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| RESEARCH ARTICLE

Design and Implementation of an Intelligent Solar Panel Management System with Automated Fault Detection and Swapping Capabilities

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| ABSTRACT

This study presents the design and implementation of an intelligent solar panel management system equipped with automated fault detection and panel-swapping capabilities. In response to the need for consistent power in off-grid and solar-dependent systems, this project aims to enhance the reliability and sustainability of photovoltaic (PV) arrays by mitigating the impact of panel failures. The proposed system identifies faults by monitoring output parameters—primarily the short-circuited current—and promptly isolates faulty panels. Leveraging a microcontroller-based mechanism, the system then initiates a swap with a designated spare panel, ensuring an uninterrupted power supply. Components such as relays, voltage sensors, and an LCD for monitoring further support real-time detection and fault management. Testing outcomes demonstrated the system's effectiveness in automatic fault identification and swapping under specified conditions, making it a valuable, low-cost solution for maintaining solar panel efficiency and longevity. The developed system offers a robust approach to minimizing downtime and operational disruptions in solar energy applications, particularly in rural or remote areas where maintenance access is limited.

| KEYWORDS

Solar-dependent systems, Photovoltaic arrays, Power supply

| ARTICLE INFORMATION

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1. Introduction

1.1 Background of the study

The need for consistent and steady power supply has become paramount not only in the electricity-dependent world but also in developing rural areas. Electricity in itself may not bring development but may foster highly desired commodities and prerequisites to rural development in a long-term perspective. This development in the light of the contemporary world is socio-economic development with the production of a reliable electricity supply for powering devices, appliances, and machines, which facilitates the production of goods and services. (Ahlborg and Hammar 2011).

The production of this electricity is dependent on the renewable and non-renewable energy sources. Advancements in technology have decentralized electricity generation more in renewable energy sources like solar, wind, biomass, and others to off-grid areas.

Solar energy, particularly photovoltaic (PV), has become the preferred alternative for off-grid areas where there is great exposure to sunlight and difficulty in accessing the grid.

Ndagijimana (2019), in his findings on solar power, argued that in spite of the huge success recorded relatively, it constitutes only 0.2% of the global electricity generation and 4.7% of all renewable energy except hydro-electricity.

The efficiency of solar PV, according to Abu-Jasser (2010), depends on the proper system maintenance and management practices, which, aside from causing inconsistency in power supply, pose a threat to the users' lives and equipment.

1.2 Statement of the problem

There is no ideal condition in real life for any component; therefore, no system has 100% efficiency, and so is the solar panel. Failure of a panel in the array of panels causes a voltage drop in the overall system and so the need for a sspare or redundant panel to enable automatic replacement or swap with the faulty panel in order to annul its effect.

1.3 Aim

The aim of this project is to design and construct a low cost fault detection system for a photovoltaic (PV) array with swapping capability.

1.4 Objectives of the project

The objectives of this project are;

1. To detect faulty solar panel using its output parameters precisely the short-circuited current (when voltage is zero).
2. To isolate the faulty panel from the system.
3. To design a swapping or switching mechanism of the faulty panel with the spare.
4. To monitor the overall performance of the PV array prior to the inverter.

1.5 Significance of the project

The following are the importance of this project;

1. Swapping of the faulty solar panel helps the end user of this energy to maintain a steady supply from the panel.
2. It identifies the exact solar panel that is faulty by auto-switching with the spare, therefore telling the maintenance personal the location of the fault.
3. It helps to lessen the time for manual swapping, eliminating system downtime in that regards.

1.6 Scope of the study

This study is intended to cover the DC region of the solar panel system prior to the inverter stage with a series-parallel array of four panels and a spare with the same ratings. The system should be able to detect faulty panels and replace a panel at a stance.

2. Literature Review

This chapter covers the theoretical framework, conceptual framework, and review of related literature.

2.1 Theoretical Framework

Brief information on the theory of main components used in the course of this project is discussed in this section.

2.1.1 SolarPanel

A solar panel's primary role in any solar energy system is to convert solar energy into electrical energy, a process facilitated by its photovoltaic (PV) cells. Each PV cell includes multiple layers: an antireflection layer to minimize energy loss, energy-conversion layers (top junction, absorber, and back junction) for efficient energy transfer, and electrical contact layers to channel the generated current. The absorber layer is especially critical, as it captures sunlight and excites electrons, which then flow to create an electric current enabled by junction layers that produce an electric field. These layers, made of semiconductor materials like silicon or gallium arsenide, efficiently absorb visible light. The structure and materials used are akin to those in solid-state electronics, but in solar cells, the focus is on maximizing surface area to increase power output, unlike microelectronics, where minimizing component size is key.

Figure 1: Solar panel modules.

2.1.2 Relays

A relay is an electrically operated switch with input terminals for control signals and contact terminals for operation. Traditional relays use an electromagnet to open or close contacts, while solid-state relays (SSRs) utilize semiconductor properties to achieve switching without moving parts. An SSR has three main components: an input circuit (which activates with a specific voltage range, typically 3-32 VDC), a control circuit (which manages when the output is energized or de-energized), and an output circuit (which switches the load). SSRs generally have one output contact, allowing for zero, instant ON, or peak switching options, the latter of which is used in this project.

Figure 2: A solid state relay

2.1.3 Voltage Sensors

A voltage sensor is used to monitor, calculate and determine the voltage supply in a system or at any point of a system. This sensor can determine the AC or DC voltage level with great advantages over conventional methods ofmeasurement; they include less size and weight, high safety, high accuracy, non-saturable, and eco-friendly.

2.1.4 Microcontroller

A microcontroller is a computer present in a single integrated circuit that is dedicated to perform one task and execute one specific application. It contains memory, programmable input/output peripherals as well as a processor. Microcontrollers are mostly designed for embedded applications and are heavily used in automatically controlled devices such as cell phones, cameras, microwave ovens, washing machines, etc.

In this project, the Arduinonano microcontroller was used. It is based on the ATmega328p or ATmega168 microchip, a platform used in electronic projects consisting of oth pa hysical programmable circuit board and a piece of software that runs on the computer. The microcontroller has specifications as shown in table 1.

Figure 4: An Aarduino Nano

Table 1. Specifications of Arduino Nano microcontroller.

Microcontroller	Atmega328p/Atmega168
Operating voltage	5V
Input voltage	7-12V
Digital I/O pin	14
PWM	6 out of 14 digital pins
Maximum current rating	400mA
Analog pin	8
Flash memory	16Kb or 32 Kb
SRAM	1Kb or 2 Kb
Crystal oscillator	16MB
EEPROM	512bytes or 1Kb
USART	Yes

2.1.5 Liquid Crystal Display

Liquid crystal display (LCD) is composed of several layers which include two polarized panel filters and electrodes. LCD technology is used for displaying the image in some electronic devices like mini computers. Light is projected from a lens on a layer of liquid crystal. This combination of colored light with the gray scale images of the crystal (formed as electric current flows through the crystal) forms the colored image. This image is then displayed on the screen.

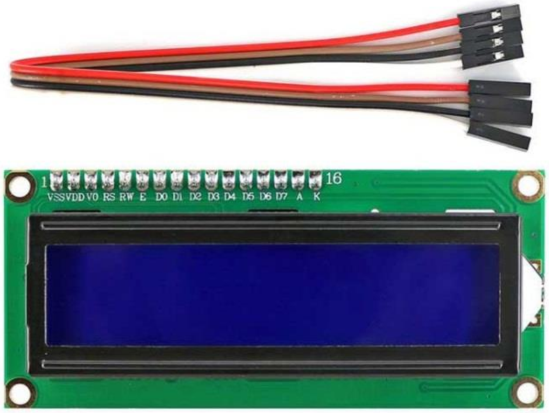


Figure 5: An LCD

2.2 Conceptual Framework

This section consists of the concept behind the working principle of the solar energy management system with the wapping capability of faulty panel.

The principle is in four stages: the ultraviolet (UV) reception and sensing stage, the processing stage, the swapping stage, ,and the display/notification stage. The UV reception and sensing stage comprises the UV-ray, the solar modules, and the sensors. The processing stage is the control stage made up of the microcontroller and relay. The swapping stage consists of the spare module and relays. The display notification stage comprises the LCD and the buzzer.

