

A Fault Diagnosis Algorithm for Solar Photovoltaic Systems with a Minimal Number of Sensors

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ABSTRACT: Solar photovoltaic (PV) energy is a promising type of energy, but it is not efficient compared to non-renewable sources and thus less reliable. Since most solar power plants contain hundreds or even thousands of solar panels, there may be high costs associated with maintenance, especially voltage sensors. In this proposal we introduce a new model to reduce the number of voltage sensors required for fault detection. It detects open-circuit, short-circuit, and hotspot faults quickly and accurately.

KEYWORDS: Photovoltaic array, Fault detection, Voltage sensors, Automatic switch

I. INTRODUCTION

Electricity plays an important role in our daily lives. Generating sufficient amounts of this energy is a major challenge because of many types of energy production consume inordinate amounts of natural resources, thus depleting or destroying the environment. The search for clean, renewable sources of energy is critically important and solar energy is the most promising alternative. Renewable energy is a clean, non-polluting and sustainable energy such as solar, wind, hydroelectric. Of all these renewable sources. Solar photovoltaic energy is gaining rapid popularity around the globe [1]. Most solar panels operate without a status tracking system, especially when the other power is less than 25 kWp [2]. In order to improve their efficiency, work has been done to discover failure points of the PV systems and to determine the type of fault and its exact location, and thereby minimizing the cost by using as few voltage sensors as possible to find and localize faults.

This paper is outlined as follows. Section II describes related work that has been done on fault detection. The proposed framework is explained in section III. Next, section IV discusses the proposed detection algorithm. The experimental results and simulations are presented in section V. Finally, Section VI presents conclusion and future work.

II. RELATED WORK

In [3], researchers tried a new method using voltage and current sensors to detect the faults, their type (open circuit, short circuit and hotspot) and their location. To find the location of the fault, they compared the measurements of voltage sensors. In [4] they used hybrid methods of data analysis and a network of voltage-current sensors to detect the faults, their location and type, and they used sensors as in [3]. In [5], they applied the machine learning tool as an effective diagnostic tool for fault detection and localization in solar PV arrays. They detected, classified, and located the same three faults and locate the faults by using a new machine learning algorithm. In [6], Alajmi and his team developed an efficient fault detection method using infrared technology to detect the hotspot faults and to determine their location. They were able to determine whether each spot was a permanent or transient fault. In [7], Ze Cheng et al. used voltage sensor, current sensor and panel temperature for fault diagnosis. While solar illumination and environmental temperature used to increase or decrease the probability of fault in their work, they did not show what types of faults were detected or how sensors were connected to PV array. In [8], the fault in this project is detected by thermal cameras and Charge-Coupled Device (CCD), then verified by drones. There is a ground station for each camera that works to detect errors and also uses the multi-core CPU as a tool to improve the speed of processing time. They improved the fault detection process by using digital image and signal processing to find the highest pixels in them, but the type of faults is not specified. In [9] Suman et al. used Clustering-Based Self-Imputation to detect the unlabeled error data in PV array. In this method they could find the fault, but did not mention which type of fault they found in the PV system. In [10], authors proposed a method to locate the fault using sensors, but they did not need a

current sensor for each branch. They also used a mini number of voltage sensors between modules to determine accurately the location of partial shading, short circuit, open circuit and degradation faults, but in this method, they did not classify the fault. In [11], Muhammed Hussain and his team applied Artificial Neural Network to identify faults for photovoltaic systems. They achieved a 97 % fault detection rate. In [12], Nurmalessa Muhammad and his team detect faults by using predicted DC array current and DC string voltage value. Their method required analysis of signal failure and the current or voltage ratios to detect the fault. In [13], Turhal et al. used Photovoltaic Fault Detection and Classification Using Common Vector Approach Based on I–V Curve. They detect the fault with accuracy 97.5%. In [14], Yilmaz et al. used undecimated wavelet transform (UWT) to detect the fault, but they did not mention what types of faults were identified. In [15], Tsafarakis et al. analyze data to detect the Partially Shaded fault in PV array, but they focused on shadow fault and did not mention any other types of faults. In [16], Hamied and his team employed smart remote sensing to detect the fault. They also used Internet of Things (IOT) to monitor the fault online. In our proposed method, we developed a new sensing model using voltage and current sensors. This model is capable to detect the significant faults (open-circuit, short-circuit, and hotspot). Then the fault can be localized and classified accurately. In this method, we reduced the number of voltage sensors to approximately 50%.

