Distribution Grid Voltage Regulation for Power Quality Improvement Using UPQC

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Abstract— Poor voltage regulation is experienced for the costumers connected at the end of low voltage distribution grid. In the proposed paper, voltage regulation is achieved in the distribution grid using Unified Power Quality Compensator (UPQC). Different control techniques are used for shunt inverter in UPQC to improve the power quality of the Distribution Grid. Control techniques, including the PI control, DQ control and Minimum Power Point Tracking (mPPT) for voltage control are analyzed and simulated in the proposed paper. Simulation with UPQC is done for three different control techniques and its performances are compared. The mPPT avoids the circulation of unnecessary reactive compensation for voltage regulation by operating at the Minimum Power Point (mPP). Comparative analysis is made for UPQC with the different control techniques during sag, swell and fault condition. The simulation of distribution Grid for voltage regulation using UPQC is carried out using MATLAB Simulink.

Keywords- *Unified power quality conditioners (UPQC), Minimum Power Point Tracking, Power Quality, DQ control, Total Harmonic Distortion(THD)*

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I. INTRODUCTION

Power quality mainly deals with the interaction among the customers and the utility or it can be said that it provides an interaction between the power system and the consumers. The ultimate goal of power system is the supply of electric energy to its customers. In the last 50 years or so, because of the extensive growth of industries electricity demand has tremendously increased which has led to establishment of many power generation and distribution grid. The demand for large amount of power for industrial and domestic use increased the burden on the generation. Electrical utilities working today are working as a subsystem of a large utility network that are tied together in order to form a complex grid. All these factors have put the power system under the requirement of a power quality.

To improve the power quality, devices and equipments like DSTATCOM (distribution static compensation) DVR (dynamic voltage restorer), UPQC (Unified Power Quality Conditioner) etc are used. The active power component theory (APCT) has used to control shunt active power, reactive power and non-linear load compensation [1]. To meet the voltage regulation requirement, a voltage-controlled DSTATCOM-based voltage regulator is proposed with shunt connection to PCC [2]. The shunt connection avoids power supply interruption while the voltage regulator is installed or disconnected.

Co-operative control on voltage harmonics and unbalances in a grid is used by UPQC which provides a solution for Power Quality problem. For frequency tracking and extraction of harmonics in grid voltage and load currents the concept of neuro-fuzzy controller is proposed [3].

A review on the UPQC to enhance the electric power quality at distribution level[4]. The UPQC is able to compensate supply voltage power quality issues such as, sags, swells, unbalance, flicker, harmonics, and for load current power quality problems such as, harmonics, unbalance, reactive current and neutral current. In this paper several UPQC configurations have been discussed. Among all these configurations, UPQCDG could be the most interesting topology for a renewable energy based power system.

The combined operation of UPQC with DG is explained [5]. The proposed system is composed of series and shunt inverter, wind energy system connected to the DC link through rectifier. The proposed system is able to compensate voltage sag, voltage swell, voltage interruption and current harmonics in interconnected and islanding mode.

The new configuration is named unified power-quality conditioner with Photo Voltaic System (UPQC-PV) [6]. Compared to a conventional UPQC, the proposed topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell, and interruption in both islanding and interconnected modes.

Distribution grid is the final stage of the electrical power system in which electricity is supplied to homes, industry and other end users. Distribution grid with UPQC as a voltage regulator is proposed in this paper to control the quality of power. Voltage of the shunt inverter is maintained using two control techniques such as Minimum Power Point Tracking for voltage control and DQ control.

The performance of the distribution grid with and without UPQC is compared for different control techniques during the sag, swell and fault condition.

II. UNIFIED POWER QUALITY CONTROLLER

In the context of up-gradation of quality of power UPQC plays a very vital role. It provides both parallel and series active power filter. Being a multitasking power conditioner UPQC can be utilized for compensation of numerous voltage disturbances, voltage flicker and it also provides prevention to the harmonics in the load current and doesn't allow them to enter into the power system. This custom power equipment has the ability to mitigate the problems which affect the sensitive equipment or loads. UPQC provides compensation to harmonics in current (shunt part) as well as that to the voltage (series part), controls the flow of power and also overcomes the disturbances in voltage like voltage swell, sag etc. The essential parts of unified power quality conditioner are shunt inverter, series inverter, Dc link capacitor, Shunt coupling inductor and series transformer.

