GROUND FAULT IDENTIFICATION AND LOCATION DETECTION SYSTEM FOR SOLAR PV ARRAYS

W.G.S.D. Bandara*, K.M.G.Y. Sewwandi

Department of Electrical and Computer Engineering, The Open University of Sri Lanka

INTRODUCTION

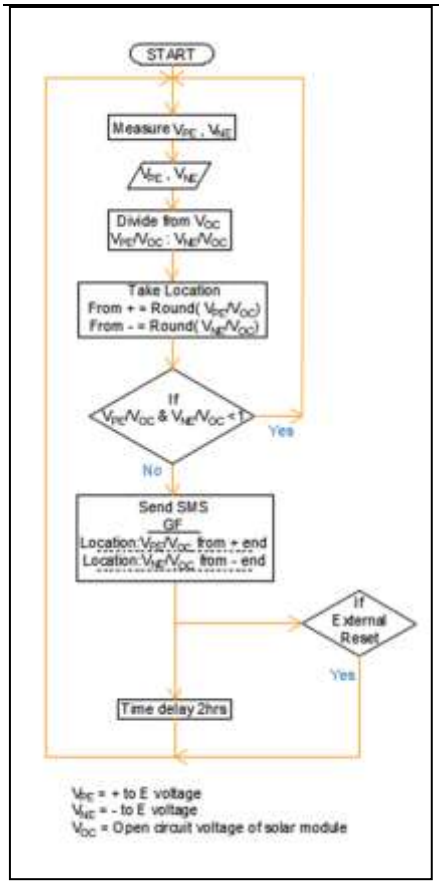
Amidst the global energy crisis, the renewable share in power generation has rapidly increased in the recent past. Solar energy is one of the prominent renewable- based generating methodologies. However, solar technologies are still improving and there are still some technical constraints in the solar industry that should be addressed. One of the major drawbacks in the existing solar systems is the difficulty in identifying Solar Direct Current (DC) ground faults [1]. This Solar DC ground fault is an abnormal condition of current flowing through the instrumentation grounding conductor when the DC array carries DC power to the inverter. These DC ground faults frequently occur in solar photovoltaic (PV) systems due to various reasons such as insulation damage, aging, water leakage and corrosion [2]. Due to these ground faults, a significant amount of energy is wasted, and fire risks are also associated with these faulty systems [3, 4]. Currently in the solar industry, no convenient devices are available to find the exact location of the ground fault in a solar PV array remotely and instantly.

When a ground fault happens in a PV system, most of the available solar inverters indicate it as an error and the inverter will turn off as a result. Due to this, a considerable amount of energy is wasted during peak hours [4]. For the low-capacity inverters (i.e. capacity less than 10 kW), the input array voltage could reach to maximum 600 V and for the high-capacity solar inverters (i.e. capacity greater than 10 kW), this PV array input voltage reaches to 1000 V. Therefore, these faulty voltages are very high and the energy losses occurring due to ground faults could be hazardous as it might lead to a fire [5, 6].

As there are no devices to trigger the exact location of the ground fault in a solar PV array remotely and instantly, the aim of this research is to develop a ground fault identification and location detection device prototype for solar PV arrays. Initially, the proposed ground fault detection system was developed under the MATLAB/Simulink platform to check its functionality. Then the hardware prototype was implemented, and it was successfully able to identify a ground fault and its location by the implemented prototype.

METHODOLOGY

Initially, the proposed ground fault detection system was developed under the MATLAB/Simulink platform to check its functionality. Then the hardware prototype was implemented. This project is solely based on voltage measurements and there is no involvement with the leakage current or insulation resistance. The main components used are the Arduino Mega2560 board, a voltage divider circuit and the SIM800L GSM module. The entire programming part was done based on the Arduino IDE software. Generally, when a ground fault occurs, there must be a voltage between the positive or negative conductor with respect to the ground conductor [7]. Normally, these fault voltages vary between 0 to 1000 V depending on the panel arrangement and the fault location. Here, the faulty voltages are taken as an input to the system and an algorithm was developed to identify ground fault location based on the faulty voltage. Finally, a text message alert with fault location data will be sent to a prescribed mobile number when a fault is detected by the system. The entire design of the process is illustrated in the following system design block diagram and the flow chart.