2.2.1 Block diagram

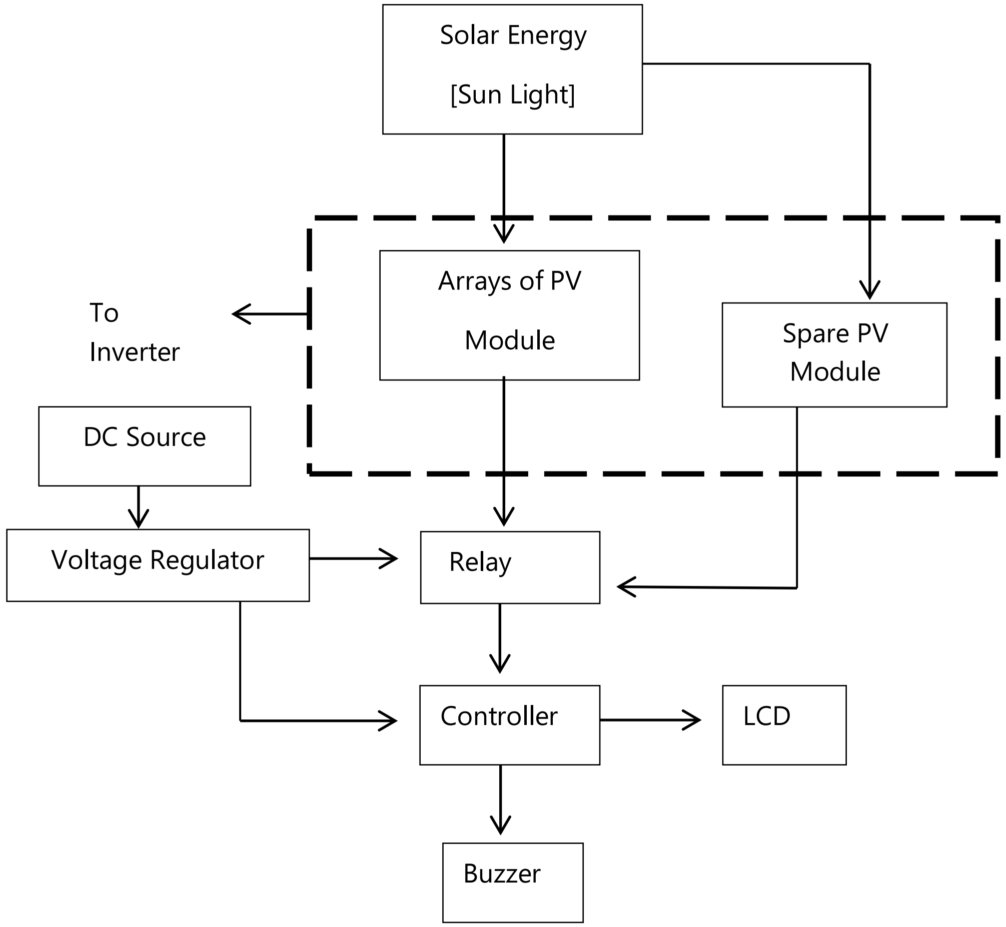


Figure 6: Block Diagram of a fault detection system for photovoltaic (PV) array with swapping capability.

2.2.2 Power supply unit

The power unit is the unit that supplies power to the microcontroller. The power source is a Lithium Polymer (LIPO) rechargeable battery. Since a single cell of 5V cannot be readily available, a charge regulator IC was implored to keep the output voltage at a onstant value of 5V irrespective of the input voltage ,maintaining a constant Amp in hours.

2.2.3 Solar Energy Source

This produces ultraviolet ray whose source is the sun. A floodlight was used in the course of this work to produce the rays.

2.2.4 Arrays of Solar Panel

The arrangement of these panels determines the output current and voltage. Solar panel, like other DC battery arrangements concept, when arranged in series, add up voltages and maintain constant or same current, but on the other hand, when arranged in parallel, voltage is the same ,but current add up.

This project is a series-parallel arrangement of panels of the same ratings, two pairs of series connected panels connected in parallel; therefore, current and voltage doubles.

2.2.5 The Control Unit

The microcontroller is the central or the heart of this control unit, as every other units receive control from the microcontroller. In this design, the microcontroller, through the sets of instructions, switch between the faulty panel and the spare panel, thus giving rise to automatic rectification of the fault for uninterrupted power supply.

2.2.6 The Spare Panel

This is a panel of the same rating set asideas standby in the case of fthe ault within the array of solar modules. Irrespective of the position of the faulty panel, the spare will replace automatically.

2.2.7 The voltage regulator

Voltage regulators are very common in electronic circuits. They provide a constant output voltage for a varied input voltage. In our case, the 7805 IC is an iconic regulator IC that finds its application in most of the projects. The name 7805 signifies two meaning, "78" means that it is a positive voltage regulator, and "05" means that it provides 5V as output. So our 7805 will provide a +5V output voltage.

For a typical application circuit of the 7805 IC, two capacitors of value 33uf and 0.1uf are needed to get this IC working.

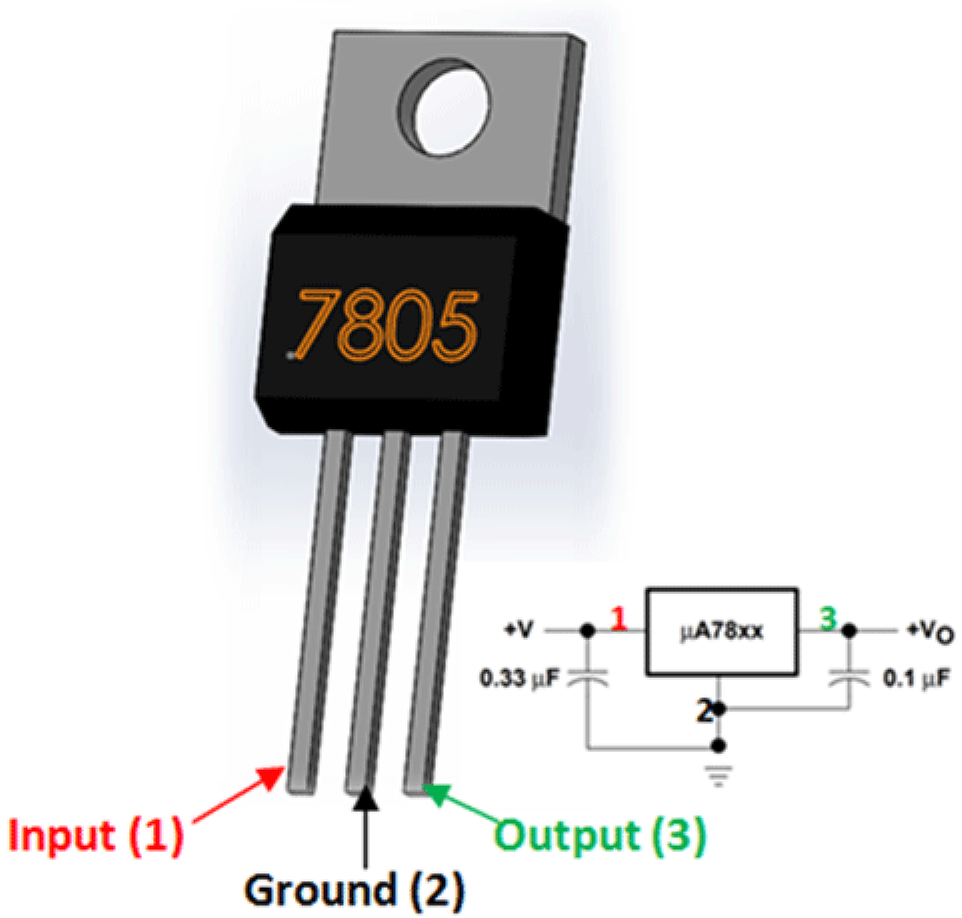


Figure 7: A Voltage Regulator

2.2.8 The AuxiliaryDevices

This comprise the LCD, sensors, buzzer, crystals, transmitter/receiver module, and relays. They help in monitoring voltage level, breaking and making contacts of the panels, notifying and displaying data of the system on a screen.

2.3 Review of Related Empirical Studies

Hu and Cao (2016) opined that fault detection in PV arrays are best detected in levels. These levels include the cell, module, string, and array level ,whose fault can either be minor, medium, or heavy fault, depending on the intensity. Fault diagnosis techniques need to be implored in order to increase operating efficiency and extend effective service time. The description of the various levels is shown in figure 8.

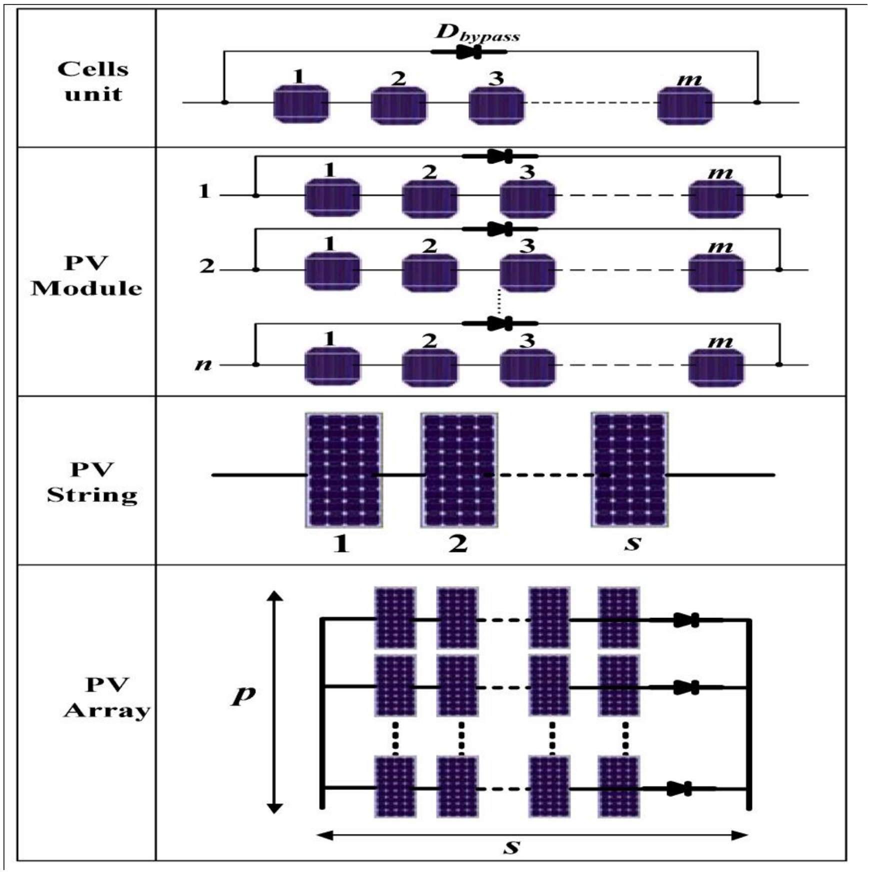


Figure 8: Description of PV Arrangement in Levels.

