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Simulation of Photovoltaic Array in DC Microgrid with MPPT using Perturb & Observe Method

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Abstract: If The stand-alone dc microgrid system with a PVA i.e solar renewable energy source is operated without any supportive energy storage sources like battery and supercapacitor, then it will lead to an unstable operation of a DC microgrid, so it necessitates the usage of energy storage devices for maintaining stability in the system and also to improve the efficiency of PVA we have used an MPPT controller with P&O algorithm which provides a required duty ratio for DC-DC boost converter and this converter sees that the maximum power can be transmitted from PVA to loads. In this paper, we present how we performed a simulation study by integrating Simulink models like PVA, MPPT, battery, and Supercapacitor at Point of common coupling with DC loads and observed the stability of the system with different conditions like the change of irradiances during charging and discharging processes of storage devices and observed how is the power-sharing from PVA, Battery, and supercapacitor concerning change in load.
Keywords: Photovoltaic array, Dc microgrid, Battery, Supercapacitor, MPPT, P&O

I. INTRODUCTION

Day by day depletion of nonrenewable energy sources such as fossil fuels like coal, nuclear, Diesel...etc and also another reason like pollution during its generation, so such few factors, forcing us to switch to the pollution-free and economical electrical energy generations, such as wind farms, photovoltaic or solar, geothermal...etc which utilizes abundantly available natural resources such as wind, solar radiations ...etc to produce and supply pollution-free electrical energy. But using PVA alone without any control mechanism to supply power to DC loads has very less efficiency, because the sun radiations and temperatures changes from time to time according to weather conditions throughout the day, so due to this extraction of maximum power output from PVA is not possible, so the solution for the problem is MPPT (maximum power point tracking), with the help of perturbing & observe algorithm, it tracks the maximum power point on the PVA array from instant to instant and provides a Duty ratio to the DC-DC Boost converter and thus this converter matches its input impedance to terminal impedance of PVA and thus the maximum power transmitted to Dc loads and hybrid storage devices, this phenomenon is based on the principle of "maximum power transfer theorem" it says that whenever a load impedance will become equal to source impedance then maximum power transfers from source to load. In our simulation work, we have used a PVA (photovoltaic array) with MPPT as a renewable energy source, which supplies power to the Dc microgrid to which DC loads and hybrid storage devices (battery & supercapacitor) are interconnected, these hybrid storage devices play a crucial role in the stabilizing the power-supply in dc microgrid by storing charge in them during normal operation of PVA and discharges that power to Dc bus of the grid during the abnormal operation of PVA, the battery supplies power for longer duration because it has a low power density and high energy density, while surge power demands meaning demand for delivering of high power in short duration is delivered by supercapacitor as it has a high power density and low energy density.

A. Objective

The objective of our work is to show the simulation of how the maximum power of PVA is changing concerning change in irradiances and temperature with the implemented MPPT, P&O algorithm, and also the charging and discharging processes of battery and supercapacitor are observed before and after changing the load to check whether with their support the system is becoming stable or not, using MATLAB/SIMULINK

B. PV cell modeling

A typical silicon PV cell generates only about 0.5v. Each PV cell of a solar module or a panel converts the light energy into electrical energy, a group of such PV panels is connected in series and parallel strings, and a group of strings is considered as one solar/PV array. Each PV modules are connected in series and parallel fashion, the series-connected modules are responsible for output voltage increment, while the parallel-connected modules are responsible for output current increment of PV array, so the output power rating of PVA depends on the combination of series and parallel connected PV modules of an array.

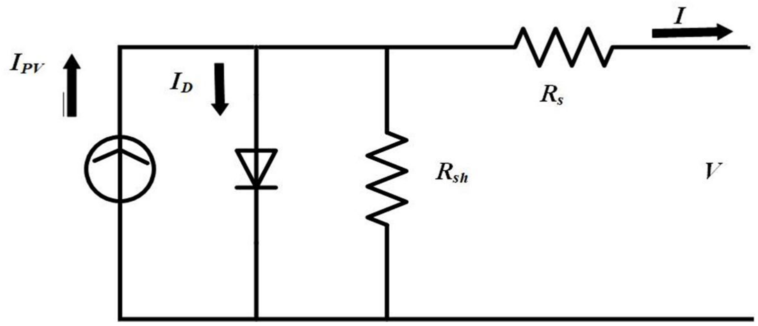

Fig .1 Single diode model of the PV cell

$$Ipv = ID + IRsh + I \quad (1)$$

$$I = Ipv - ID - \left(\frac{V+IRs}{Rsh}\right) \quad (2)$$

$$ID = Io\left(e^{\frac{V+I\,Rs}{n\,VT}} - 1\right) \quad (3)$$

$$VT = \frac{KT}{q} = \frac{T}{11600} \quad (4)$$

Substitute equation (3) in equation (2)

$$I = Ipv - Io\left(e^{\frac{V+IRs}{n\,VT}} - 1\right) - \left(\frac{V+IRs}{Rsh}\right) \quad (5)$$

Where

ID= diode current
IRsh = shunt current
Ipv= photon current
n= diode ideality factor
Io= cell reverse saturation current
VT= equivalent voltage of temperature
K= Boltzmann's constant, ($1.38*10^{-23}$ J/K)
q = electronic charge, ($1.6*10^{-19}$ C)
T = PV cell temperature in Kelvin

C. *Graphs*

This is how the I-V, P-V nonlinear curves of a PV cell varies from time to time, which is shown in following Fig .2 and Fig .3 respectively for different fixed temperature and irradiance levels, so due to these characteristics of a PV cell, it is difficult to find an MPP (maximum power point) on a PVA.

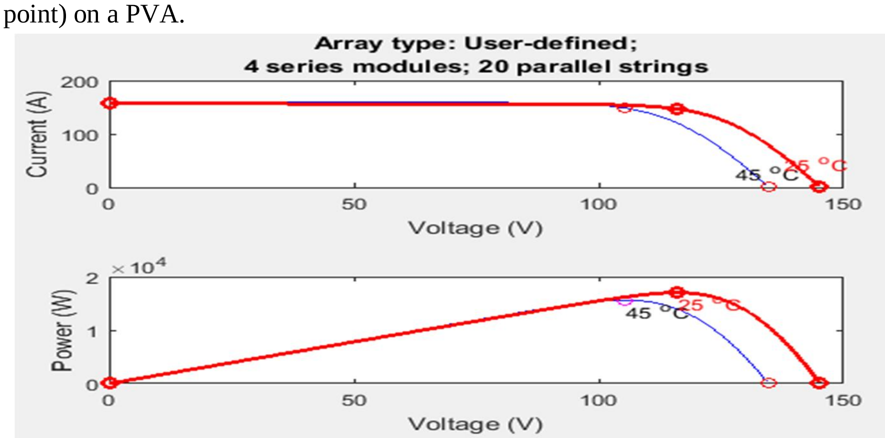

Fig 2. I-V, P-V characteristics curve of a photovoltaic cell at given fixed temperatures

