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Protection Mechanism for Solar Photovoltaic Grid

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ABSTRACT- Since the industrial revolution, environmental changes have begun to affect both human life and natural systems such as weather patterns. The increased usage of fossil fuels since their discovery has been blamed for this. Annual fossil fuel usage for transportation, energy, and other sectors is projected to be over 15 billion metric tons, resulting in harmful gases that cause severe health im. This has resulted in a significant push for alternative energy sources like wind and solar. Solar is becoming more popular since it is more dependable than wind.. With the rise in solar systems, protection measures are becoming more important than ever. These protection solutions must account for a variety of system components while enhancing redundancy, such as safeguarding the solar panels themselves, storage devices, and loads. This paper provides a feasible protective mechanism for solar-photovoltaic installations operating in island mode. In the conclusion, the findings are analyzed and summarized.

KEYWORDS- Photovoltaic Cell, Protection, Loads

I. INTRODUCTION

Since the invention of semiconductors and the discovery of the photoelectric effect, semiconductor physics has progressed. Solar energy has been shown to be one of the most powerful sources of energy capable of efficiently powering the entire world. As a result, various attempts are being undertaken to effectively convert this energy to electricity. Furthermore, since the 1973 oil crisis and as the impacts of climate change become more apparent, a greater focus has been placed on renewable energy, such as solar photovoltaics (Solar-PV). Due to lower solar-PV equipment prices and government incentives, the adoption rate of solar in both commercial and residential settings is now growing. Energy storage issues and the need for new protection methods are becoming more prevalent. In this research, a solar-PV powered load with an AC converter is given and analyzed alongside one such protective system.[1]

A. *Methodology*

Simulink/MATLAB is used to carry out the simulation. The data utilized is mentioned in here that discusses the setup's creation.

The analysis employs the following methodology.

To begin, a single solar PV module is used to power a dynamic demand. The fault is then introduced into the system to ascertain the fault characteristics and their values, which are subsequently utilized to assess potential installation damage. The recommended protective mechanism is then implemented, and the answer is double-checked. Finally, a conclusion is reached, and the findings are summarized[2].

II. LITERATURE REVIEW

As the demand for solar energy grows, and new technologies that rely on electricity, such as electric mobility, develop, the generation infrastructure will face new hurdles. This also applies to solar. To enhance the uptime of such infrastructure even during fault circumstances, protection scheme design becomes critical. This is especially important in off-grid communities like Kenya, where the solar and battery combo has a greater efficiency of more than 90% when compared to diesel-powered alternatives[3]. The photovoltaic modules themselves are divided into two categories based on the manufacturing process: mono-crystalline and poly-crystalline. The former is more expensive but has a greater conversion efficiency, while the latter is less expensive but has a lower conversion efficiency. Thus, whereas mono-crystalline structured solar-PV silicon is preferred, the latter is commonly employed in smaller applications like as portable solar devices [4] [5]. The protection of the solar-pv itself is critical, hence various studies have been conducted to identify fault current levels and their impact on the solar cell structure[6].

As previously stated, as compared to the diesel alternative, the solar-PV and battery combo provides superior power delivery efficiency. Off-grid PV systems are a possible option for areas that are disconnected from traditional electric infrastructure, or for self-energy generation, such as powering a small facility that is not connected to other sources, such as a farm. This distributed generating concept can also benefit the conventional grid since it will not affect the traditional grid's transmission system's loading and constraints. As a result, any grid failure will have no effect on the islanded solar-PV [7][8].

III. METHODOLOGY

The solar cell, panel, and model are all introduced here. After that, a quick introduction to MPPT and Microgrids is given.

A solar cell, also termed as a photovoltaic cell, is a device that converts sunlight into electricity. A semiconductor is made by forming a p-n junction that is exposed to light from outside sources. Doping is done in such a way that the sort of irradiance that stimulates it may be regulated or at least influenced. A transparent ITO sputtered layer is frequently used as the top contact for the cells. Silver wire is used to link the cells together. To get greater voltages and currents at the output, several of these cells are coupled in series and parallel. This results in a single solar panel or unit. The device is then enclosed in resin or glass, allowing the radiation or light to pass through while keeping the ambient elements out[8].

Several of these modules are then linked in series and parallel to form a solar-PV plant or array that can produce greater voltage and current with a kilowatt power rating. A good example is seen in the image below in figure 1 [10].

Figure 1: Solar panel field

Each black square represents a tiny unit made up of numerous solar cells. After that, the black squares are linked to form a panel (the white color base mount). There are numerous of these panels to boost the installation's power rating.

To simulate output voltage and internal drops, the cell is treated as a diode and current source in parallel with resistors. The equations for irradiance, temperature, output voltage, and current are discussed in more detail. The diode model may be seen in the image below. In figure 2

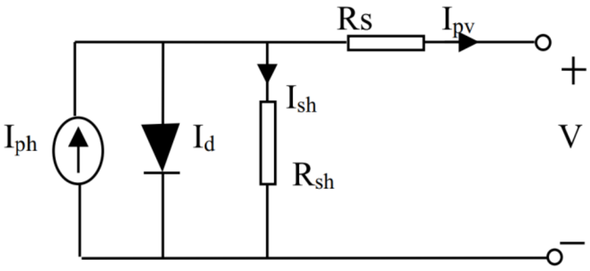


Figure 2: Diode Circuitry diagram

This is the type with only one diode. As can be seen, Iph represents the current created by the photoelectric effect, Id represents the current across the solar cell's inner p-n junction, and Ish and Rsh are used to mimic the output open circuit voltage. Internal resistance causes a series voltage drop, which is represented by the resistor Rs. The ultimate output current of the cell is therefore Ipv, and the output voltage is V.

