

Power Quality Improvement in Distribution Systems Using a Single-Phase to Three-Phase UPQC

Ch Suresh Kumar¹ G K S S G Bhavani² K S Karthik³
A Syam Manikanta⁴ K Ramesh⁵

Asst.Professor,Department of EEE, Srinivasa Inst.of Engg &Technology, Amalapuram,AP,India.¹

B.Tech Students, Department of EEE, Srinivasa Inst.of Engg &Technology, Amalapuram,AP,India.^{2,3,4,5.}

ABSTRACT:

This paper deals with the deployment of a local three-phase four-wire (3P4W) electrical power distribution system (EPDS), using a single-phase to three-phase unified power quality conditioner (UPQC) topology, called UPQC-1ph-to-3ph. The topology is indicated for applications in rural or remote areas in which, for economic reasons, only EPDS with single wire earth return are accessible to the consumer. Since the use of three-phase loads is increasing in these areas, access to a three-phase distribution system becomes preponderant. By adopting a dual compensation strategy, the proposed UPQC-1ph-to-3ph is able of draining from the single-phase electrical grid a sinusoidal current and in phase with the voltage, resulting high power factor. Furthermore, the system is also able to suppress grid voltage harmonics, as well as to compensate for other disturbances, such as voltage sags using fuzzy logic controller. Thus, a 3P4W system with regulated, balanced and sinusoidal voltages with low harmonics contents is provided for single and three-phase loads. An analysis of the power flow through the series and parallel converters is performed in order to validate the proposal, as well as evaluating the static and dynamic performance of the proposed topology.

Index Terms— Dual Compensation Strategy, rural and remote areas, single-wire earth return (SWER), unified power quality conditioner (UPQC), fuzzy logic controller.

I. INTRODUCTION

Natural 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 [1] - [5], since lower installation and maintenance costs are achieved [4], [6]. 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 [7].

The demand for electrical energy in single-phase rural distribution grids has considerably increased in the last decades, both in agriculture and in livestock, mainly due to the increasing evolution and modernization of the technologies used, as well as the increase in the mechanization of production processes. It is possible to mention, for example, the automation of irrigation, as well as the post-harvest agricultural processing involving seed selection and milling, ventilation and refrigeration, washing and packaging lines, among others. Within this context, there is an imminent trend of increasing energy demand in rural properties, as well as the need to improve power quality enhancement due to the change in the characteristics of the loads. The voltage regulation is characterized as one of the main problems of power quality (PQ) found in the rural single phase grids [4], [5], because when subjected

to large loads, these grids have significant voltage drops, whereas at times of low consumption the voltage tends to rise [1]. Nevertheless, a solution not so efficient due to constant load variations can be adopted by adjusting the taps of the transformer of the SWER network. Another solution, more efficient in this case, is the use of single-phase voltage regulators [5]. Some ways to bypass large capital investments to meet the growing demand of rural properties have been adopted [3], [8]. In [3] the impacts caused between distributed generation systems implemented through photovoltaic systems and the SWER distribution systems are presented.

On the other hand, in [8], the use of energy storage systems by means of batteries and their use at peak demand is discussed. It is possible to notice an increasing need to use three-phase distribution grids to meet the demand for electrical energy in rural areas due to changes in the characteristics of the loads. Currently, most of them could be driven by three-phase induction motors instead of single-phase motors, for they have a higher starting torque [7]. Furthermore, the use of medium and high power three-phase voltage inverters involved in modern automated systems also justifies the need for three phase grids in rural areas. Therefore, the presence of a local three-phase energy distribution system in areas that make use of the SWER distribution system becomes more and more indispensable. For this purpose, several solutions and/or configurations of single-phase-to-three-phase (1Ph-to-3Ph) converters have been addressed in the literature [6], [7], [9]-[11]. These include 1ph-to-3Ph four-wire converters, which are able of supplying three-phase and single-phase loads [6], [7], [9], or 1Ph-to-3Ph three-wire converters intended to supply only three-phase loads [10], [11]. Dedicated to feed three-phase three-wire loads and integrating the functioning of the unified power quality conditioner (UPQC), the 1Ph-to-3Ph converter presented in [12] performs universal filtering, i.e., it operates as series parallel active power filter, in which the series converter is composed of a single-phase full-bridge inverter (two inverter legs), while the parallel converter is composed of a three phase three-leg inverter, totaling five inverter legs.

