RESEARCH ARTICLE OPEN ACCESS

Comparative Analysis of PV-Connected Power Quality Conditioners under the Source Voltage Disturbances

Nidhi Kurmeti*, Dr. Deepak Agrawal, Saurabh Vishwakarma,
Sakshee Chouhan
Department of Electrical & Electronics Engineering, Prestige Institute of Management and Research, Bhopal,
Madhya Pradesh, India

ABSTRACT
A new face of research is witnessed in recent decade to incorporate the dual functionality in designing the PV inverter which are merged with the benefits of customized power conditioner. The benefits of reactive power control strategies with PV inverters are provided. These inverters do the dual function of Grid interconnection as well as PV inverter behaves as a source for DC supply of CPD. In literature a special class of theses inverters are sited frequently which can perform both function of integrating solar with the grid as well as mitigating power quality issues. In the view of present scenario this paper presents the performance analysis of such customized converters with PV integration namely; PV-DSTATCOM, PV-DVR, PV-UPQC. The combination of solar PV systems and CPDs offers multiple solutions of power quality enhancement and clean energy generation. This thesis presents most popularly used three types of compensating devices namely STATCOM, DVR and UPQC. These devices in conjunction with solar energy presents an energy efficient compensation system which can supply active as well as reactive power as per the requirement. These devices are discussed in detail in the coming section with simulation results to presents their utility in enhancing power quality of distribution system.
***Keywords* -** Custom Power Devices (CPDs), Dynamic Voltage Restorer (DVR), Unified Power Quality Conditioner (UPQC), Solar Power Generation, DC-DC boost converter, Maximum Power Point Tracking (MPPT).

Date of Submission: 18-05-2024 Date of acceptance: 03-06-2024

I. INTRODUCTION

India is heading towards increased Distributed generation (DG) based on sustainable has appeared as a demanding part of research between investigators to conflict the issue of maximizing the penetration of solar [1]. In PV based Distributed Generation Systems (PVDGS), electronic interfacing originates critical Power Quality (PQ) issues [2-4] of harmonics in generation and compensation of reactive power which make the distribution of power system inferior. To boost PVDGS penetration, reactive power adjustment is required to maintain a sufficient level of power standard. A wide range of converter topologies are being investigated in order to lower these agitated barriers in the expanding microgrid system [5]. Current trends center on obtaining gadgets that serve several purposes in order to address different standardization issues related to electricity simultaneously. PQ issues include voltage spikes and dips brought on by network outages, lightning strikes, and switching capacitor banks. Reactive power disturbances and harmonics in the power distribution system are caused by the overuse of non-linear loads (computers, lasers, printers, rectifiers, etc.) [6]. It is very essential to overcome this type of problems as its effects adversely to the other connected loads and power system devices.

Modern day power grid has a number of DG sources integrated into the grid [7, 8]. This involves the use of Power Electronic Controllers for controlling the power flow that has led the idea of Custom Power [9]. Custom power is relevant to the use of power electronic controllers for distribution systems. This enables the end consumer to receive a pre-specified quality power. It not only meets the rising demand, but improves the quality and fidelity of power supply.

These are Custom Power Devices, which led a new face of research in recent decade to improve the power quality of the system as well as it can incorporate the functionality of PV inverter. The benefits of reactive power control strategies with PV inverters are provided. These inverters do the dual function of Grid interconnection as well as PV inverter behaves as a source for DC supply of CPD [10]. In literature a special class of theses inverters are sited frequently which can perform both function of integrating solar with the grid as well as mitigating power quality issues. In the view of present scenario this paper presents the performance analysis of such customized converters with PV integration namely; PV-DSTATCOM, PV-DVR, PV-UPQC. Their comparative analysis is also presented on the basis of their performance efficiency.

II. POWER QUALITY IMPROVEMENT (PQI) TECHNIQUES

In India, Numerous PQI studies that focus on reducing PQ difficulties are documented and encourage the seamless integration of renewable energy sources into the grid; however, each mitigating techniques have significant shortcomings, there will be ongoing study conducted in this field in the future. As shown in Figure 1, PQI techniques that emphasize the integration of renewable energy can be roughly divided into two categories: voltage quality improvement (VQI) and current quality improvement (CQI) [11].

