SINGLE-PHASE TO THREE-PHASE UPQC FOR POWER QUALITY IMPROVEMENT

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Abstract: This paper presents a single-phase to three-phase unified power quality conditioner applicable in three-phase four-wire (3P4W) electrical power distribution systems (EPDS) in rural or remote areas. In remote areas, only EPDS with single-wire earth return (SWER) is possible to access for the end users due to economic reasons. Now days the usage of three phase loads is increasing gradually, therefore it is much required to get access to the three-phase distribution system. UPQC 1-ph-to-3-ph uses dual compensation principle makes possible to draw sinusoidal current, in phase with the grid voltage, from the single-phase grid to improve the power quality. The system compensates the voltage disturbances such as voltage sag, voltage swell and other voltage unbalances. The proposed system allows the balanced and regulated voltage with lower harmonic content. Synchronous Reference Frame (SRF) based controllers are considered to organize the input grid current and the output voltages of the UPQC. The present paper analyzes the compensation and control strategies using PI controller. The control strategies are simulated using MATLAB/SIMULINK.
Keywords: Unified power quality conditioner (UPQC), single-wire earth return (SWER), electrical power distribution system (EPDS), synchronous reference frame (SRF), active power filter (APF), phase locked loop (PLL), Total harmonic distortion (THD).

I. INTRODUCTION

The practice of using power quality conditioners in electrical power distribution system is increasing gradually in recent time due to the incorporation of non-linear loads in the system. It draws harmonic current from the load and produces voltage disturbances. Higher order harmonic currents with network impedances produces causes voltage disturbances such as sags, swells and voltage transients and voltage harmonics causing utility voltage drop in the system to worsen the power quality. Power quality conditioning devices such as Unified Power Quality Conditioners (UPQC), Active Power Filters (APF) and Uninterruptible Power Supply (UPS) systems [3] aid the electrical power system in improving their power quality by avoiding the power supply variations. In conventional UPQCs, series APF is used to mitigate voltage disturbances and the parallel APF is used to nullify the harmonic currents produced by the non-linear loads and provides reactive power compensation. Here series APF is voltage controlled and parallel APF is current controlled and the control references, for the series and parallel APFs are calculated by using complex methods. UPQC is a very versatile device as it mitigates the problem both due to current and voltage harmonics [13]. UPS uses dual compensation approach [3]. In rural areas SWER is adopted as a most viable solution for electrical power supplying. Single Wire Earth Return (SWER) systems are a well-recognized economical technique of providing supply to a broadly dispersed area with a quite low power demand. SWER systems, a cost–effective method, have been used widely for supplying electrical power to the end users in rural or remote areas of Australia, particularly in the State of Queensland. Now days the utilization of three-phase loads is increasing in rural or remote areas, so the requirement for three-phase distribution systems is also enlarged. Due to the wide usage of three phase loads the power quality has been decaying day by day due to the fact nonlinear devices involves non-linear characteristics. This paper presents a single-phase to three-phase unified power quality conditioner system with single wire earth return which performs single-phase into three-phase and series-parallel active power line conditioning. Dual compensation strategy is employed in UPQC 1-ph-to-3-ph different from conventional UPQC. In dual compensation sinusoidal references are synthesized to provide the compensation control whereas in basic UPQC configuration non-sinusoidal references are obtained to provide the control, which are complex to calculate. In dual compensation the series APF is controlled to operate as a sinusoidal current source rather than a non-sinusoidal voltage source, while in parallel filter conditioning the parallel APF is controlled to function as a sinusoidal voltage source rather than a non-sinusoidal current source. Dual Compensation strategy offers less complex algorithms to attain the required objective [4][5]. Synchronous Reference Frame (SRF) based controllers are used to get the series and parallel APFs control references [12]. The coordinates of the unit vector sinθ and cosθ, used in SRF-based controllers, are obtained from the three-phase Phase-Locked Loop (PLL) system [8]. Due to the sinusoidal voltage and current references, the purpose of using continuous control references into the SRF-based controllers is permissible, which lessen the steady-state errors when conventional Proportional-Integral (PI) controllers are used [6].