III. THE PROPOSED THE PROPOSED METHOD STRUCTURE

A. SOLAR PV ARRAY CONNECTION

Solar cell or photovoltaic is an electronic device that converts light energy from the sun directly into electrical energy, producing an electric DC current. It can also produce 0.6 DC volts. A PV module is a group of PV cells connected in series. The PV module can be 36 cells or 72 cells or even more. A photovoltaic array contains a group of PV modules connected in parallel so that the photovoltaic array can be created according to the size required to meet the needs. There are many ways to form the photovoltaic array among them is serial-parallel [SP] connection, which is the best configuration for detecting a hotspot and photovoltaic cell accurately [17][18].

B. MODEL FOR PHOTOVOLTAIC ARRAY

The proposed PV array model is depicted in Fig 1. We used 36-cell modules by using [SP] configuration. The size of the PV array is [MxN] where (N) is the number of PV modules in one branch connected in series and M is the number of branches that are connected in parallel. In our method we we have one current sensor for each branch, divided into zones (Z) where each zone has two PV modules. The accuracy of the fault detection reduces as a number of PV modules increases for each zone. We can calculate the number of zones (Z) for each branch by using (1).

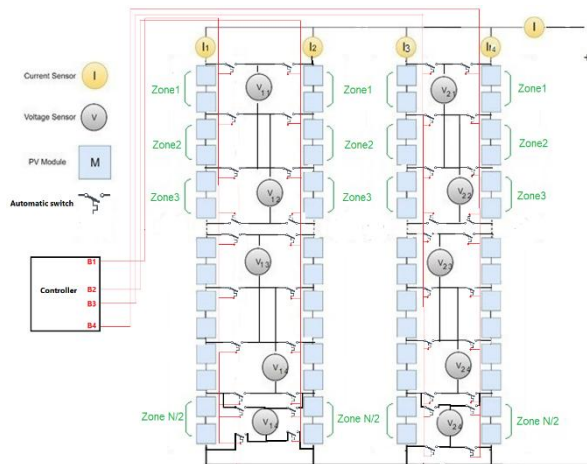


Fig 1: The proposed model for the PV array (NxM) used for the fault detection.

$$Z = \frac{N}{2} \tag{1}$$

Round-up means that, if $Z=5.1$, then make $Z=6$ and we used round-up function to make sure that every zone in the array is totally covered and there are no uncovered sensors.

C. VOLTAGE SENSORS CONNECTION

The distribution of voltage sensors occurs between every two branches because we need to reduce the number of voltage sensors as shown in (2).

$$S_v = \frac{(Z \times 2)}{3} \tag{2}$$

Forexample,if the size of a PV array is [2x6], then N=6. Next we can calculate the zones number of zones (Z) in (3) as well as the voltage sensors number (S_v) in (4)

$$Z = \frac{N}{2} = \frac{6}{2} = 3 \tag{3}$$

While the number of voltage sensors (S_v) equals to

$$S_v = \frac{(Z \times 2)}{3} = \frac{(3 \times 2)}{3} = \frac{6}{3} = 2 \tag{4}$$

Inproposedwork,overlappingmethod is usedtominimizethenumber of voltage sensors (S_v).

IV. FAULT DETECTION ALGORITHM USING SENSING FRAMEWORK

If the system is healthy, the values of the current sensors are equal as shown in (5).

$$I_1 = I_2 = I_3 = I_4 = I_M \tag{5}$$

Where (I_1) is the value of current in the first branch , (I_2) is the value of current in the second branch and (I_M) is the value of current in branch M, where the total current in (6).

$$I_{total} = I_1 + I_2 + I_3 + I_M \tag{6}$$

While voltage sensors values are as shown in (7).

$$V_{11} = V_{12} = V_{13} = V_{21} = V_{22} = V_{23} = V_{N \times M} \tag{7}$$

V_{11} is the voltage measurement (1) that is between branch (1) and branch (2). V_{12} is the voltage measurement (2) that is between branch (1) and branch (2). V_{13} is the voltage measurement (3) that is between branch (1) and branch (2). V_{21} is the voltage measurement (1) that is between branch (3) and branch (4). V_{22} is the voltage measurement (2) that is between branch (3) and branch (4). V_{23} is the voltage measurement (3) that is between branch (3) and branch (4). Case of fault scenarios are clarified in Table1. The flowchart of the proposed fault detection, classification, and localization algorithm is demonstrated inFig2.

