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Current Harmonic Minimization by Using Optimized DSTATCOM

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Abstract - In present days loads used by the various consumers are of nonlinear in nature such as industrial, residential, and commercial loads. All these nonlinear loads required harmonic current for their function, due to these harmonic components of load current power quality of power system gets reduced. Efficiency of the power system network also gets reduced due to same harmonic component of line current. Therefore for the elimination of harmonic from the power system network shunt active power filters are widely used in recent days. Basically shunt active power filter produces harmonic current same as that produces by the nonlinear load but opposite in phase. So that only the fundamental component of current flow from the supply mains and power factor of supply source maintained near to unity. In this paper a voltage controlled voltage source inverter is used with PWM method for controlling the switching of the converter. Here the reference voltage signals are generated with the help of the d-q theory method also called as the instantaneous reactive power theory method. This paper shows the application of the proposed method for harmonic elimination under different load condition, simulations are done using MATLAB.

Key Words: Shunt Active Power Filter (SAPF), Proportional controller (PI), Power quality(PQ), Instantaneous reactive power theory (IRPT),Total Harmonics Distortion(THD), Energy Storage System(ESS).

1. INTRODUCTION

The DSTATCOM technology is now a mature technology for providing reactive power compensation, load balancing, and/or neutral current and harmonic current compensation (if required) in AC distribution networks[1]. It has evolved in the past quarter century with development in terms of varying configurations, control strategies, and solid-state devices. These compensating devices are also used to regulate the terminal voltage, suppress voltage flicker, and improve voltage balance in three-phase systems[2-3]. These objectives are achieved either individually or in combination depending upon the requirements and the control strategy and configuration that need to be selected appropriately. This section describes the history of development and the current status of the DSTATCOM technology.

1.1 CLASSIFICATION OF DSTATCOMS

DSTATCOMs can be classified based on the type of converter used, topology, and the number of phases. The converter used in the DSTATCOM can be either a current source converter or a voltage source converter (Converter-Based Classification). Different topologies of DSTATCOMs can be realized by using transformers and various circuits of VSCs (Topology-Based Classification) [4]. The third classification is based on the number of phases, namely, single-phase two wire, three-phase three-wire, and three-phase four-wire systems (Supply System-Based Classification).

1.2 DSTATCOM

A DSTATCOM is a fast-response, solid-state power controller that provides power quality improvements at the point of connection to the utility distribution feeder. It is the most important controller for distribution networks. It has been widely used to precisely regulate the system voltage and/or for load compensation. It can exchange both active and reactive powers with the distribution system by varying the amplitude and phase angle of the voltage of the VSC with respect to the PCC voltage, if an energy storage system (ESS) is included into the DC bus [5-6]. However, a capacitor-supported DSTATCOM is preferred for power quality improvement in the currents, such as reactive power compensation for unity power factor or voltage regulation at PCC, load balancing, and neutral current compensation.

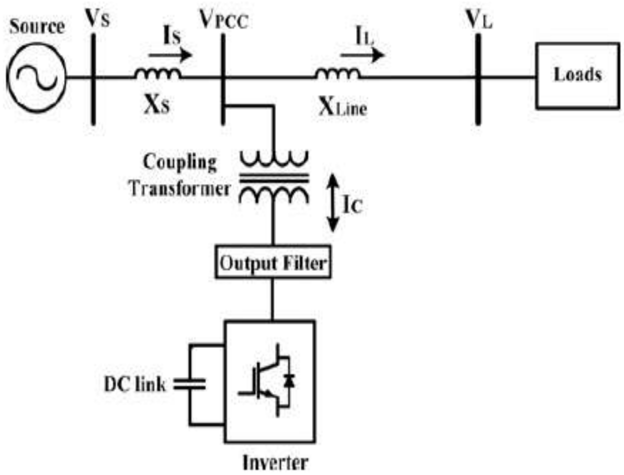

Figure1. DSTATCOM

1.2 *Principle of Operation of DSTATCOMs*

The main objective of DSTATCOMs is to mitigate the current-based power quality problems in a distribution system. A DSTATCOM mitigates most of the current quality problems, such as reactive power, unbalance, neutral current, harmonics (if any), and fluctuations, present in the consumer loads or otherwise in the system and provides sinusoidal balanced currents in the supply with its DC bus voltage regulation [7].