Single-Phase to Three-Phase Upqc Topology

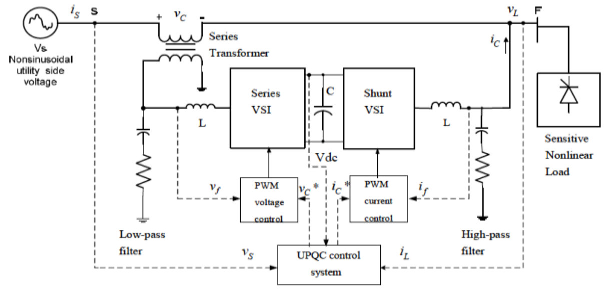

Figure 1: Conventional UPQC diagram

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A basic UPQC configuration is shown in figure 1. Unified /Power Quality Conditioner (UPQC) is principally consisted of two active power filters (APF) connected back to back through a DC link, one APF is connected in series with the grid and other is connected in parallel with the load. In UPQC parallel APF is applied as a controlled current source and draws unwanted current component generated by the load by suppressing the load current harmonics and provide the source current to be fully sinusoidal and without harmonics and distortions. Here Series APF, exists on the source side, is intended to mitigate voltage distortions and unbalances and maintains the voltage at load side completely balanced, sinusoidal and regulated [2].

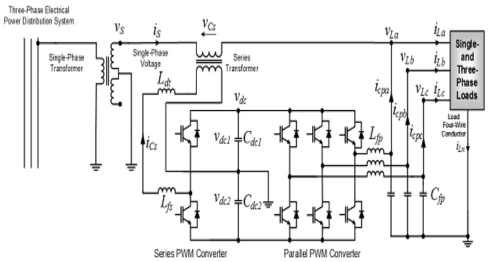

Figure 2: UPQC 1-ph-to-3-ph

A Single-phase to three-phase UPQC shown in figure 2, is the integration of two active power filters connected to a common DC-link. At the DC-link a split capacitor configuration is employed whose mid-point has been connected to earthed return conductor of the load same as employed in single wire earth return system. Total four half-bridge PWM converters are used for the formation of UPQC, of which one half-bridge converter acts as series active power filter (S-APF) and three half-bridge converters together act as parallel active power filter (P-APF). Series APF operates as a sinusoidal current source in phase with the grid source voltage and draining the harmonic currents. P-APF is controlled to function as a sinusoidal voltage source which provides regulated and balanced voltages [3][9][10].

II. DUAL COMPENSATION PRINCIPLE

The basic structure of UPQC 1-ph-to-3-ph is a combination of a series active filter and parallel active filter, as in conventional UPQC as shown in Figure 1. In basic UPQC arrangement the series active filter is voltage controlled so as to suppress the grid distortion such as voltage sag, swell and voltage unbalances. The parallel active power filter is current controlled and responsible for compensating load current.

The drawbacks of the basic unified power quality conditioner is that it poses complicated calculation of voltage and current control reference generation and interference in the voltage compensation generated by the series filter due to the leakage impedance of the connection transformer [7]. These limitations can be resolved by using the dual strategy based UPQC presented in this paper. Both in Dual configuration and in conventional configuration the basic structure of formation is same, the difference is in the manner the series and parallel filters are controlled or regulated. In dual compensation strategy, sinusoidal voltage and current references are applicable to regulate series and parallel APFs. Only sinusoidal references are used to control the PWM converters. In this way the control references generation is much easier to attain, and uses less complex algorithms to obtain the control. Synchronous Reference Frame based controllers (d-q-0-axes) are intended to manage the input current.

Controller

A. Series Converter Current Reference Generation

The Series converter controller needs a single phase current reference in the rotating frame. To obtain the same, three phase load currents in the stationary reference frame (abc - axes) are measured. Currents are transformed firstly into the two-phase stationary reference frame (αβ0-axes) using the Clarke's transformation. Then by using the Park's transformation these two-phase current quantities are converted into the synchronous reference frame (d-q axes) [11].

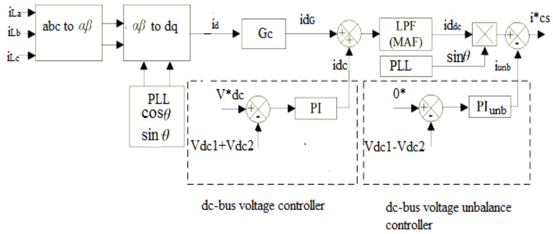

Figure 3: Reference generation scheme for series controller

For the realization of Single-phase to three-phase UPQC, the main condition is that the average single-phase input power must be equivalent to the average three-phase output power.

