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ENHANCEMENT IN WORKING PERFORMANCE OF CUSTOM POWER DEVICE USING DIFFERENT CONTROLLING METHODS

[1]M. KALYANASUNDARAM,[2]Dr. S. SURESHKUMAR
[1]Assistant Professor, Department of Electrical & Electronics Engineering, Vivekanandha College of Engineering for Women, Tiruchengode (Tk), Namakkal (Dt), Tamilnadu. INDIA.
[2] Principal, Vivekanandha College of Technology for Women, Tiruchengode(Tk), Namakkal (Dt), Tamilnadu. INDIA.
E-mail: [1]mkalyanasundaram79@gmail.com, [2]nice.ssk@gmail.com

ABSTRACT

With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, Power-Quality (PQ) problems, like harmonics, neutral current elimination, reactive power has become an unavoidable issue. The Unified Power Quality Conditioner (UPQC) of shunt and series inverter having a common Direct Current (DC) link. The UPQC in distribution has made it possible to mitigate the following problems effectively. The UPQC has been realized by Voltage Source Inverter (VSI). The controlling algorithm determines the production of controlling signals which is used by the VSIs for the generation of their gating signals. The variation of performance of the device occurs with the different controlling algorithms .This paper proposes the comparison of performance of two mainly used algorithms namely Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). The two controlling algorithms are used in a Fuzzy Controller (FC). In addition to this Synchronous Reference Frame (SRF) theory with modified Phase Locked Loop (PLL) is used in both cases for better performance. The main PQ issues concentrated in this paper relates to reactive power compensation, harmonics elimination and neutral current elimination. The performance is being investigated in an IEEE 118 bus system. Simulation outputs have been obtained through MATLAB/SIMULINK.

Keywords: *Power Quality, Unified Power Quality Conditioner, Particle Swarm Optimization, Synchronous Reference Frame, Genetic Algorithm.*

1. INTRODUCTION

Electric power systems are real-time energy delivery systems. An electric power system is a network of electrical components used to supply, transmit and use electric power. This can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centers to the load centers and the distribution system that feeds the power to nearby homes and industries.

Electric PQ is a term which has captured increasing attention in distribution system. The measure of PQ depends upon the needs of the equipment that is being supplied. Usually the term PQ refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. There are two approaches to the mitigation of PQ problems [1]. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances.

A flexible and versatile solution to voltage quality problems is offered by Active Power Filters (APF). Currently they are based on Pulse Width Modulation (PWM) converters and connect to low and medium voltage distribution system in shunt or in series [2]-[5]. The Power Angle Control (PAC) concept is suggests that with proper control of shunt and series inverter. Just as facts improve the reliability and quality of power transmission system, the custom power enhances the quality and reliability of power that is delivered to customers.

The application of power electronics to power distribution system for the benefit of a customer or group of customers is called custom power devices. Like Flexible AC Transmission System (FACTS), the term custom power use for distribution system. The UPQC is one of the key custom power device,

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which can compensate both current and voltage related problems, simultaneously [4].

The UPQC is connected before the load to make the load voltage free from any distortions and at the same time, the reactive current drawn from source should be compensated in such a way that the currents at source side, would be in phase with utility voltages [3]. Control strategy plays the most significant role in any power electronics based system. It is the control strategy which decides the behavior and desired operation of a particular system. The effectiveness of a UPQC system solely depends upon its control algorithm. The UPQC control strategy determines the reference signals (current and voltage) and, thus, decides the switching instants of inverter switches, such that the desired performance can be achieved [5].

2. SYSTEM CONFIGURATION

One of the foremost custom power devices that are competent of alleviating the consequence of PQ problems at the non linear load is the UPQC. In addition to removal of harmonics, recompense for reactive power, load current unbalance, source voltage sags, source voltage unbalance and power factor correction are provided by UPQCs [9]-[14]-[15]. Generally, an UPQC is comprised of two VSIs sharing with one DC link capacitor [3]. Here, the main problem is that the discharging time of DC link capacitor is very high. To mitigate this problem, a FC with SRF theory is made [13]. For the performance evaluation of UPQC, two controlling algorithms namely PSO and GA are fed to this FC. Rather than the conventional PLL, this paper proposes the usage of modified PLL due to its large advantages [4].