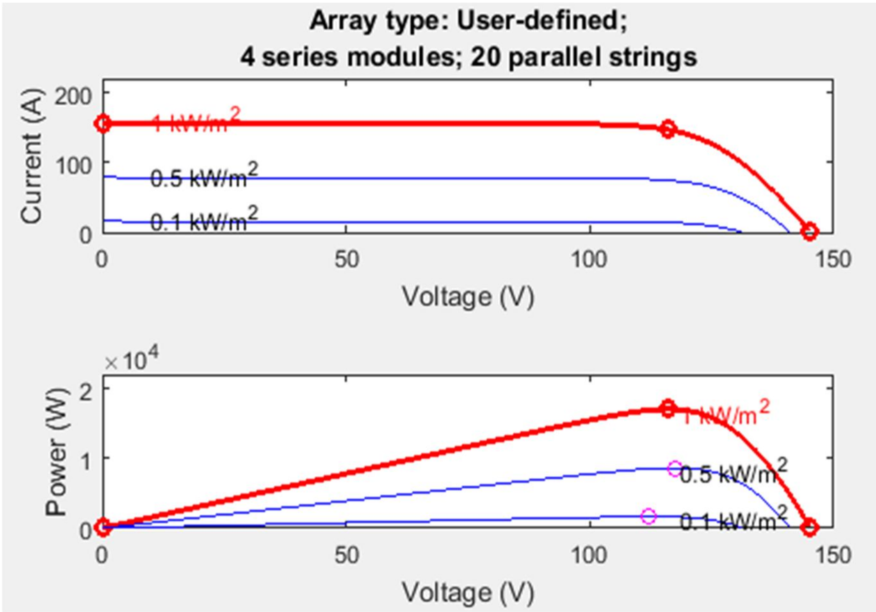

Fig .3 I-V, P-V characteristics curve of a photovoltaic cell at given fixed irradiances

II. BOOST CONVERTER

A. Circuit Diagram

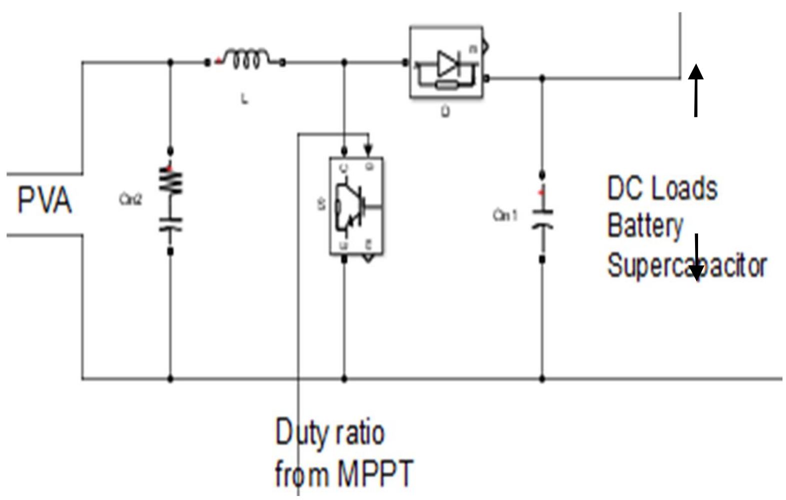

Fig .4 circuit of the DC-DC boost converter

This DC-DC boost converter is used as an impedance matching device, according to control inputs i.e duty ratio from MPPT it can regulate the PVA terminal impedance in such a way so that the PVA terminal impedance and its input impedance will be maintained always constant, and when the two impedances are constant then maximum power will be transferred from PVA to load Throughout the operation of PVA.

Generally Boost converter operates in two distinct states they are ON state and OFF state. In the ON state the switch is closed and the inductor stores the energy in the form of the magnetic field, and soon after that in OFF state, The inductor releases its accumulated energy by reversing its polarity to maintain a current direction same as earlier, and supplies that to the load and capacitor, and that voltage in OFF state is greater than input voltage because that was the addition of source voltage as well as inductor voltage, so that’s why it is called as Boost or step up converter. The filter elements mainly capacitor and inductor are used for smoothening out of ripple contents from the input voltage and input current respectively.

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III. MPPT WITH P&O

A. MPPT Introduction

In the case of a photovoltaic module, there is one single operating point at any given point in time where maximum power can be drawn, so we need to locate that point or track that point and see that the operating point of the MPPT module is always at that point and it should be hovering near and around that point, so the process of always trying to maintain the operating point of the PV panels at maximum power point is called the "Maximum power point tracking"

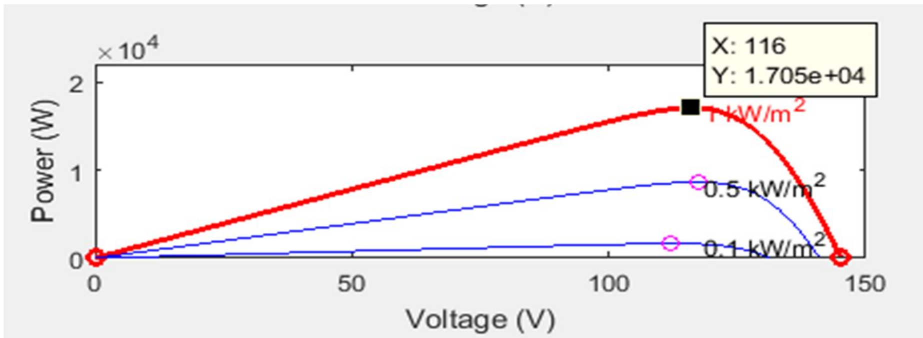

Fig .5 curve for maximum PowerPoint

In the above fig .5, it is showing that for the irradiation level 1000 W/m2 at 250C The obtained maximum power is 17.05 KW at 116 V. so basically this MPPT tracks the maximum power point on a solar panel with the help of certain MPP tracking algorithms such as perturb & observe (hill-climbing method), Incremental conductance method, Fractional short circuit current, Fractional open-circuit voltage, Neural networks and Fuzzy logic based MPP tracking methods, among these algorithms the P&O, and Incremental conductance are very popularly used. In our project, we have used a P&O algorithm to track a maximum power point on the PV array.

B. Perturb and Observe Algorithm

By doing continuous perturbations and observations the maximum power point on PVA can be tracked which is shown on top of the curve in below fig .6, the perturbations are made periodically on output power and voltage of PVA, and by making the comparison of present values (K) with previous values (1-K) as shown in below Fig .6 and Table .1 and the respective duty ratio will be generated and given to Boost converter.

