International Journal of Scientific Research and Engineering Development-– Volume 9 Issue 6, Nov – Dec 2026
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Comparative Analysis Between Different Power Quality Controllers in Distribution System

Syed Waseem Ali, Kishor Thakre, Anil Kumar Kurchaniya
Department of Electrial & Electronics Engineering
Rabindranath Tagore University
Bhopal, India

----------**********----------

Abstract:

In competitive power market environment, Power Quality (PQ) is utmost important. Any deviation in the standard PQ of supply leads to the system instability as well as system suffers from economic loss. To mitigate the PQ problem in Distribution System (DS) various high power devices are installed. In this context DSTATCOM, DVR and UPQC are widely adopted PQ conditioner dedicatedly designed to enhance PQ in DS. This work presents the comparative analysis of these devices in terms of harmonic reduction and voltage regulation when the DS suffers the condition of voltage sag. Voltage sag is a frequent type of PQ problem which occurs due to the fault in system. Fault is a commonly occurring phenomenon in DS which is characterized by dip in voltage and high increase in current. If it is not cleared it causes severe threat to the system and can also damage the connected devices and equipments. This paper addresses the issues related to fault and the power conditioner mentioned above helps to retain the stability as well as PQ of the supply.

Keywords— Power Quality (PQ), Distribution Static Compensator (DSATCOM), Dynamic Voltage Restorer (DVR), Unified Power Quality Conditioner (UPQC).

----------**********----------

I. INTRODUCTION

The deregulation market structure of has imposed the bottleneck competition in Deregulated Distribution System (DDS). It does not have room for any Power Quality (PQ) issues. Contrary the advancement in Power Electronic Devices (PED) has increased the Non-Linear Load (NLL) pattern [1]-[2]. The NLLs are the main causes of several PQ issues like harmonics, flickers, resonance, reactive power imbalance, etc. and deteorate the PQ of supply. NLL are the leading source of inter-harmonics, which circulates the harmonic currents and results in distortion of sinusoidal waveform. Also, in DDS single phase NLLs is also connected which results in phase-unbalance. These side effects of NLL, severely effects the sensitive loads and may damage them completely or partially.

On the other hand, in distribution system fault is a frequently occurring event. Fault results in voltage

fluctuation in the interconnected system and also results in phase unbalance. This further generate various PQ issues. Hence DDS in DDS various customized PQ improvement devices are connected to improve the performance of the system under the condition of PQ issues. In the early phase of development of theses devices, they were installed as Active Power Filter. Theses filters were either connected as shunt compensator or series compensator.

As well as combine compensation is also provided. As the technology evolved and they became popular, these devices were combined termed as Customized Power Quality Conditioner (CPD). CPD were dedicatedly designed to mitigate the PQ issues in DDS. The broad

 ©IJSRED: All Rights are Reserved

classification of theses CPDs is presented in figure 1. CPDs are network-regenerative and compensating type.

In this work Application and performance comparison of compensating type CPD is presented. The shunt connected APF is called as Static Compensator/STATCOM, the series connected CPD is termed as dynamic Voltage Restorer/DVR and the combine series-shunt configuration is Unified Power Quality Conditioner/UPQC. These devices have different applications and usage. In this work the comparative analysis of the three mentioned CPD is presented under the condition of NLL and voltage sag. Firstly, performance analysis of individual CPD is presented and then they are compared in terms of THD percentage as well as voltage restoration capability. All the CPDs of compensation category are individually disused for there control architecture and concept, then there performance analysis for NLL and three-phase fault is carried out. In the last section comparative analysis is presented for THD percentage and filter size using DSTATCOM, DVR and UPQC topologies.

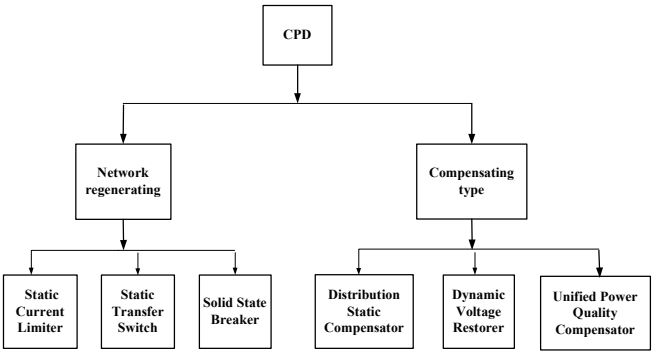


Fig. 1. Example of a figure caption.

