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PV-Battery and Super Capacitor based DC Micro Grid Power Management

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A B S T R A C T

Solar power generation is a straightforward idea that turns sunlight into electrical energy. A source of energy from the natural world is sunlight. Solar natural resources have been extensively utilized to power communication satellites with electricity using solar cells. These solar cells have no rotating parts and no fuel requirements, and they can generate an infinite amount of electrical energy that is taken directly from the sun. Consequently, the solar system is frequently cited as being pure and environmentally good. A solar system that is unconnected to the main grid is called a standalone system. Therefore, it is vital to have a backup supply, given the day and night cycle, where solar radiation is at 0 W / m2 at night. The backup supply is commonly networked in a grid system, but in an off-grid system the backup supply must be an energy storage system, such as a battery, hydro pump storage, heat storage, or supercapacitor. Since the voltages and currents for these stand-alone systems are insufficient for many purposes, a solar module is typically created by connecting many solar cells in series. Design and simulation of a DC microgrid power management system using super capacitors and PV batteries in the MATLAB/ SIMULINK environment. During the startup power from battery to load, the supercapacitor is used to make up for any power deficiency. The limitations of the battery's charging and discharging current are also taken into account. The results of the simulation demonstrate the effectiveness of the suggested power management method. In all simulation cases, the state of charge of batteries and supercapacitors is kept within the allowed range and the power flow between the sources and the load is balanced. The Perturb and Observe (P&O) algorithm for Maximum Power Point (MPP) in PV and PID tuned the best result at the load in accordance with the load requirement after the best tuning result by power management strategy. It is evident from the simulation results that the system has a better outcome since it compensated for the excess load power during the 1000 W/m2 and increased the battery input by 162.261 W, or 69.836%. Due to the supercapacitor's role as secondary energy storage, there has been little impact.

Keywords:DC-Microgrid, PV, Super-Capacitor, Energy Management

1. Introduction

One renewable energy source that has grown in popularity recently because it is environmentally friendly and sustainable is solar energy. The use of DC microgrids has increased as more rural locations rely on renewable energy sources to meet their electricity needs. The intermittent nature of solar electricity, however, seriously impairs the reliability of such systems. A power management system that efficiently controls the energy generated by solar PV, battery, and supercapacitor can be used to address this issue. A solar PV system typically consists of solar panels, a charge controller, a battery bank, and an inverter. The inverter converts the DC energy generated by the solar panels into AC energy, which is then used to power appliances or is fed back into the grid. For use at night or during periods of low light, the battery bank saves any surplus energy generated throughout the day. A charge controller manages the battery bank's charging to avoid damaging overcharging or discharge.

1.1. Photovoltaic System

Solar power generation is a straightforward idea that turns sunlight into electrical energy. A source of energy from the natural world is sunlight. Solar natural resources have been extensively utilized to power communication satellites with electricity using solar cells. These solar cells have no rotating parts and no fuel requirements, and they can generate an infinite amount of electrical energy that is taken directly from the sun. Consequently, the solar system is frequently cited as being pure and environmentally good. A solar system that is unconnected to the main grid is called a standalone system.

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Given the day and night cycle, where solar radiation is at 0 W / m2 at night, a backup source is therefore required. In a grid system, backup supplies are frequently networked; however, in an off-grid system, backup supplies must be energy storage systems, such as batteries, heat storage, hydro pump storage, or supercapacitors. Since the voltages and currents for these stand-alone systems are insufficient for many purposes, a solar module is typically created by connecting many solar cells in series. Under normal irradiation circumstances (Air Mass 1.5), a solar module typically comprises of 28–36 solar cells and generates a total DC voltage of 12 V. The total voltage and output current of solar modules can be increased by connecting them in series or parallel, depending on the amount of power needed for a given application.

1.2. Energy Storage System

The power system cannot function without the energy storage system. They guarantee constant energy supply and boost system dependability. Systems for storing energy come in a variety of forms and sizes. The type of energy stored has a significant impact on the size, cost, and scalability of energy storage systems. Potential, kinetic, chemical, electromagnetic, thermal, and other forms of energy can all be stored. Some energy storage technologies are better suited for small-scale systems, while others are only employed for large-scale storage systems. For instance, a chemical battery is ideal for tiny systems such as watches, computers, and backup systems but is still pricey when compared to megawatt-scale systems. Conversely, only big power plants use pumped hydropower storage, which may store a significant quantity of energy as water potential energy. Systems for chemical energy storage such as batteries, flow batteries, and fuel cells are examples. Flywheel, pressurized gas storage, and pumped storage hydropower are examples of mechanical (kinetic and potential) energy storage technologies. Molten salt is a form of thermal energy that may be stored and is mostly employed in large-scale systems. Superconducting magnet storage devices, a still-evolving and pricey technology, can store magnetic energy. One of the best options in this situation is the use of an energy storage system (ESS). Engineers may now manage the power system optimally thanks to this new category.

1.3. Supercapacitor

Supercapacitors can be thought of as a bridge between (regular) electrolytic capacitors and rechargeable batteries because their capacitance values significantly outweigh those of normal capacitors (although with a lower voltage limit). The fact that the supercapacitor has two operating frequencies makes it a storage device for the electrical system. When the supercapacitor's working frequency is low, it behaves like a regular capacitor and exhibits capacitance characteristics. However, the Supercapacitor functions with resistive characteristics if a stable frequency of 50 Hz to 60 Hz is applied. Super capacitors have more cycle endurance than rechargeable batteries and can store 10 to 100 times as much energy per cubic charge as electrolytic capacitors. They also receive and disperse charges more quickly.

