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Solar-Wind Hybrid Power Plant Monitoring Based on Free Libre Open Source Software (FLOSS) Internet of Things

Winasis, Azis Wisnu Widhi Nugraha, Imron Rosyadi, Daru Tri Nugroho and Hari Prasetijo
Department of Electrical Engineering, Universitas Jenderal Soedirman,
St. Mayjend. Sungkono km 5 Kalimanah, 53371 Purbalingga, Indonesia

Abstract: Hybrid power plants are usually located in remote areas with a capacity of power generated is also relatively small. For the purposes of analyzing the performance of the system, the monitoring system becomes very important. Internet of Things (IoT) offers a solution for remote monitoring. On the other hand, the development of embedded devices is increasingly towards lower power consumption. This study proposes an IoT based system for monitoring the electrical energy at hybrid power plant based on Free Libre Open Source Software (FLOSS). The system was built consisting of components of network and internet access, IoT server components and sensor node components. Sensor node components connected to the server through the network and internet access components using the 802.11 protocol. Systems designed using two servers, local and public with local server power requirement is 2 W. The network and Internet access component power usage is 2.4 W and each sensor node requires about 0.3 W.

Key words: Internet of things, hybrid power plant, monitoring, FLOSS based IoT, development, network

INTRODUCTION

Renewable energy utilization such as solar and wind power, curently has become an alternative in the provision of electrical energy, especially in remote locations that are not reached utility power grid. Utilization of renewable energy system not only increase electrification ratio but also help in reducing carbon emissions (Akinyele *et al*., 2015) due to it is clean energy. Conversely, the relatively high cost of electricity of such a remote region increase the competitiveness and promote the wider incorporation of technologies based on renewable energy sources (Petrakopoulou, 2016). Furthermore, the development of renewable energy generation in the remote areas provides benefits for communities that have a positive impact on improving economic, social and cultural conditions.

The concept of hybrid power plant combines several new and renewable energy sources is one alternative solution in overcoming the fuel crisis and the lack of electricity in rural, remote areas and outer islands. The combination of these energy sources is expected to provide continuous power supply with optimum efficiency. Hybrid systems can complement each other and component capacity is better utilized, there by increasing the load factor of the generator, exploiting the renewable energy better and saving on maintenance and replacement costs (Kellogg *et al*., 1996). In the operation of hybrid renewable energy systems, in order to obtain effective and efficient operations, monitoring of plants conditions is necessary to evaluate and determine their performance. Unfortunately, most renewable energy power plants are installed in remote rural areas and have small plant capacity. Consequently, it is quite difficult to reach. Moreover, generation capacity is also limited. For the purposes of analyzing the performance of this hybrid power plant, a remote monitoring system is necessary built. A remote monitoring capabilities provide the information of system condition and research data. Based on this information, preventive maintenance can be carried out to improve the performance and lifetime of the system (Tejwani *et al*., 2014). There by it may maintain plant efficiency and reduce the overall operation cost. Due to the site of the plant in remote areas and limited generating capacity at least, the monitoring system built is expected to meet two basic requirements, namely: a remote monitoring system and low power.

Several studies have been done in the development of power generation remote monitoring systems such as: monitoring locally generating system using a microcontroller in the PV (Photovoltaic) plant (Zahran *et al*., 2010; Fuentes *et al*., 2014) monitoring of PV plants in remote areas by utilizing the GSM as a transmission medium (Peijiang and Xuehua, 2008)

Corresponding Author: Winasis, Department of Electrical Engineering, Universitas Jenderal Soedirman,
St. MayJend. Sungkono km 5 Kalimanah, 53371 Purbalingga, Indonesia

monitoring of PV plants by utilizing the website (Kopacz *et al*., 2014) as well as the monitoring of the solar-wind hybrid power plant using a web-scada through the internet (Soetedjo *et al*., 2014). A comparison between different system with their characteristics is presented (Balasubramanian, 2015).

Today the Internet of Things (IoT) technology has developed quite rapidly. IoT can be defined as a network that connects the "something" (uniquely identified) with the internet. Therefore, it has an ability of sensing or actuating and can be programmed (Minerva *et al*., 2015). By using the concept of IoT, then in principle any "something" can be connect to the internet. "Something" that is connected to the Internet can be a sensor. Thus, the data logging process can be done online.