In particular, VQI approaches address the reduction of voltage and frequency fluctuations in distributed generators (DGs), while CQI techniques address the correction of current harmonics resulting from the DG systems or load bus and grid bus, respectively.

While current harmonic correction is the focus of CQI techniques, voltage and frequency variation in DGs is primarily mitigated by VQI approaches. Because of the DG systems themselves, or the grid bus and load bus, in turn. Custom power devices (CPDs), energy storage (ES) techniques, energy conversion optimization, [12], spinning reserve (SR), and a few other specialized techniques based on variable frequency transformer (VFT) [13] and virtual synchronous machine (VSM) concept are further subclassifications of VQI techniques. Passive filters (PFs), shunt and series active power filters (APFs), hybrid filters, smart impedance, [14], and multifunctional differential generators (DGs) are among the further subcategories of the [15] CQI approaches. This work presents the PQI using PV-connected CPDs.

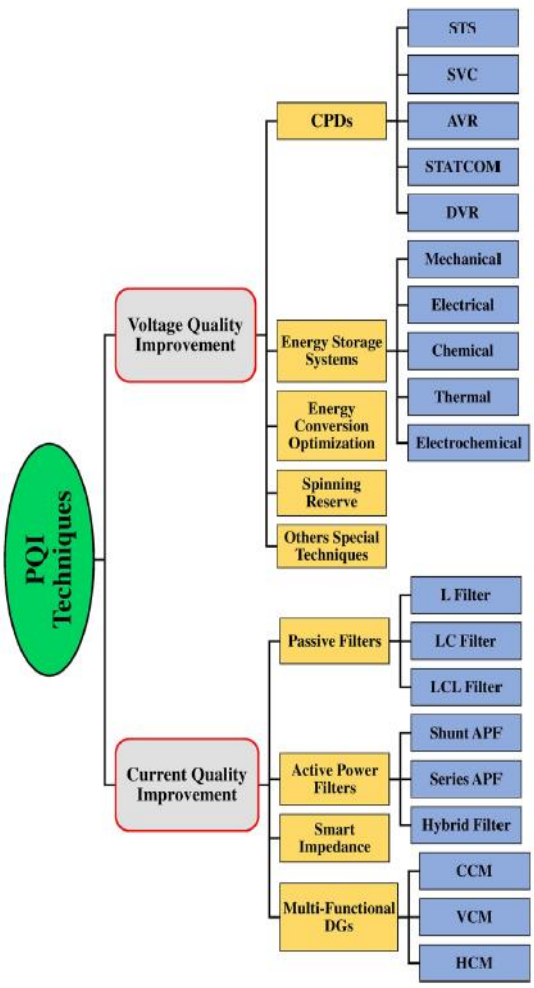

Fig. 1 Power quality improvement (PQI) techniques

The combination of renewable energy and conventional distribution networks has changed power companies' policies about management, control, and dependability. PQ as well as distribution network security. An essential component of a dependable electric power supply to the loads is good power quality (PQ). In both modern (using renewable energy) and traditional (not using renewable energy) distribution networks, CPDs are crucial in offering a cost-effective improvement of

PQ. When Hingorani initially proposed the concept of custom power (CP) in 1995, it was defined as value-added electricity that other service providers, such as electric utilities, may deliver to their clients in the future. Custom Power Devices (CPD) are a group of power electronic devices or a collection of instruments designed to address power quality problems that have been seen in low voltage (LV) distribution networks. The increasing accessibility of semiconductor switches and state-of-the-art advancements in power electronics technology help the advancement of CPD technology. Since, CPDs can significantly reduce the PQ problems related to renewable DG systems, their use and all forms of research development are widely documented in the literature.

III. PROPOSED WORK

For supplying reactive power, converters of the renewable can be improvised to response as a compensating device. This is the concept used in this work for designing power quality conditioner based on solar power conversion system. This paper presents most popularly used three types of compensating devices of distribution system, namely STATCOM, DVR and UPQC. These devices in conjunction with solar energy presents an energy efficient compensation system which can supply active as well as reactive power as per the requirement. These devices are discussed in detail in the coming section with simulation results to presents their utility in enhancing PQ. This research work is divided into two parts; firstly, to integrate large solar farms with the existing utility system and secondly to improve the power quality of the grid under various contingency conditions. All the three CPDs under study is modelled in MATLAB.

