Modelling and Simulation of Power Quality Compensation for Single-Phase to Three-Phase System

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***Abstract*: This project illustrates how to perform series-parallel power-line conditioning in single wire earth return (SWER) electric power delivery grids utilizing single phase to three phase with power quality compensation. It is used in rural or isolated regions where the only electrical power delivery device with a single wire earth return is open to the customer for economic reasons. The suggested power quality compensation 1 Ph-to-3 Ph uses a dual compensation technique, resulting in a high power factor since the regulated amounts are still sinusoidal. As a consequence, for single- and three-phase loads, a 3P4W device with controlled, balanced, and sinusoidal voltages with low harmonic content is given. In order to help in the design of the power converters, a study of the power flow between the series and parallel converters is conducted.**

Keywords: Distribution System, Power Quality, single-wire earth return (SWER), unified power quality conditioner (UPQC).

1. INTRODUCTION

The primary purpose of an electricity distribution system is to meet the customer's demands for energy after receiving the bulk electrical energy from transmission or sub transmission substation. There are basically two major types of distribution substations: primary substation and customer substation. The primary substation serves as a load center and the customer substation interfaces to the low voltage (LV) network. Customer substation is referred to a distribution room which can accommodate a number of HV switchgear panel and the transformer to enable LV connection to the customer incoming switchboard. Depending on the geographical location, the distribution network can be in the form of overhead lines or underground cables. Cables are commonly used in urban areas and overhead lines are adopted for rural areas. Different network configurations are possible in order to meet the required supply reliability. Protection, control and monitoring equipment are provided to enable effective operation of the distribution network. Planning of the distribution network is essential to enable the required demand. There are three categories of planning namely, the long-term planning, the network planning and construction planning. Long-term planning is to determine the most optimum network arrangements and the associated investment with consideration on future developments. Stage-by-stage development must be in line with the forecasted load growth so that electricity demands can be timely met. The construction planning or design is the actual design and engineering work when the required circuits and substations have been planned and adopted.

The need for single-phase electrical energy in rural areas has extensively raised in the last decades, both in domestic and agricultural requirements. This is mainly due to the increasing evolution and modernization of the technologies used, as well as the increase in the automation of cultivation processes. It is possible to mention, for example, the automation of irrigation, as well as the postharvest agricultural processing involving seed selection and milling, ventilation and refrigeration, washing and packaging lines, among others. The voltage regulation is characterized as one of the main problems of PQ found in the rural single-phase grids, because when subjected to large loads, these grids have significant voltage drops, whereas at times of low consumption the voltage tends to rise [1].

We can see that an increase in the use of three-phase distribution grids in order to meet the demand for electrical energy in rural areas due to the changes in the characteristics of the loads. Presently, three-phase induction motors instead of single-phase motors could drive most of the agricultural machineries, because of a higher starting torque they have [2]. Numerous solutions and/or configurations of single-phase-to-three-phase (1Ph-to-3Ph) converters have been proposed in the literature [3] [4]. Dedicated to feed three-phase, three-wire loads and integrating the functioning of the Unifi ed Power Quality Conditioner (UPQC), the 1Ph-to-3Ph converter presented in [5] implements universal filtering. In this paper we presented experiments to validate the UPQC-1Ph-to-3Ph intended to feed single-and three-phase loads from the SWER power distribution systems, which is commonly found in rural and/or remote areas and suffer with PQ problems. The proposed system simultaneously can accomplish two important functions such as: (i) Convert the single-phase grid into a three-phase grid, generating a 3P4W distribution system with neutral wire is earthed to the final consumer, permitting to connect single-and there-phase loads; (ii) Perform the series and parallel active power filtering in order to improve the PQ indicators, such as power factor and harmonic distortion.

2. LITERATURE REVIEW

In this section we have reviewed some of the important researches proposed in the literature in the power distribution systems. In [6] Huang et al have presented the combined-step-size (CSS) affine projection sign algorithm (APSA) to improve the poor tracking capability of the conventional variable-step-size APSA. To achieve a good tracking capability, the variable mixing factor of the proposed CSS-APSA is investigated by using a modified sigmoidal activation function. Meanwhile, the variable mixing factor is indirectly updated by minimizing the L 1 -norm of the system error to ensure robustness in the presence of non-Gaussian impulsive interferences. The good performance of the proposed CSS-APSA is demonstrated in the system identification and echo cancellation scenarios that include the impulsive interferences.

