Power Quality Improvement using PV Integrated Unified Power Quality Conditioner in Distribution System

Manjima R[1*], Shaini AP[2]

[1]Dept. of Electrical and Electronics Engineering, Govt. Engineering College, Bartonhill, Thiruvananthapuram, India

[2]Assistant professor, Dept. of Electrical and Electronics Engineering, Govt. Engineering College, Bartonhill, Thiruvananthapuram, India

*Corresponding author's e-mail: manjima.trv21eepn12@gecbh.ac.in

doi: https://doi.org/10.21467/proceedings.160.51

ABSTRACT

Power Quality is unease in modern power systemfor all. Incorporating renewable energy systems, power electronic equipments have brought numerous problems in power system. Here this paper handles with the power quality difficulties that occurs on the distribution network due to various reasons. Here, the proposed one have integrated photovoltaic (PV) Unified Power Quality Conditioner (UPQC) with synchronous reference frame (SRF), instantaneous reactive power, and PI control theory is presented. But those devices are vulnerable to the variationsin input voltage generated by involvement between the otherparts of system. In the modern age, as there is an increase in costlier sensitive electronic equipment, quality of power received is required by all for a well founded and safe operation in a power system. Power quality problems and low power factorat the PCC in a single load as well as in bus system are here efficiently compensated by the system, which is connected with shunt and series compensaters and a dc link capacitor. The efficacy of the system is studied using MATLAB/Simulink in a 16 bus distribution system under various conditions that causes sag in the system.

Keywords: Unified Power Quality Conditioner, Synchronous reference frame theory, Point of common coupling

1 Introduction

Use of conventional energy sources for meeting global energy demand is at risk now a days. The integration of green energy to distribution network are now becoming popular. This integration reduces the dependence on imported fuels. But for the amalgamation, we need power electronics converters. But these converters as well as the non-linear loads in system causes some problems in power quality such as when power factor is poor, voltage sag, swell, and when harmonics occurs. These power quality issues at distribution level causes the decrease in efficiency of all the systems near to the bus system where the problem occurs [8]. Voltage sag can be said as the reduction in magnitude of voltage in between 0.1 to 0.9 pu rms voltage for less than 1 minute [16]. Sag of voltage are produced in a distribution network due to fault in any of the buses or can be due induction motors starting. Voltage swell is said to be rise in voltage level occurring due to the sudden thrown off high loads lasting for few seconds to minutes. These power quality problems can be harmful to equipment and appliances and even cause fire.

Some ways to reduce power quality issues in distribution network are maintaining voltage within limits using voltage regulators and tap changing transformers or by reactive power compensation [6] since its necessary to maintain magnetic field in inductive loads using capacitors, inductors and static VAR compensators or by harmonic mitigation using filters and harmonic mitigating transformers or by fault detection and isolation or by usage of energy storage systems like batteries or flywheels. So power quality improvement have to be a combination measures and technologies to ensure better quality of power supply [8].

Proceedings DOI: 10.21467/proceedings.160; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-965621-9-9

To dwindle these problems customised devices have been mainly used in distribution side for example, DSTATCOM (Distribution static compensators), DVR (Dynamic voltage regulator) and UPQC (Unified power quality conditioners) were used. DVR acts against voltage related problems [5] which is a disadvantage of the device and its subjected to long reactive power deficiencies. And DSTATCOM acts for current related problems and UPQC combines both of these functions more effectively. UPQC serves similiar to a UPFC in transmission side. UPQC can be said as an extension of UPFC at the distribution level.

Different types of UPQCs are there on the basis of configuration, constructions etc like Open UPQC [7], single and three phase, UPQC-D, UPQC-DG, UPQC-I etc [14]. Open type UPQC has many disadvantages such as its bulky, high losses and low efficiency [4]. In multi level converter based UPQCs voltage unbalances may occur between different levels and there is a centralised controls [9]. The CSI based UPQC configuration have higher losses and cost. It have an inductor in common whereas in VSI based UPQC there is capacitor in common as energy storage. To level out sag, UPQC-P uses active power regulation in this scenario, but an increasein magnitude of source current during that period can be noticed. In case of reactive power control using UPQC-Q, sag is reduced by injecting reactive power via a series inverter, but it could not lessen swell in the system when VA loading is in minimum series voltage injected at a particular angle concerning source current. In [13], conventional controls were used in together with a Low pass filter applied to d-axis component that causes the distribution network's PQ to drop. A mixed strategy for compensation for PQ in LV secondary electrical distribution system is investigated here in [13] which have three separate compensation mode using micro compensator.

