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Peak Power Shaving Through Grid Connected Pv Plants Using Partial Power Converter

S Lourdujame, A. Sahaya Ponrekha, Debanksh Mohanty, Aryan, Aman Kumar Srivastava
Assistant Professor, Dept. of Electrical and Electronics, SRM Institute of Science and Technology, Chennai, India
B. Tech, Electrical and Electronics, SRM Institute of science and technology, Chennai, India

***Abstract* - Energy management is one of the key tools that is used for proper planning, execution and operation of the distribution system. As day by day the energy requirement and consumption is increasing without the increase of the suitable generating capacity, it is difficult to meet the demand due to which there is blackout, grid frequency disturbances and bad power quality to the consumers. As the renewable sources of energy are added into the grid it is causing problems like harmonics, voltage imbalance due to improper scheduling. This makes difficult to balance the grid and creates complex situations. As the world is moving towards the renewable energy resources in which harnessing power from the solar is one of the most useful methods, but as these method has its own disadvantages like it's efficiency is low, not very reliable power cannot be extracted at any time. So to lessen the drawbacks and to have an effective energy management, this project gives a method to harness the solar power from the PV plant using a bidirectional partial power converter(PPC) integrated between an energy storage system(battery) and a Voltage source inverter connected to the grid. This project is used to provide peak shaving capability for energy management. In this project the excess energy that is generated from the PV power plant is stored in the battery through the converter circuit and when the excess energy is demanded from the grid is sent back through the converter and inverter to the grid, a control strategy to manage the power flow was designed for the power flow from the energy storage system to the grid and from PV to the energy storage system. This project was simulated in the MATLAB simulation and the results were verified with the hardware model of a small setup and the results obtained were promising**.

KeyWords: Energy Management, Harmonics, Peak Shaving, Solar Power

1.INTRODUCTION

In India, we are currently the third largest producer and consumer of electricity in the world, currently we have 367.28GW of electricity installed in our grid (as of 2019). And a country with a population of 1.3 Billion the demand of electricity is increasing day by day at a rate of 4.3% per year. India mainly depends upon the coal based power generation through the thermal power plants which acquire the share of 55.6% of the total power generation, but as these plants are not much efficient causing pollution and environmental threats world is moving towards renewable energy sources. Government has decided to step up it's maximum power demand from Solar Power Plants by 2030, Thus the use of clean energy is the main focus of the government. But using this renewable sources of energy has its own disadvantages also creating problems. These renewable sources of energy help in creating stand-alone, isolated grid or help in distributed generation of power, these sources can help in generating power with negligence fuel or resources cost.

1.1 Distributed generation

Recently, Distributed Generations(DG's) have been in more use and is receiving attention due to the use of renewable sources of energy, and is a great solution for the environmental and economic challenges faced today. DG's are defined as electric power generation directly connected to the load or the distribution grid, they range from a few KW to few MW in size, they also have a lower investments compared from erecting a large power plant. Since DG's are near to the load they have less transmission loss also, in a deregulated market it can sell its generated power to the grid.

Consequently, these points make distributed generation a competitive alternative to conventional power plants in supplying the increasing power demand. But as with every advantage there is also some disadvantages that have been confronted (renewable energy and grid interface challenges-)

1. Non-controllable variability
2. Partial unpredictability
3. Location dependency

Mostly the new renewables add recurrent behavior and high unpredictability to the electric markets, forcing other renewables and themselves to use new techniques to adopt new methods to minimize these losses. For that they are performing power curtailments, and/or having extra generating units working in parallel to compensate power, voltage and frequency variations. In order to handle the energy scenario now days Energy storage systems(ESS) are used which can be battery, fuel cells etc.

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1.2 Peak Power Shaving

Peak shaving is a process in which we reduce the energy purchase from the utility during the peak power demands hours, there are several ways in which we can peak shave the demand for instance we can turn off the non-essential loads, we can install solar and battery solutions that can assist with reducing the demands.

So in this project we are using the concept of peak power shaving technique for energy conservation and incorporating with the PV plants to make it more efficient and reliable and minimizing the losses that are occurring, we have a bidirectional partial power converter(PPC) which is used as an interface between a battery and a grid tied photovoltaic power plant(PV), it's control loop is designed and it works in two modes.

1.2 Project Overview

The PV plant is used to generate electricity from harnessing the solar power, battery is used to store the energy by flow of power from the converter circuit, and inverter is used to transmit the DC power to AC power into the grid. The two modes of operation are-

1. Mode 1-PV plant will supply Power directly to the load that is grid, and charge the battery to its rated SOC.
2. Mode 2-When there is the extra demand that's the grid requires more power battery will be ON and then the battery will supply Power to the load along with the PV plant. When the battery will dip below the cutoff SOC it will disconnect.