II. SHUNT COMPENSATOR

The D-STATCOM is a VSI based Flexible AC Transmission Controller System (FACTS) which provides reactive power compensation. Its response time for providing dynamic compensation is very low of about 1-2-cycles. Hence it is widely adopted to provide quick voltage control. The STATCOM is designed by shunting VSI at a point of application in the MD [3] as shown in Fig. 2. VSI consist of three arms for 3-phase having 6 switches. The operation of switches is controlled using gate pulses. AC-side of VSI is connected across non-linear and unbalance load [4] The D-STATCOM injects current to mitigate harmonics hence the current drawn (Is) becomes in-phase sinusoidal with the voltage.

The D-STATCOM in the figure consists of VSI unit shunted between source and load [5]-[7]. It injects required current IINJ to compensate for load-current harmonic so as to draws sinusoidal source current. The VDC is the DC voltage across the DC side of Voltage Source Inverter (VSI) which is supplied by DC-link-capacitor.

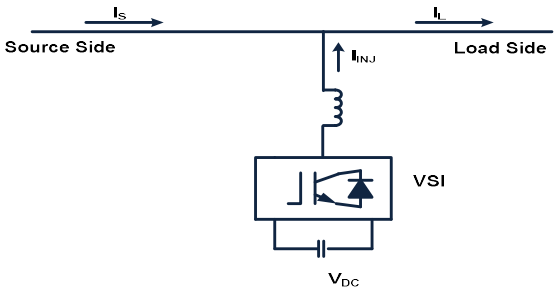


Fig. 2. Schematic diagram of D-STATCOM

A. Converter Control

To obtain sinusoidal-AC output from PV-DSTATCOM, gate pulses is controlled for the IGBT switches of VSI. In this paper synchronous rotating reference frame (SRF) technique is used to obtain reference current and with the help of S-PWM, the switching control of PED is obtained as demonstrated in Fig. 3 [8]-[11]. SRF draws the three-phase reference signal of voltages and currents (V-I) from grid [12]-[16]. Three phase to two phase i.e., park's (d-q) transformation is carried out to simplify the control design as presented Eq. (1). Phase Lock Loop (PLL) is used as a synchronization technique. A filtering element removes the harmonics and PI controller calculates the magnitude of the pulses generated and fed to the two-level PWM block.

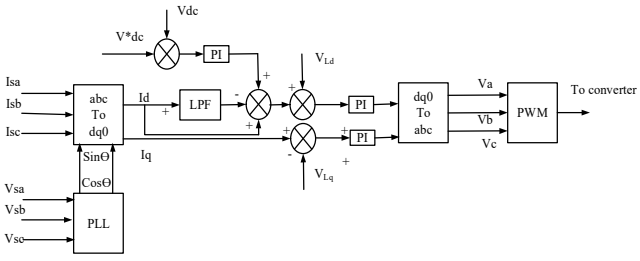


Fig. 3. Converter control diagram for DSTATCOM

 ©IJSRED: All Rights are Reserved

B. Simulation results

In this DSTATCOM is designed using MATLAB (R2016a) in simulation environment of simulink tool-kit. Simulation model configuration is displayed in figure 4. Starting from left the system design of figure 4 consist of three phase AC-supply followed by a source bus which measures source voltage and current. The source voltage is fed to the inverter control a reference signal. At right side of the model load is connected and the VSI based DSTATCOM is installed at load side with a passive filter element at output of the VSI. The parameters used for designing the system is presented in Table 1.

