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A COMPARISON OF DISTRIBUTION STATIC SYNCHRONOUS COMPENSATOR (DSTATCOM) CONTROL ALGORITHMS FOR HARMONIC ELIMINATION

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ABSTRACT
This paper evaluates the performance of Distribution Static Synchronous Compensator (DSTATCOM) using a Voltage Reference Configuration (VRC) and the Instantaneous Power Theory (PQ) control scheme for power quality improvement in three-phase three-wire distribution system. It is used for harmonic elimination according to IEEE-519 standards under nonlinear loads. The Voltage Reference Configuration (VRC) is a simpler and robust control scheme for extracting reference current signals. The performance of the control schemes are simulated and analyzed under MATLAB environment with its Simulink and PSB set toolboxes.

Keywords: DSTATCOM, Voltage Reference Configuration, PQ theory, harmonic elimination.

INTRODUCTION
Fast industrialization has increased power electronic loads tremendously in electric power distribution system. These nonlinear loads produce harmonic distortions which cause non-sinusoidal current in distribution network. Harmonic distortions have become the main concern for power quality problem since the distorted current flow through different impedances in the power supply system and affect the AC mains. These nonlinear loads such as transformers, adjustable speed drives (ASDs), High-voltage DC (HVDC) systems, renewable energy sources, switch mode power supplies (SMPSs), uninterruptible power supplies (UPSs), arc furnaces, welding systems, telecommunication towers and many others generate multiple power quality distortions at the point of common coupling (PCC) in the AC mains and led to waveform deviation. Poor power quality will affect both utilities and consumers such as malfunction of sensitive equipment in industries, loss of revenue, increase power losses and resonance with source impedance[1]–[6].

In order to mitigate power quality problems in the distribution network, custom power devices (CPDs) or active power line conditioners (APLCs) are capable to provide remedial measures with a more cost effective solution [7]–[9]. These compensating devices are capable to compensate necessary reactive power and harmonic component from connected nonlinear loads [10]. The APLCs can be categorized into series, shunt and hybrid devices. As an example, distribution static compensator (DSTATCOM) is a shunt device and dynamic voltage restorer (DVR) is a series device whereas unified power quality conditioner (UPQC) is a hybrid of series and shunt compensating devices. Among these, DSTATCOM has been considered as one of the most effective compensating device with a very fast response for reactive power compensation [11]–[13]. The DSTATCOM injects the compensating current through the interface inductor at the Point of Common Coupling (PCC) to eliminate harmonics and compensate reactive power as well as load current [9]. Several international standards have been enforced in order to mitigate power quality problem at the Point of Common Coupling (PCC) such as IEEE-519, IEC-61000–3-2 and others [14][15]. In this paper, the total harmonic distortion (THD) of source current is observed to be less than an IEEE-519 standard limit of 5%.

Due to the increasing concern of power quality issues, development and applications of DSTATCOM has increased from the last 10 years and become the most widely used in the industrial processes [16]–[19]. The effectiveness of a DSTATCOM is mainly depends on control algorithms for the generation of reference signals and switching scheme [3],[20]. Based on previous literatures, many control algorithms have been reported such as the instantaneous reactive power theory (PQ) [21], synchronous reference frame (SRF) theory [22][23], synchronous detection method [24], adaptive interference canceling technique [25] and other neural network techniques [26][27][28]. PQ and SRF theory are the most widely used control algorithms for active power line conditioners [29].

In this paper, a DSTATCOM is controlled with PQ theory for harmonic elimination and compared with new Voltage Reference Configuration (VRC) in three phase system under nonlinear load. The performance of these control algorithms will be simulated in MATLAB environment.

SYSTEM CONFIGURATION
Figure-1 represents three phase DSTATCOM circuit diagram with a nonlinear load in a three-phase three-wire distribution system. The nonlinear load is represented by three phase rectifier supplying a fix resistive inductive (RL) load. The DSTATCOM is a three

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phase voltage source inverter (VSI) with IGBTs and anti-parallel diodes.

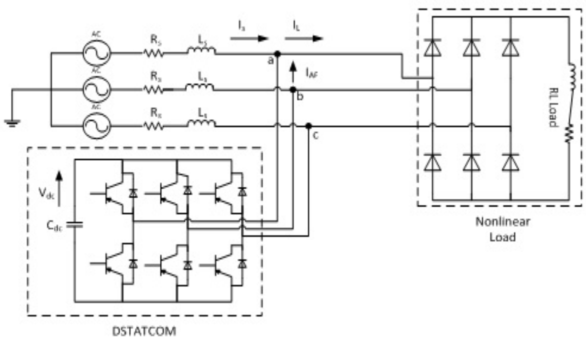

Figure-1. Three phase DSTATCOM circuit diagram.