The installation of PV system nationwide, according to Rakesh*etal.* (2020) follow the protection standard as stated in the U.S National Electric Code (NEC) or International Electro-technical Commission (IEC) to use Over Current Protective Device (OCPD) and Ground Fault Protective Device (GFPD) for detecting and clearing short circuit faults like line to line and ground fault respectively. But due to Maximum Power Point Tracking (MPPT), blocking of diode in power system, and environmental condition, conventional OCPD and GFPD often fail to detect these faults; therefore ,the need to develop efficient detection and management system comes into play.

Natarajan*et al.* (2020) argued that a PV module in operation can have its parameters extracted using a thermal image processing algorithm and compare them with the parameters of a healthy module using the Support Vector Machine (SVM). This machine, being a classifier tool, classifies the parameter of the module to be either defective or non-defective. These defects can be caused either by;

1. cracks

2. climatic condition
3. tilted angle of module or
4. type of liquid used for cleaning.

Fault diagnosis methods for solar photovoltaic (PV) systems include three main types: virtual perception, thermal, and electrical methods, with electrical methods best suited for large-scale plants and virtual perception for small-scale plants (Sonawane et al., 2019). Appiah et al. (2019) identified four major fault types—line-to-line, ground, arc, and hot spot faults—which can be analyzed using techniques like Comparison Based, Statistical and Signal Processing Based, Reflectometry Based, and Machine Learning Based Techniques.

Haque et al. (2019) noted that PV module defects can lead to rapid degradation and reduced service life, with about 2% of modules failing to meet warranty due to issues like delamination. Thermography and artificial intelligence can detect these faults in under 9 seconds. Dhemish (2018) found that faults in PV systems, such as shading or faulty modules, can be effectively detected by an Artificial Neural Network (ANN) with two hidden layers, achieving 92.1% accuracy in detecting faults like multiple direction and diagonal cracks, which decrease output power by 8% and 4%, respectively.

Mellit et al. (2020) highlighted the use of the Internet of Things (IoT) in fault detection for stand-alone PV systems, enabling device communication and data sharing without human interaction, crucial for managing the global PV capacity of about 400 GW. Ramakrishna et al. (2017) emphasized monitoring parameters like current, voltage, solar radiation, and temperature to enhance PV plant performance by early detection of energy losses and faults.

2.4 Summary of Literature Review

The literatures reviewed have laid the basic knowledge on which this work is intended. They explicitly explained the concept, working principles of a PV module, and ways of maintaining then.

3. Circuit Analysis

3.1 Introduction

The ever increasing demand for a better and save energy void of pollution and less of a nuisance to the environment and the humans which it services may be a good pointer as to why the world embraced solar energy as a source of energy upon its arrival. This energy has been converter to various forms in order to better our lives. Getting a single solar panel that can effectively supply the required amount of energy might be quite expensive and, in the other hand might be too much for one who requires them in la ittle size. This calls for the reasons of arranging panels in series and parallel, as the case may be, to either increases voltage (series arrangement) or increase the capacity of current (parallel arrangement). In an event in which they are arranged in series or parallel for larger demands, this usually leads to an increases in their numbers. Sometimes, this might be in tens or hundreds.

When a particular panel is faulty amidst, them this might be difficult to trace and replace it, hence the subject matter of this project. This chapter deals with the mathematical derivation and theories upon which the various components in this work have been selected, and the conditions for their functioning have been based.

Since the panels are voltage sources, this research took the value of the voltage generated as a parameter to determine whether a panel is faulty or not.

3.2 Filtration or Decoupling of Voltage from the panel

It is expedient to decouple the voltage from the panels in order to reduce ripples and provide better regulation. A capacitor has been used as the filter or decouple. The figure shows the arrangement. The value of the capacitor selected is not based on any theory rather on preference, as larger values may be selected for better filtration ,or low values may be used to save cost and materials. But with an idea of the designed load, the capacitor to be used may be estimated according to the following formulae

$$V_O = V_p e \frac{-t}{RC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The formulae above represent the value of the voltage across a capacitor at any time of frequency t.

R is the resistance of the load being supplied, C is the capacitance of the capacitor, ,and t is tau, the time constant, which is the rate of charging and discharging of the capacitor

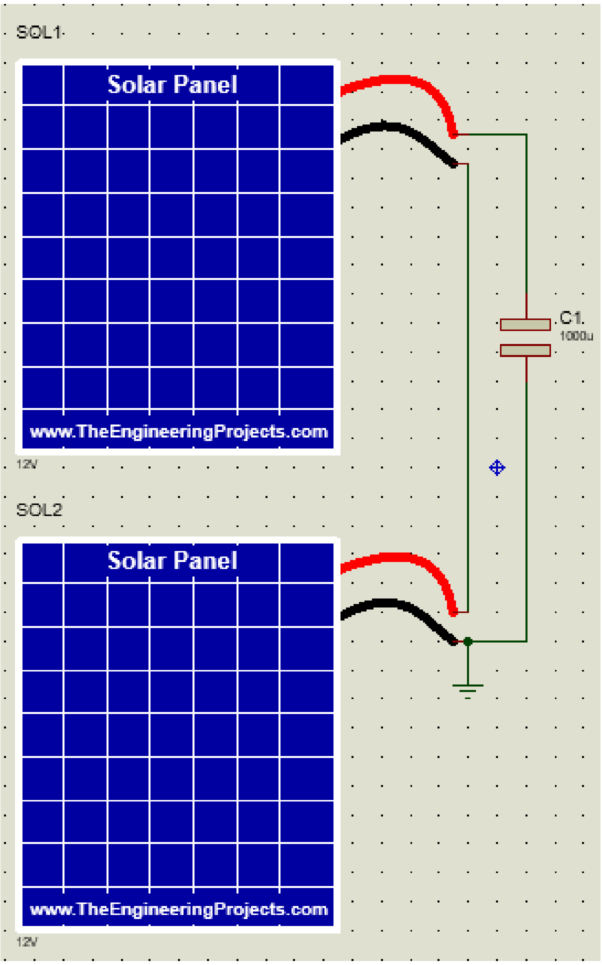


Figure 9: Filtration circuit for solar panel supplies

3.3 Analysis of Power Supply

The power supplied to the microcontroller, which is the brain of the research, is taken from a direct current (DC) battery to ensure that power is always available to the controller even when there is a fault in the panels. The circuit for the supply is shown in figure 10.

The battery is a DC 12 V supply, which is way too high for the controller; hence, a voltage regulation circuit is designed

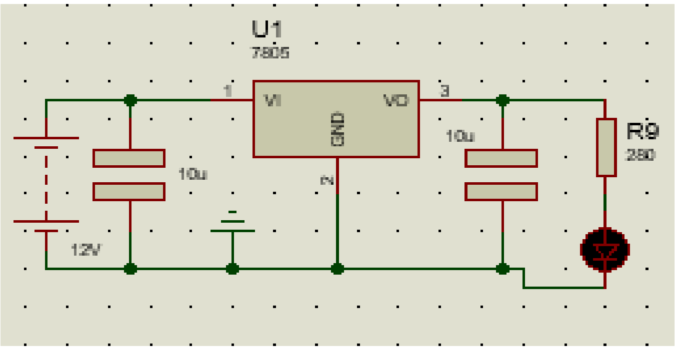


Figure 10: Power Supply and Power indicator Circuit

3.3.1 Circuit for Power Indicator

$V_{bb} - IR_9 - V_{led} = 0$ ……………………………………………….(2)

Where V_{bb} is the base supplied voltage, V_{led} is LED forward voltage drop = 2.2 V and R_9 is the current limiting resistor. I is the amount of brightness required, which is 10 mA

$R_9 = \frac{V_{bb}-V_{led}}{I} = \frac{5-2.2}{10\ mA} = 280\ \text{Ohms}$ ……………………………………….(3)

3.4 Analysis of the Switching Relays

The relay has been used as an electrical isolator and for the transfer of larger power from high current sensitive electronics components to high source of supplies. Relay has been employed in this research to isolate panels that are bad and engage a spare. Because enormous amount of current will have to pass through the terminals of the relay as demanded by the connected load, hence the analysis and selection of the relay has to be done with utmost care since the relays will be connected directly to the batteries to deliver power.

For a 12 V,2 W PV module, the rated current I, from the equation

P = IV …………………………………………………………………….(4)
$I = \frac{P}{V} = \frac{2}{12} = 0.167\ A$ ………………………………………………….(5)

This is the same as 167 mA, which a relay rated 1 A can handle effectively without overheating. 1 A and 12 V rated relay has been selected.

3.5 Analysis of the Relay Driving Circuit.

For the relays to be actuated from the microcontrollers when required, transistors have been used to perform these duties since they require a little voltage greater than their base emitter voltage to drive them to saturation. Amidst the three mode of operation of a transistor, the saturation and cut-off mode has been employed. For a transistor to exist in this mode, the current through the collect must be far less than beta multiplies by the base current.

That is;

$I_C \ll \beta I_B$ This implies that ……………………..(6)
$I_B \gg \frac{I_C}{\beta}$ ……………………………………………………………….(7)

Relay data: 12 V, 30 mA (coil current).

Transistor Saturation Mode data: $V_{BE(SAT)}$= 0.80 V, $V_{CE(SAT)}$= 0.2 V and h_{FE}= 100.