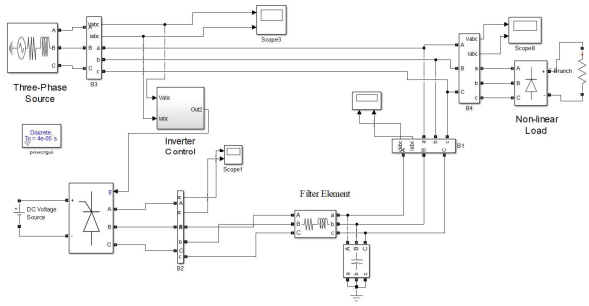


Fig.4. Matlab-model of DTSATCOM

TABLE I DESIGN PARAMETERS FOR DSTATCOM

Parameter	***Values selected***
Voltage, RMS (L-L)	415 V
Source impedance	1.58mH
Frequency	50 Hz
Switching Frequency	7KHz
Filter inductance L_f	310mH
Filter resistance R_f	0.1Ω
Filter capacitor C_f	500 uF
Coupling capacitance	4500 µF
PI gains	0.04, 500
Linear load	10KW
Non-linear load	8KW

The performance of the system is analysed for linear loading, NLL and voltage sag generated due to system fault. For linear loading the voltage output as well s current in load and source terminal is perfectly sinusoidal as shown in figure 5 with negligible harmonic content.

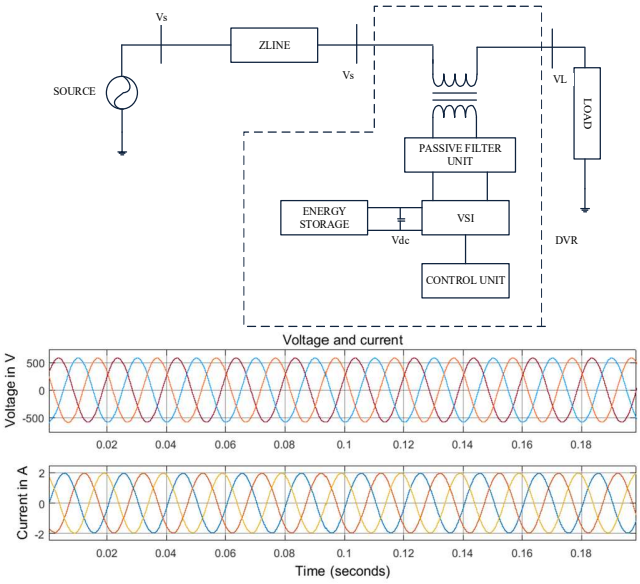


Fig. 5 Output V-I both at grid side as well as load side for linear loading with D-STATCOM

The simultaneous analysis is carried out for NLL as well as Three-Phase Fault (THP). A THP is applied at grid side for the 0.2-0.3 sec. The fault will distort the grid profile and NLL will distort the source as well as load current waveforms as shown in figure 6. DSTATCOM mitigates the source current harmonics and try to negotiate the fault current at load side as shown in figure 7. The THD at this condition for source V & I is reduced as shown in graph 8 on the other-hand THD of load current is very high as shown in figure 9.

