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Power Quality Challenges in Grid Integrated Renewable Energy Systems and Associated Mitigation Techniques

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***Abstract*— Globally, utilization of renewable energy sources in traditional power systems has expanded. With the modernization of power grids, it is crucial to ensure that voltage profile at each bus is maintained within an allowable threshold, improved voltage stability, reduced power and increased system reliability. These can be accomplished by integrating reactive power compensation devices into distribution or transmission networks, such as Flexible Alternating Current Transmission System (FACTS) devices, synchronous condensers, and capacitor banks.**

The proposed technique focuses on the active power sharing with the grid and the integration of solar PV with STATCOM for reactive power compensation. The characteristics of STATCOM and fixed capacitor are evaluated and assessed from the perspectives of output voltage, current, active, and reactive power. The correctness and efficacy of the suggested methodology are validated by simulations.

***Keywords*— STATCOM, renewable energy sources, Reactive Power Compensation**

I. INTRODUCTION

The exploration of renewable energy sources, such as photovoltaic (PV) cells, fuel cells, wind turbines, etc., has been prompted by the continued rise in global energy demand one reason to this is the confined presence of fossil fuels, and also harmful effects of these fuels on the eco system. Through grid-tied inverters, these renewable energy sources are incorporated into the pre-existing electrical grid.[1]

One of the most promising renewable energy sources, photovoltaic (PV) systems are widely used in a variety of applications and power levels, including large-scale power plants, homes, water pumps, street lighting, powering telecommunication transmitters, vehicles, space applications, etc[1][4]. Since PV modules cannot be directly linked to the grid, numerous studies on maximum power point tracking (MPPT) algorithms, DC-DC converter and inverter topologies, and current control mechanisms have been suggested for the grid-integrated PV applications. The perturb and observe (P&O) method is the most often used among the several proposed MPPT algorithms.[2]-[5] Despite its simplicity, there is an oscillation near the system's MPP. The incremental conductance (IC) method which is one of the common methods, enhances performance in respect of oscillation about the MPP, tracking speed, and MPPT effectiveness.

In applications requiring DC-DC converters, it performs exquisitely [9]. Additionally, certain artificial intelligence-based techniques for MPPT applications have been implemented, including the fuzzy logic controller, artificial neural network, and genetic algorithms. Although these advancements offer better performance, the real-time application is severely constrained by their calculation burden. With the emerging modernization of the power grids and the use of diverse RESs, the efficient utilization of the networks is vital as the cost of construction and the establishment of new transmission and distribution networks is high and also takes significant amount of time and effort[6][8]. In order to achieve a highly efficient network in the smart grid system, the power system complexities such as voltage profile issues, voltage instabilities, excessive power losses, excessively loaded lines, reliability problems, power quality, etc. must be mitigated[4]. These issues can be obviated by incorporating the Reactive Power Compensation (RPC) in transmission and distribution system. To reduce voltage irregularities at a particular transmission or distribution bus, voltage support via RPC is significant, particularly when non-dispatchable intermittent renewable energy sources are present. [3]

Flexible alternating current transmission system (FACTS) devices have been extensively employed in the literature for voltage regulation within the permitted limits to tackle the aforementioned issues in the grid integrated PV system. However, STATCOMs are observed to be the most effective amongst them as it does not contain any mechanical component has quick response time, and capability to compensate for the required quantity of leading and lagging volt-ampere reactive power (VAR) [2].

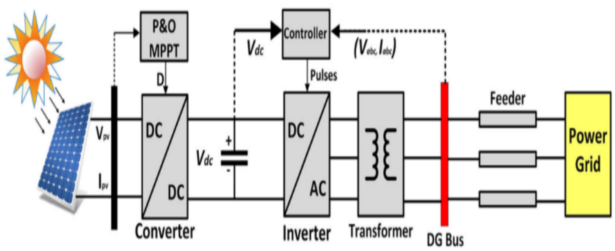

Fig 1. Basic topological configuration of grid connected solar PV.