This study aimed to establish a system to monitor performance of solar-wind hybrid power generation system based on Free Libre Open Source Software (FLOSS) IoT. The proposed system monitor both electrical and also environment parameters of hybrid power plant. Compared to the previous system our system is modular, internet of things based, low power and uses open source software.

MATERIALS AND METHODS

General architecture: Solar wind hybrid power plant monitoring system consists of three main components, network and internet access components, IoT server components and sensor components. Figure 1 illustrates general architecture of proposed monitoring system. Selection of sensing device and monitoring solution consider some key factor, i.e., accuracy, ease of development (Ahmad *et al*., 2016). Furthermore, power consumption of monitoring device is also take into consideration. Network and internet access component is used as data connection between sensor and IoT server. It's consist of a wireless network router and a modem for internet access. On IoT server component sensor's data is stored. Then stored data can be processed via. web interface to make it easy for access and utilized.

The sensor component is used to measures electrical quantities for power plant monitoring. The sensor components was design using wireless communication protocol 802.11 standards to communicate with network and internet access components. Wireless sensors will reduce installation cost and provide greater flexibility (Ahmad *et al*., 2016) whereas the use of WiFi communication protocol provide an advantage of being able to connect with existing local area networks.

Network and internet components: This component is connector between sensors components to the internet. Basically, this component consists of two main parts. First, a 4G/3G GSM modem and a wireless router. 4G/3G GSM router used as system connector to the internet. Wireless router is used to provide local network for sensor component and local server. The usage of 4G/3G GSM modem was based on the network availability. The 3G/GSM network was the widest network in Indonesia. In addition, the hybrid power plant is usually located in remote area where the availability of cable network was

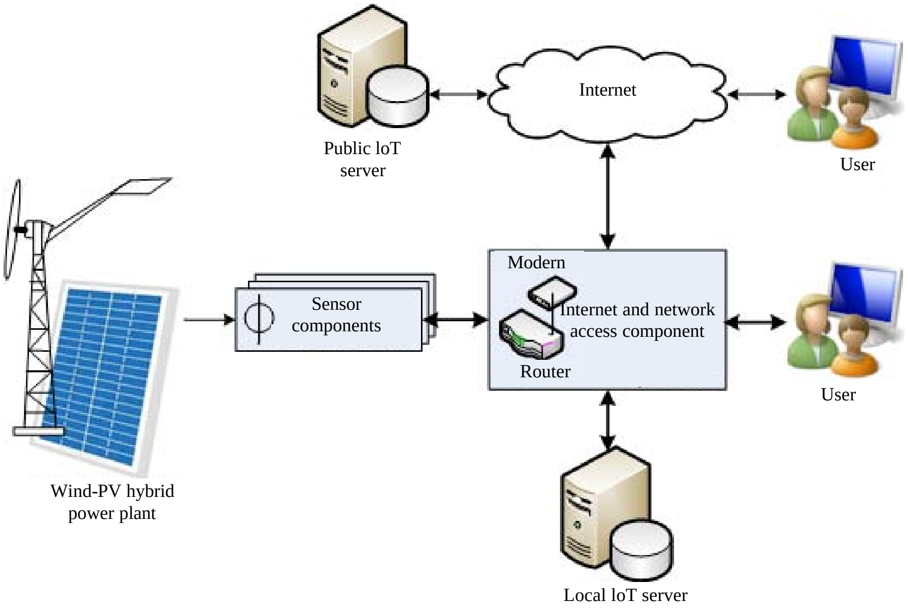

Fig. 1: General system designs

limited or even not exists. Wireless router was used is an open WRT-based router and powered by an Atheros 9331 chip (GL-iNet 6416). Open WRT is ones of Linux distribution that specializes for the embedded system escpecially router. The license of openWRT is free software. Open WRT has some features for connecting into internet using a USB 3G/GSM modem. The wireless router specifications that used in this research was shown in Table 1.