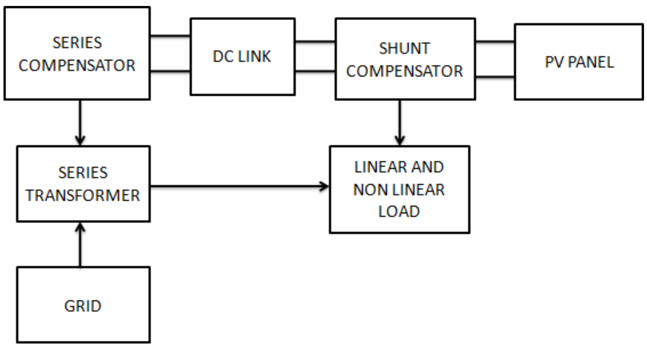

Figure 1: *Block diagram of PV-UPQC*

When there is no sources to support UPQC other than grid system, unbalance may occur. To mitigate the problem renewable sources can be added to the network [2]. As we know the most abundant energy sources is solar energy. The rate at which solar energy is received is greater compared withthe rate of usage. Therefore the combination of PV with UPQCis the most suitable solution to the continuous unbalances that may occur in the system as shown in fig.1. The benefits of using PV-UPQC in distribution network include improved power quality, decreasein system losses, and increase in power transfer capability. ThePV system can provide clean and renewable energy to network while UPQC compensates for power quality issues [3].

For the proper functioning of the system, control signals have to be given which generates the corresponding reference signals for determining the two converters switching which helps to get the desired outputs [10]. Here in PV combined UPQC, range scale of PV depends on voltage across the dc link exists with respect to two converters. In here, a singular configuration of PV is considered [1]. The implemented control strategy should help to get balance between PV, load and grid.A three phase four wire system needs more compensations. Sovarious types of shunt configurations for inverter have been tried [8]. The control can be divided into frequency domain which consists of wavelet transform which are inefficient during dynamic conditions due to large memory its needs and time domain controls which mainly consists of soft computingtechniques like ANN [11].

UPQC have two VSCs connected parallel to a capacitor which is the dc link [15]. And three of these systems need to receive a control signal. Synchronous reference theory with instantaneous reactive power theory were applied for formation of reference current signal as well as voltage signal for the VSCs. Proportional-Integral control were applied for the maintenance of dc link capacitor voltage. Both of these converters along with efficient control helps in diminishing the voltage current issues in a single load network with an RL load connected via diode bridge rectifier of three phase and voltage issues in distribution network bus system[12].

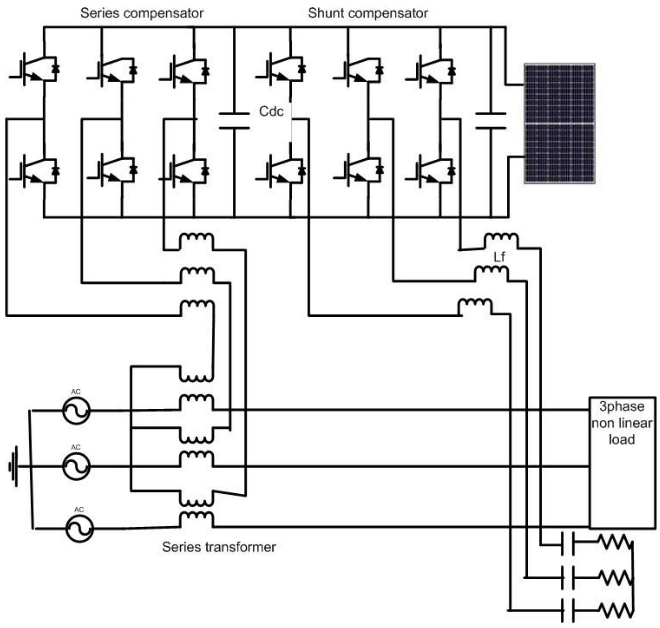

Figure 2: *Circuit diagram of PV-UPQC*

1.1 Research contribution

- Implementing UPQC will help a 16 bus distribution network's power quality problems related to voltage and current to be minimised.
- Improving performance of series VSC when voltage sag and swell conditions appears.

1.2 Paper organisation

- UPQC implementation of UPQC for minimizing power quality problems relating to voltage and the current in presence of non linear load.
- Performance improvement of series VSC when voltage sag and swell appears.
- Implementating UPQC in a 16 bus distribution network for minimizing voltage related issues.