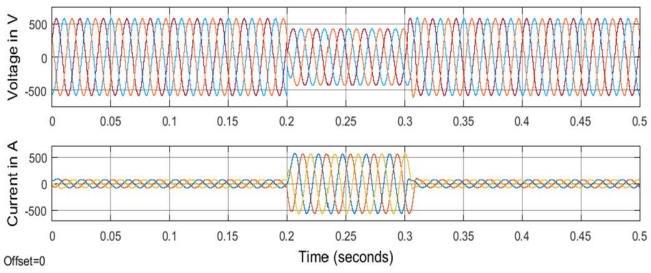


Fig. 6. Source V - I with THP at source side and NLL at load side with DSTATCOM

 ©IJSRED: All Rights are Reserved

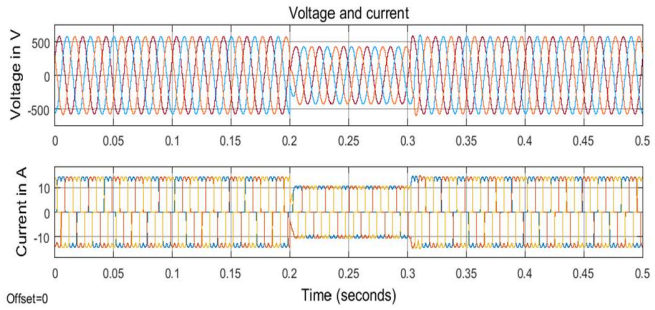


Fig. 7 Load V - I with THP at source side and NLL at load side with DSTATCOM

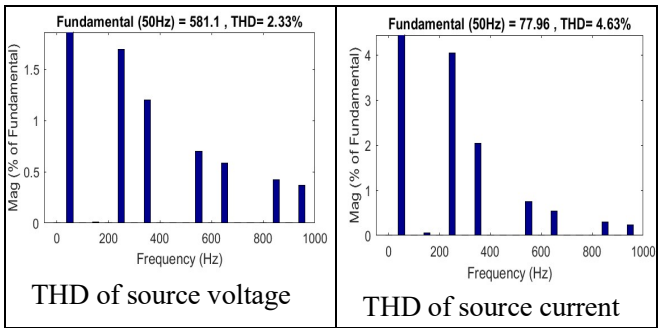


Fig. 8 Source V - I THD with THP at source side and NLL at load side with DSTATCOM

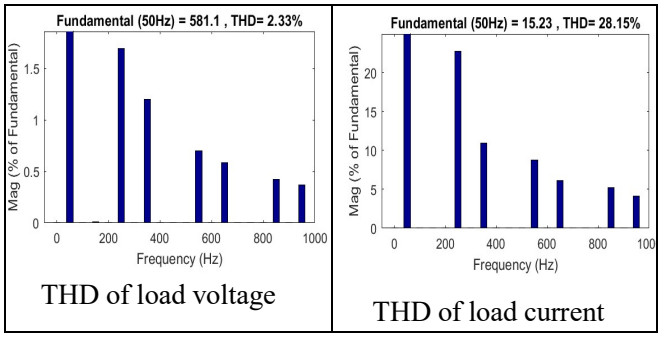


Fig. 9 Load V - I with THP at source side and NLL at load side with DSTATCOM

III. SERIES COMPENSATOR

Series compensator helps in regulating the output voltage under various operating condition of voltage sag/swell and harmonics. Either load side or source side where it is connected. The commonly used series-compensator is Dynamic Voltage Restorer (DVR). DVR system configuration is presented in figure 10.

Fig. 10. DVR schematic diagram

It comprises of coupling transformer to make the impedance of the DVR in series with the system impedance, passive filter, series VSI which generate three phase output, and an energy storage to supply VSI and control system which designs gate pulses for VSI. The Matlab model and design parameter is shown in figure 11 and table 2.

TABLE II DESIGN PARAMETERS FOR DVR AND UPQC

Parameter	Value
Nominal utility voltages (rms)	415 V
Nominal Frequency (ω)	50Hz
DC-link Voltage	140V
Parameters for DVR	
Inverter inductance (L)	45mH
Filter Capacitance (C)	360 µF
Switching frequency	3kHz
Parameters for UPQC	
DC link Capacitance (Cdc)	1200 µF
Inverter inductance (L)	0.5mH
Filter Capacitance (C)	45 µF

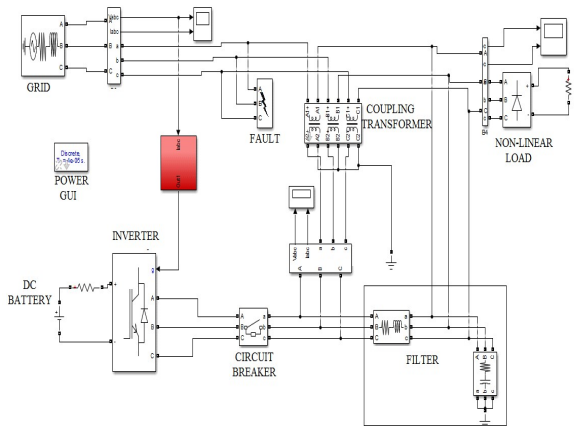


Fig. 11 Matlab model for DVR

A. Simulation Results

In DVR VSI is connected in series with the system at load side via-coupling transformer. Under normal operation with linear loading, source as well as load voltage and current are sinusoidal with 0.9 Power Factor (PF). When NLL is connected at load bus and source side suffers the THP, the voltage distortion at as well as sag is witnessed at both the ends. Also the NLC of load also

