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Power Quality Improvement Using a Novel Seamless Control Strategy for DSTATCOM

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ABSTRACT: This paper presents the modeling and implementation of a three-phase DSTATCOM (Distribution Static Compensator) using STF (Self Tuning Filter) based IRPT (Instantaneous Reactive Power Theory) control algorithm for power quality improvement. An adaptive fuzzy logic controller is used to control the dc bus voltage of VSC (Voltage Source Converter) based DSTATCOM to improve the response and to reduce the overshoot and undershoot of traditional PI (Proportional-Integral) controller under unbalanced loading conditions and supply voltage fluctuations. The effectiveness of the proposed control algorithm is demonstrated through simulation using MATLAB SIMULINK.

Keywords: DSTATCOM, Fuzzy Logic, Power Quality.

INTRODUCTION

Modern bulk power systems cover large geographic areas, e.g. the European UCTE system and the North American systems, and have a large number of load buses and generators. Additionally, available generating plants are often not situated near load centers and power must consequently be transmitted over long distances. To meet the load and electric market demands, new lines should be added to the system, but due to environmental reasons, the installation of electric power transmission lines must often be restricted. Hence, the utilities are forced to rely on already existing infra-structure instead of building new transmission lines. In order to maximize the efficiency of generation, transmission and distribution of electric power, the transmission networks are very often pushed to their physical limits, where outage of lines or other equipment could result in the rapid failure of the entire system. With such increasing stress on the existing transmission lines the use of Flexible AC Transmission Systems (FACTS) devices becomes an important and effective option. FACTS technologies offer competitive solutions to today’s power systems in terms of increased power flow transfer capability, enhancing continuous control over the voltage profile, improving system damping, minimizing losses, etc. FACTS technology consists of high power electronics based equipment with its real-time operating control [1, 2, 6].There are two groups of FACTS controllers based on different technical approaches, both resulting in controllers able to solve transmission problems. The first group employs reactive impedances or tap-changing transformers with thyristor switches as controlled elements; the second group employs self-commutated voltage-sourced switching converters. The sophisticate control and fast response are common for both groups. The Static VAr Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC) and Phase Shifter, belong to the first group of controllers while Static Synchronous Compensators (STATCOM), Static Synchronous Series Compensators (SSSC), Unified Power Flow Controllers (UPFC) and Interline Power Flow Controllers (IPFC) belong to the other group. The power system may be thought of as a large, interconnected nonlinear system with many lightly damped electromechanical modes of oscillation. If the damping of these modes becomes too small, or even positive, it can impose severe constraints on the system’s operation. It is thus important to be able to determine the nature of those modes, find stability limits and in many cases use controls to prevent instability. The poorly damped low frequency electromechanical oscillations occur due to inadequate damping torque in some generators, causing both local-mode oscillations (1 Hz to 2 Hz) and inter-area oscillations(0.1 Hz to 1 Hz) [19]. The traditional approach employs power system stabilizers (PSS) on generator excitation control systems in order to damp those oscillations. PSSs are effective but they are usually designed for damping local modes and in large power systems they may not provide enough damping for inter-area modes. Hence, in order to improve damping of these modes, it is of interest to study FACTS power oscillation damping (POD) controllers [17]. In large power systems the number of inter-area modes is usually larger than the number of control devices available [3]. Generally, damping of power system oscillations is not the primary reason of placing FACTS devices in the power system, but rather power flow control [6, 7].In this paper, an improved reference supply currents extraction algorithm for an indirect current control is proposed using a STF(Self Tune Filter) in DSTATCOM under distorted AC mains along with an adaptive fuzzy PI controller to regulate its DC bus voltage. As the proposed control algorithm is based on an indirect current control technique where extraction of fundamental components of load currents has major role in the control, it has less switching ripple in supply currents, superior performance during load perturbations and a simple structure compared to direct current control technique. It improves the dynamic performance due to the elimination of low pass filters. The proposed control algorithm of a DSTATCOM is implemented for the compensation of nonlinear loads in a distribution system with an adaptive fuzzy logic control of DC bus voltage of VSC of DSTATCOM. This effectively performs the functions of DSTATCOM such as reactive power compensation, harmonics attenuation and load balancing.

