Low-cost Hierarchical Monitoring System for Solar Photovoltaic Systems

Hyeonkyu Kim[*], Soyeon Choi[*], Yeonshin Joo[**], Woocheol Shin[**], Hoyoung Yoo[*]
[*]Chungnam National University, [**]Dong Yeok Engineer
hkkim.cas@gmail.com, sychoi.cas@gmail.com, dydusnew14@gmail.com,
shwoch@gmail.com, hyyoo@cnu.ac.kr

Abstract

In this paper, the proposed monitoring system adopts a hierarchical configuration, in which the low complexity sensing node measures voltage, current and temperature data of each PV cell and the high complexity sensing node analyze data from the low complexity sensing nodes. According to the experimental results, the proposed monitoring system improves data efficiency by 30% by removing unnecessary data transmission, and reduces total building cost more than 40% by employing a mix of many low-end and few high-end sensing nodes. In addition, the proposed monitoring system can quickly detect and identify the impaired PV solar cell within whole PV system.

Keywords: Solar photovoltaic monitoring, Bluetooth Low Energy

1. Introduction

The power generation efficiency of a solar power plant varies depending on the amount of incoming light or the state of the photovoltaic (PV) module. A typical solar power plant is additionally equipped with a monitoring system to manage solar power plant. These monitoring systems have increased in demand as solar power plants become popular. In general, PV plants consist of PV cells, the smallest units that convert sunlight into electricity, PV arrays, a collection of solar cells to generate large units of power, and inverters that convert DC power generated by PV arrays into AC, as shown in Fig.1. the conventional solar monitoring system collects power data on the level of PV arrays, and the accumulated power data are used to detect failures and analyze power efficiency of the whole solar PV system. However, the traditional monitoring systems suffer from several failure miss and late failure response, and it also requires time consuming manual inspection to find an exact impaired PV cell position within the PV array [1]. To mitigate this problem, we present a hierarchical monitoring system by employing the

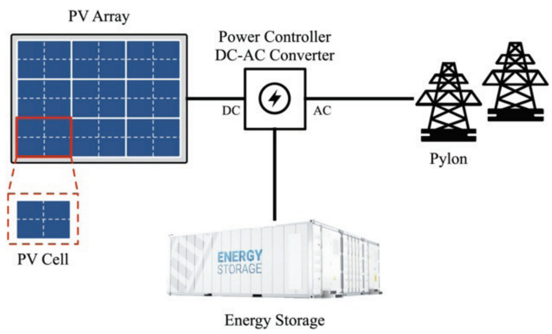


Fig. 1 Typical structure of PV system

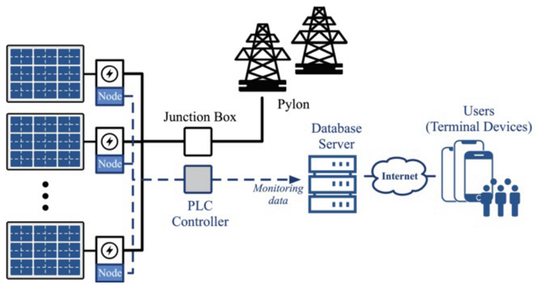


Fig. 2 Conventional PV monitoring system

natural configuration of PV plants. A low complexity sensing nodes are attached to each PV cell, and a high complexity sensing or communication nodes are attached to each PV array in a hierarchical manner. Aa a result, the proposed system can reduce maintenance cost required to inspect an exact position of faulty PV cell, and decrease the total build cost of monitoring nodes using the proposed configuration.

2. System configuration

Conventional monitoring systems [2-5] typically use Power Line Communication (PLC) or a separate communication line to monitor the status of a PV array at the inverter level. As shown in Fig. 2, the monitoring information collected at PV arrays is transmitted to the database server through the communication controller of power plants. Using the internet connection, a user can monitor the status of a