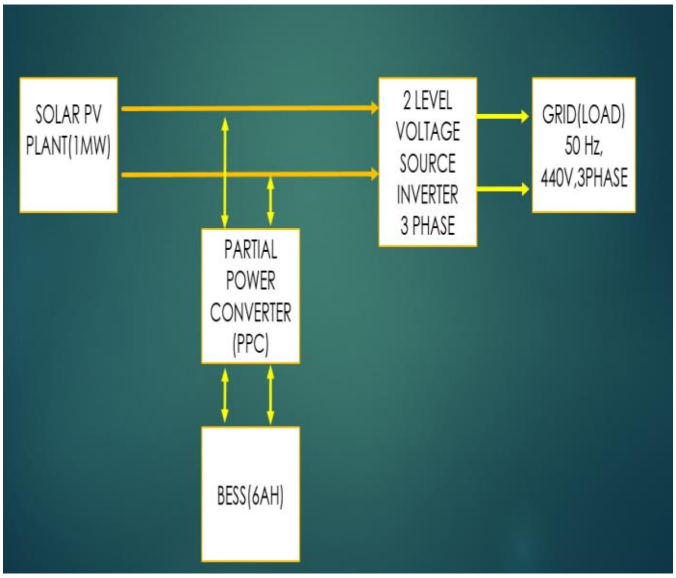

Fig -1: Project Overview block diagram

1.2 Proposed Plan

In the conventional grid connected PV plant, there is either a buck or a boost converter which converters the full PV voltage and is transferred to the inverter through a DC link capacitor to the grid but the efficiency is reduced in this method due to the losses in the converter circuits. Currently one more upgraded circuit is used in which transformer less converter circuit is used, but there is a danger of getting electrically shock while the maintenance of the PV due to the chances of creating a grounding path for the PV leakage capacitance.So for to overcome all of this drawbacks we are using a bidirectional partial power converter, it's specialty is that it uses only a partial power for the converting process and as it is bidirectional it can operate in both buck and boost mode. Which will reduce the uses of more number of converter circuit and bulky transformer and increases the efficiency.

2.PV POWER PLANT

A Solar Plant is any type of facility that harness solar power either directly, like the photovoltaics, or indirectly like the solar thermal power plants into electricity. Photovoltaic Power plants require huge amount of area for the photovoltaic cells, also called as the PV cells, which are used as to directly convert sunlight into usable electricity. These cells are made up of semiconductor materials like silicon alloys and are the technology that most people have become used to with.Any PV solar plant has the following basic criteria that it follows for basic structural components-

1. The solar panels which converts sunlight to electricity generates a direct current(DC) wit voltage up to 1500V.
2. The inverter setup that transforms direct current(DC) into alternating current(AC).
3. The control system that monitors and control the whole plant.
4. Finally, there is a external grid or a standalone power grid to which plant is connected.

Power systems that are used to generate power of more than 500KW or higher are usually accompanied with a step-up transformer for external connection to the grid.

1.2 Modelling and Power Calculation

There is a global formula that is used to estimate the electricity generated in the output of a solar photovoltaic system is

$$E = A * r * H * PR$$

E= Energy(Kwh)	10058
A= Total solar panel area(m2)	36
R= Solar panel Yield (%)	15
H= Annual average irradiation on tilted panels	2500
PR= Performance ratio, coefficient of losses	0.75
LOSSES DETAILS (PERCENTAGE%)-	5
Inverter Losses	
Temperature Losses	
Other Losses	

For the simulation in the matlab we have taken the values for the PV module as follows-

Maximum Power-	1MW
Open Circuit Voltage-	970V
Short circuit Current-	1327A
Maximum power Point Voltage-	796V
Maximum power point Current-	1256A
Module connected in series-	21
Strings connected in parallel-	140

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2.1 Maximum Power Point Tracking(P&O)

The output power of PV module depends on the various external parameters like solar irradiance, cell temperature and the output voltage of the PV module. Since PV module has nonlinear characteristics it is required to model and obtain a perfect control loop for the Maximum Power Point Tracking of the PV system application. There are already many methods for the MPPT calculations for the PV, some of them are Incremental method, Hill Climb method, successive addition method. The one we have used in our project is the P&O method known as the Perturb and Observe, it is the simplest method of the MMPT to implement. In this method only the voltage is measured and used as the reference value so it is common and easy to implement. In this method the power output of the system is varied by the varying supplied voltage. While on increasing the voltage, power seen also increases then further 'δ' is increased otherwise we start decreasing the 'δ'. Similarly, while decreasing voltage if power increases the duty cycle is decreased further till we reach negative deviation. These steps continue till maximum power point is reached. The exact voltage at which MPP is reached is known as reference point (Vref) and the PV is used to operate at that given condition.

2.2 Simulation Circuit of PV block and MPPT block

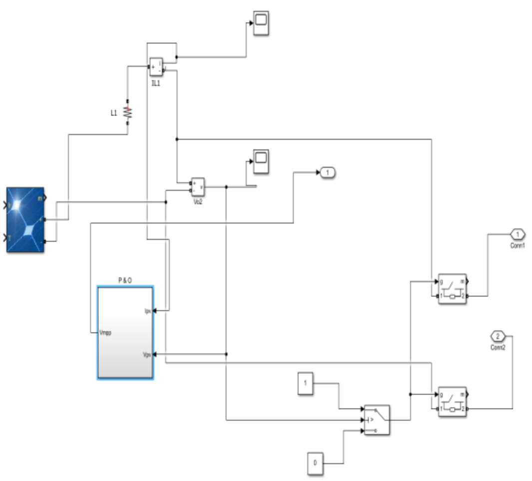

Fig -2: PV block

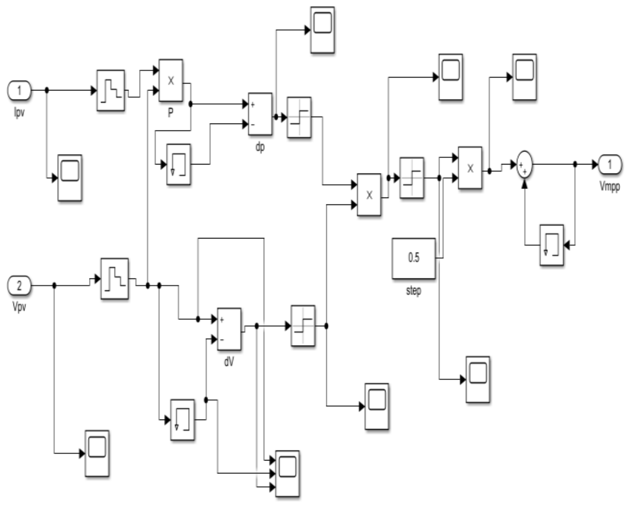

Fig -3: P&O MPPT block

3.ENERGY STORAGE SYSTEM

Energy storage system (ESS) is used in our system to deal with the generation demand mismatch. To overcome the problem of mismatch in the demand of the generation the best solution was to develop an energy storage system and connect it with the grid and use the same system in the case of surge in load. Here we have used a battery to store electrical energy, the energy produced during the low load period is stored in the energy storage system and this energy can be utilized during the increase in load.