A. UPQC configuration

UPQC mainly consists of Shunt inverter and series inverter.

Shunt inverter: A shunt connected voltage source inverter acts as shunt inverter. It is helpful in cancellation of current distortions i.e. compensates the harmonic current of the load. It also provides assistance in keeping up a steady value for the DC link capacitor voltage. It helps in improvement of system power factor. Furthermore it is also helpful in compensation of load reactive current. PWM techniques are used for controlling the shunt inverter. Its main function is to compensate for the reactive component and the harmonic component of load current and to compensate for interruptions and inject the active power generated by DC link capacitor or voltage source to the load.

Series inverter: It is a series connected VSI (voltage-source inverter) acting as a source of voltage. Its connection is in series with the line by using a series transformer. It helps in overcoming the voltage based distortions. It helps in maintaining a sinusoidal load voltage by eliminating the load voltage imbalances and the flickers in the terminal voltage. Its main function is to mitigate voltage sag and swell and to compensate for voltage distortions, such as Harmonics.

DC link capacitor: It is used for back to back connection of the series and shunt VSIs. The DC voltage developed across the capacitor acts as a constant voltage and helps in proper operation of both shunt and series inverters. If regulated properly the voltage provided by this capacitor can be used as source for both active and reactive power and the use of any outer DC source e.g. battery etc. can be eliminated.

Shunt coupling inductor: It is helpful in interfacing of the shunt inverter to the network. The main benefit of this is to smoothen the wave shape of the current by elimination of the ripples produced in the current.

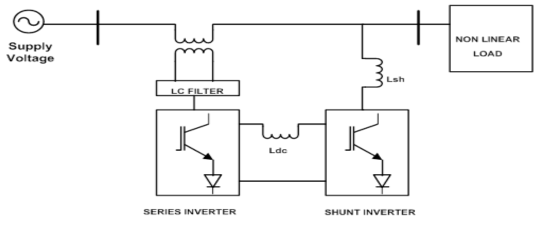

Fig1 Block diagram of UPQC

LC filter: It is present near the series inverter output of UPQC. Acting as a low-pass filter (LPF), it is helpful in attenuation of high-frequency voltage components of the output voltage of the series inverter.

Series transformer: Series inverter helps in injection of load voltage through the series transformer. It is required to maintain a particular turn's ratio in order to maintain a low current flow through the series inverter.

III. CLOSED LOOP CONTROL TECHNIQUES

The control techniques used for shunt inverter are as follows:

1. Minimum Power Point Tracking for voltage control
2. DQ control

A. Minimum Power Point Tracking for voltage control

The Voltage is controlled using mPPT control technique using P&O algorithm. By using mPPT method shunt inverter is controlled to absorb the extra voltage in the system and inject the voltage when voltage falls below the required voltage.

The Perturb & Operation (P&O) algorithm is implemented in PV systems to track the maximum power point (MPPT) [7]. But in the proposed paper, P&O algorithm is used for minimum power point tracking for reactive power control of the system. When the voltage amplitude is increased and the power is reduced the next perturbation will be in the same way. The second is the sample time, which must be If the power is increased and voltage is reduced then perturbation will be in the opposite way. If voltage is increased or it is decreased then same analysis is applied.

Simplified voltage conrol loop block diagram is as shown in fig 2. Fig 3 represents its flowchart. The apparent power S_a ,S_b, S_c and voltage 'v' of the shunt inverter are measured. Three phase RMS voltage is added and compared with the previous iteration. Then voltage of current iteration and previous iteration are compared. If power and voltage is more in current iteration then voltage is decreased or else it is increased. If power is more and voltage is less than the previous iteration then the voltage is increased or else

 ISSN: 2321-8169
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voltage is decreased. And thus the voltage at PCC is controlled.

