IoT-Based Smart Photovoltaic Arrays for Remote Sensing and Fault Identification

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Abstract. In this paper a smart remote sensing prototype for fault detection and identification of photovoltaic arrays is presented. A simple fault detection and identification algorithm has been incorporated into the designed prototype. The designed system detect automatically the fault, and then identify the origin of some investigated faults (such as open circuit, short circuit, dust accumulation and shedding effect). The prototype has been tested experimentally at the Renewable Energy Laboratory of Jijel University, Algeria. The experimental results showed the capability of the prototype to remote sensing, detecting and faults identification. The status of the system can be checked online via a website using Internet of Things (IoT) and the user could be also notified by a SMS.

Keywords: Photovoltaic · Monitoring · Faults detection and identification · Remote sensing · IoT

1 Introduction

With reference to IEA, the overall capacity of photovoltaic (PV) installations around the world is about 500 GW [1]. Millions of PV plants were installed worldwide, so in order to avoid losses due to some faults, the status of the systems should be checked and monitored online. Some equipment are recently commercialized, however, most of them are mainly used to protect and isolate the system from faults [2], and they are not able to identify the type of faults, even to predict the nature or the origin of the faults.

Recently, some works have been started to develop and incorporate intelligent fault detection and diagnosis methods to detect and diagnosis of PV plants [3]. However, designing a sophisticated equipment that can detect, localize and identify different faults remain a challenging issue. Remote sensing of PV plants paly a very important role in supervising and monitoring of the plants, in addition, remote sensing and monitoring abilities can provide the information in advance when any abnormal happen on the PV plant without any additional efforts, particularly in plants located in inaccessible areas (e.g. remote Saharan areas in Algeria).

Internet of Things (IoT) has attracted enormous attention from different sectors including renewable energy applications. It enables communication and data sharing among a wide variety of devices, by using the Internet or others networks, without

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human interaction. Furthermore, the IoT can help users in checking and identifying malfunctioning of the systems in real time (online) [4]. The main role of the application of IoT in PV systems is to make it possible to access and check the status of the plant remotely via Internet.

Recently, there are some attempts about remote sensing, monitoring, fault detection and diagnosis of PV plants based on IoT. For example in [5], the first real-time remote monitoring of PV system was developed based on a low cost ZigBee wireless network, the system allows to control the power point. In [6], another application of remote sensing of solar power generation system using a ZigBee network. According to the authors the designed remote monitoring system can help users by decision-making reference to the safe operation and daily maintenance as well as management of PV power generation. An effective implementation of an intelligent remote MS for solar PV Power Conditioning Units (PCU) is presented. The system can be installed in solar PV-PCU to provide support for management and maintenance operations, is proposed in [7]. The most application of IoT in photovoltaic array are reported in [8] including monitoring, control, supervisor and remote sensing. A smart monitoring device has been designed in [9], the device is integrated with a PV module and can transmit data to IoT central for energy management and control of a PV array. An on-line IoT based remote monitoring system for PV arrays is proposed in [10], the authors also proposed a fault diagnosis approach based on extreme learning machine. In [11] the authors designed a low cost IoT based embedded photovoltaic monitoring system using a GPRS module.

In our previous works we have designed an IoT based prototype for monitoring current and voltage data of a PV array, as well as environmental data (such as air temperature and in-plane solar irradiance) [12], and then we have designed a low–cost prototype for monitoring data and fault detection of a stand-alone PV system [13]. The main contribution in this work is to implement and verify experimentally a new fault detection and identification procedure, as well as improving the low-cost prototype presented in [12, 13]. The investigated faults are short circuit, open circuit, dust accumulation, and shading effects on a PV array.

The paper is organized as follows: Sect. 2 presents a description of the investigated PV array, the experimental design, including procedure development and prototype designing. Results and discussion are reported in Sect. 3.

2 Methodology and Materials

The investigated PV array is installed at the RELab of Jijel University (Algeria). It consists of 18 PV modules, 12 storage batteries, two regulators and one inverter. More details about the system can be found in our last papers [12, 13]. The experiment has been carried out at the RELab, the investigated system consists of 3 PV modules connected in parallel, PV module specifications are reported in [13]. Figure 1a shows the facility test and Fig. 1b depicts the designed prototype, it consists of an acquisition board using an Arduino Mega 2560 microcontroller, a 16 $\times$ 4 LCD display to show the system status and monitored data in real time, a CDN package in MatLab environment has been used instead of using the ESP-01 Wifi [13], for data transmission to a host PC.

