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Simulation of Charging and Discharging Process of a Hybrid Storage System in DC Microgrid

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Abstract: Due to intermittency in the natural resources and discrepancies in DC load, the stable power supply demands a storage device, generally low power density battery storage used, but the demand of quick power surges increases its rate of charge & discharge cycle which leads to a reduction in life of the battery (High energy density device), so which is compensated by using a supercapacitor (High power density device) which delivers high power in a short period, whereas battery delivers energy for a longer duration, however in this project work we have used an ideal Dc voltage source to simulate how the adopted control strategy is making power-sharing from battery & supercapacitor to DC bus and to observe their charging and discharging processes, also prevents them from overcharging and undercharging.

Keywords: Renewable energy sources, DC microgrid, Battery, Supercapacitor

I. INTRODUCTION

The need for electricity is increasing day by day as today's generation is completely relying on electrical energy to do their Major amount of works through it easily. As we know the conventional resources which are used to produce electrical energy are at an end-stage, and also they are polluting our environment, so to keep our environment pollution free we must and should go for using non-conventional electrical energy based resources such as solar, wind, geothermal...etc but in case of any renewable energy source connected DC grid, it is important to use the energy storage devices to maintain the stable power supply because the renewable energy sources are not available at all the time, so the combination of battery and supercapacitor is the better solution to deal with this problem as the battery has a higher energy density so it can provide power to the grid for a longer duration while the supercapacitor can deals with the sudden spikes of power demand from loads because it has higher power density. so in our project simulation work, we are using a Constant DC voltage source of 115V, and hybrid storage devices (Battery & Supercapacitor), we have mainly focussed on the charging and discharging process of these storage devices i.e we have observed that how the battery and supercapacitors are sharing power to the loads and also we have provided a control strategy by using a PI controller to protect the battery from the overcharging and over-discharging,

II. MODELING OF BATTERY AND SUPERCAPACITOR

The following fig .1 is a general block diagram of a DC microgrid system. Which is integrated with various power generating units, power storage devices, and DC loads, it is also connected with the utility mains grid, in an isolated mode of operation this Dc microgrid is disconnected from utility mains in this case it is completely dependent on renewable energy sources and storage devices.

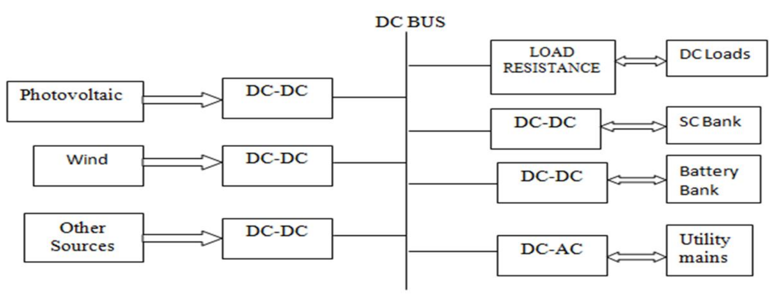

Fig .1 General Schematic Block Diagram of DC Microgrid

The hybrid storage devices are connected to DC Bus at 115V. Various DC-DC bidirectional converters are used for storage devices and renewable energy sources and DC-AC converter is used at utility mains.

A. Battery

The lead-acid battery Simulink model is used for the simulation, the nominal voltage of the battery we kept at 90V, and its rated capacity is at 20Ah. The battery controller provides a gate signal to the Boost switch When once the battery initial state of charge reaches 80% then the battery starts discharging, and at the 20% initial state of charge the gate control signals are given to Buck switch then again the battery starts charging, so mainly this SOC controlling is provided at 20% and 80% is to protect the battery from undercharging and overcharging respectively.

