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REACTIVE POWER COMPENSATION BASED INVERTER CONTROL FOR A GRID-CONNECTED SOLAR PV SYSTEM

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Abstract: The purpose of this study is to optimize the management of reactive power in grid-connected solar photovoltaic (PV) systems by utilizing the STATCOM(Static Synchronous Compensator) and SVC's (Static Var Compensator) capabilities. Its overall goals cover a number of crucial areas.By reducing voltage fluctuations and service disruptions, the project aims to greatly improve power quality. Voltage stability is also crucial, and the control algorithms have been carefully built to keep grid voltages within acceptable limits while still ensuring dependable operation.Additionally, strict adherence to grid regulations and standards is crucial for expediting the grid integration process and meeting regulatory requirements like power factor caps and voltage range restrictions.The grid optimization of renewable energy integration, especially solar PV, is a crucial goal. In order to maximize efficiency and work in harmony with grid dynamics, this includes minimizing losses and transferring as much energy as possible. In conclusion, our research aims to design a grid-connected PV system that is more dependable, effective, and sustainable, supporting the worldwide shift towards cleaner and more sustainable energy paradigms.In order to demonstrate the benefits of the current controller for efficient utilization of inverter rating according to changes in irradiance, simulation results are shown.

Keywords **- Reactive power management, Grid-connected solar PV systems, STATCOM, SVC, Power quality improvement, Voltage stability, Grid regulations, Renewable energy integration, Efficiency optimization, Sustainable energy.**

I. INTRODUCTION

The world's transition to renewable energy, especially solar photovoltaic (PV) systems, is altering the energy landscape. Although solar photovoltaic energy (PV) offers a sustainable energy source, its smooth integration into current networks poses complicated difficulties, particularly with regard to the control of reactive power. Despite not being immediately used, reactive power is essential for maintaining the stability of the grid and the quality of the electricity. This work adopts a targeted method to address these issues by presenting an innovative control technique that makes advantage of the STATCOM and SVC's (Static Var Compensator) capabilities.The main goals of this study include several aspects. First, it employs a sophisticated control method to improve power quality. The goal of this strategy is to manage reactive power as efficiently as possible, which will lower voltage fluctuations and improve the overall dependability and quality of electrical services. The suggested control algorithms, driven by STATCOM and SVC, are painstakingly designed to manage and stabilize grid voltages within allowable ranges. Voltage stability is a key problem in grid operations. By preventing problems like voltage sags and swells, this enables the reliable and constant operation of electrical equipment that is connected to one another.Additionally, this study is firmly devoted to following the recognized grid codes and standards. This commitment is necessary for the planned control approach to be seamlessly included into the grid architecture. It adheres to regulatory requirements including power factor caps and voltage range restrictions. Last but not least, the study emphasizes on the incorporation of renewable energy sources, notably solar PV systems. The control mechanisms need to be precisely calibrated in order to realize the full potential of renewable energy. The research places a strong emphasis on maximizing energy flow to the grid while also minimizing losses. This strategy promotes a more grid-friendly and sustainable energy future by improving the integration of renewable energy while also ensuring that it works in harmony with grid operations.

II. DESCRIPTION OF MODEL

A) Elements in grid connected PV system

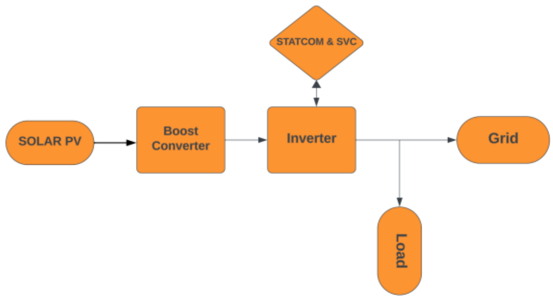

Fig. 1: Grid & load connected PV system block diagram

A grid-connected solar PV (photovoltaic) system is made up of many essential parts that cooperate to produce energy from sunshine and feed it into the power grid. The essential elements are as follows:

1) Photovoltaic (or solar) panels:

Multiple photovoltaic cells comprised of semiconductor materials, mainly silicon, make up solar panels. Through the photovoltaic effect, these cells absorb sunlight and produce direct current (DC) power.Figure (2) shows the equivalent circuit of a PV, from which non linear I-V characteristic can be deduced.To shield the photovoltaic cells from external elements like rain, dust, and debris, solar panels are encased in robust frames with tempered glass coverings.Arrays of solar panels are set up to gather energy as much as possible. Arrays can be incorporated into the design of buildings or put on roofs or ground-based racks.Based on how well they are able to produce power from sunshine, solar panels are graded.