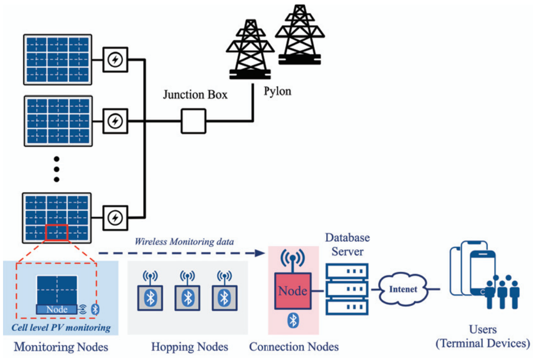


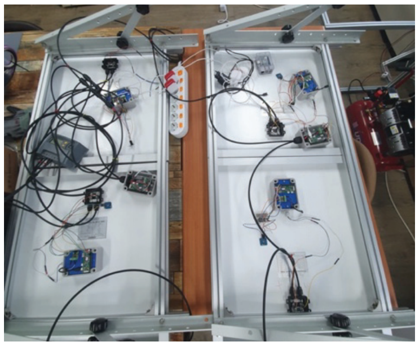
Fig. 3 Proposed hierarchical monitoring system

total PV plant through a terminal device such as smart devices. However, conventional monitoring systems can provide only monitoring information at the PV array level not PV cell level due to the position of sensing nodes. Thus, manual inspection is inevitable to search the position of the problematic PV cell within the problematic PV array. This means additional manpower is required to manage the solar power plants when adopting the conventional PV monitoring system. One straightforward solution is to employ a sensing node at each PV cell, but this solution suffers from high build cost although it succeeds providing precise monitoring information at PV cell level.

To alleviate this problem, we propose a low-cost hierarchy monitoring system according to the natural structure of solar power plants. As shown in Fig. 3, the proposed monitoring system composes of three layers; monitoring node, hopping node, and connection node. The low layer or monitoring node measures electrical status at each PV cell to provide a precise PV monitoring information. The middle layer or hopping node equipped at each PV array distinguish effective information among received information from the low layer and retransmit meaningful information to the high layer. The high layer or connection node uploads all the received data to a data server so as to provide a real time monitoring access to a user. Note that Bluetooth low energy (BLE) is used to communicate between layers to adopt advantages of a low cost wireless communication.

The low layer, also called the monitoring node, performs voltage, current, and temperature monitoring for a PV cell. The monitoring node collects real-time voltage, current, and temperature information of each PV cell from voltage, current and temperature sensors connected by a serial I2C interface. The collected monitoring information is transmitted to the middle layer through broadcast packets of BLE. The transmitted data can be distinguished based on the Bluetooth address and the user defined name. More importantly, the monitoring node may not transmit data to the hopping node when the solar cell operates normally to maintain the data transmission efficiency of the monitoring system.

(a) Solar power plants testbed



(b) Monitoring nodes at back side of testbed.

Fig. 4 Proposed PV monitoring system testbed

Through this function, the proposed system increases the data transmission efficiency.

Next, the middle layer, called the hopping node, serves as a repeater for receiving and retransmitting monitoring information transmitted from a monitoring node. Eventually, monitoring information is delivered to the connection node physically separated from the monitoring node by going through the hopping node. Unlike the other layers, the hopping node includes a communication distance extension module for improving the communication range of the BLE.

Finally, there is a higher layer called the connection node. The connection node receives the meaningful information of the monitoring nodes transmitted through the hopping node and reformats the data into a uploadable form to the database server. The reformatted monitoring information is uploaded to the database server over the IEEE 802.11n wireless Internet. The monitoring information uploaded to the database allows the user to access information on each PV cell through terminal devices such as a smartphone, tablet, or PC.

3. Experimental result

To apply the proposed hierarchical monitoring system to the practical solar power plant and investigate the build cost of system, we prototyped the monitoring system in 2kW test bed with ten 200W PV array consisting of four 50W PV cells in Fig. 4.

Node type	(a) Parallel	(b) Serial
Current Sensor	-	INA226
Voltage Sensor	INA226	-
Temp Sensor	LM75A	-
MCU	BCM2835 SoC	
Bluetooth Spec	BLE 4.0	
Serial Interface	I2C Standard mode	