In general, a DSTATCOM has a VSC connected to a DC bus and its AC sides are connected in shunt normally across the consumer loads or across the PCC. The VSC uses PWM control; therefore, it requires small ripple filters to mitigate switching ripples. It requires Hall effect voltage and current sensors for feedback signals and normally a DSP is used to implement the required control algorithm to generate gating signals for the solid-state devices of the VSC of the DSTATCOM [8-9].

A few of these control algorithms are as follows:

- Unit template technique or PI controller-based theory
- Power balance theory (BPT)
- Current synchronous detection (CSD) method
- Instantaneous reactive power theory (IRPT), also known as PQ theory or α–β theory
- Synchronous reference frame (SRF) theory, also known as d–q theory
- Instantaneous symmetrical component theory (ISCT)

Similarly, there are around the same number of frequency-domain control algorithms. Some of them are as follows:

- Fourier series theory
- Discrete Fourier transform theory
- Fast Fourier transform theory
- Recursive discrete Fourier transform theory
- Kalman filter-based control algorithm

2. Instantaneous reactive power theory (IRPT)

The IRPT-based control algorithm of DSTATCOMs is shown in Figure 2. Three-phase load currents and PCC voltages are sensed and used to calculate the instantaneous active and reactive powers. Three phase PCC voltages are sensed and processed through BPFs before their transformation to eliminate their ripple contents and are denoted as (vsa, vsb, vsc). A first-order Butterworth filter is used as a BPF [11]. These three-phase filtered load voltages are transformed into two-phase α–β orthogonal coordinates (vα, vβ) as

$$\begin{bmatrix} Vs\alpha \\ Vs\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix}$$

These three-phase filtered load current are transformed into two-phase α–β orthogonal coordinates (Iα, Iβ) as

$$\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ila \\ Ilb \\ Ilc \end{bmatrix}$$

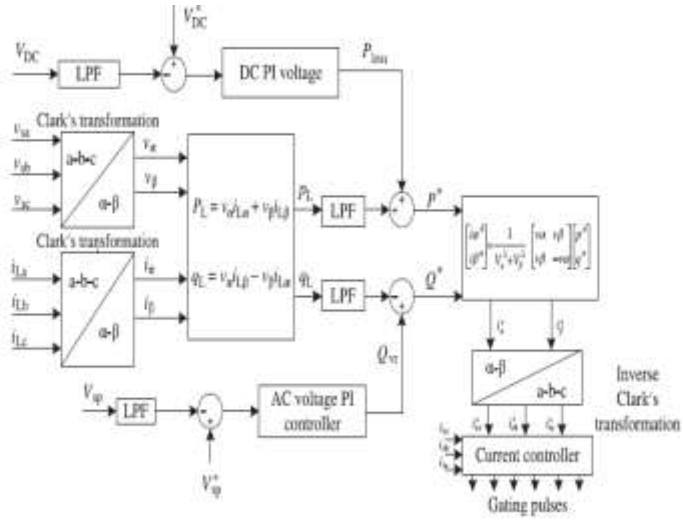

Figure 2: Instantaneous reactive power theory-based control algorithm of DSTATCOMs

The instantaneous active power pL and the instantaneous reactive power qL flowing into the load side are calculated from these two sets of expressions.

$$\begin{pmatrix} p_L \\ q_L \end{pmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{pmatrix} \begin{pmatrix} i_{L\alpha} \\ i_{L\beta} \end{pmatrix}.$$

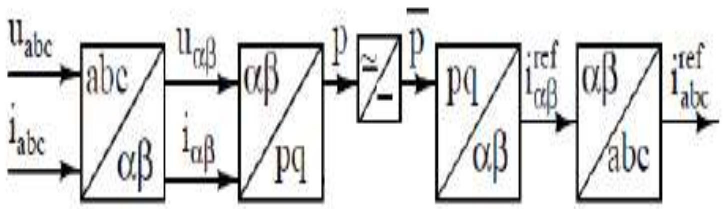

Figure 3: Block diagram of controlled current approach

Let and be the DC component and the AC element, and let and be the DC component and the AC element, alternately.