 ©IJSRED: All Rights are Reserved

distort the source current as shown in figure 12 when no compensating device is connected. When DVR is connected, it regulates the load voltage by keeping the voltage constant even in the condition of THP and reduces the harmonics as shown in figure 13. Also it eliminates the source voltage and current harmonics a shown in figure 14. From the result figure it can be observed that though

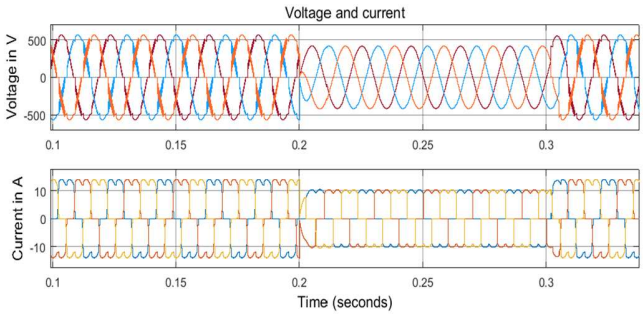


Fig. 12. Source V - I with THP at source side and NLL at load side without compensator

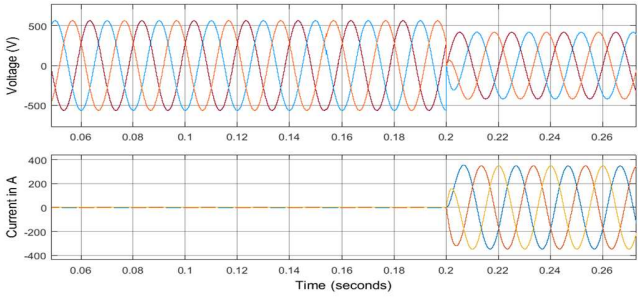


Fig. 13. Source V - I with THP at source side and NLL at load side with DVR

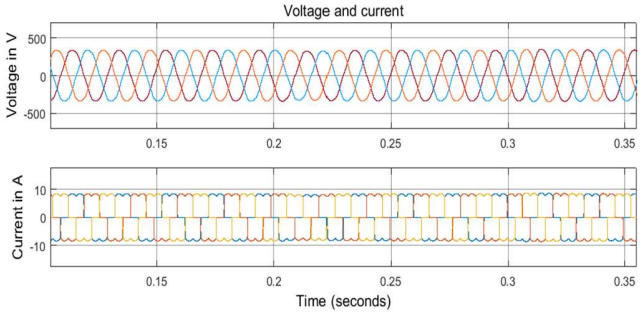


Fig. 14. Load V - I with THP at source side and NLL at load side with DVR

The Source profile harmonics and load profile harmonic graph is shown in figure 15 and figure 16 respectively under the condition of NLL and THP.