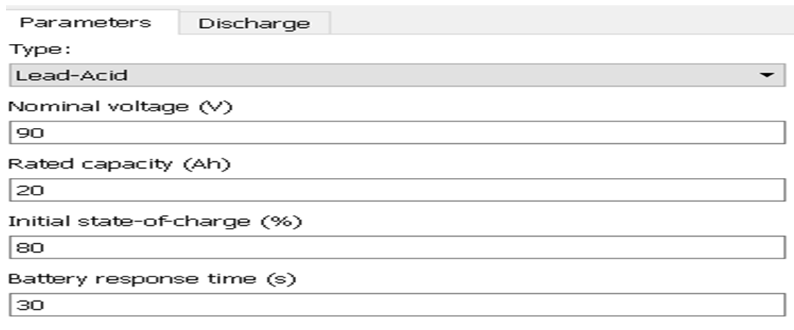

Fig .2 parameters of battery Simulink model

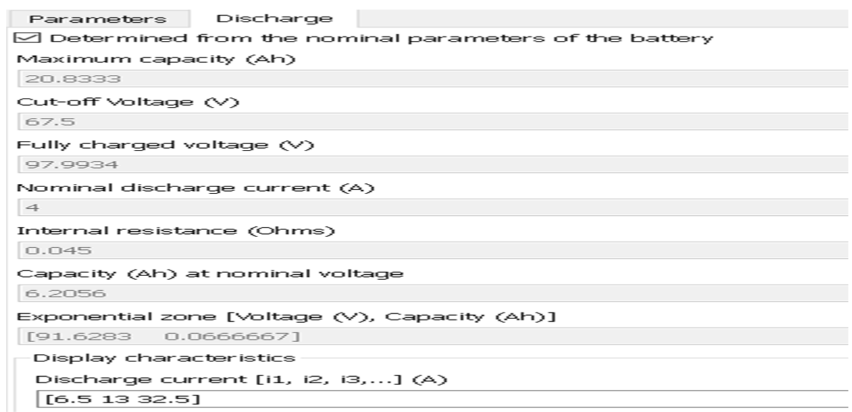

Fig .3 Discharge parameters of the battery

From Fig .3 we can see that the maximum capacity of the chosen battery with a nominal voltage of 90V is 20.8333Ah, this battery can fully charge up to the voltage 97.9934V and it can fully discharge to 67.5V.

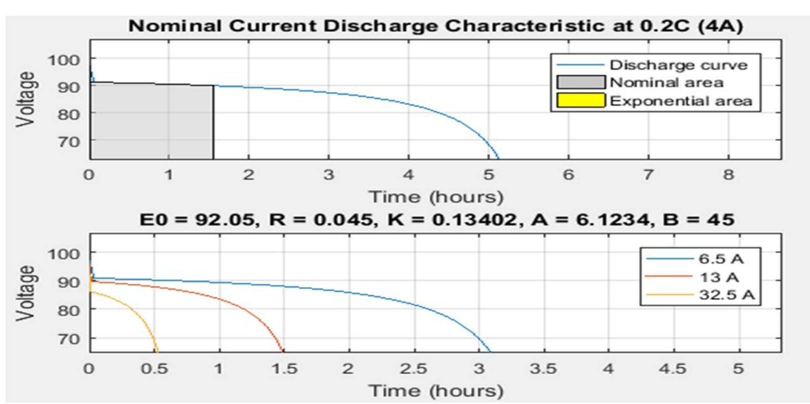

Fig .4 Nominal current discharge characteristics

From the above fig .4 it is clear that the nominal current discharge at a nominal voltage of the battery is discharging at the rate of 32.5A in 0.5 hours, 13A in 1.5 hours, and 6.5A in 3.1 hours. So from these characteristics, one thing is clear i.e if the rate of discharge current decreases then the battery discharging period increases.

B. Supercapacitor

The supercapacitor or ultracapacitor is different from the normal electrostatic capacitor because it can stores more amount of charge compares to a normal capacitor, this supercapacitor has a high power density so it supports the battery by supplying a sudden load power demand. In this simulation study, we have used a supercapacitor with its rated voltage 115V and its rated capacitance is 99.5F we have observed from our simulation results i.e the supercapacitor is discharging from 115V to 110V and again it is charging from 110V to 115V.

