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New control approach for capacitor supported DSTATCOM in three-phase four wire distribution system under non-ideal supply voltage conditions based on synchronous reference frame theory

Bhim Singh [a], P. Jayaprakash [b,*], D.P. Kothari [c]

[a] Department of Electrical Engineering, Indian Institute of Technology, Delhi, Hauz-Khas, New Delhi 110 016, India
[b] Centre for Energy Studies, Indian Institute of Technology, Delhi, Hauz-Khas, New Delhi 110 016, India
[c] Vellur Institute of Technology, Vellur, Tamil Nadu, India

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ABSTRACT

A large number of single-phase linear and non-linear loads may be supplied from three phase ac mains with neutral conductor. They cause excessive neutral current, harmonics and reactive power burden and unbalance. A four wire DSTATCOM (distribution static compensator) is used for neutral current compensation along with reactive power compensation, harmonics elimination and load balancing. A novel control approach is proposed for the control of four wire DSTATCOM under non-ideal supply voltage conditions. A four-leg voltage–source converter (VSC) with a dc capacitor is used as a four wire DSTATCOM. The proposed control approach is based on synchronous reference frame (SRF) theory and an indirect current control technique. The switching signals for the voltage–source converter (VSC) of the DSTATCOM are derived from the estimated reference supply currents. The load balancing, harmonics elimination and the neutral current compensation are demonstrated along with unity power factor (UPF) and zero voltage regulation (ZVR) modes of operation. Simulation results based on MATLAB software with its Simulink and power system blockset (PSB) toolboxes are presented to validate the control strategy. The DSTATCOM is able to maintain the self-supported dc bus under various disturbances.

1. Introduction

The distribution systems are facing severe power quality problems due to the proliferation of different types of linear and non-linear loads such as solid-state controllers, which draw harmonics and reactive currents from ac mains [1–3]. Similarly, the single-phase linear and non-linear loads in the three-phase four wire distribution systems may lead to unbalance and excessive neutral current resulting in low power factor and increased loss [3]. Moreover, it may lead to poor power quality at AC source such as sag, swell, notch, flicker, unbalance, etc. Because of such severity of power quality problems, several standards have been developed and are being enforced on consumers and utilities [4]. The remedial options reported for these problems include distribution static compensators (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) and are called under the generic name of custom power devices [2].

The DSTATCOM is connected in shunt and is used for mitigating the power quality problems in the current and the DVR, which is connected in series, compensates the power quality problems of supply voltage at the point of common coupling (PCC). The UPQC is a combination of both DSTATCOM and DVR and it provides solution for power quality problems for both current and voltage. A three phase active device can provide an added feature of regulating the voltage at the PCC [5]. Though three-phase three-wire systems of DSTATCOM without neutral conductor have been successfully developed and commercial installations are reported [6], three-phase four-wire DSTATCOM is still under investigation [7–23]. The different topologies such as a VSC with four leg, three single phase VSC based and VSC with three leg and a split capacitor of DSTATCOM are reported in the literature [7–10]. Some researchers select the four-leg converter topology [8] as the best alternative compared to others considering number of switching devices, complexity of control, etc.

There are different control techniques reported for deriving the reference control signals for the DSTATCOM. The instantaneous reactive power theory (p–q theory) [3], synchronous reference frame (SRF) theory [19], power balance theory [11], SVPWM [22], etc. have been proposed to control DSTATCOM for three-phase four wire systems. The control of three-phase four-wire compensation

* Corresponding author. Tel.: +91 09497609509, +91 011 26591045; fax: +91 011 26581606.
E-mail addresses: bsingh@ee.iitd.ac.in (B. Singh), jayaprakashpee@gmail.com (P. Jayaprakash), dpk0710@yahoo.com (D.P. Kothari).

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under non-sinusoidal supply condition is verified to be satisfactory in [23] and the method is based on p–q theory. The instantaneous active and reactive powers are calculated after filtering out the harmonics in voltage and the theory is evaluated for three phase four-wire four-leg VSC based system. However, SRF theory is considered superior than p-q theory in the three-wire system due to reduced computation and directly using the currents only.

In this paper, a control approach based on synchronous reference frame (SRF) theory is used under non-sinusoidal supply conditions for the three phase four-wire four-leg VSC based DSTATCOM system. Moreover, the control scheme for non-sinusoidal supply conditions is implemented using an indirect current control method. The estimated reference supply current is used for generating the gate pulses for the four-leg VSC of the DSTATCOM. The DSTATCOM features the following characteristics.