2 System Structure

A PV integrated UPQC block diagram is shown in fig 1. UPQC is an electronics based device which can be utilisedin recompense power quality issues which can be said as the merging of series and a parallel compensator connected acrossthe dc link capacitor as common.

As the PV-UPQC depicted in fig.2 [1] comprises of an active filterthat is coupled to the grid in series whereas another activefilter is connected parallel to grid. Here a single phase PV is used and is connected to shunt converter. Based on the limit ofcurrent distortion and limit of loss of control in shunt compensater, voltage across the DC link should be greater than double the system phase voltage. So the dc link voltage and voltage from PV would be same and therefore no boost converter is needed here. A series injection transformer of three phase is connected from the source side to the series connected VSC. And the load connected to the shunt compensator through interfacing inductors (L_f). There are some current components that are produced as a result of dynamic conditions. It cannot be controlled by compensators, so they can be limited by using interfacing inductors. Interfacing inductors helps in blocking dc offset voltage between the two converters. Due to the switching of the VSCs high frequency components of voltages were developed which can be eliminated using filters (L_r, C_r) and (C_f, R_f). For protecting UPQC from electric surges and transients a low impedance path for high frequency components had been created. To study the efficacy of system when a non-linear load is connected, load of RL is provided through a bridge diode rectifier.

3 Scheme of Control

The PV-UPQC is a complex device which consists of series voltage converter and shunt voltage converter and PV is integrated to increase renewable energy share and reduce fossil fuel usage. Effective control of the components in the system will result in efficient compensation of problems related to power quality due to presence of nonlinear load connected and harmonics which is present in the system. The com- pensator in series solves sag and swell and harmonics of load voltage and shunt compensator mitigates current related issues and helps in regulating dc link capacitor voltages. As for control mainly three controls are needed. One for shunt compensator, other for series compensator and for dc link voltage control. The control scheme helps in generating reference signal for determining switching periods and timings of compensators and thereby giving results. Reference phase for the control have been generated using PLL in simulink. The reference angle determines the relationship between UPQC output voltage and grid voltage and is used to ensure UPQC operates effectively in mitigating power quality issues.

3.1 Series converter control

In a PV integrated UPQC, series converter is essential in managing PQ in a system. SRFT and the IRPT were the one used in here for controlling of series converter. In a three phase system, SRF theory helps in decoupling of reactive and active power components. Here components of a three phase system is converted to rotating reference frame so that power components will be easily and independently managed. Here the voltages currents from both source side and load side are measured and are converted to dq0 frame. By converting to dq0 axis, the computation can be made much easier and also the power component controlled separately. But IRPT is a control strategy which uses instantaneous power theory to control the power flow with in a system. Here instantaneous reactive and active power of system are calculated by using the voltage and current signals. The voltage level of any system can be regulated by having control over the reactive power component. Load power and reference power are then calculated. Voltage is calculated using these power and current which is converted back to abc frame and used as series converter pulse with the help of hysteresis controller.

3.2 Shunt converter control

The systematic control helps in generating reference current for the switching of shunt converter. Dc link voltage provides switching losses of the converters. Since PV is also merged to shunt converter controller must be efficient to stabilise the dc capacitor voltage across converters. PI controller can be applied to understand the error between measured and desired capacitor values. Resulting control signal can be applied to shunt control technique. Reference current can be found out by SRF and IRPF integrating it with error of capacitor voltage. The reference current hence found out is converted back to abc parameters and pulses are generated by using hysteresis controller.

3.3 Voltage control in DC link

In PV-UPQC, dc link voltage have to be maintained and its crucial. Controller tracks error between desired and measured values of capacitor voltages for balancing the voltage across dc link. This paper have a PI controller. PI controller is simple and its easier to implement. The voltage across link capacitor will be balanced with help of shunt converter. The difference in the reference and actual voltage measured at the link capacitor was calculated by P-I controller. The proportional term of PI controller helps in providing a sudden response to error, and whereas integral term reduces error in steadystate .

4 Distribution Network

To analyse the effect of compensation using UPQC in electrical distribution system, a distribution network of 16 bus is created as shown in Fig.3. The 16bus distribution network is here modeled as an radial network, where the distribution lines is a tree-like structure with a single source node at the start and multiple load nodes at the end. The radial networkis the simplest and its useful when the generation is in low voltage. The distribution network is of 600 V, 100 MVA, 50 Hz input. Different conditions to create sag are applied, andin each cases the performance of UPQC is studied.