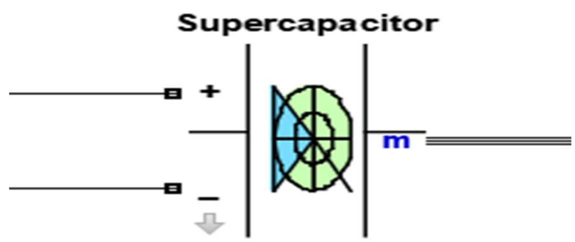

Fig .4 Generic Supercapacitor Simulink Model

III.DC-DC BUCK-BOOST CONVERTER MODEL AND IMPLEMENTED CONTROLLERS

In the following fig .5, the DC-DC buck-boost converter is acting as a power interface between DC Link (DC voltage source) and hybrid storage devices, this bidirectional converter is used for providing charging and discharging paths for hybrid storage devices, the DC-Link voltage is maintained at 115V, so here it necessitates the use of Boost switch (IGBT S2) during discharging mode to boost the battery voltage which is in the range of (80V~95V), the buck switch (IGBT S1) is operating in charging mode where it has to reduce the Dc-Link (or DC Bus) voltage from 115V to almost 90V. The L and C components are acting as a filter circuit which is useful for stabilizing the Dc voltage by smoothing out riffle contents from it.

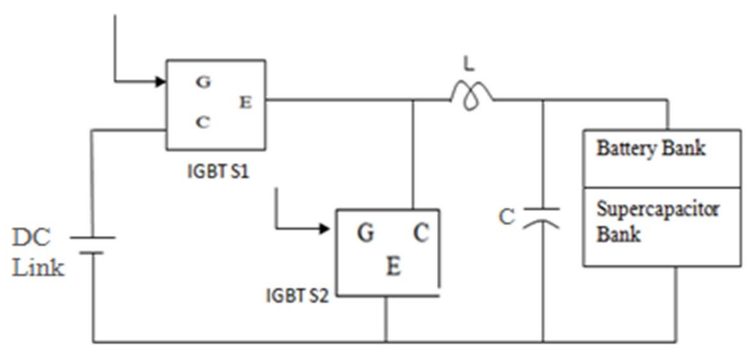

Fig .5 General model block diagram of the DC-DC converter

These IGBT switches are needs to be controlled for turning ON and OFF in a particular charging and discharging state of storage devices, so the PI Buck controller and PI boost controller are used to provide a gate pulses to the respective Buck and boost switches, and further from this we have used a CH-DSCH (charge discharge) control circuit, it can mainly decides which switch has to be ON and which should be remain OFF, so from the Fig .6 we can see that where the SOC of the battery is taken as input along with external reset signals so it can provides a output control signals based on the %SOC of the battery so in this control model we have predefined a condition i.e when the SOC of battery reaches to 80% then it has to be discharge, so now this CH-DSCH circuit sends a lower bit of digital signal i.e 0 to the Switch then this switch considers that as a FALSE condition and establishes a connection between the Boost controller of the battery and boost switch so then the Gate pulses will be given to boost switch which then initiates a discharging operation, and again during discharging at battery SOC with 20% a higher bit of digital signal i.e 1 is given to switch which considers it as FALSE condition and now it establishes a connection between buck controller and buck switch of battery where the buck switch Turns ON and initiates a charging operation, this digital signal is provided by S-R Flip Flop which is being used in charge-discharhe circuit , so all this control operation is same for supercapacitor also.

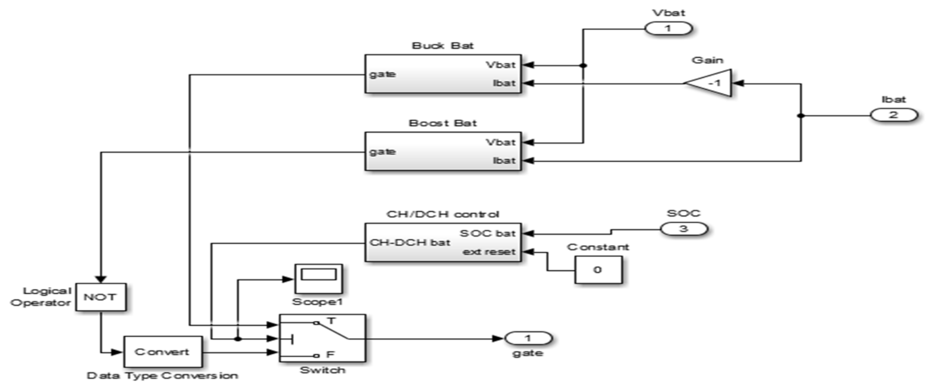

Fig 6. Buck-Boost controller selection as per battery SoC

So now all the different controllers whichever we have used are shown in the following figures, Total they are four controllers like buck and boost controllers of battery, and Buck and Boost controllers of the supercapacitor these are PI controllers.