IoT server components: IoT server component was used for storing measuring data and displaying measuring result for further analysis. IoT server software is thing speak (thing speak. com). It has free libre open source software license GNU GPL 3 (http://www.gnu.org/licenses/). Thing speak is web application and API intended to controlling devices, creating devices interactions and storing data. Data delivery and data request on thing speaks using simple HTTP request. Data can be from anything and can be retrieved and further use by other applications such as decision-making and reporting.

Table 1: Wireless router specification

Features	Values
CPU	Qualcomm Atheros 9331, @400 MHz
Memory/storage	DDR1 64MB/ FLASH 16 MB
OS	OpenWRT
Interface	1 WAN, 1 LAN, 1 USB 2.0, 1 micro USB (power) 1 reset button
Working frequency	2,4 GHz
Transmission rate	150 Mbps
Max Tx's power	18 dBm
Protocol	802.11 b/g/n
Storage media format	FAT32/EXFAT/EXT4/EXT3/EXT2/NTFS
Webcam support	MJPG, YUV
IO port's	UART, 5 GPIO
Power consumption	<1 W

On this system design, IoT server component consist of two servers, first a public server on internet working and a local server on local network. Each server act as backup for each other. Public servers were used in the system hosted by www.thingspeak.com. Local server was build based on source code available at https://github.com/iobridge/ThingSpeak. This software was release under free software license.

To meet the low power requirements, local server hardware is use Single on Chip (SoC) device raspberry Pi (raspberrypi.org). In general Raspberry Pi is a credit card sized mini computer with quadcore ARM Cortex-A7 900 MHz processor, 1GB LPDDR2 SDRAM, 5 V power supply and maximum current drawn without USB load is 420 mA. Operating system used on Raspberry Pi 2 is Linux based distribution. Official Raspberry Pi 2 distribution is raspbian.

Connection between network and internet access components, IoT server and sensor component is shown at Fig. 2. From Fig. 2, sensor connected to the local network using WiFi 802.11. Local IoT server connected with Ethernet cable RJ45. Every sensor node will send data to local and public server simultaneously.

Sensor node components: Electrical and environment system parameters was sensed by set of internet connected sensor system called IoT (Internet of Things) sensor nodes. The sensor nodes are wireless which perform three main role: commnunication, computation and sensing (Dehwah *et al*., 2015). Therefore, the node at least consists of three main parts, sensors (i.e., voltage, current sensors or environment sensors), microcontroller for sensor data computation and data transmission to IoT server and WiFi communication modules. Analog

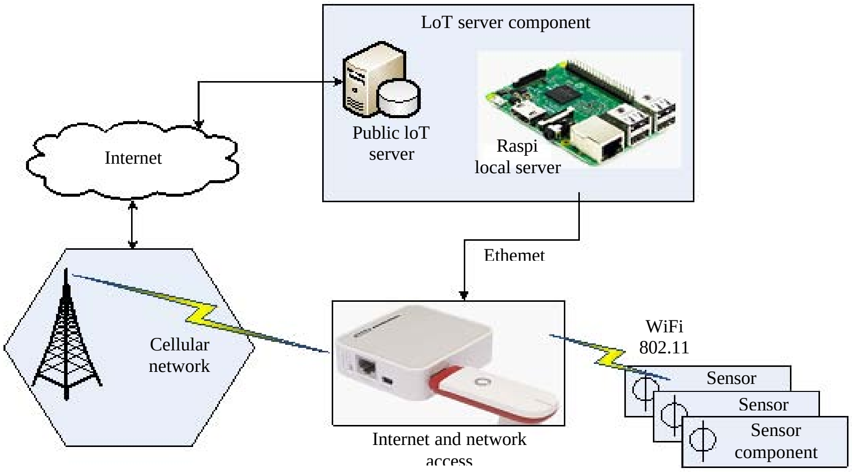

Fig. 2: Connection between system components

quantities from sensor measurement was converted to digital quantities by ADC ports of the microcontroller before computed to the other desired quantities and transmitted to the server using WiFi module. In this research, we use Arduino nano board, an AT mega 38-based open-source microcontroller as the platform for the prototype. The board has eight analog inputs, fourteen I/O digital inputs with PWM input support in 6 of them and a serial communication port. The board has 32 kB flash memory, 2 kB RAM and 1 kB EEPROM with 15 MHz clock speed.