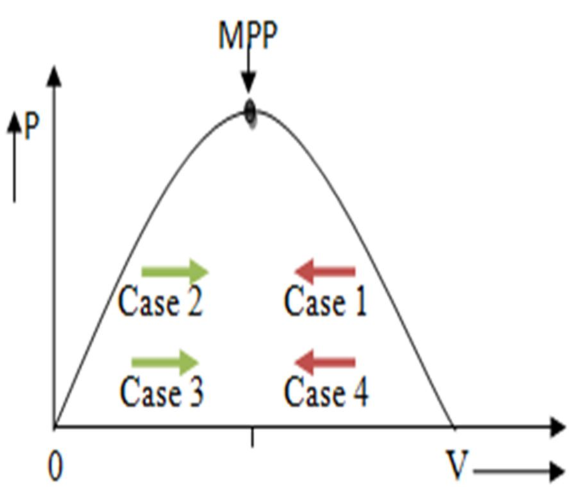

Fig .6 curve for varying duty ratio to track MPP

$$\Delta P=P(K)-P(K-1);\quad \Delta V=V(K)-V(K-1);\quad \Delta D=D(K)-D(K-1)$$

Where

K=Present time, K-1=One second before

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Table 1.summary of four cases of P&O algorithm

The operation of the P&O algorithm is summarized in four cases	
Case.1 If ΔP> 0(power is increasing) ΔV< 0 (voltage is decreasing) Then **-ΔD** (Subtract duty ratio) to reach MPP by reducing voltage	Case.2 If ΔP>0 (power is increasing) ΔV>0 (voltage is increasing) Then **+ΔD** (Add duty ratio) to reach MPP by increasing voltage
Case.3 If ΔP<0 (power is decreasing) ΔV<0 (voltage is decreasing) Then **+ΔD** (Add duty ratio) to reach MPP by increasing voltage	Case.4 If ΔP<0 (power is decreasing) ΔV>0 (voltage is increasing) Then **-ΔD** (Subtract duty ratio) to reach MPP by reducing voltage

From the above fig .6 for adding or subtracting Duty ratio (ΔD), it should be in proportionate with voltage.

C. P&O flowchart

The P&O flowchart has a certain set of blocks which are representing various conditions required for the P&O algorithm to track an MPP, initially it measures the output current and voltage of PVA, and based on these inputs it calculates a reference power, and now again the output voltage of PVA is compared with this reference power at every instant and after few perturbations and observations it will track down the MPP, which is as shown in the following flow chart, if initial condition ΔP= 0 is true then it will directly go to return it means no perturbations are required but if it is false then it needs to go for certain perturbations where again the condition is like ΔP > 0 if it is true or even false for each of then we have further two conditions for ΔV > 0 they are four cases, which are as shown in the above table fig .6 and also in following flow chart fig .7 so in all those cases necessary perturbations are made to find out the maximum PowerPoint.