In [12], also integrating the 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), while the parallel converter is composed of a three-leg split-capacitor inverter, totaling four inverter legs. Thus, it was allowed feed single and three-phase loads. On the other hand, limited results have only been presented by means of simulations. In addition, no detail regarding to the dimensioning and control of the converters were suitably treated.

In this paper, the 1Ph-to-3Ph converter presented is Simulation validated. It is called UPQC-1Ph-to-3Ph and its power circuit configuration is shown in Fig. 1. This system is indicated for applications in rural or remote areas where, for economic reasons, only single-phase EPDS, such as SWER system, is accessible to the consumer. Once the proposed system deployed in this paper was conceived based on the UPQC functionalities, some discussions related to the UPQC should be performed. Since they simultaneously 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. For this compensation strategy, some calculation method capable of generating the voltage and current compensation references should be used. On the other hand, some studies presented in the literature have used the dual compensation strategy to control the series and parallel converters of the UPQC. In this strategy, sinusoidal voltage and current references are employed to control both the converters. In this case, the series converter synthesizes sinusoidal current quantities and, consequently, operates as a sinusoidal current source, providing a high impedance path for the current harmonics of the load. The parallel converter synthesizes sinusoidal voltage quantities and, in this case, operates as a sinusoidal voltage source, providing a low impedance path for the current harmonics of the load. It is also observed that the performances of the controllers are notably better when they operate with sinusoidal references, when compared to those that use non-sinusoidal references. In addition, since the control

references are sinusoidal, the controllers implemented in the synchronous reference frame will have continuous reference of voltage and current, facilitating even more the control. Another advantage of dual compensation is in the form of generation of control references, which is performed only with the use of a Phase-Locked Loop (PLL) system.

The main contribution presented in this paper is to validate simulation the UPQC-1Ph-to-3Ph destined to feed single and three-phase loads from the SWER power distribution systems, commonly found in rural and/or remote areas and suffer with PQ problems. By adopting the dual compensation strategy, the proposed UPQC-1Ph-to-3Ph makes possible to drain from the single-phase electrical grid a sinusoidal current in phase with the grid voltage. Furthermore, the system can also suppress harmonics from the grid voltage, as well as compensate for voltage disturbances, such as voltage sags/swell. In other words, the UPQC-1Ph-to-3Ph can conceive a local 3P4W system with regulated, balanced and sinusoidal load voltages with low harmonic contents improving the PQ indicators. 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. Furthermore, in order to assist in the proper dimensioning of the UPQC-1Ph-to-3Ph power converters, an analysis involving the power flow through the serial and parallel converters is also presented.

II. PROPOSED TOPOLOGY

The topology of the UPQC-1Ph-to-3Ph is shown in Fig. 2.1. This one is formed by two PWM converters, being a half bridge inverter and a split-capacitor 3-Leg inverter sharing the same dc-bus. As can be noted, a half-bridge inverter is used to compose the series converter, while in [12] it was composed of a full bridge inverter. Thus, besides using one leg less compared to the topology presented in [12], the dc-bus is formed by the split-capacitor configuration, allowing access to the earthed return conductor of the load, as well to be used in SWER distribution systems. As can be noted in Fig. 1, the four-wire of the load is connected to the dc-bus central point. The series converter, also called SAPF, is current controlled so that the input drained current is sinusoidal

and in phase with the grid voltage, resulting in a power factor (PF) very close to one. A filter inductor (L_{fs}) is placed in series with the primary winding of the single-phase series coupling transformer.