We are using lead- acid battery in our project, which is of rating 12V,6Ah rating which is used to store the energy that is generated by the PV plant and the surplus power that is obtained from the grid. Charge controller is there to monitor the battery operating conditions. In the project we have designed a control loop which sets into action according to the SOC of the battery. As shown in fig 4.

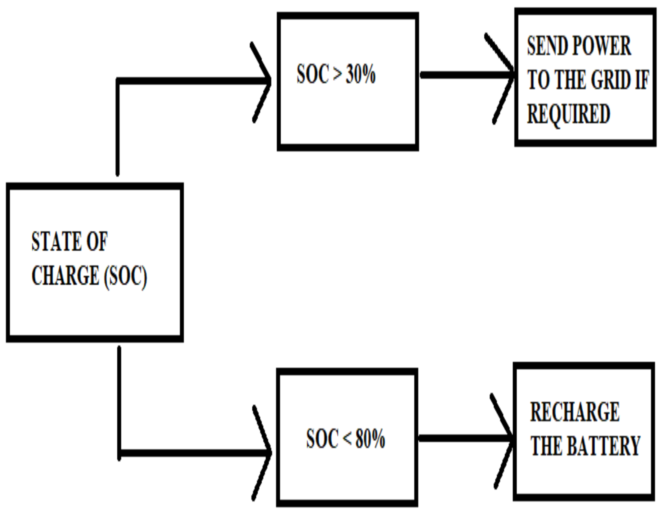

Fig. - 4 Battery Control Loop

3.1 Battery Energy Calculation

Required no of batteries-

Suppose we are going to install 100Ah, 12V batteries

$$12V * 100Ah = 1200Wh$$

Now for one battery (i.e. the backup time of one battery)

$$\left(\frac{1200Wh}{800W}\right) = 1.5\ Hours$$

Calculating the backup hours of batteries

$$1200Wh * 2\ Batteries = 2400Wh$$

$$\left(\frac{2400Wh}{800W}\right) = 3\ Hours$$

We will connect the batteries in parallel, because the voltage of batteries that is 12V remains same, while its Ah (Ampere Hour) rating will be increased i.e. the system would become= 12V and 100Ah+100Ah= 200Ah.

Charging time required for the battery formula is

$$charging\ time\ of\ battery = ((battery\ Ah)/(charging\ current))$$

For example, for a single 12V, 100Ah battery, the charging time will be

$$T = \left(\frac{Ah}{h}\right) = \left(\frac{100Ah}{10A}\right) = 10\ hours\ (ideal\ case)$$

Due to some losses, (it has been noted that 40% of losses occurred during the battery charging), this way we take 10-12A charging current instead of 10A, this way the charging time required for a 12V,100Ah battery would be,

$$100Ah * \left(\frac{40}{100}\right) = 40(100Ah * 40\%\ of\ losses)$$

The battery rating would be 100Ah + 40Ah= 140Ah (100Ah + losses)

Now the required charging current for the battery would be,

$$\left(\frac{140\ Ah}{12A}\right) = 11.6\ Hours$$

3.2 Simulation Circuit of Battery and its control

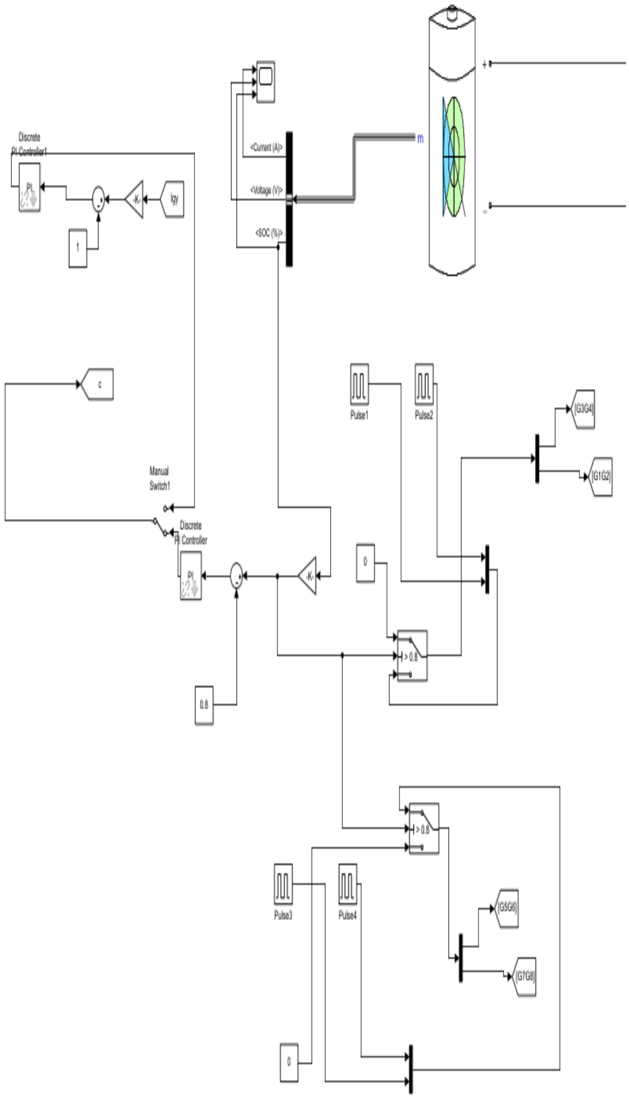

Fig -5: Battery circuit and control loop

4.BIDIRECTIONAL PARTIAL POWER CONVERTER

Partial power converter is a type of power converter in which the output power converted is less then the input power. The relationship between the output power and input power is termed as partial power ratio (kpr), it can be defined as the ratio of the power processed to the input power processed. Commonly used DC-DC converters topologies used for PV power plants consists of two stage conversion and the applications are based on high frequency isolated full bridge converters, in some cases operating as a resonant converter. There is drawback working with them there is a circulating current produced by the stored energy in the magnetization inductance which decrease the