Supercapacitors have a high power density, rapid charge/discharge rates, and a long cycle life, making them the ideal energy storage choice for DC microgrids. They can help stabilize the DC microgrid by responding quickly to brief changes in power demand and supply. Supercapacitors can also extend the life of the battery bank by reducing the number of charge/discharge cycles that the battery undergoes.

1.4. Power Management Strategies

Power management involves combining energy production, storage, and delivery to guarantee a consistent supply of electricity. Using solar PV, batteries, and supercapacitors in a DC microgrid allows for the application of these power management strategies:

Maximum Power Point Tracking (MPPT)

By modifying the impedance of the load to correspond to the maximum power point of the panels, MPPT is a technique used to maximize the energy production from solar PV panels. A controller that modifies the duty cycle of the DC-DC converter linked to the solar panels can be used to do this.

Battery Management

In order to ensure optimum performance and longevity, battery management entails tracking the state of charge (SOC) of the battery bank and controlling the charging and discharging. A battery management system with a smart charge controller and battery balancer can accomplish this.

Supercapacitor Management

To maintain optimum performance and endurance, supercapacitor management entails tracking the state of charge (SOC) of the supercapacitor bank and controlling the charging and discharging. A supercapacitor management system that uses a smart charge controller and supercapacitor balancer can do this.

Load Management

A load management system that prioritizes the appliances based on their power consumption can be used to manage the power demand of the appliances connected to the DC microgrid to guarantee that it does not exceed the power supply capacity.

Energy Management

To ensure optimal performance and longevity, energy management involves controlling the energy flow between the solar PV, battery, and supercapacitor. An energy management system that coordinates the charging and discharging of the various energy storage components can be used to accomplish this.

2. Objectives

The main goal of this work to some improvements based on the control system in the energy management system.

- To design the PV-battery and supercapacitor-based DC microgrid power management system.
- The aspect that acted as the parameter is the voltage and power stability.
- The result without control and with PI controller is compared.

3. Research Methodology

Figure 3.1 depicts the operation of PV-Battery and Super Capacitor based DC Micro Grid Power Management. PV-Battery and Super Capacitor based DC Micro Grid Power Management has the following section:

1. Bidirectional DC-DC convertor Battery
2. Bidirectional DC-DC convertor Super capacitor
3. Combined Control Battery/Super capacitor
4. DC-DC boost convertor
5. MPPT PnO
6. Power Calculation