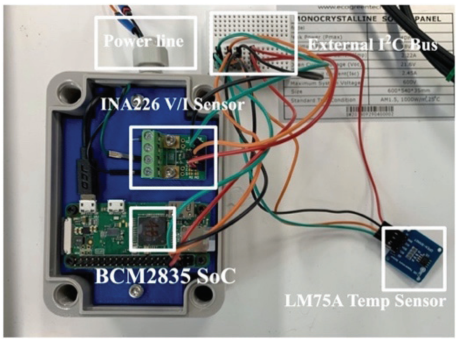


Fig. 5 (a) Parallel type monitoring node

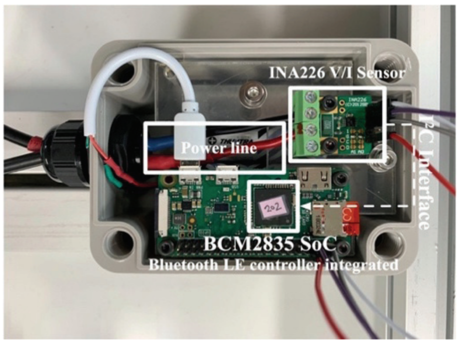


Fig. 5 (b) Serial type monitoring node

Figure 4(a) depicts the entire testbed and Figure 4(b) shows the monitoring nodes equipped at the backside of each PV array. More precisely, Fig. 5 shows the prototype monitoring node, which consists of a Host Micro Controller Unit (MCU) with a built-in Bluetooth controller and an IC sensor module that measures the voltage, current and temperature of the PV cells. Since the PV array is a form of PV cells connected in series or in parallel, we developed two types of monitoring nodes; (a) parallel monitoring nodes which measures the voltage and temperature of unit cells at parallel connection (b) serial monitoring nodes which measures the current at serial connection. Figure 6 depicts the prototype hopping node, which includes a USB interface low-power Bluetooth module with 1.9dBi dipole antenna to extend the communication range of low-power Bluetooth and Host MCU to control the Bluetooth controller. Figure 7 shows the prototype connection node, which consists of Host MCU that supports IEEE 802.11n wireless LAN connection. The connection node requires Internet communication to upload the monitoring information to the database server. Lastly, the prototype we built can also access information in the database from smart devices such as a table PC or

Node Type	Hopping
MCU	BCM2837 SoC
Bluetooth Extender	LM1010
Bluetooth Spec	BLE 4.0
Communication Range	110m (measured)
Antenna	1.9dBi

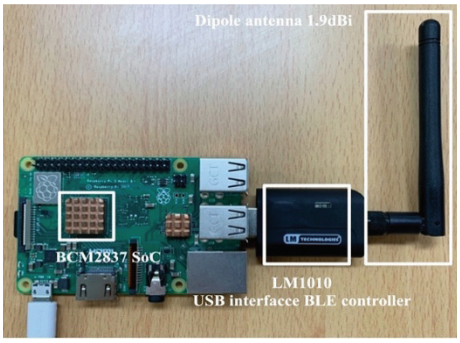


Fig. 6 Hopping node at the middle layer

Node Type	Connection
MCU	BCM2837 SoC
Bluetooth Spec	BLE 4.0
Wireless LAN	IEEE 802.11n

Fig. 7 Connection node at the high layer

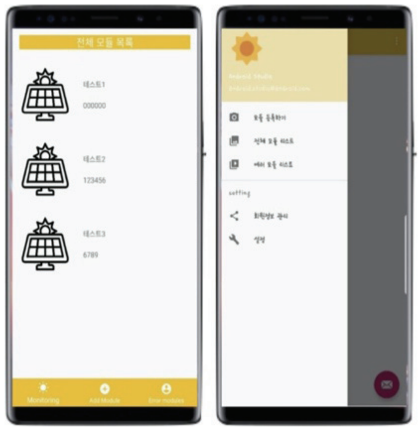


Fig. 8 PV Monitoring user application

smartphone. As shown in Fig. 8, the status information of each PV cell can be monitored and managed by the developed user android app. As a result, the proposed monitoring system carefully tested using integrated PV testbeds.