Taking Kirchhoff's voltage law (KVL) of the C – E loop and making I_C the subject of the relation:

$$I_C = \frac{12 - V_{CE}}{R} \quad \text{……………………………………………………………(8)}$$

Where R is relay resistance.

$$R = \frac{Relay\ voltage}{maximum\ relay\ current} \quad \text{…………………………………………9}$$

$$= \frac{12\ V}{30\ mA} = 400\ \Omega.$$

So substituting into $V_{CE(SAT)}$ = 0.2 V and R= 400 Ωfrom equation (4) yields:

$$I_C = \frac{12-0.2}{400} = 29.5\ \text{mA.} \quad \text{………………………………………………10}$$

Similarly, taking KVL of B – E loop yields:

$$I_B = \frac{V_{BE} - V_{BE}}{R_B} = \frac{5.0 - 0.80}{R_B} \quad \text{…………………………………………11}$$

$$I_B = \frac{4.2}{R_B} \quad \text{…………………………………………………………12}$$

Condition for saturation

$$I_C < h_{FE} \times \frac{4.2}{R_B} \quad \text{…………………………………………………………(13)}$$

Substituting I_C and I_B into the above equations above and making R_B subject:
R_B <1 kΩ.

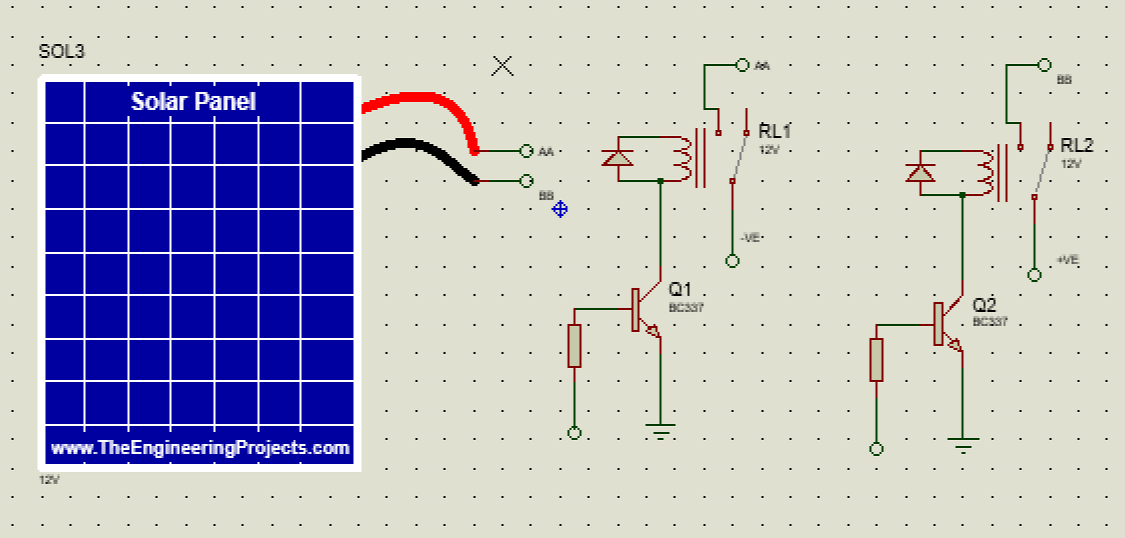


Figure 11: Circuit Configuration for standby Panel to replace any bad one Automatically

3.6 Voltage Divider Network

The figure below shows the voltage divider network which was used to feed the microcontroller, taking note of the voltage supplied by the solar panels. Because the controller may not accommodate voltage greater than 5 V and because it is greatly under stress when such a voltage is supplied to its analog to digital pins, a resistor voltage divider network was used to step down the input voltage from the panels to a tolerable value for the microcontroller.

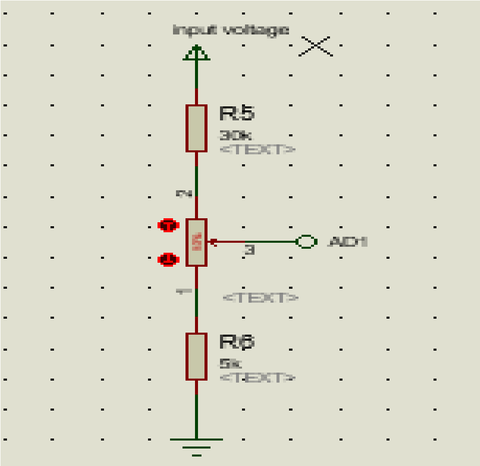


Figure 12: Voltage Divider Network

$V_{AD1} = \frac{V_i \times (R_V + R_6)}{R_5 + (R_V + R_6)}$ ………………………………………………(14)

From the equation (14) let R =$R_V + R_6$, therefore
$V_{AD1} = \frac{V_i \times \mathrm{R}}{R_5 + \mathrm{R}}$ ……………………………………………………(15)

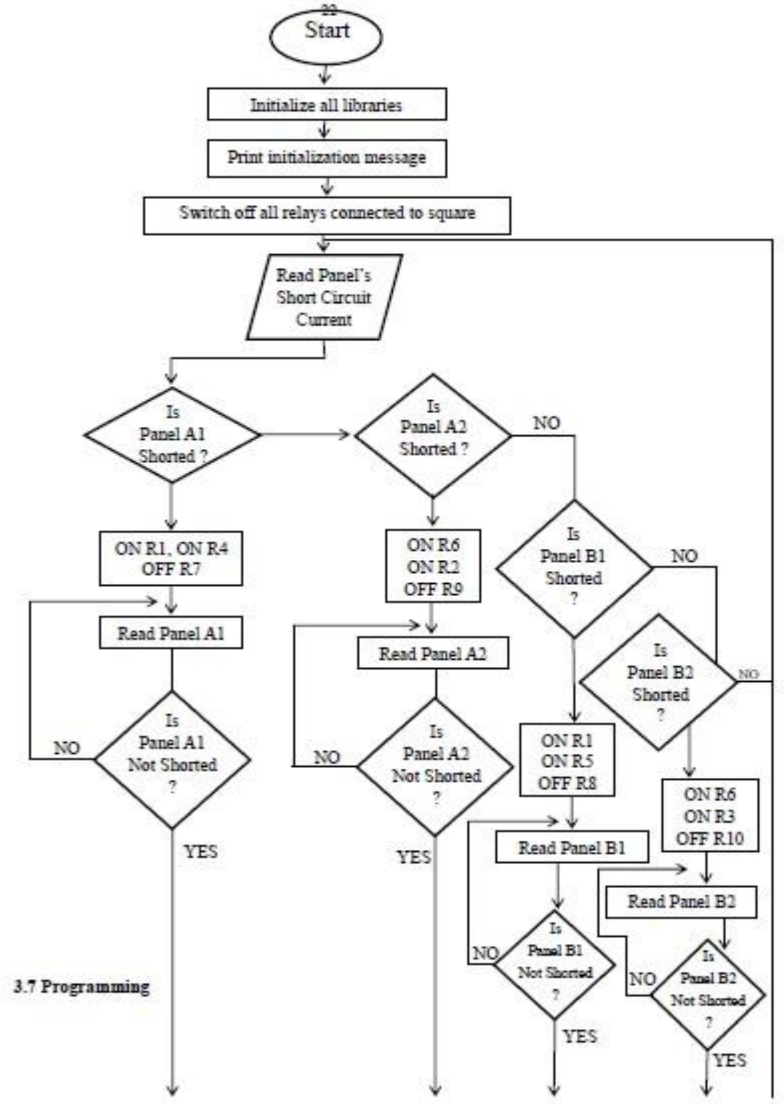
Given that the value of the input voltage may rise up to 17 V under very high solar day then, it is required that the voltage been read by the controller should not be greater than 5 V, hence $V_{AD1} = 4$, $V_i = 17\ V and \mathrm{R} = 10\ \mathrm{k}$

Making $R_5 thesubjectofformularfrom$ equation (15)

$R_5 = \frac{V_i \times \mathrm{R} - V_{AD1} \times \mathrm{R}}{V_{AD1}}$ ………………………………………………(16)

Substituting the values yields $R_5 = \frac{17 \times 10 - 4 \times 10}{4}$ = 30 k ohms

3-7 FlowChat:



3.7 Programming

The system's programming was completed in the Arduino environment, leveraging its extensive libraries and debugging features. The microcontroller reads the voltage from solar panels connected to analog inputs A0 to A5 to detect panels producing below expected values. When a panel is identified as faulty, the microcontroller deactivates it and activates a spare panel by controlling relays via transistor signals. Each panel's terminal connects to a unique pin, allowing for accurate switching.

An LCD (connected to pins D4 to D9) displays the faulty panel for physical replacement. The replacement logic follows a specific relay activation sequence:

- **Panel B1 fault**: Relay 1 and 5 are ON; Relay 8 is OFF.

- **Panel A1 fault**: Relay 1 and 4 are ON; Relay 7 is OFF.
- **Panel A2 fault**: Relay 6 and 2 are ON; Relay 9 is OFF.
- **Panel B2 fault**: Relay 6 and 3 are ON; Relay 10 is OFF.

The controller holds its position after a panel swap to avoid replacing multiple panels since only one spare is available.