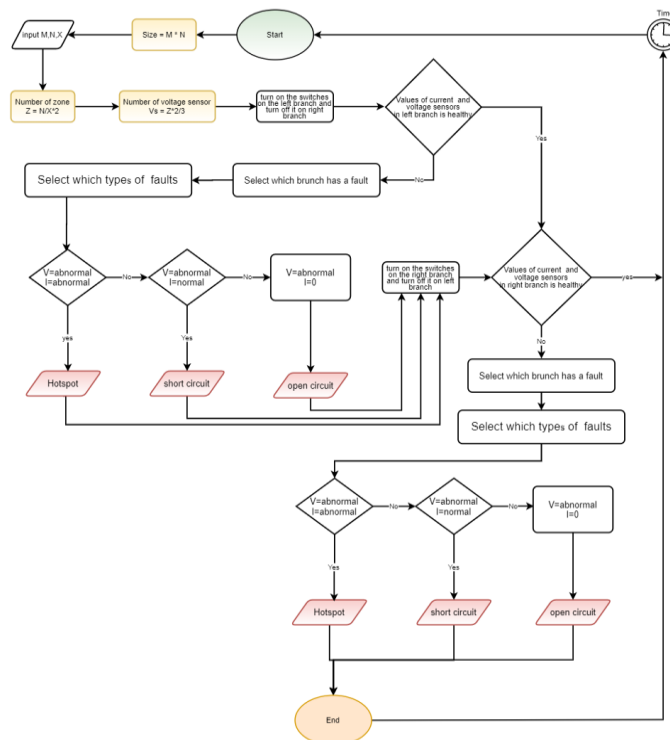


Fig 2: The flowchart of the proposed fault detection algorithm.

TABLE 1:

SHOWS HOW TO KNOW THE TYPE OF FAULT.

Value of voltage sensors	Value of current sensor	Type of fault
Healthy	Healthy	Healthy system
Faulty	0	Open-Circuit
Faulty	Healthy	Short-Circuit
Faulty	Faulty	Hotspot

V. THE EXPERIMENTAL RESULT AND SIMULATIONS

We made simulated 8x4 and 8x6 PV system by using Simulink as in Fig.1 and setting M=4, N=8 and M=6, N=8 as in Fig.3 and Fig4. This simulation was tested under standard test conditions (STC) as shown in Table 2[19].

TABLE 2:

STANDARD TEST CONDITIONS(STC) VALUES FOR TESTING PERFORMANCE MEASUREMENTS [19].

STC	
The value of voltage in open circuit	$V_{oc} = 0.6 \text{ Volt}$
irradiate of solar	1000 W/m^2
The value of current in short circuit	$I_{sc} = 7.34 \text{ Ampere}$
series resistance	$R_s = 0 \Omega$
threshold voltage	0.0014 Volt
Temperature of the cell	25.0°C