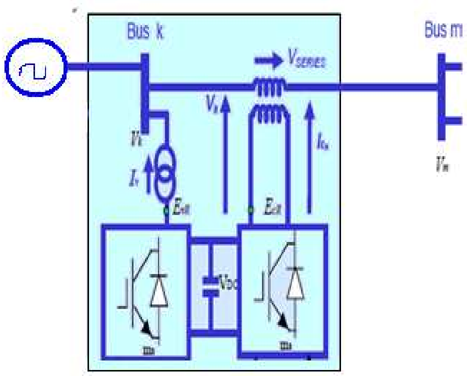

Figure 1: Control circuit of UPQC

The control circuit of UPQC is shown in Figure 1. In this paper IEEE118 bus system is being realized and the Figure 1 shows a UPQC connected between two buses, say **m** and **k** [10].

UPQC Specification:

AC Voltage per Phase V_{abc} [V] = 415 Vrms
Line Frequency = 50Hz
PWM Switching frequency =5 KHz
DC link Capacitance = 1000µf
VSC – I Series Inverter = C_f -8mH & L_f -36 µf
VSC – II Shunt Inverter = C_f -1100mH & L_f -15 µf
Source Resistance [R_S] = 1.0 Ω
Source Reactance [X_S] = 1.0 Ω

3. SYNCHRONOUS REFERENCE FRAME [SRF] THEORY

In this study a SRF based theory is adapted for the UPQC. The proposed SRF control method uses **a–b–c** to **d–q**–0 transformation equations and filters also. The proposed SRF-based controller for the UPQC under 3P4W topology is used for the series and shunt APF parts [3]-[5]. In the SRF, the load current signals are transformed into the conventional rotating frame d-q by using the transformation matrix (T) as given in Equation (1)

$$\mathbf{T} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \sin(\omega t) & \sin(\omega t-\frac{2\pi}{3}) & \sin(\omega t+\frac{2\pi}{3}) \\ \cos(\omega t) & \cos(\omega t-\frac{2\pi}{3}) & \cos(\omega t+\frac{2\pi}{3}) \end{bmatrix} \quad (1)$$

And the comets pointing inverse matrix is given by,

$$\mathbf{T}^{-1} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & \sin(\omega t) & \cos(\omega t) \\ 1/\sqrt{2} & \sin(\omega t-\frac{2\pi}{3}) & \cos(\omega t-\frac{2\pi}{3}) \\ 1/\sqrt{2} & \sin(\omega t+\frac{2\pi}{3}) & \cos(\omega t+\frac{2\pi}{3}) \end{bmatrix} \quad (2)$$

3.1. Modified –Phase Locked Loop [PLL]

For both shunt and series parts of the UPQC in this work the transformation angle (ωt) is given by a PLL. Due to the less efficiency of conventional PLL, modified PLL has been used [4].

The conventional PLL circuit works properly under distorted and unbalanced system voltages. However, a conventional PLL circuit has low performance for highly distorted and unbalanced system voltages. In this paper, the modified PLL is employed for the determination of the positive sequence components of the system voltage signals [13]. The reason behind making a modification in conventional PLL is to improve the UPQC filtering performance under highly distorted and unbalanced voltage conditions.

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4. SIGNAL GENERATION FOR SHUNT- APF

The active power is injected to the power system by the series APF in order to compensate the active power losses of the UPQC power circuit, which causes DC-link voltage reduction [7]. Some active power should be absorbed from the power system by the shunt APF for regulating DC-link voltage. For this purpose, the controller is used in shunt part. This paper aims at the usage of FC as shown in Figure 2 and comparing its two algorithms, PSO and GA [8]-[12].