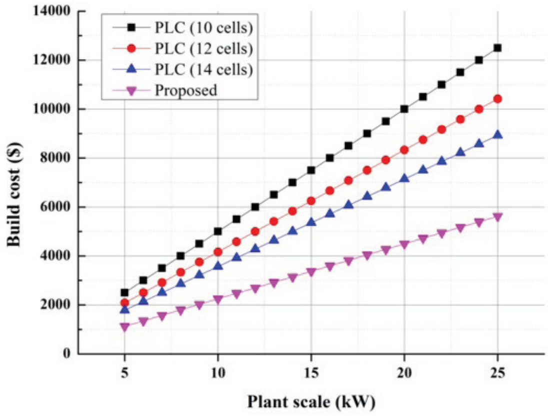


Fig. 9 Build cost comparison via plants scale

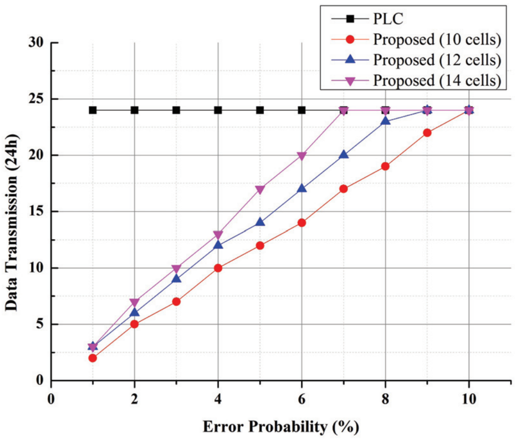


Fig. 10 Data transmission comparison via error probability on a PV cell

Furthermore, we analyze the build cost of proposed monitoring system according to the size of solar power plants (kW) compared to the previous PLC monitoring system. The proposed monitoring system uses the mix of the low-cost sensing nodes and medium-cost hopping and connection nodes in a form of hierarchical configuration, but the previous monitoring system places the high-cost sensing nodes at each PV array. Since the total building cost for the previous monitoring system varies as the number of PV cells constituting PV array, we estimate three types of PV array configurations for the previous monitoring system. As shown in Fig. 9, on average the proposed system requires 44% less construction cost than a commercial PLC monitoring system.

Figure 10 depicts data transmission efficiency according to an error probability on a PV cell. We assume that the period of the monitoring system is 1 hour for data transmission efficiency analysis. The conventional system transmits 24 monitoring data to the server during a day, but the proposed system transmits monitoring data to the server only when the PV cell does not operate normally. When an error occurs at k cells in a PV array composed of N cells with a probability of p during 1 hour, the average transmission for the proposed system can be obtained as

$$\begin{aligned} data\ transmit\ &= \sum_{k=1}^{N} {}_{N}C_{k} \cdot p^{k} \cdot 24 \\ &\approx {}_{N}C_{1} \cdot p \cdot 24 \end{aligned} \quad (1)$$

Based on (1), Fig. 10 graphically shows the number of data transmissions according to the probability of error in a PV cell. As shown in Fig. 10, the proposed system has 37% fewer data transmissions for 5% error probability of a PV cell.

4. Conclusion

The proposed low cost hierarchical solar monitoring system supports the PV cell level monitoring by constructing a layered monitoring node. Monitoring at the PV cell level requires less manpower to manage solar power plants compared to conventional monitoring systems. In a typical environment, where the PV array consists of 10 to 14 cells, it takes 44% less build cost and 37% less data transmission than conventional monitoring system. The proposed low-cost monitoring system which provides the low-level monitoring can be magnificent solution when trying to operate a solar power plant with limited manpower and cost.

References

[1] B. Oh and J. Lim, “Fault Detection of PV module for Photovoltaic System”, *2016 Korea Society for Precision Engineering (KSPE) Autumn Conference*, 2016

[2] C. Kim, J. Kim and K. Jang, “An Implementation of Realtime Remote-Monitoring System for Distributed Photovoltaic Power Plants”, Journal of the Korea Institute of Communication Engineering, Vol. 19, No. 10, pp. 2450-2456. Oct 2015.

[3] H. Je and Oh Yang, “Remote Monitoring System of Photovoltaic Inverter using Zigbee Communication”, Journal of Korea Institute of Information Technology, Vol. 10, No. 2, pp. 94-101. Feb 2012.

[4] H. Je and Oh Yang, “Remote Monitoring System for Photovoltaic Inverter using a Smartphone”, Journal of Korea Institute of Information Technology, Vol. 10, No. 1, pp. 241-249. Jan 2012.

[5] A. Gupta, R. Jain, R. Joshi and R. Saxena, "Real time remote solar monitoring system," *2017 3rd International Conference on Advances in Computing,Communication & Automation (ICACCA) (Fall)*, Dehradun, 2017