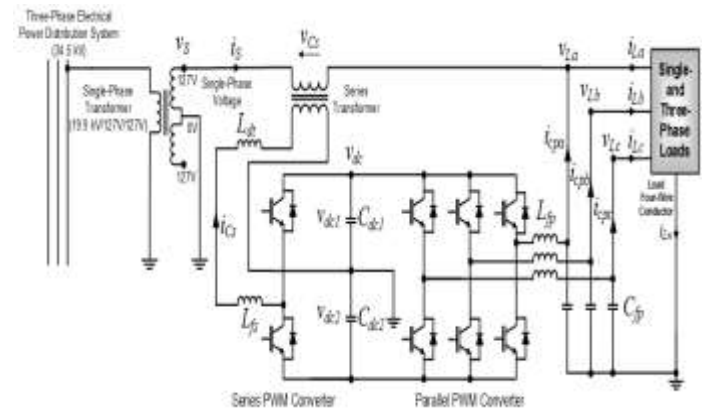


Fig. 2.1. Topology of the UPQC-1Ph-to-3Ph.

The parallel converter, called PAPF, is voltage controlled and it imposes three-phase sinusoidal, regulated and balanced voltages to the loads. The load voltage of phase “a” (V_{La}) is controlled to be in phase with the grid voltage (v_s). Second order LC filters are used to attenuate the high-frequency voltage components. Since the inverter leg connected to phase “a” is controlled to operate as a sinusoidal voltage source, the harmonic and fundamental components of the grid voltage are indirectly compensated by the system, and there is no need to use any specific algorithm to calculate/extract such components. The compensation voltage components, which are composed of harmonic and fundamental components, will appear across the terminals of the series coupling transformer. The power flow through the UPQC-1Ph-to-3Ph will depend on both the load characteristics, such as fundamental power factor and total harmonic distortion (THD) of current, as well as the characteristics of the grid, such as the differences between the amplitudes of the grid and load voltage (phase “a”), as well as the grid voltage THD.

2.1 Current Reference of the Series Converter

The single-phase current reference used to control the SAPF is obtained in the synchronous reference frame dq, as shown in Fig. 2. 2Thus, the load currents (I_{La} , I_{Lb} , I_{Lc}) are measured and transformed from the three-phase stationary reference frame (abc-axes) to the two-phase stationary reference frame (dq0 axes) using the Clarke transformation. Then, by means of the Park

transformation, the stationary current quantities of the reference frame dq0 are transformed to the synchronous reference frame (dq-axes). In the rotating frame, the coordinates of the unit vector $\sin(\theta)$ and $\cos(\theta)$ are obtained using the PLL system presented in [11], in which θ is the estimated phase-angle of the grid voltage. The quantity i_d , shown in Fig. 2, represents the active components of the load currents, i.e., it is composed of an average component and oscillating components in the reference frame d (d-axis).

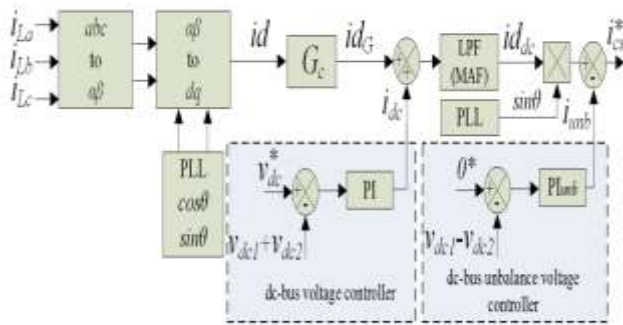


Fig.2. 2. Generation scheme of the series converter current reference the synchronous reference frame dq.

2.2 Voltage Controller of the Parallel Converter:

Fig 2.3 presents, by means of a block diagram, the voltage control loops as well as the average model of the parallel converter considering only phase “a”. The multi-loop control is implemented by an internal current control loop, where only a proportional controller is used, and an external voltage control loop, in which a PI controller is used.