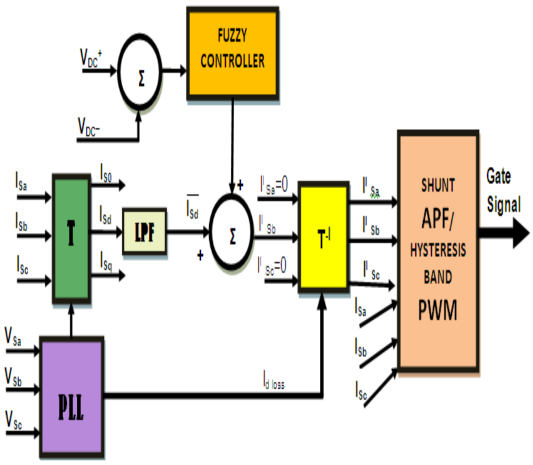

Figure 2: Signal generation for shunt APF

4.1. Fuzzy Controller

The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Control schemes of UPQC based on PI controller has been widely reported. The PI control based techniques are simple and reasonably effective. However, the tuning of the PI controller is a tedious job [3]. Further, the control of UPQC based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows. The FC is basically nonlinear and adaptive in nature. The results obtained through FC are superior in the cases where the effects of parameter variation of controller are also taken into consideration [10].

The FC is based on linguistic variable set theory and does not require a mathematical model. Generally, the input variables are error and rate of change of error. In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC. In this paper PSO and GA based FC are proposed [11]-[12].

4.2. Particle Swarm Optimization Algorithm

PSO optimizes a problem by having a population of swarm of particles and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity [6]. Each particle's movement is influenced by its local best known position and is also guided toward the best known positions in the search-space, which are updated as better positions. This is expected to move the swarm toward the best solutions. PSO is initialized with a group of random particles (solutions) and then search for optima by updating generations. Let as Consider the every iteration each particle is updated by following two best values. The first one is the best solution (fitness) it has achieved so far. This value is called P_{best} [10]-[11] . Another best value is tracked by the PSO is the best value, obtained so far by any particle in the population. This best value is a global best and called G_{best}.

When a particle takes part of the population as its topological neighbors, the best value is a local best and is called P-best. After finding the two best values, the particle updates its velocity and positions [8].

In this work, the algorithm compares (PSO and GA) a voltage value with a reference value and it will help to use the best voltage value that suits the reference voltage value [13]. For this purpose, the DC-link voltage is compared with its reference value (v' DC), and the required active current (i_{dloss}) is obtained by a FC based PSO controller. The source current fundamental reference component is calculated by adding to the required active current and source current average component [6]-[7].

The main steps are,

Step 1: Initialization of condition for each particle
Initial searching points and velocities are randomly generated within their limits. P_{best} is set to each initial searching point. The best evaluated values among the P_{best} are set to G_{best}.

Step 2: Evaluation of searching point of each particle. The objective function is evaluated for each particle. If the value is better than the current P_{best} of the particle, the P_{best} value will be replaced by the current value. If the P_{best} value is better than the current G_{best}, the G_{best} will be replaced by the best value and the best value is stored.

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Step 3: Updating each search points after finding the two best values, the current searching particle is updated using,

$$v[\,] = v[\,] + c_1 * rand() * (P_{best}[\,] - present[\,]) + c_2 * rand() * (G_{best}[\,] - present[\,]) \quad (3)$$

$$W = W_{max} - ((W_{max} - W_{min})/iter_{max}) * iter \quad (4)$$

$$present[\,] = present[\,] + v[\,] \quad (5)$$

Step 4: Terminate condition If the current iteration number reaches the pre-determined maximum iteration number the process is terminated else the process proceeds to step 2.

4.3. Genetic Algorithm

In nature, the individual that has better survival traits will survive for a longer period of time. This in turn provides it a better chance to produce offspring with its genetic material. Therefore, after a long period of time, the entire population will consist of lots of genes from the superior individuals and less from the inferior individuals. In a sense, the fittest survived and the unfit died out [10]-[15]. This force of nature is called natural selection. The molecular explanation of evolution proves that this is biologically impossible. The Figure 3 shows the basic operation that occurs in a GA.

