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Advance Technology in Application of Four Leg Inverters to UPQC

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ABSTRACT

This article presents a novel application of four leg inverter with conventional Sinusoidal Pulse Width Modulation (SPWM) Scheme to Unified Power Quality Conditioner (UPQC). The Power Quality problem became burning issues since the starting of high voltage AC transmission system. Hence, in this article it has been discussed to mitigate the PQ issues in high voltage AC systems through a three phase Unified Power Quality Conditioner (UPQC) under various conditions, such as harmonic mitigation scheme, non linear loads, sag and swell conditions as well. Also, it proposes to control harmoincs with various artificial intelligent techniques. Thus application of these control technique such as Neural Networks (ANN) Fuzzy Logic makes the system performance in par with the standards and also compared with existing system. The simulation results based on MATLAB/Simulink are discussed in detail to support the concept developed in the paper.

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1. INTRODUCTION

In these days, Power Quality has become the most important factor for both power suppliers and customers due to the deregulation of the electric power energy market. Efforts are beingmade to improve the Power Quality. Total Harmonic Distortion (THD) is acts as standard to measure the quality of power. Power Quality (PQ) problem is one of the important issue from last three decades. With the introduction of power electronic component in HVAC systems make the system more complex and prone to generate harmonics in the system. While the case would be worst in application of nonlinear loads.Active power filters (APF) have been one of the high performance equipment for PQ improvement.One of the interestingproposals to mitigate the power quality problems is the Unified Power Quality Conditioner (UPQC) topology that integrates the capabilities of the series and shunt filter, with back-to-back connection of the power converters. It mitigates the current and voltage distortions simultaneously and independently. Many control strategies have been developed to control the voltage sags and swells. However, still there is a limitation with the usage of 3 level power converters. This UPQC provides compensation for voltage harmonics, terminal voltage regulation, prevention of voltage collapse, voltage instability etc. These objectives could be achieved using proper control strategy. The electrical power quality is defined as maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency. Most of the power quality problems occurs in distribution systems due to non-linear loads available at end user levels. In [9], it explained about two categories for the deterioration in power quality. The first category contains natural causes such as lighting strikes, falling of tree, equipment failure and so on. The second category contains the man made causes such as switching on / off large loads (transients), induction heating systems, Adjustable Speed Drives (ASD), UPS and so on. Many researchers has gone through the UPQC systems, to improve the power quality in Electrical Power Distribution System. The main aim of the UPQC is to completely suppress the disturbances that affect the performance of power system connected to critical loads/ non-linear loads. This implies that UPQC is one of the powerful solutions to large capacity loads sensitive to supply voltage imbalance distortion [1]. In the proposed control method, load voltage, source voltage, and source current are measured, evaluated, and tested under unbalanced and distorted load conditions using Matlab/Simulink software.

In [1], optimal control strategy for UPQC was explained in detail with feedback linearization. Eventhough the UPQC composed with shunt and series converters with three legs and worked as current and voltage source respectively. In [3], it proposes control strategy for reactive power for three-phase systems with and without neutral wire, and validated its results for steady state and transient conditions. In [2], it was proved that sinusoidal source currents and load voltages under unbalanced and distorted three-phase supply voltages and load currents in a power distribution network. To mitigate those issues, a particle swarm optimization-(PSO) based controller is designed. It was shown with operating under various harsh conditions and controlling robustly.A hybrid energy system, which consists of a diesel-engine generator and a supercapacitor, for improving performance of a rubber tyred gantry crane (RTGC) is proposed in conjunction with UPQC [4].Centre node unified power flow controller [5] was proposed and it was shown for flow control objectives, such as the needs of reactive shunt and series compensation, phase shifting and ensure higher degree of control freedom. In [6], a command generator tracker-based direct adaptive control technique (CGT-DAC) in a three-phase three-wire unified power quality conditioner (UPQC) was implemented. It was shown that to resolve the power quality issues. Also, it was proved to apply the same scheme to regulate the DC-link capacitor voltage without utilising additional controller. It seems the system to be most robust and powerful for unbalanced conditions.In [7], a dual compensation strategy was implemented to control the nonsinusoidalquantites, which consectively helps in reducing the complexity of algorithms. These current and voltage controllers are implemented into the synchronous reference frame [21]–[23], their control references are continuous, decreasing the steady-state errors when traditional proportional-integral controllers are employed. A nonlinear discrete-time model along with an optimal stabilizing controller was implemented in [8] withrelatively small stored energy levels, which adversely affect their stability, as opposed to larger grids. The discrete-time Hamilton-Jacobi-Isaacs optimal control method is employed to design an optimal grid stabilizer. Both the voltage and current controllers are implemented into the synchronous rotating reference frame, and the converters use the three-dimensional space vector modulation technique. In [9], the advance dual compensation techniques were employed with two four–leg converters. To overcome the above drawbacks, in this article a new control algorthms was developed and applied to the 4 leg converters. These converters will help in mitigating the power quality issues. Perhaps, the system has been used with ANN and Fuzzy logic techniqueswhich are quite different from the the conventional strategies. All the proposed system was executed in Matlab/Simulink and results are explored with its conclusive remarks.