Zheng,et al.[7], have proposed a fast and robust phase estimation algorithm (PEA), a counterpart of the phase-locked loop (PLL), for heavily distorted grid conditions. The PEA, named as the WLSE-PEA, consists of the moving average filter (MAF), the weighted least squares estimation (WLSE), the frequency-locked loop (FLL), and the zero crossing detection (ZCD). The MAF can eliminate all the odd-order harmonics in the distorted grid voltages. The WLSE is employed to estimate the fundamental positive-sequence component. The combination of the ZCD and the FLL enables the WLSE-PEA to be adaptive to frequency deviations.

Sharma et al.[8] have proposed the automatic reactive power control of isolated wind-diesel hybrid power systems having a permanent-magnet induction generator for a wind energy conversion system and a synchronous generator for a diesel generator set. To minimize the gap between reactive power generation and demand, a variable source of reactive power is used such as a static synchronous compensator. The mathematical model of the system used for simulation is based on small-signal analysis. Three examples of the wind-diesel hybrid power system are considered with different wind power generation capacities to study the effect of the wind power generation on the system performance.

A novel family of adaptive filtering algorithms based on a relative logarithmic cost is introduced by Sayin [9]. The competitive or regret based approaches stabilize or improve the convergence performance of adaptive algorithms through relative cost functions. The new family elegantly and gradually adjusts the conventional cost functions in its optimization based on the error amount. They have introduced the important members of this family of algorithms such as the least mean logarithmic square (LMLS) and least logarithmic absolute difference (LLAD) algorithms.

A new affine projection sign algorithm (APSA) is proposed by Shao et al. [10]. It is robust against non-Gaussian impulsive interferences and has fast convergence. The conventional affine projection algorithm (APA) converges fast at a high cost in terms of computational complexity and it also suffers performance degradation in the presence of impulsive interferences. The family of sign algorithms (SAs) stands out due to its low complexity and robustness against impulsive noise.

In [11] Badoni et al have presented a three-phase shunt active power filter (SAPF) for mitigating power quality problems at the distribution level. Power quality problems such as harmonics, reactive power, and unbalancing in the loads are mitigated for both unity power factor and voltage regulation modes. A three-phase voltage-source converter (VSC) is used as an SAPF for performing all these functions. The linear optimum discrete time filtering technique namely, Wiener filtering-based control algorithm is developed for the extraction of reference supply currents from distorted load currents. The performance of Wiener filter is compared with least mean square (LMS) adaptive filter-based control algorithm. Experimental validation of proposed control algorithm has been performed on a prototype developed in the laboratory. The filtering action of SAPF is able to achieve the total harmonic distortion (THD) of supply current within the limit specified by an IEEE-519 standard.

3. PROPOSED SYSTEM

The key contribution proposed in this paper is to verify experimentally the UPQC-1Ph-to-3Ph destined to feed single- and three-phase loads from the SWER power distribution networks, usually found in rural and remote areas and suffer with PQ problems. Through following the dual compensation technique, the planned 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 device can also suppress harmonics from the grid voltage, as well as compensate for voltage fluctuations, such as voltage sags/swell. In other terms, the UPQC-1Ph-to-3Ph will conceive a local 3P4W device with controlled, balanced and sinusoidal load voltages with low harmonic contents enhancing the PQ indicators.

3.1 Working Principle

The UPQC-1Ph-to-3Ph topology is comprised of two PWM converters, one of which is a half-bridge inverter and the other of which is a split-capacitor 3-Leg inverter sharing the same dc-bus.

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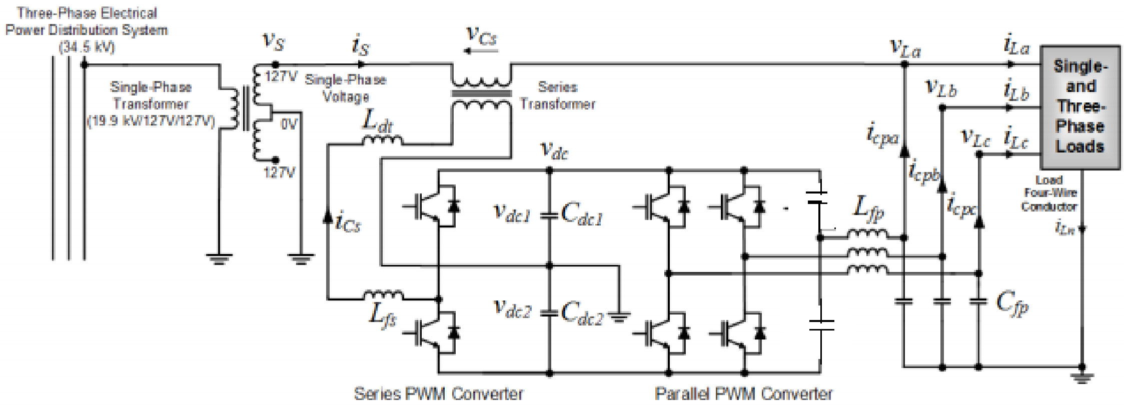