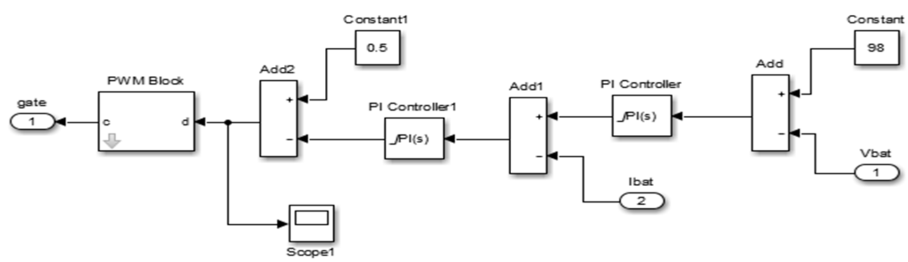

Fig 7. Block Diagram of Buck Controller of Battery

The PI buck controller of the battery is shown in Fig .7, it compares the reference voltage of 98V with the battery voltage, and an error voltage signal is generated, which is further given to the PI controller and this controller now provides a reference current which is compared with actual battery current and then again an error current will be produced which is further given to a PI controller1 and this PI controller1 generates a Duty ratio which is further compared with initial duty ratio i.e 0.5 and the final modulated duty ratio is compared with carrier signals in PWM block and thus the final PWM signals are given to buck switch of the converter.

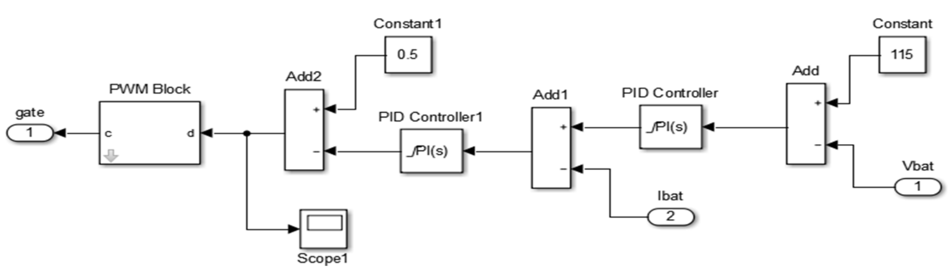

Fig 8. Block Diagram of Boost Controller of Battery

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The PI boost controller of the battery shown in Fig .8 it compares the DC bus voltage i.e 115V with battery actual voltage and provides a required duty ratio to the boost switch of the converter so then the switch remains in ON condition till the battery provides a voltage equal to DC bus voltage i.e 115V.

The buck controller of the supercapacitor is shown in Fig .9 it provides gate pulses to the buck switch of the supercapacitor converter, in this initially we have set a limit to the power flow from DC Bus to supercapacitor and that is we see from the below figure in which the DC Bus power is compared with a reference power 500W, and duty ratio to the Buck switch of DC converter will be given till the 500W of power to be supplied to the supercapacitor during its charging mode.

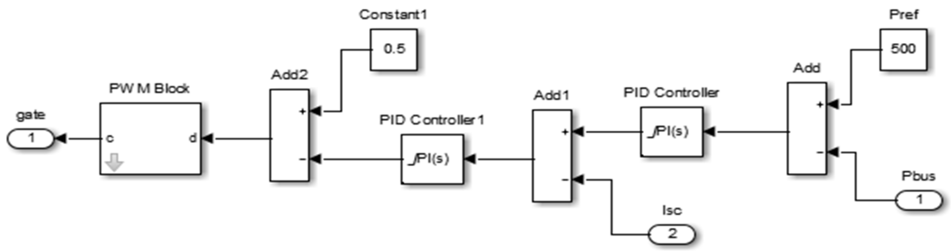

Fig 9. Block Diagram of Buck Controller of SC

In.10 shown The Boost controller of the supercapacitor, in this controller the reference voltage value taken is 115V and it is compared with the DC Bus available voltage, and based on the error signal generated, the duty ratio for the Boost switch of the supercapacitor DC converter is provided so that this switch remains in ON condition till it delivers a required power to the Dc Bus.