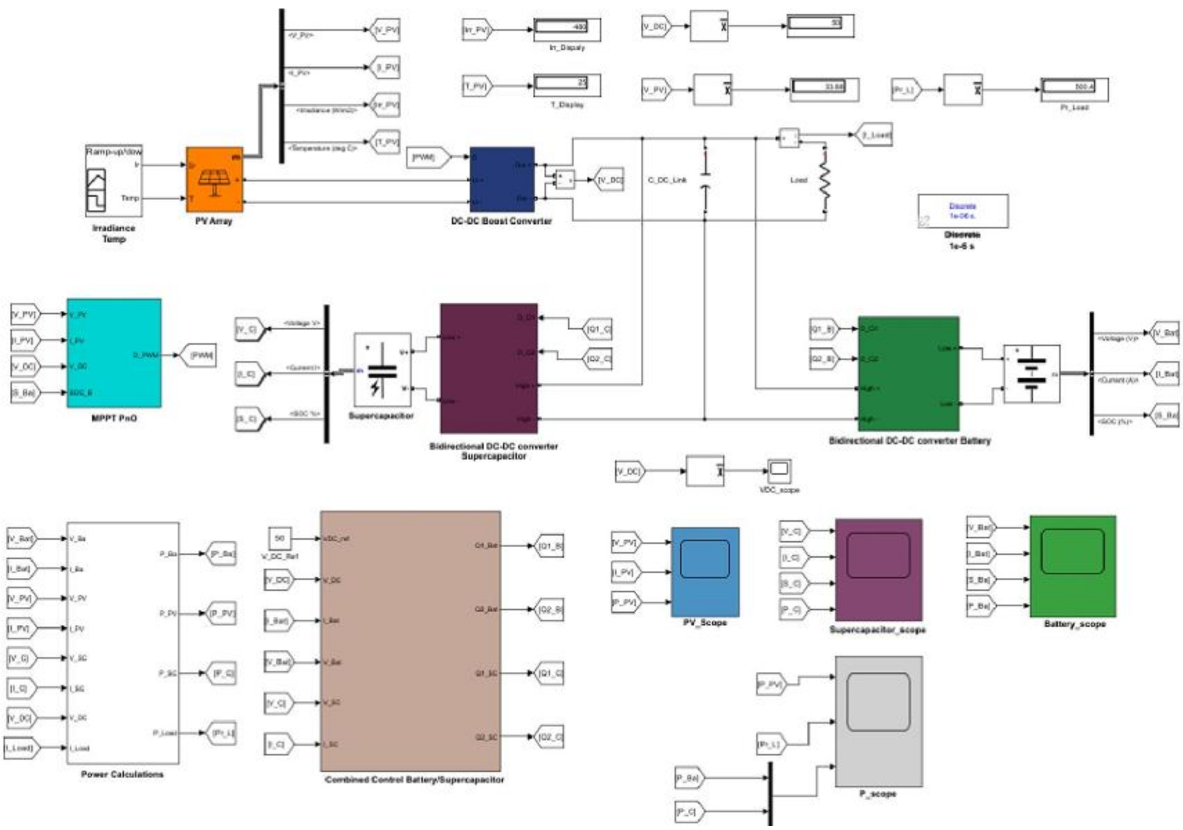


Figure 3.1 MATLAB/SIMULINK diagram of proposed work

3.1 Bidirectional DC-DC convertor Battery

The Bidirectional DC-DC Converter block illustrates a converter that is powered by a connected controller and gate-signal generator to step up or step down DC voltage from one side of the converter to the other. For example, in electric vehicles, bidirectional DC-DC converters can be used to transition between energy storage and utilization. Storage devices are used to store excess energy that dispersed production units produce. It is possible to use stored energy when generation and load cannot be balanced or when load demand surpasses energy generation. Super capacitors and batteries are a couple of examples of energy storage technologies. Chemical energy is used by battery systems to store electrical energy. Storage capacity is defined as the amount of time that the nominal energy capacity can provide the load at the rated power.

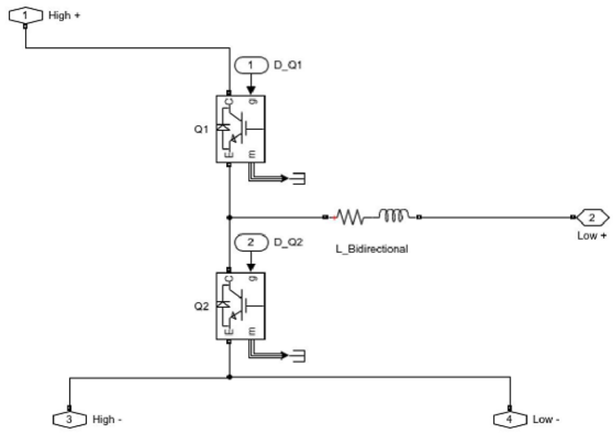


Figure 3.2 Bidirectional DC-DC convertor Battery

3.2 Bidirectional DC-DC convertor Super capacitor

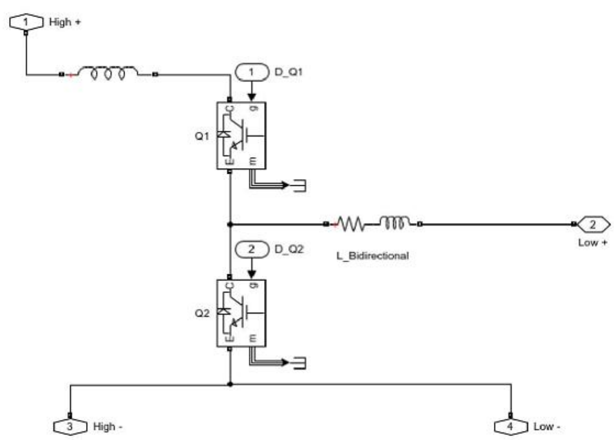
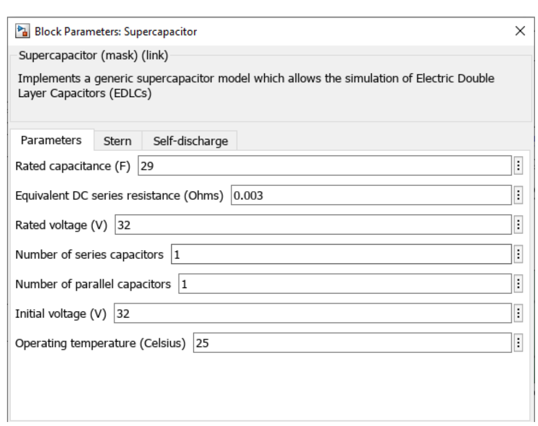


Figure 3.3 Bidirectional DC-DC convertor Supercapacitor

The supercapacitor used is electric double layer capacitors (EDLC) type with parameter as shown in Figure 3.4.



Block Parameters: Supercapacitor

Supercapacitor (mask) (link)

Implements a generic supercapacitor model which allows the simulation of Electric Double Layer Capacitors (EDLCs)

Parameters | Stern | Self-discharge

Rated capacitance (F)	29
Equivalent DC series resistance (Ohms)	0.003
Rated voltage (V)	32
Number of series capacitors	1
Number of parallel capacitors	1
Initial voltage (V)	32
Operating temperature (Celsius)	25