In this work, a two-stage grid-tied inverter configuration is suggested in order to efficiently transfer the energy from the PV system to the grid. The DC-DC converter in the proposed scheme is operated by the MPPT algorithm [3]. The study's employing a DC-DC converter has some advantages, including reductions in load current ripple, fixed output voltage polarity, and maintaining the desired value of output voltage.

II. Power Quality Issues

On grid integration with PV systems for exploiting RESs more effectively, their grid integration introduces several problems, including voltage, frequency fluctuation, and harmonic distortion [3]. If renewable energy penetration in a system exceeds a certain amount, known as the network's hosting capacity (HC), and no harmonic filtering mechanism is used, it may worsen grid power quality and increase power losses[5][7]. The ability of the connecting inverter to use modulation techniques to filter out harmonics and provide a pure sinusoidal current has a substantial impact on how much harmonics the RESs emit into the grid [8]. However, several cutting-edge inverter switching approaches can effectively guarantee the healthy quality of power produced by renewable energy systems working in standalone mode.

Numerous PQI studies with a focus on minimizing PQ problems and encouraging seamless grid integration of renewable energies have been reported; nevertheless, each mitigation strategy has its drawbacks, thus it will continue to be a focus of study in the future[6][2]. Voltage quality improvement (VQI) and current quality improvement (CQI) strategies can be roughly classed as PQI techniques that underline the integration of renewable energy [1]. CQI techniques deal with compensating for current harmonics caused by DG systems themselves or load buses and grid buses, while VQI techniques are particularly focused on DGs' mitigation of voltage and frequency fluctuation [8].
Custom power devices (CPDs), energy storage (ES) approaches, energy conversion optimization, spinning reserve (SR), and a few more specialized techniques based on variable frequency transformer (VFT) and virtual synchronous machine (VSM) concepts are further sub classifications of VQI techniques. Further sub categorization of CQI approaches includes passive filters (PFs), shunt and series active power filters (APFs), hybrid filters, smart impedance, and multifunctional DGs.

In this study for improving the issues related to voltage profile custom power devices are used specifically STATCOM as it gave the promising results. Also, for the reactive power compensation traditionally capacitor banks were used, but since fixed capacitor are of certain value and cannot be varied so limits its further applications. For the compensation of current harmonics passive filters are employed [4]. Despite having low inductance values, the third-order LCL filter provides greater current ripple attenuation. As a result, it does not require a high inverter switching frequency. Due to the LCL filter's compactness, cost-effectiveness, and ability to achieve improved decoupling between the filter and grid impedance, it has been investigated for high power grid integrated inverters.

III. Voltage and Quality Improvement

A. FC and STATCOM

A shunt capacitor is an example of early reactive power compensation technology. It has a simple structure and can improve the voltage quality and reduce the power loss. These can effectively reduce the impulse current when the capacitor bank is mechanically switched[2]. However, the mentioned compensation technologies can only achieve graded compensation but cannot continuously adjust the reactive power, and, generally, overcompensation or under compensation occurs. With the development of power electronics technology, a static synchronous compensator (STATCOM) has been proposed.

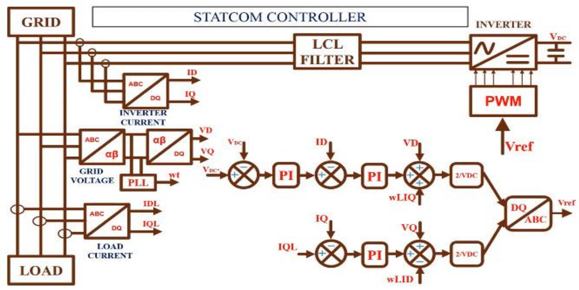

Fig 2. STATCOM controlling procedures.