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efficiency of the DC-DC converter this effect is mitigated with the PPC configurations, since the DC-DC converter is handling a small portion of the total power due to which it's losses are less and efficiency is more. From the conventional full power converter, partial power converter is emerging technology as it processes K times power (Kpr=Ppc/Ppv), this helps in reducing the converter losses.

$$Kpr = Ppc/Ppv$$

Parameter	PPC	FPC
Input power(W)	275	275
Processed Power(W)	226.9	275
Power Ratio (%)	82.51	100
Efficiency (%)	97.6	97.1

4.1 Modes of operation of converter

The partial power converter designed in the project works in two modes one is step-up mode and the other is step down mode. When the power is transferred from the PV panels to the battery the it works in the step-down mode while when is transferred from the battery towards the grid it works in the step-up mode. These two modes can be seen in the figure below in Fig-6, Fig-7

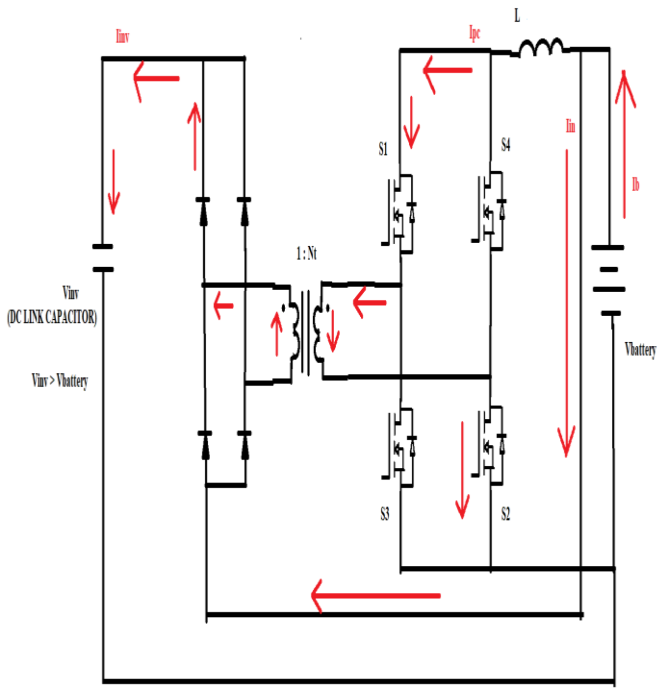

Fig -6: Step down mode of operation

4.2 Simulation Circuit of PPC

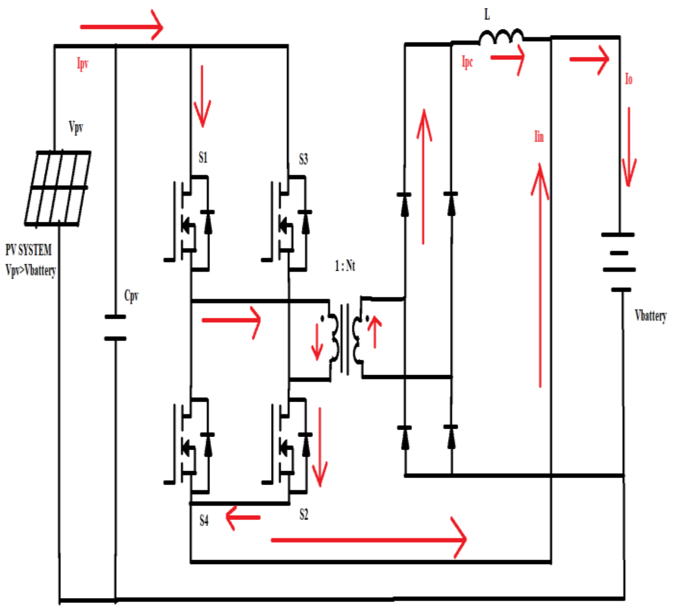

Fig -7: Step Up mode of operation

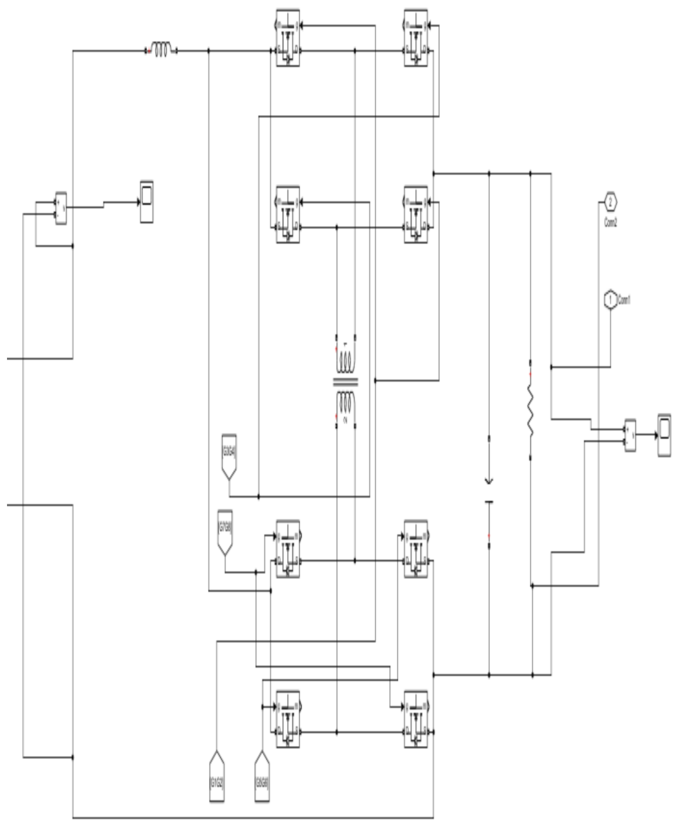

Fig -8: Bidirectional PPC matlab Circuit

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5.VOLTAGE SOURCE INVERTER AND GRID CONTROL