The operating principle of the DSTATCOM is very much similar to a shunt active power filter. The DSTATCOM will provide compensating currents in order to eliminate the harmonic at the point of common coupling (PCC) which is located at point of a, b and c in Figure-1. The harmonics injected by the nonlinear load will be compensated by DSTATCOM by injecting the same current in different direction [30]. Thus, the total harmonic distortion (THD) at the PCC can be maintained according to IEEE-519 guidelines.

CONTROL ALGORITHMS

In order to maximize the performance of the DSTATCOM, the control algorithm used to generate reference current (harmonic current) is a very important factor. In this paper, the proposed control algorithm will be compared with instantaneous reactive power theory (PQ) for harmonic compensation.

Instantaneous reactive power theory (PQ)

The PQ theory is widely used to control three phase active power filter which is based on the transformation from three phase quantities (abc) to two phase quantities (αβ) and calculation of instantaneous active and reactive powers [21][31]. The PQ theory consists of Clarke transformation, phase lock loop (PLL), power losses calculation, digital low pass filter and hysteresis current controller. The inputs required for this control system are line voltages (va, vb and vc), line currents (ia, ib and ic) and dc bus voltage (vdc) as show in Figure-2. The line voltages and currents will be transformed to vα, vβ, iα and iβ. On the other hand, the dc bus voltage (vdc) will be compared with dc bus reference voltage (vdcref) to produce dc power signal (Pdc). Then, the dc power and active power signal will be used to produce reference current signal (ia*, ib* and ic*). The hysteresis current controller will generate PWM signal from PLL signals and the reference currents [32].

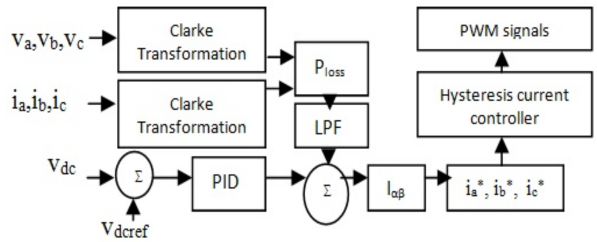

Figure-2. Block diagram of PQ control strategy.

Voltage reference configuration (VRC)

The voltage reference configuration control algorithm extracts the fundamental magnitude of load currents. Then, the switching of H-bridge IGBTs will be controlled by using hysteresis controller signals to generate harmonic compensation currents. Since the load currents are assumed to be symmetrical, Equation. (1) is the harmonic equation in Fast Fourier Transform (FFT). The source current is shown as Equation. (2).

$$I_L(t) = \sum_{n=1}^{\infty} \frac{2I_A}{n\pi} \sin\left(\frac{n\pi}{2}\right) \cos(2\pi f t) \quad (1)$$

$$I_s(t) = I_A \sin(wt + 90°) \quad (2)$$

Since the compensator current is the result from subtraction of load current from source current, then it can be represented as Equation. (3).

$$I_{Comp}(t) = I_L(t) - I_s(t)$$
$$= I_A \sin(wt + 90°) - \sum_{n=1}^{\infty} \frac{2I_A}{n\pi} \sin\left(\frac{n\pi}{2}\right) \cos(2\pi f t) \quad (3)$$

The voltage reference configuration consists of hysteresis gap, comparator and flip flop as shown in Figure-3. The hysteresis gap is used to measure upper and lower envelope of reference signal. Then, the switching of the H-bridge IGBTs for PWM signals is generated from flip flop outputs [32].

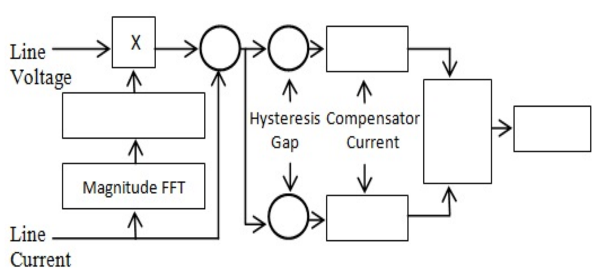

Figure-3. Block diagram of voltage reference configuration control strategy.

DSTATCOM SYSTEM MATLAB BASED MODEL

The basic simulation model of DSTATCOM in three phase three wire system is simulated in MATLAB as represented in Figure-4. The nonlinear load is a three phase rectifier supplying a fix resistive inductive (RL) load with 20 ohm and 50 mH respectively. Then, this DSTATCOM model is simulated with different control algorithms stated above. The models of control algorithms simulated are given in Figure-5 and Figure-6.