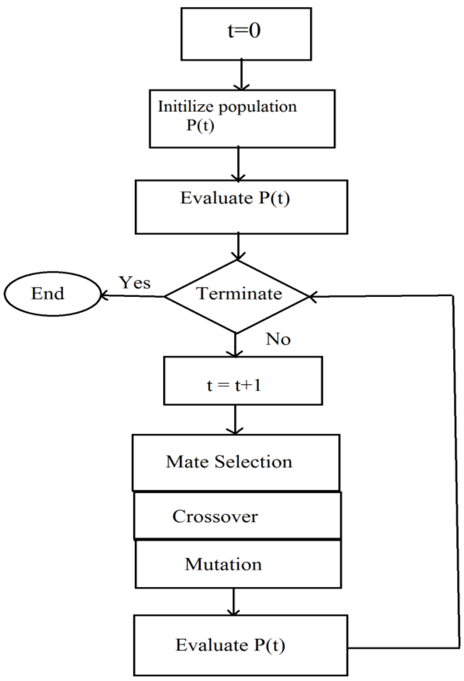

Figure 3: Genetic Algorithm

GAs has been proved to be effective and quite robust in solving the optimization problems. GAs can provide near global solutions and can also handle effectively the discrete control variables. GAs does not stick into local optima because GAs begins with many initial points and search for the most optimum in parallel. GAs considers only the pay-off information of objective function regardless whether it is differentiable or continuous [10]. Consequently, the most realistic cost characteristic of power plants can be formulated. Discontinuity and non-differentiability of cost characteristics can be effectively handled by Gas.

5. SIGNAL GENERATION FOR SERIES-APF

The rating of a UPQC is governed by the percentage of maximum amount of voltage need to be compensated. However, the voltage variation is a short duration PQ issue. Therefore, under normal operating condition, the series inverter of UPQC is not utilized up to its true capacity [3]-[15]. The PAC concept suggests that with proper control of series inverter voltage, the series inverter successfully supports part of the load reactive power demand, and thus reduces the required VA rating of the shunt inverter. Most importantly, this coordinated reactive power sharing feature is achieved during normal steady-state condition without affecting the resultant load voltage magnitude [2]-[8].

5.1. Fundamentals of PAC Concept

According to this theory, a vector V_{Sr} with proper magnitude V_{Sr} and phase angle δ_{Sr} when injected through series inverter gives a power angle δ boost between the source V_s and resultant load V_L^1 voltages maintaining the same voltage magnitudes [8]. This power angle shift causes relative phase advancement between the supply voltage and resultant load current I_L^1 denoted as angle β. In other words, with PAC approach, the series inverter supports the load reactive power demand and thus, reducing the reactive power demand shared by the shunt inverter [9].

The series inverter maintains the load voltage at desired level, the reactive power demanded by the load remains unchanged (assuming load on the system is constant) irrespective of changes in the source voltage magnitude [10]. Furthermore, the power angle δ is maintained at constant value under different operating conditions. The reactive power shared by the series and shunt inverter can be fixed at constant values by allowing the power angle δ to vary under voltage condition. The control block

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diagram for series inverter operation is shown in Figure 4.

The instantaneous power angle δ is determined. Based on the system rated specifications, the value of the desired load voltage is set as reference load voltage k. The instantaneous value of factors K_f and n_o is computed by measuring the peak value of the supply voltage in real time. The magnitudes of series injected voltage V_{Sr} and its phase angle δ_{Sr} are then determined using equations. A modified PLL is used to synchronize and to generate instantaneous time variable reference signals $V_{Sr}{}^*,a$, $V_{Sr}{}^*,b$, $V_{Sr}{}^*,c$ [4]-[10] .The reference signals thus generated give the necessary series injection voltages that will share the load reactive power and compensate for voltage as formulated using the proposed approach. The error signal of actual and reference series voltage is utilized to perform the switching operation of series inverter [14].