Figure 3.4 Supercapacitor parameter

3.3 Combined Control Battery/Super capacitor

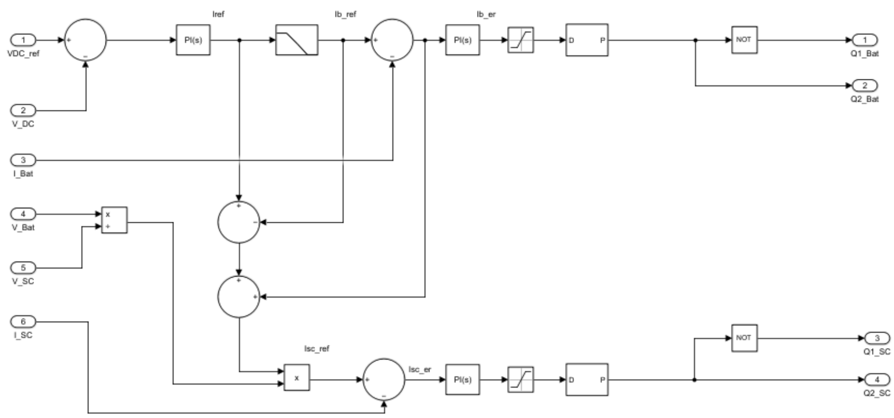


Figure 3.5 Combined Control Battery/supercapacitor

The PI-LPF approach is the straightforward control strategy for HESS in most applications. By supplementing the SC reference current with uncompensated battery current, the standard PI control techniques are improved. By producing reference current based on battery current, the power sharing between the battery and SC is improved further. However, in all of the aforementioned scenarios, the direct linked LPF in the battery control loop lengthens the battery reference current monitoring latency.

3.4 DC-DC BOOST CONVERTOR

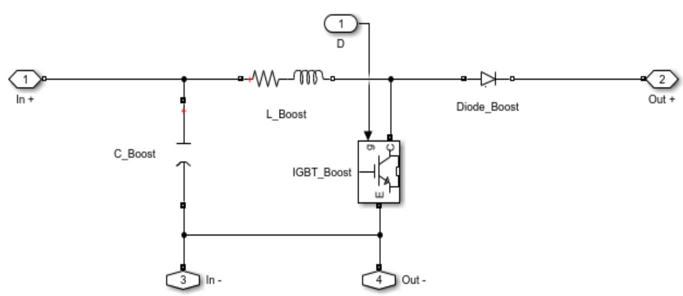


Figure 3.6 DC-DC Boost Convertor

Supercapacitors and batteries can be connected in parallel directly, but this is not the best option for a number of reasons. First off, the maximum usable energy is constrained by the fundamentally different charge and discharge profiles of batteries and supercapacitors. Secondly, the current and power distribution between the two components is a direct function of internal characteristics (internal impedance and voltage), current rate, time, lifetime and operating temperature. Consequently, an estimation of the power distribution and total lifetime is difficult and too unpredictable. These potential issues can be resolved by adding a DC/DC converter between the supercapacitors and the DC-link, which also opens up the possibility of individually controlling the power flow from and to the batteries and the supercapacitors. On the other side, it makes the energy storage system more expensive and complex. This effort will model and treat the DC/DC converter as an ideal part with a fixed efficiency across the whole voltage and current range**.**

3.5 Maximum Power Point Tracker

The MPPT approach finds the operating point that generates the most power. The Maximum Power Point (MPP) is the location where power is generated at the highest rate. In order to achieve the greatest power, MPPT adjusts the operating voltage. The MPPT operates by sensing photovoltaic current and voltage. The MPPT algorithm will process currents and voltages and create a duty cycle that can provide electricity at the MPP point. The Duty Cycle will regulate when the converter is turned on. Solar energy is converted into electrical energy by employing photovoltaics. Next, each photovoltaic module's sensor will read the voltage and current. To obtain the most power, MPPT will function in accordance with its algorithm. The switching on of the multi-input converter will be controlled by a duty cycle produced by the MPPT algorithm. The excess energy will be utilised by the converter and will not create electricity when the power produced by the PV is greater than the load power (P_{load}).

When the load power (P_{load}) and the power generated by the PV are equal, no power is generated. The supercapacitor will provide electricity to make up for the shortage of energy when the power generated by the PV system is less than the load power (P_{load}). This hybrid system will still be able to function if one of the input voltages is unable to supply voltage. As a result, it is anticipated that a hybrid energy storage system using the MPPT P&O algorithm will increase the efficiency of the power generated so that the system's output power is more ideal.

3.6 Perturb and Observe Algorithm

The Maximum Power Point (MPP) algorithm, which uses perturbation and observation (P&O), is frequently used in PV. This method can be used to a variety of PV features and does not require knowledge of energy storage system parameters. The P&O method's drawback is that steady state conditions oscillate as a result of the continual duty cycle adjustments. The algorithm known as the "perturb and observe" or "hill climbing" method. The MPPT approach of this algorithm is based on calculating output power. The perturbation in this procedure changes the system's output power. Voltage must be raised if disturbance rises toward the maximum power point. Additionally, if the perturbation falls off after reaching its peak power, the voltage must be lowered. This causes the duty cycle to alter as well, and the cycle repeats itself until the maximum power point is achieved.

