

An Improved iUPQC with ANN Controller providing Grid Voltage Regulation as a STATCOM

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ABSTRACT: This paper introduces a new Interline Unified Power Quality Conditioner (iUPQC) with an improved controller which integrates an extra functionality of Static Synchronous Compensator (STATCOM), to provide additional grid voltage regulation besides all the functionalities of conventional iUPQC. An Artificial Neural Network (ANN) controller is incorporated to track the reference signals more effectively. This new topology will significantly reduce the overall system cost. The whole system is simulated in MATLAB/SIMULINK to validate the performance.

KEYWORDS: iUPQC, power quality, STATCOM, Unified Power Quality Conditioner (UPQC), ANN.

I. INTRODUCTION

Nowadays the term 'Power Quality' is conquering an excessive popularity. Poor quality of supplied power leads to improper functioning of equipment or appliances, amplified power loss, interference with the nearby communication system etc. One of the most significant reason for the low quality of the supplied power is the tremendous increase in the usage of the power electronic devices. These devices have several advantages like improved controllability, high power density etc. They have their inherent shortcomings such as reactive power disturbances, increased sensitivity to supply voltage and harmonic problems. Moreover the integration of the renewable energy into the existing system is a challenging problem that makes the existing system more susceptible to power quality variations [1].

In earlier days the power quality issues are mitigated using the passive filters, which does not respond properly as the nature of the power system condition changes. Later the downsides of the passive filtering equipment are alleviated by active power filter which are categorized into two series Active Power Filter (APF) and Shunt Active Power Filter (APF). Shunt APFs solve all the current related power quality issues and the series APFs mitigate all the voltage related issues. Attempts were done to combine the functionality of the both shunt and series APFs together. It is from this idea the back-to-back converter system configuration was introduced by Fujitha and Akagi for the first time in 1995. They named this device as Unified Power Quality Conditioner (UPQC), one most promising solution for this issue is the UPQC [2]. UPQCs are classified into different categories. Interline UPQC (iUPQC) or Dual UPQC is one of the most important one among them [3].

Traditionally, the shunt converter of the UPQC behaves as controlled current source that compensates the load current likewise the series active filter behaves as controlled voltage source to compensate the voltage imperfections. In the dual configuration of UPQC, called iUPQC (Interline Unified Power Quality Conditioner) the shunt active filter acts as a sinusoidal voltage source and series converter as sinusoidal current source. There are several advantages for the iUPQC over the conventional UPQC, i.e. the using the fundamental positive sequence components of the current and voltage references for the series and shunt compensators, whereas in conventional UPQC the nonsinusoidal compensating voltages and currents are used [4]. Hence the PWM control of the iUPQC is a well-known frequency spectrum, since it is controlled by voltage and current sinusoidal reference different from conventional UPQC approach [5]. The PWM control in conventional UPQC should deal with non-sinusoidal compensating voltage and current reference, which is impossible to theoretically ensure the zero steady state error in all frequency components [6].

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The interline UPQC (iUPQC), which is the dual topology of UPQC, overcomes all the disadvantages of the conventional UPQC. In recent days Static Synchronous Compensators (STATCOMS) are widely used for voltage regulation [7], But UPQC and iUPQCs are utilized for more specific uses. The applicability of iUPQC can be reached into smart grids and grid tied microgrid, if its functionality can be extended. This can be achieved by incorporating an extra functionality of STATCOM to the present iUPQC system. This results in the reduction in the overall system cost. The efficiency of iUPQC depends on how accurately the reference signals are tracked, for this purpose an Artificial Neural Network (ANN) controller is employed.

Paper is organized as follows. Section II describes configuration of iUPQC. The dynamic response comparison of UPQC and iUPQC is described in Section III. Section IV presents improved iUPQC controller. Section V details the simulation and results. Finally, Section VI presents conclusion.

II. STRUCTURE OF IUPQC

An iUPQC is the dual topology of UPQC. In conventional UPQC the series converter acts as a controlled voltage source and shunt active filter acts as a controlled current source. Whenever the voltage undergoes Sag/swell, the series compensator will inject a suitable amount of voltage in order to mitigate the voltage imperfections. The shunt converter mitigates the current related imperfections by injecting the suitable current. Even if the supply voltage remains unbalanced the voltage at the load end will always be balanced at the suitable value [8]. In iUPQC the shunt converter acts as controlled sinusoidal voltage source and the series converter acts as controlled sinusoidal current source as shown in Fig .1.