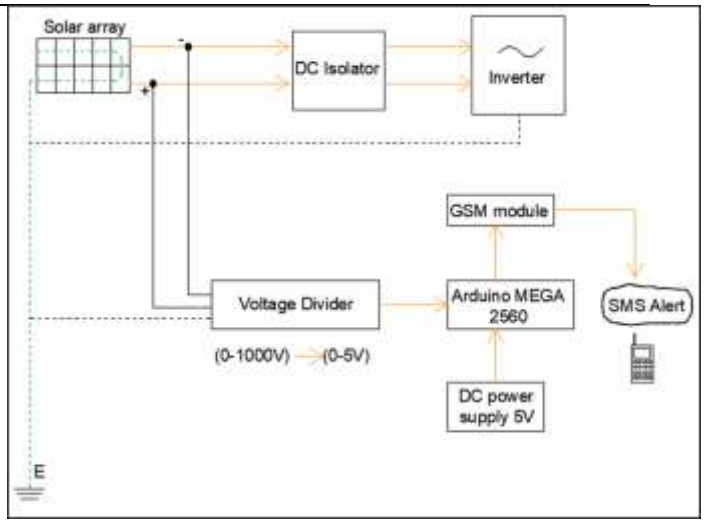


Figure 02: System Design Block Diagram

Figure 01: System Flow Chart

According to the developed algorithm which is depicted in figure 01, the system checks the fault voltages (Positive to Earth & Negative to Earth) once every three seconds. When a ground fault is detected, either Positive to Earth (V_{PE}) or Negative to Earth (V_{NE}) will be greater than zero. The system then divides those voltage values by an open circuit voltage value (V_{OC}) of a single module. Then at least one of those values (V_{PE}/V_{OC} or V_{NE}/V_{OC}) will be greater than or equal to one. From that the system will be able to identify the fault condition. Also, by using both output values, it is possible to identify fault location in the PV array with respect to both ends within three- seconds. Finally, that fault alert will be sent to the system owner within a three second period. If the system owner is unable to rectify the fault within a two-hour period, the system's self-test runs again and a reminder will be sent. This process is repeated every two-hour period. If the system owner rectifies the system within the two-hour period, the system will go back to normal operation. And this mechanism also involves carrying out a self-test if the user prefers.

RESULTS AND DISCUSSIONS

Initially, the proposed ground fault detection system was developed under the MATLAB/Simulink platform to check its functionality. A thirteen module solar array was used for the simulation and the ground fault was created in random locations of the array and results were observed and analysed several times. Then the hardware prototype was implemented. The prototype design is shown in figure 03 below.