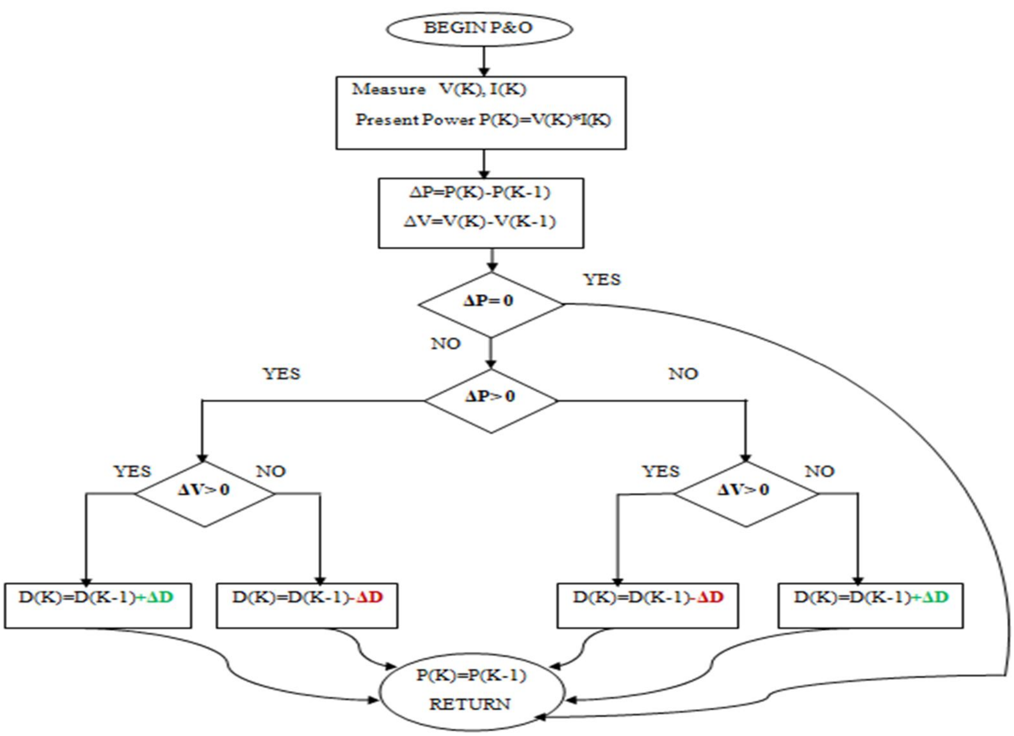

Fig .7flow chart of P&O algorithm

IV. SIMULINK MODEL BLOCK DIAGRAM

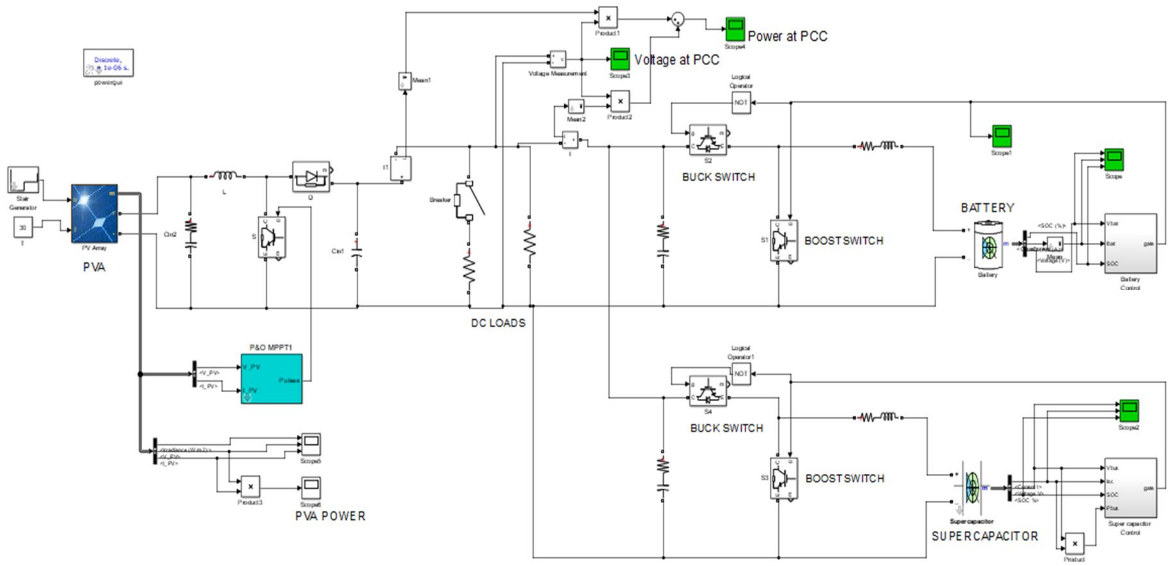

Fig .8 Simulink model block diagram of PVA connected to DC micro gid with MPPT

In this Simulink model block diagram, we have used a" power graphical user interface" which is used mainly for power system components modeling in Simulink, the PVA receives varying irradiations like 1000W/m^2, 500 W/m^2, 700 W/m^2, 900 W/m^2 at every 0.1 sec of interval and temperature is kept constant at 30^{0}C, now that the MPPT senses the output voltage and current from the PVA and calculates a reference power which is further compared with the varying output voltage of PVA and a respective Duty ratio is produced and provided to gate terminal of the DC-DC boost converters Switch, now this boost converter regulates the PVA terminal impedance in such a way so that it could be maintained constant concerning input impedance of boost converter itself since both the impedances are equal then Maximum power output is delivered from PVA to loads and as well as to charge battery and supercapacitor. Whenever the PVA is generating an excess power then it supplies power to loads and also charges the storage devices but sometimes it couldn't able to supply a load demanded power due to varying weather conditions, then battery and supercapacitor starts discharging to loads in order to maintain a stability in the DC micro grid system, and another thing the supercapacitor is used which can helps the battery to extend its life and service by supplying a peak demand of power in short duration, during charging operation of both the storage devices BUCK switch of bidirectional DC-DC converter is ON and BOOST switch is OFF and during discharging a BOOST switch is ON and BUCK switch is OFF, and this ON and OFF controlling is provided from the PI controllers used in the control model of this storage devices which provides a gate pulses to these switches based on status of available charge in them i.e by considering %SOC, and finally we are observing due to the varying power generation of PVA and also due to sudden increase in Load resistance (in our case we have added a 30 ohms at 0.2 seconds to a previous 10 ohms load) the output DC voltage at PCC is maintained stable or not with a minimum permissible fluctuations are to be observed in the simulation results.

V. BATTERY & SUPERCAPACITOR

A. *Battery*

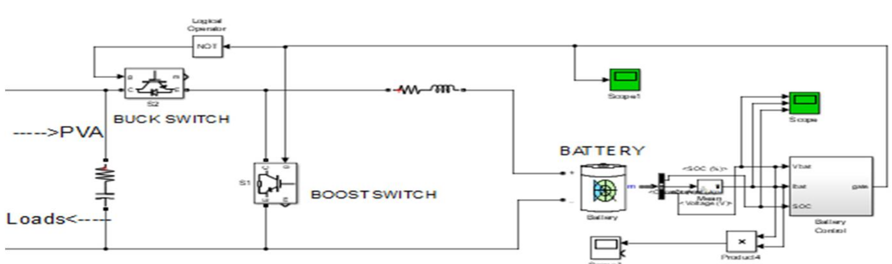

Fig .9 Battery circuit diagram

We are using a lithium-ion battery which is far better than its counterpart i.e lead-acid battery in terms of capacity per unit volume, light in weight, more life cycle…etc. the lithium-ion battery which we have used has a nominal voltage of 90V, rated capacity is 20Ah, this battery is mainly used to provide a power backup in the autonomy case of PVA, this battery has a high energy density so it can supply base loads for a longer duration, its operation is like whenever PVA generates a surplus power it charges and whenever the PVA generates a low power then this battery discharges power to the DC load. We have defined the control conditions for a battery like Whenever its initial state of charge reaches 90% it has to discharge, and when it drops to a 10% state of charge then again it has to charge.

B. Super Capacitor

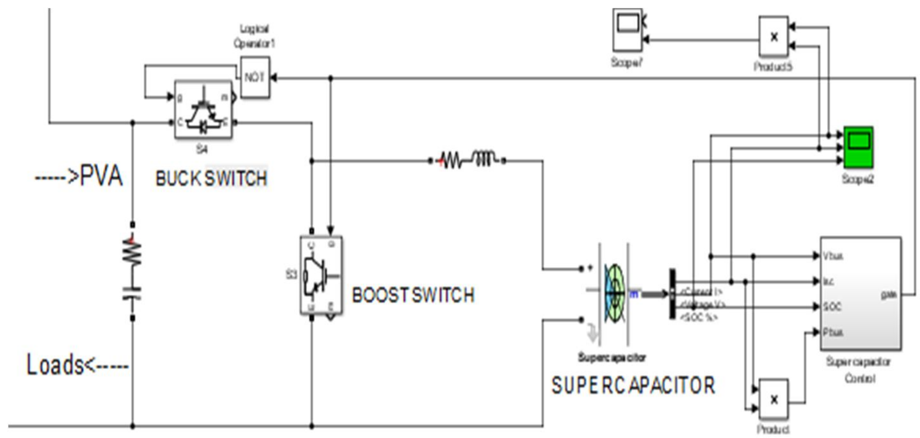

Fig .10 Supercapacitor circuit diagram

The supercapacitor is mainly used to supply the transient loads because these transient loads demand a huge power supply in a short duration and that can be supplied instantly by the supercapacitor which is shown in the below simulation results because supercapacitor has a high power density, the supercapacitor we have used has a rated voltage of 115V, it starts discharging when its initial voltage reaches 110V and starts charging when it reaches to 10v.

