RESEARCH SCRIPT

IJREE - International Journal of Research in Electrical Engineering ISSN: 2349-2503

"MODELING AND SIMULATION OF SINGLE PHASE TO THREE PHASE UNIFIED POWER QUALITY CONDITIONER (UPQC)"

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Abstract— *This project presents a single phase to three phase unified power quality conditioner applied in single wire earth return (SWER) electric power distribution grids. It is applied in rural or remote areas in which, for the economic reasons, only electrical power distribution system (EPDS) with single wire earth return are accessible to the consumer. By adopting a dual compensation strategy, the proposed UPQC-1Ph-to-3Ph is able of draining from the single-phase electrical grid sinusoidal current and in phase with the voltage, resulting high power factor. Hence, a 3P4W system with regulated, balanced and sinusoidal voltages with low harmonic contentsis provided for single- and three-phase loads. An analysis of the power flow through the series and parallel converters is performed in order to help the designing of the power converters. Experimental results are presented for validating the proposal, and evaluating the static and dynamic performances of the proposed topology.*

Keywords— Dual Compensation Strategy; Rural and Remote Areas; Single-Wire Earth Return (SWER); Unified Power Quality Conditioner (UPQC)

1. INTRODUCTION

In rural or remote regions in Brazil, as well as in some areas of countries such as Australia and New Zealand, for instance, electrical power distribution systems (EPDS) with single-wire earth return (SWER) have been commonly adopted as a solution for electrical power supplying. This is due to the fact that the reduction of costs in the distribution of energy to serve large territorial extensions with low demographic densities is an important requirement since lower installation and maintenance costs are achieved. Other alternatives are the use of energy distribution by means of two conductors (phase-to-neutral) without earth return or even using two-phase systems (phase-to-phase). Considering these alternatives, capital investments for the realization of SWER distribution grid facilities installations are still lower. The voltage regulation is characterized as one of the main problems of power quality (PQ) found in the rural single-phase grids, because when subjected to large loads, these grids have a significant voltage drops, whereas at time of low consumption the voltage tends to rise. It includes 1ph-to-3Ph four-wire converters, which are able of supplying three-phase and single-phase loads or 1Ph-to-3Ph three-wire converters intended to supply only three-phase loads. The integrating functionality of a UPQC, a 1Ph-to-3Ph converter was dedicated for creating a local three-phase four-wire (3P4W) EPDS from a single-phase distribution system. The series converter is composed of a half-bridge inverter (one inverter leg),

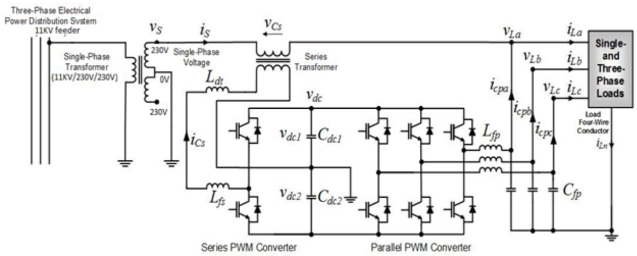


Fig.1 Topology of the UPQC-1Ph-to-3Ph

While the parallel converter is composed of a three-leg split-capacitor inverter, totaling four inverter legs. Hence, it was allowed feed single- and three-phase loads. On the other hand, limited results have only been presented by means of simulations. Also simultaneously they perform the functions of series active power filter (SAPF) and parallel active power filter (PAPF), the UPQCs have been commonly employed to mitigate PQ problems, both in single-phase distribution systems and in 3P4W distribution systems.

Usually, the UPQCs are controlled to perform series and parallel compensation, synthesizing non-sinusoidal quantities of voltage and current, i.e., the series converter synthesizes non-sinusoidal voltage quantities to compensate for grid voltage disturbances, while the parallel converter synthesizes non-sinusoidal current quantities with the purpose of suppressing harmonic currents and compensating the reactive power of the loads. Therefore, the proposed system can achieve two important functions simultaneously, as described: i) Convert the single-phase grid into a three-phase grid, generating a 3P4W distribution system with earthed neutral wire to the final consumer, allowing to connect single- and there-phase loads; ii) Perform the series and parallel active power filtering improving PQ indicators, such as power factor, harmonic distortion.