4.1 Induction motor connected in one of the buses

Connection of an induction motor to a distribution network have significant effect in quality of power and stability of the whole network. When induction motor is added to any of the buses, voltage sag occurs in other buses also. Induction motor have a low power factor and have high starting current and these causes voltage drop in buses. Induction motor starting on full voltage have effect of taking five to ten times or more of motor full load current which is undesirable in terms of per-formance. Voltage sag may cause equipment malfunctioning as well as disruptions and losses. To prevent these protective devices can be used and operators can implement soft starters to reduce starting current, or can adjust network configurations to minimize the impact of sag caused by induction motors.

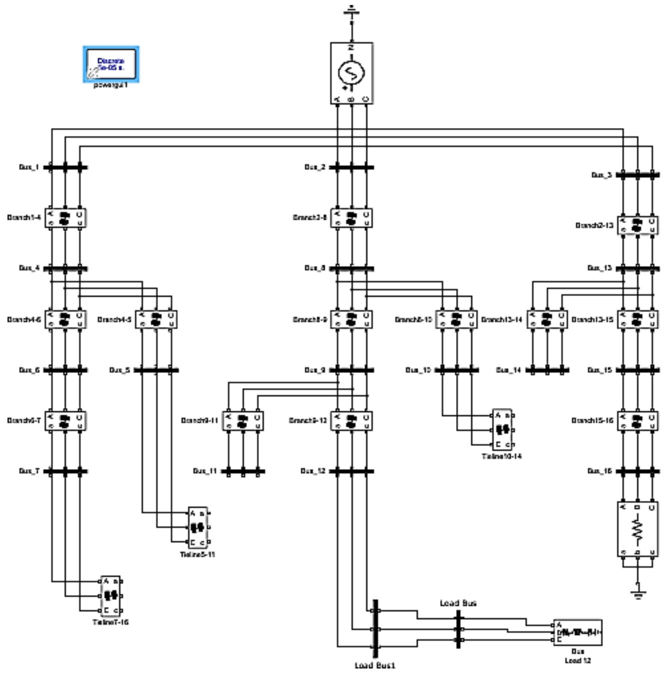

Figure 3: *16 bus distribution network*

Proceedings DOI: 10.21467/proceedings.160
ISBN: 978-81-965621-9-9

4.2 Fault occurs in one of the buses

In a distribution network, faults will occur because of manyreasons such as failure of equipment, breakdown of insulation, or other factors as external like lightning-thunder strikes. Fault in distribution network can cause dip in voltage which is the temporarily dip in voltage at time during fault. When fault occurs, it may spread to different parts of the network depending on the R/X ratio of the system. Closer the fault, the greater the voltage sag. When fault occurs in any of the buses, it will causes voltage sag in neighbouring buses too. When fault occurs in a system then current increases and voltage decreases. Current increase occur due to decrease in system impedance and voltage decrease due to demagnetizing nature of armature reaction. UPQC may not be able to fully compensate for all type of faults. The degree upto which UPQC can compensate depends on several factors such as duration of sag and severity, load characteristics etc.

5 Simulation Results

5.1 Performance under sag condition

To study the performance of shunt and series converter, a sag as 0.6 pu is applied from 0.4 to 0.6 s. Its shown as Fig.4. During sag, series converter converts dc voltage across dc link capacitor to ac and injects it through a injection transformer as shown in fig. 5 and 6. And thereby the sag can be compensatedand a sinusoidal waveform of equal magnitude is obtained at output as shown in Fig.9 and Fig.10. PV and the grid are working intogether to meet the load balancing requirements byusing shunt VSC. This whole performance of UPQC depends on the duration of sag as well as size and capacity of UPQC. But it have limitation when the sag exists for a prolonged duration. Even when non linear load is present, UPQC helps maintaining power factor as unity at common coupling point.

