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Fault detection and monitoring of solar photovoltaic panels using internet of things technology with fuzzy logic controller

Purpose. *This article proposes a new control monitoring grid connected hybrid system. The proposed system, automatic detection or monitoring of fault occurrence in the photovoltaic application is extremely mandatory in the recent days since the system gets severely damaged by the occurrence of different faults, which in turn results in performance degradation and malfunctioning of the system.* ***The novelty*** *of the proposed work consists in presenting solar power monitoring and power control based Internet of things algorithm. In consideration to this viewpoint, the present study proposes the Internet of Things (IoT) based automatic fault detection approach, which is highly beneficial in preventing the system damage since it is capable enough to identify the emergence of fault on time without any complexities to generate Dc voltage and maintain the constant voltage for grid connected hybrid system.* ***Methods.*** *The proposed DC-DC Boost converter is employed in this system to maximize the photovoltaic output in an efficient manner whereas the Perturb and Observe algorithm is implemented to accomplish the process of maximum power point tracking irrespective of the changes in the climatic conditions and then the Arduino microcontroller is employed to analyse the faults in the system through different sensors. Eventually, the IoT based monitoring using fuzzy nonlinear autoregressive exogenous approach is implemented for classifying the faults in an efficient manner to provide accurate solution of fault occurrence for preventing the system from failure or damage.* ***Results.*** *The results obtained clearly show that the power quality issue, the proposed system to overcome through monitoring of fault solar panel and improving of power quality. The obtained output from the hybrid system is fed to the grid through a 3ϕ voltage source inverter is more reliable and maintained power quality. The power obtained from the entire hybrid setup is measured by the sensor present in the IoT based module. The experimental validation is carried out in ATmega328P based Arduino UNO for validating the present system in an efficient manner.* ***Originality.*** *The automatic Fault detection and monitoring of solar photovoltaic system and compensation of grid stability in distribution network based IoT approach is utilized along with sensor controller.* ***Practical value****. The work concerns a network comprising of electronic embedded devices, physical objects, network connections, and sensors enabling the sensing, analysis, and exchange of data. It tracks and manages network statistics for safe and efficient power delivery. The study is validated by the simulation results based on real interfacing and real time implementation.* References 22, tables 2, figures 8.

Key words: **photovoltaic system, automatic fault detection, DC-DC boost converter, perturb and observe algorithm, fuzzy nonlinear autoregressive exogenous approach, renewable energy source.**

Мета*. У цій статті пропонується нова гібридна система керування моніторингу підключення до мережі. Пропонована система автоматичного виявлення або моніторингу виникнення несправностей у фотогальванічному обладнанні наразі вкрай необхідна, оскільки система серйозно ушкоджується при виникненні різних несправностей, що, у свою чергу, призводить до погіршення показників і некоректної роботи системи.* ***Новизна*** *запропонованої роботи полягає у поданні алгоритму моніторингу сонячної енергетики та управління потужністю на основі Інтернету речей. Зважаючи на цю точку зору, у цьому дослідженні пропонується підхід автоматичного виявлення несправностей на основі Інтернету речей (IoT), який дуже корисний для запобігання пошкодженню системи, оскільки вона достатньо здатна вчасно ідентифікувати виникнення несправності без будь-яких складнощів, щоб генерувати постійну напругу. та підтримувати постійну напругу для гібридної системи, підключеної до мережі.* ***Методи****. Пропонований перетворювач постійного струму, що підвищує, використовується в цій системі для максимізації фотоелектричної потужності ефективним чином, тоді як алгоритм збурення та спостереження реалізований для виконання процесу відстеження точки максимальної потужності незалежно від змін кліматичних умов, а потім мікроконтролер Arduino використовується для аналізу несправностей у системі за допомогою різних датчиків. Зрештою, моніторинг на основі IoT з використанням нечіткого нелінійного авторегресійного екзогенного підходу реалізований для ефективної класифікації несправностей, щоб забезпечити точне вирішення несправності, що виникла, для запобігання відмови або пошкодженню системи.* ***Результати****. Отримані результати показують, що запропонована система вирішує проблему якості електроенергії за рахунок моніторингу несправності сонячної панелі та покращення якості електроенергії. Отримана з гібридної системи енергія подається в мережу через інвертор джерела напруги 3ϕ, що є більш надійним і підтримує якість електроенергії. Потужність, отримана від усієї гібридної установки, вимірюється датчиком, присутнім у модулі на основі IoT. Експериментальна перевірка проводиться у Arduino UNO на базі ATmega328P для ефективної перевірки цієї системи.* ***Оригінальність****. Автоматичне виявлення несправностей та моніторинг сонячної фотоелектричної системи і компенсація стабільності мережі у підході IoT на основі розподільчої мережі використовуються разом із контролером датчиків.* ***Практична цінність****. Робота стосується мережі, що складається з вбудованих електронних пристроїв, фізичних об'єктів, мережевих підключень і датчиків, що дозволяють сприймати, аналізувати і обмінюватися даними. Вона відстежує та керує мережевою статистикою для безпечної та ефективної подачі енергії. Дослідження підтверджено результатами моделювання, що базуються на реальному інтерфейсі та реалізації в реальному часі.* Бібл. 22, табл. 2, рис. 8.