2. METHODOLOGY

The control strategy includes three closed loop controllers each generating control references for specific part of the system they are as follows

A. Series Converter Current Reference

The series current reference is used to control the SAPF is obtained in the rotating reference frame dq, as shown in Fig. 2. The output 3 phase load currents (iLa ,iLb ,iLc) are measured and transformed from the three-phase stationary reference frame(abc-axes) to the two-phase stationary reference frame by using the Clarke transformation. Then, the stationary current quantities of the reference frame 0 are transformed to the synchronous reference frame (dq-axes). In the rotating frame, the coordinates of the unit vector sin (θ) and cos(θ) are obtained using the PLL system presented in, in which is the estimated phase-angle of the grid voltage. The quantity id, shown in Fig. 2, represents the active components of controller

The power equations in dq frame can be represented as follows

$$vd_{dc} = v_{sp}\sqrt{\frac{3}{2}}$$

$$I_{sp} = \sqrt{6}id_{dc}$$

vd_dc and id_dc are the dc bus voltages and currents V_sp and I_sp and are peak voltages of single phase current.

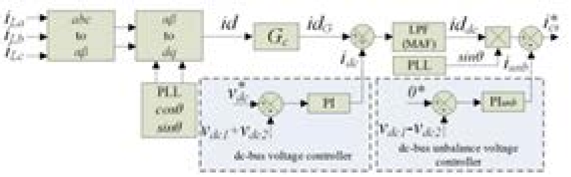


Fig. 2.Reference generation controller of the series converter

B. Series Converter Controller

The transfer function of the system of series controller can be deduced as follows

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

When i_cs^* is generated from the reference current generator is fed as input to the closed loop control to generate pwm as below fig. 3

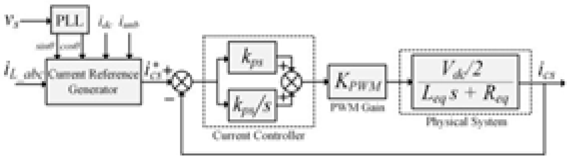


Fig. 3. Block diagram of the current controller and the average model of series converter

C. Reference Voltage Generators of Parallel Converter

The output voltage of phase "a" is controlled to be in phase with the grid voltage. Thus, given the estimated phase-angle of the grid voltage, as well as the desired voltage amplitude of the load VLp , the output voltage references are given by:

$$V_{La}^{*} = V_{Lp}\sin(\theta)$$

$$V_{Lb}^{*} = V_{Lp}\sin(\theta - 120)$$

$$V_{Lc}^{*} = V_{Lp}\sin(\theta - 240)$$

D. Voltage Controller Of The Parallel Converter

Fig. 4. Shows the block diagram of the control loop as well as the average model of parallel converter

$$\frac{V_{la}(s)}{V_{la}^{*}(s)} = \frac{A(X_1s^2 + X_2s + X_3)}{(Y_1s^3 + Y_2s^2 + Y_3s + Y\_4)}$$

Where

$$A = \frac{K_{pwm}V_{dc}}{2}$$

$$X_1 = C_{fp}K_{p_i},\ X_2 = K_{p_v}K_{p_i},\ X_3 = K_{i_v}K_{p_i}$$

$$Y_1 = L_{fp}C_{fp},\quad Y_2 = C_{fp}\left[\frac{K_{p_i}K_{pwm}V_{dc}}{2} + R_{l_{fp}}\right],$$

$$Y_3 = \left[\frac{K_{pv}K_{p_i}K_{pwm}V_{dc}}{2} + 1\right],$$

$$Y_4 = \frac{K_{pv}K_{p_i}K_{pwm}V_{dc}}{2}$$

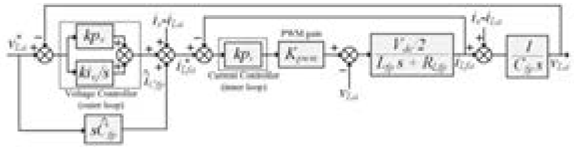


Fig. 4. Block diagram of the voltage control loops and of the average model of the parallel converter