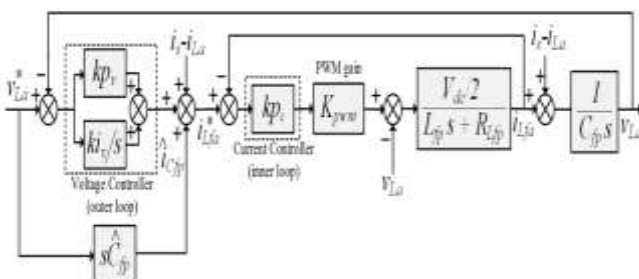


Fig.2.3: Block diagram of the voltage control loops and of the average model of the parallel converter.

III. FUZZY CONTROLLER :

The word Fuzzy means vagueness. Fuzziness occurs when the boundary of piece of information is not clear-cut. In 1965 Lotfi A. Zahed propounded the fuzzy set theory. Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. Fuzzy set theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Understanding human speech and recognizing

handwritten characters are some common instances where fuzziness manifests.

Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as “FUZZY SETS”.

Fuzzy set comprises from a membership function which could be defines by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process of converting the crisp input to a fuzzy value is called as “fuzzification.” The output of the Fuzzier module is interfaced with the rules. The basic operation of FLC is constructed from fuzzy control rules utilizing the values of fuzzy sets in general for the error and the change of error and control action. Basic fuzzy module is shown in fig.6.2

The results are combined to give a crisp output controlling the output variable and this process is called as “DEFUZZIFICATION.”