3.8 Solar Panel Arrangement

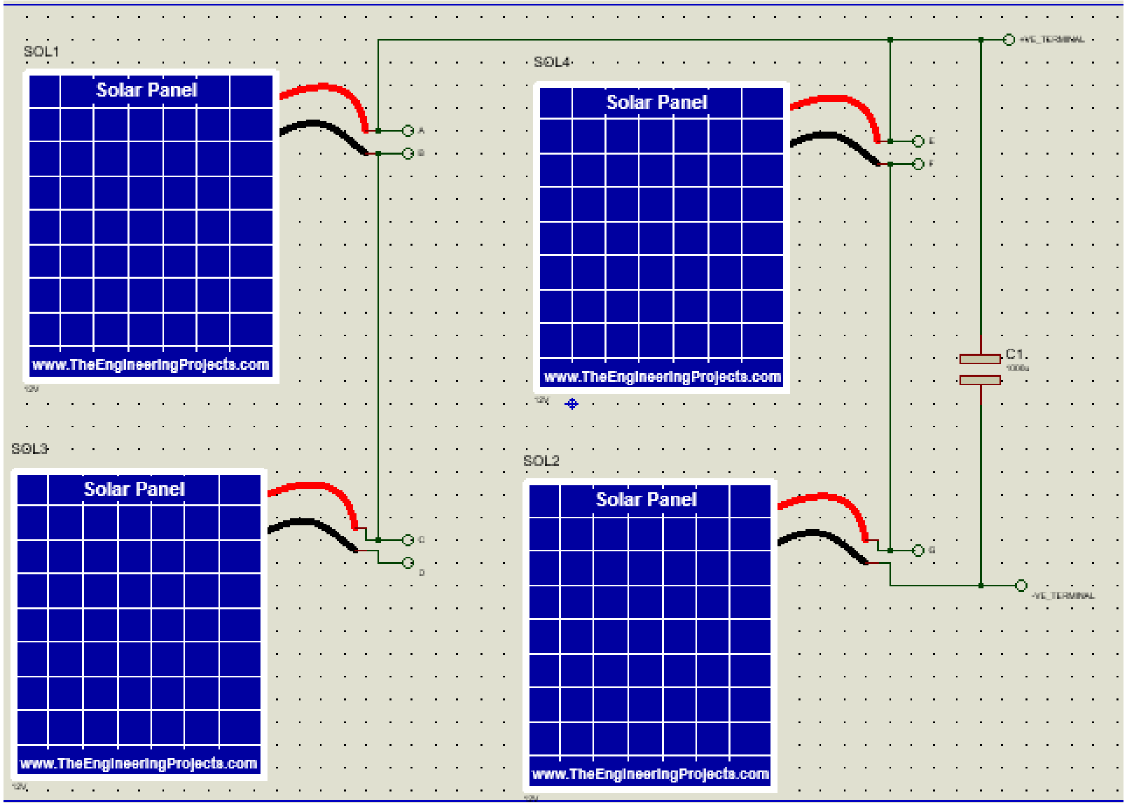


Figure 13: Solar Panel Series –Parallel Arrangement

3.9 Solar Fault detector and Controller Circuit

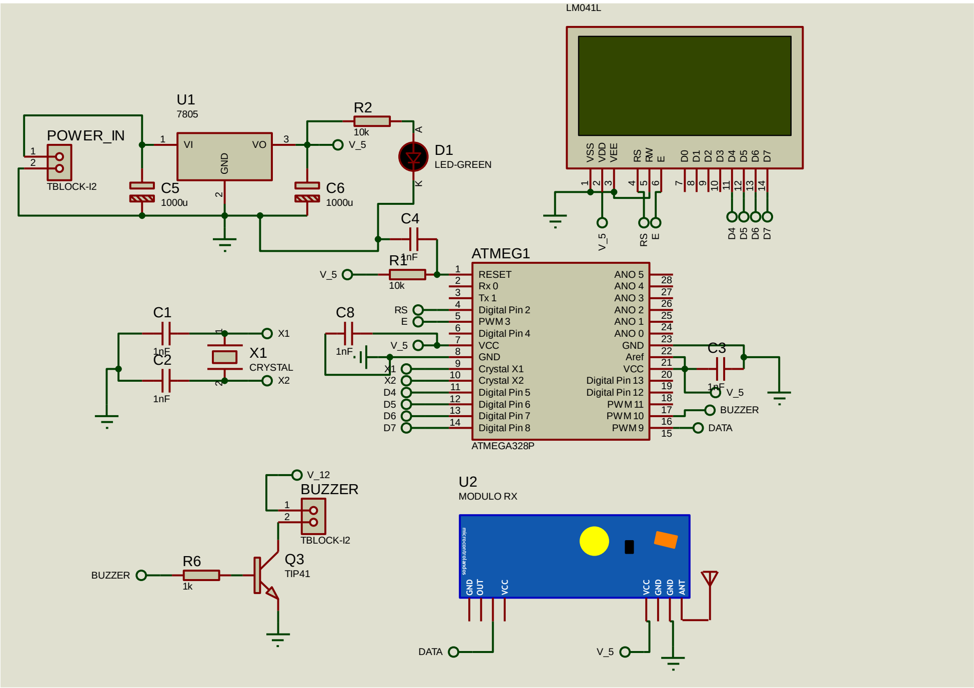


Figure 14: Fault Detection Circuit (Receiver Circuit)

Figure 13 above shows the circuit designed to measure the voltages delivered by the panels whose critical value is known and displays when a panel is faulty. The resistor networks show in figure 12 represents the potential dividers for the panels each. As shown in figure 13, the output from each panels is connected to the points labeled SOLAR_1 to SOLAR_4. The liquid crystal display (LCD) shown in figure 13 gives the result of any panel that is faulty.

3.9.1 Faulty Panel Replacing Circuit

The circuit to switch out the faulty solar panel and replace it with a good or standby one is shown in the figure below. It is an array of relays which are individually connected to a microcontroller so that they may be switched at will and when desired.

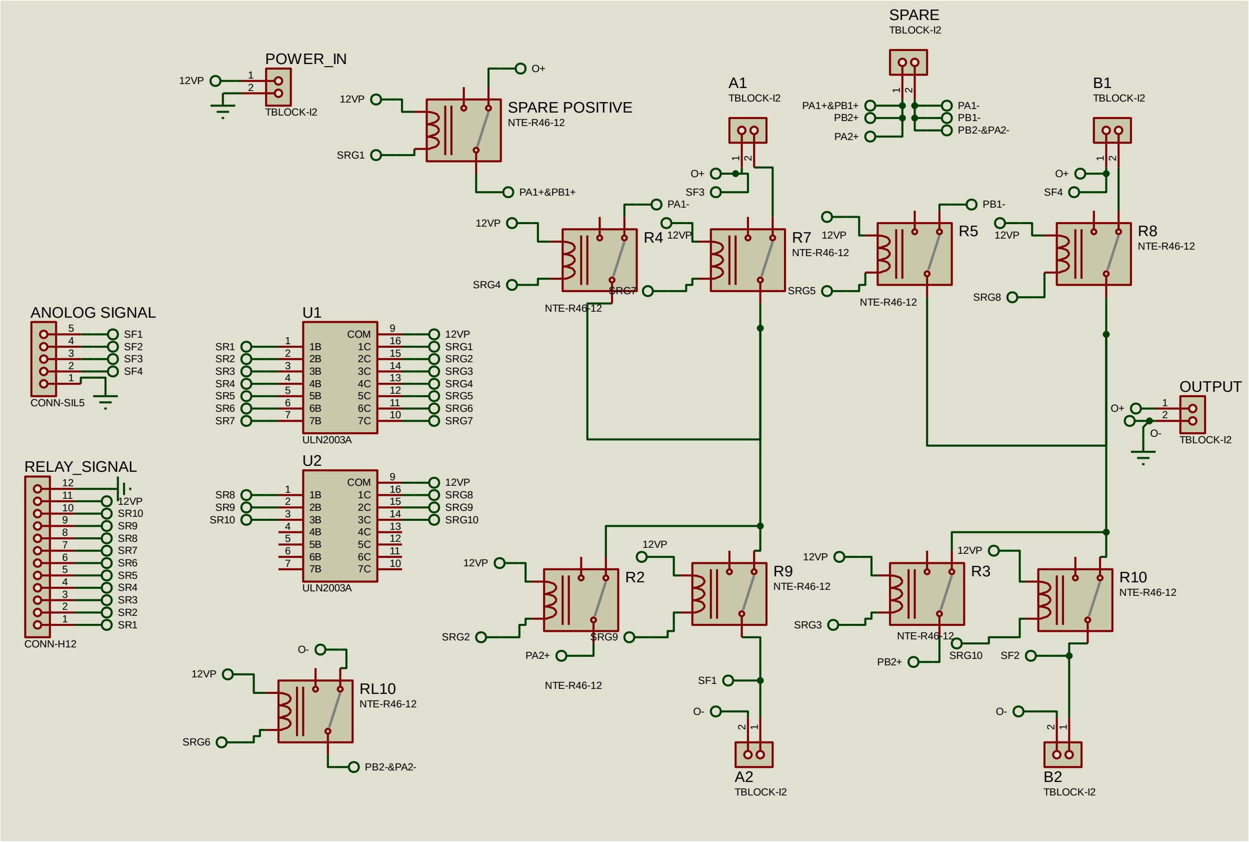


Figure 15: Solar Panel Replacing Circuit

From the circuit shown in figure 15, all the relays has been assigned numbers, numbered from R1 to R10. While the solar panels has been named A1, A2, B1, and B2, respectively. Connections were such that when a panel is faulty, two relays are switched ON while the relay that connects two panels in parallel is switched OFF. This will isolate the bad panel out of the circuit.

ULN2003A is used to sink current from the relays when a signal is given by the controller.