2. MULTI LEG INVERTER BASED UPQC

The basic clock diagram of UPQC is shown in Figure 1. It consists of a back to back connected 3 leg converter and 4 leg inverter. This paper presents the study, analysis, and simulation of a UPQC, which is in turn to be connected in transmission and distribution system. Also, a fourth leg has been implemented with the shunt conveter to coopertae with the neutral current.

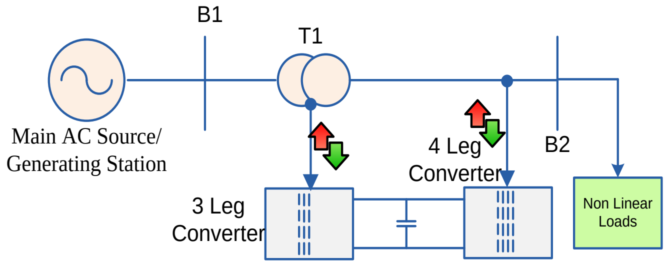

Figure 1. Basic UPQC with DC MLI

Different from the control strategies used in the most of UPQC applications in which the controlled quantities are nonsinusoidal, this UPQC employs a dual compensation strategy such that the controlled quantities are always sinusoidal. Thereby, the series converter is controlled to act as a sinusoidal current source, whereas the parallel converter operates as a sinusoidal voltage source. The main generating station is connected via bus B1, transformer and then to nonlinear loads. However, another bus has been designated as bus B2 is connected to other grids and nonlinear loads as shown in Figure 1. The circuit is simulated for carrier frequency of 1kHzwith amplitude modulation index, m_a=0.9. The circuit topology has a DC capacitor voltage source supplied by a 100V constant DC battery as the energy supply. The output of the inverter gives output at fundamental frequency of 50Hz and AC magnitude of 100V peak to peak. The output drives star connected R load of 10Ω each to achieve proper operation of the VSI topology. The Phase Disposition (PD) firing pulse is generated by comparing triangular waveform of carrier frequency 1050Hz with modulating sine wave of 50 Hz. The two carrier triangular waves whose magnitude varies from 0 to 1 and -1 to zero respectively and the modulating wave. For three-level inverter in PD scheme two carrier waves are used. For M-level inverter M-1 number of carrier waves will be used. The pulsating signals used to trigger the switches S1ap, S2ap, S1an and S2an respectively, whose width varies as sine wave, which control the MOSFETs. -120° and +120° out of phase signals are used to generate the pulses to trigger the rest two arm switches. The %THD value for each modulation schemes is obtained by using powergui tool (FFT analysis) in MATLAB.

The UPQC consists of two Voltage Source Inverters, that share DC link, can compensate the swell, sag and harmonics in voltage and current and it can control the stability of voltage. The support of Shunt Active Power Filter & Series Active Power Filter to UPQC can also compensate interruption of voltage if it contains some stored energy in DC link.The name itself suggests that Series APF is connected in series with the line through a series transformer (ST). The shunt APF is connected in parallel with/across the load to compensate all the problems related to current such as load unbalance, neutral current, current harmonics, reactive power, voltage regulation of dc link and also to improve power factor. The series APF acts as voltage control source and is responsible for compensate the problems related to voltage, such as voltage swell, sag, harmonics, noise etc. In this paper, the proposed synchronous-reference-frame (SRF) based control method for Three phase Four wire UPQC system. This UPQC is optimized through PI controller and Fuzzy Logic Controller for reducing Total Harmonic Distortions in source & load voltages and currents.