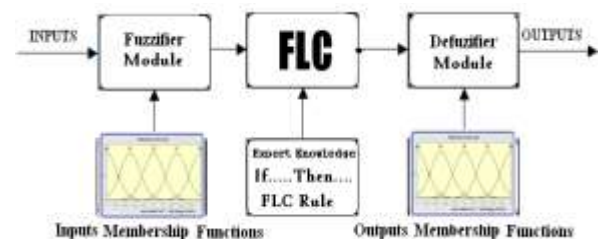
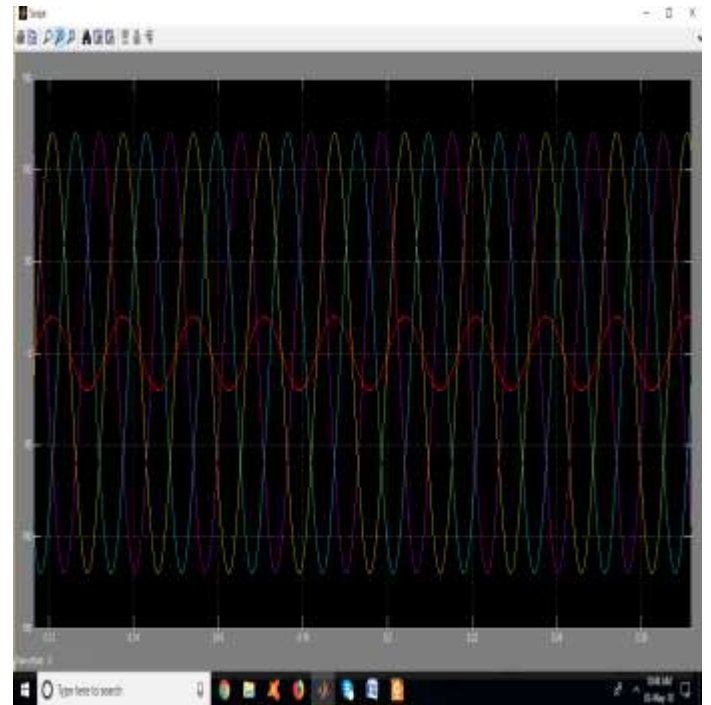
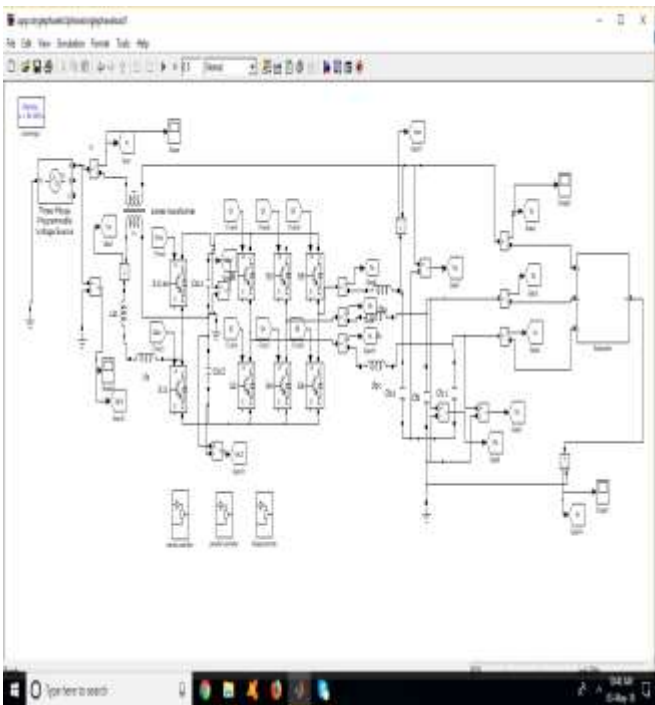
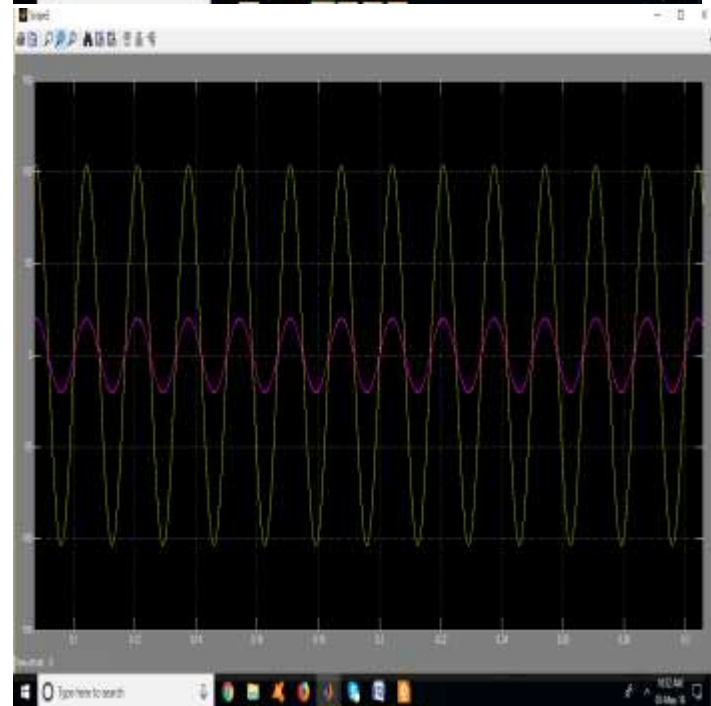
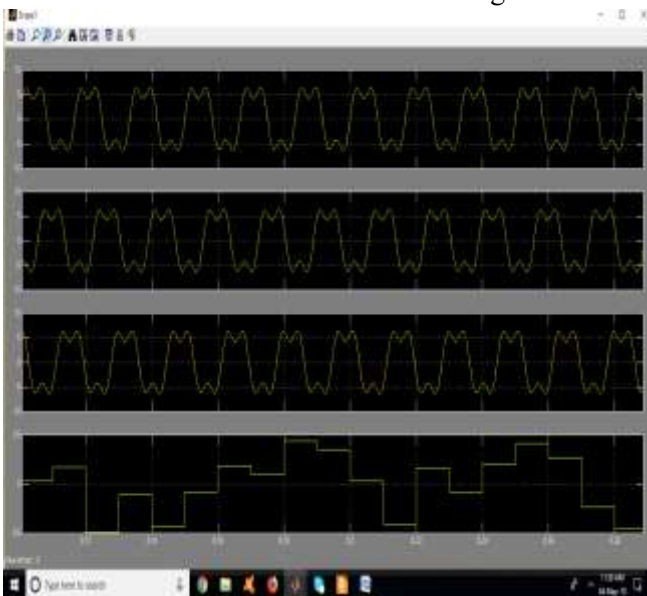


Fig 3.1: Block diagram fuzzy logic

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow to fully customize the appearance of graphics as well as to build complete graphical user interfaces on MATLAB applications.