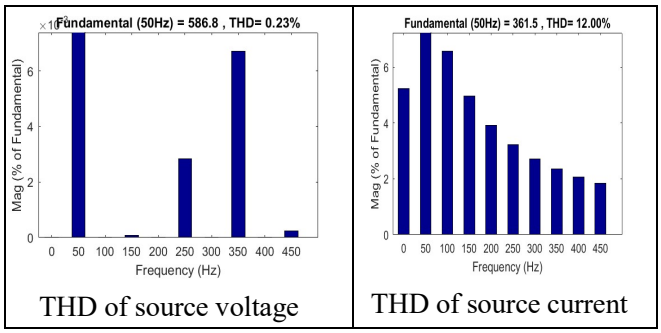


Fig. 15 Source V - I THD with THP at source side and NLL at load side with DVR

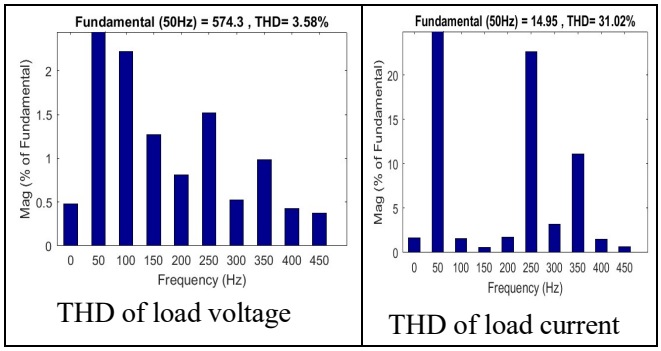


Fig. 16 Load V - I with THP at source side and NLL at load side with DVR

IV. Combine Series-Shunt Compensation

DSTATCOM can mitigate harmonics by graining out NLL current from the system. DVR can regulate the output voltage even under the condition of sag it can keep the bus voltage constant where it is connected, but harmonics are still high under the condition of NLL. Both DSTATCOM and DVR can mitigate source or load profile one at a time. For simultaneous mitigation of current and voltage related abnormalities, Combine Series-Shunt Compensation (CSSC) is connected. The CSSC is termed as Unified Power Quality Conditioner (UPQC). UPQC is a two converter device coupled via DC-link capacitor. The two converters are either connected in series with source side and shunted at load side or vice-versa. The series converter performs the function of DVR and shunt converter performs the function of DSTATCOM. Hence simultaneous voltage-current compensation can be obtained. The schematic diagram of CSSC is given in figure 17.

 ©IJSRED: All Rights are Reserved

The CSSC is designed using 2-VSI converters linked via coupling capacitance at DC side. One convert acting as a current source is shunted directly at load side and compensates the NLL harmonics as well as maintains PF. The another 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 matlab simulation diagram for UPQC is presented in figure 18.

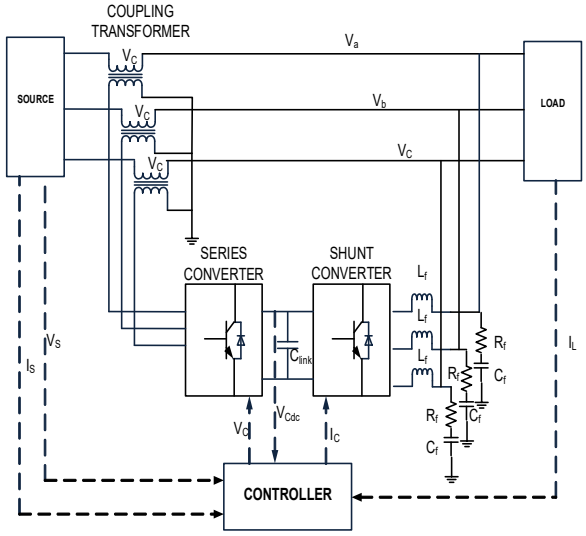


Fig. 17. UPQC schematic diagram

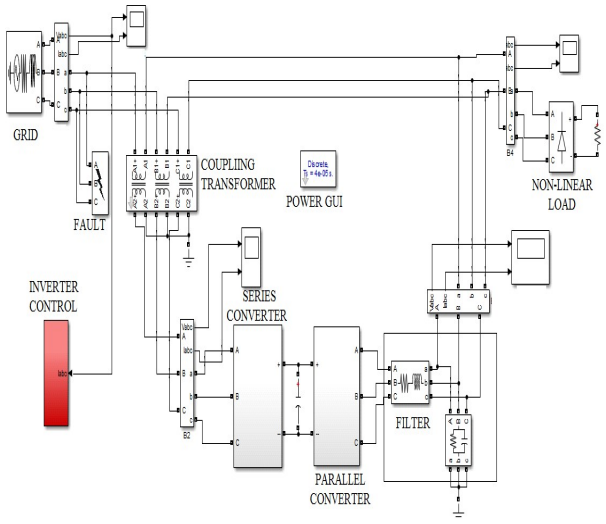


Fig. 18. UPQC matlab model

A. Simulation Results

The performance of the CSSC is analysed for the linear load of 10KW, NLL of 8KW and THP for t=0.2-0.3sec at source side. For linear loading system only supplies the converter losses and V-I waveforms are sinusoidal at load and source side. The UPQC has to compensate for simultaneous NLL and THP. Under such condition, the designed UPQC regulates source as well s load voltage and keep the out voltage constant as shown in figure 19, the source voltage is constant even though THP is applied just after the source bus due to this source current suffers the high fault current condition during the system fault. Also the source current harmonics are eliminated, even though simultaneous NLL is applied with THP at load side as shown in figure 20. The load voltage is also regulated via series VSI and constant voltage is obtained.