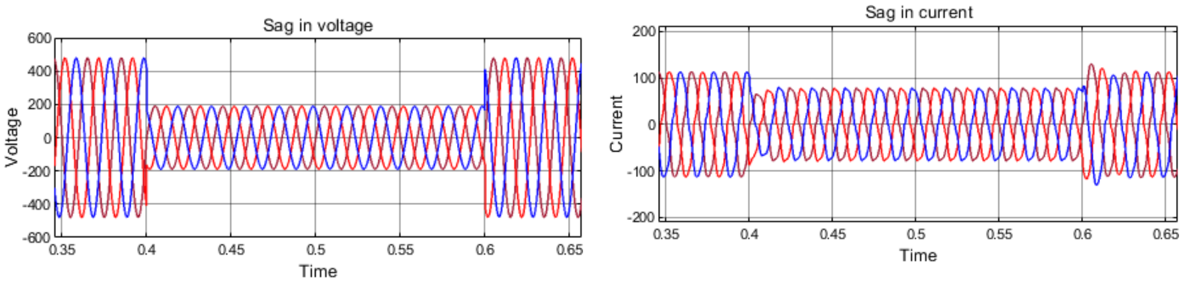

Figure 4: *Behaviour of system with sag*

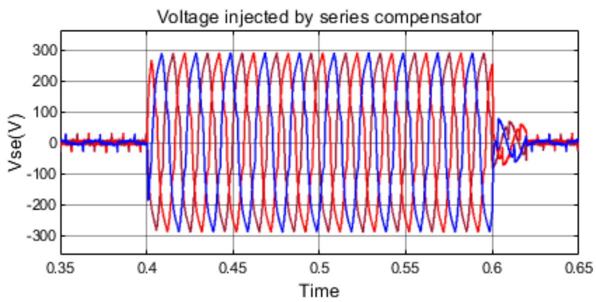

Figure 5: *Injected voltage during sag*

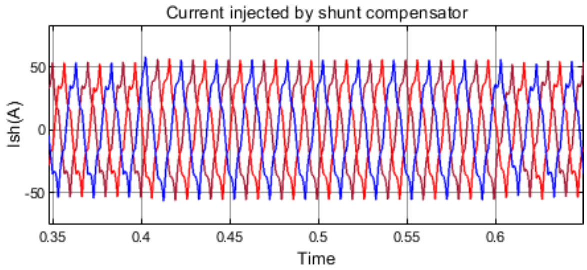

Figure 6: *Injected current during sag*

5.2 Performance under swell condition

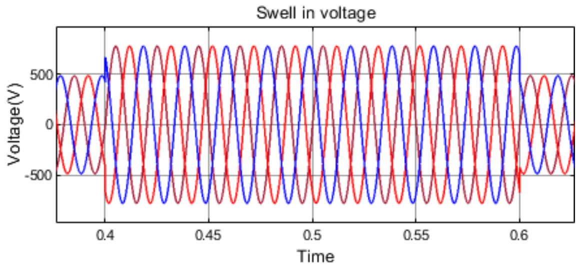

Figure 7: *Behaviour of system with swell*

To study the performance of system under swell conditions,swell is applied as in Fig.7. Swell may cause damage and malfunctioning to the other equipments in the system. Herewe can see that the injection transformer injects voltage which have a phase shift of 180 degrees as shown in fig. 8 andhence cancel out the swell as shown in fig. 9. The shuntcompensator in the UPQC system detects increase in voltage and reactive power was getting injected to our system forregulating the voltage at coupling point. By cancelling out the swell in voltage, UPQC can protect the devices from damageand the system from shut down.

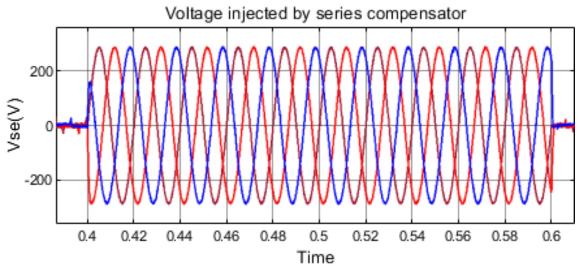

Figure 8: *Injected voltage during swell*

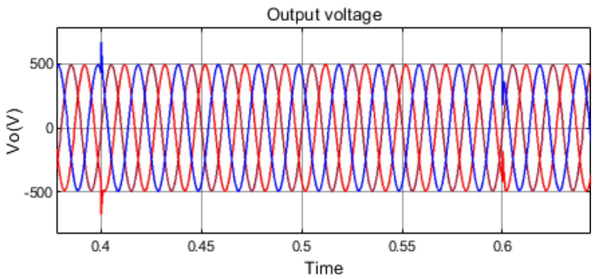

Figure 9: *Output voltage*

Proceedings DOI: 10.21467/proceedings.160
ISBN: 978-81-965621-9-9

Series: AIJR Proceedings
ISSN: 2582-3922

5.3 Performance when induction motor is connected in system

Since induction motor draws a large starting current, it causes a voltage sag. An induction motor has been connected to a 16 bus distribution network system in 16th bus. Then as shown in Fig.11 sag can be seen in buses 13, 14, 15 and 16. And the amount of sag is seen more in 16th bus. So UPQC is added to 16th bus. And due to the effect of UPQC, sag is compensated as seen in Fig.13.