$$p_L = \bar{p}_L + \tilde{p}_L, \quad q_L = \bar{q}_L + \tilde{q}_L$$

In these terms, the basic load power is transformed into pL and qL DC components and the distortion or negative sequence is transformed into ~pL and ~qL AC components. The effective and passive power parts of DC are obtained using two LPFs.

The reference current in two phase system is Type equation h

Isa* Isb* Isc* are the reference three-phase storage signals

$$\begin{pmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}^{-1} \begin{pmatrix} p^* \\ q^* \end{pmatrix}$$

This IRPT-based control algorithm may easily be modified for the control on supply currents for indirect current control. In this case, for power factor correction mode of operation of the DSTATCOM, p* = PL + Ploss and q* = qL - qvr after the transformation from the α–β frame to the abc frame, three-phase transformed currents are reference supply currents and these must be compared with sensed supply currents in the PWM current controllers for indirect current control of the DSTATCOM. The term Ploss is an instantaneous active power necessary to adjust the voltage of the DC capacitor of the VSC used as a DSTATCOM to its reference value. In addition, qvr is instantaneous reactive power necessary to adjust the PCC voltage to its reference value , and PL and qL are the extracted load fundamental active and reactive power components, respectively. In the case of ZVR at PCC (voltage regulation mode of operation of the DSTATCOM), a PI voltage controller over the PCC voltage is used similarly to the above algorithms and its output is used to estimate p* and q* as p* = PL + Ploss and q* = qL - qvr . After the transformation, three-phase transformed currents are reference supply currents and these are compared with sensed supply currents as shown in figure for indirect current control of the DSTATCOM.

3. Cuckoo Search Optimization

Each egg in the nest represents a solution and a cuckoo egg represents a new occurred solution. The aim is to employ the new and potentially better solutions (cuckoos) to replace not-so-good solutions in the nests. In the simplest form, each nest has one egg. The algorithm can be extended to more complicated cases in which each nest has multiple eggs representing a set of solutions (Yang 2009; Yang 2010). The CS algorithm is based on three idealized rules: Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest. The best nests with high quality of eggs (solutions) will carry over to the next generations. The number of available host nests is fixed, and a host can discover an alien egg with probability pa (ε) [0,1] . In case, the host bird can either throw the egg away or abandon the nest to build a completely new nest in a new location (Yang 2009).

4. PI CONTROLLER

P In control systems, it is very important to obtain controller parameters that make the system stable. One of the methods used to obtain these parameters is the SBL method. The SBL method is a graphical method used to determine the controller parameters that make the control system stable. The choice of the suitable controller type is crucial to achieve the desired design criteria. In most applications, simple structured controllers are preferred. PID controllers are often preferred by the industry for reasons such as simple structure and robust performance characteristics. The optimization process can be defined as selecting the most appropriate one from the current situations. Simulink models have been developed for optimizations based on the integral performance criteria. The optimization process begins by entering initial values in controller parameters. When the smallest error value is reached, the optimization stops and the most suitable controller parameters are obtained. Now here to tuned the parameter of PI controller IAE, ISE and ITAE criteria are used.

1. $IAE = \int |e(t)|\, dt$
2. $ISE = \int e^2(t) dt$
3. $ITAE = \int t\, |e^2(t)|\, dt$