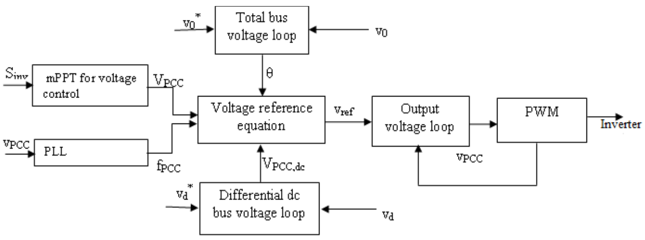

Fig.2. Control block diagram of voltage controller

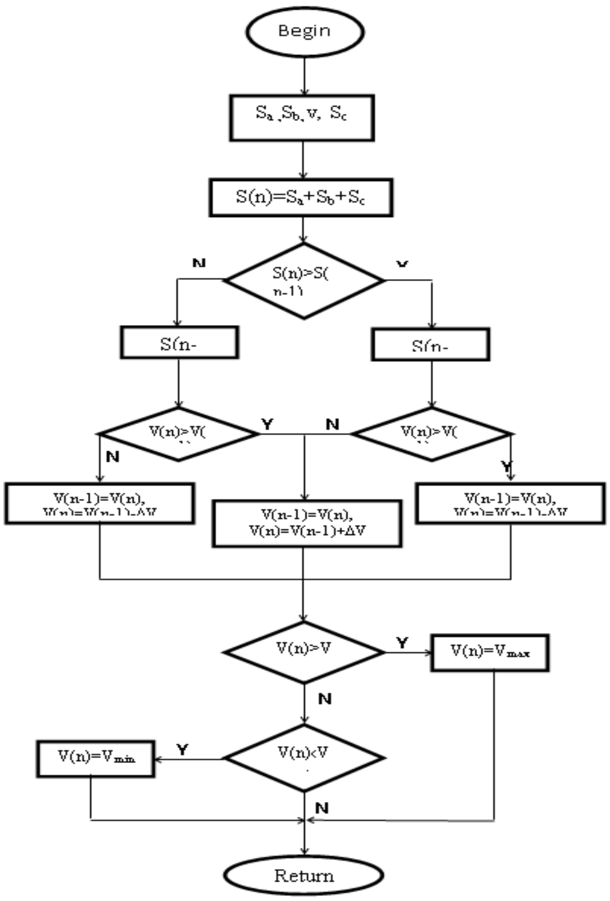

Fig 2. mPPT flow chart

B. D-Q control

The control strategy of DQ control is shown in fig 7. DQ control system consists of ‘abc’ to DQ conversion block for which system voltage and currents are converted to DQ form. DQ of the system current is compared with reference current and given tp PI controller which is then compared with DQ voltage. Then it is converted back to ABC form which is given as reference for SPWM from which gate pulses are generated to the shunt inverter.

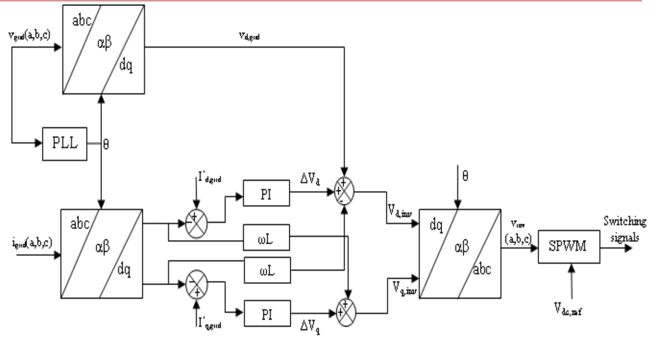

Fig 4. Block diagram of DQ control

VI. Simulation And Results

Source of the distribution grid 220V (RMS) is distorted due to the sag and swell introduced by the disturbances on source side. Sag is introduced in the system from 0.1s to 0.2s with voltage magnitude 0.8 thus there is a dip in the voltage. Swell is introduced in the system from 0.3s to 0.4s with voltage magnitude 1.2 from which the voltage is increased. Also system was simulated under three phase fault condition. Three phase fault is introduced from 0.6s to 0.7s. Table I. shows the system parameters which are used in the simulation. Fig 5 shows the simulation circuit of distribution grid without UPQC during fault. Fig 6 shows the simulation circuit of distribution grid with UPQC.

