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Power Quality Improvement Using Unified Power Quality Conditioner Based on Particle Swarm Optimization

R. Saravanan[1], P.S. Manoharan[2]
Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering
e-mail: rsharankiruthika@gmail.com[1], psmeee@tce.edu[2]

Abstract

A unified power quality conditioner (UPQC) to compensate current and voltage power quality problems of sensitive loads. The UPQC consists of a shunt and series inverter having a common dc link. The shunt inverter eliminates current harmonics originating from the nonlinear load side and the series inverter mitigates voltage sag/swell originating from the supply side. The developed controllers for shunt and series inverters are based on an enhanced phase-locked loop and nonlinear adaptive filter. The proposed UPQC achieves superior capacity of mitigating the effects of voltage sag/swell and suppressing the load current harmonics under distorted supply conditions. Particle swarm optimization is discussed for its character of simple computation and high measurement accuracy. Simulation results are shown to verify the effectiveness and superiority of the algorithm.

Keywords: *Series inverter, Shunt inverter, Unified power quality conditioner, particle swarm optimization (PSO), Harmonic measurement*.

1. Introduction

The power electronics-based equipment has produced a significant impact on the quality of electric power supply. Nowadays, much of the equipment is based on power electronic devices, often leading to problems of power quality (PQ) such as harmonics, flicker, and imbalance have become serious concerns. [1]. A shunt inverter can compensate for distortion and unbalance in a load so that a balanced sinusoidal current flows through the distribution system. A series inverter can compensate for voltage sag/swell and distortion in the supply-side voltage Various control approaches, such as the PI, PID, fuzzy-logic, sliding-mode, predictive, unified constant frequency (UCF) controllers, etc., are in use [2]–[4]. Similar to the PI conventional controller, the PID controller requires precise linear mathematical models, which are difficult to obtain, and fails to perform satisfactorily under parameter variation nonlinearity load disturbance, etc. Modern control theory-based controllers are state feedback controllers, self-tuning controllers, and model reference adaptive controllers, etc. These controllers also need mathematical models and are therefore sensitive to parameter variations [5].In recent years, a major effort has been underway to develop new and unconventional control techniques that can often augment or replace conventional control techniques. A number of unconventional control techniques have evolved, offering solutions to many difficult control problems in industry and manufacturing sectors. Unlike their conventional counterparts, these unconventional controllers (intelligent controllers) can learn, remember, and make decisions. Artificial-intelligence (AI) techniques, particularly the PSOs, are having a significant impact on power-electronics applications proving to be inadequate for an increasing number of applications, and this fact has attracted the attention of power engineers to develop dynamic and adjustable solutions to power quality problems. Thus, between the different technical options available to improve PQ, active power filters (APFs) have proved to be an important alternative to minimize the financial impacts of PQ problems [6]. One modern and very promising solution is the unified power quality conditioner (UPQC)—a power conditioning device that consists of two APFs connected back-to-back on the dc side and deals with both load current and supply voltage imperfections [7], [8].Although the APFs have higher cost and complex control, they are much

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superior in filtering performance than the passive filters. Therefore, APFs are preferred over passive filters as the solution to various PQ problems arising from the load or the supply side.