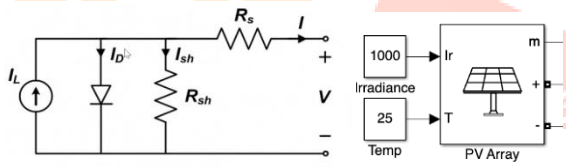

Fig. 2. Equivalent circuit of photovoltaic cell & PV array

2) Boost Converter:

The Reactive power Compensation Based Inverter Control for a Grid-Connected Solar PV System, which includes the Boost Converter with MPPT P&O Algorithm, is crucial for maximizing the production of solar electricity,which is shown in fig3. By accurately detecting the maximum power point (MPPT), it increases the DC power output from solar panels while assuring successful energy conversion. This system ensures reliable grid integration and adherence to grid codes when used in conjunction with Static Synchronous Compensator (STATCOM) and Static Var Compensator (SVC). While SVC fine-tunes the inductive or capacitive power, STATCOM quickly adjusts reactive power injection to reduce voltage swings, thus boosting voltage stability. Together, they enable solar power generation that is consistent and efficient while still complying to grid norms, ushering in a more sustainable and environmentally friendly energy model.

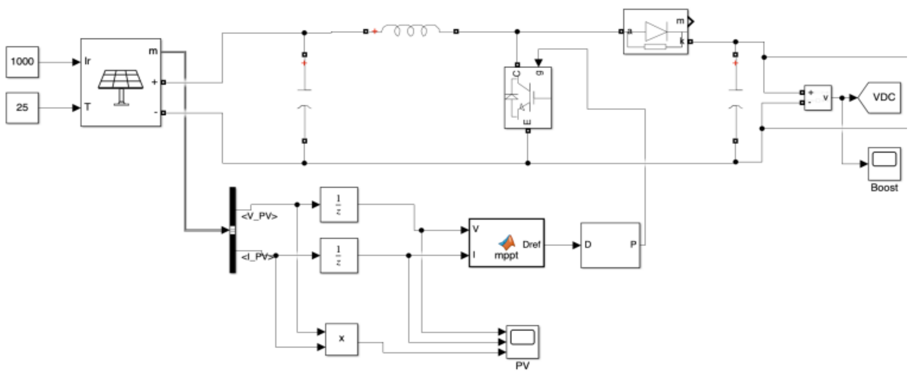

Fig. 3. Boost Converter Circuit with MPPT Algorithm

3) Inverter:

The inverter, commonly referred to as a universal bridge, is a crucial part of Reactive Power Compensation Based Inverter Control for a Grid-Connected Solar PV System employing STATCOM and SVC. It completes the crucial work of converting the direct current (DC) power produced by solar photovoltaic (PV) panels into alternating current (AC) electricity, which is appropriate for the electrical grid. This inverter works with STATCOM and SVC to control reactive power in addition to regulating voltage and synchronizing the PV system with the grid. As a result, the efficiency and dependability of the grid-connected solar PV system are increased. It is crucial in ensuring that the electricity injected into the grid is within the necessary limits.The inverter is a key component in the project's success since it has safeguards and control features to ensure secure and effective energy transmission while adhering to grid regulations.

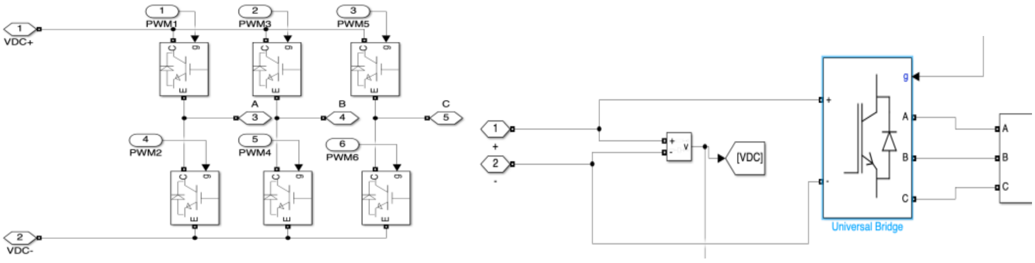

Fig. 4. Three phase Inverter & Universal Bridge

4) Load:

Loads in a grid-connected solar PV system are electrical devices such as homes, businesses, and industries that consume electricity produced by the PV system. Managing these loads is essential to maintain voltage stability and power quality within acceptable limits.

5) Grid:

The electrical power distribution network that links different energy sources, including solar PV systems, to consumers is referred to as the grid Its job is to reliably and effectively distribute power. Effective control mechanisms are crucial to guarantee the seamless integration of solar energy while preserving grid stability and power quality in this environment, where the grid acts as the injection platform for solar power. By managing voltage stability and guaranteeing grid compliance, reactive power compensation makes sure the grid can effectively handle the fluctuating power production from solar PV installations.

III. PROPOSED METHODOLOGY

The following components make up the bulk of the system:

Solar radiation is converted into dc voltage and current by a photovoltaic array, and a DC-DC boost converter tracks the array's highest power point by using the (P&O) method. In order to interface with the grid or to power a local load, a three-phase inverter converts the DC voltage to AC .