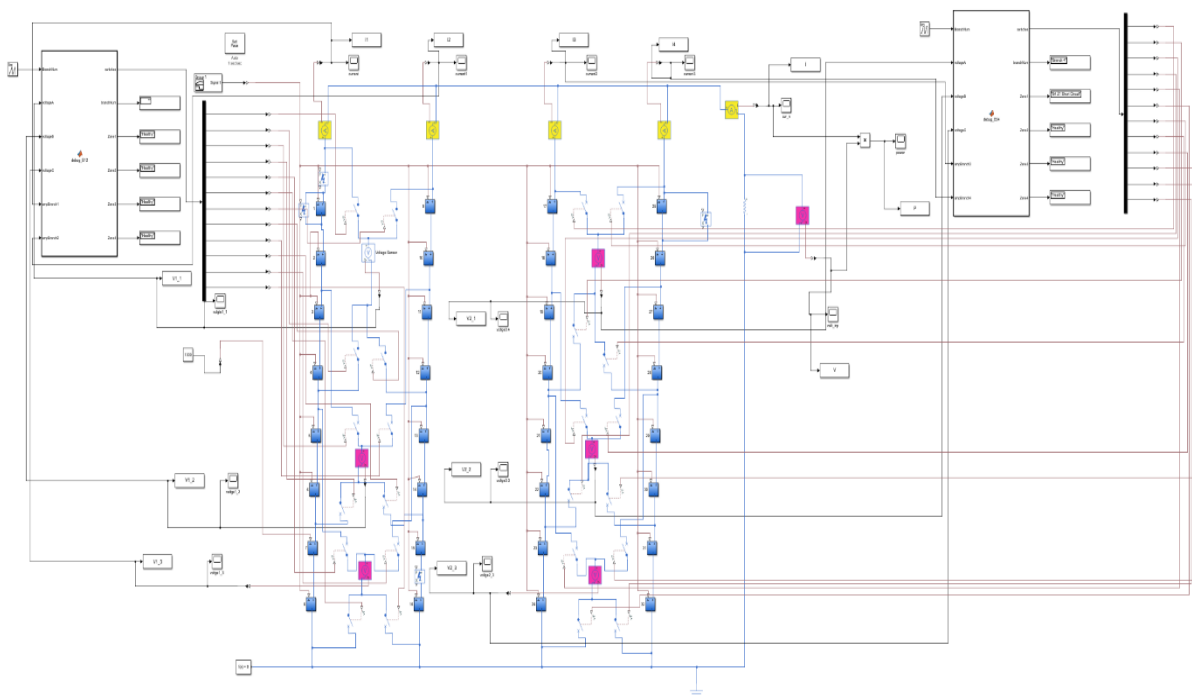


Fig3: 4x8 Photovoltaic array fault detection Simulink model in faulty condition.

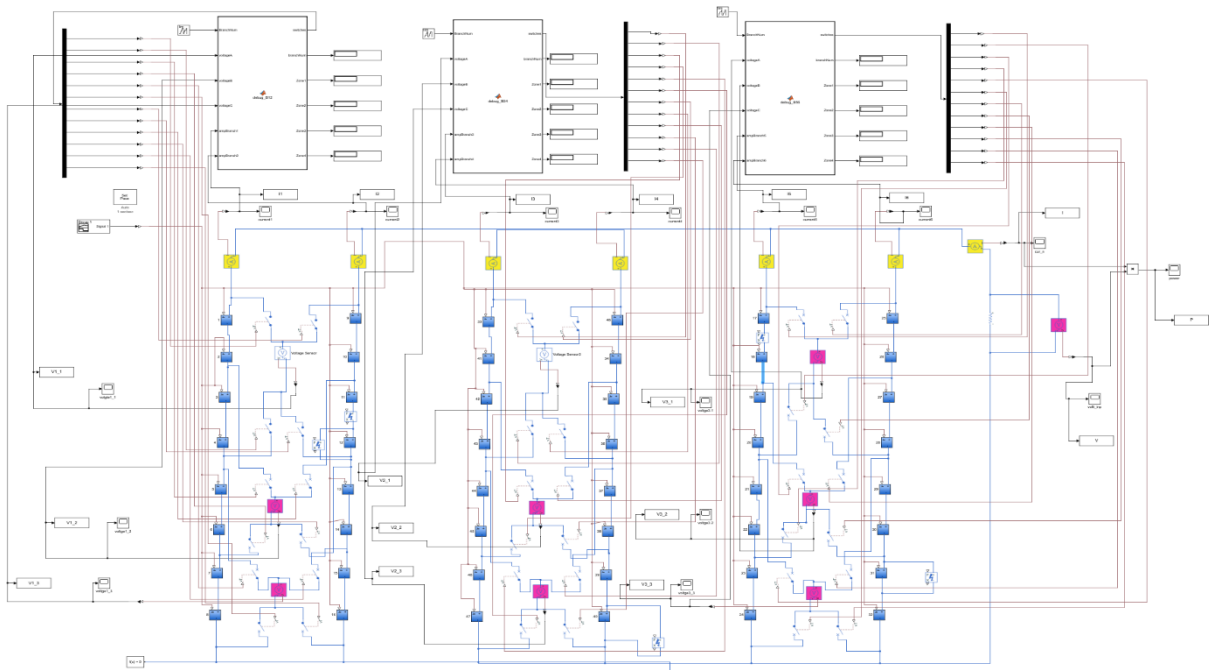


Fig4: 6x8 Photovoltaic array fault detection Simulink model in Faulty condition.