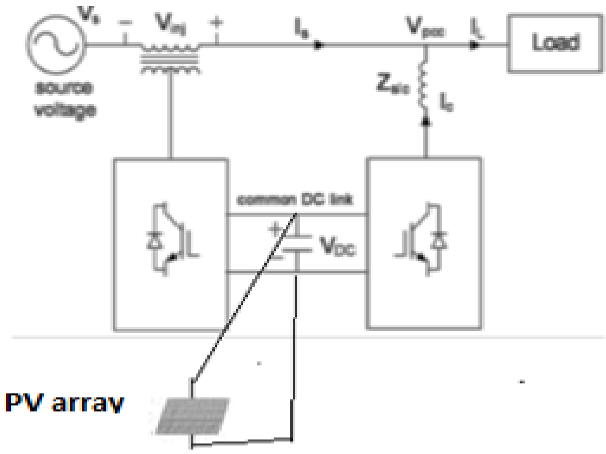


Figure 1. Topology of UPQC

2. Power Circuit Configuration of UPQ

In this paper the combined operation of UPQC and PV system is introduced. The proposed system is consists of a unified power quality conditioner with series and shunt inverters, PV system which is connected to DC link. The UPQC shown in Fig. 1 consists of two inverters VSCs (series and shunt inverter) that are connected back to back through a common energy storage dc capacitor .Series inverter is connected through transformers between the supply and point of common coupling (PCC). Shunt inverter is connected in parallel with PCC through the transformers. Series inverter operates as a voltage source while shunt inverter operates as a current source [9]. The power circuit of series inverter consists of three single-phase H-bridge voltage-source PWM inverters. H-bridge inverters are controlled independently. The main objective of series inverter is to mitigate voltage sags/swells originating from supply side. The ac filter inductor and capacitor are connected in each phase to prevent the flow of harmonic currents generated due to switching [10]. The transformers connected at the output of each H-bridge inverter provide isolation, modify voltage/current levels, and prevent the dc capacitor from being shorted due to the operation of various switches [11].

The objectives of shunt inverter to regulate the dc link voltage between both inverter and to suppress the load current harmonics [7].The switching devices in series inverter and shunt inverter are insulated-gate bipolar transistors (IGBTs) with anti-parallel diodes. C_{dc} provides the common dc-link voltage to series inverter and shunt inverter.

3. Control Scheme of the UPQC

UPQC control is explained in detail in this section. The important aspect in the operation of proposed UPQC is control strategies of shunt and series compensators. The main function of the proposed UPQC controller is to detect voltage and current distortions and then to generate gating signals to IGBTs.

3.1. Shunt inverter control

In this paper, shunt inverter undertakes two main duties. First is compensating both current harmonics generated by nonlinear load and reactive power, second is injecting active power generated by PV system. The shunt inverter controlling system should be designed in a way that it would provide the ability of undertaking two above duties. Shunt inverter control calculates the compensation current for current harmonics and reactive power when PV is out of the grid. The power loss caused by inverter operation should be considered in this calculation. Also, shunt inverter control undertakes the duty of (stabilizing) DC link voltage during series inverter operation to compensate voltage distortions. DC link capacitor voltage controlling loop is used here by applying PI controller.

3.2. Series inverter control

The duty of series inverter is compensating voltage distortions which are caused by fault in distribution grid. Series inverter control calculates the voltage reference values which are injected to grid by series inverter. In order to control series inverter of UPQC, load sinusoidal voltage controlling strategies proposed. In this condition, UPQC series inverter would be controlled in a way that it compensates the whole distortions and helps the voltage of load voltage stay (balanced sinusoidal 3-phase). In order to reach this aim, synchronous reference frame theory is applied .In this method the desired value of load phase voltage is replaced in d and q-axis instead of high pass and low pass filters.

4. Particle Swarm Optimization

Particle Swarm Optimization algorithm, originally proposed by Kennedy and Eberhart, is an evolutionary computation technique inspired by social behavior of a flock of birds and insect swarms [13]. In PSO, each particle is treated as a point in a d-dimensional space, where the it h particle is represented as Xi(t)=(Xi1(t), Xi2(t),…, Xid(t)), the best previous position (the position giving the best fitness value) of the it h particle is recorded and represented as Pi(t)=(Pi1(t), Pi2(t),…, Pid(t)), the index of the best particle among all the particles in the population is represented as Pg(t)=(Pg1(t), Pg2(t),…, Pgd(t)),the velocity of the position change for i^{th} particle is represented as Vi(t)=(Vi1(t), Vi2(t),…, Vid(t)). The particles are manipulated according to the following equation:

$$V_{id}(t+1) = \omega\ Vid(t)+c_1 r1\ P_{id}(t)-X_{ik}(t))+c \quad (1)$$

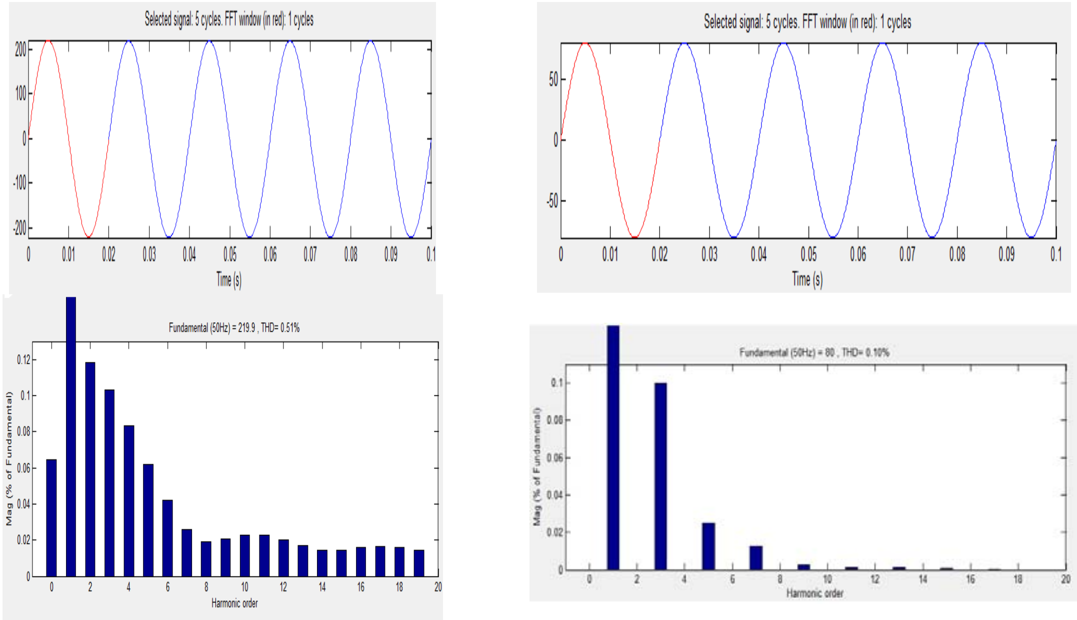
$$Xid\ (t+1) = Xid(t)+V_{id}(t+1) \quad (2)$$

$$\omega = \omega_{max} - k\ (\omega_{max} - \omega_{min})\ /k_{max} \quad (3)$$

Where, c1 and c2 are the cognitive and the social velocity, respectively; r1 and r2 are two random functions in the range[0, 1]; according to equation (3), ω which introduced as inertia factor can dynamically adjust the velocity over time; kmax is the total cycle index, k is the cycle index of current Computation. Equation (1) is used to calculate the particle's new velocity according to its previous velocity and the distances of its current position from its individual extreme value p Best and global extreme value g Best. Then the particle flies toward a new position according to equation (2). The performance of each particle is measured according to a pre-defined fitness function, which is related to the problem to be solved.

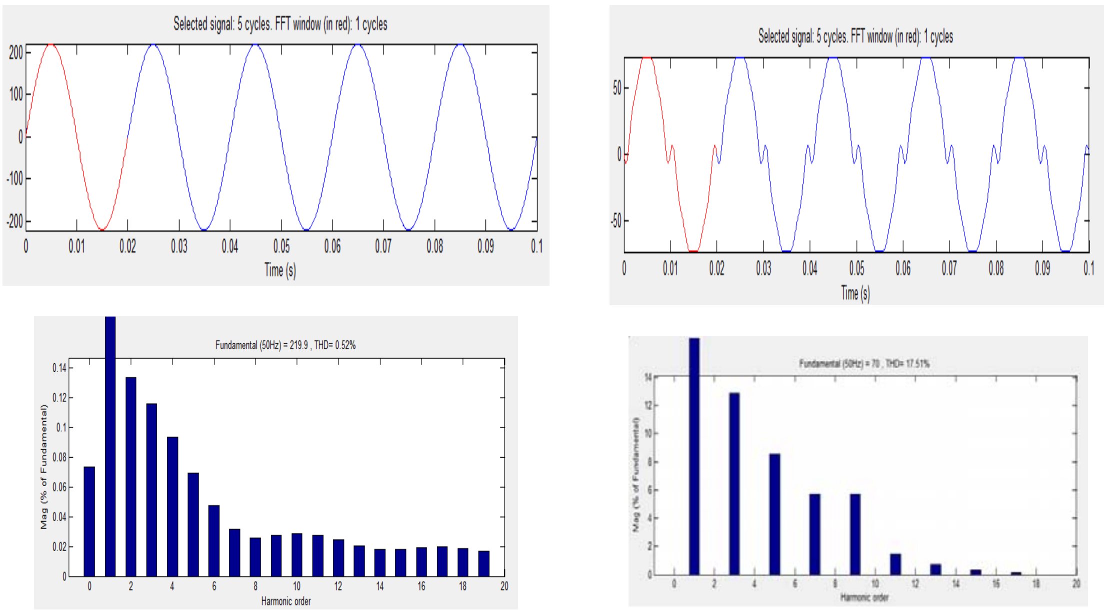
5. Simulation Results

Simulation waveforms and spectrum of system with PSO signal detection method without voltage sag and current are shown in Figure 2 and 3 (a), (b).