Local and internet communication was handled by ESP8266 an SoC system which can provide WiFi communication 802.11. ESP 8266 has software development kit released with open-source-like MIT licence. ESP 8266. ESP 8266 has some important features such as an ADC port and communication using SDIO, SPI and UART ports. The device may be used as point-to-point communication, AP client or soft-AP. It was powered by a 32 bit low power CPU which can be utilized as an application processor.

Figure 3 shows the sensor node component part. The sensor node has an Arduino as data processing and acquisition device. ESP8266 WiFi module then will send the data wirelessly to the server. The step-by-step processes in the system to perform data measurement, calculation and transmission is described as follows:

- Starting the system
- Initializing communication between Arduino and ESP8266
- Initializing ADC port
- Loops
- Reading ADC values of current sensor
- Calculating current value
- Reading ADC value of voltage sensor
- Calculating voltage value
- Calculating power value
- Sending current, voltage, power and energy values to local and public IoT server

Calculation of current, voltage in Direct Current (DC) circuit is done using average approach from instantaneous sampling data as presented in Eq. 1. For Alternating Current (AC) circuit, effective voltage and current is root-mean-square value while active power is calculated using average of instantaneous power formula (Lea, 2017). Equation 2 and 3 show the AC value calculation:

$$U_{DC} = \frac{\sum_{n-0}^{N-1} u\,(n)}{N} \text{ and } I_{DC} = \frac{\sum_{n-0}^{N-1} i\,(n)}{N} \quad (1)$$

Fig. 3: Sensor components structure

$$U_{rms} = \sqrt{\frac{\sum_{n-0}^{N-1} u^2\,(n)}{N}} \text{ and } I_{rms} = \sqrt{\frac{\sum_{n-0}^{N-1} i^2\,(n)}{N}} \quad (2)$$

$$P = \frac{1}{N}\sum_{N=0}^{N-1} u(n)\times i(n) \quad (3)$$

Where:

U_{DC} and I_{DC} = DC voltage and current

U_{rms} and I_{rms} = AC effective voltage and current

u (n) and I (n) N = Instantaneous sampled voltage and current

P = Real average power

N = Number of sampling data

RESULTS AND DISCUSSION

In this study, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily. The discussion can be made in several sub-chapters.

Developed monitoring system: The IoT based solar-wind hybrid power plant monitoring system developed in this research uses several modular sensor nodes which were placed in plant sub system, i.e., solar PV module, wind plant, battery bank and plant load. Meanwhile, monitoring of environment parameters is done with a separate node. Figure 4 shows hardware configuration of power plant and developed monitoring system. In addition, it is possible to enhance any nodes on different parts of system that necessary to be monitored flexibly. Therefore, the monitoring system can be easily developed following the development of power plants and monitoring data needs.

Parameters of solar wind hybrid system for remote monitoring are measured using sensors then processed by signal processor (Tejwani *et al*., 2014) in microcontroller. For PV system parts, parameters to be measured is referring to the IEC61724 (Fuentes *et al*., 2014). Table 2 show such parameters to be monitored and sensors used.