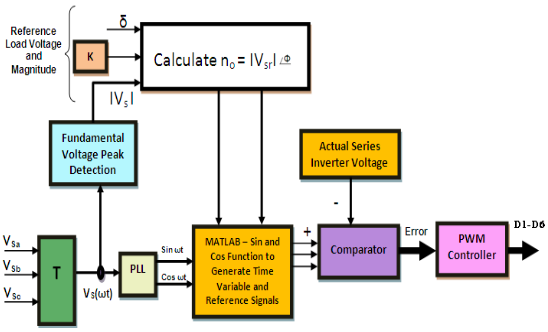

Figure 4: Signal Generation for Series APF

A bus is electrically equivalent to a single point on a circuit, and it marks the location of one of two things: a generator that injects power, or a load that consumes power.

At the degree of resolution generally desired on the larger scale of analysis, the load buses represent aggregations of loads (or very large individual industrial loads) at the location where they connect to the high-voltage transmission system [9].

There are many different electrical bus system schemes available but selection of a particular scheme depends upon the system voltage, position of substation in electrical power system, flexibility needed in system and cost to be expensed.

The main criteria's for the selection of buses are as follows:

- Simplicity of the system.
- Easy maintenance of different equipments.
- Maintain the outage during maintenance.
- Future provision of extension with growth of development.

In this paper, IEEE 118 bus test system containing 118 busses, 186 lines, and 20 generators. 118 bus systems have been divided into 3 control areas as shown in Figure 5 and 6. Each control area consists of an UPQC with the corresponding algorithms as mentioned above [9]-[10].

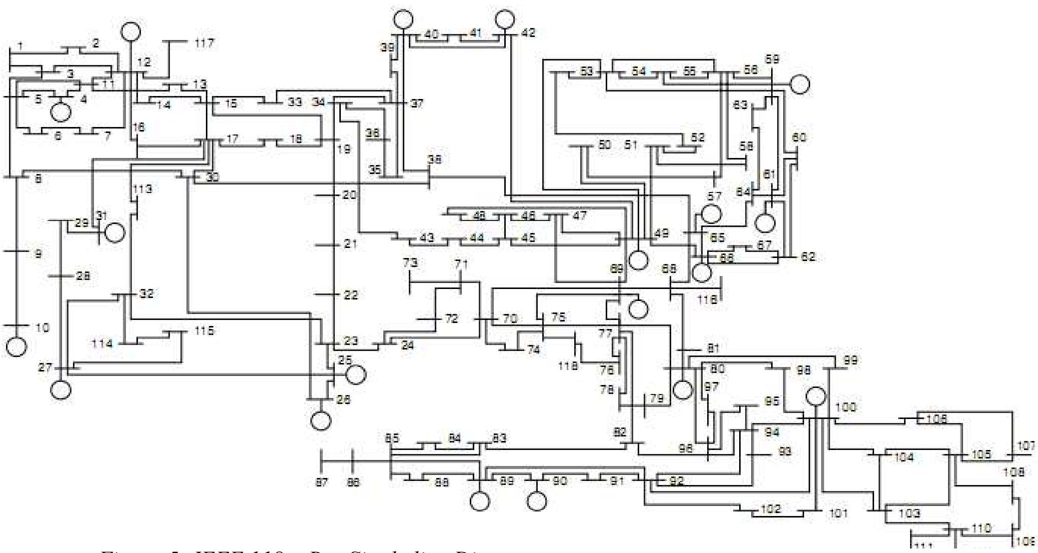

Figure 5: IEEE 118 – Bus Single line Diagram

6. IEEE 118 - BUS SYSTEM

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The UPQC is being connected between two buses in each control area .The main aim of this work is to compare the effects of UPQC with two algorithms namely PSO and GA when the load which the device connected is of a nonlinear device [6]-[7].