Ключові слова: **фотогальванічна система, автоматичне виявлення несправностей, перетворювач постійного струму, що підвищує, алгоритм збурення та спостереження, нечіткий нелінійний авторегресійний екзогенний підхід, відновлюване джерело енергії.**

Introduction. In the process of power generation, the demand of renewable energy (RE) sources is extremely high for compensating the power requirement of people and overcoming the exhaustion of fossil fuels in an efficient manner. The usage of RE sources has gained huge attention in different industrial or domestic applications as it aids in generating electricity with plenty of beneficial impacts like zero CO_2 emission, trouble free maintenance, easy installation and less expenditure. The increasing cost of conventional fossil fuels in the recent days causes the people to switch to the usage of RE sources as these sources are easily available and cost effective. Moreover, the usage of these sources has widely influenced the economic growth of the nation as it contributes enough in maximizing the uninterrupted generation and transmission of electricity without requiring any expensive processes [1-4].

The solar energy is one of the significant RE sources that is comparatively better than the other sources like tidal, biomass, geothermal and wind energy since the profitability of this photovoltaic (PV) source is extremely higher than the others. The usage of PV system in the process of electricity generation is extremely advantageous as it is capable enough to be installed even in the rural places without any complexities. Furthermore, the environmental friendly features of this PV system are highly preferable for the future projects in multiple sectors since the government has aimed to make the green society with pollution free applications [5, 6]. In spite of having all these advantageous measures, the PV owns the limitation of delivering low voltage as output and so it is highly mandatory to maximize the PV output in an optimal manner [7]. Therefore, the usage of DC-DC converters are emerged in the process of maximizing the PV output voltage to compensate the voltage requirement of load in an optimal way and so this present study proposes the boost converter for improving the PV output as it elevates the voltage with less components without affecting the efficiency or reliability of the system.

Due to the intermittent nature or non-linear features of solar energy, the PV delivers the output with extensive oscillations and so the process of tracking maximum power from PV is extremely mandatory for the complete use of PV output irrespective of the varying weather condition. Various maximum power point tracking (MPPT) algorithms are used for the extraction of maximum available power from PV panel and all these approaches have involved in finding the operating point of PV in an efficient manner [8-11]. Hence, this present study employs the Perturb and Observe (P&O) approach to effectively track the maximum power from PV by accurately identifying its operating point in an optimal way because this approach owns the beneficial measure of high tracking efficiency with lesser complexity.

The operating condition of PV system gets affected by the occurrence of different faults that initiate potential energy loss, which in turn influence the safety of the system in a wider range and these faults affect the efficiency of the system in delivering the desired outcomes. It is thus extremely mandatory to monitor the entire system to protect it from being affected by the faults in order to maximize safety and productivity of the system [12, 13]. The timely detection of fault occurrence for the purpose of enhancing the system performance with high efficiency is extremely crucial because it assists in preventing the panel damage or output current disruptions and hence various fault detection approaches are employed in the past decades to obtain fault free operation [14]. Though multiple approaches with different conceptual variations are used in the process of identifying the emergence of fault in PV system, the ultimate motive of achieving fault detection on time is not effectively accomplished as all these approaches have only given temporary solution. Thus, the detection capability of the conventional strategies are not sufficient enough to prevent the system free from damages or malfunctioning and hence the Internet of Things (IoT) based detection approaches are introduced in the field for identifying the fault occurrence [15, 16].

The implementation of IoT based approach in the process of automatically identifying the faults in the system is highly advantageous since it is wrapped with plenty of beneficial measures like cost minimization, anytime-anywhere device control and real-time data assess, which makes is highly preferable for the applications that require automatic detection. In addition, it effectively involves in lessening the limitation of distance range, which is regarded as one of the significant features of this approach [17-19]. Various intelligent based optimization approaches are involved in the IoT based operation but all these methods are not capable enough in delivering optimal outcomes and so the present study prefers the implementation of Fuzzy system for acquiring optimal results in the process of identifying the system faults in an efficient manner [20-22].

In all the previously used methods for monitoring of solar power plant was discussed in brief. First, we had discussed on traditional approaches like Zigbee, Bluetooth and WSN, and then moved concentration on the PLC and SCADA system, which are most widely used methods nowadays from last 2 decades. After the review on traditional methods for remote monitoring and control for solar power plant, we have turned our focus on recent trends like IoT.