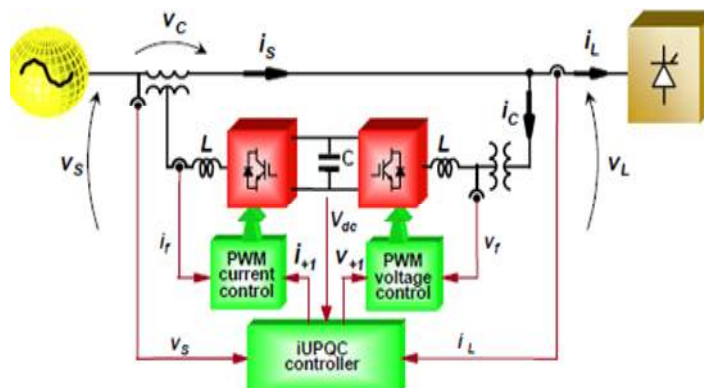


Fig.1.Power Circuit of iUPQC

The drawback of the conventional UPQC controller to generate and synthesize the harmonic current and voltage required to be compensated can be mitigated using iUPQC, Thereby reducing the switching losses in the UPQC.

III. DYNAMIC RESPONSE COMPARISON OF UPQC AND IUPQC

The conventional UPQC system compensates a system disturbance by generating compensation voltage and current depending upon the control algorithm's ability to identify the disturbance and process the reference signals effectively. Hence dynamic response of UPQC depends upon the fast action of the controllers and switching converters. Whereas the iUPQC itself act as a sinusoidal current and voltage source for the load. The Fig.2 represents the dynamic performance of UPQC and iUPQC

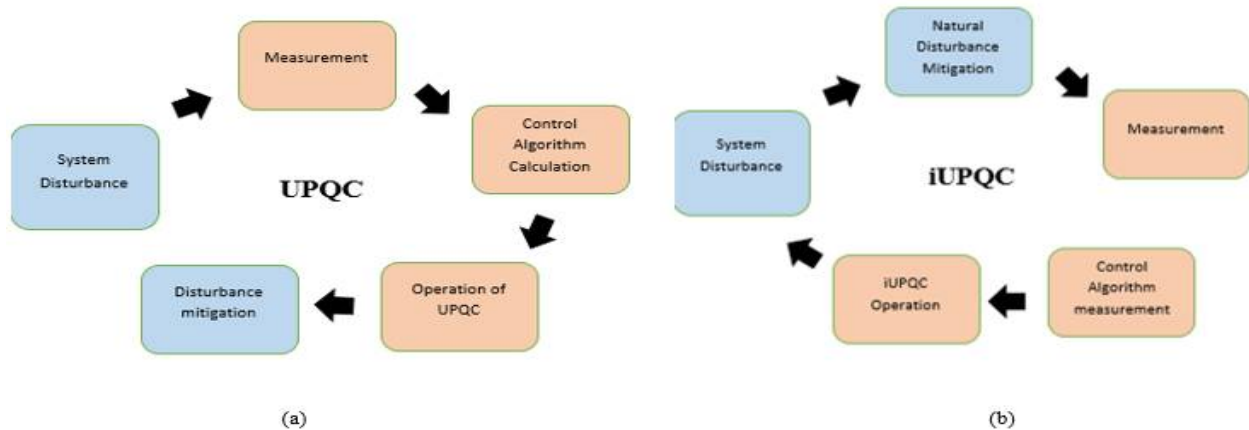


Fig.2. Dynamic response of (a) UPQC, (b) iUPQC

For instance, if a nonlinear load is connected at the consumer end then the current has to be measured, synthesized and then finally mitigated in case of UPQC, Conversely in case of iUPQC under same load condition the series converter is a high impedance to the harmonic current which will be drained through the shunt voltage source i.e., without the need of identification by any control algorithm. Hence iUPQC provides more quick dynamic performance than UPQC. Three processes are taking in action in between the system disturbance and its mitigation. Whereas there is no process taking place between the disturbance and mitigation in case of an iUPQC operation

