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Differential Evolution Based Power Quality Disturbance Identification and Mitigation in Power Systems

K.VEERA SUKUMAR	M-Tech Scholar, Power Electronics & Electrical Drives, Department of Electrical and Electronics Engineering Gudlavalleru Engineering college, Krishna, (A.P), India
Dr. L. RAVI SRINIVAS	Professor, Department of EEE, Gudlavalleru Engineering College, Krishna, (A.P), India
B. MAHESH BABU	Asst Professor, Department of EEE, Gudlavalleru Engineering College, Krishna, (A.P), India
Dr. S. S.. TULASI RAM	Professor, Department of EEE, , JNTU Hyderabad, (A.P),India

ABSTRACT

Power quality problems such as voltage imbalance, sag, swell, and current harmonics are due to non-linear loads. The device unified power quality conditioner (UPQC) is used to mitigate both the voltage and current disturbances. The synchronous reference frame theory is used to generate reference signals of UPQC. In UPQC, the DC link capacitor voltage is controlled by conventional PI controller then optimized PI-DE is used to estimate new reference values. Here the optimization is carried out by taking minimization of the THD as objective function. The performances are observed by using simulations conducted in MATLAB 7.9 / simulink software.

I. INTRODUCTION

The loads based on power electronic devices generally pollute the nearby network by drawing non sinusoidal currents from the source. In three phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. In addition to this, the power system is subjected to various transients like voltage sags, swells, flickers etc, [1]-[2]. These transients might affect the voltage at distribution levels. Excessive reactive power drawn by loads would increase the generating capacity of generating stations and increase the transmission losses in lines. Hence, supply of reactive power at the load ends becomes essential.[3]-[5]. Power Quality mainly deals with issues like maintaining a fixed voltage at the Point of Common Coupling for various distribution voltage levels, Irrespective of voltage fluctuations, maintaining near unity power factor, blocking of voltage and current imbalance from passing upwards from various distribution levels, reduction of voltage and current harmonics in the system.[6]-[7]. This paper focuses on optimized method for derivation of new compensation signals in UPQC. The differential evolution with hysteresis control is the one chosen. The proposed system can improve the power quality at the point of common coupling on power distribution systems. The performance of the proposed system has been validated through simulations using MATLAB/SIMULINK.

II. SYSTEM CONFIGURATION

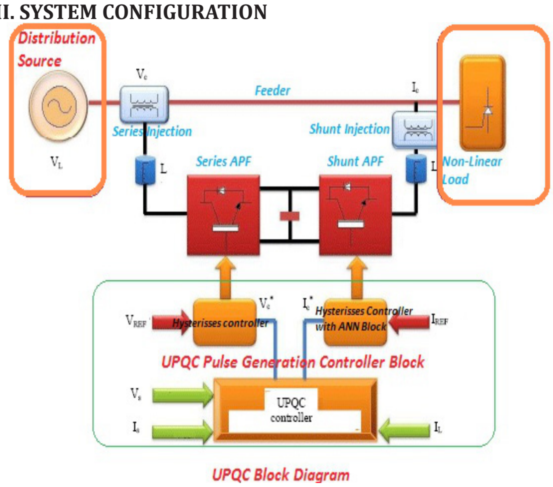

Fig.1 Basic Block Diagram

The overall circuit is shown in the Fig.1. A general UPQC with series and shunt APFs. The main aim of the series APF is to obtain harmonic isolation between the load and supply. It has the capability of voltage imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer PCC. The shunt APF is used to absorb current harmonics, to compensate for reactive power, and to regulate the dc-link voltage between both APFs.

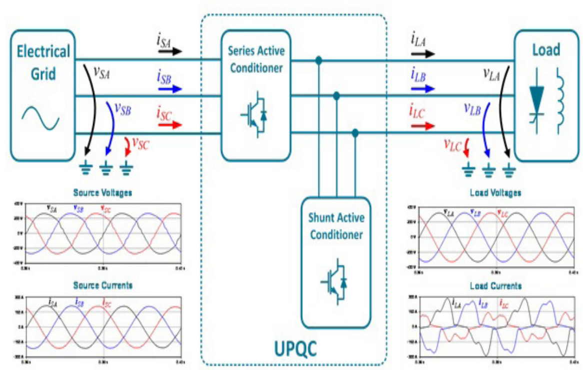

Fig.2 The Simplistic Representation of UPQC

The simplistic representation of the UPQC is shown in the Fig.2. At PCC, the voltage may or may not be distorted depending on the other non-linear loads connected at PCC. Here, the assumption of the voltage at PCC is distorted. Two voltage source inverters are connected back to back sharing a common dc link, [8]-[10]. One inverter is connected parallel with the load. It acts as shunt APF, helps in compensating load harmonic current as well as to maintain dc link voltage at constant level. The second inverter is connected in series with utility voltage by using series transformers and helps in maintaining the load voltage sinusoidal, [11]-[12].