Figure 1. Topology of the UPQC-1Ph-to-3Ph

The series converter is composed of a half-bridge inverter, while in it was composed of a full-bridge inverter. Thus, in addition to having one less leg than the topology, the dc-bus is generated by a split-capacitor arrangement, which allows access to the load's earthed return conductor and allows for usage in SWER delivery systems. As shown in Figure 1, the load's four-wire connection is made to the dc-bus central stage.

The series converter, also known as SAPF, is current regulated to ensure that the input drained current is sinusoidal and in phase with the grid voltage, resulting in a power factor (PF) near one. A filter inductor ( ) is connected in series with the ingle-phase series coupling transformer's primary winding.

The change is as follows: The parallel PWM converter is substituted with a four-switch three-phase inverter to eliminate the switch losses caused by semi conductor systems. The parallel converter, dubbed PAPF, is voltage-controlled and supplies the loads with three-phase sinusoidal, governed, and balanced voltages. The step "a" load voltage is controlled to be in phase with the grid voltage. Attenuation of high-frequency voltage components is accomplished using second-order LC filters. Since the inverter leg attached to phase "a" is operated to serve as a sinusoidal voltage source, the device compensates for the harmonic and fundamental components of the grid voltage indirectly, and no special algorithm is needed to calculate/extract these components. Compensation voltage components consisting of harmonic and fundamental components will appear around the sequence coupling transformer's terminals.

The power flow through the UPQC-1Ph-to-3Ph

converter is dependent on both the load characteristics, such as fundamental power factor and complete harmonic distortion (THD) of current, and the grid characteristics, such as the disparity in the grid and load voltage amplitudes (phase "a"), as well as the grid voltage THD.

3.2 Components of the UPQC

3.2.1 Voltage compensation(Series APF)

Series Active power filter (APF) is helpful in compensating the voltage, i.e it will calculate the voltage error that is present in the grid and how much voltage has to induced in the grid to make the voltage sinusoidal with the desired voltage magnitude and frequency. The supply voltage has to be subtracted by reference voltage (Vabc*), it calculates the error in voltage which is then compared with error voltage produced in 3 lines and then will proceed to PWM control to produce the pulses to minimize the error produced by the difference in calculated error voltage and produced error voltage.

3.2.2 Current Compensation (Shunt APF)

Current compensation will decide how much current error is present in the grid and how much current has to induced in the grid to make the current sinusoidal with desired current magnitude and frequency. The load current has to be subtracted by reference currents (Iabc*) which will be sinusoidal where Id and Iq currents are purified by collecting load currents, it will calculate the error in current which is then compared with error current produced in 3 lines and then will proceed to PWM control to produce the pulses to minimize that error produced by the difference in calculated error current and produced error current.

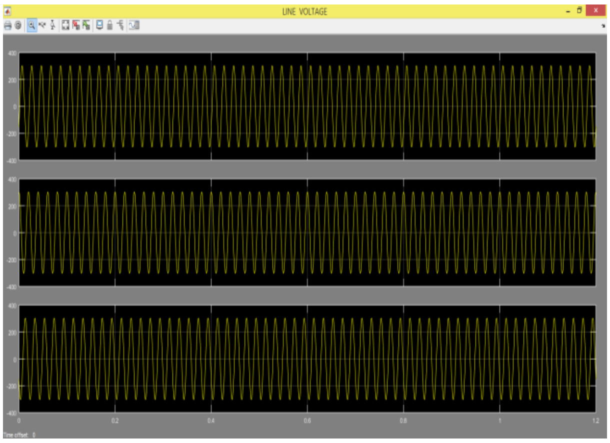
3.2.3 DC capacitor voltage controller

The DC capacitor voltage has to be maintained at some desired value. The reference value has to be subtracted by measured DC voltage and the error has to be minimized to zero by a transfer function and the control signal has to be added to Id current.