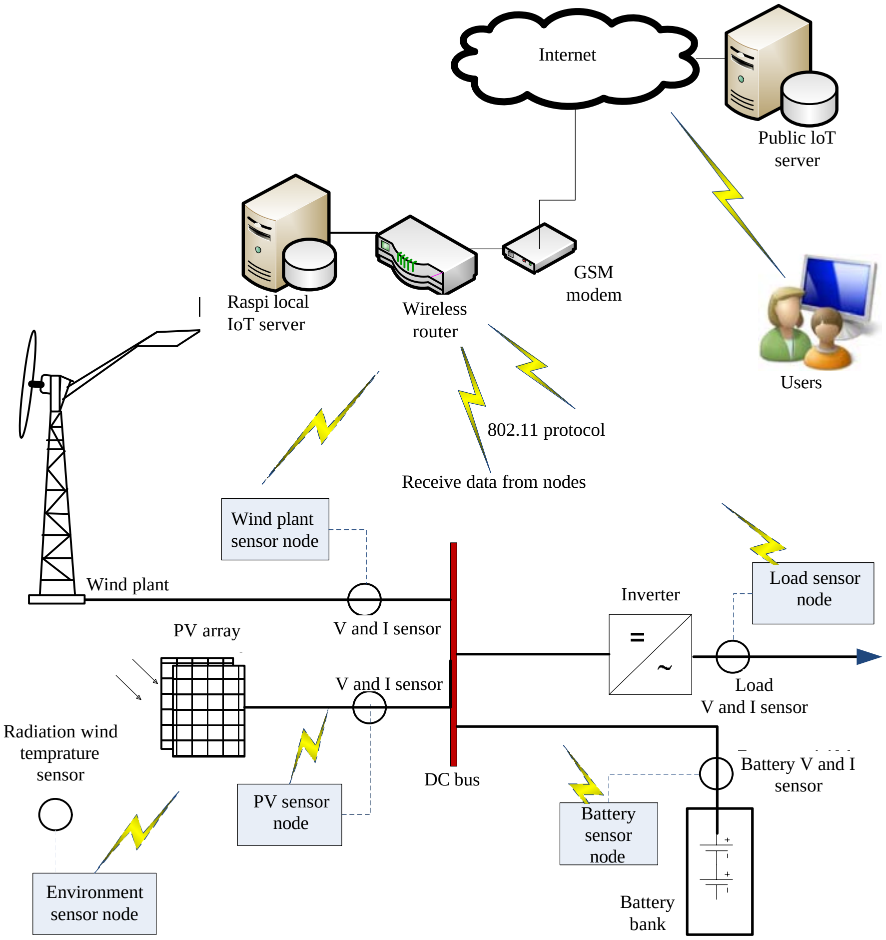

Fig. 4: PV-wind hybrid monitoring hardware configuration

Table 2: Parameters to be monitored

General parameter	Spesific parameter to be monitored	Sensor used
Meteorology	Total irradiance	Pyranometer SP-Lite 2
	Ambient temperature	DHT22 temperature sensor
	Wind speed	Anemometer
	Wind direction	Wind vave
PV array	PV output voltage	DC Voltage divider
	PV otput current	Current sensor (ACS712)
	PV otput power	-
Wind plant	Output voltage	Voltage divider
	Output current	ACS712
	Output power	-
Storage (battery)	Storage operating voltage	Voltage divider
	Storage current (to or from battery)	ACS 712
	Storage power (to or from battery)	-
Load	Load voltage	AC voltage sensor
	Load current	AC current sensor
	Load power	-

Two typical electrical sensors, voltage and current sensors are applied to measure electrical quantity in each sub system. Voltage divider or voltage sensor is utilized for voltage measurement in both DC and AC system. For current metering, bidirectional hall effect current sensors ACS712 are applied since it can measure current flow in forward and backward direction. Others electrical quantities such as electric power can be computed from the voltage and current records.

Different calculation methods are applied to measure electrical parameter in each power plant sub system. Electrical energy from PV array and battery is a direct current whereas electrical energy from wind power plant can be direct current or alternating current. At the same time on load side an inverting device transform electricity from direct to alternating current to supply AC load. In this case calculation of voltage, current and power on each side is solved using Eq. 1-3.

In order to quantify environment paramaters or meteorological data such sensors and measuring instruments are employed. First, apyranometer SP Lite 2 measure and quantify solar radiation om the surface. It is a compact and light weight sensor which receives solar

Fig. 5: Anemometer and wind vane to measure velocity and wind direction

energy from the entire hemisphere in its view and produces a small voltage output that can be converted into the radiancein Watts per square meter. On the other measurements an anemometer readswind speed while wind vane detects wind direction data. Then DHT 22 temperature sensors sense temperature and humidity variable (Fig. 5).

System test and implementation: The proposed monitoring system is designed to monitor installed solar wind hybrid power plant located in District of Kalimanah purbalingga, Central Java Province, Indonesia. Figure 6 shows the existing power plant to be monitored. The plant consist of three Photo Voltaic (PV) arrays with capacity are 200, 300 and 1000 Wp. Wind turbine generators have total capacity 1 kW. They supply electrical energy to 24 V nominal DC bus which is connected with 17 kWh battery bank. The plant supply AC load trough 1 kVA inverter.

