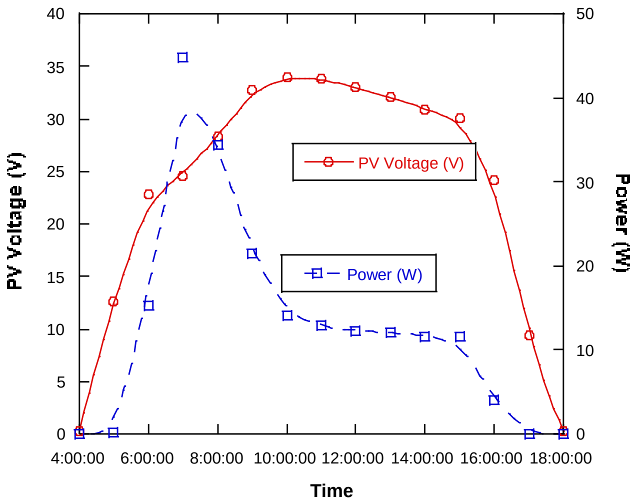

Fig. 7: PV monitoring system on September 4

4.2. Data Analysis

Measured data form from online monitoring system have been recorded and characterized to obtain PV profile during measurement. The voltage and power generated from PV is a representation of the increasing light radiation at midday. this value is also followed by a temperature value that also increases in these conditions. However, the increasing graph occurs at an earlier voltage than the increase in ambient temperature. During the day the relative humidity (RH) decreases from morning to evening. Analysis is needed of spectral scattering against changes in this phenomenon to support existing theories. The influence of temperature and humidity can indicate changes in the power that occurs in the measured PV. The voltage and power that are measurement profiles are shown in Figure 8.

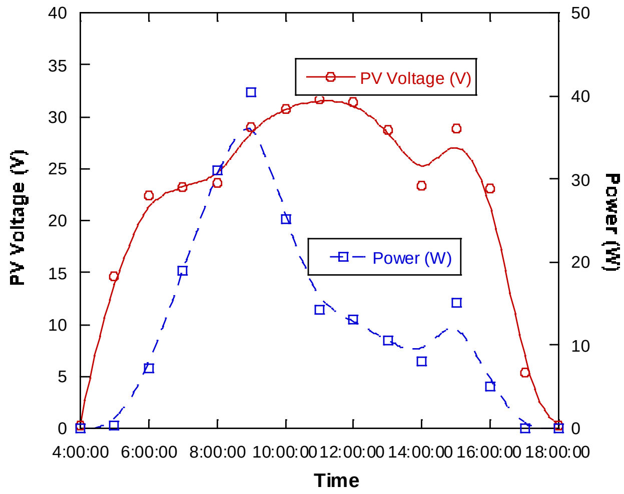

Fig. 8: PV monitoring system on September 7

5. Conclusion

According to the proposed Internet of Things (IoT) design applied in a blank spot area, it shows that this system can be developed and evaluated for transfer data mechanism through data communication lora. Moreover, real-time wireless monitoring method in the rural or remote area can be established by using point-to-point data transfer. This mechanism can be developed for wide-range smart grid, showing that in the remote area. Through this mechanism, real-time monitoring for wide-range of smart grid in the remote area can output so many benefits both in price and accessibility

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