IV. IMPROVED iUPQC CONTROLLER

In order to include the additional functionality of STATCOM the UPQC controller has to be modified. The improved controller is shown in Fig.3. Source and load voltages (v_s, v_L), load current (i_L) and the dc link voltage (v_{DC}) are the inputs to the controller. The current and voltage references for the series and shunt converter respectively are the outputs of the improved controller, which are then fed to PWM controller. In the conventional iUPQC system the shunt converter voltage reference is either the PLL outputs or the fundamental positive sequence components. Incorporating positive sequence values is more beneficial because it reduces the circulating power through the converters. However there is a difference in the case of the improved iUPQC, here the degree of freedom q , the reactive power of the series converter of the series converter is modified for additional grid voltage regulation therefore now the load as well as the source voltages are regulated. Which means both load and source will be regulated independently to track their reference values.. The improved iUPQC controller with additional functionality is depicted in Fig .3. The sum of active power required by the load and the power losses in the converter gives the average active power. The load active power is given as

$$P_L = V_{+1,\alpha} \cdot i_{L,\alpha} + V_{+1,\beta} \cdot i_{L,\beta} \quad (1)$$

$i_{L,\alpha}, i_{L,\beta}$ represents the load current and $V_{+1,\alpha}, V_{+1,\beta}$ represents the shunt voltage references in (1). $Q_{STATCOM}$ is the additional control signal to incorporate an extra functionality to the iUPQC controller to work it as a STATCOM to provide additional grid voltage regulation[9]. $Q_{STATCOM}$ Is obtained as the output of PI controller whose input signals are the error between the aggregate voltage value and its reference values given by

$$v_G = \sqrt{V_{S+1,\alpha}^2 + V_{S+1,\beta}^2} \quad (2)$$

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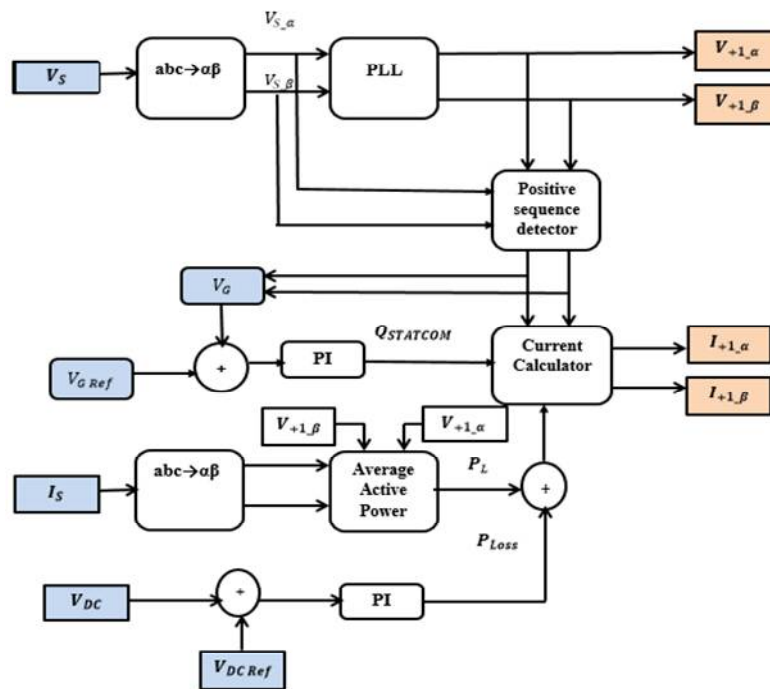


Fig.3. Improved iUPQC controller

The active power control of the series converter of iUPQC (p) is sum of P_L and P_{Loss} . The reactive power control variable q , of the series converter is $Q_{STATCOM}$. Finally $i_{+1,\alpha}$ and $i_{+1,\beta}$, the current reference signals of the series converter is given as

$$\begin{bmatrix} i_{+1,\alpha} \\ i_{+1,\beta} \end{bmatrix} = \frac{1}{V_{S+1,\alpha}^2 + V_{S+1,\beta}^2} \begin{bmatrix} V_{S+1,\alpha} & V_{S+1,\beta} \\ V_{S+1,\beta} & -V_{S+1,\alpha} \end{bmatrix} \chi \begin{bmatrix} P_L + P_{Loss} \\ Q_{STATCOM} \end{bmatrix} \quad (3)$$