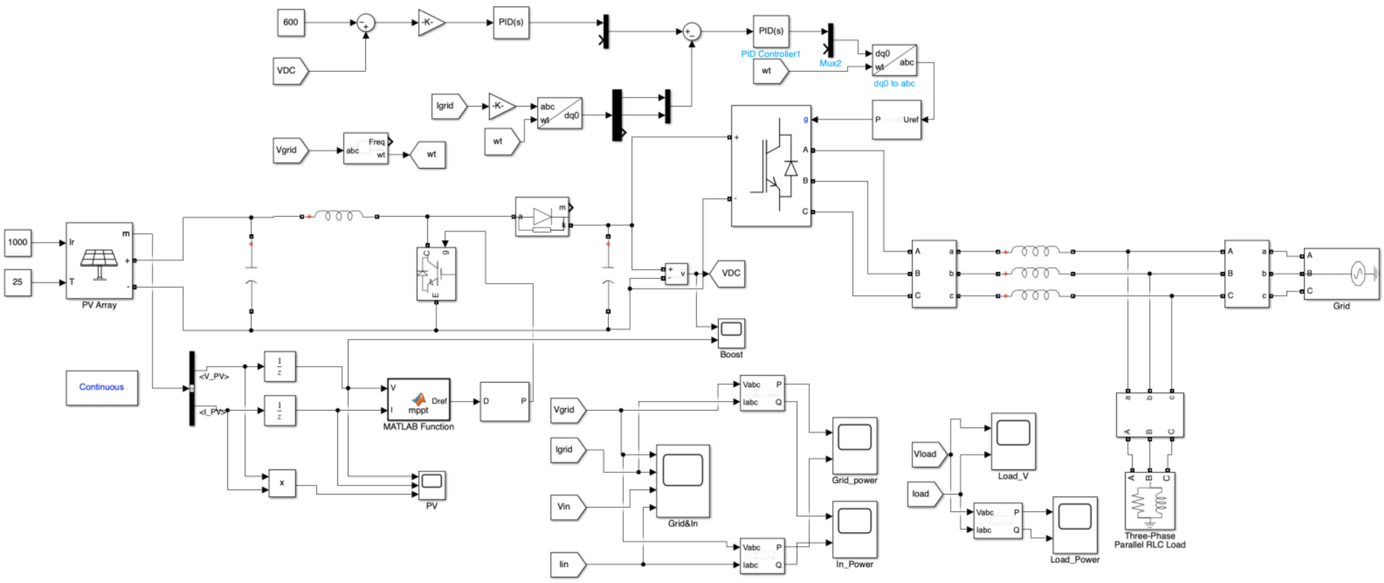

Fig. 5. MATLAB Model of Grid connected PV

A) MPPT Algorithm:

The MPPT Perturb and Observe (P&O) algorithm is a widely used method in solar PV systems. It continually adjusts the system's operating parameters to find the maximum power point (MPP) by perturbing and observing changes in power output. While simple and adaptable, it may oscillate in rapidly changing conditions and has limitations in partial shading or non-well-defined MPP scenarios. Nonetheless, it's cost-effective and versatile for optimizing energy harvesting.

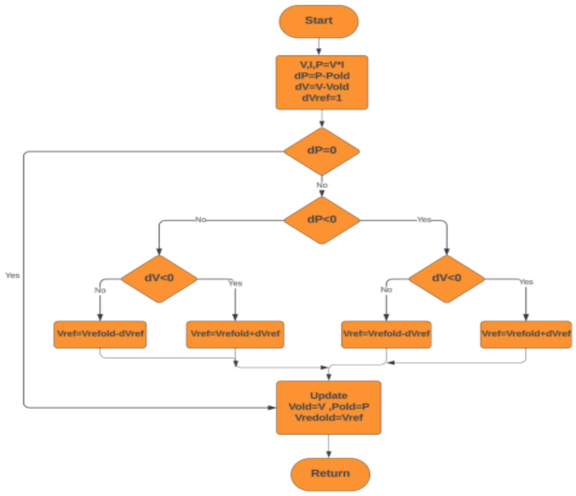

Fig. 6. Flowchart of MPPT P&O algorithm

B) Inverter Control Strategy:

The control strategy is crucial in determining how the solar PV system interacts with the grid, controls reactive power, and makes sure that it operates in an effective, dependable, and legal manner.

- Voltage control is essential for preserving the stability of the grid and making sure that linked equipment runs within the permitted voltage ranges.In order to keep grid voltage levels within acceptable bounds, control algorithms continually monitor grid voltage levels and modify the output of the solar PV system. safeguards against voltage sags, swells, and fluctuations, guaranteeing stable and trustworthy functioning of electrical equipment.
- For grid stability and effective power transmission, reactive power must be managed.Power factor adjustment and voltage stability are ensured by real-time control algorithms that direct devices like STATCOM and SVC to inject or absorb reactive power as necessary.maintains voltage stability, makes power factor corrections, and reduces reactive power losses to improve system performance as a whole.