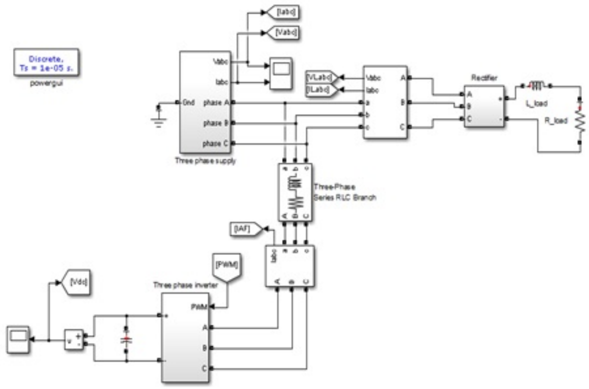

Figure-4. DSTATCOM system MATLAB based model using PQ theory.

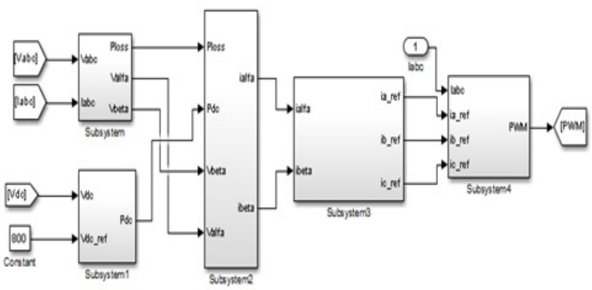

Figure-5. DSTATCOM system MATLAB based model using PQ theory.

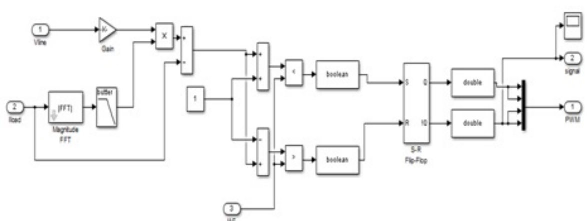

Figure-6. DSTATCOM system MATLAB based model using voltage reference configuration.

RESULTS AND DISCUSSIONS

Figure-7 shows the dynamic performance of PQ theory with its three phase voltage sources, nonlinear load currents and line currents after compensation whereas the performances of DSTATCOM with voltage reference configuration are shown in Figure-8. The polluted load current with 28.86% total harmonic distortion (THD) has been improved up to 0.34% as presented in Figure-9 by using PQ theory control algorithm. Thus, this classical theory has been verified that it can improve the THD at the point of common coupling according to the IEEE-519 standard limit. However, the disadvantage of PQ theory is any voltage distortion will affect the accuracy of reference current calculation due to voltage signals that will be used to estimate the instantaneous active and reactive powers [31].

Furthermore, the simplified voltage reference configuration manages to improve the total harmonic distortion up to 0.36% from 28.86% according to the IEEE-519 guidelines which is demonstrated in Figure-10. The advantages of this voltage reference configuration are less computational time and easier to implement.

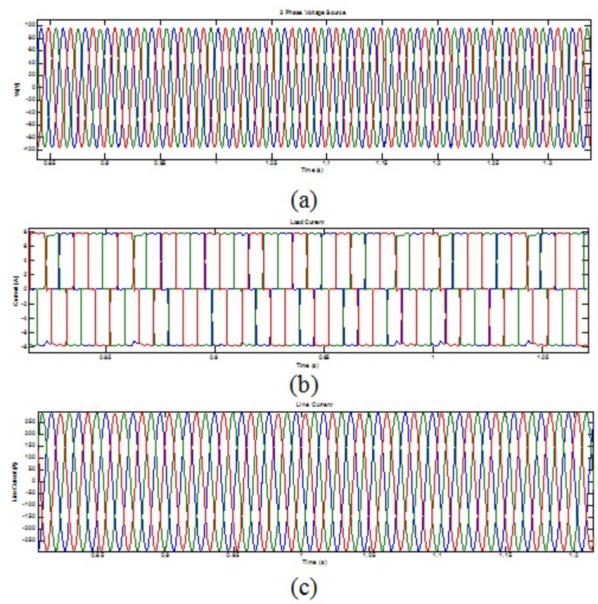

Figure-7. Performance of DSTATCOM under nonlinear load with PQ theory a) Voltage source b) Load current c) Line current.