4.1 Simulation Block Diagram



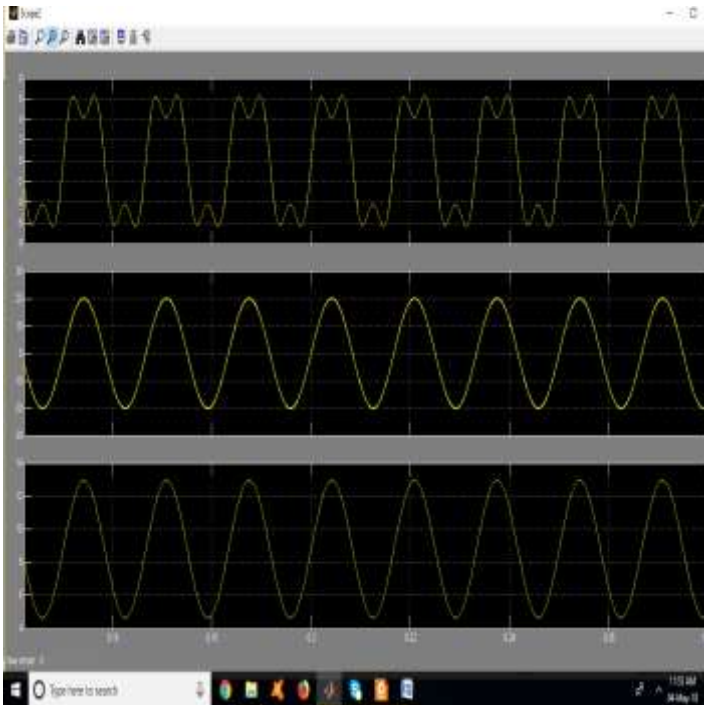


Fig. 4.1 UPQC-1Ph-to-3Ph (Load 1 Φ 1) (5 ms/div): (a) Load currents i_{La} (10 A/div), i_{Lb} , i_{Ln} (5 A/div); (b) Load voltages v_{Labc} , (50 V/div) and grid current i_s (20 A/div); (c) Voltage (50 V/div) and current (20 A/div) of the grid; (d) Currents: load i_{La} (10 A/div), grid i_s (20 A/div) and parallel converter i_{cpa} (20 A/div).