The purpose of the work is some of the drawbacks of previous methods are reduced by the use of new innovative techniques like Internet of Things. IoT allows us to remote monitoring and control the energy parameters but traditional systems can't allow us to remotely access energy parameters.

Proposed control system. The process of detecting the fault occurrence in the power generation system using IoT application is significantly introduced in this present study, which indulges in enhancing the overall performance of the system by preventing the output current from being affected by different faults that occurs in the system. As it is a sensor based system of automatic fault identification, the real time status of the power system is observed in an optimal manner and so the reliability of this system is extremely higher than the conventional fault tracking systems. The operation of this system is remarkably illustrated through the block representation in Fig. 1 for validating the proposed methodology.

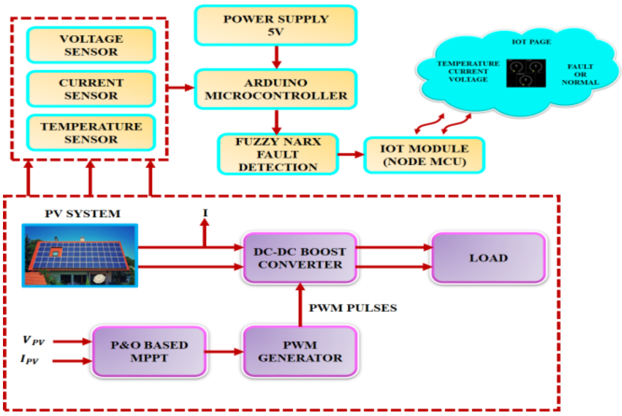


Fig. 1. Block representation of the proposed methodology

As the obtained voltage of PV is low in nature, it is not sufficient enough in compensating the voltage requirement of load in an efficient manner and so the boost converter is employed in this study to maximize the output voltage of PV in a wider range. Due to the intermittent nature of PV, the output gets fluctuated or becomes inconstant, which hurdles the overall operation of the system and hence the P&O algorithm is implemented to extract the maximum power from PV by comparing the current and voltage of PV module.

The duty cycle command of this MPPT controller is fed to the pulse-width modulation (PWM) generator that generates the pulses and delivers it to the converter for delivering the constant output voltage without any oscillation. The obtained output voltage is then given to the load and the load requirement is thus effectively compensated.

The occurrence of any fault in this system causes panel damage or interruption in current flow and so it is highly mandatory to monitor the fault occurrence for the disruption free operation of the system.

Therefore, the current, voltage and temperature of the entire system are sensed by 3 different sensors and the outputs of these sensors are fed to the Arduino microcontroller that gets operated through the supply of. The output of this controller is then given to the fuzzy nonlinear autoregressive exogenous (NARX) system that effectively detects the faults and the identified faults are evidently displayed by using the IoT module (Node MCU ESP8266) in an efficient manner. Thus, this system maximizes the overall performance of the system by effectively detecting the fault occurrence along with the observation of variations in temperature, current and voltage.

System modelling. The detailed analysis and modelling of the employed approaches are significantly provided in the subsequent section.

1. PV system. Because of providing an ideal balance between precision and simplicity, the present study uses the single diode model of PV system. Its equivalent circuit representation is significantly, which includes a series resistance R_s, a parallel resistance indicating the leakage current R_p, a diode I_D and a photocurrent I_{ph}. By applying Kirchhoff's law, the current is generated through the subsequent equation as:

$$I = I_{ph} - I_D - I_p, \tag{1}$$

where I_{ph} is the photocurrent; I_p is the current flows through the parallel resistor.

The I_p is computed as

$$I_p = \frac{V + R_s \cdot I}{R_p}, \tag{2}$$

where I_D is the diode current that is equal to the saturation current, which is expressed as:

$$I_D = I_{sd} \cdot \left(\exp\left(\frac{q \cdot (V + R_s \cdot I)}{n \cdot K \cdot T} \right) - 1 \right), \tag{3}$$

where q is the electron charge; K is the Boltzmann constant; n is the ideal factor; T is the cell temperature; I_{sd} is the reverse saturation current.

Equation (1) is thus replaced as:

$$I = I_{ph} - I_{sd} \cdot \left(\exp\left(\frac{q \cdot (V + R_s \cdot I)}{n \cdot K \cdot T} \right) - 1 \right) - \frac{V + R_s \cdot I}{R_p}, \tag{4}$$

As solar irradiation and temperature influence the photocurrent, it is expressed as:

$$I_{ph} = \left[I_{sc} + K_i \cdot (T - T_{ref}) \right] \cdot \frac{G}{G_{ref}}, \tag{5}$$

where G is the solar irradiance; K_i is the temperature coefficient; G_{ref} is the reference insolation of the cell; T_{ref} is the reference temperature; I_{sc} is the short circuit current.