For providing shunt compensation, DSTATCOM is proposed to design in matlab simulation software and performance analysis will be carried for linear loading which is the stable operating condition, non-linear loading which introduces harmonic in the voltage and current profile and under the condition of voltage fluctuations which may be the results of voltage sag or swell. Another part of DSTATCOM is to propose a control architecture which can simultaneously integrate solar with the grid in addition of providing power conditioning. The MATLAB simulation model of the PV-DSTATCOM is shown in figure 2.

DVR is a series compensation preferred to compensate for voltage fluctuations whether sag or swell [16]. It injects the voltage required for balancing imbalanced voltages. The active power required for this is obtained by DC-source, conventionally a battery is connected which charges the DC-Link Capacitor (DCLC). In this research PV charges the capacitor or battery and supplies both active power as required by the load or reactive power as required to regulate the load bus voltage. In the early phase of evolution of DVR various modes of operations were identified namely; stand-by, where it is isolated through circuit breaker when compensation is not-required. Another is injection-mode, where DVR injects the required voltages under the condition of voltage fluctuations at load bus. One more mode in which DVR operates is protection mode, when high fault current flows in the system DVR activate its protection mode to protect itself from damage due to high currents flowing in the system. The transition among these stages has changed drastically as the technology evolved in power conversion. The Matlab simulation model of PV-DVR is shown in figure 3.

In this work, UPQC is designed with VSI based converter topology and integrated with solar energy. The proposed topology of the PV-UPQC is presented in figure 4, the UPQC is designed as UPQC-L topology with VSI based converter. The controller is designed so as to generated the reference signal as per the grid parity and comparing it with V_{PV}, to generate the gating signal in synchronous references. Left side convert acting as a current source is shunted directly at load side and compensates the harmonics as well as maintains PF. Right side converter acts as controlled voltage source to regulate the load voltage and is coupled using coupling transformer. The choice of shunting the converter at load side or source side depends upon the type of compensation required in the system and same is applicable to the series converter. The PV-UPQC proposed in this work will simultaneously mitigate load current harmonics injection as well as will regulate the VSS. The design parameters for the work are shown in table 1.

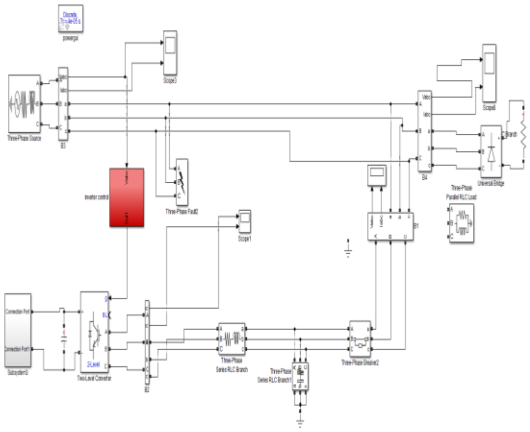

Fig. 2 Simulation Model of the proposed PV-DSTATCOM

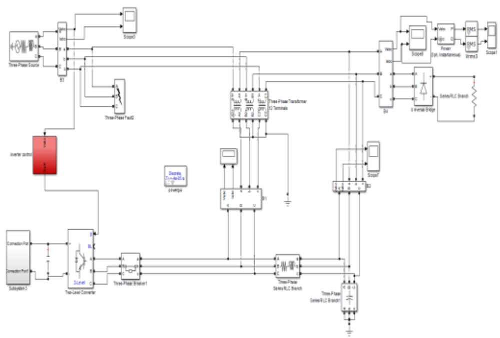

Fig. 3 Simulation model of PV-DVR

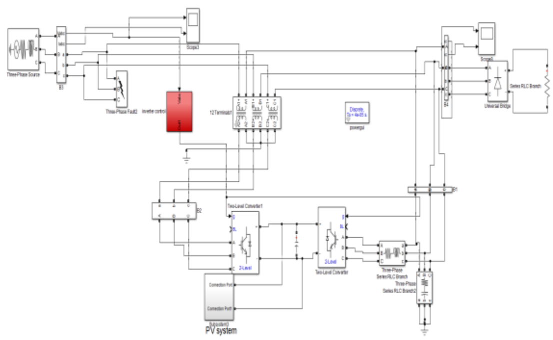

Fig. 4 Simulation model of PV-UPQC

Table- 4.1 Design Parameter

S. No.	Parameter	Values
1	Nominal Voltage	415 V
2	PV-voltage	600V
3	Supply Freq.	50Hz
4	Coupling Tran. VA rating	100 KVA
5	Coupling trans. Resistance and reactance	200 Ω, 0.05 H
Filter parameter for DSTATCOM		
6	RL series branch	1 Ω, 25mH
7	RC shunt branch	1 Ω, 450µF
Filter parameter for DVR		
8	RL series branch	0.1 Ω, 25mH
9	RC shunt branch	280µF
Filter parameter for UPQC		
10	RL series branch	1 Ω, 15mH
11	RC shunt branch	1 Ω, 160µF