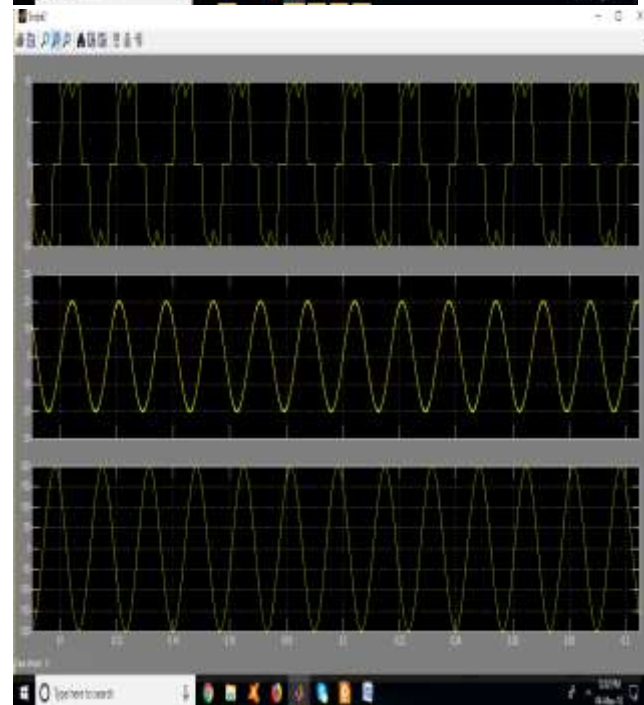
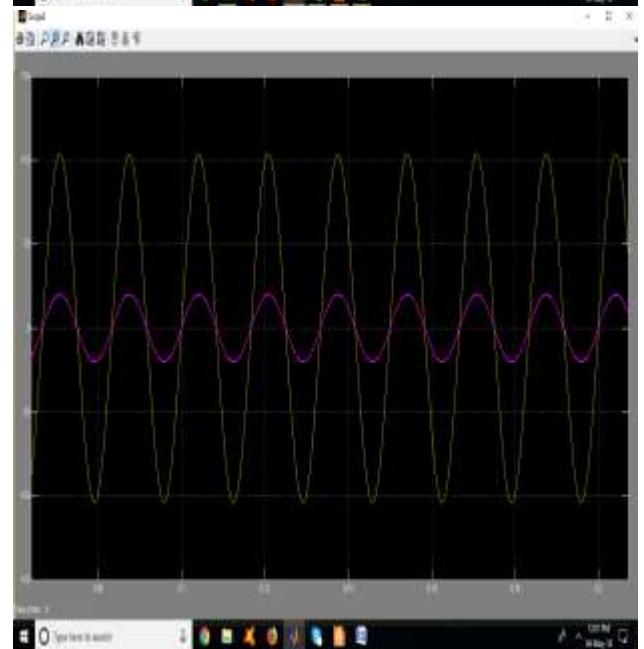
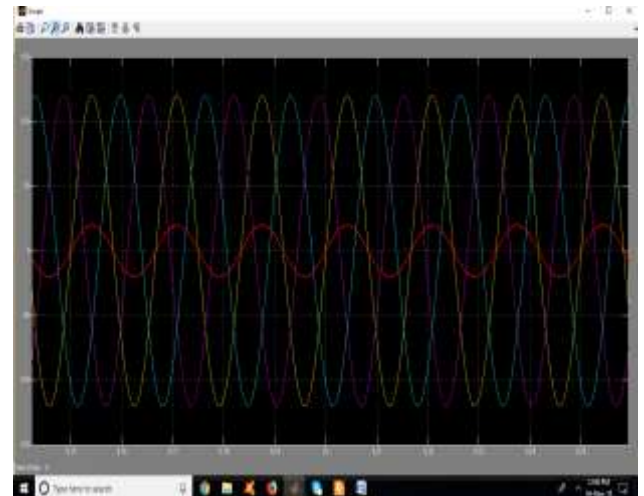
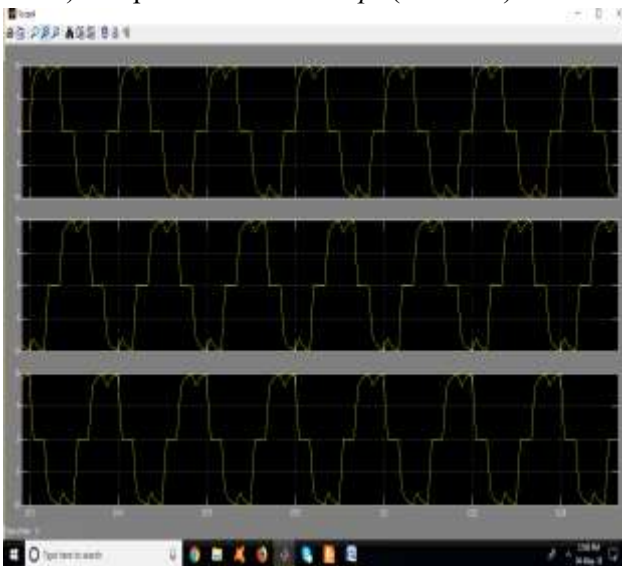


Fig. . Currents and voltages of the UPQC-1Ph-to-3Ph feeding the three-phase load 1 (5 ms/div): (a) Load currents iLa , iLb and iLc (10 A/div); (b) Load voltages vLa , vLb and vLc (50 V/div) and grid current is (20 A/div); (c) Grid voltage (50 V/div) and grid current (20 A/div); (d) Currents: load iLa (10 A/div)(phase “a”), grid is (20 A/div) and parallel converter $icpa$ (20 A/div) (phase “a”)