1. *Control algorithm and system structure*

Fig. 1 shows a schematic diagram of a three phase VSC based DSTATCOM connected to a three phase distorted voltages of AC mains feeding nonlinear loads with a source impedance (Zs). For the control of DSTATCOM, sensed input variables are PCC (Point of Common Coupling) voltages of (va,vb,vc), supply currents (isa, isb, isb), load currents (iLa, iLb, iLc) and DC bus voltage (vdc) of VSC used in DSTATCOM. Effectiveness of the compensator depends upon the accuracy of extracted fundamental active power and reactive power components of load currents. Interfacing inductors (Lf) are connected at AC output of the VSC for reducing ripple in compensating currents. A three phase series connected capacitor (Cf) and a resistor (Rf) as a passive ripple filter is used at PCC parallel to the loads to suppress high frequency switching noise at PCC voltages caused due to switching of VSC. The DSTATCOM compensating currents (iCa, iCb, iCc) are injected to cancel the reactive power components and harmonics of the load currents. For an effective operation of DSTATCOM, it is necessary to maintain constant DC capacitor voltage of VSC of DSTATCOM. It is realized using an adaptive fuzzy logic based PI controller. The designed value of different auxiliary components of DSTATCOM such as interfacing AC inductors, DC bus voltage and value of DC bus capacitor for simulation and its implementation are given in Appendices A and B respectively. Fig. 2 shows a block diagram of STF (Self Tuned Filter) based IRPT (Instantaneous Reactive Power Theory) control algorithm for estimation of reference supply currents through the extraction of fundamental load active power and reactive powers.