5. Block Diagram of DSTATCOM

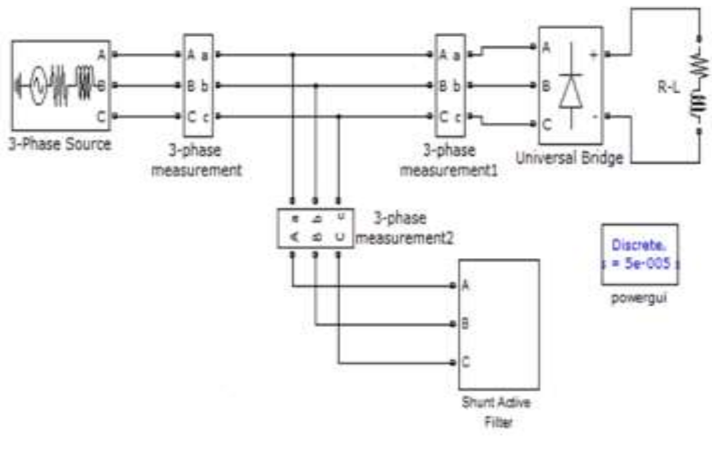

Figure 4: Block diagram of MATLAB Simulink model

6. Simulation and Results

The system is simulated under nonlinear load configuration for which the approach of PI controller based DSTATCOM. The main objective is to minimize the odd harmonic components using Cuckoo search optimization technique.

The above simulation can be performed under three criteria i.e. IAE, ISE and ITAE. From Table 1 it is clear that criteria IAE gives minimum THD as compare to ISE and ITAE.