The parameters are related by the following equation.

$$Ipv = I_{Ph} - I_d - \frac{V + IR_s}{R_{sh}}$$

Also using Shockley's equation.

$$I_d = I_0\{\exp[\frac{V_D}{nV_T}] - 1\}$$

Where Io is the reverse saturation current, Vd is the diode voltage, Vt is the thermal charge voltage, and n is the diode ideality factor.

Thus,

$$Ipv = I_{Ph} - I_0\{\exp[\frac{V_D}{nV_T}] - 1\} - \frac{V + IR_s}{R_{sh}}$$

The solar-pv cell is commonly modelled using these equations.

The solar cell's characteristic curves are illustrated below in figure 3 . These graphs show the relationship between I-V and P-V.

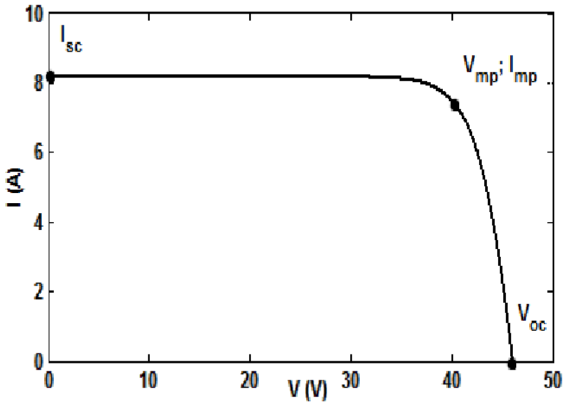


Figure 3: Relationship between IV

The IV characteristics of a solar panel with a short circuit current of around 8 amperes and an open circuit voltage of roughly 46 volts are shown in this graphic. Vmp and Imp (mp – maximum power), on the other hand, are lower in value and deliver the maximum power point.as shown in figure 4

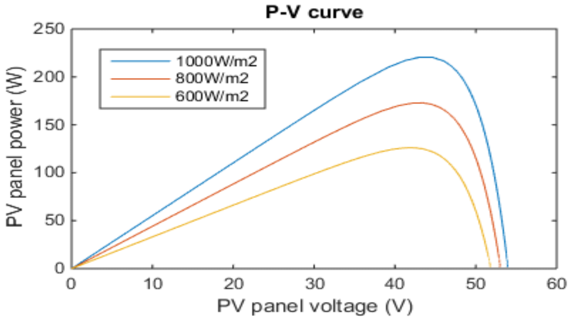


Figure 4: Relation between PV

The PV curve for various irradiance power levels is shown in this figure.

As can be seen from the PV curve, there is a maximum power value for any irradiance for a given panel voltage. On the IV plot, this voltage corresponds to a generally constant current value. By adjusting the output voltage with power regulators such as buck, boost, and buck boost regulators, we can extract maximum power from our PV panel regardless of irradiance on the installation.. There are numerous methods for determining if a power value is maximal in real time and selecting the right voltage. 'Perturb and Observe' (P&O) and 'Incremental Conductance' are two such strategies. A basic summary of the P&O approach is provided here. The power value is verified and compared to a previously recorded value; if the previous value is larger than the new value, the output voltage is decremented by a tiny voltage step; if the new value is more than the old value, the voltage is increased by a small voltage step.. The simplicity of this approach has a few disadvantages, such as being set on a local maximum in a big installation where there may be several maximum power points. It also has a minor oscillatory output, which is created by the controller pursuing the maximum power value and oscillating around that value due to the step size for voltage increases or decrements.

The problem of local maxima can be seen in the below figure 5.

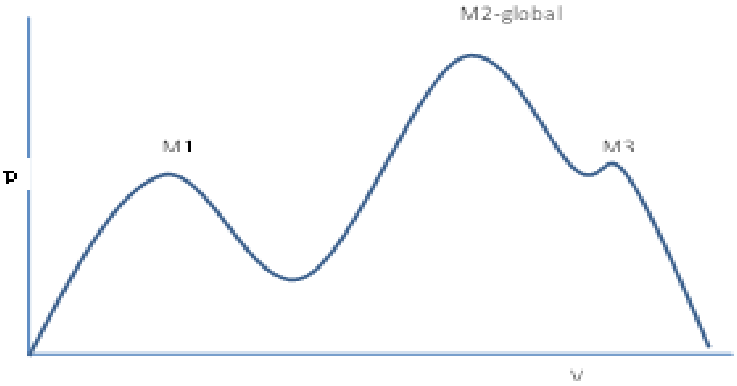


Figure 5: Local Maxima

There are three local maxima and one global maximum, as can be seen. Because the P&O trackers do not follow the whole plot, if it gets to M1, it tracks it regardless of the global maximum. This results in lower efficiency and wire losses.

Partial shadowing results in higher losses, and in the worst-case scenario, the entire plant's production is reduced to zero. Even if a single panel is entirely darkened, this results. Bypass diodes and partial shade isolation are two solutions that help to reduce this problem to some extent.

Microgrids are electrical infrastructure with their own power generation, storage, and transmission networks. Solar, diesel generators, wind, and other dispersed sources can all be used. They can be connected to traditional grids or fully separated from them (grid connected mode) (island mode). They have the benefits of dispersing generation, lowering load on existing infrastructure, and boosting power supply dependability, to name a few.