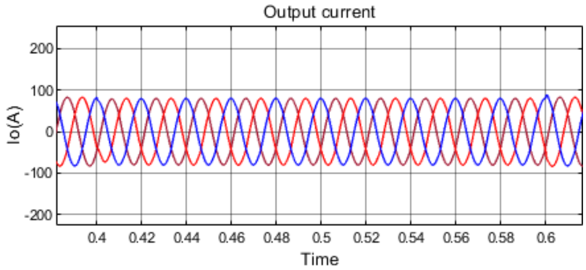

Figure 10: *Output current*

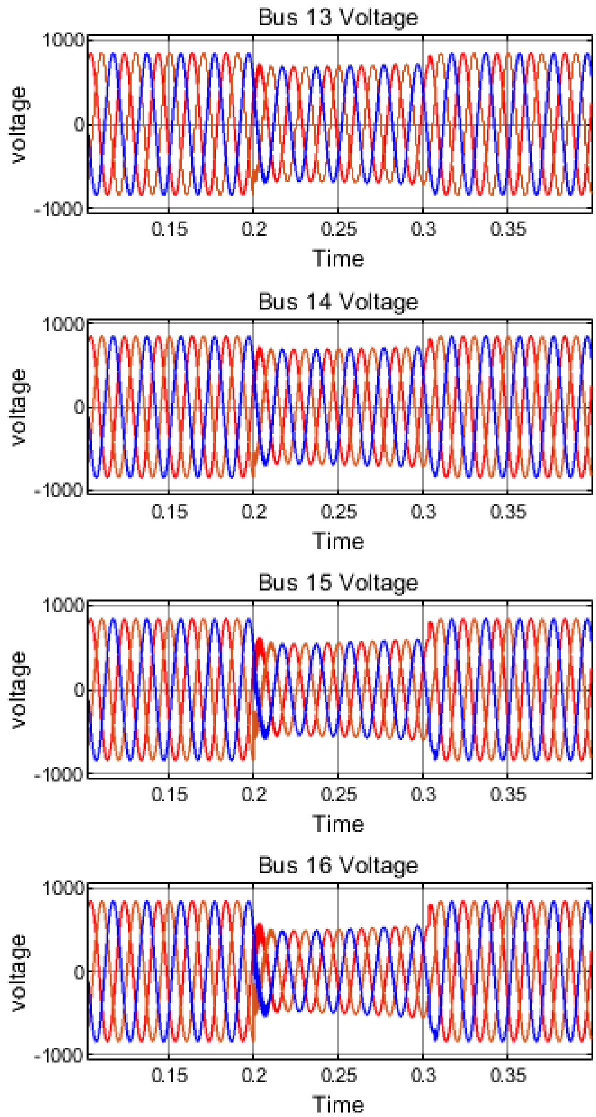

Figure 11: *Induction motor connected to network*

5.4 Performance when fault occur in system

Fault occurring in a network causes increase in current and thereby reduce the voltage. Hence sag occurs to the fault occurring bus as well as in neighbouring buses. A three phase fault is put in to bus 16 from 0.2s to 0.3s to study the effectof UPQC for compensating the sag. As shown in fig. 12. the fault creates sag in neighbouring buses; such as in 13, 14, 15, and 16th buses. The speed of spreading of fault depends on factors like impedance, response time, fault type etc. A short circuit fault may spread quickly due to low impedance whereasground fault spread slow as it has high impedance. The amount of sag is more in bus 16 because the fault is occurring nearthat bus, so UPQC is added in bus 16. The nearer the fault the greater the sag. After adding UPQC, sag is compensated effectively as shown in Fig.13. The values of variations found before and after compensation in MATLAB are given in Table 1.