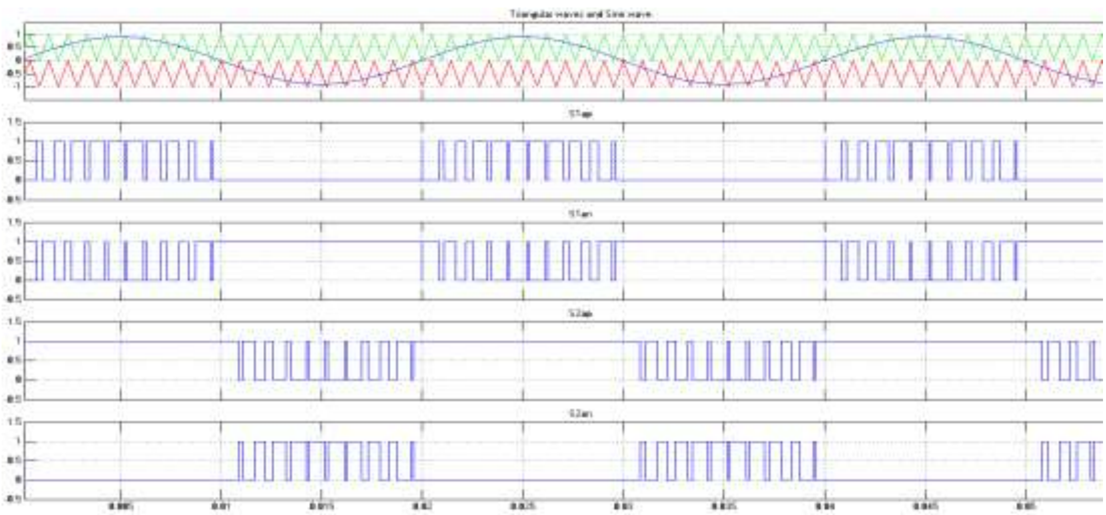

Figure 2. Firing pulses generated using PD scheme for 3 leg conventional inverter

In the simulation diagram for phase disposition pulse generation scheme, subsystem named sine_wave generates the modulating sinusoidal signal of m_a=0.9, at frequency 50Hz. Carrier wave amplitude varies from -1 to 0 and 0 to 1 for 3-leg inverter. Sine wave and the two carrier waves are compared using the relational operator block and the output signal of the relational operator blocks are used to trigger switches S1ap and S2ap. When these signals are passed through NOT logical operator then compliment signals are generated and are used to trigger S1an and S2an switches. The circuit is simulated for carrier frequency of 1050Hz with amplitude modulation index, m_a=0.9. The circuit topology has a DC capacitor voltage source supplied by a 100V constant DC battery as the energy supply.

3. CONTROL AND IMPLEMENTATION

The complete ciruit control is shown below in Figure 3 and its subsequent results are shown in subsequent Figures.