Microgrids are growing more popular as people become more reliant on power and as renewable energy sources are integrated into the traditional grid. This is because, unlike rivers, renewable energy sources are distributed across a larger geographic area. Solar-PV systems will benefit much from sunlight. This might be utilized on building rooftops when the space would otherwise be unused. This energy from roof-top solar could be enough to get by in a modest residence, but it might only be enough to light a few floors in a huge building. The remaining energy must be sourced from the grid.. This situation raises the issue of combining the two power sources so that solar power may be pumped into the grid and utilized to balance energy expenses, among other things. Consumers become prosumers as a result of this topology, a word that attempts to incorporate the notion of a consumer also being a producer and selling a resource rather than just consuming it. The images below give a rough understanding of roof-top solar and prosumer economics

IV. SYSTEM ARCHITECTURE

The simulation and control techniques employed are described in here.

A solar plant rated at 7.33kW with a lower MPP is used in the simulation. The MPPT converter uses the P&O approach, and subsequently a DC bus is given. This DC bus is connected to the battery. A SPWM-controlled DC to AC h-bridge inverter supplies AC power to loads that are switched at various times and have varying ratings. Circuit breakers are used in the protection scheme, and they trip dependent on the fault location and system circumstances. While guaranteeing that the load is available for the majority of the time. Unless there is a load failure.

There are three circuit breakers: one for the solar array, one for DC storage, and one for the inverter's load side. Internal current sensing and an external trip command are included. The external trip command switches off all systems and guarantees that the power lines are safe to operate on in the event of repair. In below figure 6 given the detail of construction.

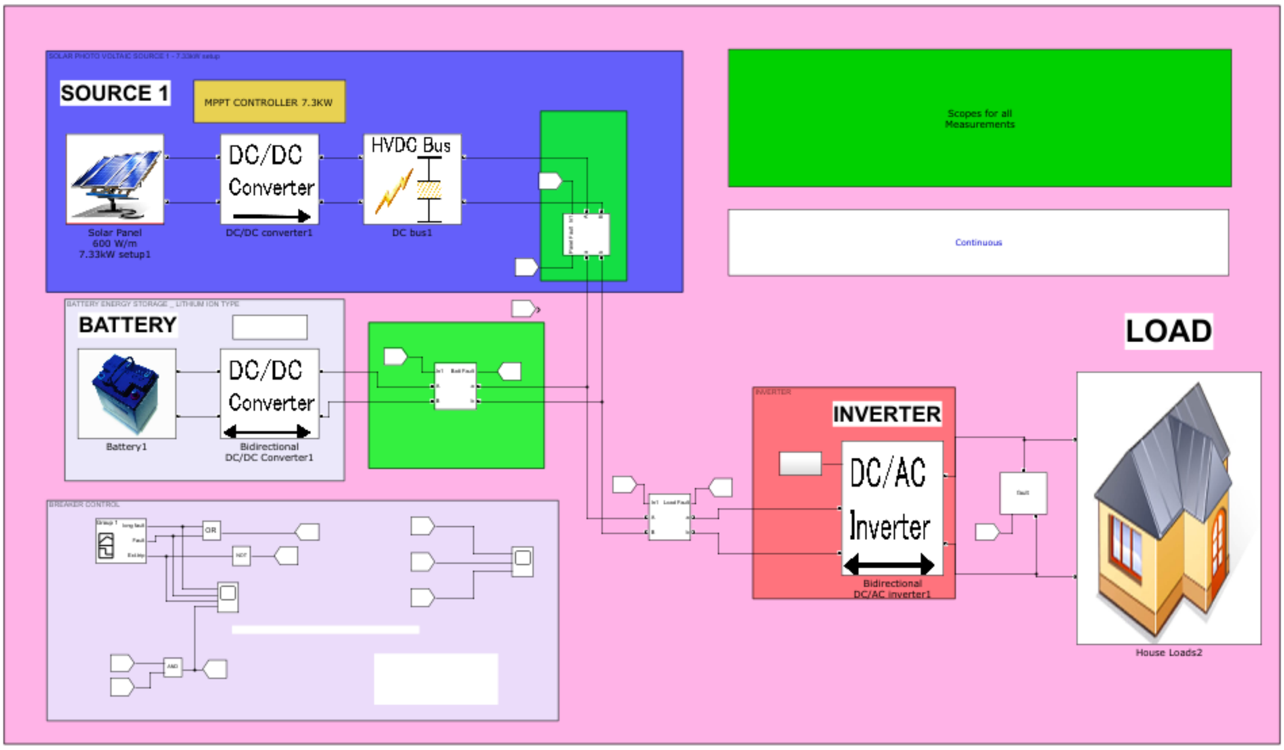


Figure 6: Construction

The entire system; The solar-pv panel, MPPT controller, DC-DC converter, and HVDC bus are all shown in blue. The vertical lines following that are the DC-bus, which is followed by a breaker (2-pole). The battery block with a bidirectional converter is below solar-pv. It is connected to the DC-bus by another breaker. The fault and status monitoring control is located below that. The DC-AC converter is regulated using the SPWM approach in the red block.. The fault simulator switch, which is typically open, follows. Then there's a simulated house load with two loads (3kW and 200W both drawing little reactive power.) A signal builder is used to switch the loads at various times. The MPPT controller employs a MATLAB graphical state space diagram, as seen below. The battery charger is a complementary switching bidirectional DC-DC converter.as shown in figure 7