VI. SIMULATION RESULTS

A. PVA Characteristics During Battery & Supercapacitor Discharging State

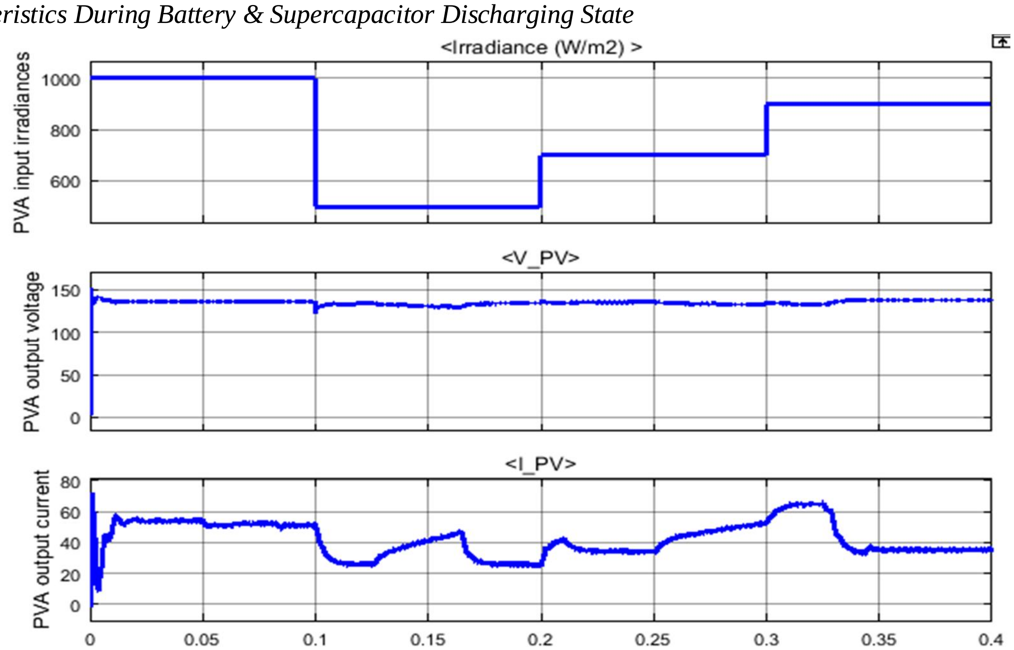

Fig .11 PVA output voltage & current at different irradiances during discharging state