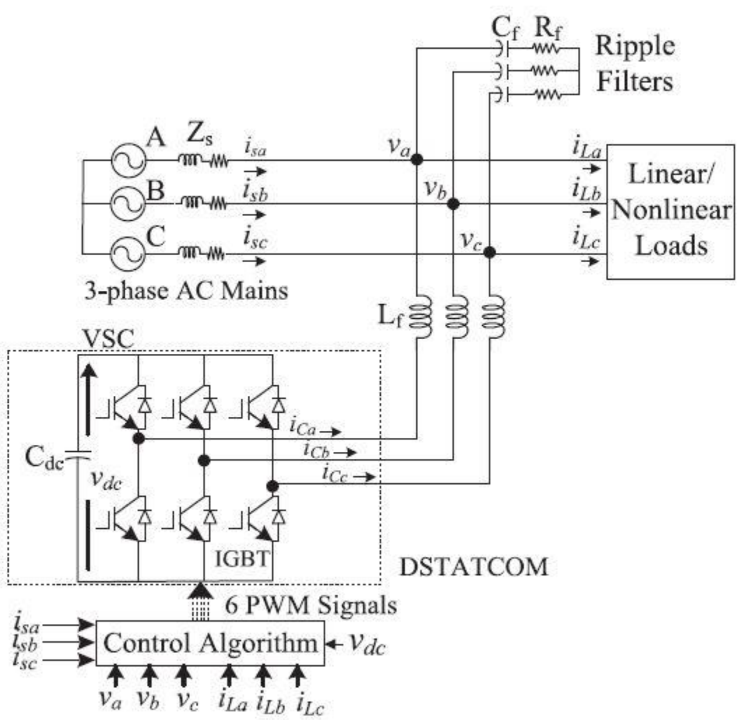

Fig. 1. Schematic diagram of VSC based three phase DSTATCOM

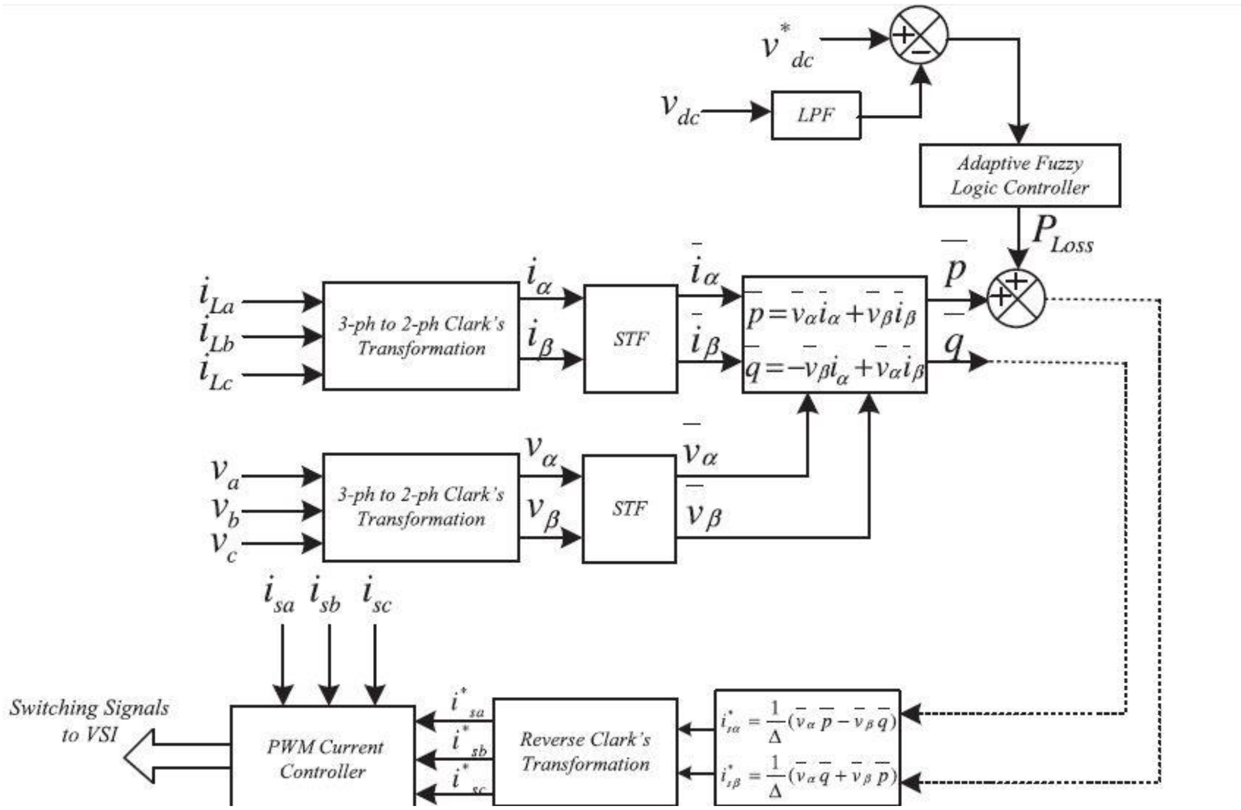

Fig. 2. Reference supply currents estimation using STF based IRPT control algorithm

2. *Design of adaptive fuzzy logic controller for DC bus voltage control*

PI (Proportional Integral) controllers are used in industries provide good performance once tuned when the parameters used are not of much variations. However, when one applies these PI controllers for nonlinear systems as conditions vary, further tuning is required. Henceforth, a supervisory control of gains of PI controller through the fuzzy logic is presented to improve the performance of the system during transients. Two inputs to the fuzzy logic controller are chosen as an error in DC bus voltage and the derivative of error in DC bus voltage respectively. The value of $k_p(m-1)$ and $k_i(m-1)$ are initialized from various inferences and then the gains achieved from fuzzy calculation are added to get the modified value as $k_p(m)$ and $k_i(m)$.

$$k_p(m) = k_p(m-1) + \Delta k_p(m-1)$$

$$k_i(m) = k_i(m-1) + \Delta k_i(m-1) \qquad (1)$$

Where Δk_p and Δk_i are the incremental changes in PI controller gains obtained from the fuzzy logic controller. A schematic of adaptive fuzzy logic controller is shown in Fig. 3 where the two inputs at *m*th sampling instant are $\Delta V_{dc}(m)$ and its derivative $\Delta \dot{V}_{dc}(m)$. Its optimized output values are k_p and k_i. Fig. 4 shows the membership functions.