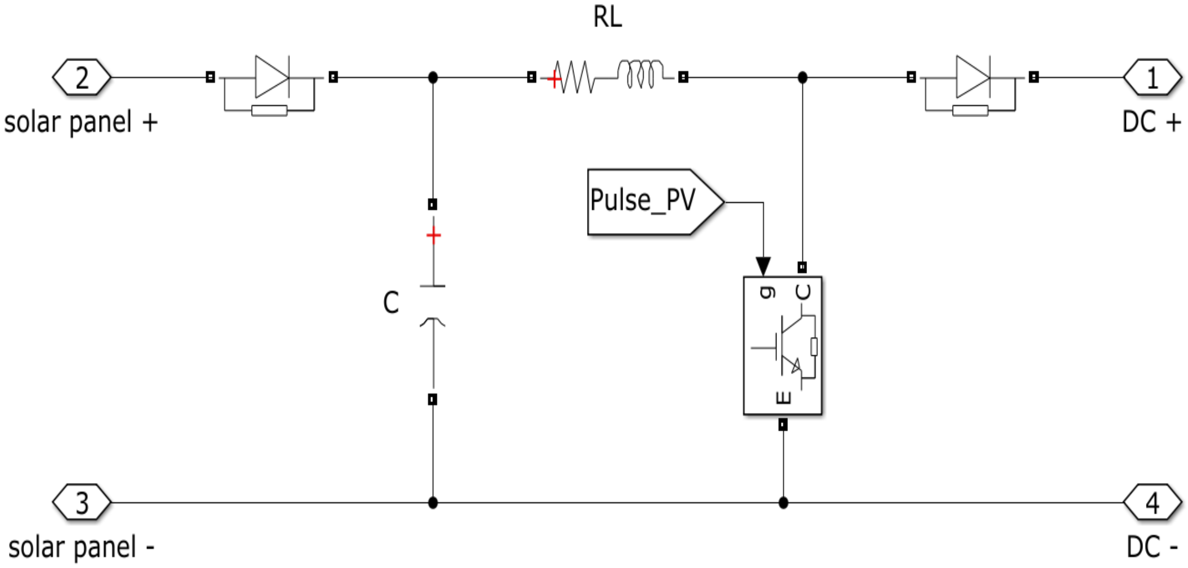


Figure 7: Battery circuitry

A. MPPT-DC-DC-converter

The RL branch in the line is used to represent a lengthy DC wire between the panel and controller.as shown in figure 8

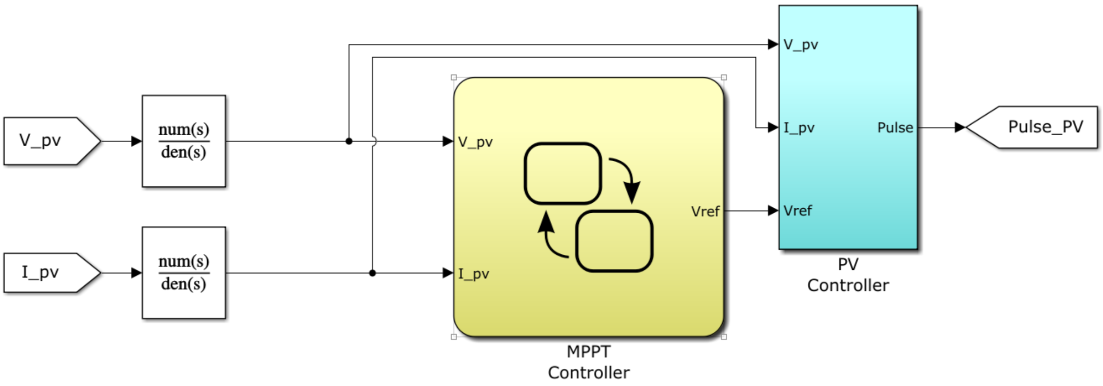


Figure 8: MPPT Controller

B. *MPPT controller*

The input first order filters in the controller are used to eliminate high frequency components from the signal, preventing the controller from malfunctioning. This is followed by an MPPT block, which is then followed by a PID closed loop for the DC-DC regulator, with PWM control signals.. A PI block in the PV controller adjusts the gain properly, compares the signal to what the MPPT block proposes, and outputs a control waveform.

The MPPT block is made up of a state-flow diagram that is used to perform the P&O method; the reference incremental voltage value is obtained via the MALAB initialization commands.

The following figure 9 on next page shows the diagram.