A. HEALTHY BRANCH:

We have a healthy branch if the values of the voltage and current sensors are normal as shown in the figures 5 and 6.

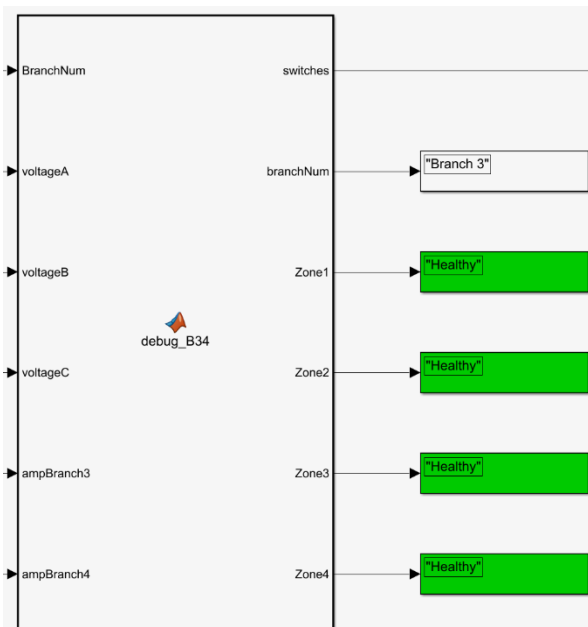


Fig 5: Healthy branch from simulation for a 4X8 PV array

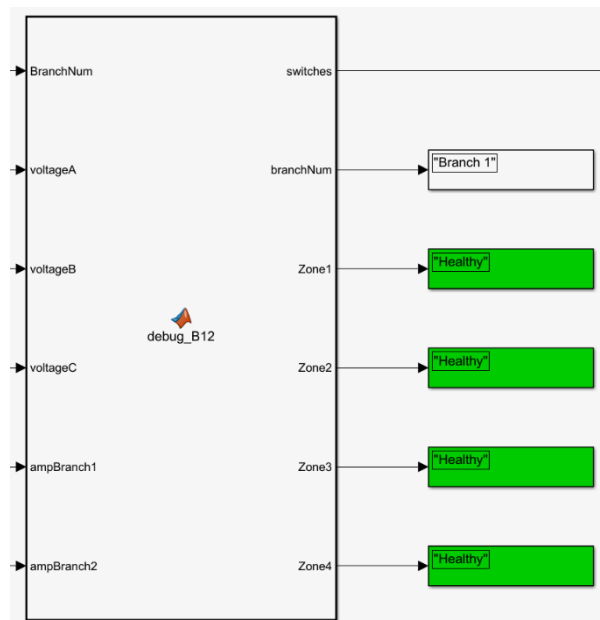


Fig 6: Healthy branch after performing simulation for a 6X8 PV array.

B. OPEN CIRCUIT FAULT:

When an open-circuit fault occurs in a module, the measurement of the voltage sensor that covers the zone where an open-circuit fault occurred will be different from the standard voltage U_s by more than the threshold voltage (0.0014 V), while the measurement value of the current sensor of the faulty branch will be zero. In the simulation 4X8 we have an open circuit in the second branch and in the simulation 6X8 we have an open circuit in

branch 5. Therefore, we see that the value of the current sensor in the second branch is equal to 0. We see that the value of the third voltage sensor in the second branch and that the value of the second and third voltage sensor in the third branch is different from the normal value. Thus, we can identify the open circuit fault in Zone 4 from the second branch, as depicted in Figures 7 and 8.