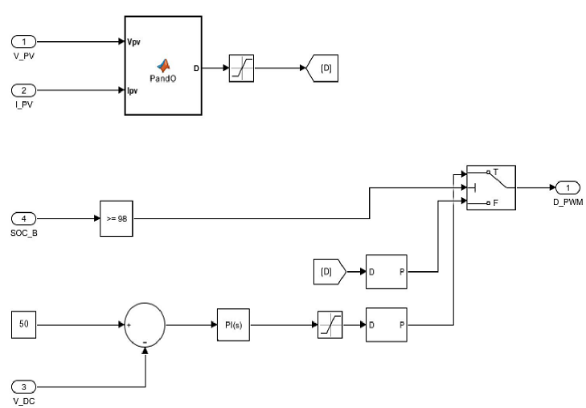


Figure 3.7 Perturb and Observe Algorithm based Maximum Power Point Tracker

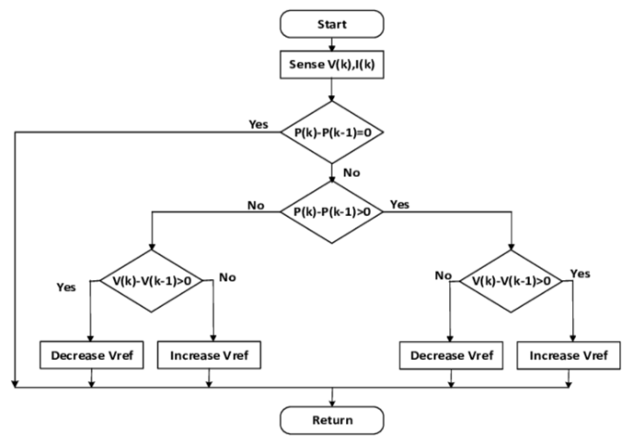


Figure 3.8 Flowchart of Perturb and Observe Algorithm

Figure 3.8 shows the flowchart of perturb and observe algorithm. First, we determine the value of V(n) and I(n). Then after finding power, we check the slope dP/dV at three different conditions.

If slope dP/dV= 0 at MPP

If slope dP/dV>0, at left of MPP

If slope dP/dV

3.7 Power Calculation

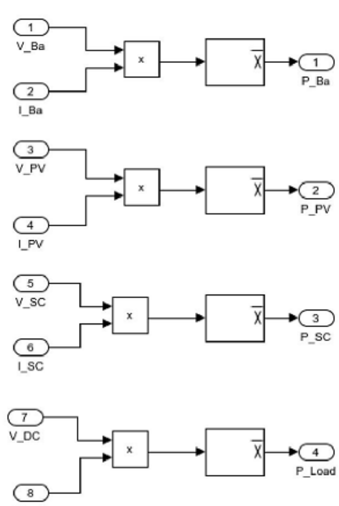


Figure 3.9 Power Calculation

The power calculation section calculates the Power of Battery, Power provided by PV solar panel, Power of Supercapacitor and Power of Load at the port of 1,2,3 and 4 respectively as shown in Figure 3.9.

3.8 Input Model

PV Cell Simulation

In the MATLAB Simscape Electrical Toolbox, the PV array block is composed of parallel strings of modules. Each string is constructed from modules that are connected in succession. Ten modules are connected in sequence on each parallel string. The parameters of the PV array are displayed in Figure 3.10, and the PV characteristics are shown in Figure 3.11.

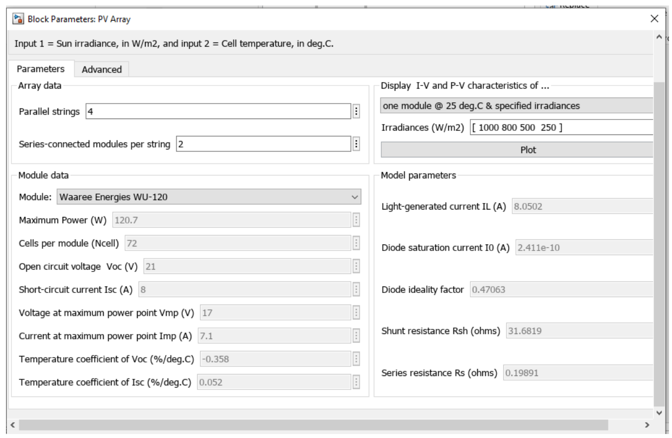


Figure 3.10 PV-modules parameter

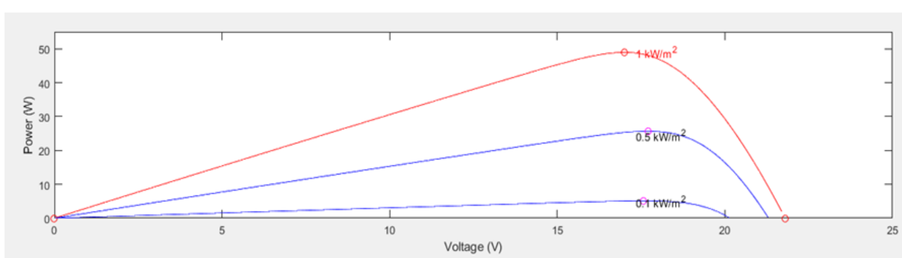


Figure 3.11 PV Characteristics plotted in MATLAB

Irradiance and temperature are the inputs for the PV array. The irradiance and temperature were computed using Simulink's Look-up table block for different times of the day. The look-up table receives its input from the clock to determine the time of day.

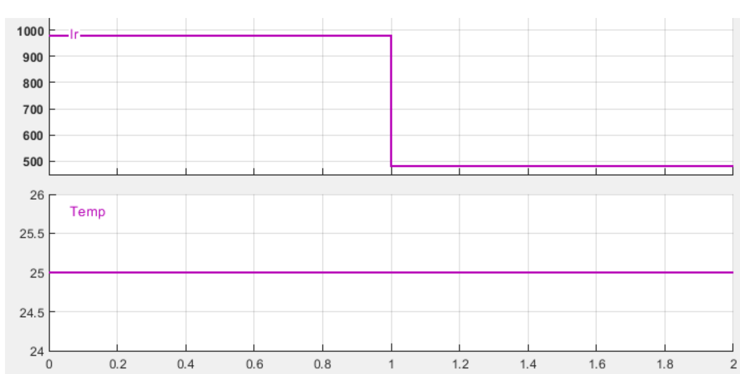


Figure 3.12 Input model for photovoltaic input

The model for PV Modules from MATLAB SIMULINK Waaree Energies WU-120 is used in the simulation. Since PV and the load are connected to the same direct current (DC) bus as illustrated in Figure 3.12, the load model in the system is the same for both simulations, 500 W with unity power factor.