The STATCOM represents an advanced and continuously adjustable static reactive power compensation device. This device can expand the range of reactive power compensation and lower the DC-link voltage, harmonics are injected into the power grid, so additional filtering devices are required[6]. STATCOM is integrated at PCC to offer voltage control through reactive power injection and improve transient stability and damping[4]. STATCOMs work without large inductive or capacitive passive components for absorbing or supplying reactive power to the distribution grid as it is done in SVCs. The topmost points of attraction in STATCOMs are fewer space constraints, improved damping characteristics, and ability to inject more reactive power at relatively low grid voltages because it works as a current source without depending on the grid voltage.

B. Passive filters

Passive filters are nothing more than specific combinations of passive components, such as inductors and capacitors, with the goal of blocking specific harmonic frequencies and supporting a significant amount of reactive power [7]. The common element among all these filter streams is that they all give very low impedance to the undesirable harmonic frequency current components originating from the source side.

The conventional use of a L filter as a basic first-order filter was investigated and found to be bulky and ineffective. The second-order LC filter has better damping capabilities than the L filter [6]-[9]. The inductance of the LC filter can be decreased by using a parallel capacitance, making it both more economical and efficient. The LCL filter is the third order filter, which provides great current ripple attenuation in spite of slight inductance values.

IV. SIMULATION AND RESULTS

The two-stage three phase grid connected PV inverter with STATCOM to compensate reactive power demand from the grid is modelled and simulated with MATLAB/Simulink. Both the quality of the current injected into the grid and the MPPT performance of the suggested two-stage system are investigated. As a result, different operating circumstances, including step changes in irradiation level, variable irradiation, and constant irradiation, have been considered.

A. Simulink model Grid connected PV Inverter with fixed capacitor.

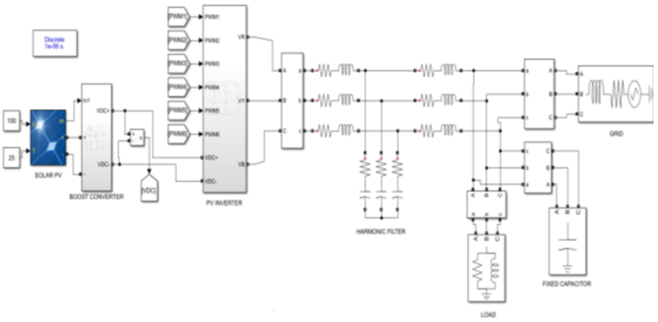

Fig.3.1 Simulink model of Three phase Grid connected Solar PV with Fixed Capacitor.

In this a fixed capacitor is added for the reactive power compensation. Using fixed capacitor is the traditional method for reactive power compensation. The fixed capacitor used in this model is expected to supply 100KVAr of reactive power and this is validated from the waveform of Load Active and reactive power.

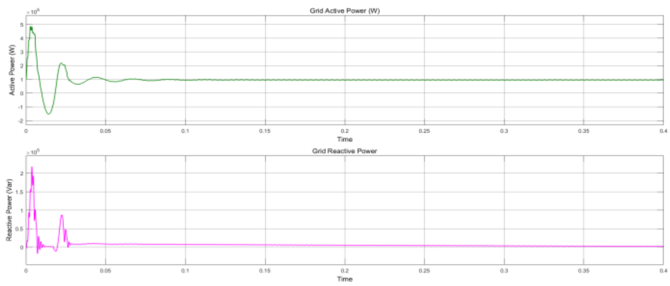

Fig.3.1.1 Grid Active and reactive power waveform on adding FC.

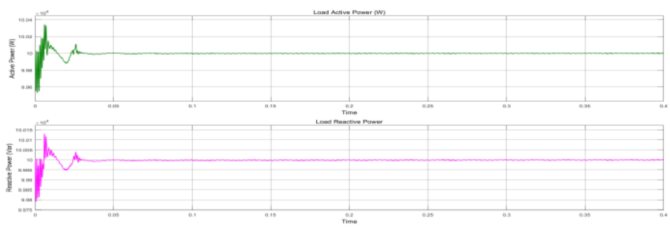

Fig.3.1.2 Load Active and reactive power waveform on adding FC.