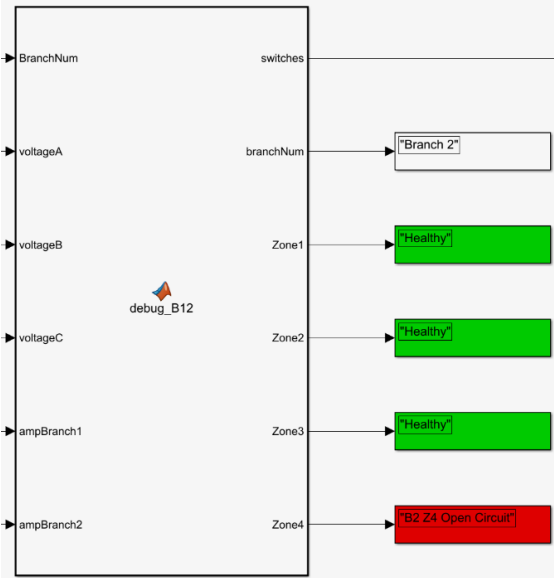


Fig 7: The simulation for a 4X8 PV array in presence of open circuit fault is clearly reported the detailed information (location and type) about the fault.

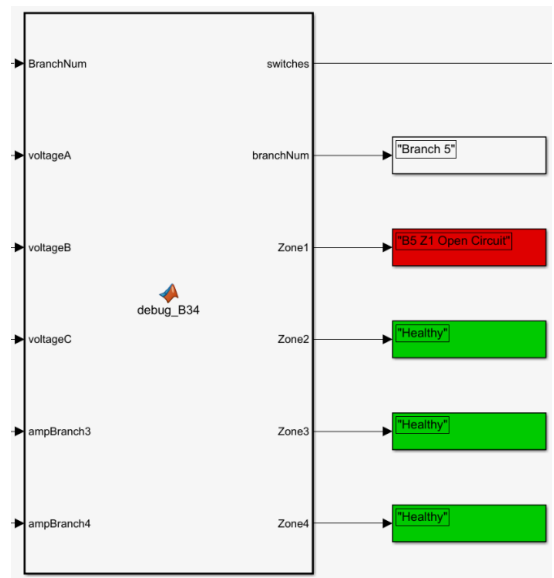


Fig 8: The simulation for a 4X8 PV array in presence of open circuit fault is clearly reported the detailed information (location and type) about the fault.

C. SHORT CIRCUIT FAULT:

When a short-circuit fault occurs in a module, current sensor measurements of all branches will be the same. However, the measurement of the voltage sensor that covers the zone which contains the faulty module will be less than the standard voltage measurement U_s by more than the threshold voltage (0.0014 V), as shown in Figures 9 and 10.

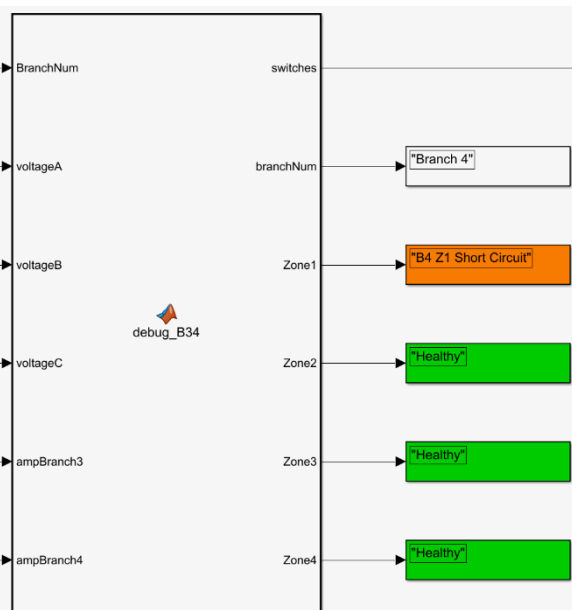


Fig 9: The simulation for a 6X8 PV array in presence of short circuit fault is clearly reported the detailed information (location and type) about the fault.

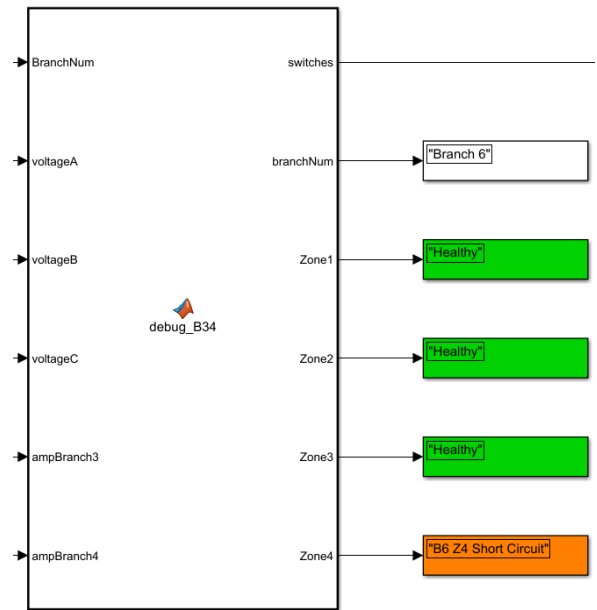


Fig 10: The simulation for a 6X8 PV array in presence of short circuit fault is clearly reported the detailed information (location and type) about the fault.