According to the schematic, one can write the following expression for adaptive fuzzy logic controller as,

$$\Delta V_{dc}(m) = V_{dc}^{*}(m) - V_{dc}(m) \qquad (2)$$

$$P_{Loss}(m) = P_{Loss}(m-1) + k_p\{\Delta V_{dc}(m) - \Delta V_{dc}(m-1)\} + k_i \Delta V_{dc}(m) \qquad (3)$$

Where k_p is the proportional gain constant and k_i is the integral gain and $V_{dc}(m)$, $\Delta \dot{V}_{dc}(m)$ and $\Delta V_{dc}(m)$ are sensed, reference and error signal of DC link voltage at *m*th sampling instant respectively. The output of the adaptive fuzzy logic controller accounts for the losses in DSTATCOM, and it is considered as the loss component of these supply currents. This component $P_{Loss}(m)$ given in Eq. (3) is added with the average real power for controlling the

DSTATCOM. In the proposed fuzzy logic controller, the input variables $\Delta V_{dc}(m)$ and its derivative $\Delta \dot{V}_{dc}(m)$ are set as (negative large, negative medium, negative small, zero, positive large, positive medium, positive small) and respective abbreviations are (NL,NM, NS, Z, PL, PM, PS}. According to the rules IF-THEN form is used to obtain Dkp and Dki values. Here PS for DVdc(m) is defined as the condition when the DC bus voltage is deviating from the reference value with a small amount which is greater than the sensed value and NS is defined as the condition when the DC bus voltage of VSC of DSTATCOM is deviating from the reference value which is smaller than the sensed value and similarly other abbreviations can be defined.

The rule structure is formed by taking the following important points into consideration.

(1) If the error is small and the derivative of error is positive small and DC bus voltage is deviating from the sensed value then increase kp with a small amount.

(2) If the error is small and the derivative of error is positive small and DC bus voltage is approaching the sensed value then increase ki with a small amount to reduce steady state error.

(3) When the error and the derivative of error are positive medium or negative medium, in order to reduce the overshoot of system response, kp and ki should not be too big. The value of kp should be medium and ki should be small to ensure good system response.