AC power is used in almost all the residential, commercial and industrial needs. But it has one big drawback i.e. AC cannot be stored. So it has to be converted into DC and then from DC it has to be stored into the batteries and ultra-capacitors. And whenever we need AC, DC is converted back to AC to run the AC based Appliances. So the device which converts DC into AC is called Inverter.
We have used a two Level Voltage source inverter in the project, the two level VSC is preferentially used in variable speed drives and wind turbine applications. The advantage that we get from this inverter is simple design and the possibility of building similar strings of series connected switching devices. The basic working principle is shown below, each switch has to block direct full voltage and two level of voltages is obtained (+Vdc and –Vdvc). Due to the large capacitance connected in parallel in the input side, the voltage is constant so it's called voltage source inverter.

2 Level Voltage Source Inverter

PV 2lvsi dc-link capacitance	4400uF
PV inverter dc-link voltage	740-1000V
Grid voltage	440 V_{LL} RMS
Grid voltage	0.25 mH
Grid voltage	50 Hz
Switching frequency	50 KHz

5.1 PV to Grid Power flow

We have injected the DC power that is generated from the PV into the grid for that we use a 3phase voltage source inverter, we always control the value of current that we are injecting into the grid, so we build up a voltage source with an inductor in series to control the value of current and limit the circulating current. In general, the power that is generated from the PV is first of all passed through a DC-DC converter which can be either buck or boost as per the ratings of the PV, then it is passed through a unfolding circuit that can be a inverter and at last it is passed from the transformer to the grid Steps for Grid Connection
The overall process including the following:

a. Measure the DC voltage from the array side
b. Measure voltage and current from the grid side and convert it into direct axis and quadrature axis components.

Generate current reference using the array side voltage and reference DC voltage.

5.2 Three Phase grid Connection

We have a PV module which is connected with a inverter, then trough a transformer connected to the grid, in the grid through a hall sensor or current sensing and voltage sensing element we are measuring the actual grid current and voltages values, these values are compared from the reference values that are obtained from the MPPT block by passing the values from the PV, we get three values of currents at each 120 degree phase difference, with a comparator we compare these reference grid values to the actual grid values and pass it to the PWM block which generates the input for the gate drive circuit which generates the gate pulses which drive the inverter and the whole control loop is made In the three phase circuit we are sensing the values of current i_a, i_b, i_c and the value of grid voltages v_a ,v_b, v_c with the help of the hall sensors and then with the help of the dq transformation theory we are changing it to a two phase system. As shown in the fig10 below, we are taking i_a, i_b, i_c and transforming them to i_α, i_β and then into i_d,i_q. for the value of ρ we are using a separate transformation in which the voltages references are used as the ρ is the angle between the αβ and the dq axis so when taking the voltage as the reference it creates the quadrature component of the voltage to zero which makes it simpler.
From the PV panel output we sense the value of the v_t and i_t which is send into the MPPT block and from the P&O MPPT technique we receive a reference current i_d^* which is then compare with i_d and passed through a PI controller and as i_q^* is zero as the quadrature voltage is zero, then we can directly pass it through the reverse dq transformation to PWM generator block and from the SVPWM technique we can generate signals for the gate driving circuit, after the gate driving circuit generates the gate pulses for the inverter triggering circuit we get an synchronized operation of the inverter as the power is flown to the grid, while using the voltages value as the reference of grid for calculation of the ρ, we have ensure phase locked loop(PLL) which ensures from the present harmonics and the disturbances of the noise that occurs and give more stability and reliability to the system.

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4.2 Simulation Circuit of Inverter And Control loop