$P_s = P_L$

And, let us assume that magnitudes of the three-phase output voltages and grid voltage are equal.

Therefore, we get

Single-phase peak current $I_p = \sqrt{6} id_{dc}$;

Where id_{dc} is direct axis voltage ac component.

$I_p = G_c id_{dc}$;

Where G_c is the gain whose value is equal to √6.

B. Series Converter Controller:-

$$\frac{i_{cs}}{i^*_{cs}} = \frac{K_{pwm}\left(\frac{V_{dc}}{2}\right)(K_{ps}S + K_{is})}{L_{eq}S^2(K_{ps}SK_{pwm}\left(\frac{V_{dc}}{2}\right) + R_{eq})S + K_{is}K_{pwm}\frac{V_{dc}}{2}}$$

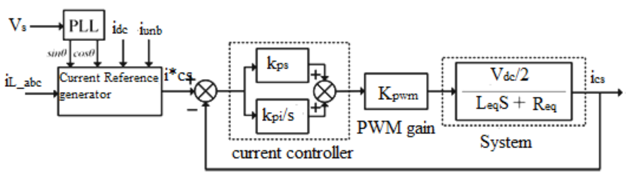

Figure 4: controller for series converter

where K_{ps} and K_{is} are the proportional-integral (PI) current controller gains; K_{pwm} is the PWM gain; L_{eq} is the equivalent

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inductance (L_{eq} = (N^2) L_{dt} + L_{fs}), such that is the series filter inductance, L_{dt} is the leakage inductance of the primary winding of the transformer (source side), N is the transformation ratio of the transformer, (R_{eq} = (N^2) R_{dt} + R_{fs}) is the equivalent resistance, where R_{dt} is the resistance of the series transformer; R_{fs} is the internal resistance of the series inductor and V_{dc} is the total dc-bus voltage, where $V_{dc} = V_{dc1} + V_{dc2}$.

C. Reference Voltage Generation of Parallel Converter

The output voltage of phase "a" is managed to be in phase with the grid voltage. The output voltage references are given as:

$V^*_{La} = V_{Lp}\sin\theta$;
$V^*_{Lb} = V_{Lp}\sin(\theta - 120°)$;
$V^*_{Lc} = V_{Lp}\sin(\theta + 120°)$

Where $^{V}{}_{Lp}$ is the desired voltage amplitude of the load and θ is the projected phase angle of the grid voltage [11].

D. Voltage Controller of the Parallel Converter:-

The multi-loop control is performed by an internal current control loop, where a proportional (P) controller is employed and an outer voltage control loop, where a proportional-integral (PI) controller is employed.

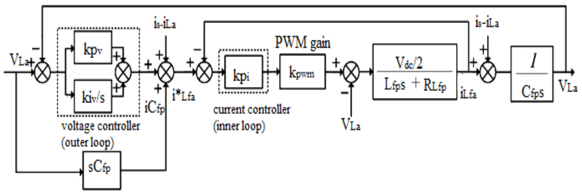

Figure 5: Voltage controller

Transfer function for voltage controller

$$\frac{V_{La}(S)}{V^*_{La}(S)} = \frac{K_{pwm}\left(\frac{V_{dc}}{2}\right)(K_{ps}S + K_{is})}{L_{eq}S^2(K_{ps}SK_{pwm}\left(\frac{V_{dc}}{2}\right) + R_{eq})S + K_{is}K_{pwm}\frac{V_{dc}}{2}}$$

where:
$A = K_{pwm}(V_{dc}/2)$;
$X_1 = C_{fP}K_{Pi}$;
$X_2 = K_{Pv}K_{Pi}$; $X_3 = K_{iv}K_{Pi}$;
$Y_1 = L_{fP}C_{fP}$; $Y_2 = C_{fP}[K_{Pi}K_{pwm}(V_{dc}/2)+R_{LfP}]$;
$Y_3 = [K_{Pv}K_{Pi}K_{pwm}(V_{dc}/2)+1]$;
$Y_4 = [K_{iv}K_{Pi}K_{pwm}(V_{dc}/2)]$.