V. SIMULATION AND RESULTS

In order to verify the system performance the improved iUPQC system was simulated in MATLAB/SIMULINK. The simulation model is as shown in Fig.4. The system is tested under nonlinear load condition both three phase diode rectifier and two phase diode rectifier condition. The Simulation model of improved iUPQC controller as in Fig 3 is modelled in SIMULINK as shown in Fig.5.

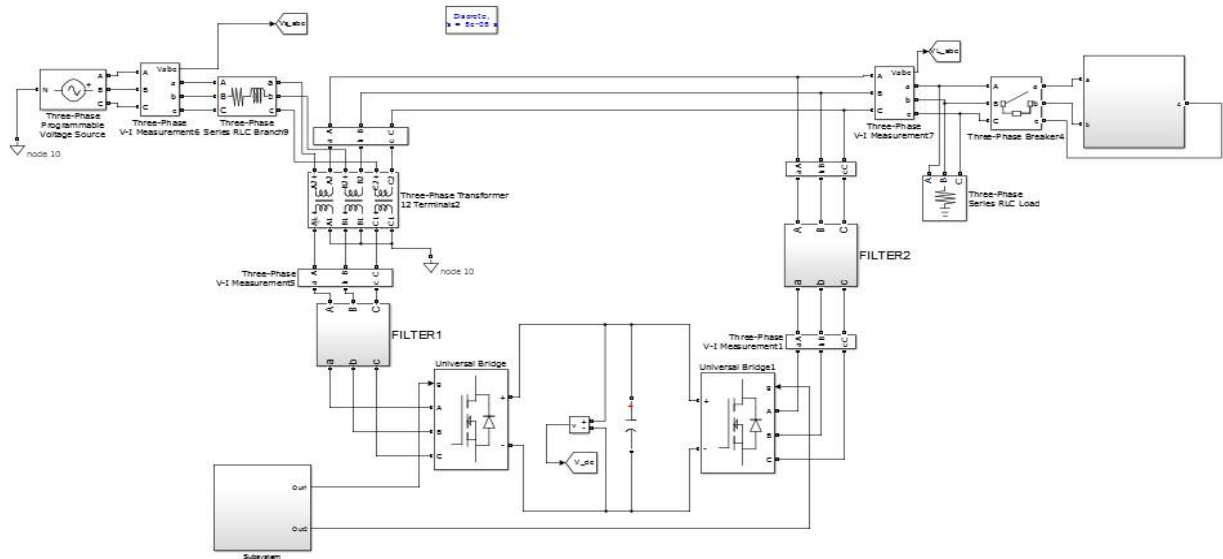


Fig.4. Simulation model of improved iUPQC

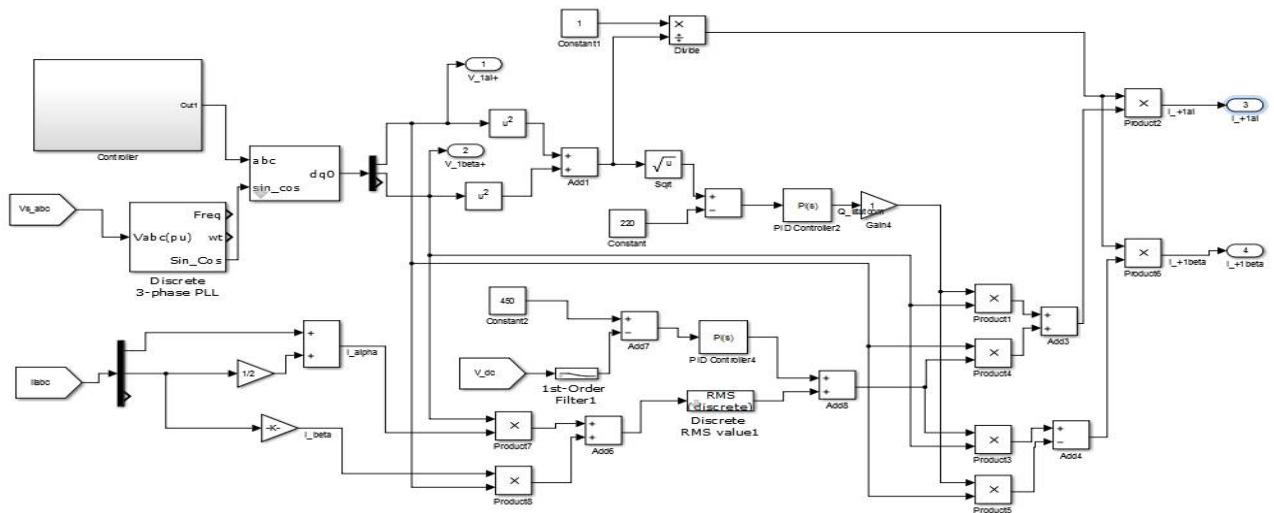


Fig.5. Simulation model of improved iUPQC

A three phase three wire system was modelled with improved iUPQC. The simulation parameters are as shown