As the temperature is varies, the saturation current gets fluctuated, which is expressed as:

$$I_{sd} = I_{rs} \cdot \left(\frac{T}{T_{ref}} \right)^3 \cdot \exp\left(\frac{q \cdot E_g \cdot \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)}{K \cdot n} \right), \tag{6}$$

where E_g is the semiconductor's gap energy; I_{rs} is the PV cell's reverse saturation current; n is the ideal factor relies on PV.

The reverse saturation current is thus expressed as:

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q \cdot V_{oc}}{N_s \cdot n \cdot K \cdot T} \right) - 1}. \tag{7}$$

The output of this PV system is then given to the boost converter as the input and the converter involves in maximizing the voltage in an optimal manner.

2. Boost converter. One of the simplest kind of switch mode converter is known as boost converter, which has the elements like a capacitor C, an inductor L, a diode D, a load resistor R_L, a semiconductor switch s as involves in significantly maximizing the low output voltage of PV in an optimal way.

By modifying the switch ON time, the converter output voltage gets varied since it highly depends on the duty cycle of the switch and hence the average output voltage for duty cycle «D» is computed as:

$$\frac{V_o}{V_{in}} = \frac{1}{(1 - D)}, \tag{8}$$

where V_o and V_{in} are the output and input voltages of the converter are respectively specified.

The input and output power of converter are proportional to each other in an ideal circuit, which is expressed as:

$$P_o = P_{in} \Rightarrow V_o \cdot I_o = V_{in} \cdot I_{in}, \tag{9}$$

The boost converter's inductor value is computed by:

$$L = \frac{V_{in}}{(f_s \cdot \Delta I_L)} \cdot D, \tag{10}$$

where ΔI_L is the input current ripple; f_s is the switching frequency.

For the accurate estimation of inductor value, the current ripple factor that is the ratio among output current and input current ripple has to be ranges within 30 %, which is expressed as:

$$\Delta I_L / I_o = 30\ \%. \tag{11}$$

The capacitor value of the converter is obtained by:

$$C = \frac{I_{out}}{(f_s \cdot \Delta V_o)} \cdot D, \tag{12}$$

where ΔV_o is the output voltage ripple that is actually regarded as the 5 % of output voltage, which is expressed as:

$$\Delta V_o / V_o = 5\ \%. \tag{13}$$

Thus, the contribution of this converter is extremely high in the process of maximizing the output voltage of PV in a wider range.

For the disruption free operation of the PV system, the maximum power has to be extracted from the PV system and so the P&O algorithm is employed in this present study.

3. P&O algorithm. As the necessity of tracking the maximum power from PV is enormously high in the process of enhancing the system operation without any fluctuation, the P&O algorithm is employed in this study for extracting the maximum power from PV irrespective of the changes in the climatic conditions. Few measured parameters and a straightforward feedback ground work are utilized by this algorithm in the initial stage for effectively tracking the MPP whereas the system gets operated at the obtained MPP for acquiring optimal efficiency along with the disruption free outputs. The functioning measures of this algorithm are evidently explained through the steps.

The power from the PV panel gets constantly fluctuated by the slight perturbation initiated by this algorithm. The direction of the perturbation remains the same when the power gets increased by the initiated perturbation whereas the direction is reversed when the power gets decreased after reaching the peak point. For lessening the power variation, the perturbation size is fixed as small and the algorithms gets fluctuated around the peak point when it reaches the steady state. Initially, it involves in estimating the current and voltage of PV for measuring the actual power and then the condition $\Delta P = 0$ is tested. If this condition is compensated, the operating point is obtained or else the condition of $\Delta P > 0$ is tested. The operating point relies on the left part of MPP when $\Delta P > 0$ is satisfied and so the condition of $\Delta V > 0$ is performed whereas the operating point relies on the left part of MPP when $\Delta P > 0$ is not compensated. This process gets repeated until the MPP is reached.

The acquired MPP is then given to the PWM generator for generating the required pulses of the boost converter in an efficient manner.