(a) Operation under non-sinusoidal supply conditions.
(b) Neutral current compensation during linear and non-linear loads.
(c) Harmonic current compensation.
(d) Load balancing.
(e) Reactive current compensation for unity power factor (UPF) or the zero voltage regulation (ZVR) at the point of common coupling (PCC).
(f) Indirect current control.
(g) Capacitor supported operation of DSTATCOM.

2. Principle of four wire DSTATCOM

Fig. 1a shows single line diagram of a three-phase distribution line, which represents complete distribution system. The three-phase voltage source corresponds to secondary voltage of step-down transformers. An inductor, L_s corresponds to a leakage inductance of a distribution transformer and line inductance and the effective resistance of the distribution transformer and line is the resistor, R_s. The capacitor, C_f and R_f represent ripple capacitor and resistance respectively installed for filtering the high frequency signals of voltage at PCC. The effective resistance of the distribution transformer and line is the resistor, R_s. The DSTATCOM is installed at the end bus of the distribution line, as shown in Fig. 1a. The installation of the active device is one of the most effective solutions to eliminate harmonics in the distribution line [5].

Fig. 1b shows the phasor diagram of the system for unity power factor (UPF) operation. The reactive current (I_c) injected by the DSTATCOM is to cancel the reactive component of the load current so that the source current is reduced to real current component only as I_s. These currents are adjusted dynamically to maintain unity power factor under variable load conditions. Fig. 1c shows the phasor diagram for zero voltage regulation (ZVR) operation. In this mode, DSTATCOM injects a current I_c, such that the load voltage, V_L and source voltage, V_s are in the locus of same circle.

Fig. 2 shows the power circuit of a four wire DSTATCOM connected distribution system. The three-phase four-wire supply system is realized by using three voltage sources connected in star and a ground point. Three phase balanced and unbalanced loads are connected at the PCC along with the three-phase four wire DSTATCOM. The DSTATCOM consists of a 4-leg pulse width modulated (PWM) voltage–source converter using eight insulated-gate bipolar transistors (IGBTs), four interface inductors, and a dc capacitor. In order to control the switching transients of the DSTATCOM, a ripple filter, which consists of a capacitor in series with a small resistance, is connected at the PCC. The DSTATCOM on the end bus provides neutral current compensation, harmonics elimination and load balancing along with power factor correction or line voltage regulation.

3. Control of three-phase four wire DSTATCOM

The control of DSTATCOM has two parts.

(a) Derivation of reference signals using the required feedback signals.
(b) Generation of the gate signals using PWM current controller by comparing the sensed and reference signals.

In this case, the proposed control technique for deriving the reference supply current is based on the synchronous reference frame (SRF) theory. The sensed load current is converted to rotating reference frame using 'sine and cosine' signals, with unity magnitude, generated by a PLL in-phase with the load voltage. Hence the influence of the disturbance of the electrical network is eliminated in the voltage waveform.

3.1. Reference signal estimation

The reference supply current is estimated using the sensed load current and voltage at PCC. The UPF and ZVR strategies of reactive power compensation are mutually independent and the estimation

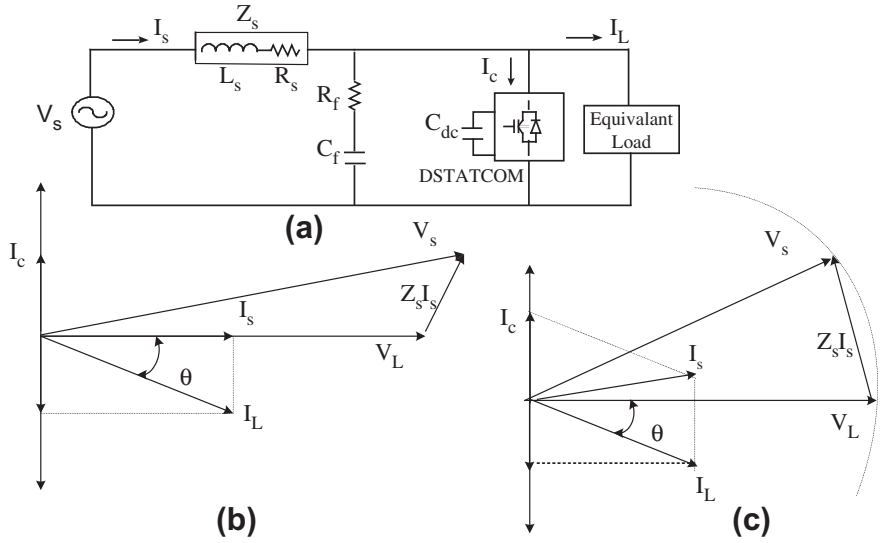

Fig. 1. (a) Single line diagram of DSTATCOM system. (b) Phasor diagram for UPF operation. (c) ZVR operation.