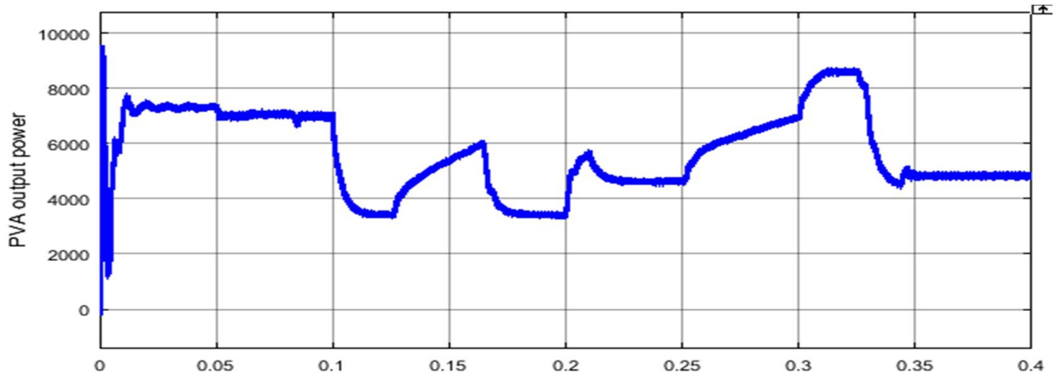

Fig .12 PVA output power during discharging state

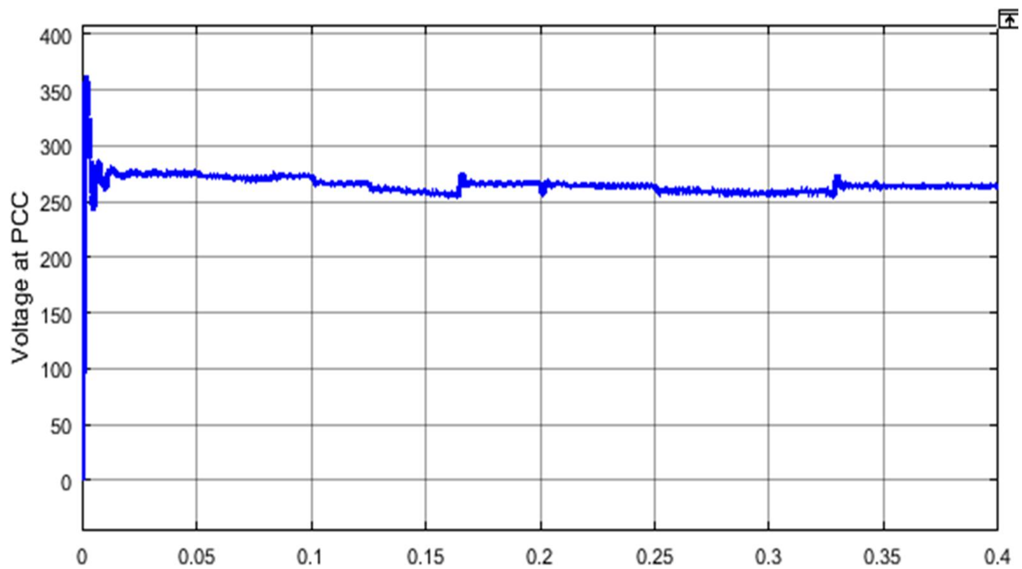

Fig .13 Voltage at PCC during discharging state

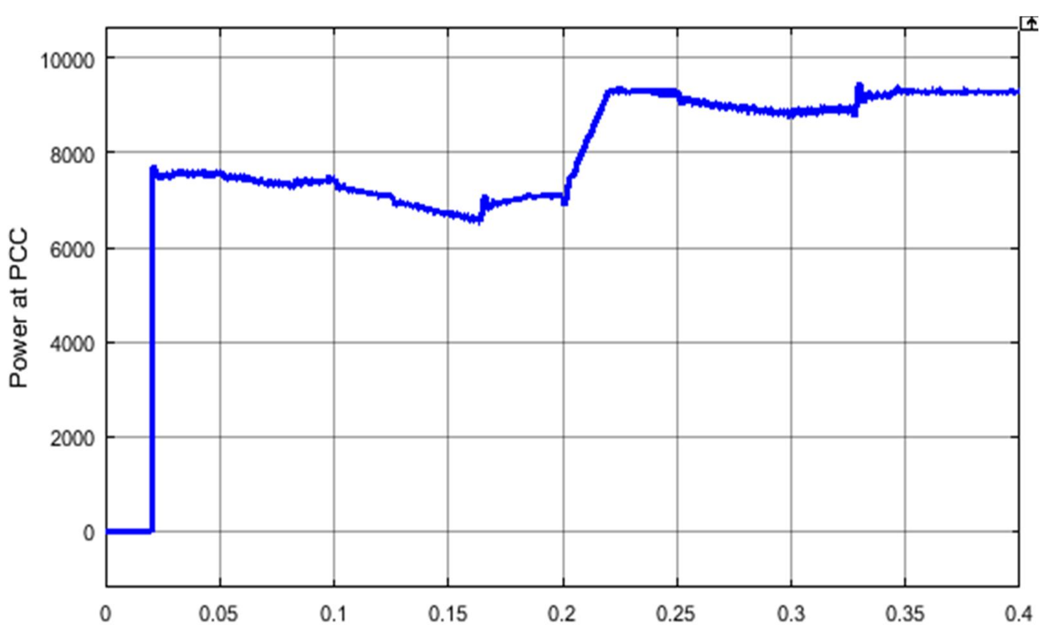

Fig .14 Power at PCC during discharging state

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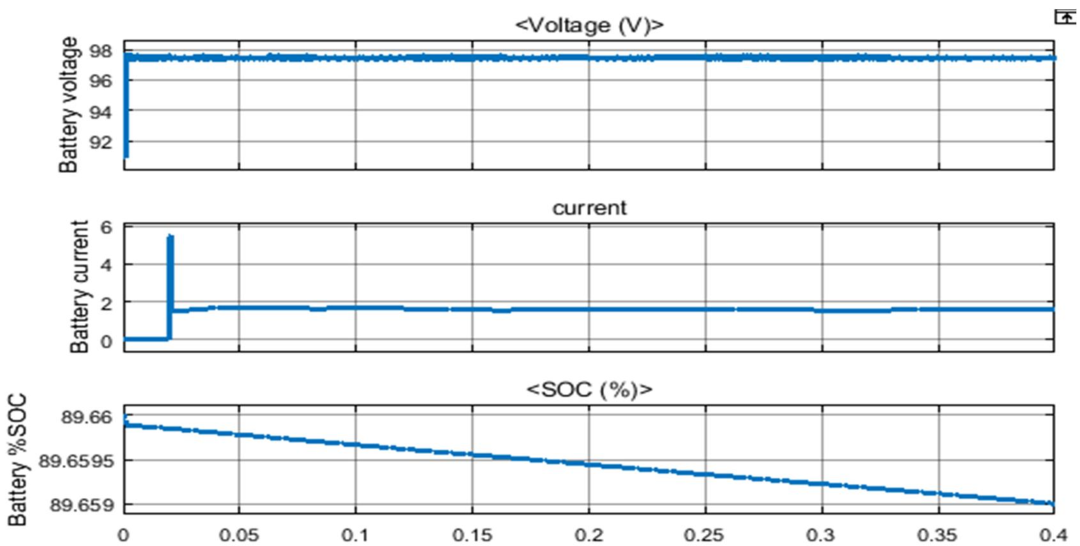

Fig .15 battery characteristics during discharging state

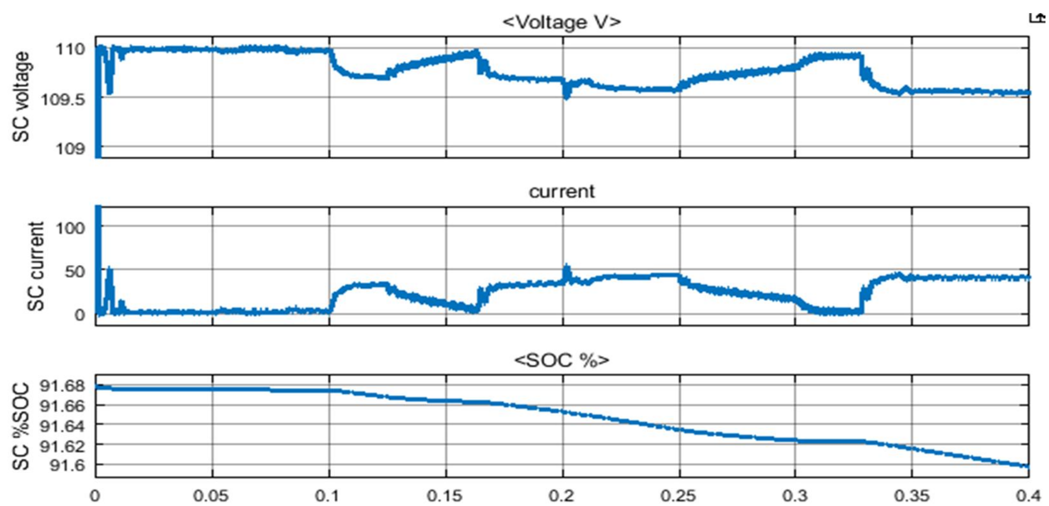

Fig .16 supercapacitor characteristics during discharging state

B. PVA Characteristics During Battery & Supercapacitor Charging State

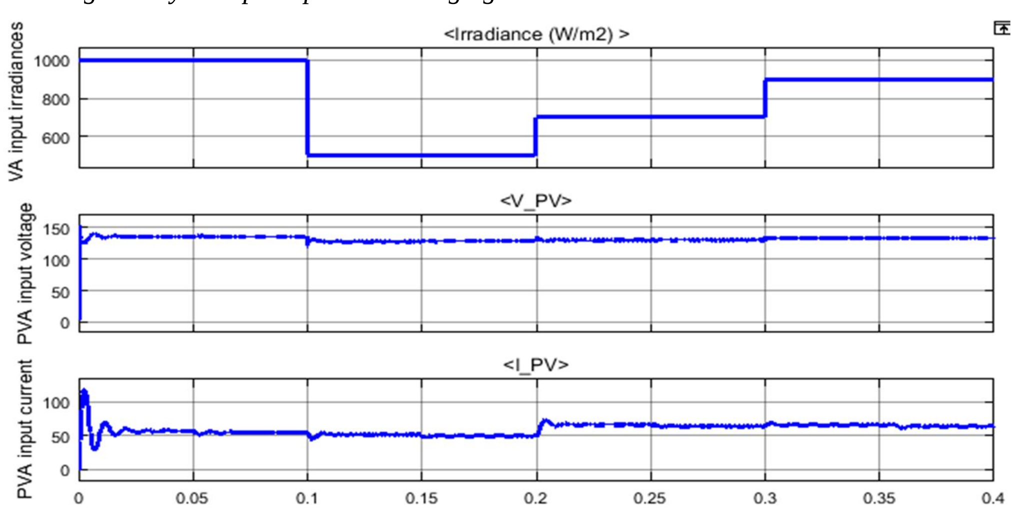

Fig .17 PVA output voltage & current at different irradiances during charging state