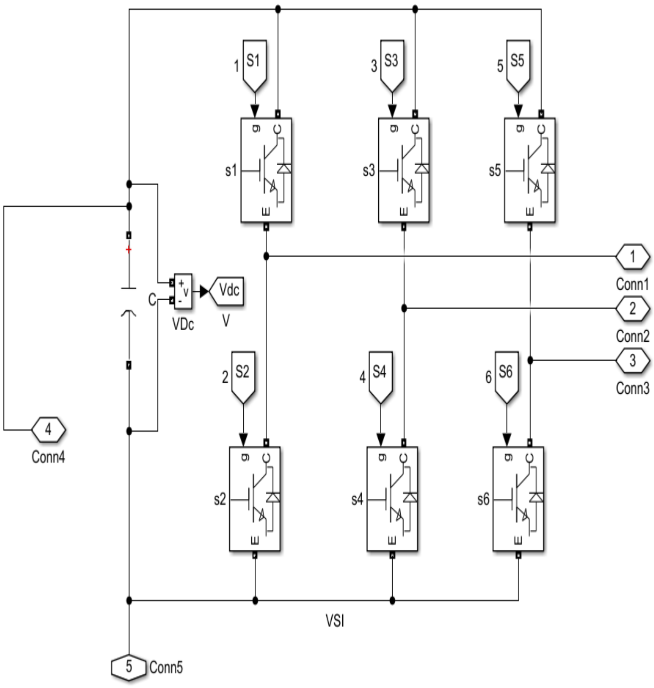

Fig -9: Inverter circuit

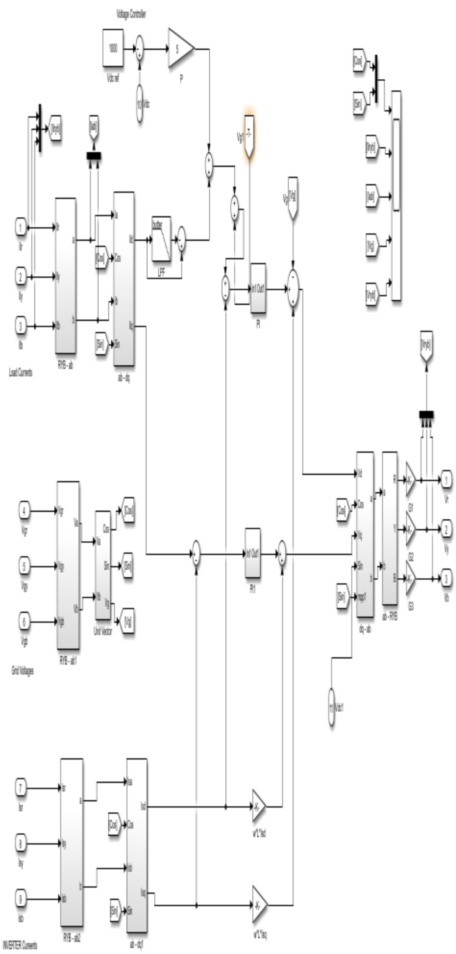

Fig- 10 Control Circuit

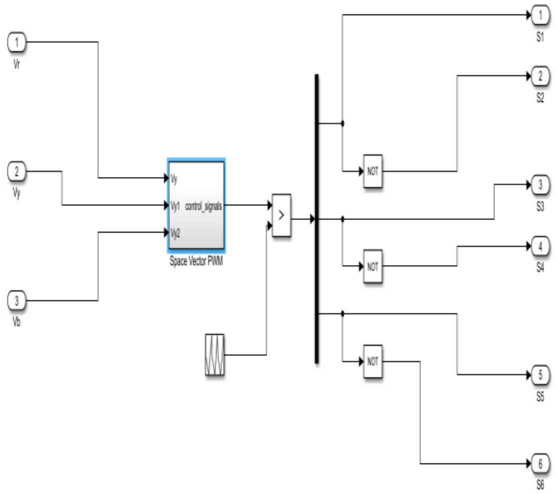

Fig- 11 PWM Block

6.RESULT AND GRAPHS

From the simulation these can be seen that the PV panel MPPT is working optimal as the load was constant at the initial period so the it was balanced at the 795V value but when there was a sudden increases of demand than the new maximum voltage has been changed and it can be inferred from the graph as the new V_{dc} is changing. It is seen as when the battery is below its rated SOC it charges and as the load is increased the battery starts to supply power towards the grid and the battery starts to discharge and the energy stored in the battery goes down. And the bidirectional partial power converter can be seen working both in step up and step down mode and it can be seen that when there was only a slight load the current that was drawn was in the range of 200A-500A but as there was a increase in demand the current surge has been seen due to which the requirement of current increased at once to the range above 2000A, which was sensed by the control loop and as the load increased from the predefined value the new voltage level of MPPT changed and the battery was made into action to surge the demand and maintain the grid voltage level and frequency, as seen in the voltage graph there is very negligence deviation from the grid voltage and the current increased due to the load increased.

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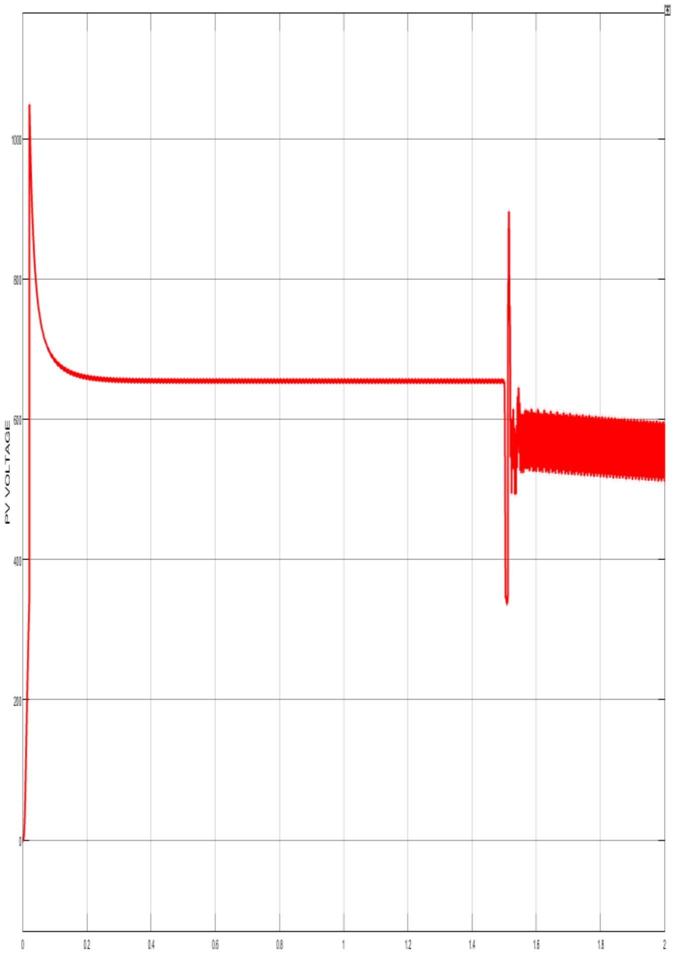