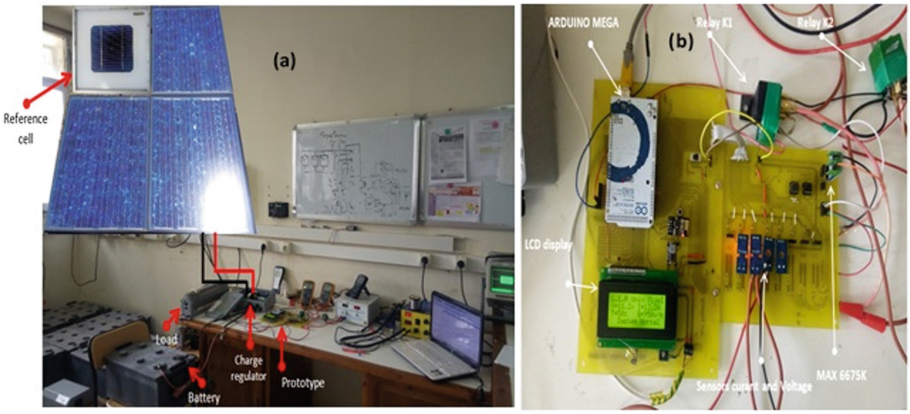

Fig. 1. (a) Test facility at RELab., Jijel University (b) Photo of the designed prototype

The employed components are reported in the following Table 1. The total cost of the prototype is about 72 euros.

Table 1. The used components, specifications and cost.

Component	Specification	Cost (Euro)
Current sensor	ACS712 (Imax = 30 A)	11
Voltage sensor	DC < 25 V	5
Temperature sensor	Max6623 Type K	10
Reference solar cell	Isofoton	15
Arduino mega2560 board	ATMEGA256016AU1738	23
Relay	MAXTOR (30 A–12 V)	5
LCD	LCD 16 × 4	6
		72 Euros

In the literature, numerous transmission techniques were developed for monitoring purpose, most typically the Ethernet or Zigbee wireless technology, etc. The well-known one diode model is used to estimate the produced output power. A detection and identification algorithm has been developed using MatLab and implemented into the Arduino Mega board for an experimental verification. The procedure of the process is shown in Fig. 2, it can be mainly divided into three parts:

- *Acquisition*
  It consists of collecting some physical parameters such as cell temperature, PV voltage, PV current, and in-plane solar irradiance (See Fig. 2 *Acquisition part*).
- *Detection*
  The detection part aims to detect the presence of any fault in the PV array. To do this, a simple comparison between measured (P_{max_mes}) and estimated (P_{max_cal})