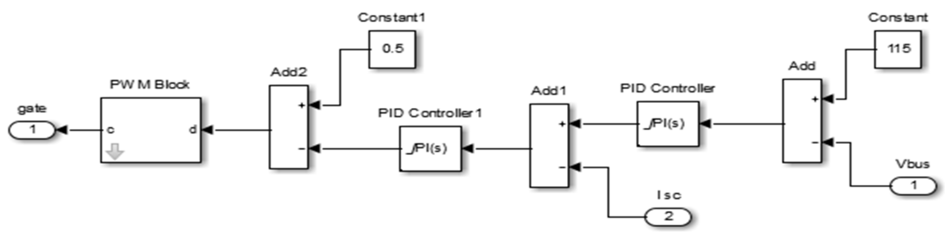

Fig 10. Block Diagram of Boost Controller of SC

IV. SIMULINK MODEL BLOCK DIAGRAM OF THE PROPOSED SYSTEM

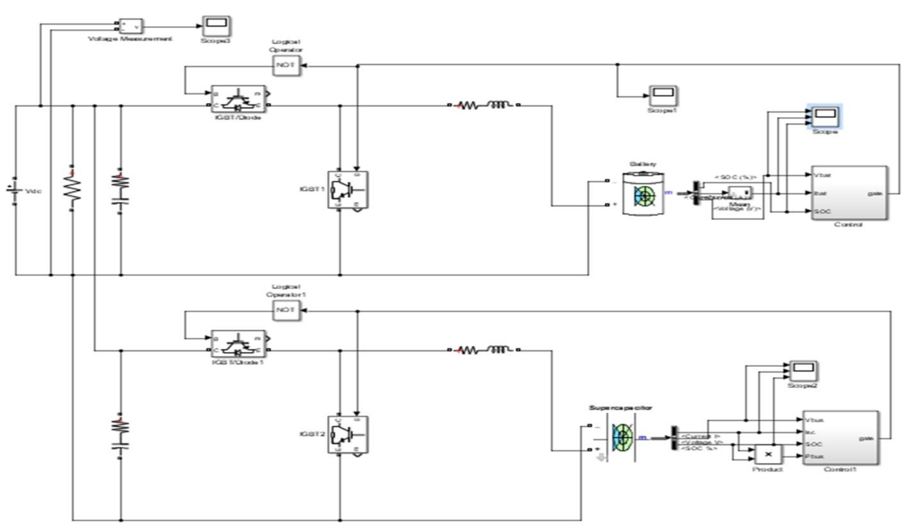

Fig .11 Hybrid DC microgrid system with ideal dc source

This is the simulink model block diagram of a hybrid DC microgrid system, so here in this we have used a battery, supercapacitor and a normal conventional DC source (ideal Dc voltage source) all these energy sources are interconnected together at DC bus, and we have used the two DC loads (resistance) in those one is fixed from starting of simulation and another load is added to the system by closing the breaker after 0.2 seconds of simulation run time and this load is added for the purpose to check whether the voltage at PCC (point of common coupling) is maintaining constant or not even after changing the load, and also how the power sharing is taking place from battery and supercapacitor and that voltage at PCC is maintained constant with the help of DC-DC bidirectional BUCK-BOOST converters of battery and supercapacitor, the closed loop feedback control using PI controllers of both battery & supercapacitor is provided to the gate terminal of the IGBT buck and boost switches of converters which operates based on gate pulses provided to them, so they accordingly switch the storage systems in charging and discharging processes

V. SIMULATION RESULTS

The simulation is carried out in two modes of the battery (charge and discharge mode). In charge mode, the SOC of the battery is at 20% and in discharge mode, the SOC of the battery is at 80%. The SOC limit during discharging is kept at 20% to prevent the battery from over-discharging and during charging the SOC is limited at 80% to prevent overcharging, this control is provided by battery controllers which are shown in the above fig .7, Fig .8 respectively.