Battery Modeling

The Lithium Ion Battery is employed. Figure 3.13 shows the BESS Parameters. Figure 3.14 shows the BESS discharging characteristics that were inherit from the nominal parameters.The battery used is Lithium-ion type with parameter as shown in figure. Initial state of charge is set in 50%.

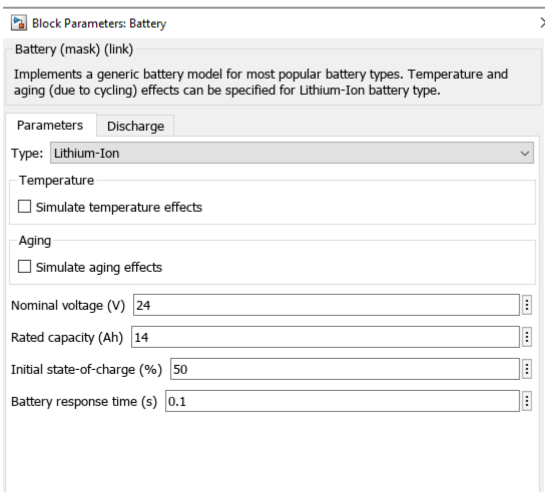


Figure 3.13 Lithium-ion Battery Parameters

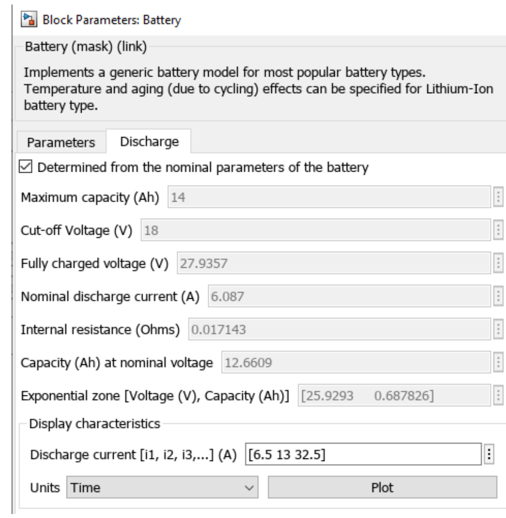


Figure 3.14 Lithium-ion Battery Discharge Parameters

4. Result and discussion

This section explains the result and discus about the output of the simulation result of the proposed work. Taking some simulation parameter as shown in Table 4.1 for MATLAB SIMULINK environment.

Table 4.1 Simulation parameter of system

Simulation Parameter	Value
Solver	ode23tb
RelTol	le-3
Refine	I
MaxStep	le-4
MaxOrder	5
ZeroCross	011

Solar PV irradiant input Voltage 980 Volt at 25 °C, Maximum Power 120.7 Watt as shown in Table 4.2. PV irradiance give the 480 Voltage after the simulation at temperature 25 °C. Get the output of PV 33.88 Volt. Power of the load 500.4 Watt. Powergui have simulation mode discrete and sample time 1e-6 Iteration 50 voltage unit kV and power unit MW solver type Tustin/Backward Euler (TBE).

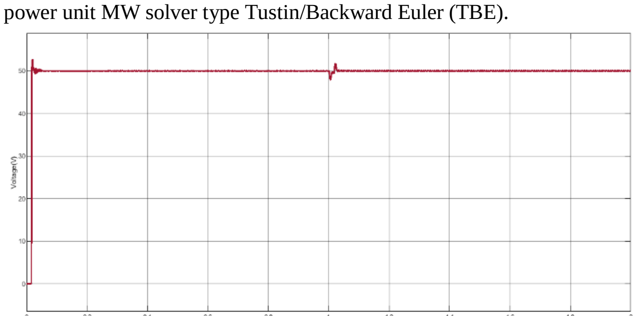


Figure 4.1 Constant Voltage V_DC 50

Providing the constant Voltage V_DC 50 Voltage as shown in Figure 4.1.

Table 4.2 Solar panel parameter

Parallel string	4
Series connected module per string	2
Maximum Power	120.7 W
Cell per module	72
Open Circuit Voltage Voc	21 V
Short Circuit Current Isc	8 A
Vmp	17 V
Imp	7.1 A

The default system simulation that was covered in the preceding section is one of the simulations that are run in MATLAB Simulink. Due to direct input power from PV to the load in the same bus, the simulation results show that the controlled system could maintain stability in various irradiance input.