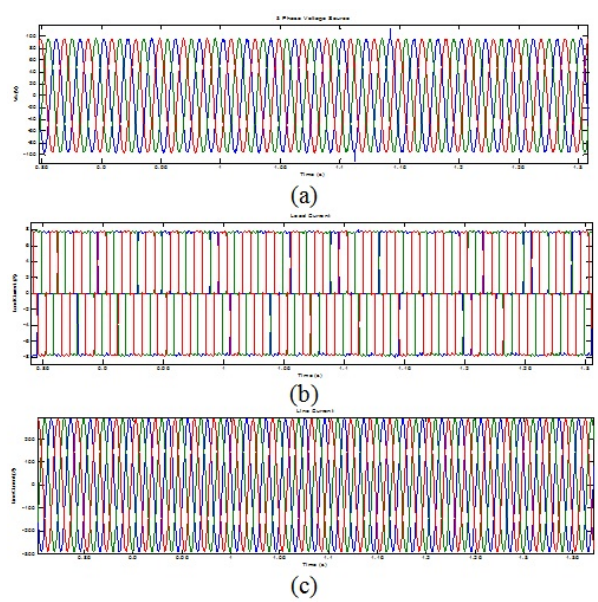

Figure-8. DSTATCOM system MATLAB based model using voltage reference configuration a) Voltage source b) Load current c) Line current.

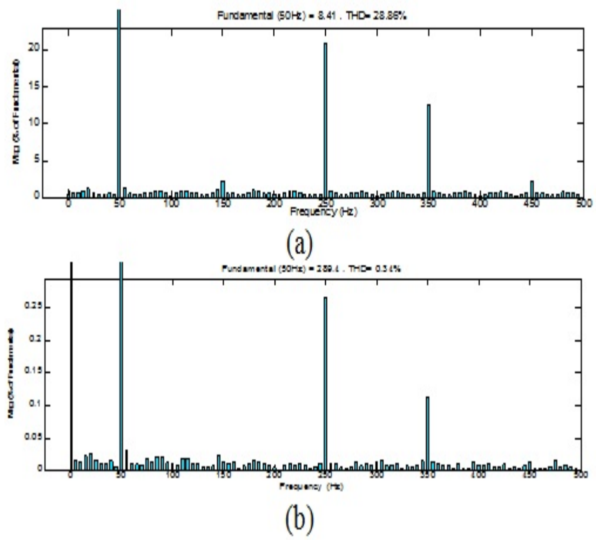

Figure-9. Harmonic spectra for a) Load current b) Line current after compensation by PQ theory controller.

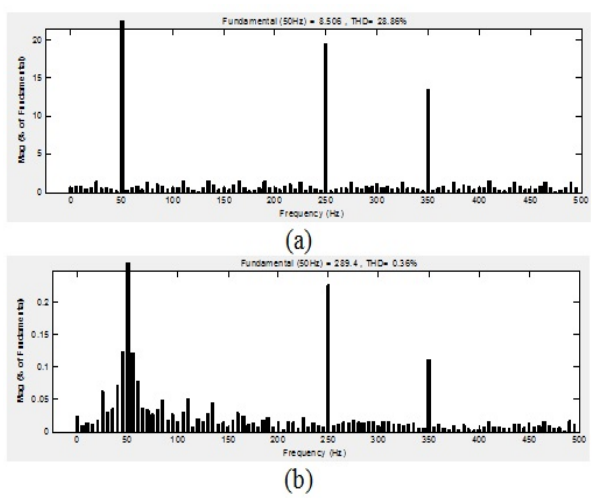

Figure-10. Harmonic spectra for a) Load current b) Line current after compensation by voltage reference configuration controller.

The THD of the line current with the nonlinear load is 28.86% which is quite high. After compensation with PQ theory, the THD of the line currents are further reduced to 0.34%. Moreover, the THD of line current are also reduced to 0.36% by using voltage reference configuration controller. Even though there are slight differences between both control algorithms, both controllers have shown that current source can be compensated and eliminate the harmonics for the power quality improvement in three phase system. Table-1 summarizes the comparison of line current THD before and after harmonic compensation by using PQ and voltage reference configuration controller.

Table-1. Comparison of THD for PQ theory and voltage reference configuration (VRC).

THD	Before Compensation	After Compensation	
		PQ	VRC
Load Current	28.86%	0.34%	0.36%

CONCLUSIONS

The performance of DSTATCOM has been modeled and simulated with PQ theory and voltage reference configuration under nonlinear loads. Both control algorithms can eliminate the harmonics and maintain the THD limit according to IEEE-519. The voltage reference configuration (VRC) control algorithm is easier to implement due to its simplicity and takes less computational time. The effectiveness of the control algorithms have been verified using MATLAB simulation.

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