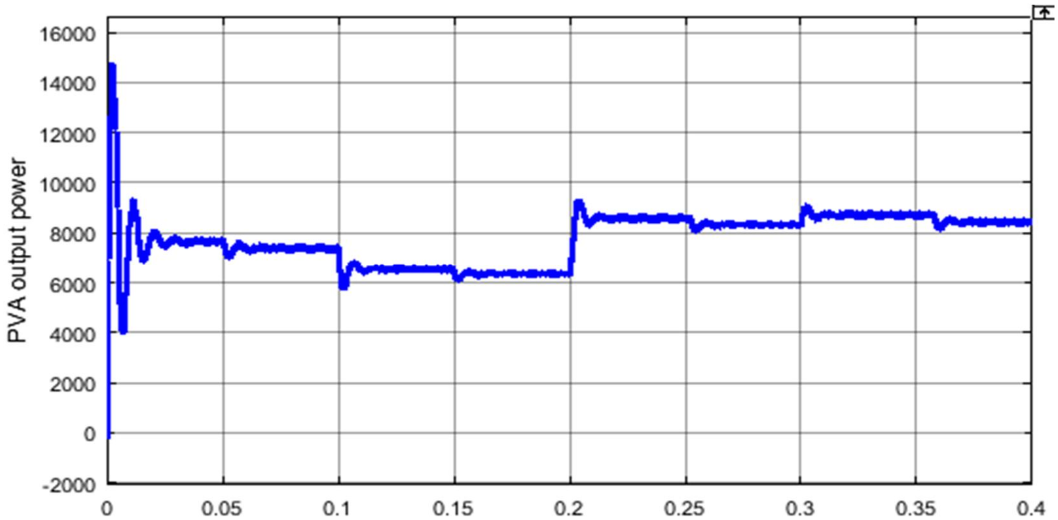

Fig .18 PVA output power during charging state

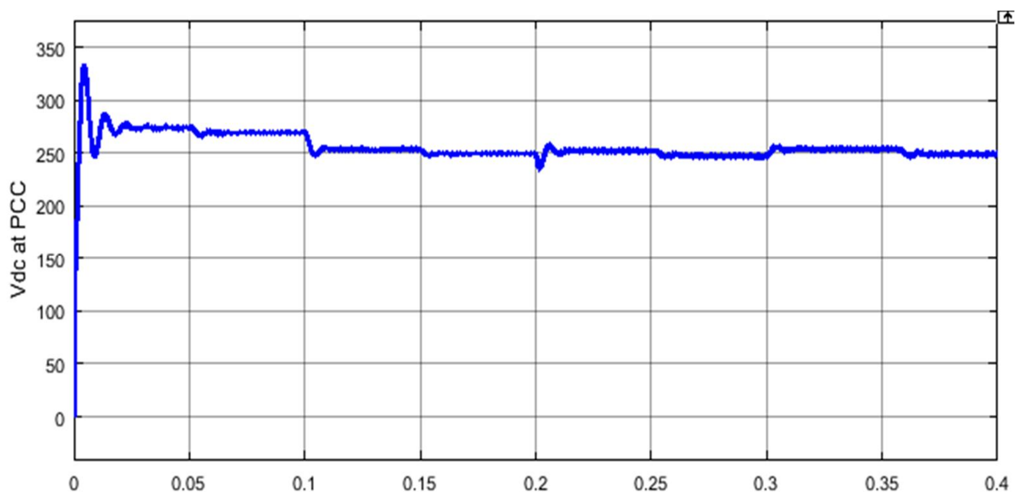

Fig .19 voltage at PCC during charging state

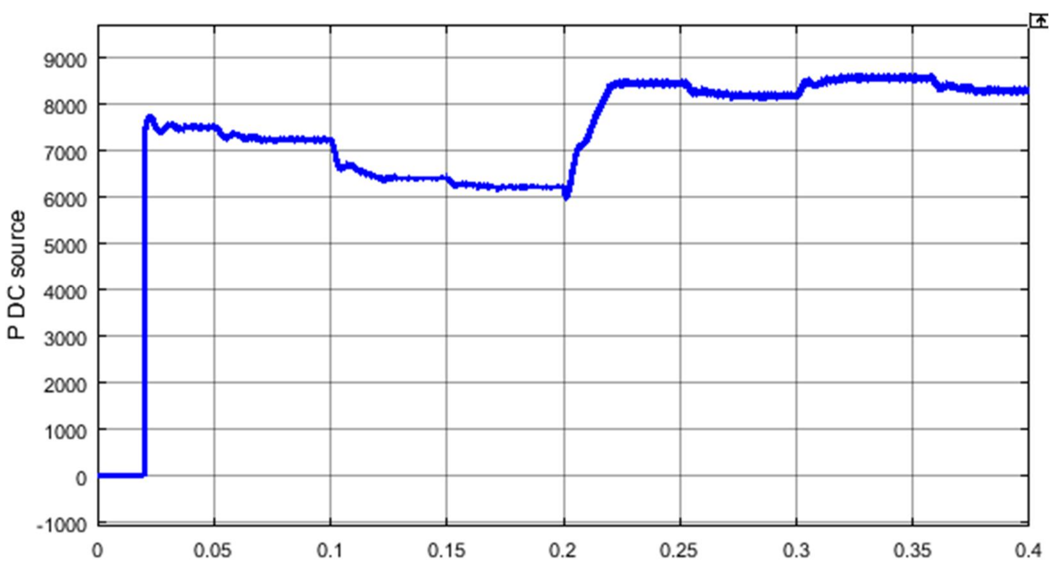

Fig .20 Power at PCC during charging state

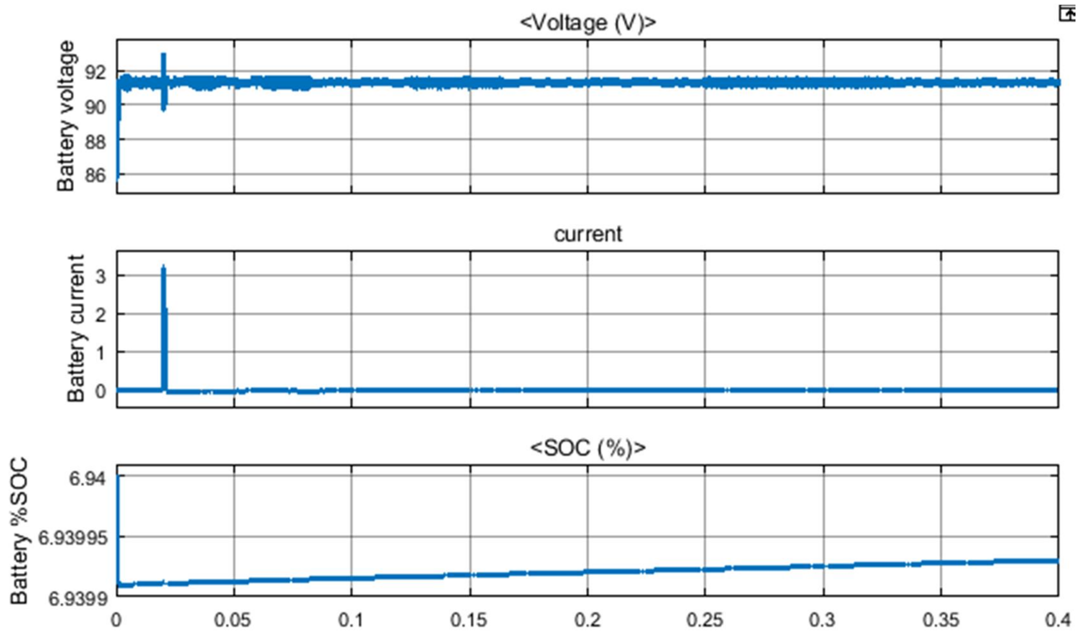

Fig .21 Battery characteristics during charging state

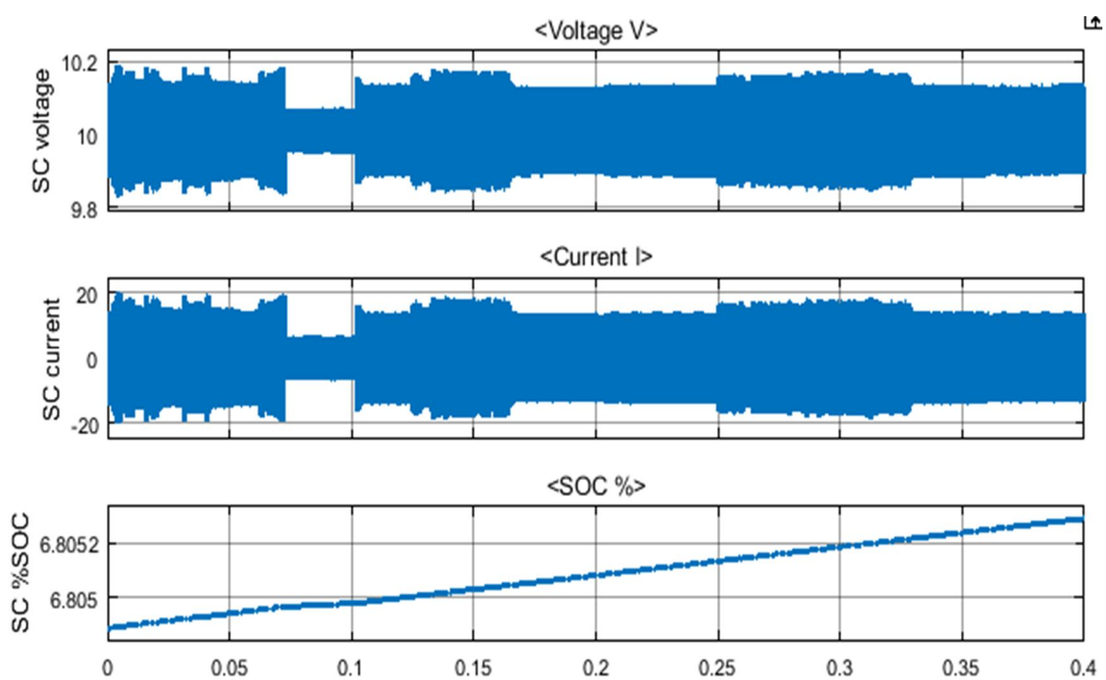

Fig .22 supercapacitor characteristics during charging state

VII. CONCLUSION

In this project work, we have implemented an MPPT with a P&O algorithm its main purpose is to maximize the output power of a PVA and improve PVA efficiency, and also we have used battery and supercapacitor banks, " energy storage devices" their main purpose is to supply load demand the variations in irradiation input of PVA