The monitoring system is tested and measurement errors of system components are calculated using calibrated instruments. Errors are calculated using Root Mean Square Error (RMSE) formula from collected data. Table 2 presents the test results. Based on the results of this test indicates that the sensor components are able to read the electrical quantities and environmental parameters accurately with an error value below 1%.

Fig. 6: Existing solar wind hybrid system in Kalimanah Purbalingga

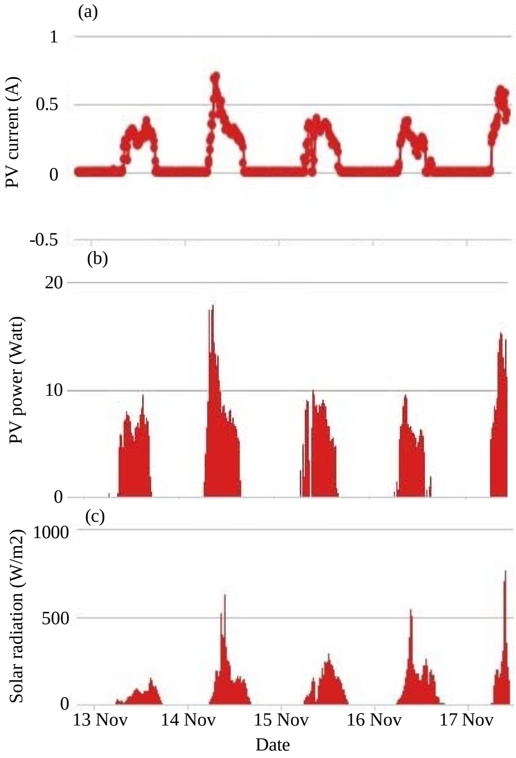

Fig. 7: Monitoring data view through web browser

To test the performance of the monitoring system that has been made, the observation of the data sent to the server through a web browser. Figure 7 presents the

Table 3: Measurement test results

Sensor module	Measurement test range	Measurement error (RMSE)	Calibrated instrument
Pyranometer SP-lite 2	0-1000 W/m^2	0.095 W/m^2	Solar power meter TES1333R
DHT 22 temperature sensor	24-37°C	0.0097°C	Standard termometer
Anemometer	0-12 m/sec	0.03%	Digital anemometer
Wind vane	0-360°	0	Standard compass
DC voltage divider	0-30 V	0.063 V	Standard voltmeter
DC current sensor	0-10 A	0.091 A	True RMS AC/DC current clamp meter
AC voltage sensor	0-220 V	2.102 V	Standard voltmeter
AC current sensor	0-10 A	0.017 A	True RMS AC/DC current clamp meter

Table 4: Devices power consumption

	Power cnsumption	
Component	24 h energy (Wh)	Average power (W)
Network and internet access component	2.24	2.24
Local server component	50.00	2.08
Sensor component (each node)	7.40	0.30

sample view of monitoring data accessed through a web browser. It can be seen that monitoring system devices can transmit monitoring data accessible through the website. The time-lapse design of monitoring data transmission is every 1 min. In fact, the average time of sending monitoring data to server is 58 sec or there is deviation of delivery time about 2 sec (3.3% from design). The test results show the system is able to transmit the monitoring data reliably.

System power consumption: In order to ensure the low power consumption requirements, the hardware monitoring system is tested in the laboratory by measuring the power requirements of each component. 24 h devices energy consumption are measured under normal research condition. Then from these we can compute average power consumption of devices by dividing energy with time. Table 3 show the power requirements of the system component have been built.

Overall, if the system consists of five nodes, namely node monitors the PV, the wind plant, the battery and the load with sensors on each node then the whole system requires less power than 6 W. Table 4 system power consumption.

CONCLUSION

The system built is suitable to meet the needs of monitoring the performance of hybrid power generation system in remote location precisely using relatively low energy. The system consist of network and internet component, IoT server component and several wireless node sensor component. Flexibility of data access makes the user can access the system from anywhere over the network connected to the internet. Whereas, the use of modular wireless sensors has the advantage of a more flexible installation and easier development. The system was made can be developed further to establish a decision-making and reporting system even remotely control the system. In addition the system components that was used allows the addition of a digital camera for visual location monitoring.

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