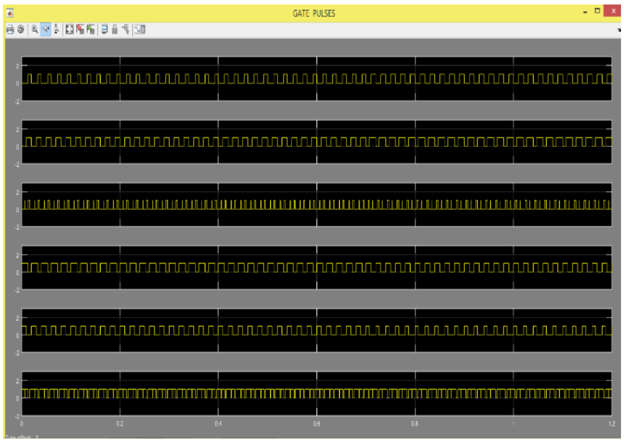
4. SIMULATION RESULTS

An 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.

The static and dynamic performances of the UPQC-1Ph-to-3Ph under study were experimentally evaluated. Table I presents the parameters of the UPQC-1Ph-to-3Ph. The passive elements of the system were designed based on the method presented in [12]. The simulation experiments were conducted in MATLAB for understanding purpose. Figures 2 (a) (b) (c) and (d) show the MATLAB simulation output.

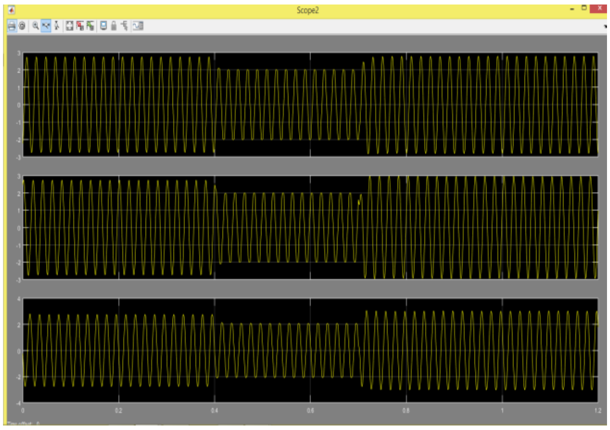


(a)

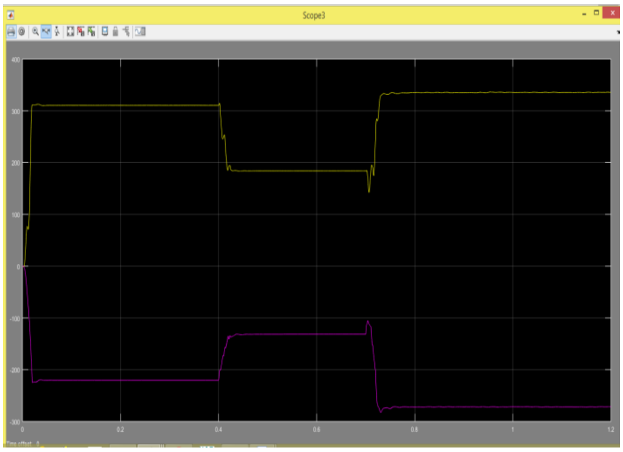


(b)

Figure 2 (a) and (b) – MATLAB simulation input screens



(c)



(d)

Figure 2 (c) and (d) – MATLAB simulation output screens

5. CONCLUSION

This project examined and validated a local three-phase four-wire power delivery device. The machine, which is intended for use in rural or remote areas without connections to three-phase delivery grids, was designed around unified power quality conditioner functionality. The UPQC-1Ph-to-3Ph is composed of two inverter topologies that support serial and parallel filtering. Thus, a half-bridge inverter was used to enforce the single-phase sequence converter, while a 3-Leg split capacitor inverter was used to implement the three-phase parallel converter. By using a dual compensation approach, the proposed device was capable of feeding linear and non-linear three-phase loads that acted as universal active filters, i.e., SAPF and PAPF. Additionally, a method was proposed for dimensioning the power systems of series and parallel converters under a variety of utility grid and load operating conditions.

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