As for the shunt active filter of the UPQC, it is represented by with as the first order low-pass interfacing filter and as the losses of the shunt VSI. represents the switched voltage across the shunt VSI output of the UPQC. The injection current of the shunt active filter is denoted by both and which take the value of either -1 or 1 depending on the switching signal of the hysteresis control.

II.A. CONTROL CIRCUIT CONFIGURATION OF UPQC

The control strategy is based on the extraction of Unit Vector

Templates from the distorted input supply. These templates will be equivalent to pure sinusoidal signal with unity (p.u.) amplitude. The extraction of unit vector templates is

$$\left.\begin{aligned} U_a &= \sin(wt) \\ U_b &= \sin(wt-120) \\ U_c &= \sin(wt+120) \end{aligned}\right\} \tag{1}$$

Multiplying the peak amplitude of fundamental input voltage with unit vector templates of equation (1) gives the reference load voltage signals,

$$V^*_{abc} = V_m \cdot U_{abc} \tag{2}$$

The error generated is then taken to a hysteresis controller to generate the required gate signals for series APF and shunt APF. Extraction of Unit Vector Templates and 3-Φ Reference Voltages is shown in the Fig.3. The unit vector templates are generated for APF to compensate the harmonic current generated by nonlinear load. The shunt APF is used to compensate for current harmonics as well as to maintain the dc link voltage at constant level, [8]-[9].

The unit vector templates are shown in Fig.2 the instantaneous current of the nonlinear load is expanded into 3 terms. The first term is the load Reference currents and voltages are generated using Phase Locked Loop (PLL).

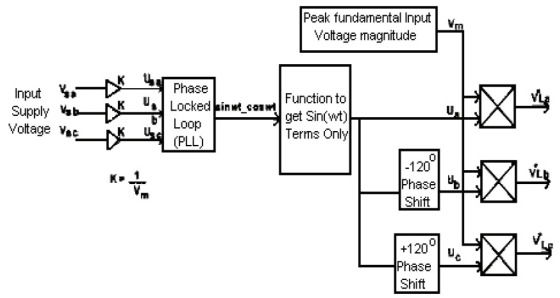

Fig.3 Extraction of Unit Vector Templates and 3-Φ Reference Voltages

When the dc link voltage is sensed and compared with the reference dc link voltage an error will be obtained. An error should be processed through the PI controller. The obtained output signal from PI controller is multiplied with unit vector templates gives reference source current signals. The source current must be equal to this reference signal. In order to follow this reference current signal, the 3-phase source currents are sensed and compared with reference current signals. The error generated is then processed by a hysteresis current controller with suitable band, generating gating signals for shunt APF. The UPQC uses two back-to-back connected three phase VSI's sharing a common dc bus. The hysteresis controller is used here to control the switching of both the VSI's.

II. B. CONTROL STRATEGY OF UPQC

UPQC consists of series compensator and shunt compensator. PWM control algorithms are used to control both the converters. The shunt converter is controlled by current control and series converter controlled by voltage control. According to the adopted control scheme, these two parts of UPQC have different functions as follows.

Static Shunt Compensator

In Fig.2 the instantaneous current of the nonlinear load is prolonged to 3 terms. The first term is the load functions sent from PLL (Phase Locked Loop) in accordance with equation (3),

$$I_{Ldq0} = T^{dq0}_{abc}\, i_{Labc} \tag{3}$$

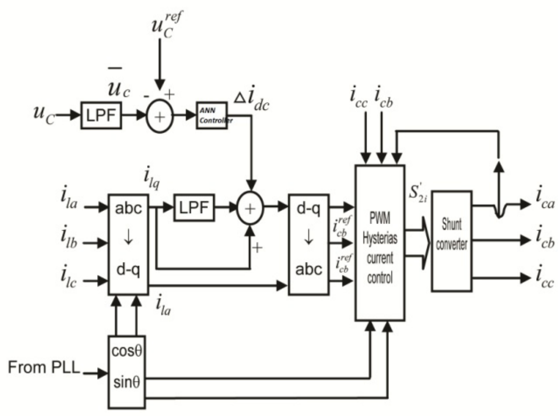

Fig.4 Control diagram of shunt Converter of the UPQC

From these, the fundamental positive sequence components are transformed into dc Quantities in d and q axes, which can easily be stretched by low pass filter (LPF). All harmonic components are changed into ac quantities with a fundamental frequency sh ift.