IV. SIMULATION RESULTS

MPDS has wild case of voltage fluctuations sometimes sags due to faults which can be either open circuit or short circuit or sometimes swell due to sudden load curtailment or impulsive generations etc. both cases are sensitive for retaining system stability. Hence, results are presented for PV-DSTATCOM for SVSS at source side. Through programmable source block swell in source voltage is created upto 1000 peak volt for the duration of 0.1-0.2 sec and simultaneously Three Phase-Fault (TPF) occurs for 0.3-0.4 sec as shown in figure 5 This causes the source voltage to fluctuate and also affects the load bus profile as shown in figure 6 The results shows that PV-DSTATCOM is unable to regulate the load bus voltages and harmonics both at source side as well as load is side is too high of the order of 30% and 12% ass shown in figure 7 and figure 8 respectively. Hence thorough analysis of results shows that DSTATCOM has capability to mitigate harmonics and can maintain power factor but voltage regulation cannot be taken care by it.

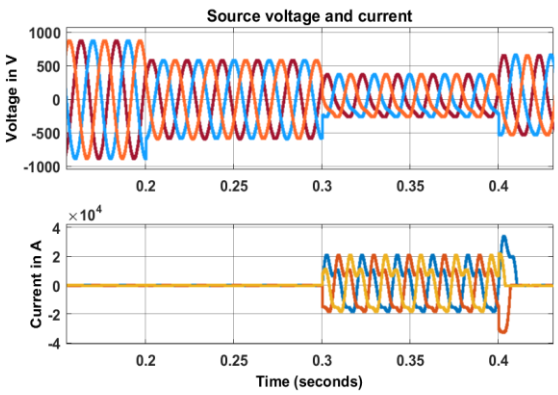

Fig. 5 Source voltage and current for voltage sag and swell with non-linear load with PV-DSTATCOM

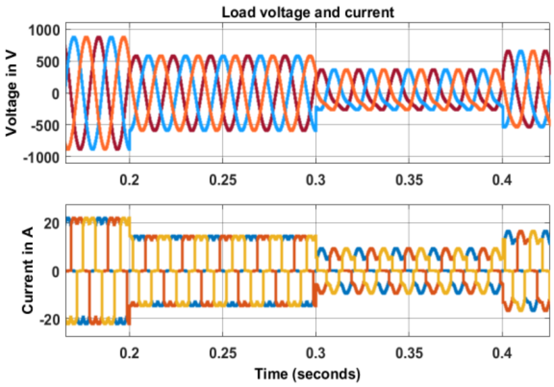

Fig. 6 Load voltage and current for voltage sag and swell with non-linear load with PV-DSTATCOM