A. Charging State

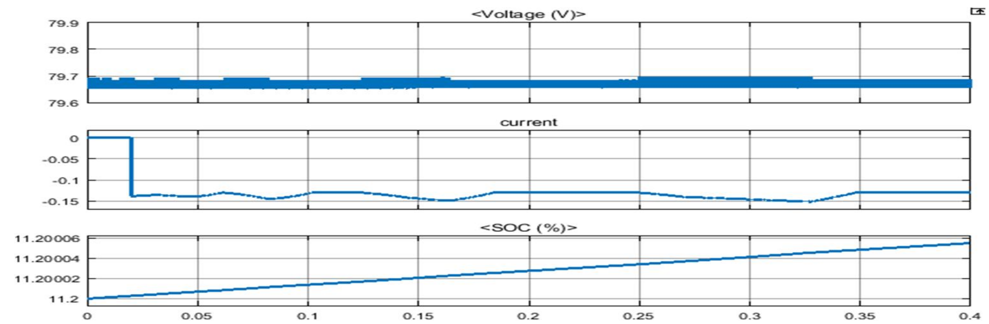

Fig 12.Battery characteristics during charging mode

In charging mode, the battery and supercapacitor currents are in a negative direction which denotes charging with SOC increasing concerning time.

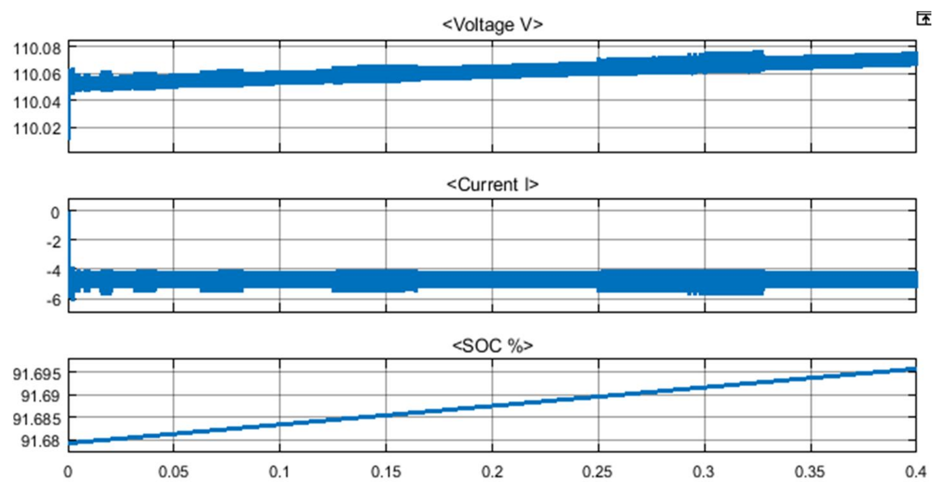

Fig 14. Supercapacitor characteristics during charging mode

The supercapacitor rated voltage is 115V, so from Fig .13 we can observe that the initial voltage of the battery is at 110V, it means before this it was in Discharge mode i.e it was being discharged from 115V to 110V, and Now again it is charging from 110V to 115V. the supercapacitor charge and discharge cycles are so quick to compare to the battery so that is the reason it is mainly used for discharging sudden rise in load power demands.

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B. Discharging State

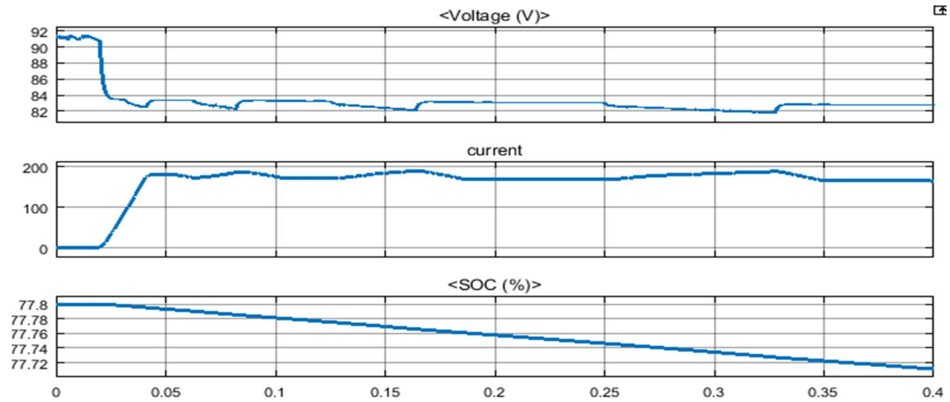

Fig 14.Battery characteristics during discharging mode

During discharge mode with an ideal DC source, the battery & supercapacitor currents are in a positive direction which denotes Discharging with %SOC decreasing with concerning time, as we defined once the SOC reaches 80% it has to discharge, and accordingly, it is discharging from 80% SOC it is shown in fig .14, the voltage exponentially dropped from 92V to 84V it means the battery is discharging. The nominal voltage of a battery is 90V.