Fig 12 PV voltage output V_{dc} at nearly 795V

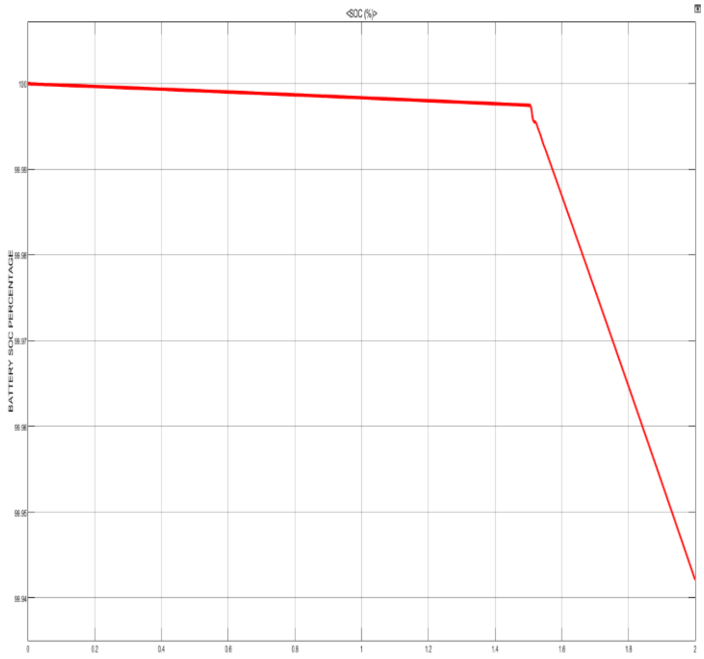

Fig-13 Battery discharging as load increased

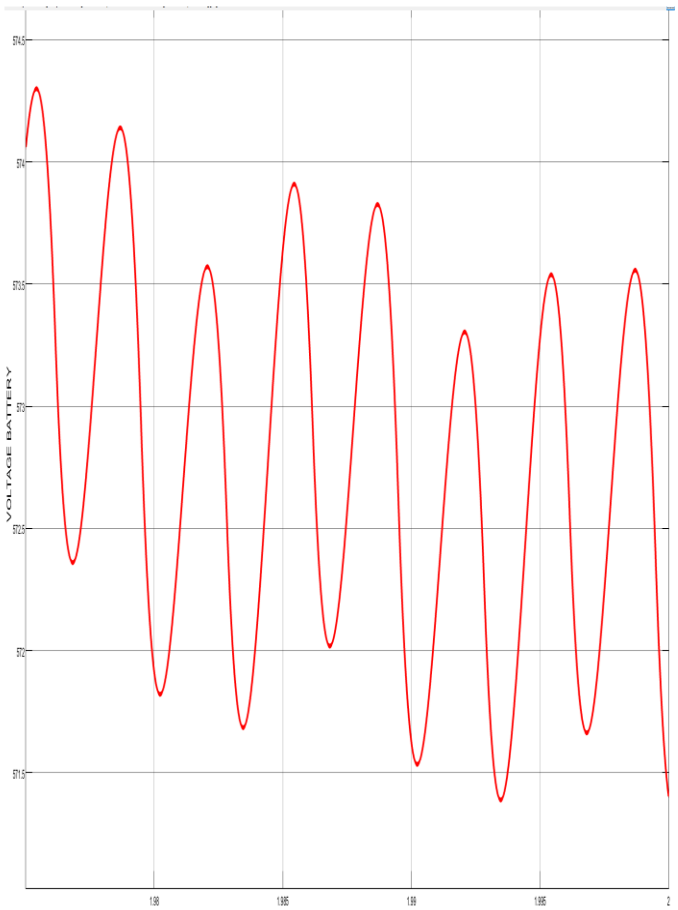

Fig-14 Output of partial power converter while working as a boost mode ESS side

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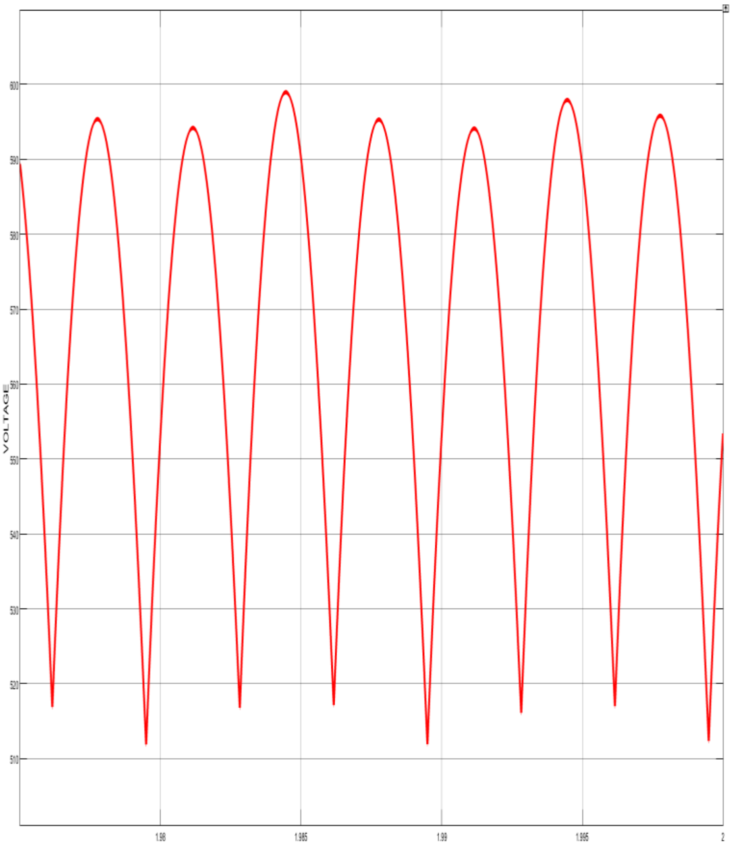

Fig-15 Output of partial power converter while working as a boost mode inverter DC link side