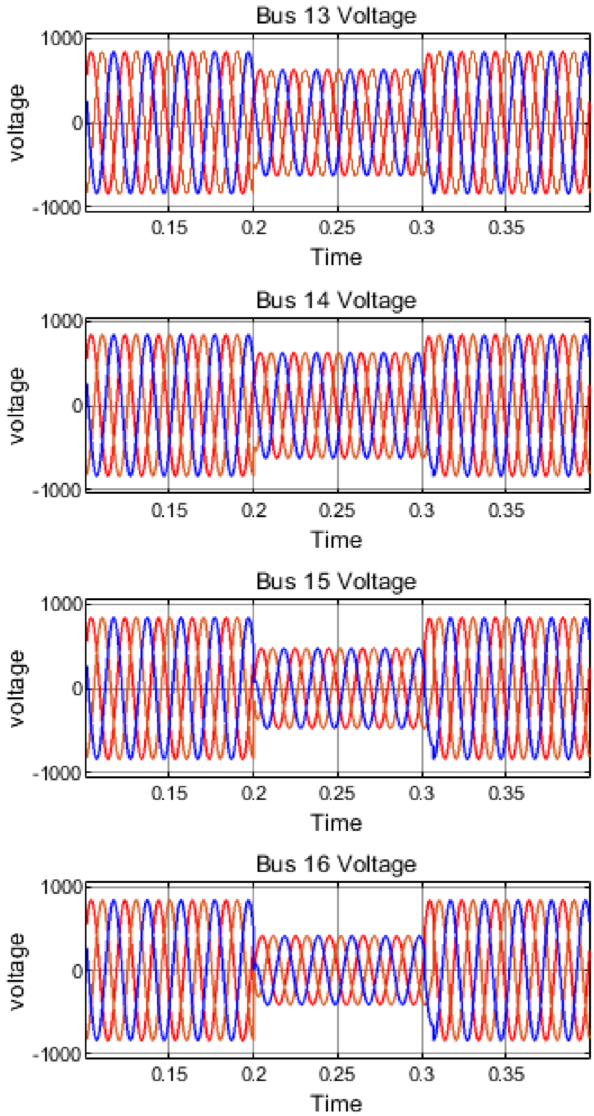

Figure 12: *Fault occurring in system*

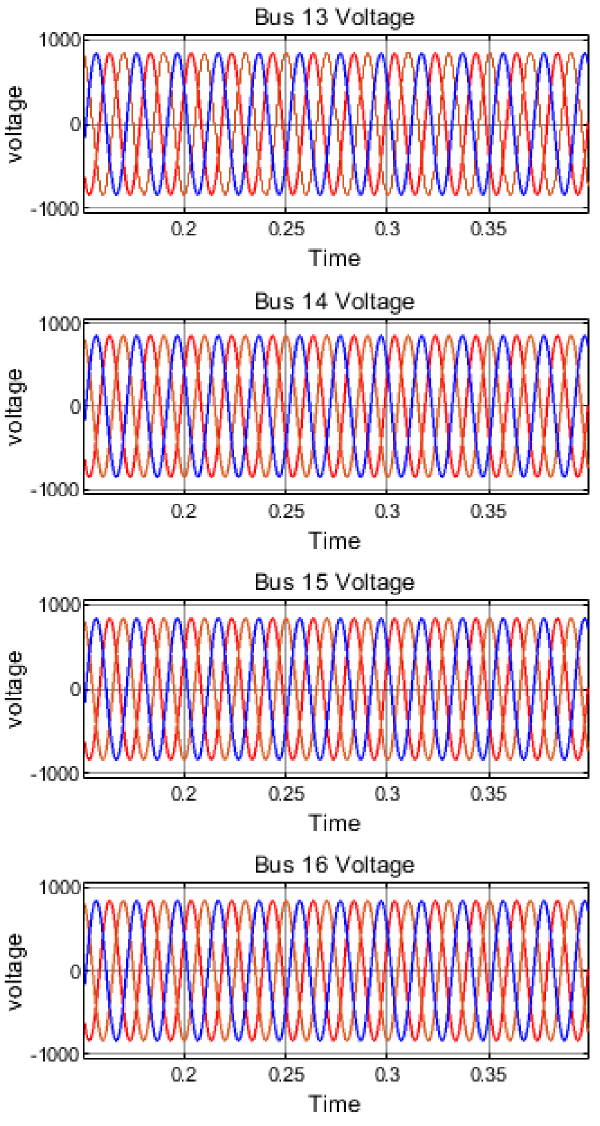

Figure 13: *Output after compensations*

Table 1: *Values before and after Compensation.*

Condition	Before compensation	After compensation
Sag	200 V	500 V
Swell	750 V	500 V
IM	500 V	600 V
Fault	300 V	600 V

6 Conclusion

The compensation of Power Quality issues that can be seen in a distribution network are presented here. The overall performance in presence of a non-linear load as well as in 16 bus distribution network are validated here through simulation. The series converter effectively compensates for sag and swell, andthe load voltage is maintained as such. And shunt compensator balances load and then make the current at grid sinusoidal. Effectiveness of system can be further increased by adding PV to the system. By making the system PV integrated the total burden can be reduced. So by effectively implementing the whole system, the overall performance can be improved.