The designed UPQC also reduces the NLL current harmonics. The harmonic analysis for source V-I and Load V-I is shown in figure 21 and figure 22 respectively.

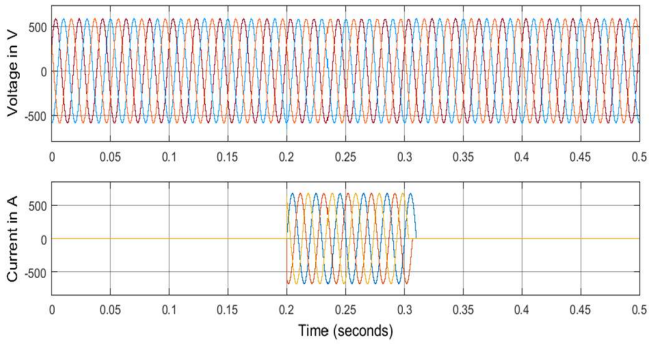


Fig. 19. Source V - I with THP at source side and NLL at load side with UPQC

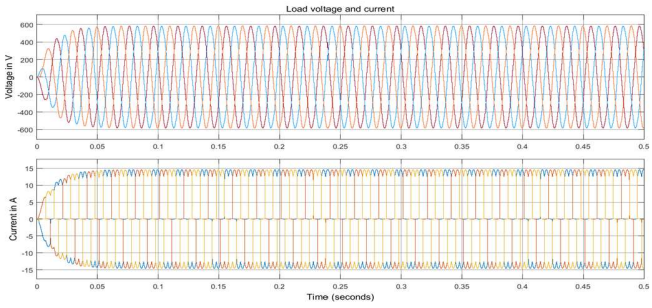
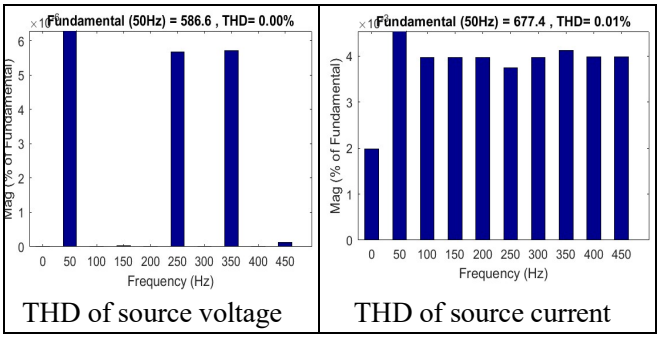


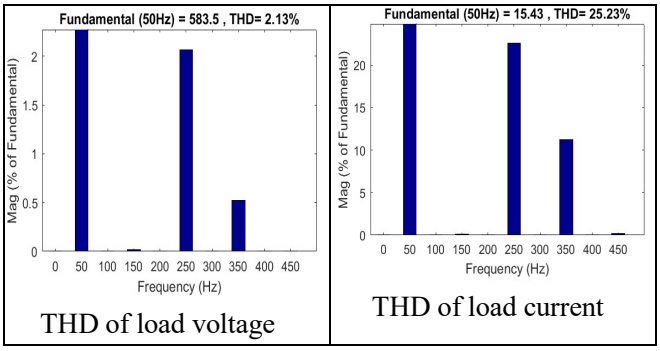
Fig. 20. Load V - I with THP at source side and NLL at load side with UPQC

 ©IJSRED: All Rights are Reserved



THD of source voltage THD of source current

Fig. 21 Source V - I THD with THP at source side and NLL at load side with DVR



THD of load voltage THD of load current

Fig. 22 Load V - I with THP at source side and NLL at load side with DVR

V. Result Comparison

This work presents the comparative analysis of DSTATCOM, DVR and UPQC under the condition of simultaneous occurring of high harmonics due to large NLL and voltage sag due to THP. It can be observed that DSTATCOM can mitigate source voltage and current harmonics by injecting required reactive current into the system. From the graphs of THDs in figure 8 the source voltage THD is limited to 2.3% and source current THD is limited to 4.6%. but, DSTATCOM failed to maintain system voltage under the condition of voltage sag. DVR is capable of regulating load voltage when sag occurs at source bus. Also, it reduces the source voltage harmonics upto 0.23 %. But source current harmonic is high due to the system fault. Contrary UPQC is capable of mitigation source voltage and load voltage sag and keeps the voltage constant even at source side for the THP at source bus. As well as the harmonics for load current are limited to 25% which were 31 % in case of DSTATCOM and 30 % in case of DVR.