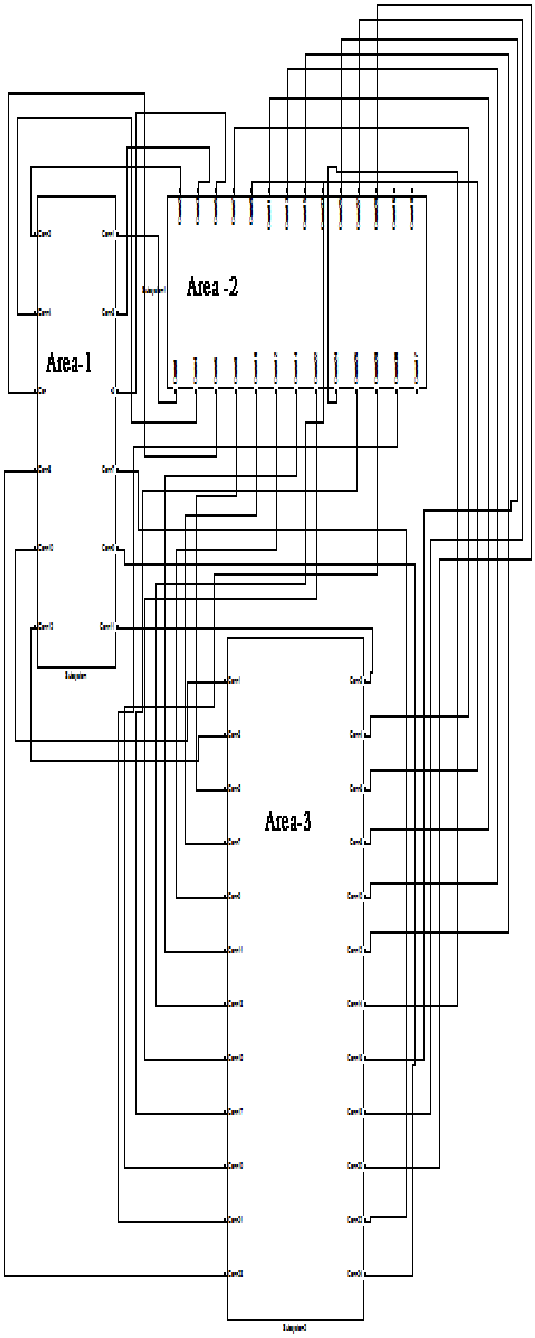

Figure 6: IEEE 118 bus system (Area)

7. OUTPUT WAVEFORMS

Since the work concentrates in the comparison part, the waveform that occurs with two algorithms (PSO and GA) with same load condition is being shown below.

7.1. Unbalanced and distorted load conditions

UPQC concentrates in eliminating distortions which are given as input to the device and mitigates the distortions.

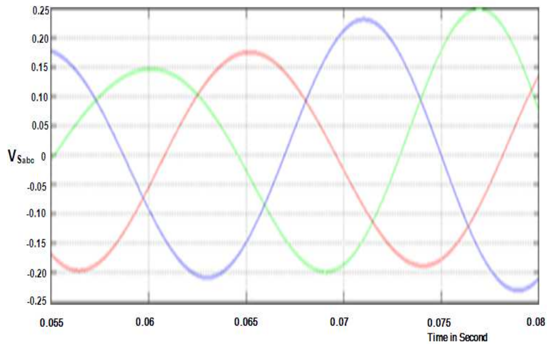

Figure 6: Voltages versus Time

From this waveform we can analyze the case of unbalancing in an effective manner , unbalancing can be identified from the magnitude of its voltages as marked.The waveforms are increasing and decreasing at equal time instances.The same waveform occurs for both cases.

7.2. Injected Compensator Current by Using PSO

It is the current which is injected by the device for the purpose of compensating unwanted distortions.