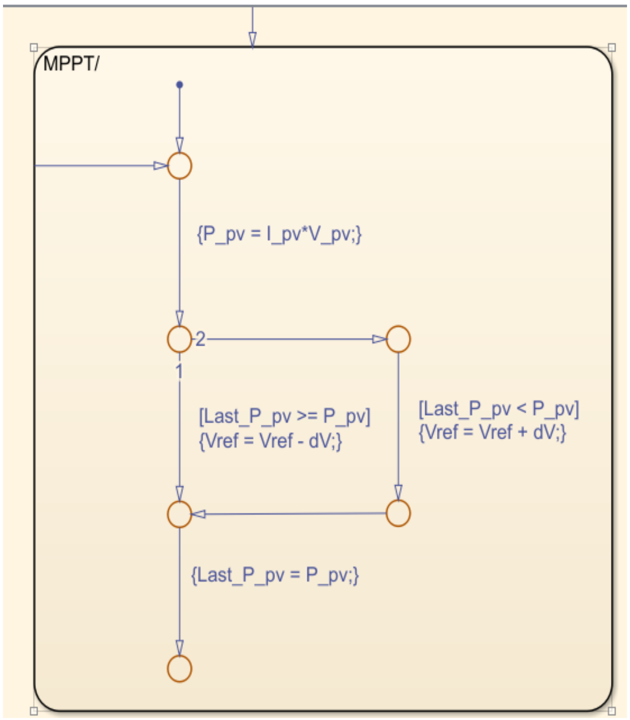
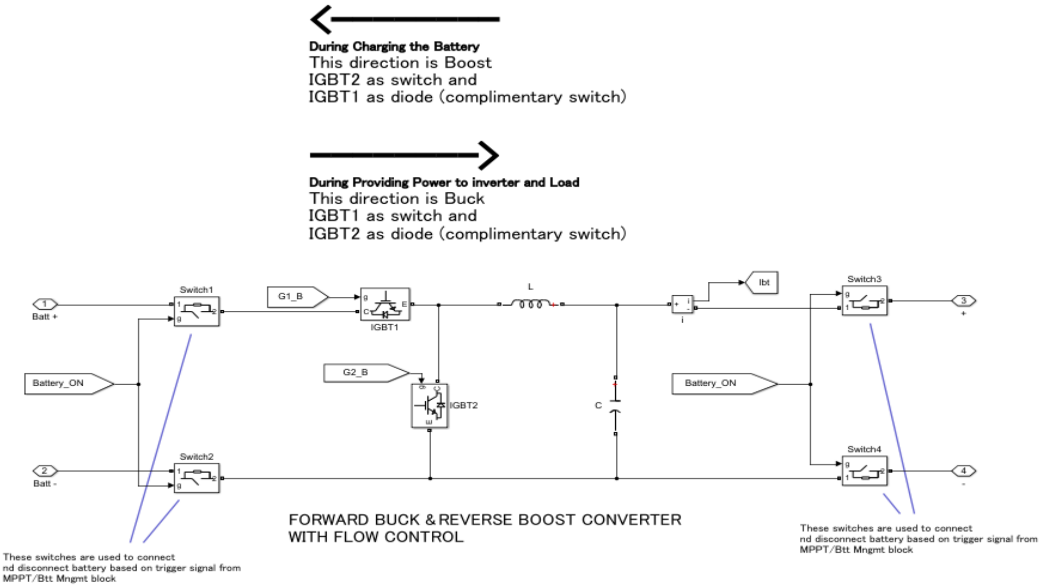


Figure 9: MPPT Block

C. *MPPT P&O algorithm*

The entry points are the two input variables V-pv and I-pv. The power is computed at node 2 and compared to a recent value from the previous simulation phase. The prior power is set to zero in the first step. If the current step's power is higher than the previous step's, Vref is lowered by dV = 0.5, a fixed step voltage established in initialization routines. Vref is decremented by dV in the other instance. The Vref voltage is then sent to the output and processed by the PV controller. The current power value is then put to the Last P pv variable, which will be used for comparison in the following phase.as shown in figure 10 MATLAB indicates the pathways or lines that the state flow follows when conducting computations during runtime, which provides visual feedback and aids in debugging. As shown in figure 101



During Charging the Battery
This direction is Boost
IGBT2 as switch and
IGBT1 as diode (complimentary switch)

During Providing Power to inverter and Load
This direction is Buck
IGBT1 as switch and
IGBT2 as diode (complimentary switch)

FORWARD BUCK & REVERSE BOOST CONVERTER
WITH FLOW CONTROL

These switches are used to connect
nd disconnect battery based on trigger signal from
MPPT/Btt Mngmt block

These switches are used to connect
nd disconnect battery based on trigger signal from
MPPT/Btt Mngmt block

Figure 10: Battery Controller

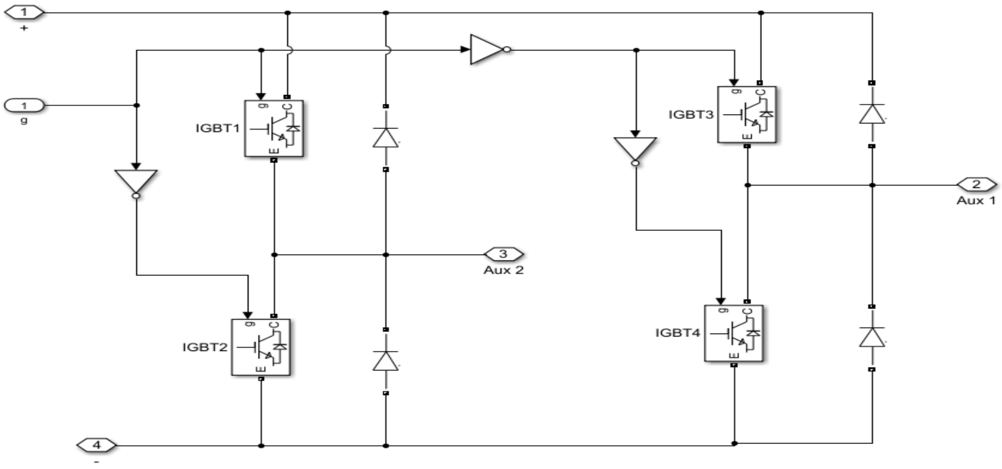


Figure 11: Battery Bridge circuitry

A single control signal is sent to the h-bridge inverter, which is then utilized to create four signals for four switches using NOT logic. To avoid shorting a leg due to non-ideal rise and fall curves of the switches utilized, a driver circuit with a delay in the signals is employed in real life. Flyback diodes, which are antiparallel diodes linked to each switch, are used to avoid voltage spikes by shorting any spikes induced by inductive loads.. A snubber circuit is utilized in such high voltage arrangements to protect the switch from high-speed voltage increase time and a series inductor is used to defend against inrush phenomena as shown in figure 12.