The supercapacitor discharge state is shown in Fig .15, in the previous charge cycle the battery was fully charged up to 115V, and now after reaching its rated voltage it is being discharged, and at the point of discharging the SOC of the supercapacitor is at 95.99%.

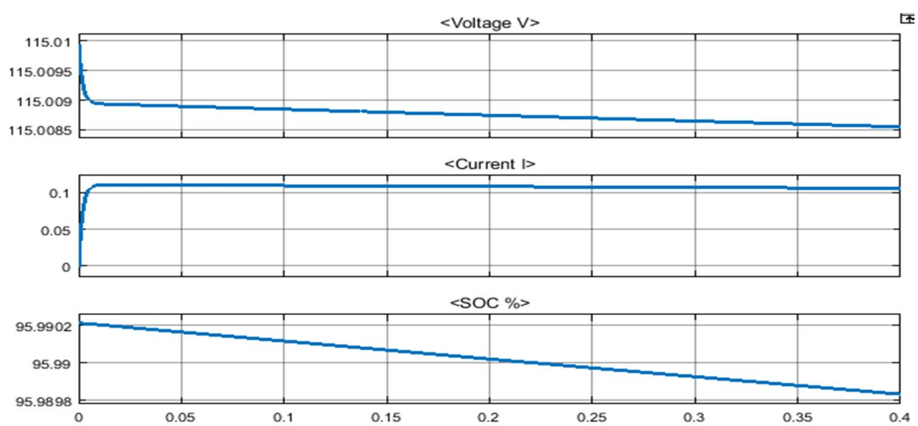

Fig 15.Supercapacitor characteristics during discharging mode

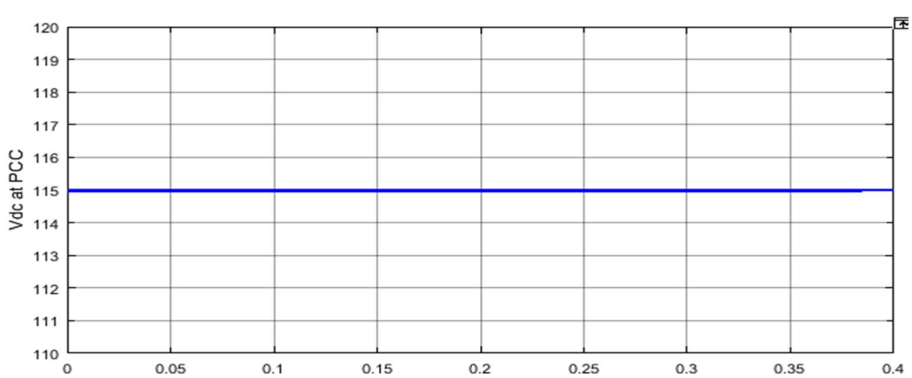

Fig.16 PCC voltage during charging mode discharging mode

This above Fig .16 shows that the voltage at PCC (point of common coupling) is maintained constant despite load changes in the DC microgrid, in this simulation the load change is taking place at 0.2 seconds, so even though after a change of load the PCC voltage still constant, also during charging and discharging of battery & supercapacitor it is observed to be constant.

VI. CONCLUSION

We mainly performed a Matlab simulation by using a DC voltage source of 115V, and observed the performance of battery and supercapacitor at various conditions like during charging, during discharging, and during the change in load, during the initial run time of simulation i.e up to 0.2 sec, we used a 10 ohms of load resistance, and after 0.2 sec further 10 ohms of load resistance added to bring the change in load and observed that, in response to change in load how the power from battery is sharing, and also how the power from supercapacitor is sharing. We also used a control strategy to control the SOC of the battery from being overcharging and undercharging i.e at 80% and 20% respectively. And finally observed that the voltage at PCC is whether maintaining constant or not.