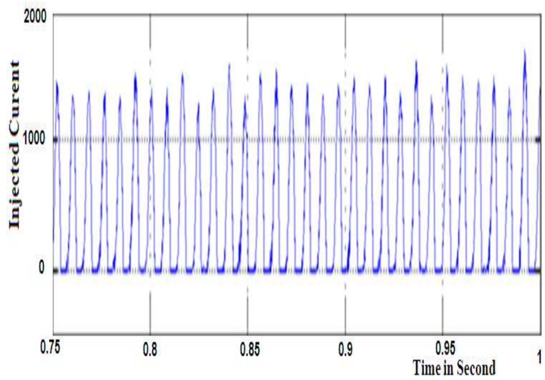

Figure 7: Current Versus Time

From the waveform it is evident that by using PSO,compensator curent has been injected at regular time intervals as marked in Figure 7 which shows that there is no time lag for injecting compensating current.

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7.2.1. Injected Compensator Current by Using GA

From the waveform shown in Figure 8, it can be note down that here injected compensator current is being given between a large time gap,which is much more than by using PSO as shown in Figure 7.

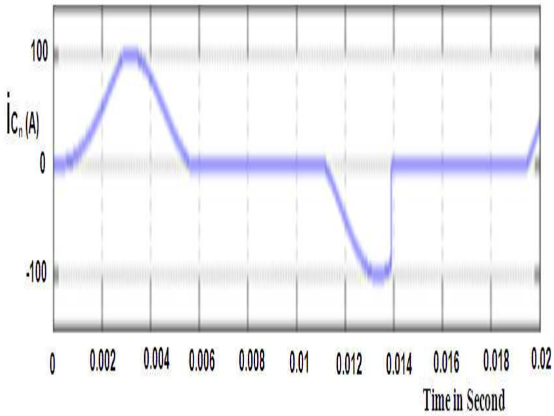

Figure 8: Current Versus Time

7.3. Load Neural Current by Using PSO

In practice for better performance the neutral current should be absent .This means that for a better performance the neutral current should lie on 0 x-axis.

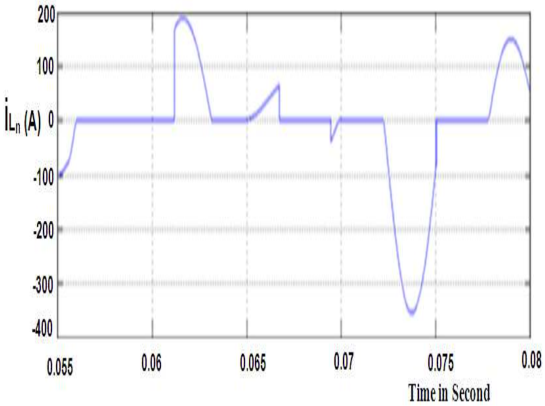

Figure 9: Current versus Time

From figure 9 it is clear that by the usage of PSO, the neutral current is almost lie in 0 x-axis.

7.3.1. Load Neural Current by Using GA

From the waveform shown in Figure 10, by using GA the neutral current will be 0 for a few instance of time, after that it will overcome its 0 position and try to oscillate within its positive and negative peaks.

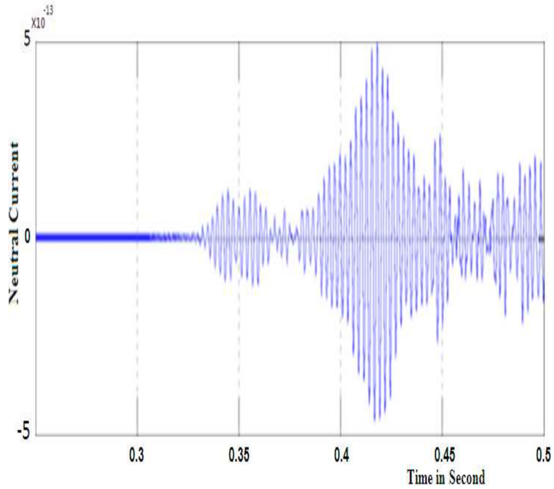

Figure 10: Current versus Time

7.4. Reactive Power Compensation

Reactive Power which is an unwanted power should be compensated for Power Quality Improvement. In UPQC, reactive power compensation is done by the capacitors which is kept as the storage element in between two Voltage source inverters. Since by using capacitors current will lead voltage thereby reactive power compensation is done

7.4.1. By Using PSO

From the waveform in Figure 11 reactive compensation has been done clearly. Because here current which is shown as green is leading voltage which is represented by blue.