Table I: System parameters

Supply voltage (RMS)	220V
Frequency	50Hz
Load resistance	0.05ohm
Load inductance	0.467H
DC link voltage source	500V

A. Simulation circuits of distribution grid with and without UPQC

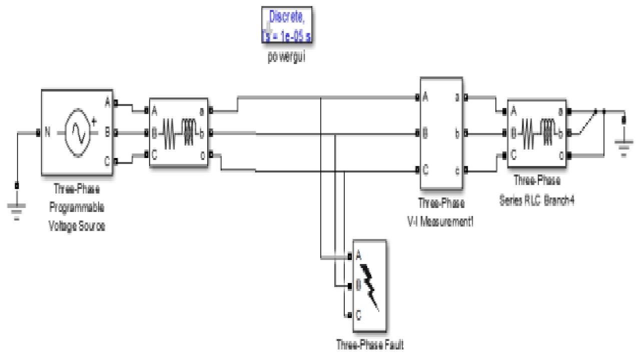

Fig 5. Simulation circuit of distribution grid without UPQC

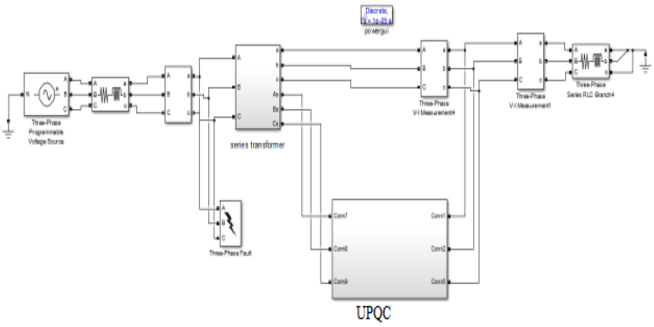

Fig 6. Simulation circuit of distribution grid with UPQC

B. Simulation results under sag and swell condition

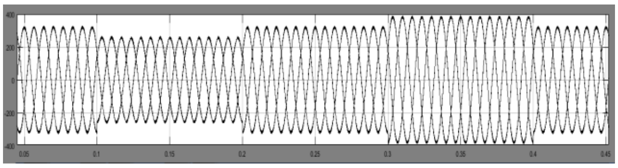

Fig 7a Load voltage without UPQC under sag and swell condition

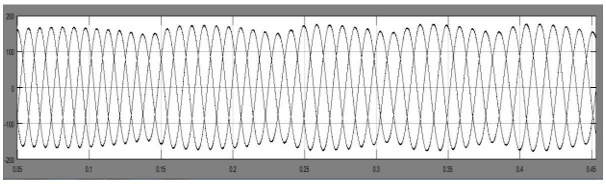

Fig 7b Load voltage with UPQC without controller under sag and swell condition

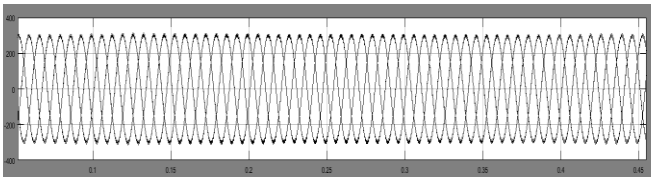

Fig 7c Load voltage with UPQC using PI controller under sag and swell condition

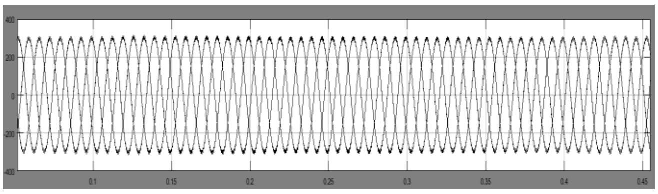

Fig 7d Load voltage with UPQC using DQ controller under sag and swell condition

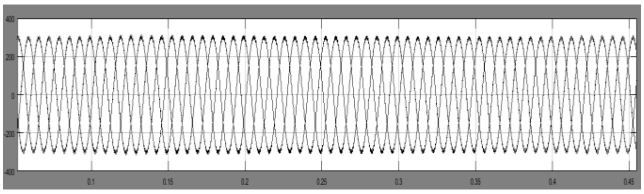

Fig 7e Load voltage with UPQC using amplitude controller under sag and swell condition