B. Simulink model Grid connected PV Inverter with STATCOM.

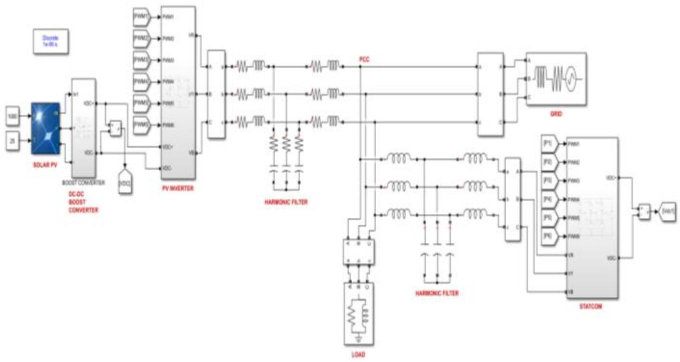

Fig.3.2 Simulink model of Three phase Grid connected Solar PV with STATCOM.

Addition of STATCOM is another approach for compensating reactive power. Fixed capacitor supplied the required power to the load but its drawback lies in providing a constant value and adjustments cannot be made. So, we moved to one of the custom power devices named STATCOM for our work.

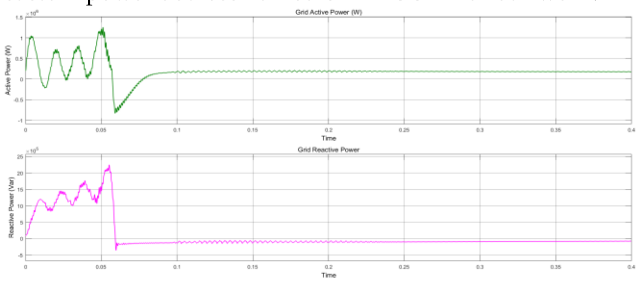

Fig.3.2.1 Grid Active and reactive power waveform on adding STATCOM.

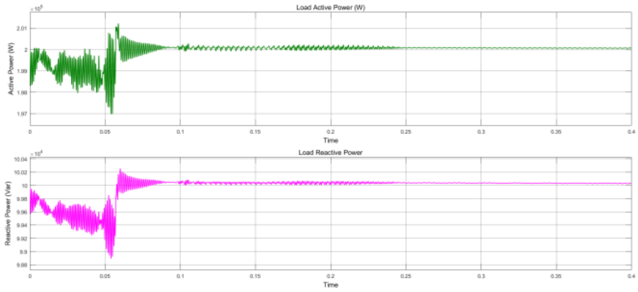

Fig.3.2.2 Load Active and reactive power waveform on adding STATCOM.

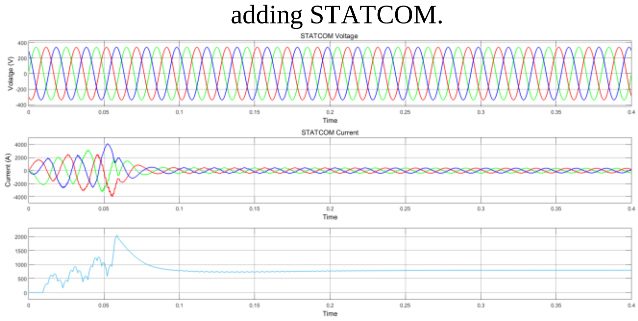

Fig.3.2.3 STATCOM voltage and current waveform.

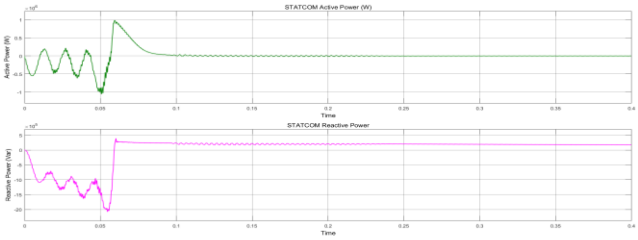

Fig.3.2.4 STATCOM Active and reactive power waveform.