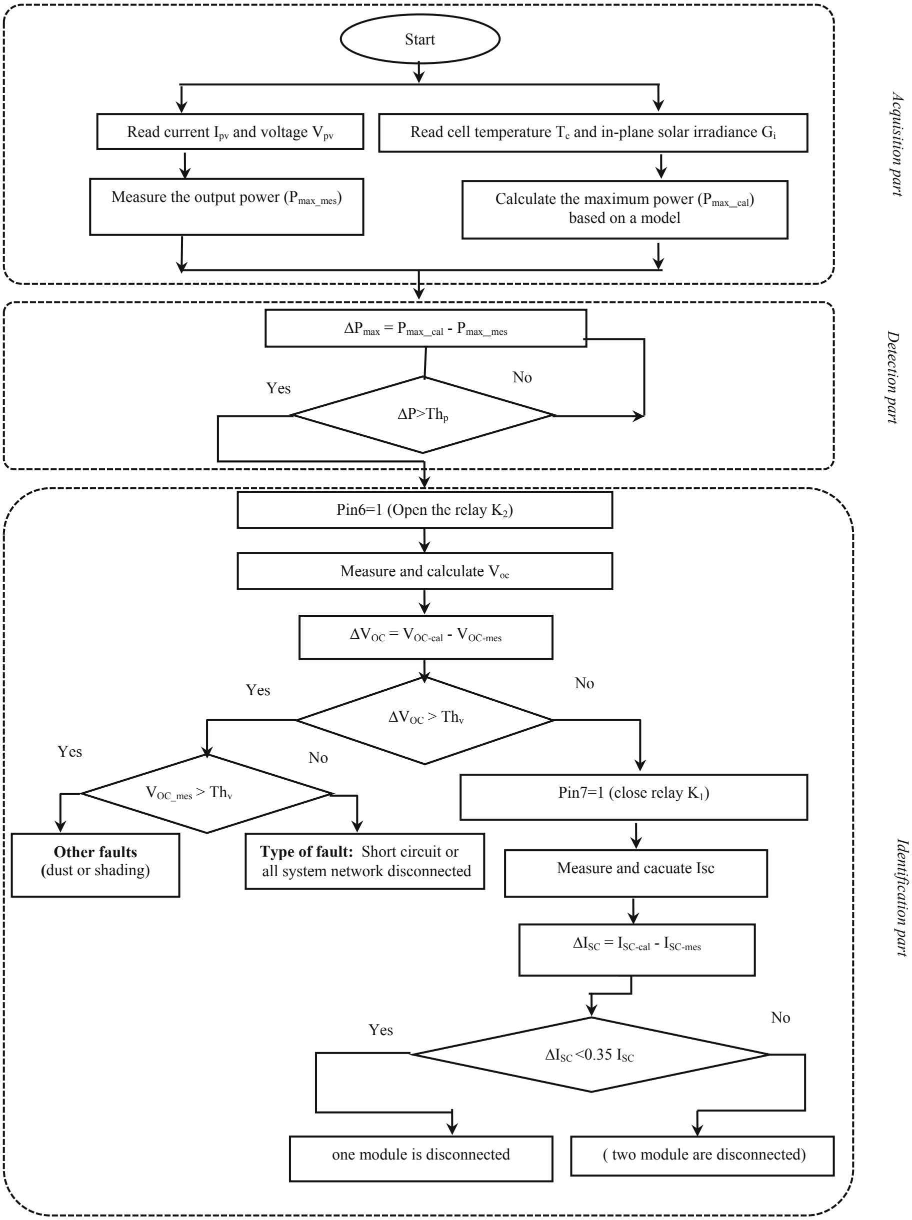

Fig. 2. Flowchart the designed procedure (detection and identification)

maximum powers under the same operating conditions, $\Delta P_{max} = P_{max\_cal} - P_{max\_mes}$ (Fig. 2, *Detection part*). A threshold Th_p has been defined after several experiments ($Th_p = 0.25$ W).

- *Identification*
  Once a fault is detected, the next step consist to determine the type of this fault. In the case of the presence of fault $\Delta P_{max} > Th_p$, so a decrease in the measured power is observed, it means that a decrease in the amount of voltage (V_{pv}) or current (I_{pv}). To identify the type of the fault, we are based on the analysis of the variation of the current $I_{pv}(t)$ or the voltage $V_{pv}(t)$ as a function of time. Thus, the identification process begin by measuring the open circuit voltage (V_{oc_mes}), so this isolation was done by opening relay K_2 (See Fig. 3). We start by comparing this quantity $\Delta V_{OC} = V_{OC\text{-}cal} - V_{OC\text{-}mes}$. There are two cases:

(1) In the case of the deviation ($\Delta V_{oc} < Th_v$), the threshold Th_v ($Th_v \approx 0.5$ V), it means that the fault don't affect the voltage, so we can exclude three types of faults (short circuit, shading effect and disconnected network), because the voltage in these types would be zero ≈ 0 V, except in the case of shading effect, less decrease in V_{OC}. As the PV modules are connected in parallel, one PV module can produce the same output voltage. So there is a possibility that one or more PV modules are disconnected. Thus, to identify the number disconnected PV modules, the short circuit current should be measured (I_{SC}_mes) and compared with the calculated one (I_{SC}_cal), and compute the difference ($\Delta I_{SC} = I_{SC}$_cal $- I_{SC}$-mes). The system isolation is done by closing relay K_1 (See Fig. 3). If ΔI_{sc} is less than 0.35 Isc_cal, one module is disconnected, otherwise two PV modules are disconnected.

(2) In the case of the deviation ($\Delta V_{oc} > Th_v$), it is necessary to re-examine the losses in voltage with respect to the threshold Th_v. If $V_{oc\_mes} < Th_v$ we conclude that there is a short circuit or our system is disconnected totally, otherwise other faults are happened, such as shading effect, dust accumulation, etc.