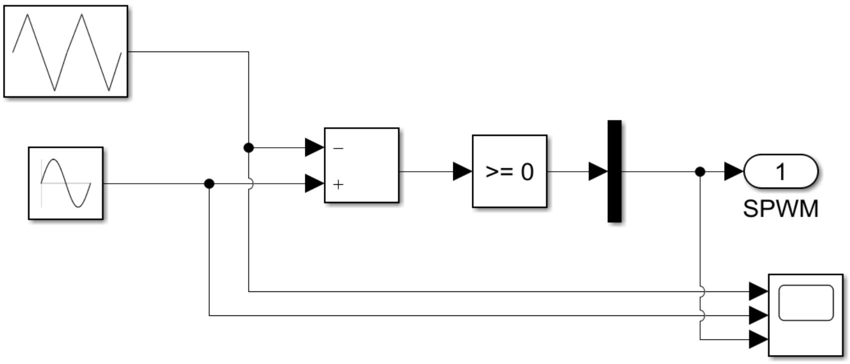


Figure 12: Snubber Circuit

When compared to a carrier wave, SPWM creation uses a single sine reference wave. This produces a PWM output . Which is delivered to the previously mentioned single h-bridge. The waveforms that arise are displayed below. The PWM wave is the one on the far left. The reference or modulating sine wave is in the middle. The carrier triangle wave at 10kHz is on the far right as shown in figure 14.

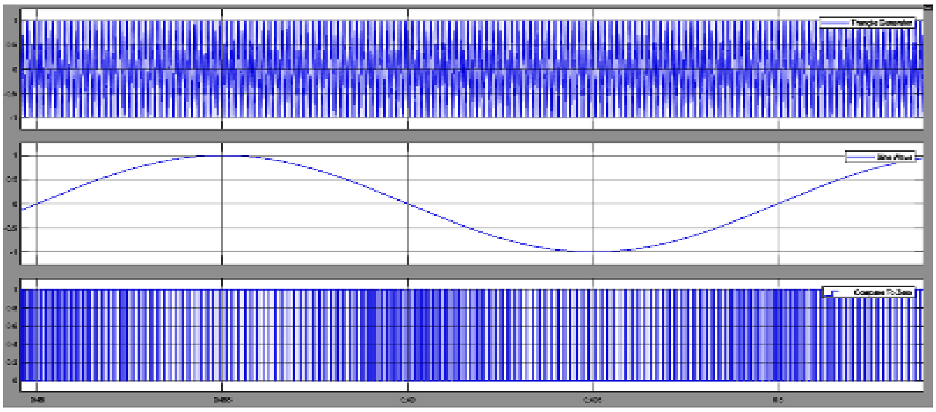


Figure 14: SPWM generation

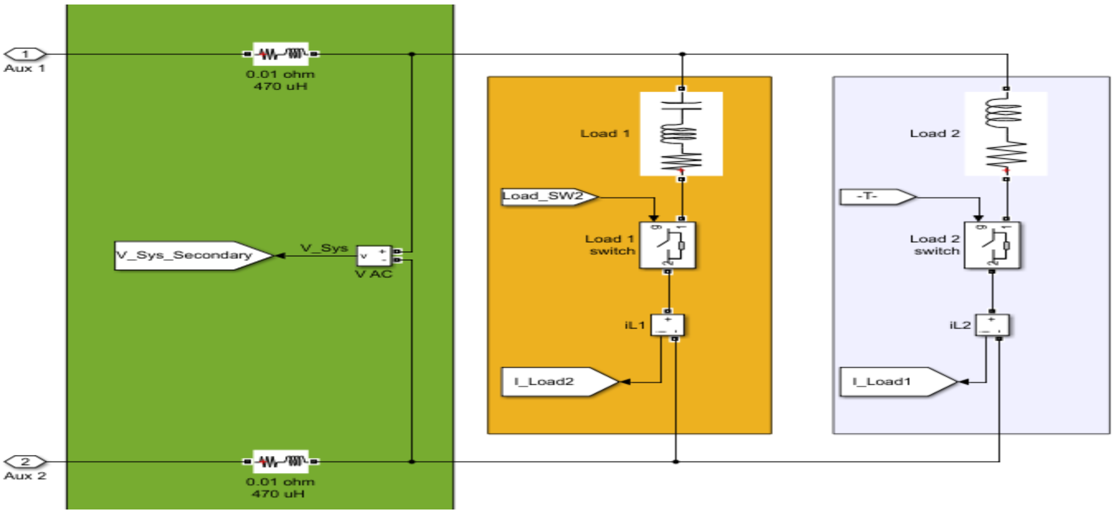


Figure 15: RL Loads

Two RL loads, each requiring 3kW and 200W, are controlled by a switch, with control signals created using a signal builder block. They're used to mimic load shift in a variety of situations and at various times.as shown in figure 15

The battery block is shown below. A battery block is included, with a Li-ion type battery being chosen. The linked scope's parameters, such as the state of charge and voltage, are presented.in figure 16.