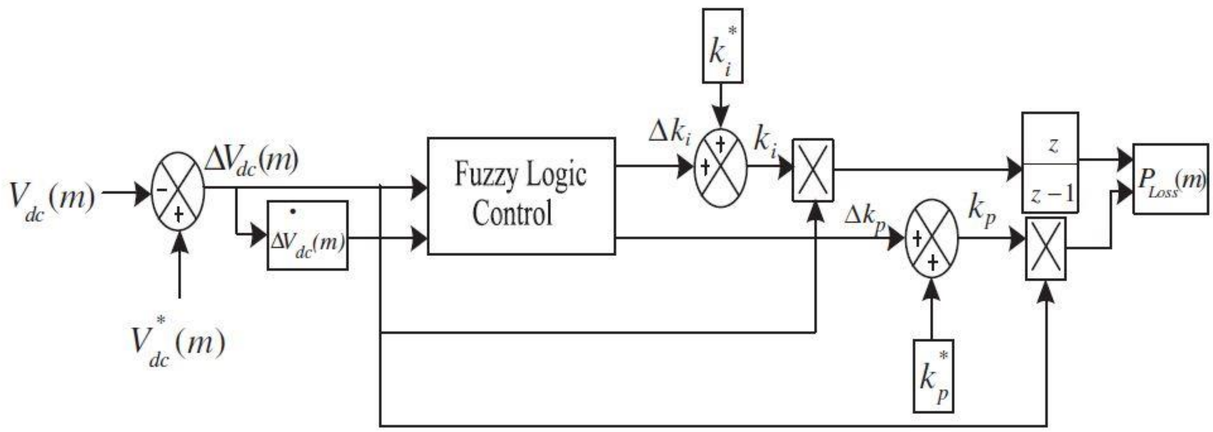

Fig. 3. Schematic of adaptive fuzzy logic PI controller

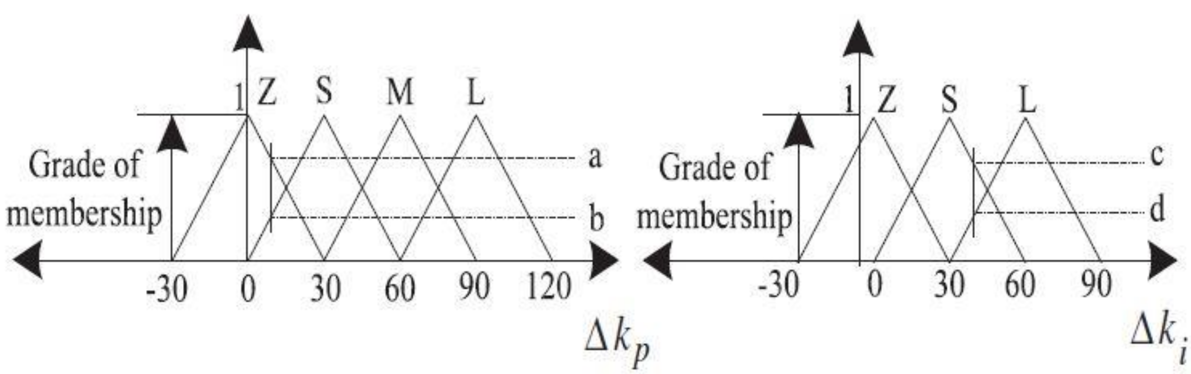

Fig. 4. Membership function for Δk_p and Δk_i

3. Simulation results

Simulation model of a DSTATCOM is developed for a three-phase distribution system in MATLAB environment using SIMULINK and Sim Power System (SPS) toolboxes. The performance of STF based IRPT with adaptive fuzzy logic control algorithm is simulated under distorted PCC voltages at both balanced and unbalanced nonlinear loads. The fault is created insource side; the corresponding waveforms are shown in Figs.5-6 for with and without DSTATCOM. As shown, with the presence of DSTATCOM, the distortion in the waveform of current is reduced and as a result, the power quality is improved.