and maintain stability of the system. From the above figures and graphs, all conditions with PVA are run with 0.4 simulation time. As per the charge and discharge characteristics of the battery and SC, the characteristics of the sources (PVA, Battery, and SC) are observed. The battery is set with two SOC modes (90% and 10%), where 90% SOC is considered to be discharge state and 10% SOC is considered as charge state. At all conditions of the system, the DC voltage at PCC is observed to be at around 255V , with minimum permissible variations because the input irrediations to PVA are also varied at t = 0.0, 0.1, 0.2, 0.3 respectively.

VIII. ACKNOWLEDGMENT

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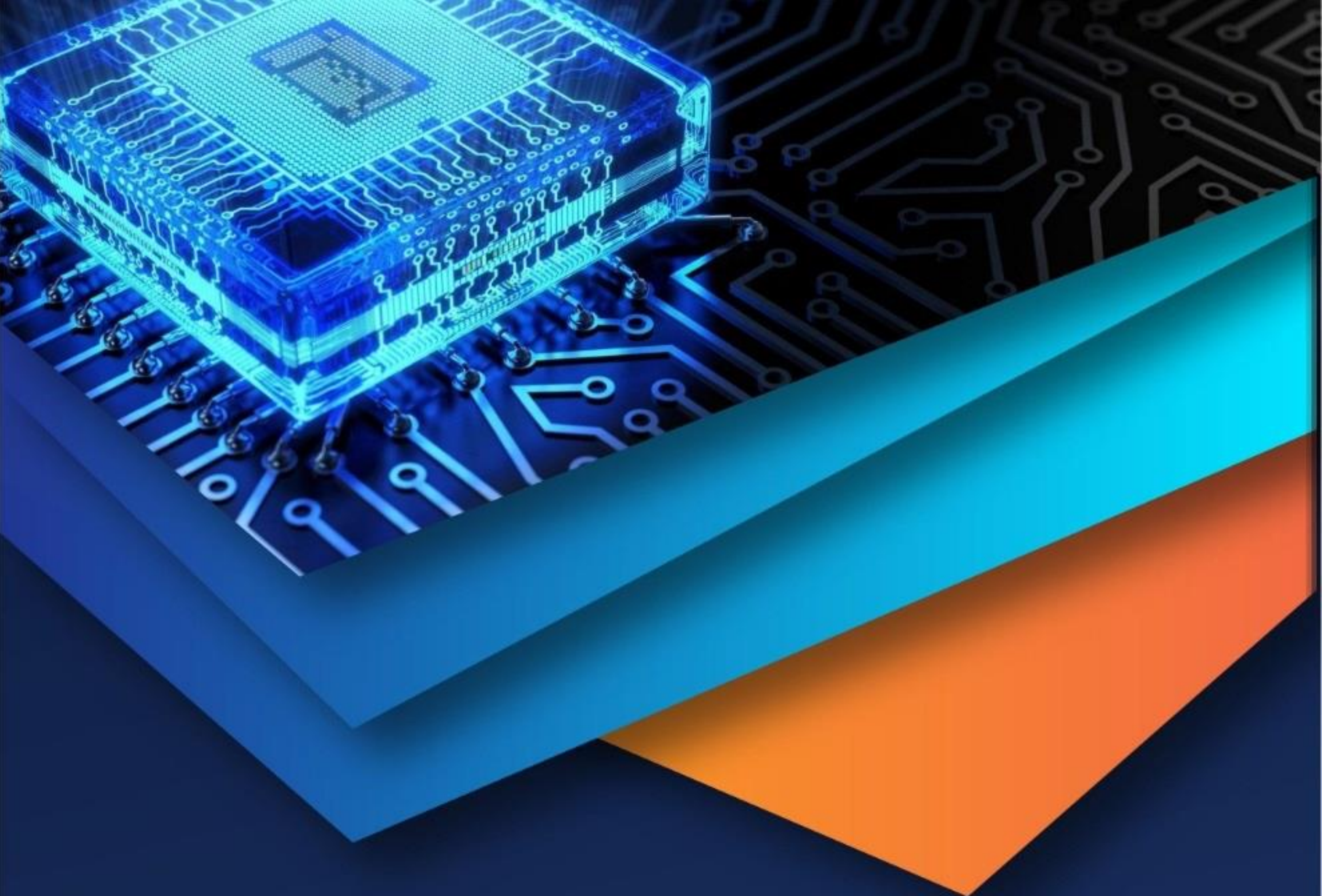

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