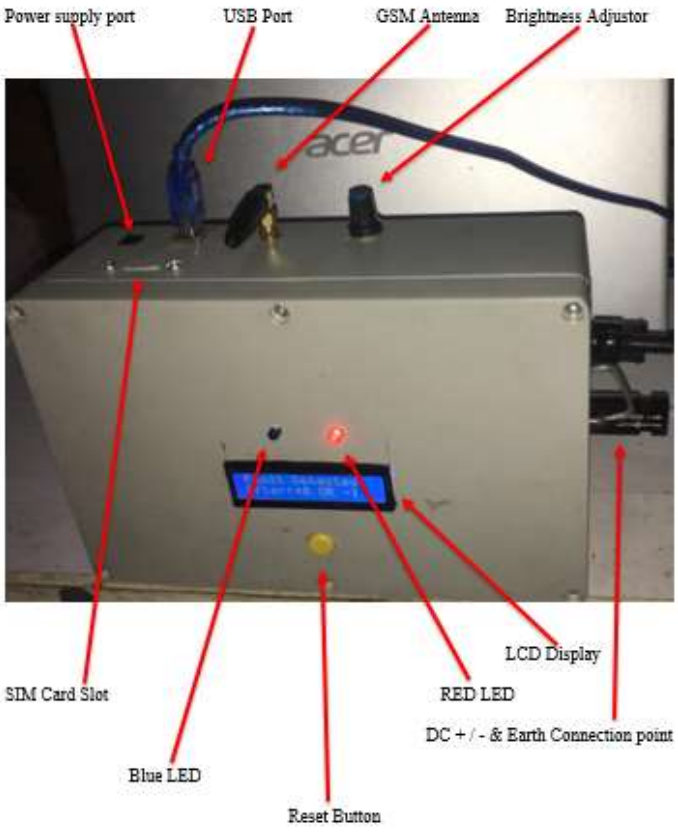


Figure 03: Prototype Design

The Prototype was designed to work under two operating states; normal operating state and fault detected state.

1. Normal operating state: During this period no ground faults are available and the system is working under check mode or steady-state. The blue LED is flashing and displays "PV is in good condition" on the LCD display as per figure 04.

2. Fault detected state: During this period, ground fault is available in the system and the system is working under fault detected mode. During this period, the red LED flashes and displays "Fault Detected & Fault Location" on the LCD display. Figure 05 shows the fault detected mode when a fault occurs at the beginning of the positive end of the five number solar PV array. Also, an SMS alert is sent to the system owner mentioning the fault location with respect to both positive (+0) and negative (-5) ends within 3 seconds.

Figure 04: Normal Operating State

Figure 05: Fault Detected State

CONCLUSIONS/RECOMMENDATIONS

DC ground fault is a common faulty condition that happens in solar PV systems. When a ground fault occurs, it is difficult to find the exact location and involves a significant number of human hours. In the case of large PV systems there are a higher number of PV arrays connected to a single inverter and the array has more than 20 solar modules. Therefore, it is difficult to detect the ground fault location in such systems and, due to a ground fault in a single array, the entire inverter goes to off state and a considerable amount of energy will be wasted.

The developed prototype design was limited to identifying ground faults in a single array unit. In the case of high-power solar systems, it comprises multiple array systems. In the future it is possible to extend this research to develop a fault detection system for multiple array solar systems. Other than that, the voltage measurement sensitivity of the Arduino is 4.9 mV and this could be improved if a DSP card was used instead of the Arduino board. However, the developed prototype was tested with a single array solar system and it was possible to detect the exact faulty location for any point in the array instantly while ensuring the solar system's safety.

REFERENCES

Alam, M., Khan, F.H., Johnson, J., Flicker, J., 2014. A comprehensive review of catastrophic faults in PV arrays: types, detection and mitigation techniques. IEEE J. Photovol. in review 2014.

J. Flicker and J. Johnson, "Photovoltaic ground fault detection recommendations for array safety and operation," *Sol. Energy*, vol. 140, pp. 34–50, 2016, doi: 10.1016/j.solener.2016.10.017.

N. Padmavathi, "Fault Detection and Identification of Solar Panels using Bluetooth," *2017 Int. Conf. Energy, Commun. Data Anal. Soft Comput.*, pp. 3420–3426, 2017.

S. E. I. Association et al., "US Solar Market Insight: 2015 Year in Review (Executive Summary),"Washington, DC March, 2016. [Online].Available: http://www.seia.org/sites/default/files/gMOip8F78iSMI2015YIR.pdf

B. Brooks, "The ground-fault protection blind spot: Safety concern for larger PV systems in the US," Solar American Board for Codes and Standards, 2012.

M. Falvo and S. Capparella, "Safety issues in PV systems: Design choices for a secure fault detection and for preventing fire risk," Case Studies in Fire Safety, vol. 3, pp.1–16, 2015.

D. B. Jason Fisher, "Ungrounded PV Power Systems in the NEC," Solar Pro, vol. 5.5, August/September 2012. [Online]. Available: http://solarprofessional.com/print-issue/august-september-2012

ABBREVIATIONS & ACRONYMS

Direct Current (DC), Photovoltaic (PV), Global System for Mobile (GSM), General Packet Radio Service (GPRS), Liquid Crystal Display (LCD), Light Emitting Diode (LED), Digital Signal Processor (DSP)