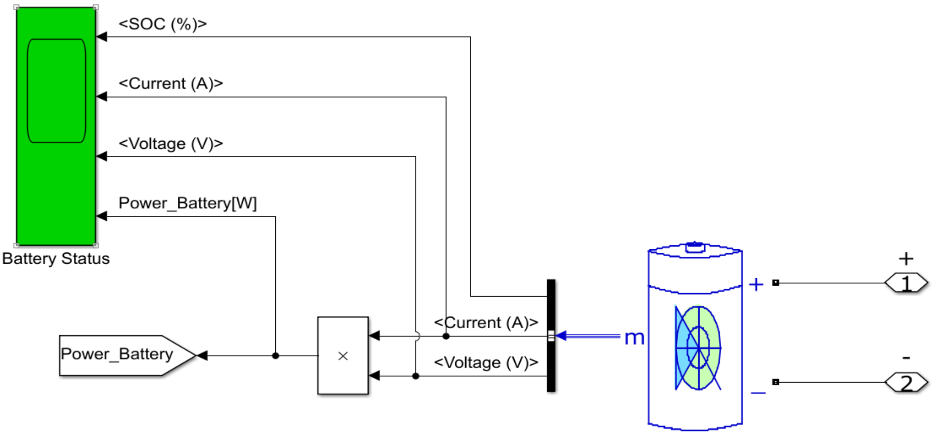


Figure 16: Battery Blocks

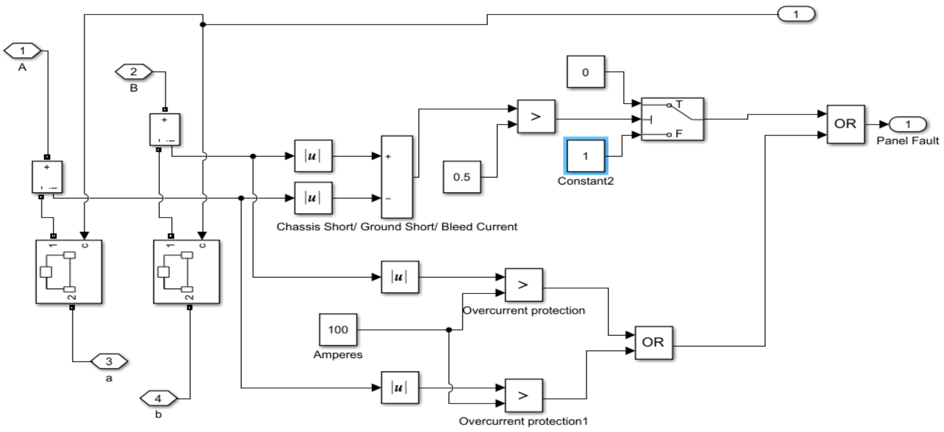


Figure. 17: Logic Circuitory

The OR logic is utilized to limit the number of communication channels necessary; in fact, individual signals will be used on the spot and combined signals will be used for distant communication as shown in figure 17.

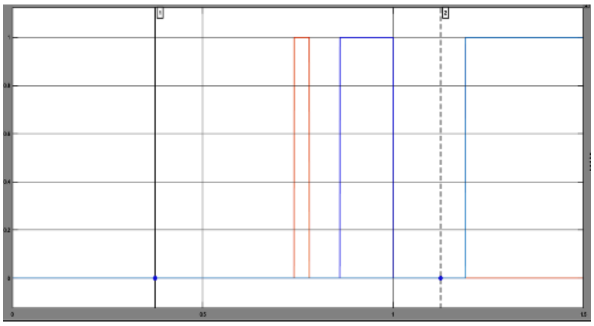


Figure 18: Generated Fault Signals

The fault signals are shown in figure 18.

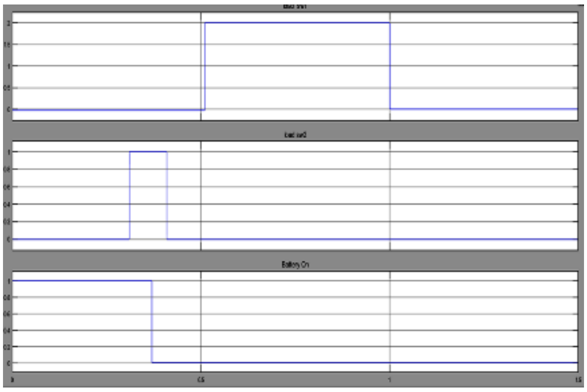


Figure 19: Battery on/off, load1 and load2 on/off signals

The initialization instructions for MATLAB are listed below. They are used to define system control parameters and component values as shown in figure 19.

V. SIMULATION AND RESULTS

According to the simulation, the solar-pv system's MPPT power production is roughly 5kW. The data also shows that the power has jitter, which is predicted for the P&O method and was detailed in previous. Breaker units are installed along vital equipment throughout the system. They monitor the current in both DC lines and create flag signals if there is any imbalance, which might be caused by leakage owing to cable insulation deterioration or by one of the wires contacting the device's body or chassis.. The other detection mechanism monitors both DC lines current levels and generates another flag signal if one of them surpasses a predetermined threshold value, henceforth referred to as a fault. Wires or wireless media can be used to send these signals to a controller. The controller then decides which parts of the grid should be turned off and which should remain operational. A problem is simulated on the load side in this example, but the battery is not disconnected; just the inverter and load are disconnected. This guarantees that the battery or any other load on the DC bus remains unaffected, increasing redundancy.

The time-based events are constructed in such a way that two faults are not identified in order to demonstrate responsiveness in the event that the faults are not protected. In the third case, depending on system input, a trip signal is issued, and the system is shut down (all breakers) due to the severity of the malfunction. Following that, only those breakers that do not have and did not trigger the fault flags are restored..