The load voltage of the system without UPQC under sag and swell condition is as shown in the fig 6a and it is observed that there is no compensation in the load voltage. Fig 7b shows the load voltage with UPQC without controller and it is observed that load voltage is maintained at 190V. Fig 7e shows the load voltage of the system with UPQC using mPPT controller under sag and swell condition. It is observed that the load voltage is compensated to the voltage around 310V. It is observed that the load voltage obtained using voltage controller is more and constant as compared to the load voltage of the UPQC without any controller, with UPQC using PI and DQ controller as shown in fig 7b, 7c and 7d respectively.

C. Simulation results under fault condition

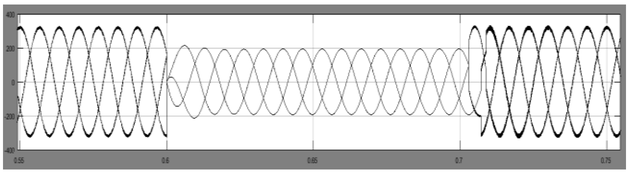

Fig 8a Load voltage without UPQC under fault condition

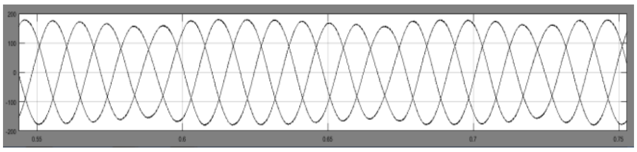

Fig 8b Load voltage with UPQC under fault condition

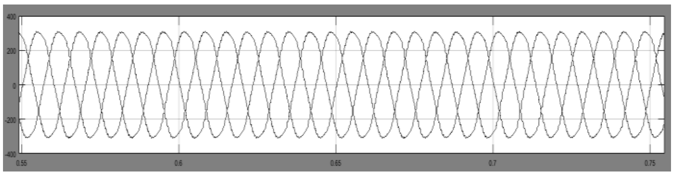

Fig 8c Load voltage with UPQC using PI controller under fault condition

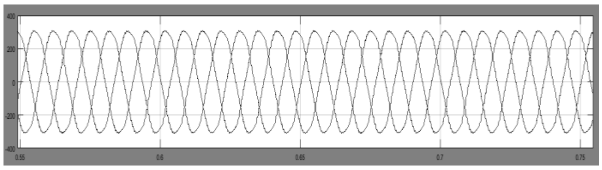

Fig 8d Load voltage with UPQC using DQ controller under fault condition

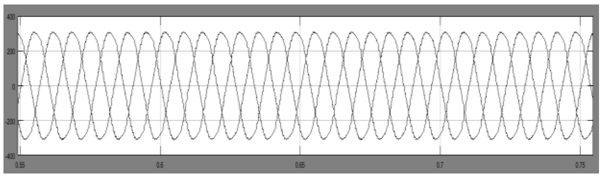

Fig 8e Load voltage with UPQC using amplitude controller under fault condition

The load voltage of the system without UPQC under sag and swell condition is as shown in the fig 8a and it is observed that there is no compensation in the load voltage. Fig 8b shows the load voltage with UPQC without controller and it is observed that load voltage is maintained at 190V. Fig 8e shows the load voltage of the system with UPQC using mPPT controller under fault condition. It is observed that the load voltage is compensated to the voltage around 310V. It is observed that the load voltage obtained using voltage controller is more and constant as compared to the load voltage of the UPQC without any controller, with UPQC using PI and DQ controller as shown in fig 8b, 8c and 8d respectively.