E. DC-BUS Voltage Controller

The small signal closed loop transfer function of the dc-bus control system is given by

$$\frac{V_{dc}(s)}{V_{dc}^{*}(s)} = \frac{V_dK_{Pdc}s + V_dK_{Idc}}{V_{dc}s^2 + V_dK_{pdc}s + v_dK_{idc}}$$

The equivalent closed loop block diagram can be represented as below

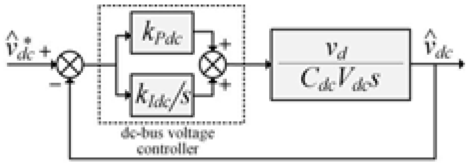


Fig. 5. Block diagram of the dc-bus control system

3. SIMULATION OF SYSTEM IN MATLAB

The system shown in fig.1.is implemented in mat lab Simulink model with following parameters and the Component values tolerance. The results are as discussed below.

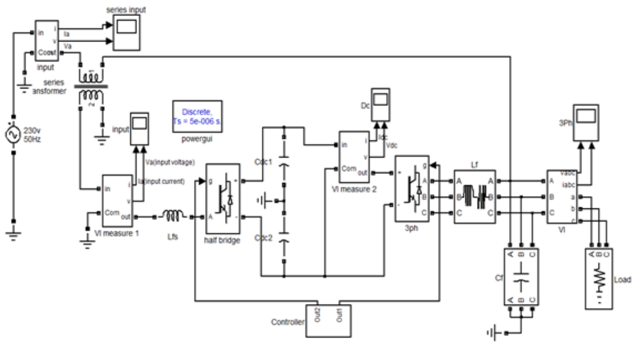


Fig. 6. Simulink model

TABLE 1: PARAMETERS USED IN SIMULATION

1ph load 1	Sla=600,Slb=300,Slc=400 VA
1ph load 2	Sla=Slb=Slc=538 VA
3ph load 1	Sl=1860VA
3ph load 2	Sl=1372 VA
Vrms 1ph grid	Vs=230V
Vrms 3ph load	Vlabc=230V
Grid frequency	Fs=50 Hz
Inverter switching frequency	Fch=20kHz
Inductors parallel converter	Lfpabc=2mH,Rfp=0.2m Ohm
Capacitors parallel converter	Cfpabc=50uF
Inductors series converter	Lfsabc=2mH,Rfs=0.2m Ohm
Series transformer	Ldt=0.2mH,Rdt=0.2mOhm,N=1
Dc bus voltage	1000 V
Dc bus capacitance	8600uF
Sampling frequency of DSc	Fa=50kHz

With the above specifications the simulation is carried out for various load conditions. the equations 1 to 12 are implemented in the control as shown in fig. 2 to 5 in the controller block of the simulation. The simulation was carried out discrete time step of 1us and +/-1 %