The following results are presented

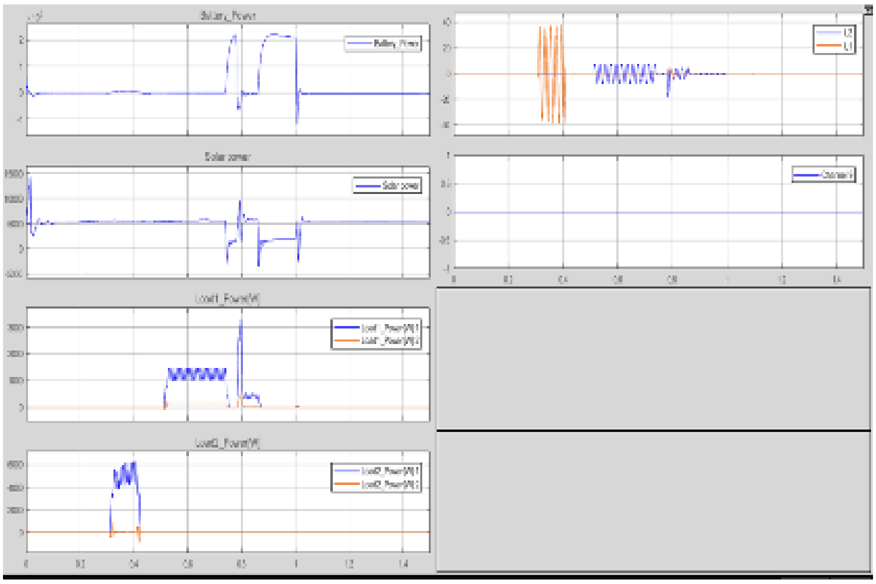


Figure 20: Load side breaker

From 0.7 to 0.8, there are two faults; however, at 0.9, the load side breaker trips and the load side is isolated, allowing the system to continue operating partially as shown in figure 20

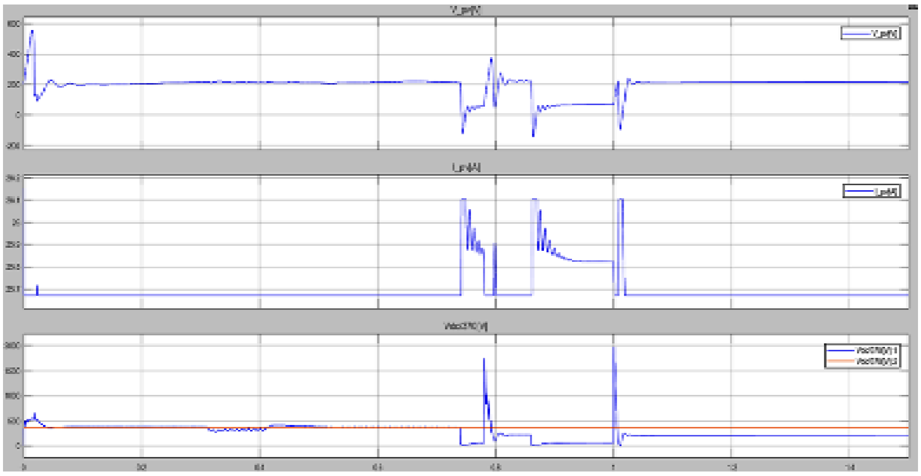


Figure. 21: DC bus voltage

As can be observed, the problem has no detrimental effect on the PV panel and the current is limited. The DC bus voltage in the figure 21 is also steady. Even if at a lower voltage

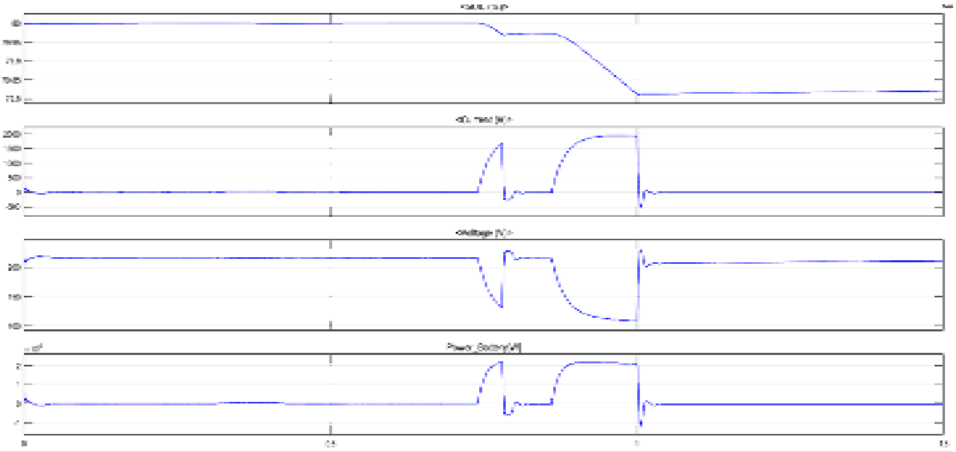


Figure. 22: Effect on battery

The battery is likewise steady, however the current is high during the first two failures as shown in figure 22 . Because this is utilized in simulation to indicate whether the controller does not intercept the errors. This might harm the battery system as well as break fuses

VI. CONCLUSION

Solar energy will become more widely used in the future, necessitating the installation of protective devices. A basic protective system was provided and studied in this paper, coupled with a fault analysis. The results suggest that the approach improves system uptime to some extent. However, primary protection, such as fuses and standard High Fault Circuit Breakers, should not be overlooked.

Further work can include pre-emptive maintenance and fault probability and wireless control of breakers to better integrate with IoT.

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