The relays are connected in a way that, when they actuate, they transfer or relay power from the solar panels to the load. This is because the solar panels have polarity, and when a solar panel is to be replaced with a good one or standby, it has to be connected without their polarity interchanged.

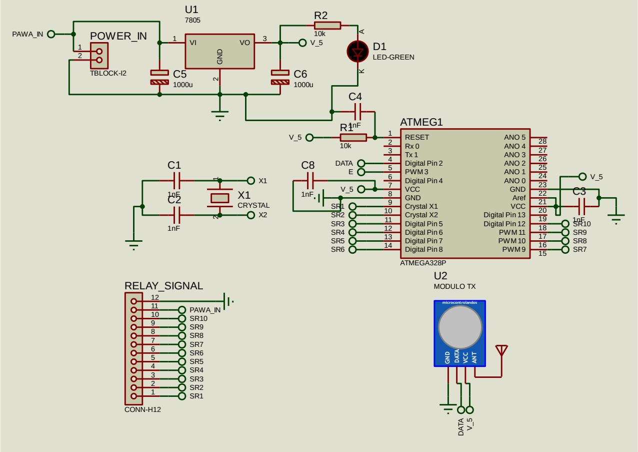


Figure 16: Fault Detection Circuit (Transmitter circuit)

4. Contruction, Testing, Results and Discussion

4.1 Construction

The designed circuit was drawn with the Proteus simulation circuit version 8.6. A printed circuit version of the circuit has to be designed, and provision for components whose printed circuit foot prints are not found on the software has to be replaced with terminal connectors. Figure 17 shows the printed circuit version of the circuit.

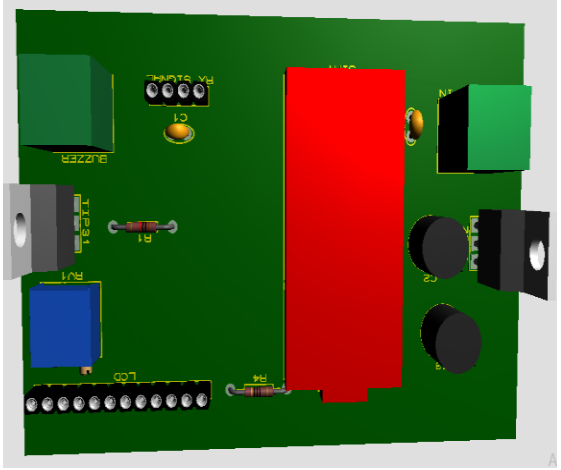


Figure 17: Printed circuit on 3D view of fault display and ReceiverCircuit.

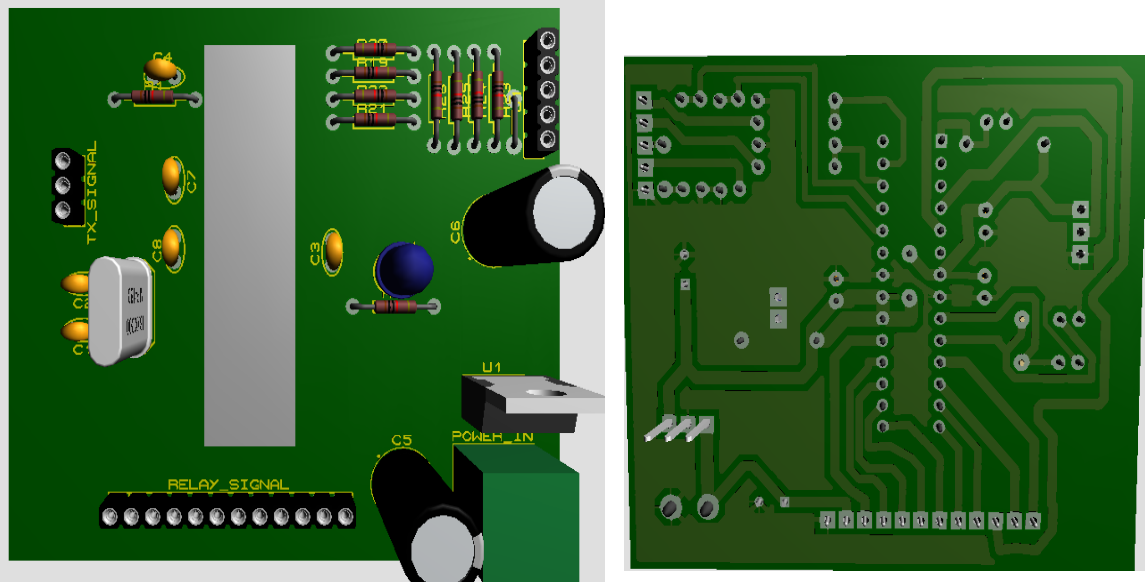


Figure 18: Printed Circuit on 3D view of Fault Detection and transmitter Circuit

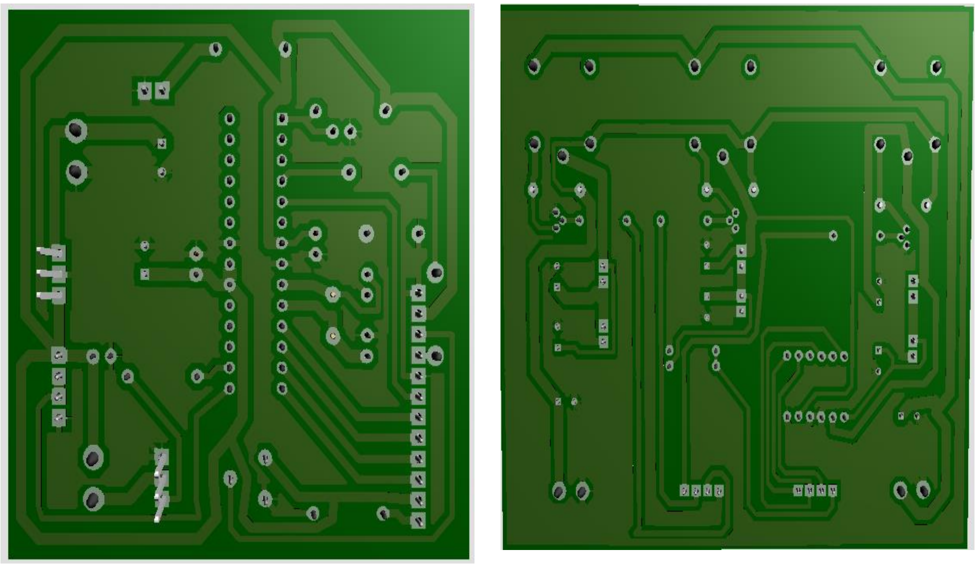


Figure 19: Printed Circuit board on 3D View for fault detection and displaying circuit

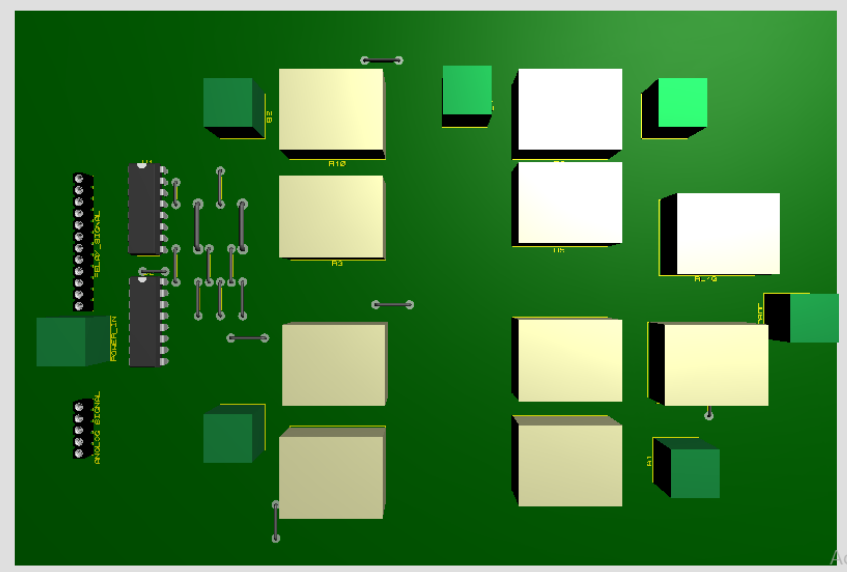
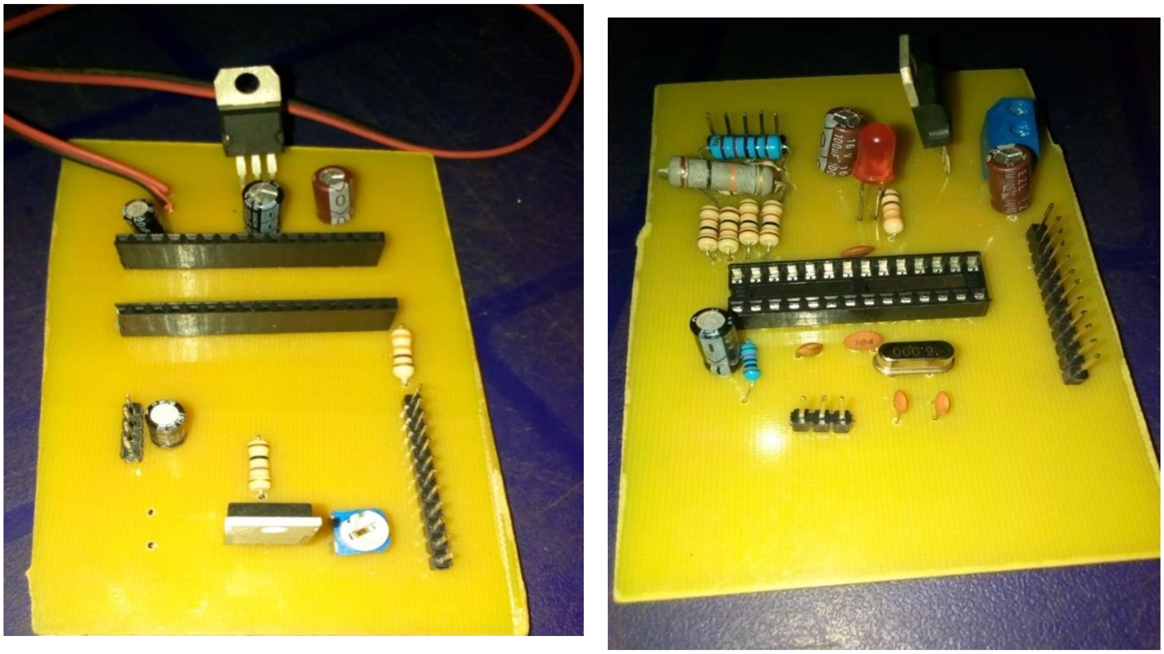


Figure 20: Printed circuit on 3D view of Solar Panel Relay Replacing Circuit.