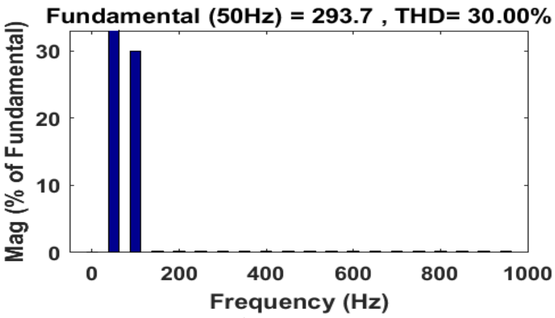

Fig. 7 THD of source side voltage

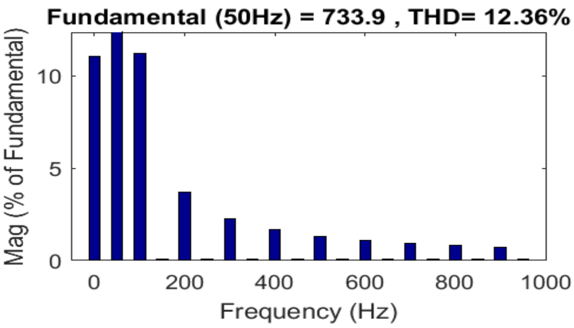

Fig. 8 THD of load side voltage

The foremost choice of DVR is in mitigation of voltage unbalance and deviation with respect to nominal rated voltage. Hence the proposed topology is also analysed for SVSS with non-linear load connected at load bus. The source undergo voltage swell and a TPF also occurs due to which source profile undergoes sever fluctuations as shown in figure 9. DVR successfully maintains the load voltage rated value as shown in figure 10. But high harmonics are injected due to non-linear load as shown in figure 11 and figure 12 respectively are very high.

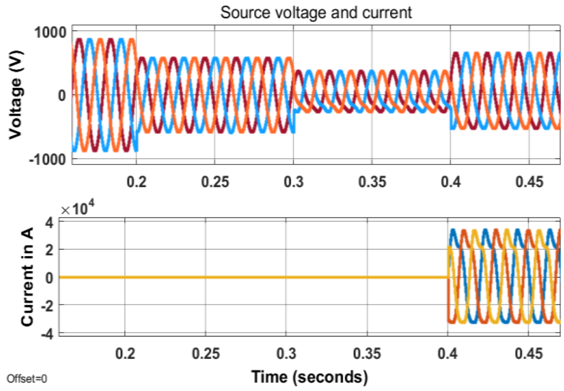

Fig. 9 Source voltage and current under the condition of voltage sag/swell

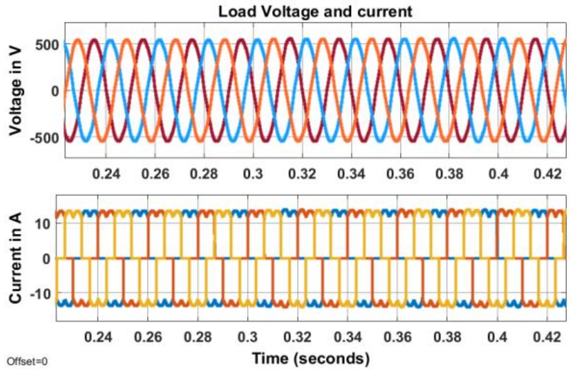

Fig. 10 Load voltage and current under the condition of voltage sag/swell

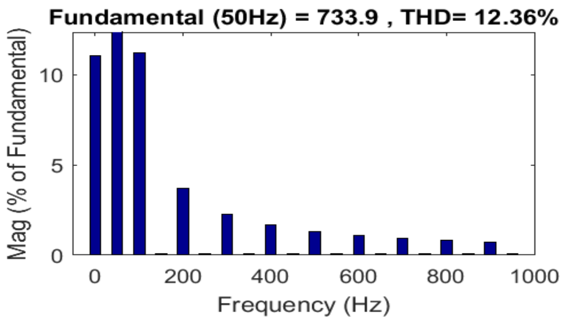

Fig. 11 THD of source side voltage

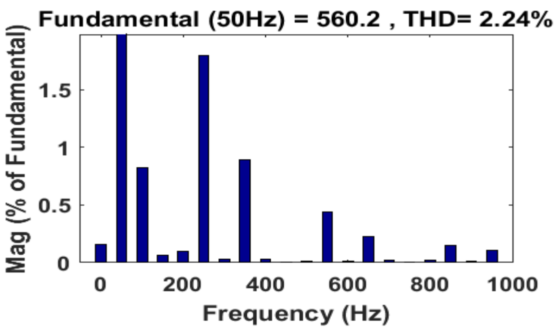

Fig. 12 THD of load side voltage

Under the non-linear load, PV-UPQC maintains the source current profile within limit of harmonics of 2.5% and load voltage harmonics are also low having 2.5% THD. For SVSS the source profile is shown in figure 13. A high fault current of the order of 160 KA flows in the system and the source voltages also fluctuates violently as shown in figure 14. The PV-UPQC eliminates the THD at source side successfully as shown in figure 15 and figure 16, also load voltages are regulated as per the grid code requirement.