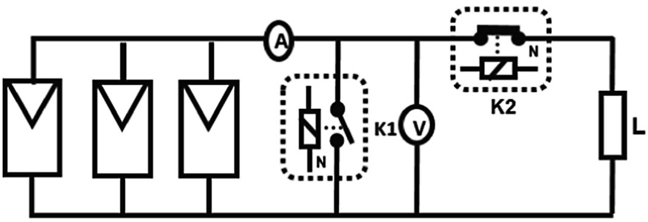

Fig. 3. Electrical circuit for measuring V_{OC} and I_{SC} using two relies K_1 and K_2

3 Results and Discussions

The experiments have been carried out on 7th July 2019. After connecting to the server, the data from the system have been sent to the network via IoT. The results can be displayed online on the designed webpage. So, the investigated faults are shown in Fig. 4, open circuit, dust accumulation, short circuit and shading effect.

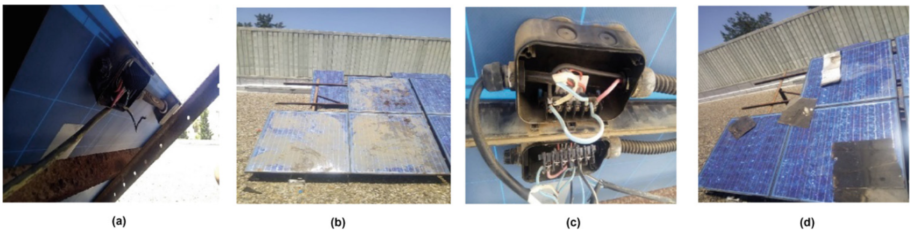

Fig. 4. The investigated faults: (a) open circuit, (b) dust accumulation, (c) short circuit and (d) shading effect.

To check the effectiveness of the procedure an experimental test has been carried out. Figure 5 shows the current variation *I(t)* during this PV modules test. As can be seen for Fig. 4, the variation of $I_{SC} \approx 19$ A, (it means three PV modules are connected, normal operation), in the case of $I_{SC} \approx 13$ A (one PV module is disconnected) and in the case of $I_{SC} \approx 6.2$ A (two PV modules are disconnected). This result demonstrate the effectiveness of the procedure.

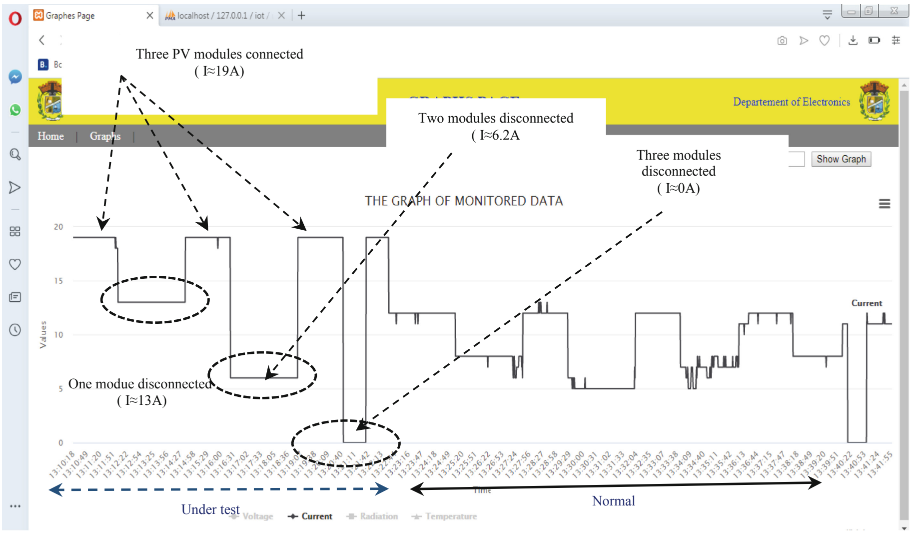

Fig. 5. Current evolution during the PV modules disconnection (online representation using IoT).

Figure 6 displays the evolution of the monitored data (current, voltage, cell temperature and in-plane solar irradiance) via IoT for a period of 3 h (7 July 2019). At the period 12 h 9 min–12 h 38 min the system work correctly (normal case), the measured current and voltage are 12.2 A and 11 V respectively, the cell temperature is 46° and the in-plane solar irradiance is 860 W/m^2. At 12 h 38 min 15 s the system detect automatically a fault, and then the identification procedure start by measuring the open