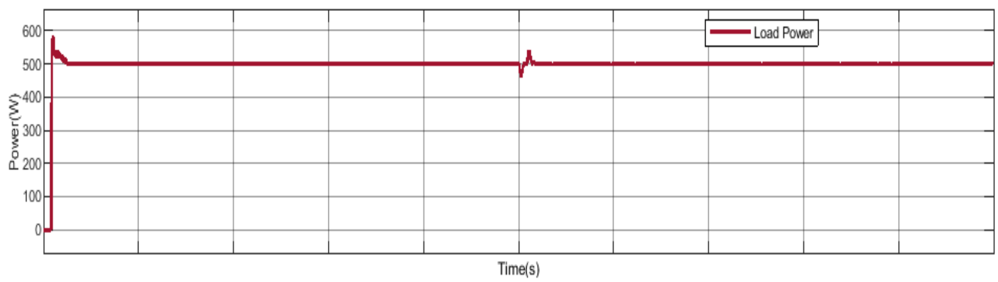


Figure 4.2 Load Power Stability

According to Figure 4, the nominal load voltage at the series load RLC is 50 volts, and the active power is 500 watts.2. Model with rated lithium ion battery capacity of 14 Ah, nominal voltage of 24 volts, and initial state of charge of 50%. Cutoff voltage is 18 volts, full charge is 27.9357 volts, and the nominal discharging current is 6.087 A from the perspective of discharging. The PID was utilized to adjust the output of the battery and supercapacitor from the combined battery and supercapacitor portion. It was first order filter having Tc =0.015 and Ts = 0. PID controller having P = 1.477 and I = 3077, Kt = 1 for the controlling the output voltage of Vdc. PID controller 1 having P = 0.043, I = 0.65 and Kt = 1 which was controlling output from the battery and reference voltage by using tuner app. PID controller 2 having P = 0.45, I = 14800 and Kt = 1 which was controlling the out from the battery, reference voltage and supper capacitor. All the cases sampling time Ts = 2 second.

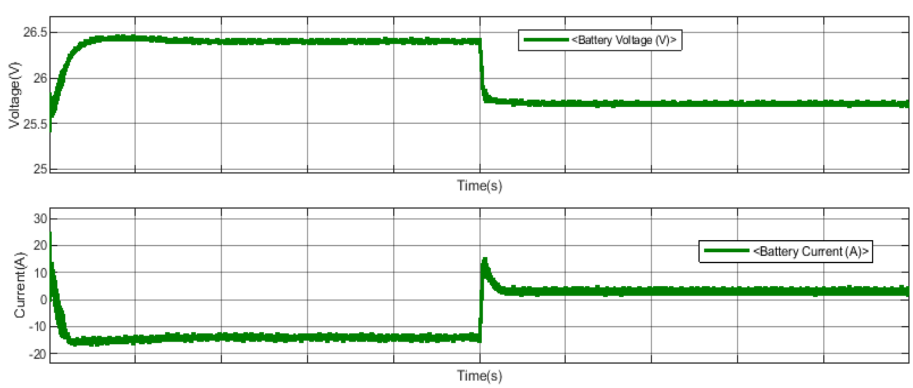


Figure 4.3 Battery Voltage and Current

From the simulation result, the battery shows there is more control during the 500 W/m2 than the without controlled system as shown in Figure 4.3.

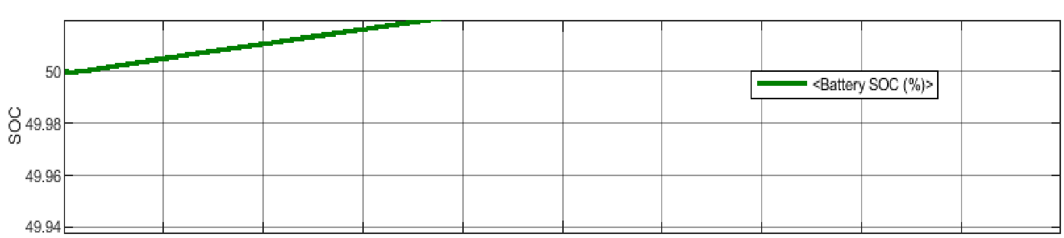


Figure 4.4 Battery State of Charge (%)

State of charging for the battery is maintained the level more than 50 % as shown in Figure 4.4.

Supercapacitor having maintained their voltage as 32 Volt and discharging current 6.087 A as shown in Figure 4.5 and Figure 4.6 respectively.