4. RESULTS AND DISCUSSIONS

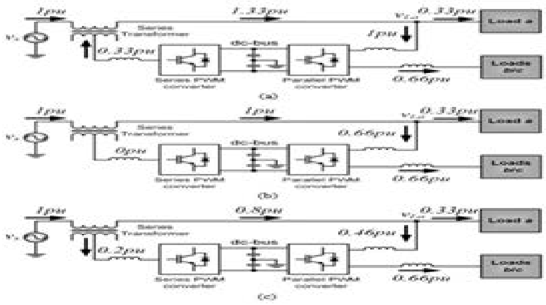
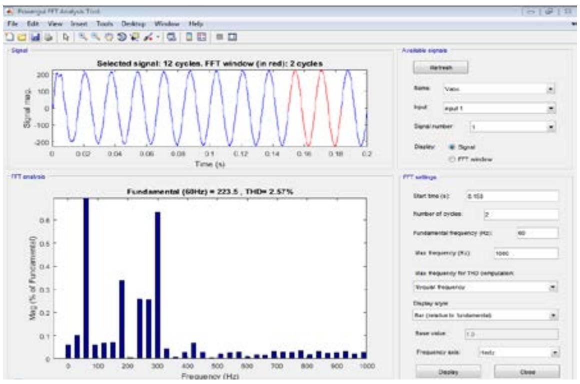


Fig.7. Active Power Flow (a) Vsl=0.8Vl (b)VSl=Vl; (c)=1.2Vl

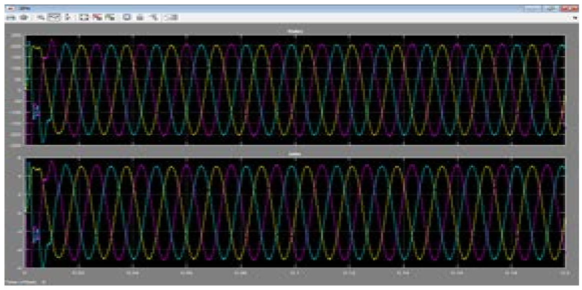
As shown in above figure during an voltage swell the parallel compensator phase a will act as a rectifier and absord the excessive voltage and the series control also works as a rectifier and transfers the energy to phase b and c.

During normal condition the series converter will be inactive and the parallel converter will control and suply the total load.

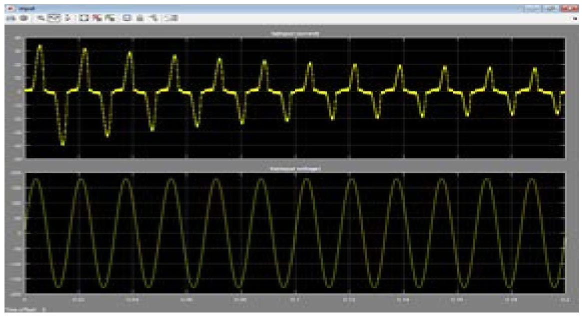
During sag condition the series converter injects voltage into the system to compensate for the sag and the parallel converter will supply phase b and c.



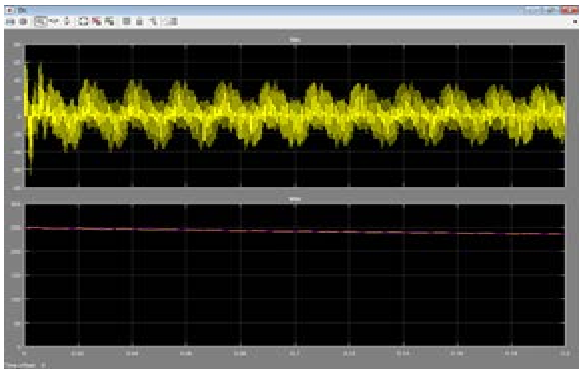
(a)



(b)

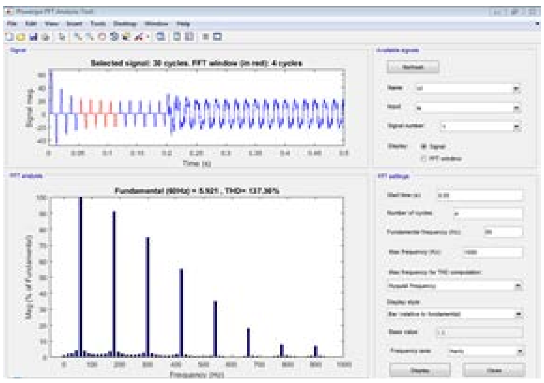


(c)