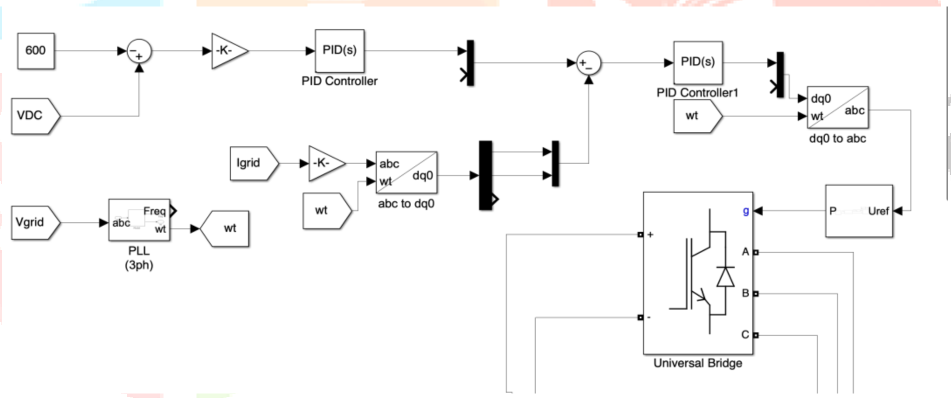

Fig. 6. Inverter Controller Circuit

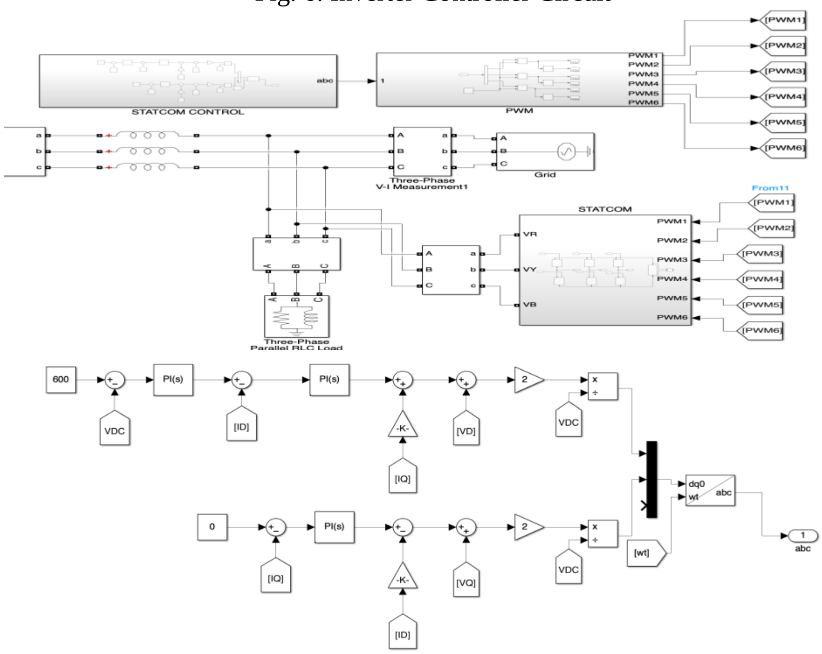

Fig.7 . STATCOM & SVC Controller Circuit

C) Calculations for Grid connected PV:

1) RLC calculations for boost converter:

P=3000580;
Vin=383.5;
fs=10e3;
Vout=600;
Ioutmax=P/Vout;
delIL=0.01*Ioutmax*(Vout/Vin);%%ripple inductor
delvout=0.01*Vout;
L=(Vin*(Vout-Vin))/(delIL*fs*Vout)
C=(Ioutmax*(1-(Vin/Vout)))/(fs*delvout)
R=Vout/Ioutmax
d=(Vout-Vin)/Vout

2)Harmonic filter calculations in grid side:

S=3000580;
Vdc=600;
Vac=400;
delip=0.005*(S/Vac)
ma=Vac*sqrt(2)/Vdc
fsw=10e3
L=(2/3)*((ma*Vdc*(1-ma))/(delip*2*fsw))

IV. RESULTS AND DISCUSSION

The below fig.8 shows the full MATLAB simulink model of the Reactive power compensation based inverter control for grid connected PV system.

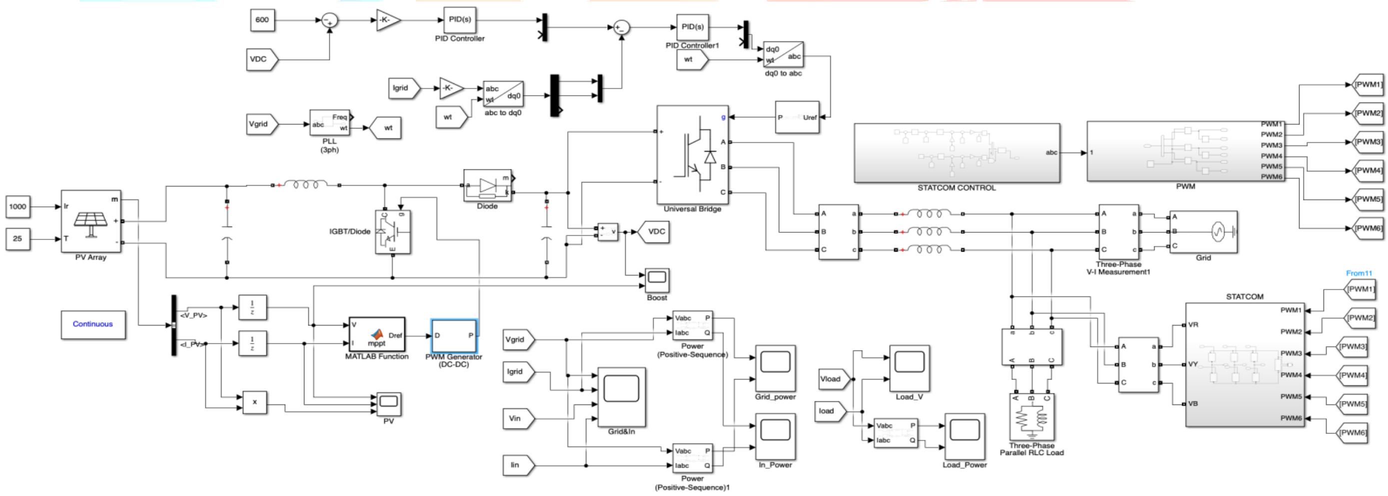

Fig. 8: Circuit model of Grid connected PV system

A) Solar PV Characteristics:

From Fig.9 we can observe that at an irradiance of 1000 W/m2 current (I) is 7824.2 A and voltage (V) is 383.5V for the maximum power (P) of 3 MW.We can also observe voltage readings for different power(P) and current(I).

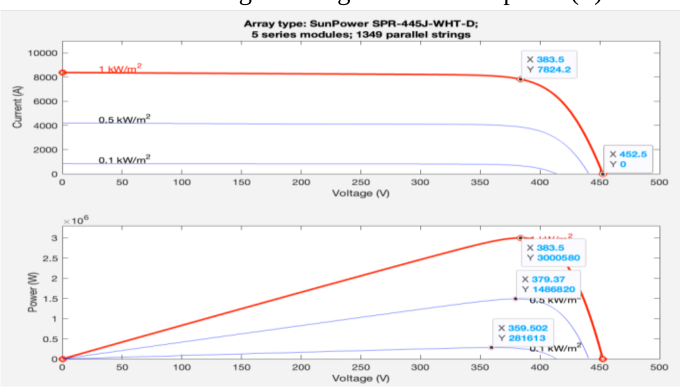

Fig. 9. I-V characteristics and P-V characteristics of Solar PV array with different irradiance conditions

B) System Simulation:

From Fig.10 we can observe that at an irradiance of 1000 W/m2 , the current(I) is around 7500-8000A , Voltage is around 350-400V and the power is maintained at 3MW.