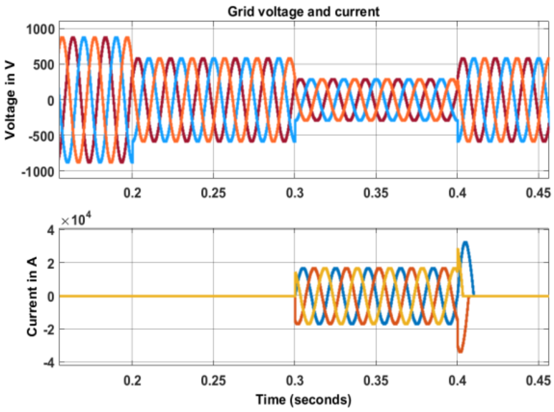

Fig. 13 Test case with PV-UPQC (source voltage and current)

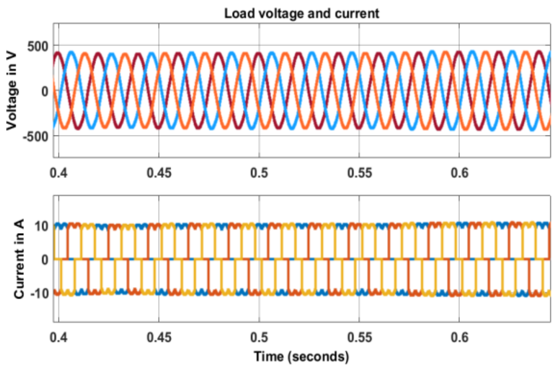

Fig. 14 Test case with PV-UPQC (load voltage and current)

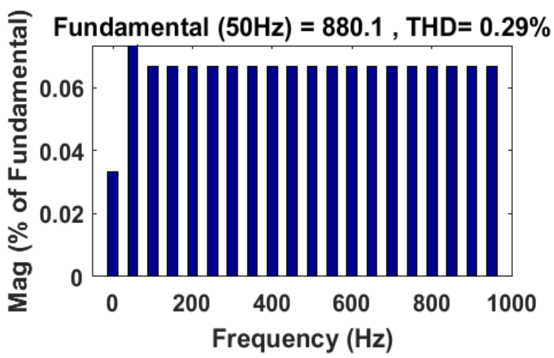

Fig. 15 THD of source side voltage

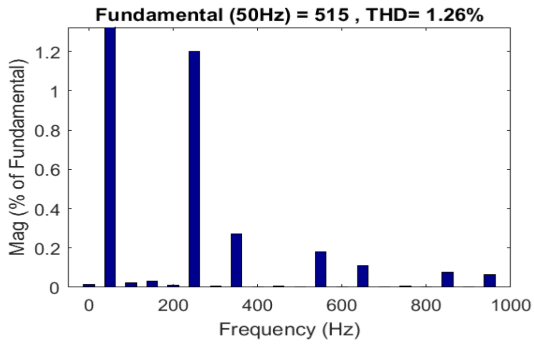

Fig. 16 THD of load voltage

V. RESULT DISCUSSION

For providing compensation, DSTATCOM, DVR and UPQC is proposed to design in matlab simulation software whose design parameter is shown in Table-1. The performance analysis is carried for linear loading which is the stable operating condition, non-linear loading which introduces harmonic in the voltage and current profile and under the condition of voltage fluctuations which may be the results of voltage sag or swell. For the result analysis of all the PQI techniques discussed in this work, it can be observed that PV-UPQC has better performance efficiency in terms of simultaneous voltage regulation at source side as well as load side. Also, it mitigates the harmonic content in source and load profile. The comparison for all the presented converters is given in Table 2.

Table-2 Comparative analysis of THD percentages

Compensating Device	**Source voltage THD %**	**Load Voltage THD %**	**Source Current THD%**	**Load current THD %**
PV-DSTATCOM	30	12.3	43	30.8
PV-DVR	12.3	2.24	43	28
PV-UPQC	0.2	1.2	0.1	28

VI. CONCLUSION

A solar photovoltaic system integrated along with power conditioning capabilities has been proposed in this work which can mitigate power quality issues. Comparative analysis of UPQC, DSTATCOM and DVR can assist to decide the use of best suitable device in addressing the numerous power quality issues. Integrating PV array along with DSTATCOM, DVR and UPQC, gives the dual benefits of clean energy generation along with active filtering which is major scope of this work. Compared to conventional grid connected inverters, the solar PV integrated power conditioners may have numerous benefits such as improving power quality of the grid, protecting critical loads from grid side disturbances apart from increasing the fault ride through capability of converter during transients. These converters can also be used as PV integrating devices in addition of mitigating PQ issues. Simulation results for all the designed converters are presented for simultaneous mitigation of sag and swell. The result comparison shows that. DSTATCOM efficiently improves harmonic profile of the load voltages, but it cannot successfully eliminate load voltage fluctuations and the DVR can regulate the voltage fluctuations but harmonic content is still high. On the other hand, UPQC can mitigate voltage fluctuations completely as well as, it can eliminate source and load voltage harmonics simultaneously.