D. HOT SPOT FAULT:

When a hotspot fault occurs in a module, the measurement value of the voltage sensor that covers the zone where the hotspot fault occurred will be less than the measurement of the standard voltage U_s , and the difference will be more than the threshold voltage (0.0014 V), and the measurement value of the current sensor of the faulty branch will be less than the maximum current measurement by more than 10 percent, as demonstrated in Figures 11 and 12.

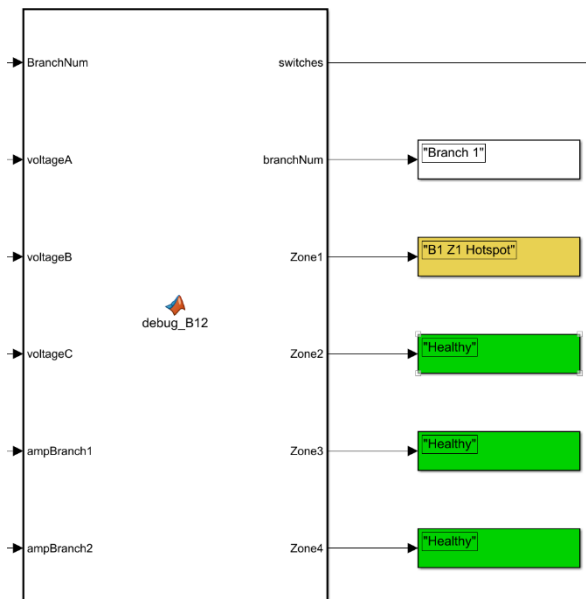


Fig 11: The simulation for a 6X8 PV array in presence of hotspot fault is clearly reported the detailed information (location and type) about the fault.

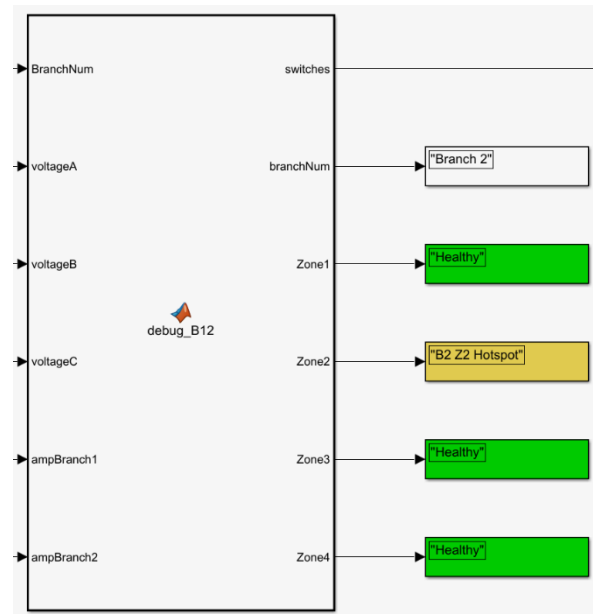


Fig 12: The simulation for a 6X8 PV array in presence of hotspot fault is clearly reported the detailed information (location and type) about the fault.

VI. CONCLUSION AND FUTURE WORK

In our paper, we outlined a new method to detect PV system fault and localization by using voltage sensors module, current sensors module, and switches. In this new technique, the safety is increased, and the cost is reduced by minimizing the number of voltage sensors in the grid. The proposed framework has been tested under different fault scenarios therefore, the results showed that the method is both effective and competitive.

This project can be developed to detect more faults, and some techniques can be added to protect the system before faults occur and further reduce. This project opens up many research areas that can improve and increase efficiency of solar PV systems, enabling more widespread and effective use of this promising new energy source.

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