VII. FUTURE SCOPE

The addition of other renewable energy sources like the photovoltaic, wind in place of Ideal DC voltage sources would be a better option, and especially a PVA with MPPT in DC microgrid with an effective algorithm to track a maximum PowerPoint on a solar cell has a huge scope in future.

VIII. ACKNOWLEDGEMENT

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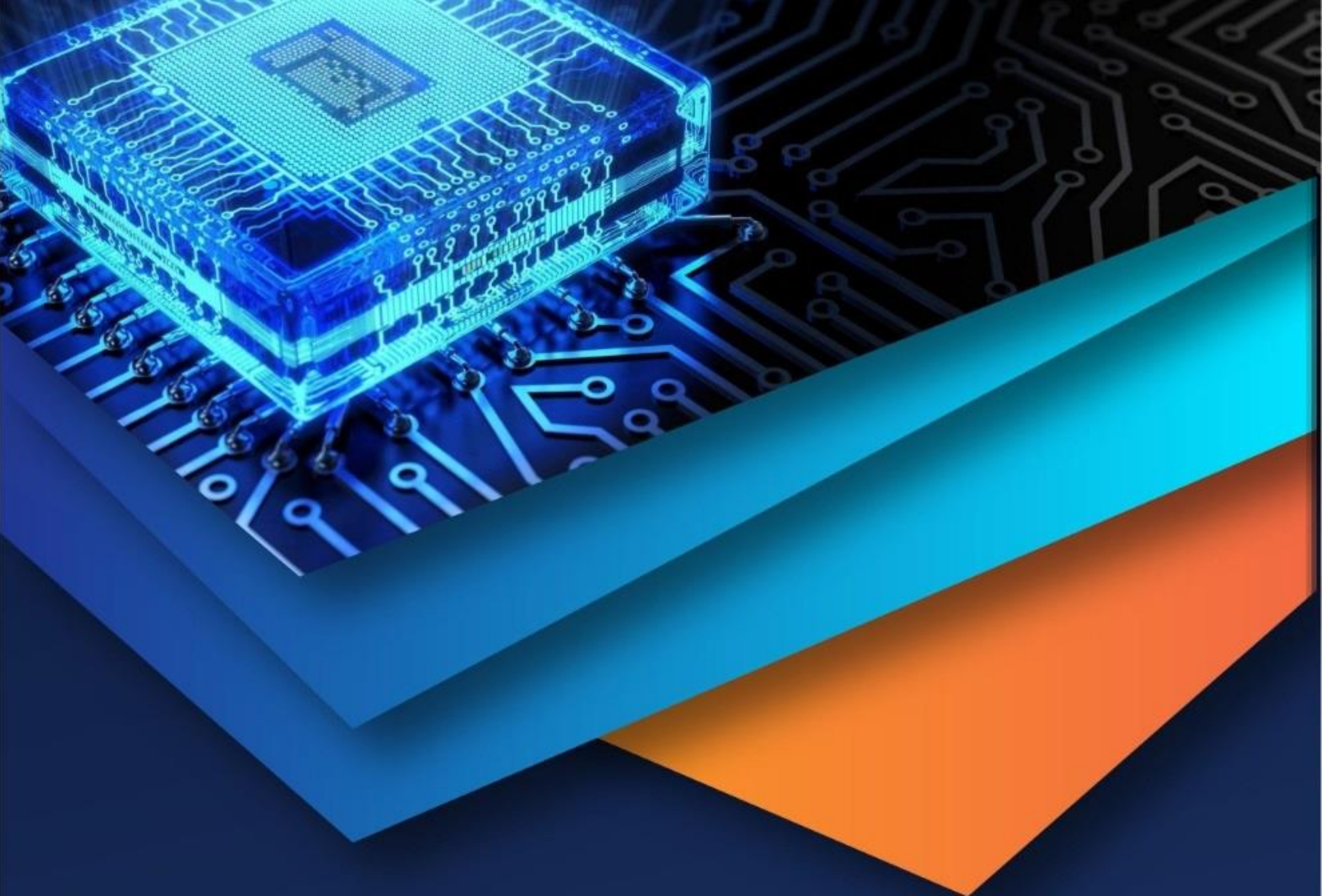

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