in Table. I. First and foremost the simulation response with three phase diode rectifier is shown. A three phase diode rectifier is switched into the system at time $t = 0.25s$. The simulation outcomes are as follows

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TABLE.I. SIMULATION PARAMETERS

Parameter	value
Voltage	220Vrms
Grid frequency	50Hz
DC-link Voltage	500Vdc
Dc-link Capacitor	9400 μ F
PI Controller(P_{Loss})	$K_p=4 ; K_i=250$
PI controller(P_L)	$K_p=0.5 ; K_i=50$

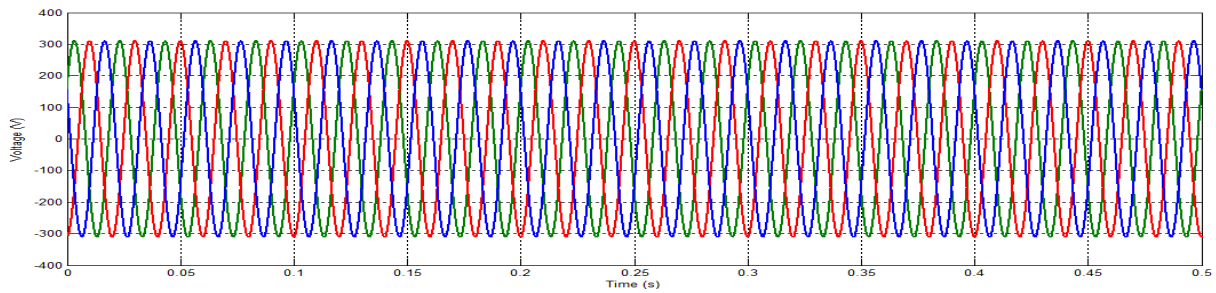


Fig.6. Source voltage with three phase diode rectifier

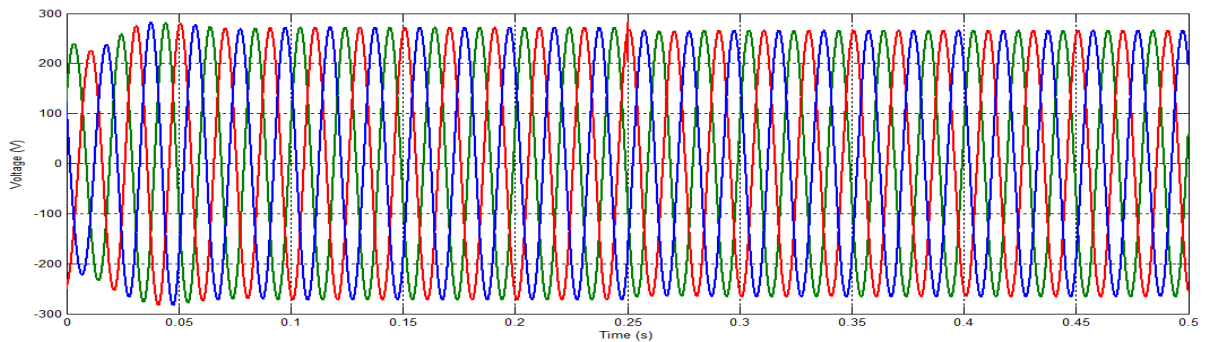


Fig.7 Load voltage with three phase diode rectifier.