CONCLUSION

This paper presented the study and the simulation validation of a local three-phase four-wire power distribution system. The system, indicated for applications in rural or remote areas where three-phase distribution grids are not accessible, was conceived based on unified power quality conditioner functionalities. With serial and parallel filtering capability, two inverter topologies were used to compose the UPQC-1Ph-to-3Ph. Thereby, the single-phase series converter was deployed using a half-bridge inverter, while the three-phase parallel converter was implemented using a 3-Leg split capacitor inverter. Using the dual compensation strategy, With Fuzzy Logic Controller the proposed 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. In addition, a procedure was presented that allows the dimensioning the power structures of the series and parallel converters, under various operating conditions of the utility grid and the load. The good static and dynamic behavior of the UPQC-1Ph-to-3Ph has been proven through extensive simulation results.

REFERENCES

- [1] Sérgio Augusto Oliveira da Silva, Member, IEEE, Fernando Alves Negrão “Single-Phase to Three-Phase Unified Power Quality Conditioner Applied in Single Wire Earth Return Electric Power Distribution Grids” DOI 10.1109/TPEL.2017.2723573, IEEE Transactions on Power Electronics
- [2] F. Rosa, and S. T. Mak, “A look into steady state and transient performance of power lines integrating single wire earth return circuits” in Proc. IEEE Power Engineering Society General Meeting, 2007, pp. 1–7.
- [3] A. Guinane, G. M. Shafiullah, A. M. T. Oo, and B. E. Harvey “Voltage fluctuations in PV penetration on SWER networks - A Case Study for Regional Australia”, in Proc. IEEE Power and Energy Society General Meeting, 2012, pp. 1–6.
- [4] P. J. Wolf, “Capacity improvements for rural single wire earth return systems” in Proc. 7th International Power Engineering Conference(IPEC), 2005, pp. 1–8.
- [5] S. N. Lowry, A. M. T. Oo, and G. Robinson, “Deployment of low voltage switched capacitors on single wire earth return networks” in Proc. 22nd Australasian Universities Power Engineering Conference(AUPEC), 2012, pp. 1–5,
- [6] M. D. Bellar, M. Aredes, J. L. Silva Neto, L. G. B. Rolim, F. C. Aquino, and V. C. Petersen, “Single-phase static converters for rural distribution system”, in Proc. IEEE International Symposium on Industrial Electronics (ISIE), 2004, pp.1237–1242.
- [7] R. Z. Scapini, C. Rech, T. B. Marchesan, L. Schuch, R. F. Camargo, and L. Michels, “Distribution STATCOM integrated to a single-phase to three-phase converter” in Proc. 40th Annual Conference of IEEE Industrial Electronics Society (IECON), 2014, pp.1423–1429.
- [8] A. Helwig, and T. Ahfock, “Long-life nickel iron battery functionality/cost comparison for peak demand SWER network voltage support application” in Proc. 23th Australasian Universities Power Engineering Conference (AUPEC), 2013, pp. 1–6.
- [9] E. C. Santos Jr, N. Rocha, and C. B. Jacobina, “Suitable single-phase to three-phase AC-DC-AC power conversion system”, IEEE Trans. on Power Electron., vol. 32, no. 7, pp. 860–870, Feb. 2015.
- [10] N. Rocha, I. A. C. Oliveira, E. C. Menezes, C. B. Jacobina, and J. A. A. Dias, “Single-phase to three-phase converters with two parallel single phase rectifiers and reduced switch count”, IEEE Trans. on Power Electron., vol. 31, no. 5, pp. 3701–3716, May 2016.
- [11] V. Verma, and A. Kumar “Cascaded multilevel active rectifier fed three phase smart pump load on single-phase rural feeder”, IEEE Trans. on Power Electron., vol. 30, 5398–5410, Jul. 2017.
- [12] E. C. Santos Jr, C. B. Jacobina, J. A. A. Dias, and N. Rocha, “Single phase to three-phase universal active power filter”, IEEE Trans. on Power Delivery, vol. 26, no. 3, pp. 1361–1371, Jul. 2011.