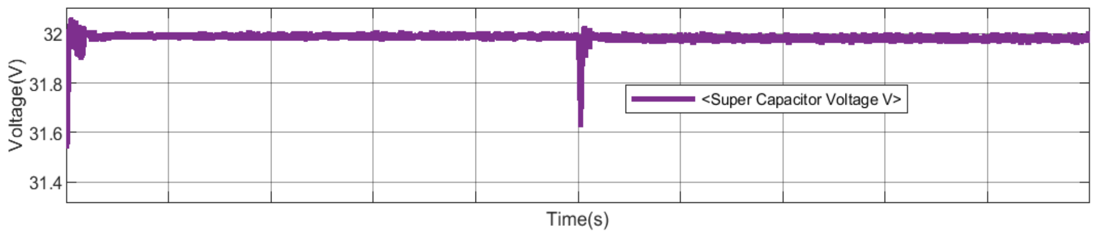


Figure 4.5 Supercapacitor Voltage

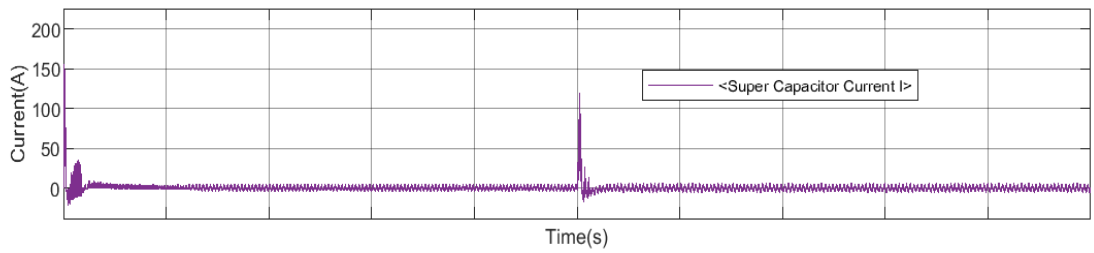


Figure 4.6 Supercapacitor Current

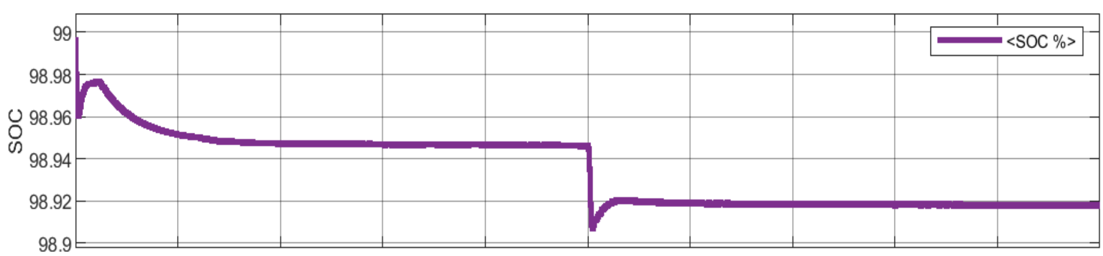


Figure 4.7 Supercapacitor State of Charge (%)

The super capacitor's state of charging is seen in Figure 4.7. Discuss the power management component of this work now. The output of the battery and supercapacitor is shown in Figure 4.8. According to the simulation results, the PI-controller could retain stability under a range of irradiance input, enhancing power efficiency by reducing the load's initial input power by 36.119% before beginning tuning.The Perturb and Observe (P&O) algorithm for Maximum Power Point (MPP) in PV and PID tuned the best result at the load in accordance with the load requirement after the best tuning result by power management strategy. It is evident from the simulation results that the system has a better outcome since it compensated for the excess load power during the 1000 W/m2 and increased the battery input by 162.261 W, or 69.836%. Due to the supercapacitor's contribution as secondary energy storage, as illustrated in Figure 4.8, there has been no impact.

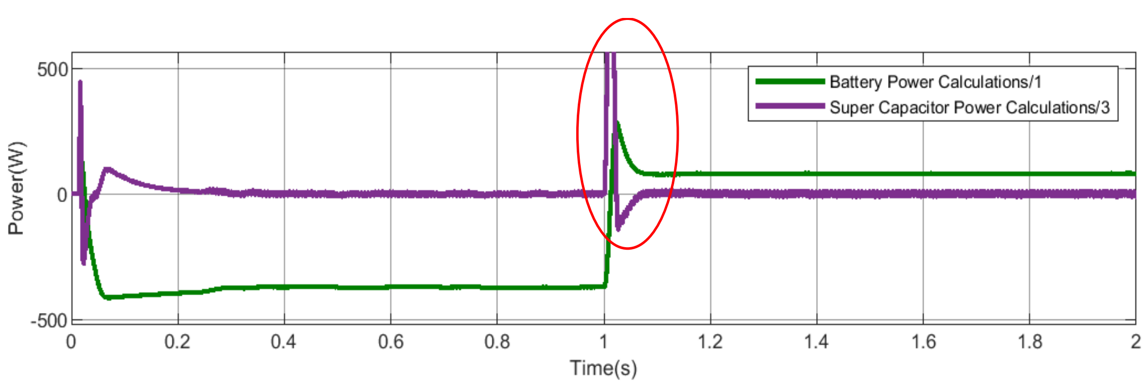


Figure 4.8 Battery and Supercapacitor Power Comparison

5. Conclusions and Future Scope

5.1Conclusions

Using the MATLAB/SIMULINK environment, a DC microgrid power management system based on super capacitors and PV batteries is designed. During the startup power from battery to load, the supercapacitor is used to make up for any power deficiency. The limitations of the battery's charging and discharging current are also taken into account. The results of the simulation demonstrate the effectiveness of the suggested power management method. The state of charge of batteries and supercapacitors is maintained within the permissible range throughout all simulation instances, and the power flow between the sources and the load is balanced.

The Perturb and Observe (P&O) algorithm for Maximum Power Point (MPP) in PV and PID tuned the best result at the load in accordance with the load requirement after the best tuning result by power management strategy. It is evident from the simulation results that the system has a better outcome since it compensated for the excess load power during the 1000 W/m^2 and increased the battery input by 162.261 W, or 69.836%. Due to the supercapacitor's role as secondary energy storage, there has been little impact.

5.2Future Scope

A PV-Battery and super capacitor-based DC microgrid power management system is used in this work. An energy management strategy for tracking power flows in a self-contained DC microgrid power generation facility needs more investigation. The plant is made up of a wind turbine, a solar generator, a battery storage system, a diesel generator, and a supercapacitor.

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