$$I_{Lq} = \overline{i_{Lq}} + \tilde{i}_{Lq} \tag{4}$$

$$\text{Since } i_L = i_S + i_C \tag{5}$$

$$U_{sdq0} = T^{dq0}_{abc} U_{sabc} = U_{sLp} + U_{sLn} + U_{sL0} + U_{sh} \tag{6}$$

This means in the system currents there are no harmonics and reactive components. The switching loss can cause the dc link capacitor voltage to decrease. Other disturbances, such as imbalances and rapid variations of loads can also cause fluctuations in voltage. To avoid this, in Fig.4 PI controller is used. The input of the PI controller is the error between the actual capacitor voltage and the desired value, its output is then added to the reference current component in the d-axis to form a new reference value.

Static Series Compensator

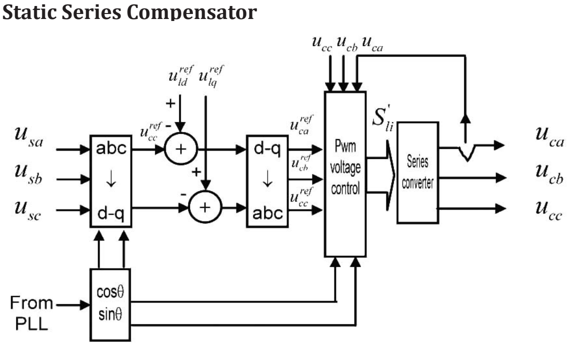

Fig.5 Control block diagram of the series converter of the UPQC.

The system side voltage may include negative-zero-sequence as well as harmonics components which need to be eliminated by the series compensator, [13]-[14]. The control of the series compensator is shown in Fig.5. The system voltages are detected and then transformed into synchronous dq-0 reference frame using equation (6).

II. C. PI-CONTROLLER

The PI control scheme for the active power filter is explained in this section. The DC side capacitor voltage is sensed and compared with a reference voltage. This error

$e = V_{dc, ref} - V_{dc}$

At the *nth* sampling instant is used as input for PI controller. The error signal is passed through Butterworth design based low Pass Filter (LPF). The LPF filter has cutoff frequency at 50 Hz that can suppress the higher order components and allows only fundamental components. The PI controller is used to estimate the magnitude of peak reference current I_{max} and control the dc-side capacitor voltage of voltage source inverter. Its transfer function represented as

$$(H)\, s = kp + \frac{Ki}{s} \qquad (16)$$

Where, 'K_p' is the proportional constant that determines the dynamic response of the Dc-side voltage control and 'K_i' is the integration constant that determines its settling time. The proportional integral controller is eliminating steady state error in the DC-side voltage.

II. D. DIFFERENTIAL EVOLUTION

Differential Evolution (DE) algorithm is one of the population-based stochastic optimization algorithm recently introduced. Advantages of DE are: efficiency, simplicity & real coding, easy use, local searching property and speediness. DE works with two populations, old generation and new generation of the same population. By the parameter NP, the population size is adjusted. Here, the population consists of real valued vectors with dimension D that equals the number of design parameters/control variables. The population is randomly initialized within the initial parameter bounds. Three main operations involved in this optimization process are mutation, crossover and selection. In each generation, individuals of the current population become target vectors. For each target vector, the mutation operation produces a mutant vector, by adding the weighted difference between two randomly chosen vectors to a third vector. The crossover operation generates a new vector called 'trial vector', by mixing the parameters of the mutant vector with those of the target vector. If the trial vector obtains a better fitness value than the target vector, then the trial vector replaces the target vector in the next generation.

The main steps of the DE algorithm are given below:

- Initialization
- Evaluation
- Repeat
- Mutation
- Recombination
- Evaluation
- Selection
- Until (termination criteria are met

III. PROPOSED METHOD

In UPQC, the 'shunt APF' is used as controlled plant and the diagram is as shown in Fig.1. The inconvenience of the conventional PI controller is its incapability to improve the transient response of the system. The conventional PI controller can be represented as,

$$y(t) = k_p * e(t) + k_i \int_0^t e(t)\,dt \qquad (17)$$

Where, Y= Control output

K_p = Proportional gain

K_i = Integral gain

The control output is fed to inverter HCC signal generator. The difference between injected current and the reference current is known as an error signal. The design of the conventional PI controller depends on the requirement. In this study, the trial and error method has been used to determine the parameters 'K_p' and 'K_i'. The key contribution in the proposed approach is to find the optimal PI parameters which are shown in fig.6. By using the optimal PI parameters, the steady state error of the system is minimized. The objective of an optimal design of currents PI controller for given plant is to find a best parameters 'K_p' and 'K_i' of PI control system such that the performance indexes on the transient response is minimum.