4.2 Construction of Printed Circuit Board

The design circuit was printed using a laser jet printer on a glossy paper then transferred onto a copper clad using heat. It was further etched using iron (III) chloride solution to remove the unwanted copper leaving behind the circuit traces. The board was drilled and populated with the required components and soldered permanently, as shown in figure 21.



(a) **(b)**

Figure 21(a) and(b): Soldered Receiver and Transmitter Circuit Respectively.

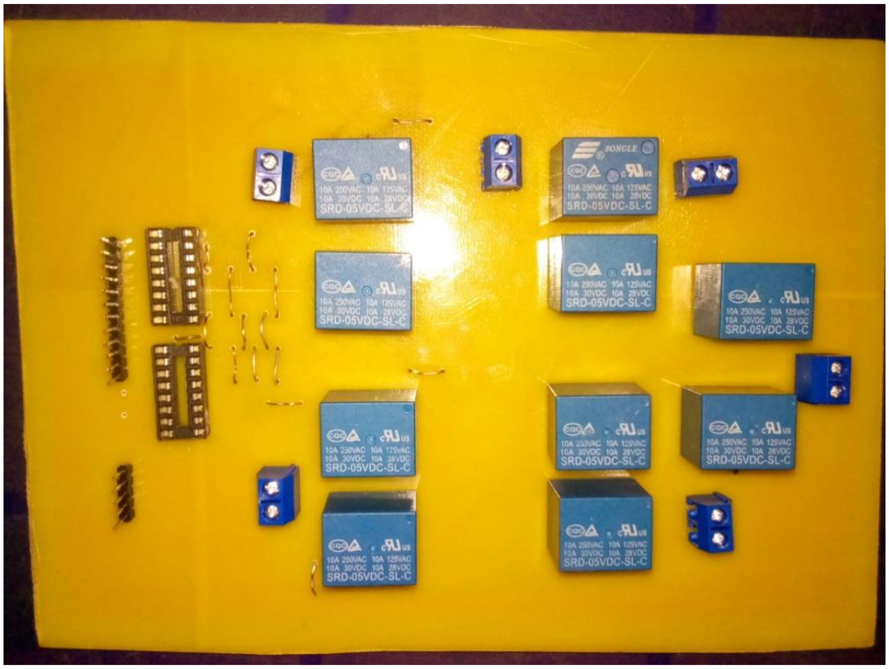


Figure 22: Relay Circuit

Figure 23: Solar Panel arrangement

4.3 Testing

The circuitswere power separately with a 12 V lithium battery. The voltage read from the 5 V linear regulators (7805) was measured to be 5.08 V. Some short circuited areas were spotted with a multimeter, but after much tracing and correction, the LEDs on the board lighted, and the microcontrollers where fixed. The temperature of the voltage regulators were at room temperature. None heated; hence no heat sink was attached.

The circuits worked appropriately, displaying and switching the relays as expected. But this was done without fixing the solar panels manually. Figures 24 – 30 show the powered transmitter circuit and the receiver circuit.