4. Algorithm:

Step-1: Input (number of strings, IoT granularity level, number of PV panel in one string)
Step-2: Test each string input for possible fault
Step-3: If faults identified then
Step-4: Issue command to IoT cloud to eliminate half of the existing nodes
Step-5: Do the step:2 again
Step-6: If (there is no further possible node elimination)
Step-7: Return the current node as the faulty node.
Step-8: No fault Exist
Step-9: Add a leaf node from the eliminated part
Step-10: Do the step:2 again
Step-11: Fault Exist
Step-12: Return the last added leaf node as faulty node
Step-13: output (the PV panel of group of PV panel causing the fault)

5. Fault analysis. The emergence of any fault in this system causes severe negative impacts like panel damage or interruption in current flow, which in turn lessens the cumulative performance of the system in a wider range and so in is extremely mandatory to identify these faults for preventing the system from being damaged. Therefore, the present study proposes the IoT based detection approach using fuzzy NARX algorithm, which contributes enough in monitoring the system and identifying the faults in an efficient manner. The working principles of this approach are evidently explained in the subsequent section with proper analysis and the flow chart of this fault detection approach is significantly illustrated in Fig. 2.

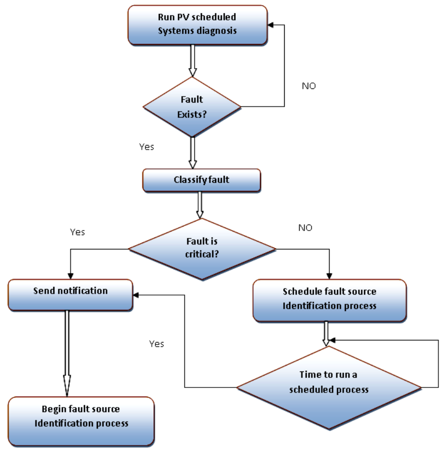


Fig. 2. Flow chart of detection algorithm

6. IoT based power monitoring. In general, the output power degradation in the power generation system occurs due to the occurrence of faults which in turn affects the overall current flow and this necessitates the continuous monitoring of various parameters. The voltage, current and the temperature obtained from the power generation system are monitored continuously by the IoT based power monitoring system. It comprises of a Node MCU ESP8266 controller along with INA219 sensor for voltage and current monitoring, DH11sensor for temperature. The obtained values of voltage, current and temperature are applied to the controller and from these values the presence and absence of faults are detected. In this work, the detection of faults is carried out by fuzzy NARX based fault detection approach as denoted in Fig. 3.

The expressions of power ratio PR and voltage ratio VR are given by:

$$VR = V_P / V_S; \quad (15)$$

$$PR = P_P / P_S; \quad (16)$$

where V_P is the maximum output voltage; P_P is the maximum output power obtained theoretically; V_S is the measured output voltage; P_S is the measured output power obtained practically.

The obtained values of VR and PR indicate the presence and absence of faults in the power generation system. The data thus monitored is stored in the IoT webpage through Node MCU.

Thus a wide analysis is performed with the usage of sensors and NARX model for fault detection in the power generation system. Depending on the obtained values of voltage, current and temperature, the effective functioning of the system is concluded which further indicates the presence and absence of faults. The NARX model effectively identifies and classifies faults generating improved fault detection outputs.

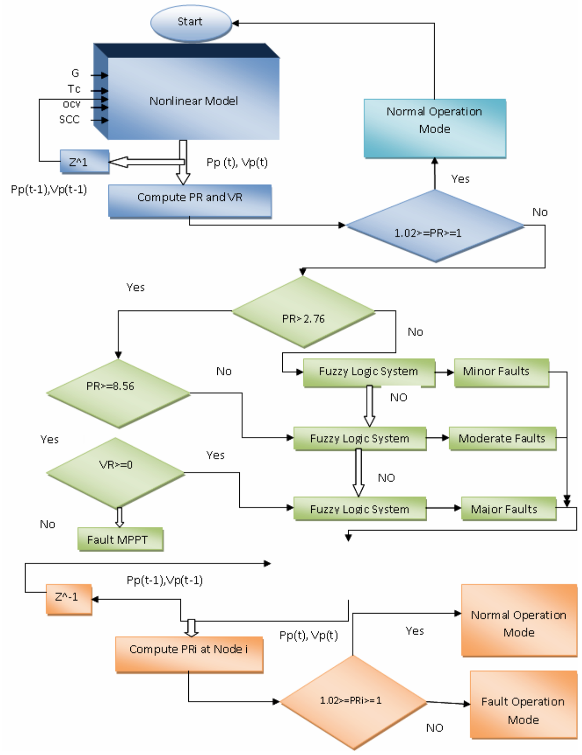


Fig. 3. Flow chart of fault detection

Results and discussions. The process of detecting the emergence faults that affect the output current of PV system is effectively performed in this study through the implementation of IoT based fault detection approach using fuzzy NARX algorithm. The experimental validation of the entire work is carried out using ATmega328P based Arduino UNO for authenticating the performance capability of this approach in the detection of fault current with optimal outcomes. After identifying the input variables VR and PR regions, the fuzzy sets and the membership functions for the three Sugeno fuzzy models are shown in Fig. 4. The waveform representing the output voltage of PV is significantly highlighted in Fig. 5, which illustrates that the output voltage gets varied from 180 V to 200 V but this obtained low DC output with oscillations is not sufficient enough to compensate the voltage requirement of load and so this obtained voltage of PV is fed to the boost converter as input for maximizing the voltage in a wider range.