CONCLUSION

In this work simulation design for DSTATCOM, DVR and UPQC is presented using matlab power system toolkit in simulink environment. The performance analysis of all the three compensating devices is presented which is widely adopted in DDS. The DSTATCOM is a preferred choice to eliminate harmonics in the system which are the results of NLL or high rating PEDs. On the other hand, DVR is installed to regulate the bus voltage when a condition of sag/swell occurs in the system. But for simultaneous voltage and current control UPQC is used. UPQC can regulate bus voltage at both load and source end and can also mitigate source and load harmonics both at load side and source side. Hence it is superior in performance when compared to DSTATCOM and DVR. UPQC is installed when high degree of precision is required in a distribution system which as a tassel of sensitive equipments.

References

[1] A. Javadi, K. Al-Haddad. (2015). A single-phase active device for powerquality improvement of electrified transportation. IEEE Trans.Ind. Electron. 62(5), 3033–3041.

[2] A.S. Kumar, S. Rajasekar, P.A. Raj. (2015). Power quality profileenhancement of utility connected microgrid system using ANFIS-UPQC. Proc. Technol. 21, 112–119.

[3] Latran, M. B., Teke, A., & Yoldaş, Y. (2015). Mitigation of power quality problems using distribution static synchronous compensator: a comprehensive review. IET power electronics, 8(7), 1312-1328.

[4] Afonso, J. L., Pinto, J. G., & Gonçalves, H. (2013). Active power conditioners to mitigate power quality problems in industrial facilities. InTech.

[5] Santos, N. M., & Pires, V. F. (2012). Three-phase STATCOM based on a single-phase current source inverter. Energy Procedia, 14, 2102-2107.

[6] Manivasagam Rajendran. (2020). Comparison of Various Control Strategies for UPQC to Mitigate PQ Issues. Journal of The Institution of Engineers (India) Series B 102(6):1-11.

 ©IJSRED: All Rights are Reserved

[7] Hossain, M. I., Rahaman, I., Rahman, M. N., Hasan, M. F., Hasan, M. M., & Sarker, R. C. (2020, November). Voltage sag compensation in distribution system using dynamic voltage restorer. In 2020 2nd International Conference on Advanced Information and Communication Techn. (pp. 492-497). IEEE..

[8] Gayatri, M. T. L., Parimi, A. M., & Kumar, A. P. (2016). Utilization of Unified Power Quality Conditioner for voltage sag/swell mitigation in microgrid. Towards Sustainable Energy (PESTSE) (pp. 1-6). IEEE.

[9] Xu, Y., Xiao, X., Sun, Y., & Long, Y. (2016). Voltage sag compensation strategy for unified power quality conditioner with simultaneous reactive power injection. Journal of Modern Power Systems and Clean Energy, 4(1), 113-122.

[10] Kurian, G. M., Jeyanthy, P. A., & Devaraj, D. (2021). Multilevel DC to AC Inverter with Superior Performance. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 3468-3477.

[11] D. Aarthi, R. Manivasagam. (2017). Design and implementation of UPFCusing ten switch converter with switch reduction. Int. J. Eng.Comput. Sci. 6(6), 21861–21869.

[12] D. Aarthi, R. Manivasagam. (2017). Design of UPFC using ten switchconverter with switch reduction. Int. J. Sci. Res. Dev. 5(4),490–493.

[13] C. Benachaiba, A.M.A. Haidar, M. Habab, O. Abdelkhalek. (2011). Smart control of UPCQ within microgrid energy system. Int.J. Energy Proc. 6, 503–512.

[14] R. Manivasagam, V. Dharmalingam. (2014). Power quality problemmitigation by unified power quality conditioner: an adaptivehysteresis control technique. Int. J. Power Electron. 6(4),403–425.

 ©IJSRED: All Rights are Reserved