Figure 24: System Initialization Display

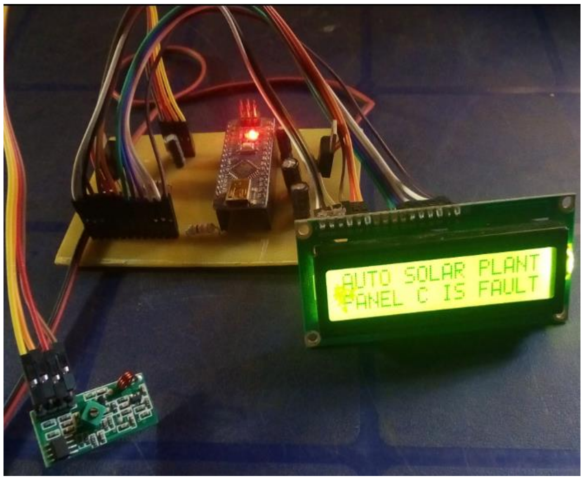


Figure 25: System reporting Panel C

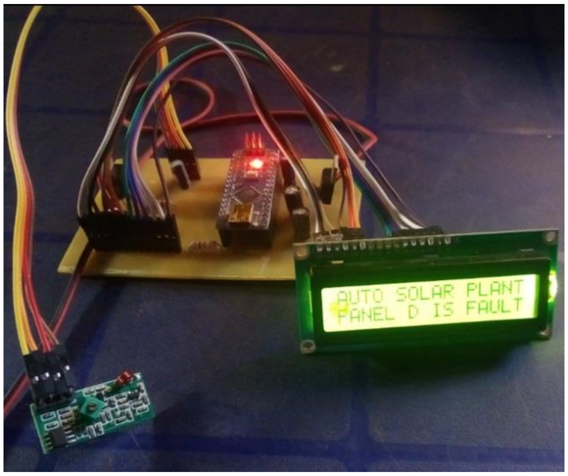


Figure 26: System reporting Panel D

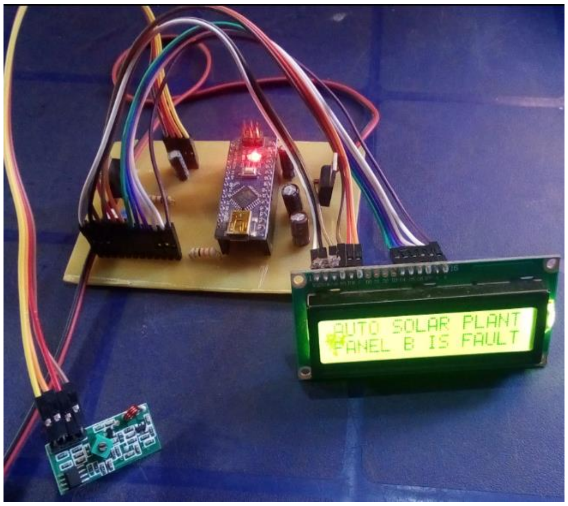


Figure 27: System reporting Panel B

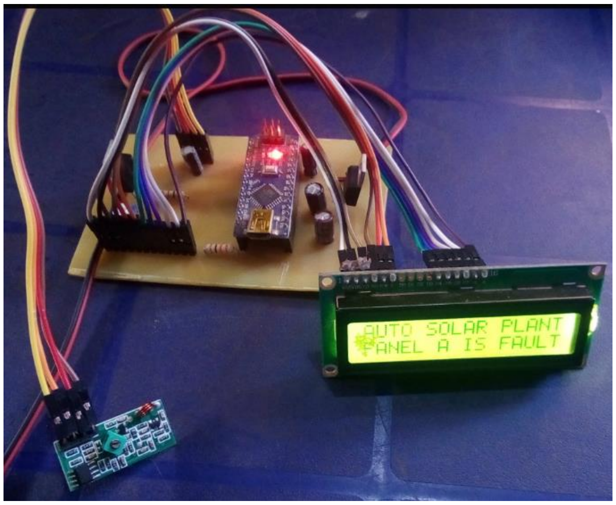


Figure 28: System Reporting Panel A

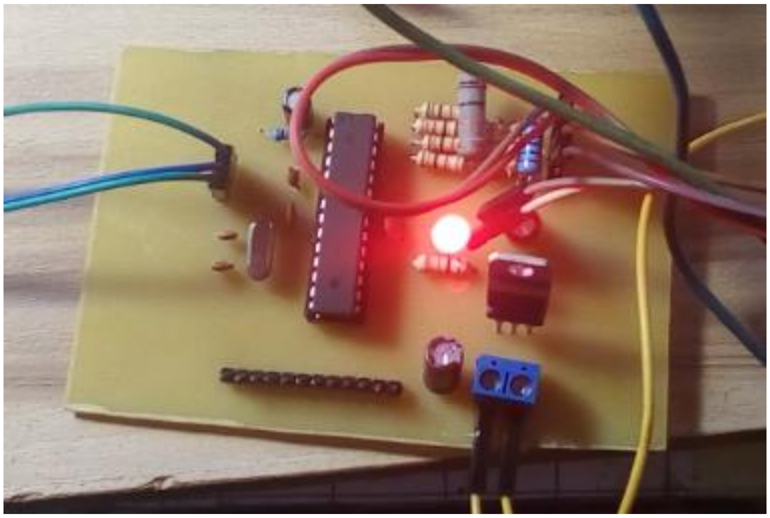


Figure 29: Testing of Fault Detection and Transmitter Circuit

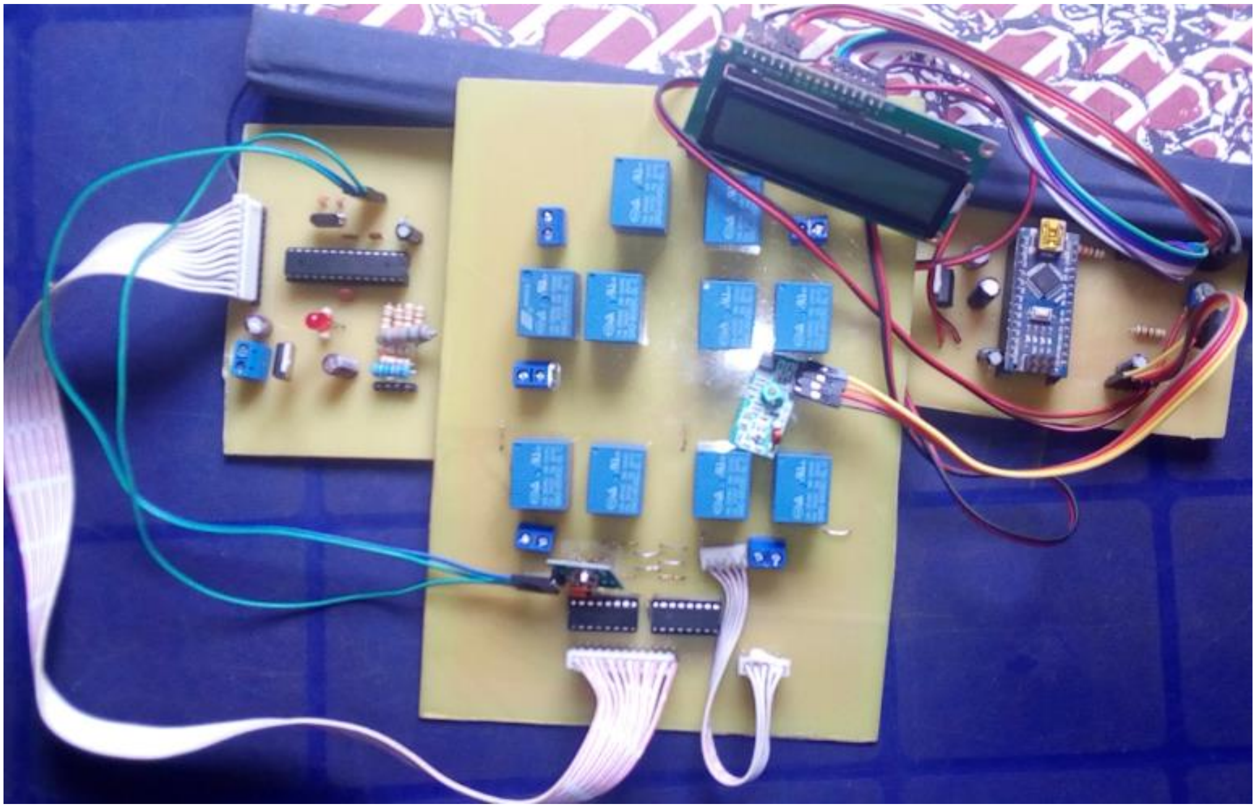


Figure 30: Completely Soldered Circuits

The entire system was tested with a voltage source of 7.5 V and 12 V supply, respectively. As each of the point where the fault voltage is experience is disconnected from the source of supply representing the panel, the system reported the fault almost immediately.

4.4 Results and Discussion

1. Successful Fault Detection: The intelligent solar panel management system successfully identified panels with zero voltage, flagging them as faulty according to the set threshold. This threshold (1V) ensures the detection of panels producing less than 70% of the expected voltage, considering consistent environmental conditions across the array.
2. Efficient Fault Isolation and Replacement: When a fault was detected, the system effectively isolated the malfunctioning panel and engaged the spare panel without manual intervention. This automated swapping mechanism significantly reduces downtime and preserves continuous power supply.
3. System Stability Under Various Conditions:
    - Night Mode Observations: At night, the system encountered challenges, as the lack of sunlight naturally reduced the panel outputs to near-zero voltage, which triggered erratic behavior. A safe mode was incorporated to address this, though future stability improvements could be considered.
    - Daytime Performance: During standard testing under sufficient sunlight, the system consistently detected faults and executed the relay-based switching to maintain array functionality.
4. Performance Testing:
    - Battery Power: Testing with different voltage levels (7.5V and 12V) indicated stable performance, with the voltage regulators operating at room temperature and not requiring additional heat dissipation.
    - LCD Display Feedback: The LCD provided real-time feedback on the status of each panel, indicating any faults, which aids in system monitoring and maintenance planning.
5. Construction and Circuit Validation:
    - The printed circuit design performed as intended after troubleshooting short circuits and adjusting

connections. With each component functioning in sync, the system demonstrated reliability in fault detection, notification, and automatic panel swapping.

4.5 Discussion Points

- Improvement Suggestions: Incorporating night mode or additional parameters to distinguish low output due to fault versus natural lack of sunlight could improve system stability.
- Significance: This automated system has broad applications in solar energy management, particularly for off-grid installations where maintenance response time is critical.

5. Conclusion and Recommendation

5.1 Conclusion

The design and implementation/construction of a solar panel management system with swapping capability for faulty panel give room for power continuity from solar grid or array ,or plant.

In this project, the output voltage has been set and used as reference parameter. The system has the capability of detecting faulty panel whose output voltage is less then the threshold voltage of 1V. it also has the ability of isolating the faulty panel from the arrays of the panel and switching in of spare panel of the same rating automatically.

The overall system is monitored by the LCD which displays the state of the system on faulty condition or normal working condition.

5.2 Recommendation

Monitoring of a solar panel array is of great necessity to both industrial and domestic users. Since the swapping mechanism is of low cost with a high degree of efficiency, it is recommended to ensure lesser down time due to corrective maintenance; the concept of this project should be implored.

References

[1] Arduino ICSPProgramming Header Pinout (2013), Retrived from http://www.echantedage.com/node/244.

[2] AppiahA.Y., Zhang X., Ayawli B. B. K., and Kyeremeh F. (2019): *Review and Performance Evaluationof Photovoltaic Array Fault Detection and Diagnosis Techniques.*International Journal of Photoenergy, 2019(2):469pp

[3] Christopher T. Mgonja N. and Hamisi S. (2017): *Effectiveness on Implementation of Maintenance Management System for Off-grid Solar PV Systems in Public Facilities*. A cace study in Tanzania.

[4] Dhimish (2018).*Fault Detection And Performance Analysis of Photovoltaic Installation.* Department of Electrical and Electronics Engineering, University of Huddersfield

[5] Gupta N., Alapatt G. F., Podila R., Singh R., Poole, K.F. (2009). *Prospects of Nanostructure-Based Solar Cells for Manufacturing Future Generations of Photovoltaic Modules*. *International Journal of Photo energy 2011.* https://www.fsec.ucf,edu/en/consumersolar-electricity/basics/types-ofpv.htm.april,2012.online available

[6] Haque A., Bharath K. V., Khan M. A. and Jaffery Z. A.(2019): *FaultDiagnosisof Photovoltaic Module. Journal of Energy and Engineering*, 7(3):622-644pp

[7] Hu and Cao (2016): *Theoretical Analysis and Implementation of Photovoltaic Fault Diagnosis.International Journal of Renewable Energy – Utilization and System Integration*, IntechOpen, DOI 10.5772/62057.

[8] Ishaq M., Ibrahim U. H. and Abubakar A. (2013): *Design of an off grid photovoltaic system*: *a case study of government technical college, Wudil, Kano State*. *International Journal of Scientific and Technology Research.2(12).*

[9] Modeti and Singh (2017): *Review onMonitoring Systems for Photovoltaic Plants*

[10] Mellit A., Hamied A., Vanni V. and Pavan A. M. (2020): *A low cost monitoring and fault detection system for stand- alone photovoltaic system using internet of things (IoT).* International Journal on Renewable energy.

[11] Nagalaxmiand Veda (2013): *Efficient Energy Management System with Solar Energy*". *International Journal of Modern Engineering Research (IJMER).*6(9)

[12] Natarajan K., Kumar P. and Kuma V. S. (2020*): Fault Detection of Solar Photovoltaic System using Support Vector Machine (SVM) and Thermal Image ProcessingAlgorithm. International Journal of Renewable Energy.10(2).*

[13] Rakesh N., Banerjee S. and babu N. (2020*): A Simplified Method for Fault Detection and Identification of Mismatch Modules*

*and Strings in a Grid-tied photovoltaic System.*International journal of Emerging Electric Power Sysyems.21(4).

[14] Sonawane P., Jog P. and Shete S. (2019): *A Comprehensive Review of Fault Detection and Diagnosisin Photovoltaic System.IOSR Journal of Electrical and Communication Engineering* 14(3).

[15] Vincent B., Umoh, J. J., Obot U. and Ekpe M. (2019): *Development of a smart Solar Energy Management System*" Department of Electrical and Electronics Engineering, Akwa-Ibom State University.

[16] Zekai (2004): *Solar energy in progress and future research trends*. Progress in Energy and Combustion Science.30(1).367-416pp