7 Publisher's Note

AIJR remains neutral with regard to jurisdictional claims in institutional affiliations.

How to Cite

Manjima & Shaini (2023). Power Quality Improvement using PV Integrated Unified Power Quality Conditioner in Distribution System. *AIJR Proceedings*, 392-402. https://doi.org/10.21467/proceedings.160.51

References

[1] P. Ray and P. K. Ray, SK Dash, "Power Quality Enhancement and Power Flow Analysis of a PV Integrated UPQC System in a DistributionNetwork," IEEE Transactions on Industry Applications Vol: 58, Feb. 2022.

[2] B. Gopal, Pannala Krishna Murthy, G. N. Sreenivas, "Power Quality Improvement Using UPQC Integrated with Distributed Generation Net- work ," International Journal of Electrical and Computer Engineering Vol:8, No:7, 2014.

[3] P. Ray and P. K. Ray, "Design and control of PV-UPQC using variable leaky LMS based algorithm for power quality enhancement," in Proc. 3rdInt.Conf.Energy, Power Environ., Towards Clean Energy Technol.,2021,pp. 1–6.

[4] V. Khadkikar, "Enhancing electric power quality using upqc: A com- prehensive overview," IEEE transactions on Power Electronics, vol. 27, no. 5, pp. 2284–2297, 2011.

[5] N. Abas, S. Dilshad, "Power Quality improvement using Dynamic Voltage Restorer," IEEE Access, vol. 8, 2020.

[6] B. Singh, A. Chandra, and K. A. Haddad, "Power Quality: Problemsand Mitigation Techniques," London, U.K.: Wiley, 2015.

[7] S. K. Dash and P. K. Ray, "A new PV-open-UPQC configuration for voltage sensitive loads utilizing novel adaptive controllers," P IEEE Trans. Ind. Inform., vol. 17, no. 1, pp. 421–429, Jan. 2021.

[8] Y.Chen,X.Zha,andJ.Wang, "Unified power quality conditioner(UPQC): The theory, modeling and application," n Proc. Int. Conf. Power Syst. Technol., 2000, vol. 3, pp. 1329–1333.

[9] D.Graovac, V.Katic, and A.Rufer, "Power quality problems compensa- tion with universal power quality conditioning system," IEEE Trans. Power Del., vol. 22, no. 2, pp. 968–976, Apr. 2007.

[10] S.Chandrakala Devi, B.Singh, and S.Devassy,"Modified generalised in- tegrator based control strategy for solar PV fed UPQC enabling power quality improvement," IET Gener., Transmiss., Distrib., vol. 14, no.16, pp. 3127–3138, 2020.

[11] SR.K.Agarwal,I.Hussain,andB.Singh,"Application of LMS-based NN structure for power quality enhancement in a distribution network under abnormal conditions," IEEE Trans. Neural Netw. Learn. Syst., vol. 29, no. 5, pp. 1598–1607, May 2018.

[12] S. Civanlar; J.J. Grainger; H. Yin, S.S.H. Lee,"Distribution feeder re- configuration for loss reduction," IEEE Transactions on Power DeliveryVol.3, July 1988.

[13] Jino M. Pattery, Sandeep Jayaprakasan, Elizabeth P. Cheriyan, RijilRamchand, "A Composite Strategy for Improved Power Quality Using Micro Compensators in Secondary Distribution Systems," IEEE Trans- actions on Power Delivery, Vol. 37, April 2022.

[14] Payal Deshpande, Amit Shrivastava, Anula Khare,"Different Modeling Aspects and Energy Systems of Unified Power Quality Conditioner(UPQC): An Overview," International Journal of Renewable Energy Research, Vol.3, No.2, 2013 .

[15] Sneha Bageshwar, Dr. D. P. Kothari, "A Review on Power Quality Improvement by UPQC ,"International Journal of Science and Research,Vol. 4, March 2015.

[16] Sneha Jose, Sreehari.S , " Synchronous Reference Frame Based Control Method for UPQC," International Research Journal of Engineering and Technology, Vol: 02, July-2015.