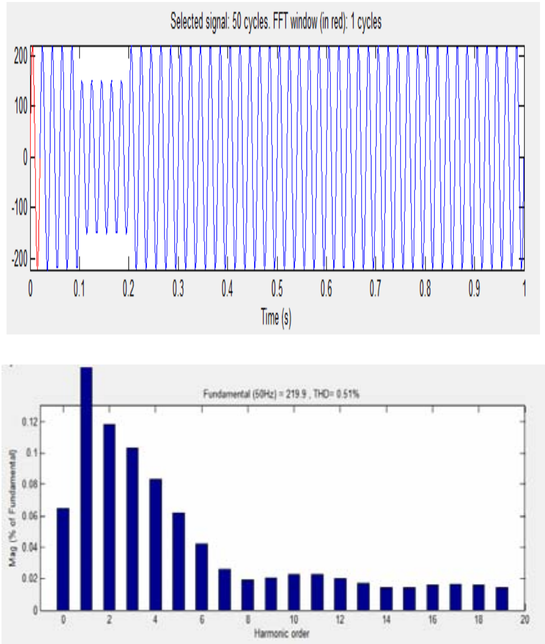
(a) Supply voltage and spectrum (THD 0.51%) (b) Load voltage and spectrum (THD 0.10%)

Figure 2. Compensation without voltage sag

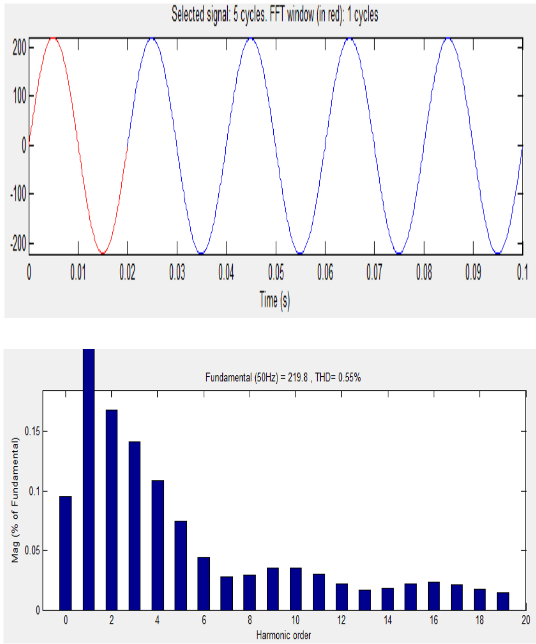


(a) Supply current and spectrum (THD 0.52%) (b)Load current and spectrum (THD 17.51%)

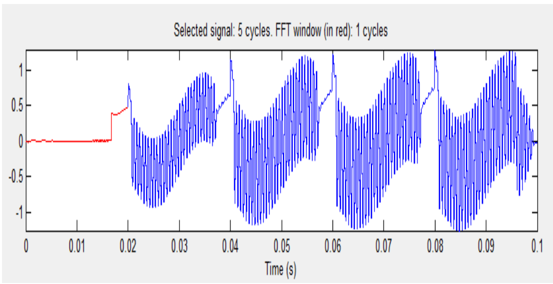
Figure 3. Compensation without current sag



(a). Supply voltage and spectrum (THD 0.51%)



(c) Load voltage and spectrum (THD 0.55%)



(b) Injecting voltage

Figure 4. Compensation without voltage sag

Simulation waveforms and spectrum of system with PSO signal detection method with voltage sag are shown in Figure 4 (a)(b) and (c).

6. Conclusion

A novel controller for the unified power-quality conditioners introduced and analyzed by controlling voltage–source inverters (series inverter and shunt inverter) and PV based on enhanced PLL and dc-link voltage with a PSO. New functionality is added to the UPQC system to quickly extract the reference signals directly for load current and supply voltage with a minimal amount of mathematical operands. The computation method is simpler than for other control algorithms of reference extraction. The number of parameters to be tuned has also been reduced by the use of the proposed controller. This paper presents an effective and fast voltage sag/swell detection method for unbalanced faults. The performance of the proposed UPQC and controller for PQ improvement is tested through the case study simulations (e.g., voltage sag and harmonic producing load using Matlab).

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