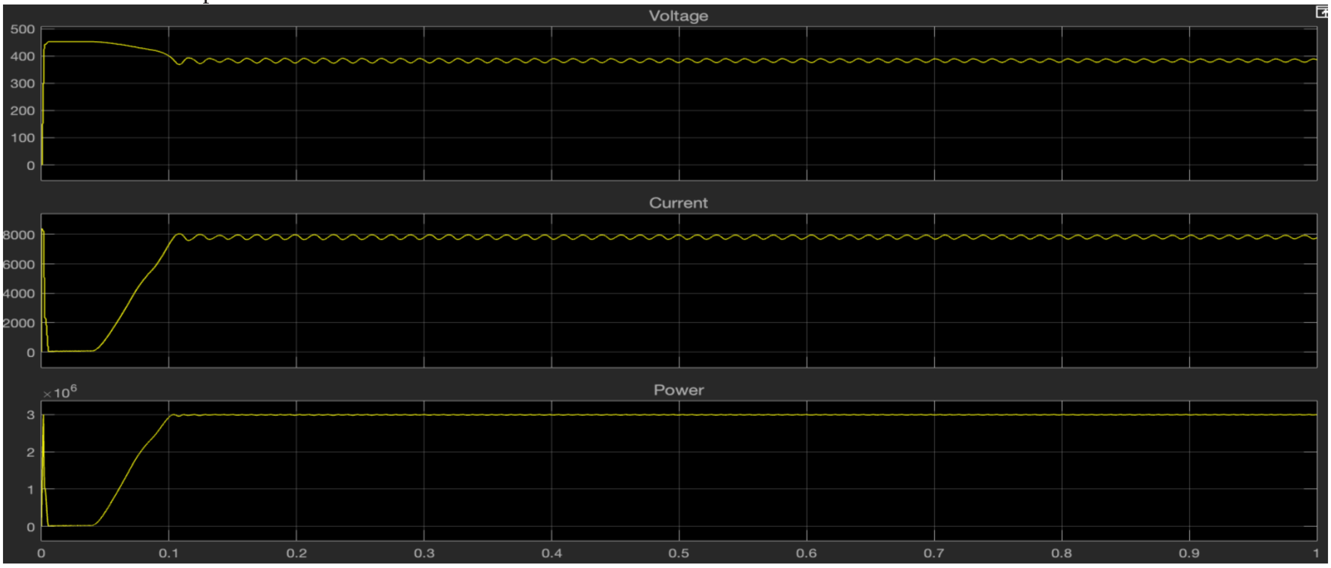

Fig. 10. Solar Voltage,Current & Power at 1000 W/m2 Irradiance

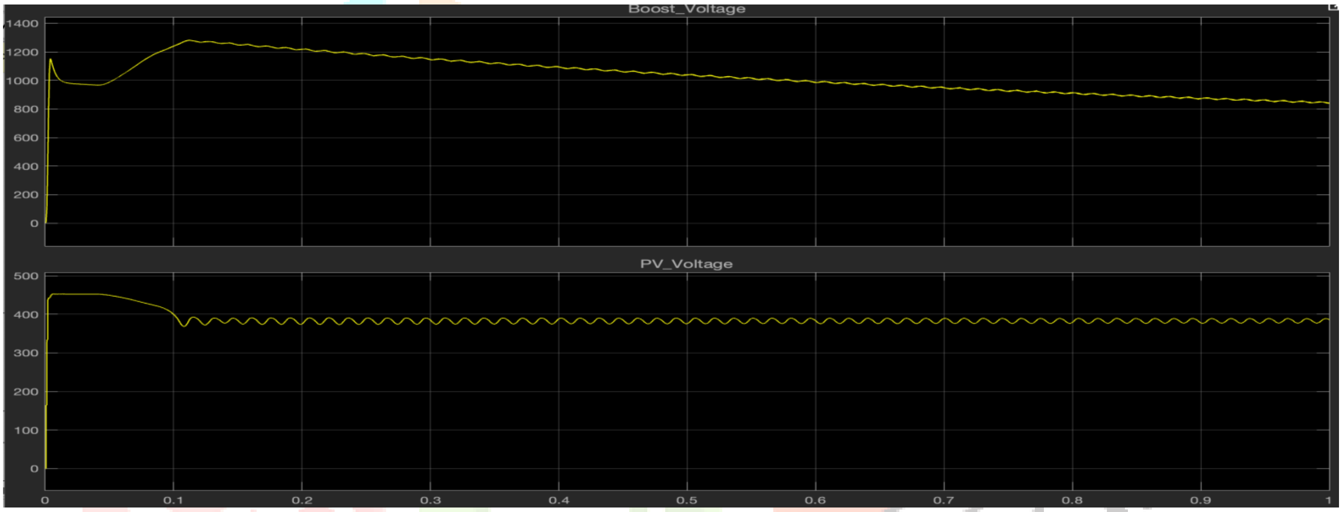

Fig. 11. Output of Boost converter & PV voltage

The output of the boost converter is shown in Fig. 11. In which the 400 volts from the PV are increased to between 1000 and 1300 volts and subsequently decreased to the value specified for the Inverter's constant voltage. The controller circuit, which reads the values of the grid voltage and inverter current, converts the voltage from DC-AC using the boost converter's predetermined 600V flow rate via the inverter, which is shown is fig 12.

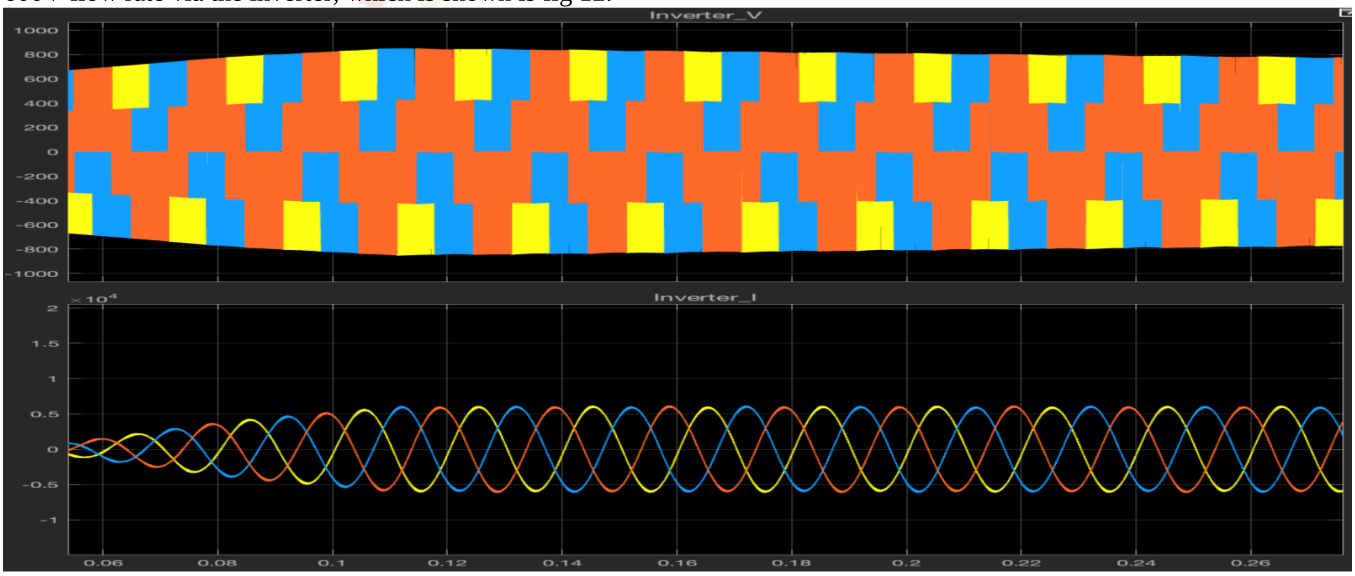

Fig. 12. Inverter Voltage and Current

There is a lot of noise interference in the inverter's output voltage. To decrease such disturbances in this case, we apply a harmonic filter.Capacitors or inductors linked to each phase make up harmonic filters. The voltage and current at grid is shown in fig 13.