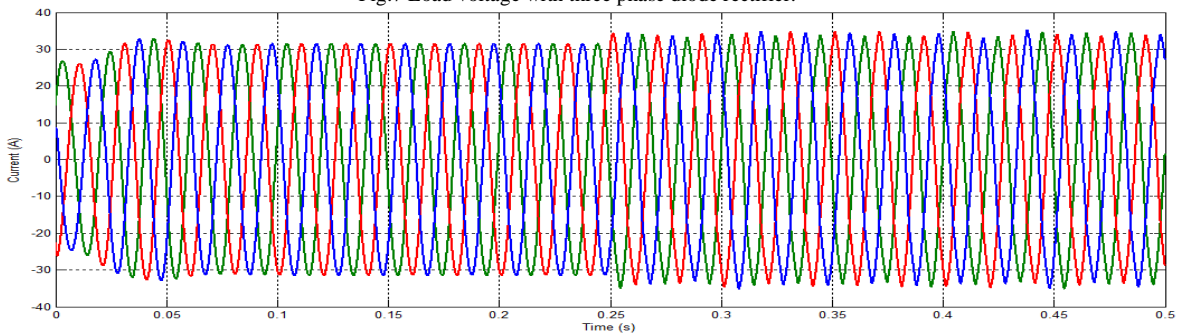


Fig.8. Source current with three phase diode rectifier

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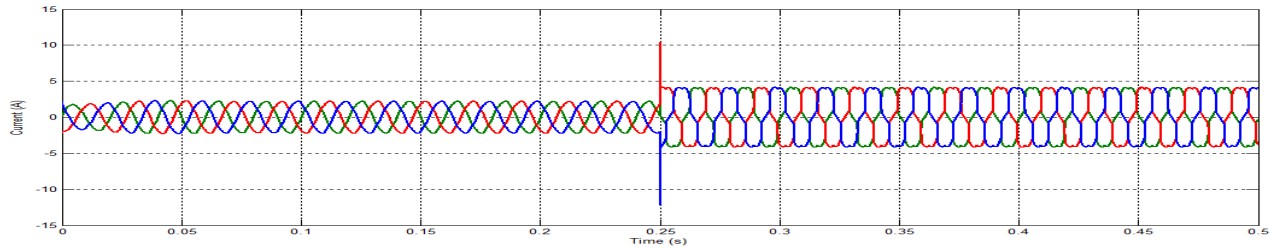


Fig.9. Load current with three phase diode rectifier.

Voltage regulation means the ability of a system to provide a near constant voltage over a wide range of load conditions. Hence it is important to test the system performance under two phase diode rectifier condition. The system is simulated under same previous condition with two phase diode rectifier as the load now. The simulation outcomes are as shown below.