After identifying the input variables VR and PR regions, the fuzzy sets and the membership functions for the three Sugeno fuzzy models are shown in Fig. 4.

The obtained PV voltage is significantly improved by the boost converter as represented in Fig. 5,*a-d*, which validates that the converter delivers the constant output voltage of 220 V without any fluctuations. Irrespective of the oscillations in the PV output, the converter delivers disruptions free output and hence the efficiency of this converter in the process of maximizing the low DC output of PV is remarkably high.

The waveform indicating the output current without fault is evidently illustrated in Fig. 6, which validates that the output current shows no oscillations during the no fault condition and the constant output current of 3 A is significantly obtained, which in turn improves the overall system performance in a wider range.

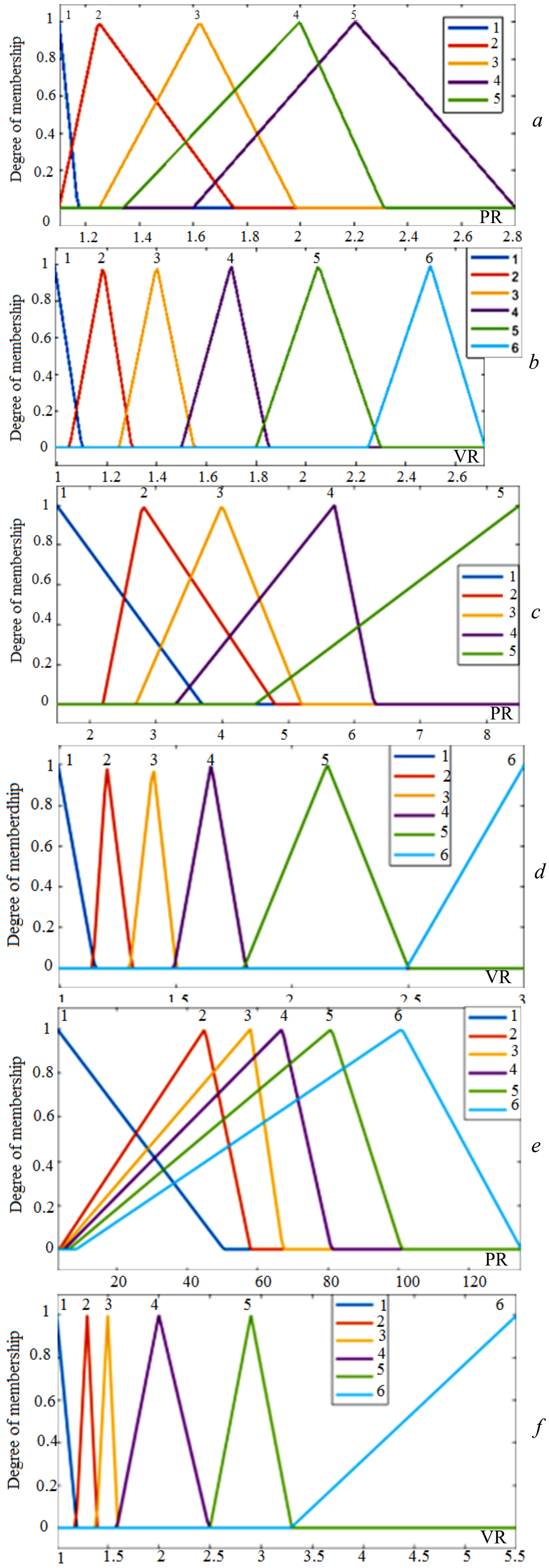


Fig. 4. Membership functions of the:
a – minor fault model power rate;
b – minor fault model voltage rate;
c – moderate fault model power rate;
d – moderate fault model voltage rate;
e – major fault model power rate;
f – major fault model voltage rate

The waveform representing the output voltage of PV is significantly highlighted in Fig. 5, which illustrates that the output voltage gets varied from 180 V to 200 V but this obtained low DC output with oscillations is not sufficient enough to compensate the voltage requirement of load and so this obtained voltage of PV is fed to the boost converter as input for maximizing the voltage in a wider range.