The evolution procedure of DE algorithm is represented in the section II. D, producing initial populations is the first step of DE. The population is composed of chromosomes that are real codes. The corresponding evaluation of a population is the "fitness function" which is the performance index of a population. The fitness value is bigger and the performance is better. After the fitness function has been calculated, the fitness value and the number of the generations determine whether or not the evolution procedure is stopped (Maximum iteration number reached?). After this, calculate the local best of each particle and global best of population (The best movement of all particles). Then update the velocity, position, global best and local best of particles and give a new best position.

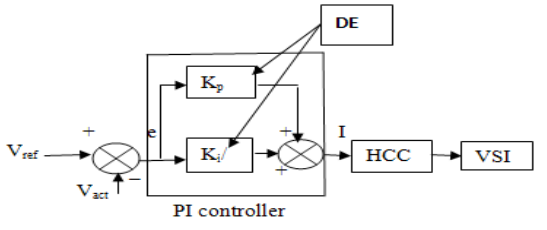

Fig.6: Control of injected current using optimized PI Controller

Algorithm for the proposed model:

Each set of PI parameters is passed to PI controller. A complete response of the system for each PI set and its initial fitness value is computed using a defined objective function. In this study, the THD is chosen as objective function. The goal of algorithm is to seek for minimum fitness value.

- Setting DE optimizing parameters
- Initialize the vector population
- Perform mutation and cross over
  - a.) Mutant vector: Mutant vector is produced by add ing the weighted difference between two randomly chosen vectors to a third vector.
  - b.) Crossover: Perform cross over for each target vector with its mutant vector to create a trail vector
- Verifying the boundary constraints
- Selection: Selection is performed for each target vector by comparing its fitness value with that of the trial vector. Vector with lower fitness value is selected for the next generation.
- Repeat step 3 to 5 until new population is produced
- tRepeat steps 6 until end of predetermined no of generations.

IV. SIMULATION RESULTS

The harmonic content of input and output of the Bridge converter are shown in Figure 7 (Three phase voltages) and Fig. 8 (Three phase currents). Harmonic contamination is caused due to non-linear loads, such as large thyristor power converters, rectifiers, voltage and current flickering due to arc in arc furnaces, sag and swell due to the switching of loads etc. Better solution is the use of a combined system of shunt and active series filters like UPQC. This device combines a shunt active filter together with a series active filter in a back-to-back configuration, to simultaneously compensate the supply current and the load voltage or to mitigate any type of voltage and current fluctuations and power factor correction in a power distribution network. The control and optimization strategies used here are based on PI & PI-DE controller of the UPQC in detail. The simulations results of various strategies are developed by using MATLAB/SIMULINK are shown below.

Fig.7. input voltage, Load voltage and Injected voltage.

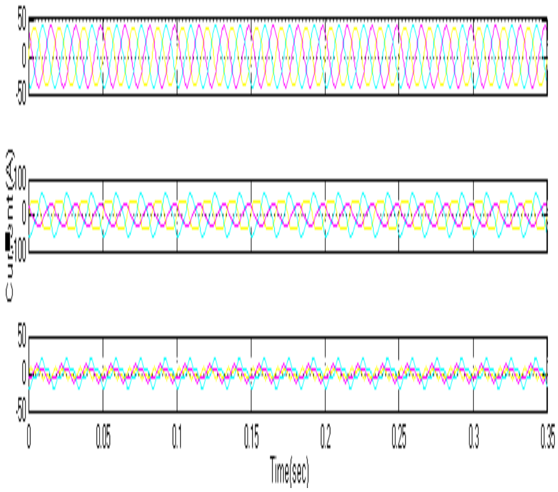

Fig.8.input current, Load current and Injected current.