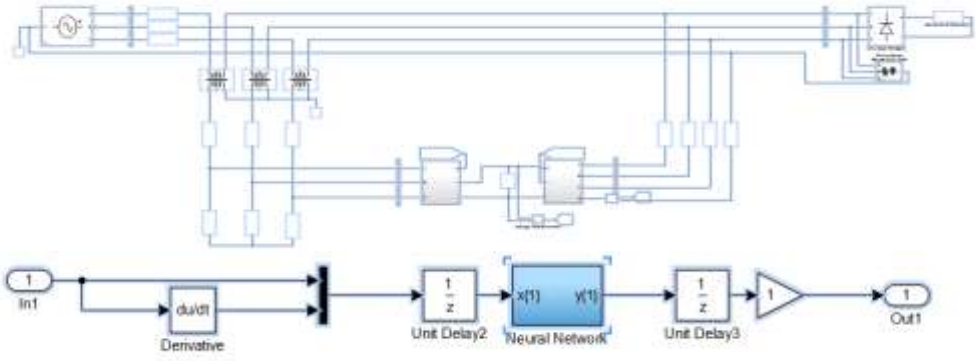

Figure 3. Implemenation of an ANN based control scheme to UPQC

The major Functions performed by UPQC are to convert the feeder (system) current into balanced sinusoidal through the shunt compensator and also convert the load voltage VL to balanced sinusoids through the series compensator. The system controller is required to control the working of UPQC whenever there is any fault in the line then the PI controller and Fuzzy Logic Controllers are used. A PI controller is actually a proportionate gainer which is in parallel with an integrator. The proportionate gainer shows the fast error response and the integrator activates the system for steady-state error. PI controller is one of the essential devices especially in industry as it is the simplest to design. For many applications Proportional plus Integral Control will be satisfactory with good stability and at the desired set point.To eliminate the offset, should be adjusted and reach a constant value when error becomes zero. The integral mode will modify the bias value until the error becomes zero and eliminate offset. The action is not immediate until the integral becomes significant. Also, the integral mode tends the system to be more oscillatory, even unstable. Advantages are Fast action, eliminate the offset. The disadvantages are oscillatory or unstable with integral control, one more parameter to tune. To over come above issues, a Fuzzy Logic Controller has been implemented. The knowledge-base module contains knowledge about all the input and output fuzzy partitions. It will include the term set and the corresponding membership functions defining the input variables to the fuzzy rule-base system and the output variables, or control actions, to the plant under control.The steps in designing a simple fuzzy logic control system are as follows:

a. Identify the variables (inputs, states and outputs) of the plant. Partition the universe of discourse or the interval spanned by each variable into a number of fuzzy subsets, assigning each a linguistic label (subsets include all the elements in the universe).
b. Assign or determine a membership function for each fuzzy subset.
c. Assign the fuzzy relationships between the inputs or states fuzzy subsets on the one hand and the outputs fuzzy subsets on the other hand, thus forming the rule-base.
d. Choose appropriate scaling factors for the input and output variables in order to normalize the variables to the [0, 1] or the [-1, 1] interval.
e. Fuzzify the inputs to the controller.
f. Use fuzzy approximate reasoning to infer the output contributed from each rule.
g. Aggregate the fuzzy outputs recommended by each rule.
h. Apply defuzzification to form a crisp output.

The harmonic currents and voltages produced by balanced 3-phase non-linear loads such as motor drivers, silicon controlled rectifiers (SCR), large uninterruptible power supplies (UPS) are positive-sequence harmonics (7th, 13th, etc.) and negative-sequence harmonics (5th, 11th, etc.). However, harmonic currents and voltages produced by single phase non-linear loads such as switch-mode power supplies in computer equipment, which are connected phase to neutral in a 3-phase 4-wire system are third order zero-sequence harmonics (triplen harmonics—3rd, 9th, 15th, 21st, etc.). These triplen harmonic currents unlike positive and negative-sequence harmonic currents do not cancel but add up arithmetically at the neutral bus. This can result in neutral current that can reach magnitudes as high as 1.73 times the phase current. In addition to the hazard of cables and transformers overheating the third harmonic can reduce energy efficiency. The traditional method of current harmonics reduction involves passive LC filters, which are its simplicity and low cost. However, passive filters have several drawbacks such as large size, tuning and risk of resonance problems. On the contrary, the 4-leg APF can solve problems of current harmonics, reactive power, load current balancing and excessive neutral current simultaneously, and can be a much better solution than conventional approach.

In 3-phase 4-wire systems, two kinds of VSI topologies such as 4-leg inverter and 3-leg (split capacitor) inverter are used. The 4-leg inverter uses 1-leg specially to compensate zero sequence (neutral) current. The 3-leg inverter is preferred for due to its lower number of switching devices, while the construction of control circuit is complex, huge DC-link capacitors are needed and balancing the voltage of two capacitors is a key problem. The 4-leg inverter has advantage to compensation for neutral current by providing 4th-leg and to need for much less DC-link capacitance and has full utilization of DC-link voltage.

E / ce	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

4. RESULTS AND DISCUSSION

Initially, the system has been executed with the neural networks and then with fuzzy logic. The results of both systems have been listed along with its harmonics calculation. The proposed system has been investigated and results are shown in above Figure 4 and Figure 5. In Figure 4, it was shown that, the system is compried with the fuzzy logic for nonlinear loads and harmonic mitigation schemes. The harmonic mitigation scheme is shown in Figure 4 with its injected voltage in phase 'a', voltage profile at the load terminals. The system has been checked with before and after application of controller. It was observed that, before application, the THD was 25.06% and where after application of fuzzy logic it camedown to 2.45%. Further, it was tested with the non linear loads and is shown in Figure 5. One can observe the nonlinear loads and phase injected currents in phase.a. These tested with before and after application of controller and results were listed as 21.47% and 2.09% THD respectively. Hecnce, with the above investigateion, it concludes that the proposed controlling scheme is robust and applies to various situations. The complete parameters list can be found in [22].