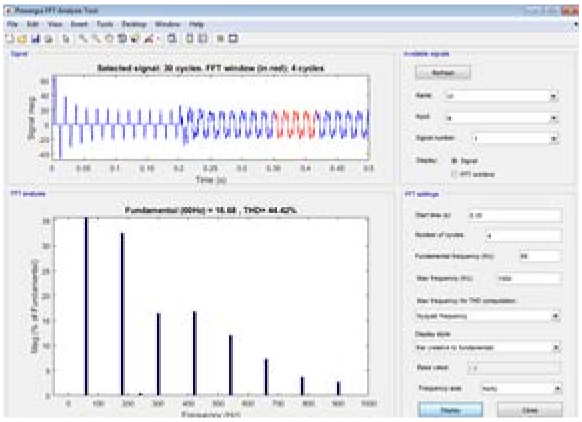


(d)

Fig. 7. 3phase output,(a) thdof the inverter output; (b)vabc load voltage (c.) single phase voltage and currents (d) dcbus current and voltages



(a)



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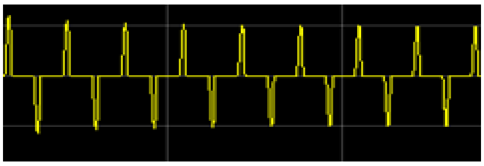
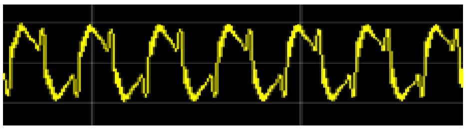


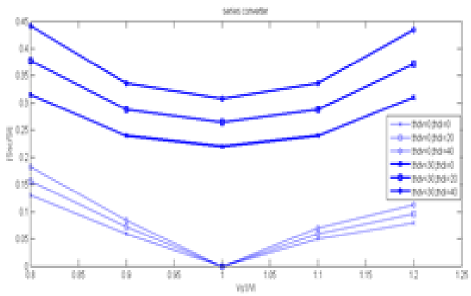
(c)



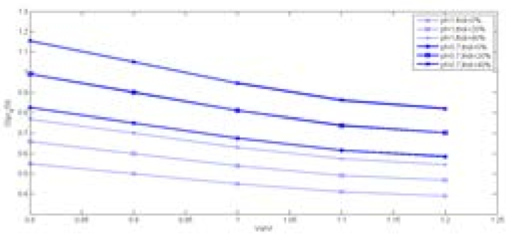
(d)

Fig. 8. (a)Thd of Is before compensation, (b) thd of current after compensation,(c) nonlinear input current (d) current after compensation.

In the above figure when single phase is supplying a non-linear load such as rectifiers the load current and input current is also nonlinear hence by using shunt compensator the nonlinear input current is being converted into sinosidual current.



(a)



(b)

Fig. 9. Normalized (a) series converter power |Ssc/Sl| (b) parallel converter of ph a |Spc_a/Sl|.

The figure in 9.a shows the power delivered by the series converter during the sag and swell of output voltage and the magnitude of the power transfer. The fig 9.b show the apparent power transferred by the parallel converter during the load and voltage changes.

5. CONCLUSION

The paper shows the study and validation of a three phase four wire ground return distribution system. This system can be implemented in rural and agricultural areas where three phase loads such as induction motors are connected and the three phases was conceived based on unified power quality conditioner functionalities. With the UPQC ability and 1Ph-to-3Ph conversion .Using the dual compensation strategy, the simulated system was able of feeding linear and non-linear three-phase loads acting with universal active filtering capability, i.e., acting as SAPF and PAPF. The simulation has shown that the system is stable for both static and dynamic loads and behavior of the UPQC achievable while 1Ph-to-3Ph conversion is also carried out and the system does not need any external source to regulate the dc bus, it has been verified through simulation results.

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