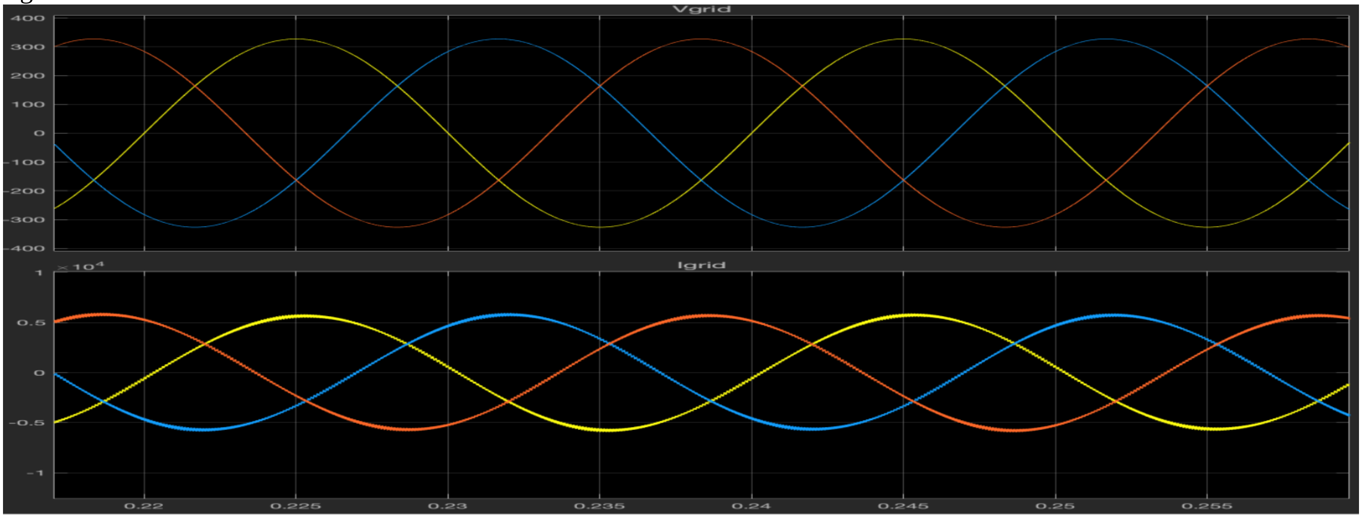

Fig. 13. Grid Voltage and Current

After the Harmonic filters we can see that both grid voltage and grid current are in-phase with each other. Fig 14 shows the voltage and current for load and fig 15 & 16 shows the real power and reactive power at Inverter and grid.