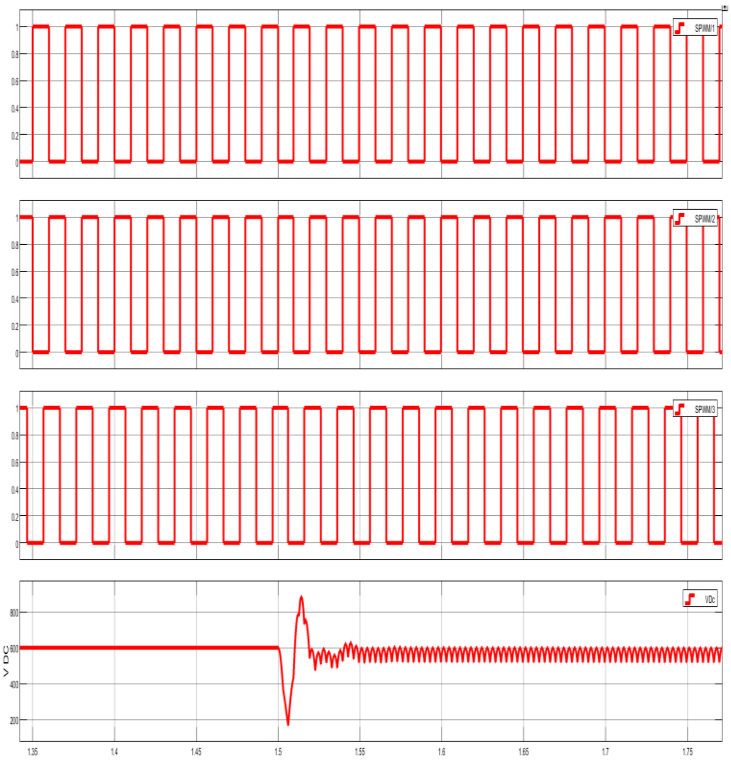

Fig-16 Switching Of Inverter

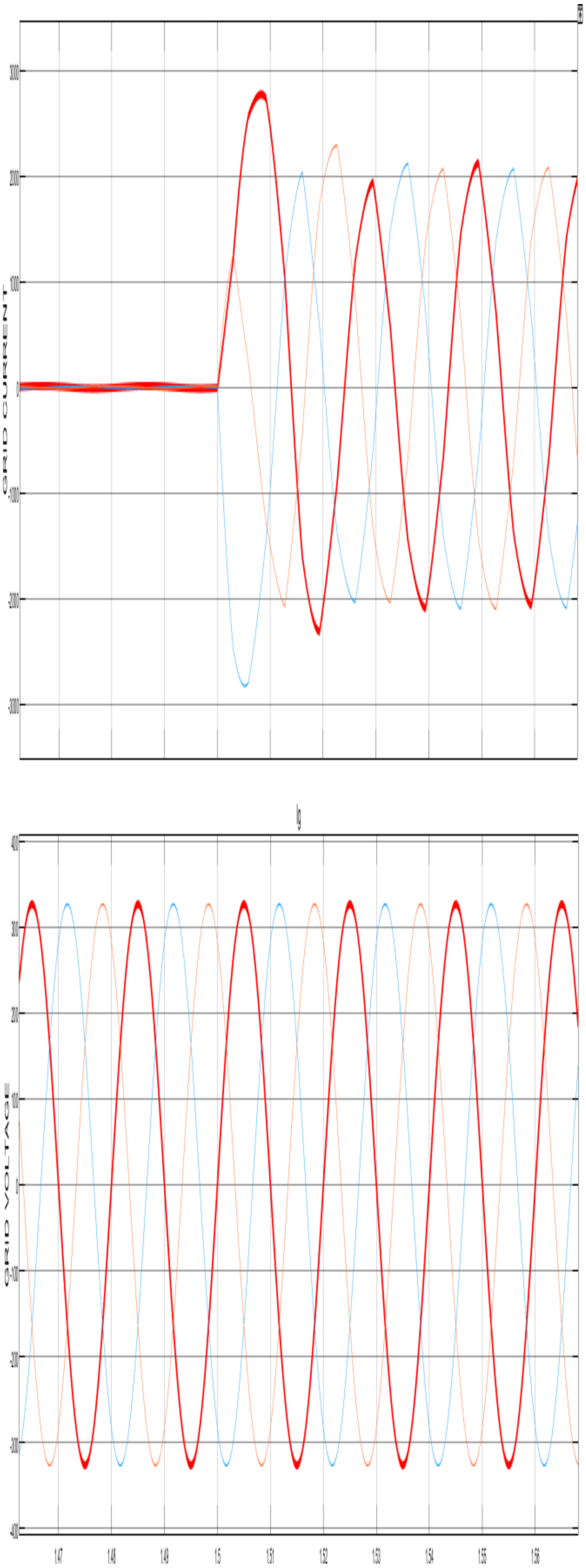

Fig- 17 Grid Voltage and Current with respect to time

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7.CONCLUSION

Energy management is the uttermost need of the present time, there are lots of losses caused due to burden of extra equipment's present in the system and in PV where in the first place the power that is produced is not at a good efficient rate so we have to transmit this generated power at a most efficient manner that can be possible, so we have to reduce the losses that is caused by the burden of the inverter, converter and energy storage system and we have to also to focus on the energy management in the grid so that the grid does not destabilize at the time of maximum peak demand and we can supply power. We in this project have tried to reduce the losses of equipment's by using a bidirectional partial power converter, and to reduce the maximum demand at peak load we have also incorporated energy storage system like the battery. We cannot complete support the sudden load for large extent of time as due to the battery constraint, but we can support the power flow till the backup come into action in this project we have tried to this by designing a control loop for the battery and used a bidirectional partial power converter which can work in both buck and boost and allow to store the charge in the battery from buck mode, and give it back to the grid in boost mode. This project helped to minimize the loss as well as help in peak shaving of the load at the maximum demand occurs.

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