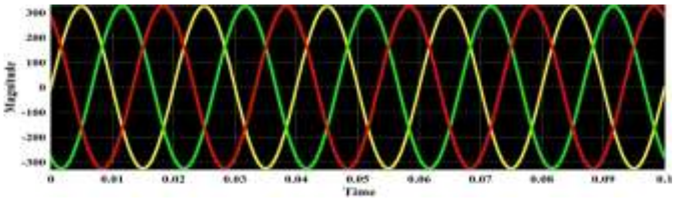

Figure 5: Source Voltage waveform Before Compensation

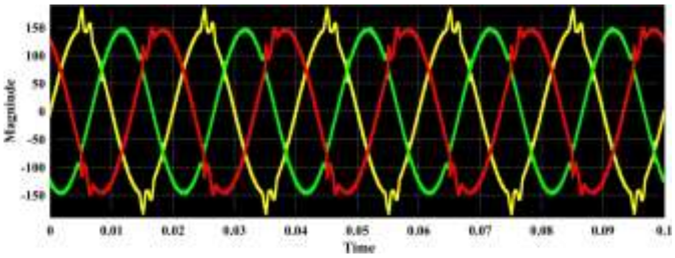

Figure 6 : Source Current Waveform before Compensation

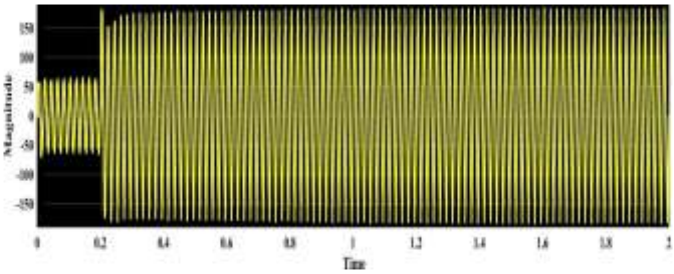

Figure 7: Waveform of Compensated Source Current Isa

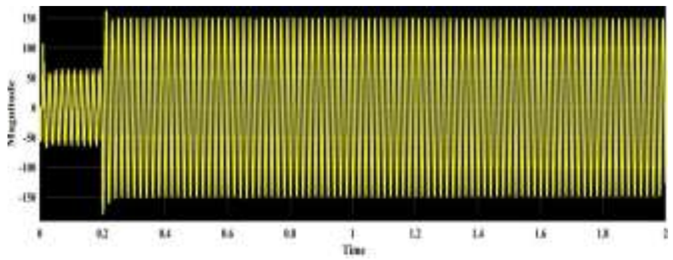

Figure 8: Waveform of Compensated Source Current Isb

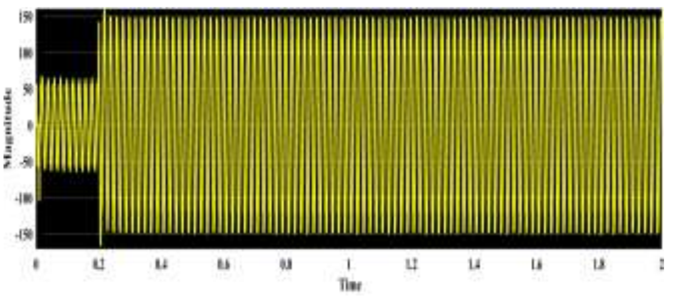

Figure 9 : Waveform of Compensated Source Current Isc

6.1 FFT ANALYSIS

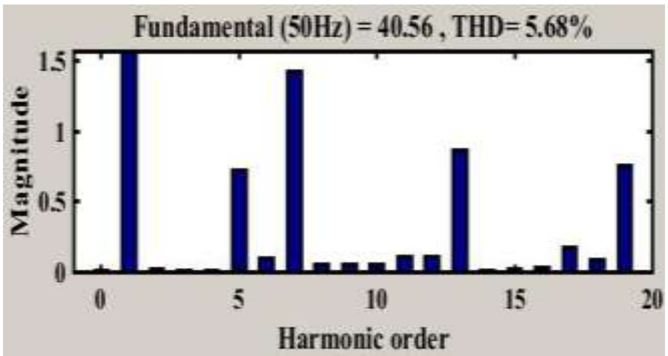

Fig. 10. FFT waveform of source current CSA (IAE Criteria)

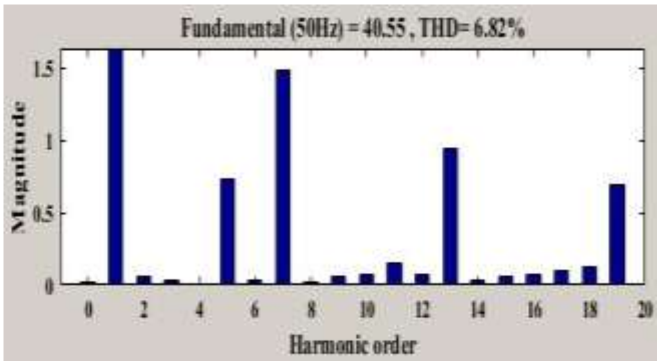

Fig. 11. FFT waveform of source current CSA (ISE)

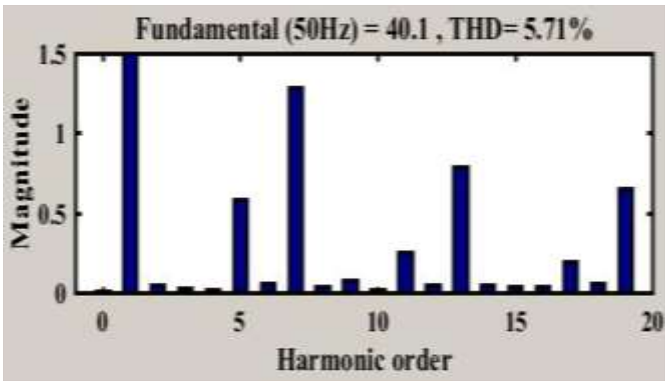

Fig. 12: FFT waveform of source current CSA (ITAE)

Table 1

CSA Parameter	IAE	ISE	ITAE
P	62.3695	76.3625	68.3695
I	69.3015	87.1459	72.1478
CURRENT THD (%)	**5.68**	**6.82**	**5.71**

7. CONCLUSION

Simulation of three phase three wire DSTATCOM with a nonlinear balanced consisting of the three phase diode bridge rectifier is done in MATLAB. Harmonic component are present in the line current of the three phase system due to the nonlinear loads. Total harmonic distortion found as very high, to reduce the harmonic from the grid current, shunt active power filter with the Instantaneous reactive power theory control and PWM technique are designed using MATLAB. Comparative analyses of THD with ISE, IAE and ITAE criteria of Cuckoo search algorithm with and without compensation of nonlinear load are shown in the Table1. ISE criteria gives better results as compare to other criteria with the same number of iteration i.e. 25 and with similar bandwidth of 0.5.

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