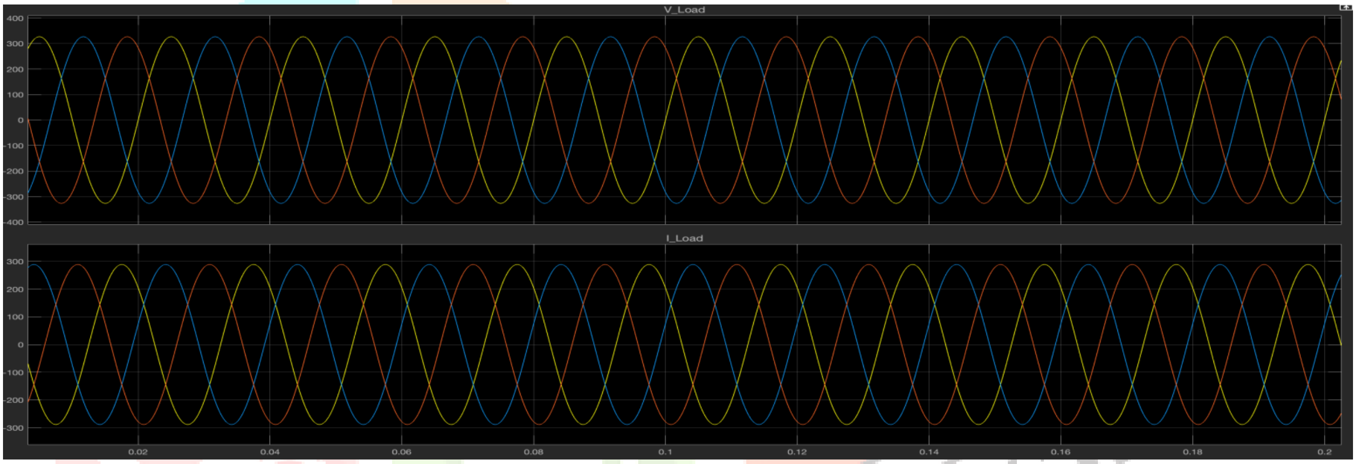

Fig. 14. Load Voltage and Current

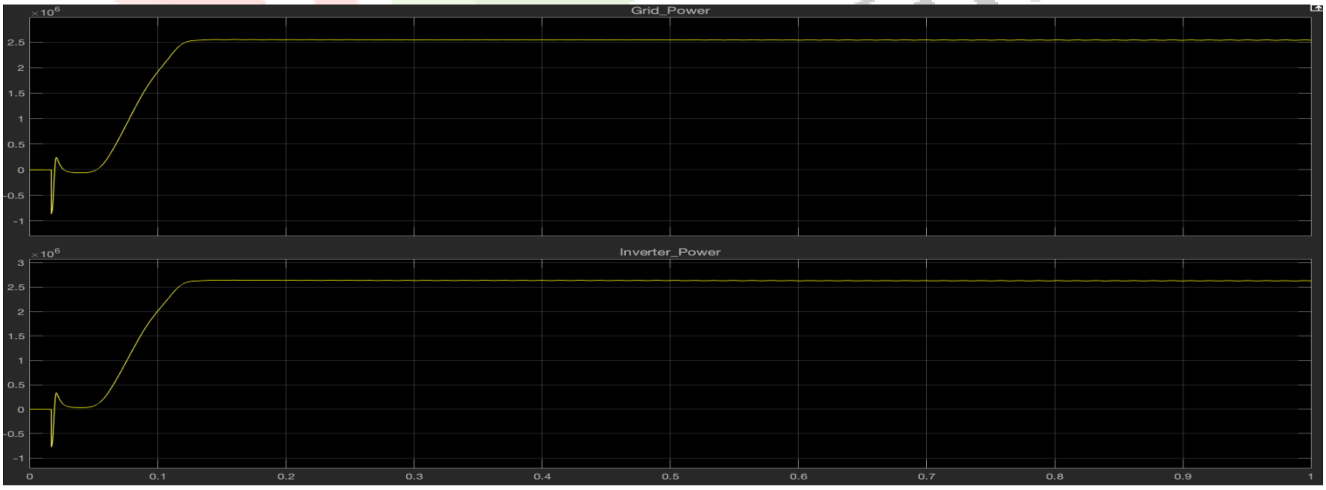

Fig. 15. Real Power at Grid & Inverter

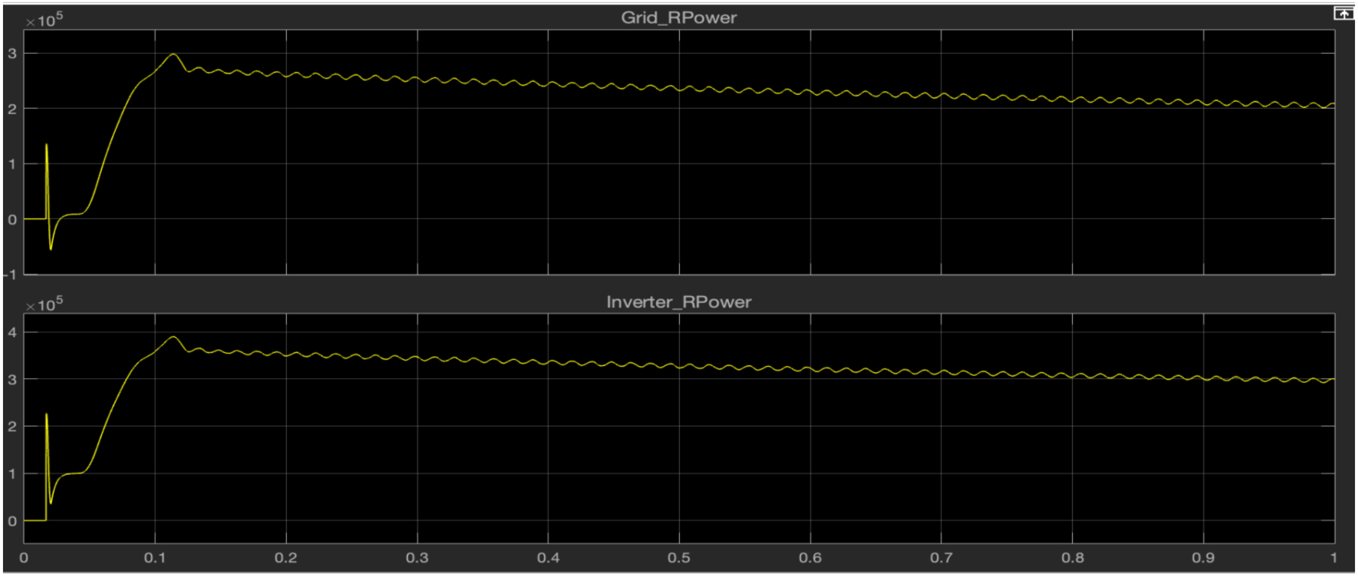

Fig. 16. Reactive Power at Grid & Inverter

Fig 10 and 15 may be compared to show how the 3MW of power is transferred from solar PV to the grid with little loss as it distributes power to the load. In order to preserve grid stability due to voltage changes, we can alter the reactive power.

V. CONCLUTION

This research presents a thorough analysis of the application of modern control strategies utilizing the STATCOM and SVC for maximizing the management of reactive power in grid-connected solar PV systems. Precise analysis and experimentation have effectively handled the key goals of improving power quality, assuring voltage stability, adhering to grid standards, and optimizing renewable energy integration. Our suggested control technique has showed notable improvements in power quality by controlling voltage fluctuations and lowering service interruptions through thorough simulations and real-world data validation. The grid's voltage stability has been successfully kept within allowable bounds, preventing voltage anomalies that would endanger the dependability of linked electrical equipment.

VI. ACKNOWLEDGEMENT

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