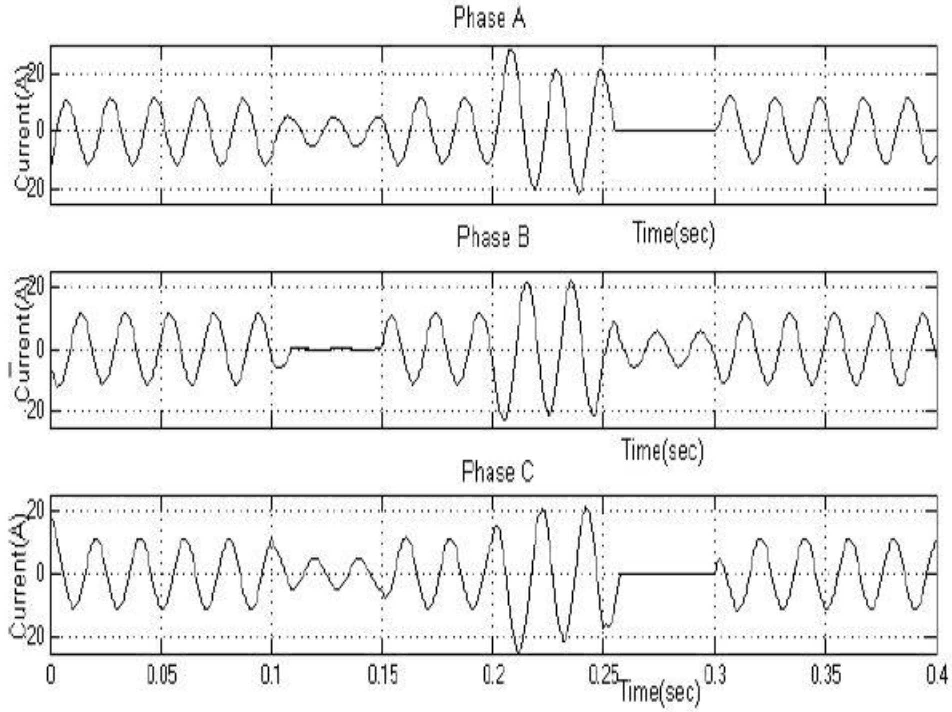

Fig. 5. Current waveform without DSTATCOM

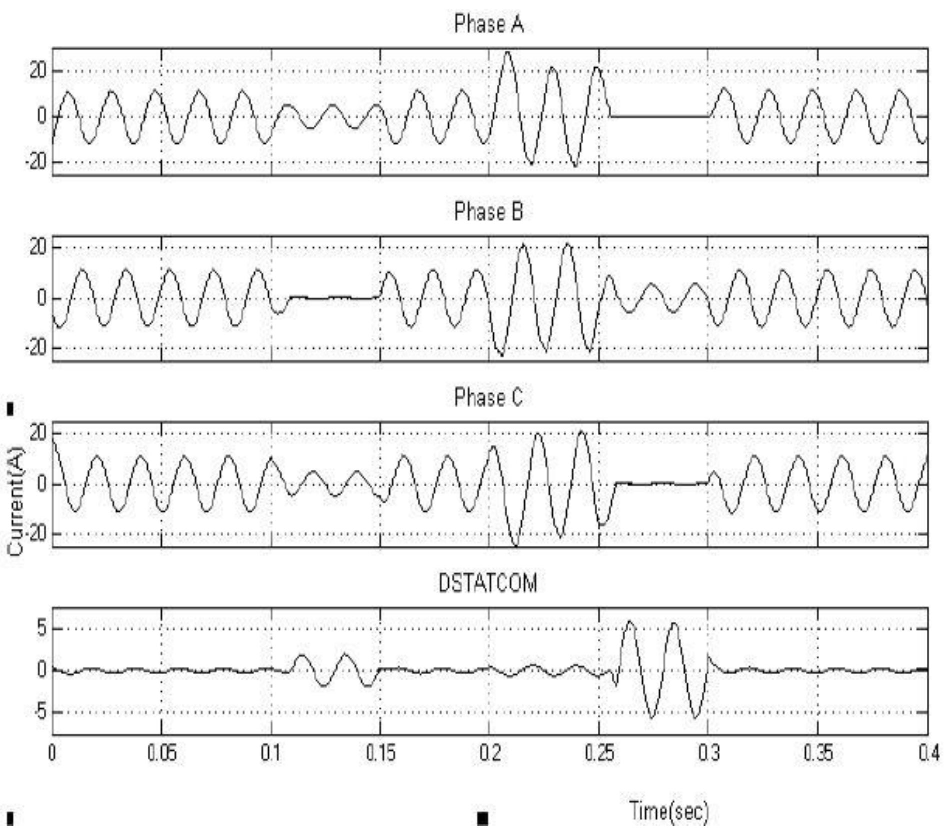

Fig. 6. Current waveform with DSTATCOM

CONCLUSION

This paper has presented the power quality problems such as voltage sags, interruption, and voltage swell. The objective of work is to study the performance of DSTATCOM for mitigating voltage sag, interruption, and to improve the power quality in distribution network with non-linear load. The investigation is made on different condition for nonlinear load. In this work the investigation is composed of power system distribution system with and without DSTATCOM. Power factor comparison for source and load side. So it can be concluded that DSTATCOM effectively improves the power quality in distribution network.

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