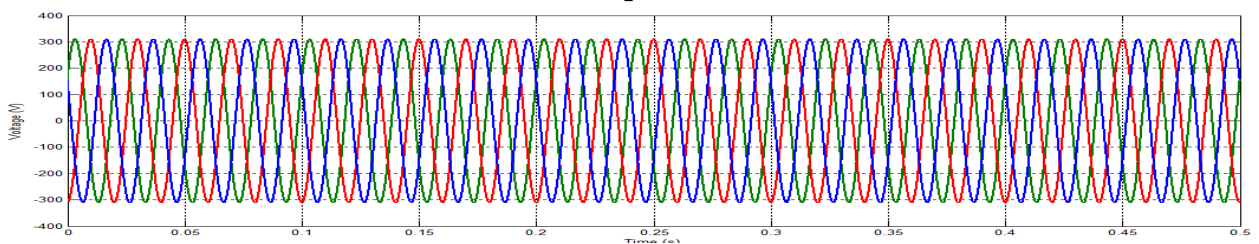


Fig.10. Source voltage with two phase diode rectifier

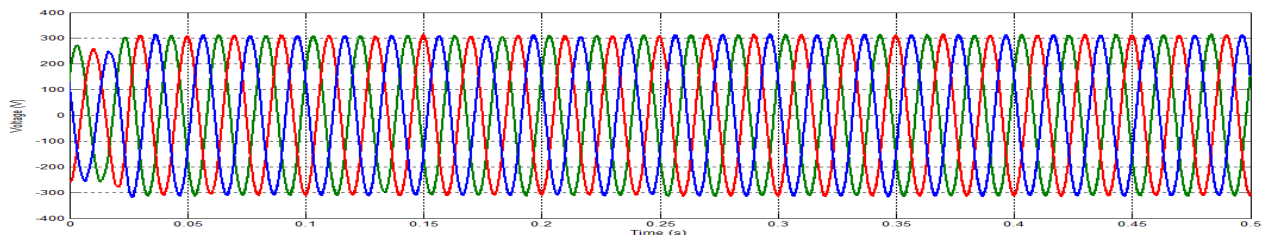


Fig.11. Load voltage with two phase diode rectifier

It is the series converter reactive power control variable (q) that provide the voltage regulation. The reactive power support for grid voltage regulation is provided by the series converter. The simulation output proves that during the connection of the load at $t = 0.25$ sec the reactive power is injected by the series converter.

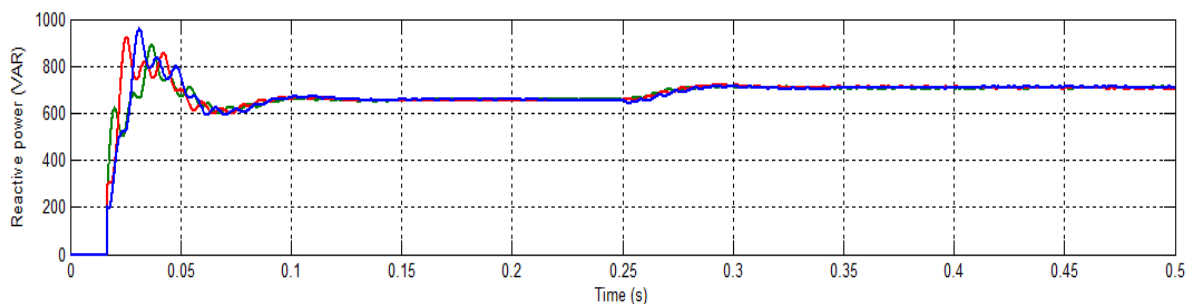


Fig.12. Reactive power support by the series converter

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As far as power quality problem compensating devices are concerned, the efficient and accurate detection of the disturbance signals are considered to be a vital requirement. Unfortunately the conventional Proportional Integral (PI) controllers fails to perform pleasingly under varying load conditions. Hence it is desirable to employ an Artificial Neural Network (ANN) controller for accurate tracking of the reference signals [10]. ANN is made up of interconnecting networks of artificial neurons. The neurons are connected by links and they interact with each other. The nodes can take input data and perform simple operations on the data. The result of these operations is passed to other neurons. Each link is associated with weight. ANN usually consist of an input layer and an output layer with a hidden layer in between them. ANN are manly described on the basis of their ability to communicate with the environment, their topology, last and most importantly their training algorithm. For the efficient detection of reference signals Levenberg Marquardt training is used here. And for the improved accuracy a multilayered feedforward network with the number of 10 hidden layers is adopted here. A comparative analysis of the THD values with and without ANN controllers are shown in table below.

TABLE.II. THD VALUES WITH AND WITHOUT ANN

THD Values	Without ANN	With ANN
Source Voltage	0.07%	0.02%
Load Voltage	0.90%	0.25%

VI. CONCLUSION

The paper explored the performance of improved iUPQC controller that provides an additional grid voltage regulation as a STATCOM. The simulation results supports that, the improved iUPQC controller can work as a STATCOM to regulate the voltage at the grid side, also giving satisfactory operation at the load end with different load conditions. An ANN controller is employed to track the reference signals more accurately, which reduced the overall THD value of the system into a negligibly small value. Therefore improved iUPQC controller can be employed for load as well as source voltage regulations.

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