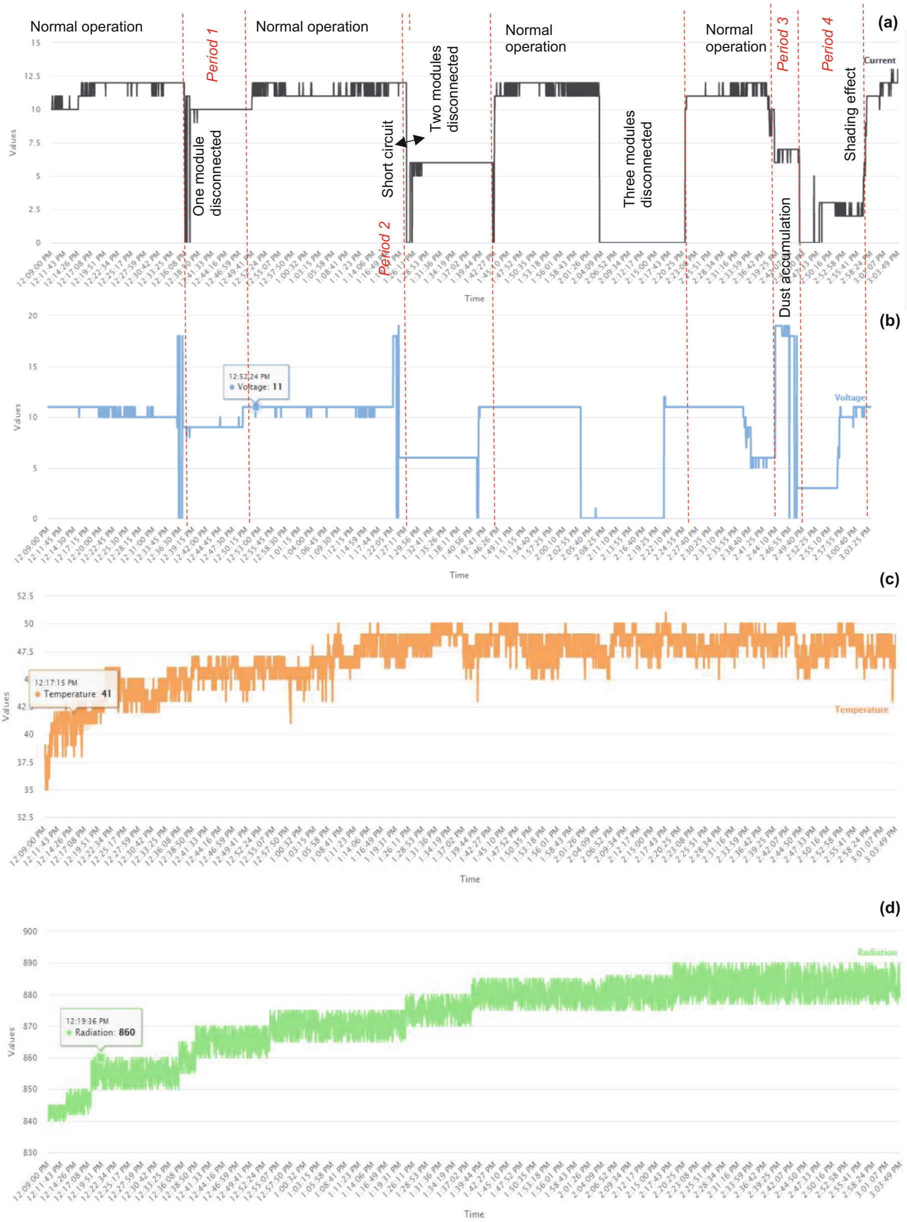

Fig. 6. Online evolution of the measured data (3 h test duration): (a) voltage, (b) current, (c) cell temperature and (d) in-plane solar irradiance. Period 1: open circuit of one PV module, period 2: short circuit, period 3: dust accumulation on the PV array and period 4: shading effect on the PV array.

circuit voltage (V_{OC} = 18 V), and at 12 h 38 min 30 s the I_{SC} is also measured (I_{SC} = 11.5A), then the system notify the user about the fault and display the type of the error online (in this case the system display this message: *One PV module is disconnected*), the duration of the fault is about 14 min. From 12 h 52 min to 13 h 26 min the system work correctly without any fault (normal case). The period from 13 h 26 min to 13 h 42 min a decrease in the current is observed and the system automatically indicate and display the type of the fault which corresponds to '*two modules are disconnected*'. The system work correctly without any fault from 13 h 42 to 14 h 4 min. While during the period from 14 h 4 min to 14 h 20 min the system is disconnected completely. At 13 h 26 min we have a short circuit, and the maximum current is about 12.2 A and voltage is 0 V. In the period from 14 h 39 min to 14 h 44 min the observed current is decreased (I_{SC} = 10A) as well as the voltage (V_{OC} = 11 V), which correspond to the '*dust accumulation*' on the PV array, the duration of the fault is about 5 min. The period from 14 h 52 min to 15 h 2 min, corresponding to the '*shading effect*', a decrease in the measured current (I_{SC} = 5A) and small decrease in the voltage (V_{OC} = 17A) is observed, the duration of the fault is about 10 min.