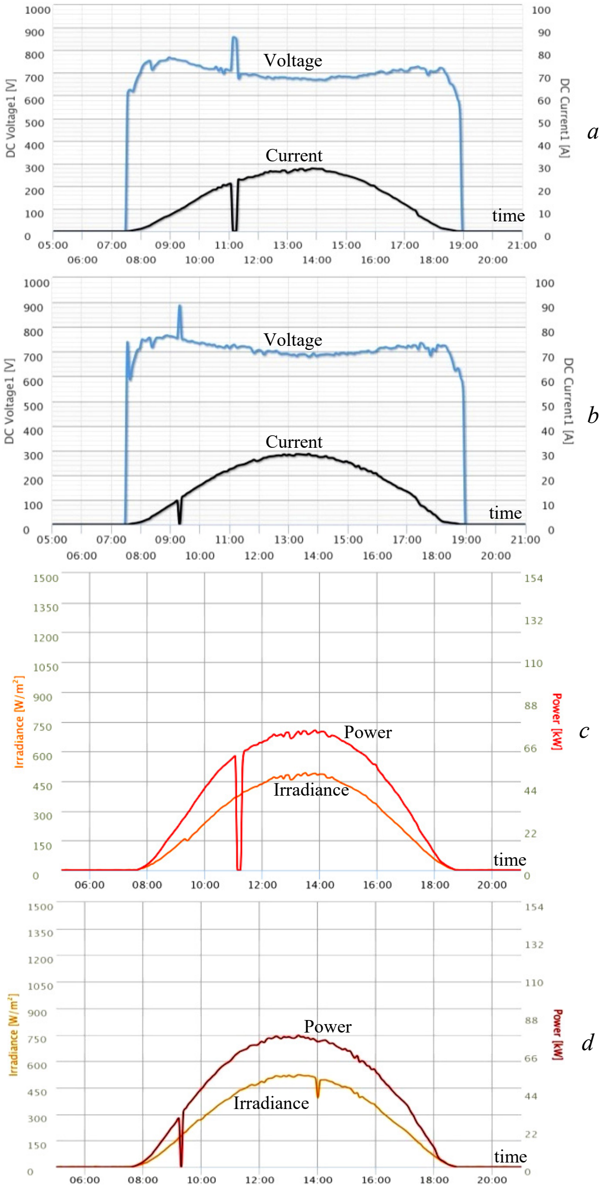


Fig. 5. *a* – fault current; *b* – fault cleared current; *c* – fault irradiation; *d* – fault cleared irradiation

When the fault is emerged in the system the output current gets extremely deviated as depicted in Fig. 7, which illustrates the fault current waveform in an efficient manner. The obtained waveform proves that the current is highly disrupted and varied up to 10.5 A, which severely affects the performance efficiency of the system or initiates the panel damage. To prevent these issues, the occurrence of fault is remarkably monitored through the IoT fault detection approach.

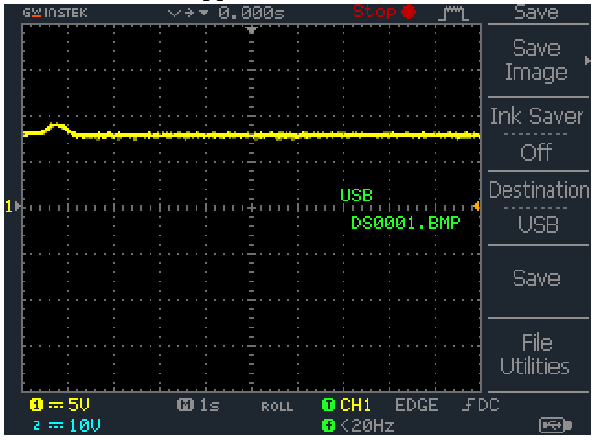


Fig. 6. Output current without fault

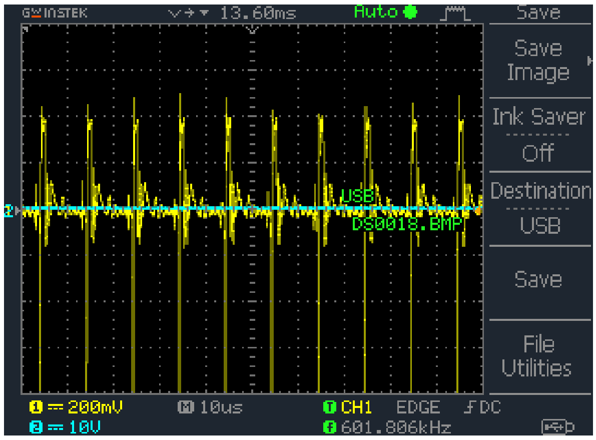


Fig. 7. Output current with fault

The hardware outcomes of the fuzzy fault classification along with the execution time and accuracy of proposed fuzzy NARX system are evidently listed out in Table 1 and Table 2, which proves that the accuracy of this proposed approach in the process of detecting the fault occurrence in the PV system is remarkably high. In addition, it consumes less time for the execution of fault analysis, which in turn makes the system free from unwanted delays.