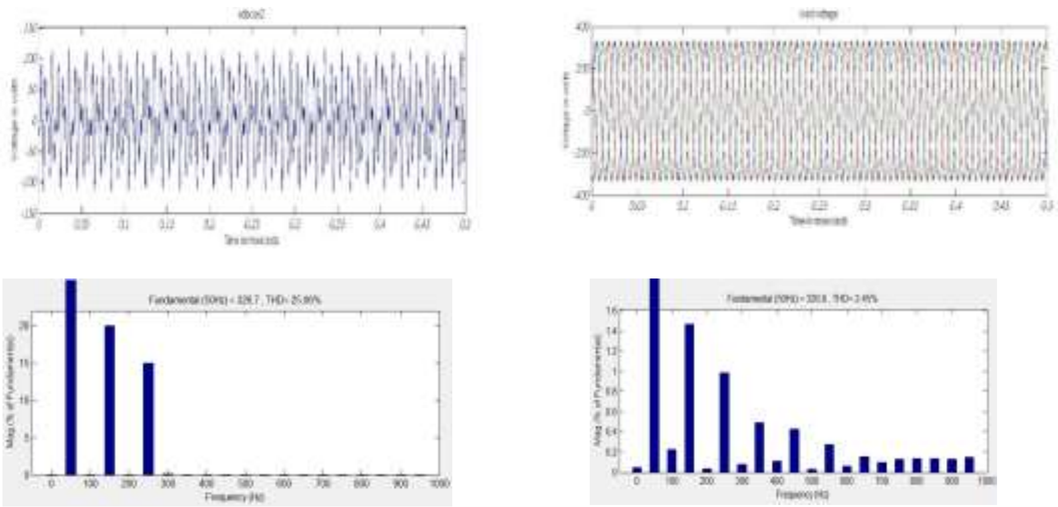

Figure 4. Executed system with fuzzy logic controller with harmonic minimization scheme (a) Injected voltage in to the phase-a (b) Load voltage (c) THD before compensation (d) THD after compensation

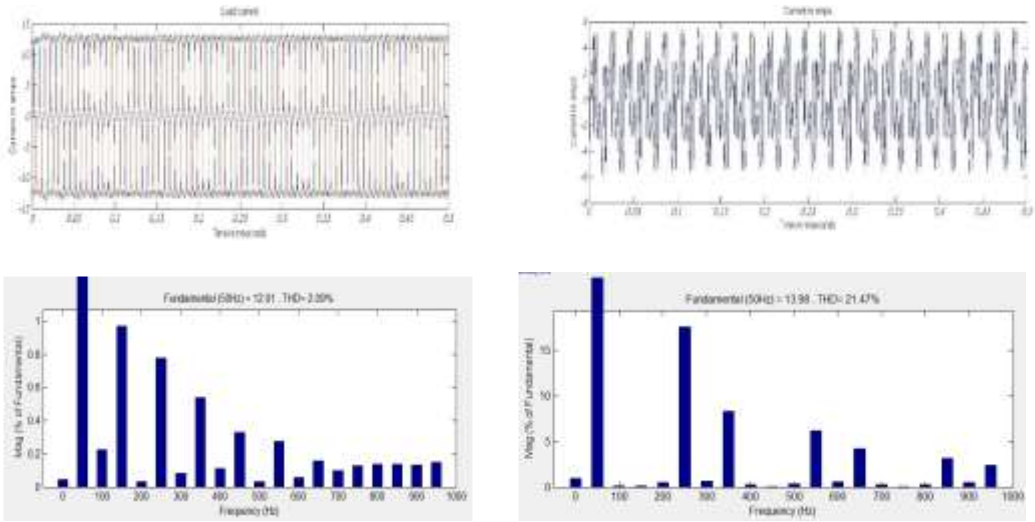

Figure 5. Executed system with fuzzy logic controller for nonlinear load (a) Non linear load in phase-a (b) Non linear current in Phase-a (c) THD before compensation (d) THD after compensation

5. CONCLUSION AND FUTURE SCOPE

UPQC with series and shunt compensators using PI and Fuzzy Controllers are proposed in this paper. Series compensator reduces harmonics present in distribution system to protect sensitive loads connected by injecting series voltages. Shunt compensator reduces current harmonics injected by non linear load and protects distribution system by injecting shunt currents. Reference voltage and currents required by series and shunt compensators are generated by synchronous frame method. For effective performance of shunt and series compensators DC link voltage regulation is important. In this paper two different controllers (PI and Fuzzy) are used and compared for voltage regulation. Because of less overshoot, ripples and steady state error ANN is showing better performance in terms of THD of source current and load voltage, peak overshoot and ripples. Simulation results are presented and compared for two controllers PI and Fuzzy.

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