K_{pv} and K_{iv} represent the respective proportional and integral controller gains of the external voltage loop, K_{pi} is the proportional gain of the internal current loop, K_{pwm} is the PWM gain, C_{fp} is the projected filter capacitance, L_{fp} is the filtering inductance, R_{Lfp} is the internal resistance of the inductor and V_{dc} is the total dc-bus voltage. A feed-forward control loop is used in the output voltage control. The i_{cfp} is the projected current of the filter capacitor C_{fp}.

III. SIMULINK MODEL

The MATLAB model shown is possible to construct and used to investigate single-phase to three-phase UPQC system and to optimize their performance. This allows fast development and provides control. For the controller design purpose, model verification and response were modeled in MATLAB using SIMULINK. Figure 6 shows the MATLAB Simulation of Dual unified power quality conditioner having series and shunt active power filters with IGBTs.

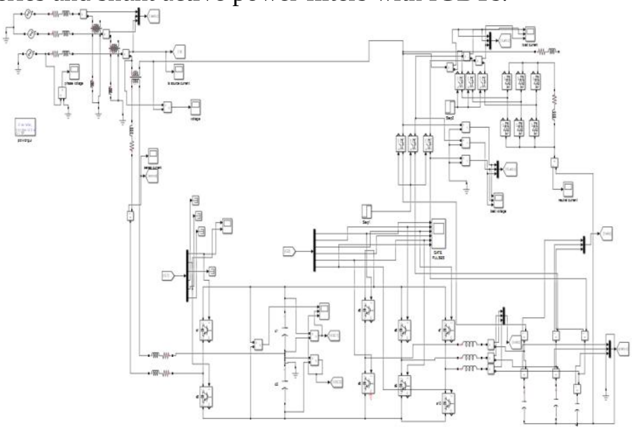

Figure 6: UPQC simulation model

Series converter controller

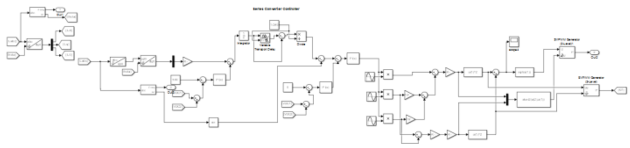

Figure 7: Series converter controller simulation diagram

Parallel converter controller simulation model

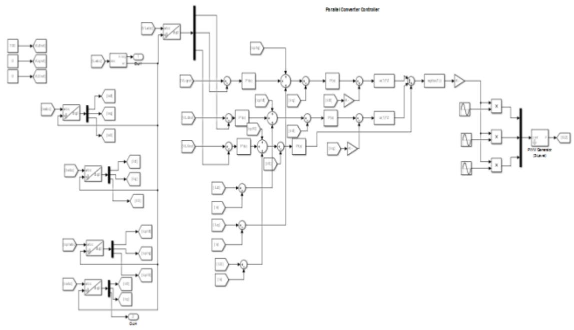

Figure 8: Parallel converter controller simulation diagram

Parameters used in simulation

rms voltage of the single phase grid Vrms	Vs = 220V
rms voltage of the 3 phase load (phase)	V = 220V
Grid frequency	fs = 50 hz
Switching frequency of the inverters	fch = 10 khz
Parallel converter inductances	Lfpabc = 10mH
Parallel converter capacitances	Cfpabc = 50µF
Series converter inductances	Lfabc = 1mH, Rfs = 0.17Ω
Series transformer	Ldt = 0.2mH, Rdt = 0.2Ω
Transformation ratio of series transformer	N = 1

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DC-bus voltage	500V
DC-bus capacitance	4000µF
3-ph full wave converter	R = 50Ω, L = 20mH