In the STATCOM applications, the DC supply voltage is used to find its AC voltage of each PWM pv inverter which needs to be individually regulated. The voltage-imbalance problem becomes more of a concern for the number of voltage levels increases. The source voltage, load voltage, source current, grid voltage, grid current and load current simulation results are presented. Matlab/Simulink based model for two stage grid connected solar PV with STATCOM are developed and simulation results are presented with negligible harmonic distortion and improved power quality of the system.

C. Performance analytics

TABLE I QUALITATIVE COMPARISON OF THE VARIOUS TECHNIQUES APPLIED TO PV CONNECTED GRID

	Voltage (V)	**Current (A)**	**Active Power (W)**	**Reactive Power (KVAr)**	**Overall THD**
Source	240	30.00	22.00	-0.45	Reduced
Load	240	80.00	57.60	30.00	
FC	240	55.00	39.60	30.20	
STATCOM	240	58.00	41.80	30.45	

The complete system was verified and respective reference (datasheet) were tracked by MPPT controller. The THD of three-phase inverter interfaced to the grid under linear load is 1.59% using LCL filter. Overall THD is reduced. The design characteristics of the presented configuration place its competence among various other contemporary designs of the era.

Finally reactive power compensation technique is applied using conventional method and with the use of custom power device for voltage stability in order to improve the overall power stability of the system. STATCOM is the custom power device used in this work.

V. CONCLUSIONS

Selection of any energy source (available in world), is primarily based on its reliability, robustness and distribution when subjected to various load demands. This work has been to compensate reactive power, improve dynamic performance of the grid interfaced solar photovoltaic (SPV) system based on reduction of the total harmonic distortion (THD) of grid connected inverter.

The performance of voltage stability and reactive power compensation depends on upon the voltage controller used. This can achieve by introduction STATCOM in PV system with intelligent voltage controller correct accordingly. The application of STATCOM effectively increases the utilization of PV systems in the grid.

REFERENCES

[1] Ayadi F, Colak I, Garip I, Bulbul HI. *Impacts of Renewable Energy Resources in Smart Grid*. In2020 8th International Conference on Smart Grid (icSmartGrid) 2020 Jun 17 (pp. 183-188). IEEE.

[2] Basit MA, Dilshad S, Badar R, Sami ur Rehman SM. *Limitations, challenges, and solution approaches in grid- connected renewable energy systems.* International Journal of Energy Research. 2020 May;44(6):4132-62.

[3] Järventausta P, Repo S, Rautiainen A, Partanen J. *Smart grid power system control in distributed generation environment*. Annual Reviews in Control. 2010 Dec 1;34(2):277-86.

[4] Bajaj M, Singh AK. *An analytic hierarchy process-based novel approach for benchmarking the power quality performance of grid-integrated renewable energy systems*. Electrical Engineering. 2020 Sep 1;102(3).

[5] Liang X. *Emerging power quality challenges due to integration of renewable energy sources*. IEEE Transactions on Industry Applications. 2016 Nov 8;53(2):855-66.

[6] Creutzig F, Roy J, Lamb WF, Azevedo IM, De Bruin WB, Dalkmann H, Edelenbosch OY, Geels FW, Grubler A, Hepburn C, Hertwich EG. *Towards demand-side solutions for mitigating climate change. Nature Climate Change*. 2018 Apr;8(4):260-3.

[7] Pereira BR, da Costa GR, Contreras J, Mantovani JR. *Optimal distributed generation and reactive power allocation in electrical distribution systems*. IEEE Transactions on Sustainable Energy. 2016 Jan 20;7(3):975-84.

[8] Adhikari S, Li F. *Coordinated Vf and PQ control of solar photovoltaic generators with MPPT and battery storage in microgrids.* IEEE Transactions on Smart grid. 2014 Feb 28;5(3):1270-81..

[9] Varma RK, Salehi R. *SSR mitigation with a new control of PV solar farm as STATCOM (PV-STATCOM).* IEEE Transactions on Sustainable Energy. 2017 Apr 5;8(4):1473-83.