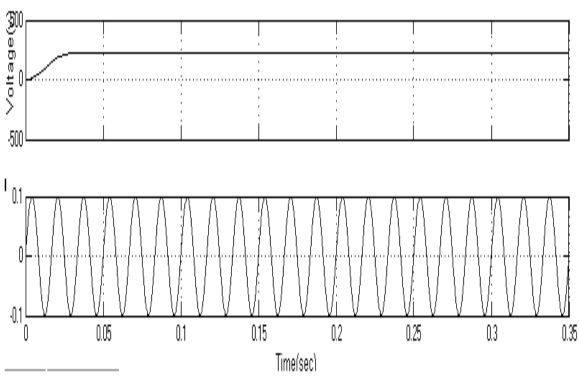

Fig.9.Dc voltage and without compensation

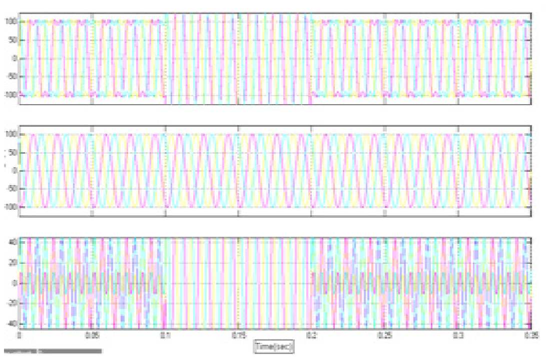

Fig.10.input Voltage, Load Voltage and Injected Voltage with Swell condition

The evident results are shown in the figure 7,9 of Load voltages and figure 10 represents source currents of both series and shunt APF's and they are put into the operation at different time instant. The shunt APF is put into the operation at instant '0.2 sec'. Within the very short time period the 'shunt APF' maintains the dc link voltage at constant level. The 'shunt APF' also helps in compensating the current harmonics generated by the non-linear load. It is evident that before time '0.1 sec', as load voltage is disturbed. As soon as the 'series APF' put in to operation at '0.1 sec' the load current profile is also enhanced. Before the time '0.2 sec', the source current is equal to load current. But after '0.2 sec', when shunt APF starts maintaining dc link voltage it injects the compensating current in such a way that the source current becomes sinusoidal. Injection of current by the 'shunt APF' model of the UPQC has been improved with PI shunt controller & optimized PI-DE are shown in simulation results.

'THD' performances of load voltage and source current by using different shunt controllers (PI & PI-DE).

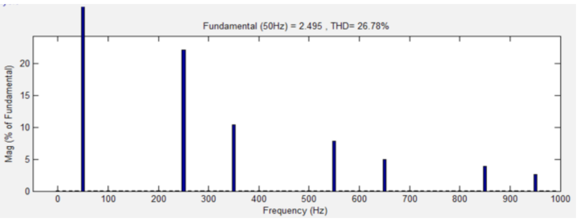

Fig.11. THD of source current without UPQC

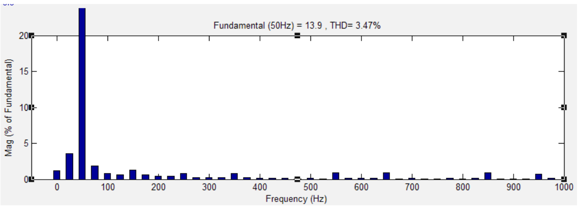

Fig.12. THD of source current using UPQC with PI

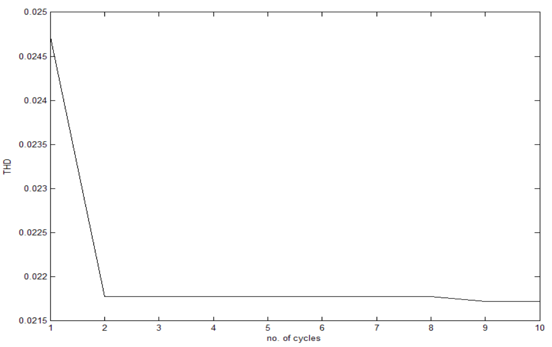

Fig.13. convergence characteristic of source current using UPQC with PI-DE

Table -1. Comparison of the THD values.

	Without UPQC	UPQC with PI using novel reference theory [16]	UPQC with PI using SRF theory	UPQC with optimized PI-DE using SRF theory
Source current THD	26.78	8.63	3.47	2.18
Settling time	-		0.25	0.04

VIII. CONCLUSIONS

The investigation demonstrates that DE is conjunction with PLL synchronizing circuit as the controller for UPQC ensures that the dc-side capacitor voltage is near constant with small ripple besides extracting fundamental reference signals. The PLL synchronizing circuits support the active filters to function even under distorted voltages or currents. Implementation of UPQC system with voltage source inverters is connected at PCC for filtering the current & voltage harmonics. The inverters gate control signals are derived from the hysteresis band controller. The performances of the system was verified and compared under unbalanced load & non-linear load. PI-DE based PLL yield least THD of the source current & load voltages that is in compliance with IEEE - 519 standards.

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