4 Conclusion

In this paper a smart photovoltaic remote sensing system for fault detection and identification has been developed. The designed prototype was verified experimentally at RELab of Jijel University, and shown the capability to identify the type of some investigated faults (e.g. short circuit, open circuit, dust accumulation and shading effect). The recorded data have been transmitted to the Internet via IoT technology. The stored data are available to the users with web-based interface, in which users can browse all recorded data in real-time and check the status of the system.

The designed prototype is more suitable for isolated areas (PV systems installed in Saharan regions, case of south of Algeria, as well as for domestic applications). The prototype enable users to monitor and check the installation remotely from anywhere and at any time. The major drawback of the identification algorithm is that is not able to identify faults that have the same symptoms or signatures, (e.g. different types of shading, dust accumulation, etc.).

This work could be further improved and extended for fault diagnosis of photovoltaic systems by using more sophisticated algorithms that are able to distinguish between faults that have the same signature and make a clear decision. Also, verification of the method for a large size PV array and faults localization.

References

1. IEA: Snapshot of global photovoltaic markets. Accessed March 2018
2. Daliento, S., Chouder, A., Guerriero, P., Pavan, A.M., Mellit, A., Moeini, R., Tricoli, P.: Monitoring, diagnosis, and power forecasting for photovoltaic fields: a review. Int. J. Photoenergy **2017**, 13 (2017)

3. Mellit, A., Tina, G.M., Kalogirou, S.A.: Fault detection and diagnosis methods for photovoltaic systems: a review. Renew. Sustain. Energy Rev. **91**, 1–17 (2018)
4. Barsocchi, P., Cassara, P., Mavilia, F., Pellegrini, D.: Sensing a city's state of health: structural monitoring system by Internet-of-Things wireless sensing devices. IEEE Consum. Electron. Mag. **7**, 22–31 (2018)
5. Xiaoli, X., Daoe, Q.: Remote monitoring and control of photovoltaic system using wireless sensor network. In: International Conference on Electric Information and Control Engineering, pp. 633–638 (2011)
6. Xu, X.L., Wang, H.: Construction of solar PV power generation remote monitoring system in the architecture of Internet of Things. In: Advanced Materials Research, vol. 347, pp. 178–182 (2012)
7. Adhya, S., Saha, D., Das, A., Jana, J., Saha, H.: An IoT based smart solar photovoltaic remote monitoring and control unit. In: 2nd International Conference on Control, Instrumentation, Energy and Communication (CIEC), pp. 432–436 (2018)
8. Kumar, N.M., Atluri, K., Palaparthi, S.: Internet of Things (IoT) in photovoltaic systems. In: National Power Engineering Conference (NPEC), pp. 1–4 (2018)
9. Spanias, A.S.: Solar energy management as an Internet of Things (IoT) application. In: 8th International Conference on Information, Intelligence, Systems & Applications (IISA), pp. 1–4 (2017)
10. Li, Y.F., Lin, P.J., Zhou, H.F., Chen, Z.C., Wu, L.J., Cheng, S.Y., Su, F.P.: On-line monitoring system of PV array based on Internet of Things technology. In: IOP Conference Series: Earth and Environmental Science, vol. 93, no. 1, p. 012078 (2017)
11. Kekre, A., Gawre, S.K.: Solar photovoltaic remote monitoring system using IOT. In: International Conference on Recent Innovations in Signal processing and Embedded Systems (RISE), pp. 619–623 (2017)
12. Hamied, A., Mellit, A., Zoulid, M.A., Birouk, R.: IoT-based experimental prototype for monitoring of photovoltaic arrays. In: 2nd International Conference on Applied Smart Systems (ICASS), pp. 1–5 (2018)
13. Mellit, A., Hamied, A., Pavan, A.M., Lughi, V.: A low-cost monitoring and fault detection system for stand-alone photovoltaic systems using IoT technique. In: ELECTRIMACS 2019 – Salerno, Italy, 21–23 May 2019 (2019)