Table 1

Test cases of fuzzy classification

No.	Power ratio	Voltage ratio	Fault mode	Fuzzy classification region	Diagnosis time, ms
1	1.8	2.0	Minor	4	4.02
2	1.4	1.1	Minor	9	4.03
3	5.3	2.7	Moderate	18	1.93
4	2.4	1.0	Moderate	7	3.04
5	116	4.5	Major	23	1.82
6	80.6	3.0	Major	22	2.01

Table 2

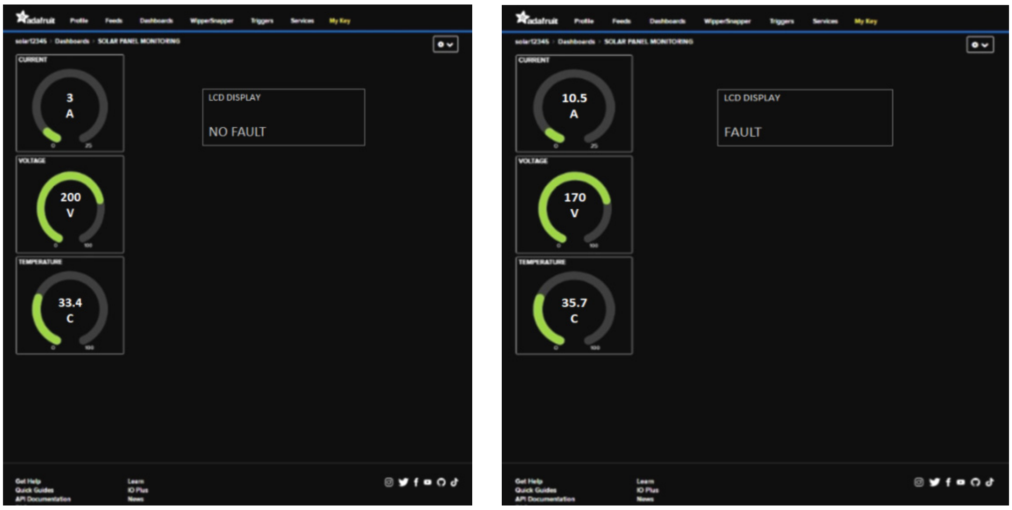
Accuracy and execution time using NARX

No.	Solar irradiation, W/m^2	Input temperature, °C	Open-circuit voltage, V	Short-circuit current, A	Hardware		Tracking time, ms
					I	V	
1	200	10	36.88	8.27	1.36	31.28	7.85
2	500	20	36.88	8.27	3.68	30.41	7.74
3	350	15	36.88	8.27	2.54	30.95	7.86
4	600	25	30	8.37	4.49	23.64	7.89
5	400	20	30	8.37	2.85	24.11	7.58
6	800	30	30	8.37	6.23	22.69	8.02

The hardware outcomes of the IoT based system monitoring are evidently illustrated in Fig. 8,*a*,*b*, which proves that fault current outcomes exhibits much variations.

The temperature, current and voltage values of the system are sensed through three various sensors to monitor the fault occurrence in an efficient manner. The sensed output is to the Arduino controller, which simultaneously fed the output to the Fuzzy NARX system to classify the faults in an optimal manner. The classified outputs are evidently displayed in the IoT webpage as represented in the subsequent figures.

Hence, the acquired outcomes have proved that the performance capability of the proposed methodology in the automatic monitoring and detection of fault occurrence in PV system is extremely high.



a *b*

Fig. 8. *a* – output of fault; *b* – no fault conditions

Conclusions. The present study describes the detailed analysis of implementing the Internet of Things based automatic fault identification in the photovoltaic application, which assists in rectifying the issues like panel damage, malfunctioning and system failure in an optimal manner. The low photovoltaic output voltage is effectively maximized through the implementation of boost converter and the maximum power from photovoltaic is remarkably extracted by the implementation of Perturb and Observe algorithm, which in turn efficiently compensated the load requirement without any disruptions. As the emergence of fault in the system affects the current flow in a wider range, the entire system is monitored through three different sensors whereas the sensed output is fed to the fuzzy nonlinear autoregressive exogenous system, which efficiently classifies the faults in the system and displays the occurred faults in the Internet of Things webpage through Node MCU. Thus, the proposed approach performs well in identifying whether the system has any faults or not and in effectively monitoring the changes in system parameters like voltage, current or temperature. The entire work is experimentally validated using ATmega328P based Arduino UNO and the obtained outcomes have proved that this approach is capable enough in automatically identifying the fault occurrence in an efficient manner without any complexities.

Conflict of interest. The authors declare no conflict of interest.

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