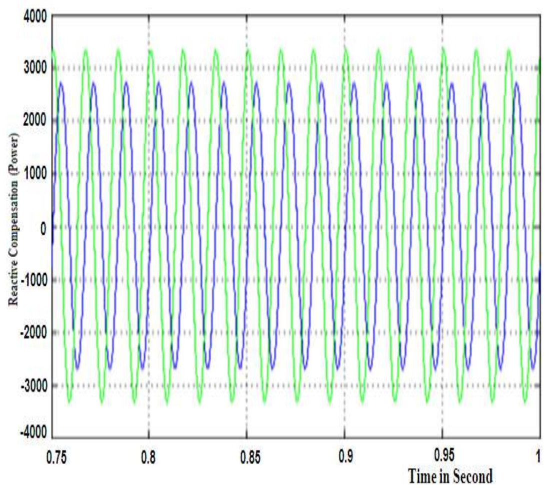

Figure 11: Power versus Time

So by using PSO reactive compensation have done in an effective manner.

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7.4.2. By Using GA

In case of GA, reactive compensation is not done in an effective manner which can be clearly viewed as in Figure 12, here current which is represented by green is lagging voltage which is represented by blue.

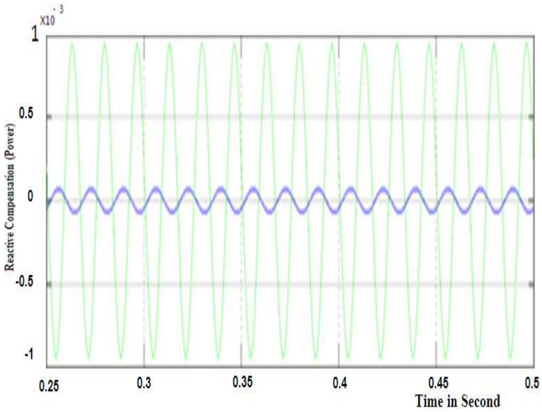

Figure 12: Power versus Time

7.5. Load Voltage

After installing UPQC the load voltage is distortion free which shows the elimination of voltage harmonics and also it will be in balanced form. This can be viewed from the graph Figure 13, that for equal time changes in x-axis, the voltage magnitude changes equally

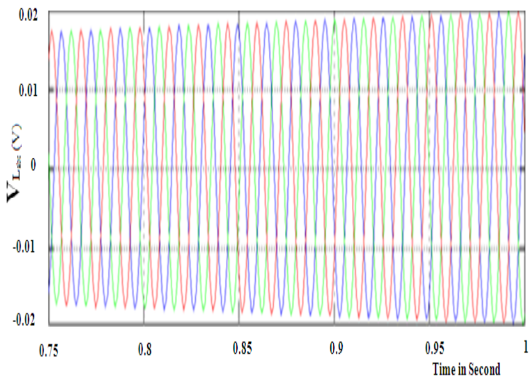

Figure 13: Voltage versus Time

8. CONCLUSIONS

In this paper Power-Quality problems, such as harmonics, neutral current elimination, and reactive power has been eliminated by the introduction of UPQC. Effective Control algorithms like Particle Swarm optimization (PSO) and Genetic algorithm (GA) in the shunt part and Power Angle Control are compared. The PQ can also be improved by using Interline Unified Power Quality conditioner in future. The FC was used for comparing the effectiveness of the algorithms. Matlab / Simulink are used as the analysis tool and the performance is investigated in a IEEE 118 bus system. It is observed from the simulation results that the major power quality issues are significantly reduced. PSO produces current with little time lag than GA in the case of injected compensator current. Also PSO performs reactive compensation in a superior way than GA. Also for neutral current PSO shows better result. Hence it is proposed that the usage of FC based PSO gives better performance than FC based on GA.

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