REFERENCES

[1] Zeng, Z., Yang, H., Zhao, R., & Cheng, C. (2013). Topologies and control strategies of multi-functional grid-connected inverters for power quality enhancement: A comprehensive review. Renewable and Sustainable Energy Reviews, 24, 223-270.

[2] Kannan, A., Kumar, V., Chandrasekar, T., & Rabi, B. J. (2013, December). A review of power quality standards, electrical software tools, issues and solutions. In 2013 International Conference on Renewable Energy and Sustainable Energy (ICRESE) (pp. 91-97). IEEE.

[3] Prasad, D., & Dhanamjayulu, C. (2022). Solar PV integrated dynamic voltage restorer for enhancing the power quality under distorted grid conditions. Electric Power Systems Research, 213, 108746.

[4] Rai, S., Kumar, Y., & Kirar, M. (2021). Technological Advancements In Grid Integration Of Solar Energy: A Review. Suranaree Journal of Science & Technology, 28(4).

[5] Pandey, Y., & Singh, A. (2021). Power quality issues in grid-integrated renewable energy systems and their mitigation using UPQC. In Smart Computing. 852-861. CRC Press.

[6] Tareen, W. U., Mekhilef, S., Seyed mahmoudian, M., & Horan, B. (2017). Active power filter (APF) for mitigation of power quality issues in grid integration of wind and photovoltaic energy conversion system. Renewable and Sustainable Energy Reviews, 70, 635-655.

[7] Abas, N., Dilshad, S., Khalid, A., Saleem, M. S., & Khan, N. (2020). Power quality improvement using dynamic voltage restorer. IEEE Access, 8, 164325-164339.

[8] Varma, R. K., & Siavashi, E. M. (2018). PV-STATCOM: A new smart inverter for voltage control in distribution systems. IEEE Transactions on Sustainable Energy, 9(4), 1681-1691.

[9] Devassy, S., & Singh, B. (2019). Implementation of solar photovoltaic system with universal active filtering capability. IEEE Transactions on Industry Applications, 55(4), 3926-3934.

[10] Kumar, V., Pandey, A. S., & Sinha, S. K. (2016, March). Grid integration and power quality issues of wind and solar energy system: A review. In 2016 International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES). 71-80.

[11] Patra, S., Kishor, N., Mohanty, S. R., & Ray, P. K. (2016). Power quality assessment in 3-Φ grid connected PV system with single and dual stage circuits. International Journal of Electrical Power & Energy Systems, 75, 275-288.

[12] Zeng, Z., Yang, H., Zhao, R., & Cheng, C. (2013). Topologies and control strategies of multi-functional grid-connected inverters for power quality enhancement: A comprehensive review. Renewable and Sustainable Energy Reviews, 24, 223-270.

[13] Alnabi, L. A., & Al-Hakeem, M. S. Stand-Alone Solar Energy Application System: Smart Sunflower Station-Case Study. September 2019.

[14] Kumar, N., Gawre, S., & Verma, D. (2014). Modeling and Simulation of Solar Photovoltaic System and Interfacing with Neutral Point clamped Multilevel Inverter. In International Conference in Electrical, Electronics and Computer Science (ICEECS-2014) (Vol. 30).

[15] Javadi, A., Hamadi, A., Woodward, L., & Al-Haddad, K. (2016). Experimental investigation on a hybrid series active power compensator to improve power quality of typical households. IEEE Transactions on Industrial Electronics, 63(8), 4849-4859.

[16] Pal, R., & Gupta, S. (2020). Topologies and control strategies implicated in dynamic voltage restorer (DVR) for power quality improvement. Iranian Journal of Science and Technology, Transactions of Electrical Engineering, 44, 581-603.