Table 1: parameters

IV. SIMULINK RESPONSE

Source Voltage

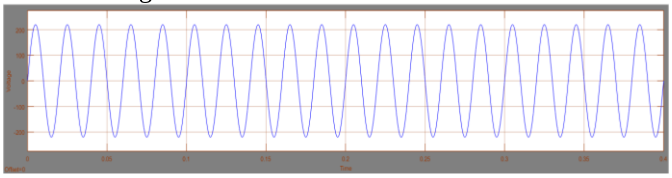


Figure 9: Balanced source voltage

Source Current

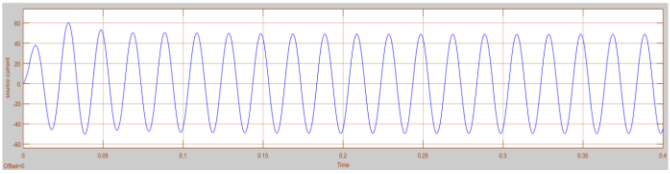


Figure 10: Balanced source current

Load Voltage

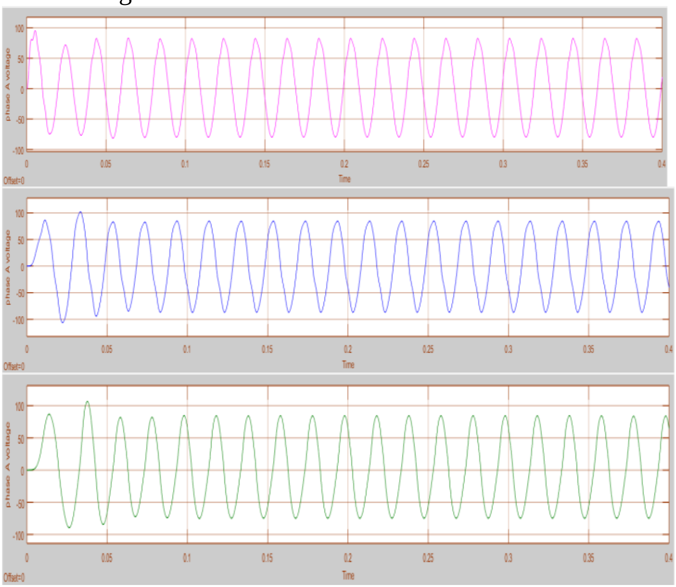
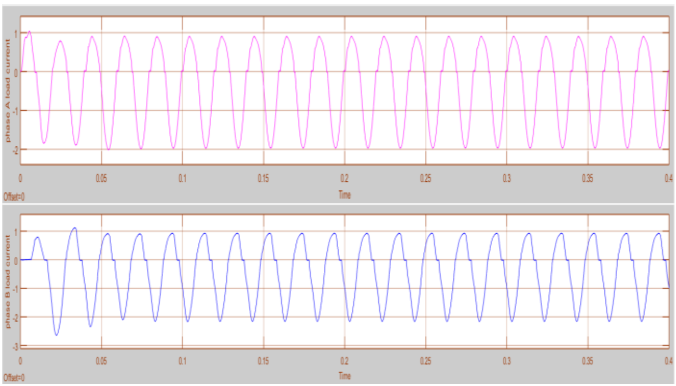


Figure 11: Load voltages

Load Current



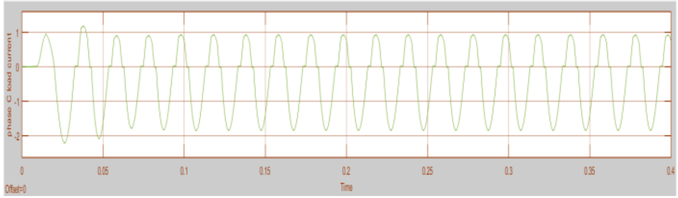


Figure 12: Load Currents

V. CONCLUSION

The Single-phase to three-phase Unified power quality conditioner using single ground return was studied and examined in the present paper. Single-phase to three- phase UPQC is build by combining series and parallel converters. Both series and shunt converters' reference generation and their controlling strategies are discussed and simulated. UPQC 1-ph-to-3-ph suppresses power quality problems associated with voltage and current at the same time. The Dual unified power quality conditioner discussed in this paper ensures the sinusoidal voltage for the load in all three phases. The main advantage of the projected control in comparison to other probable schemes is the deployment of sinusoidal references for both series and shunt active filter controls without the need for complex methods. The models for UPQC 1-ph-to-3-ph and controllers are developed using MATLAB/Simulink.

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