D. *FFT analysis of load voltage*

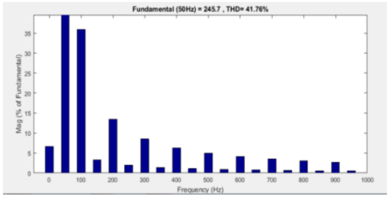

Fig 9a THD of load voltage without UPQC

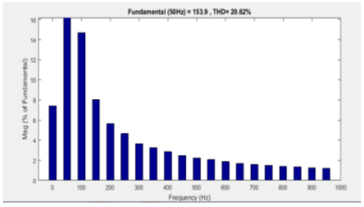

Fig 9b THD of load voltage with UPQC without controller

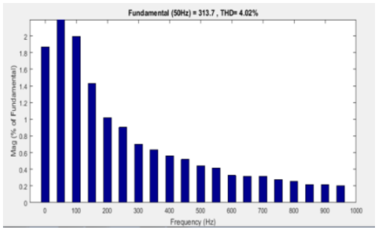

Fig 9c THD of load voltage with UPQC using PI controller

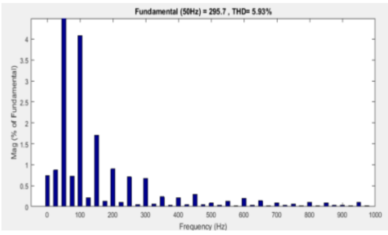

Fig 9d THD of load voltage with UPQC using DQ controller

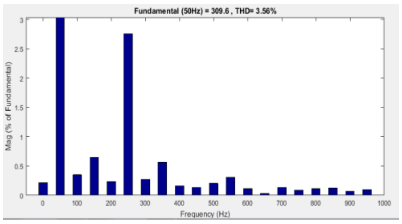

Fig 9e THD of load voltage with UPQC using amplitude controller

FFT analysis was carried out for the load voltage without UPQC, with UPQC without controller and with UPQC using different control techniques mentioned in the chapter 3. Figures 9a, 9b, 9c, 9d and 9e shows the Total harmonic distortion for load voltage without UPQC, with UPQC without controller, with UPQC using PI, DQ control and amplitude control respectively. The THD value of load voltage without UPQC is 41.79%, with UPQC without controller is 29.43%, with UPQC using PI control is 4.02%, DQ control is 5.93% and using amplitude frequency control is 3.56%. It is observed that the THD value of load voltage with UPQC using amplitude frequency control is less as compared to DQ control and PI control. Thus amplitude control technique is better than the PI and DQ control techniques. Table II is the comparison table where load voltage and THD of load voltage of system without UPQC, with UPQC without controller, with UPQC using PI controller, DQ controller and amplitude controller is listed at sag, swell and fault condition.

Table II: Comparison table of different DG conditions and disturbances

DG conditions Disturb-ances	**Without UPQC**	**With UPQC without controller**	**With UPQC with PI**	**With UPQC with DQ**	**With UPQC with mPPT**
Sag condition	250V	190V	300V	305V	310V
Swell condition	375V	190V	300V	305V	310V
Fault condition	190V	190V	300V	305V	310V
THD	41.79 %	29.43%	4.02 %	5.93 %	3.56 %

V. CONCLUSION

A three phase UPQC as a voltage regulator and its control structure, including the PI, DQ and amplitude (mPPT) control is analyzed and simulated. The simulation is done for distribution grid during sag and swell condition and under fault condition without and with UPQC. Simulation with UPQC is done with and without controllers. The three control techniques used in the proposed work improves the power quality. Total harmonic distortion for load voltage without UPQC, with UPQC without controller, with UPQC using PI, DQ control and amplitude control are discussed. The THD value of load voltage without UPQC is 41.79%, with UPQC without controller is 29.43%, with UPQC using PI control is 4.02%, DQ control is 5.93% and using amplitude frequency control is 3.56%.Comparison is done for all the conditions and THD of mPPT is lesssr than the other cases. The power quality of the distribution grid using UPQC with mPPT control is efficient. Thus mPPT algorithm is the best control technique to be used for the UPQC.

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