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A Simple Control of STATCOM for Non-linear Load Compensation

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Abstract–This paper presents a simple controller for non-linear load compensation by using a three-phase voltage source converter (VSC) based static synchronous compensator (STATCOM). The PI tuning criteria 'modulus optimum (MO)' and 'symmetric optimum (SO)' are used in order to make the system faster, robust and disturbance free. The controller forces the source quadrature current to be zero so that the source supplies only real power to the load. The proposed scheme is simulated in MATLAB environment.

Keywords–DC voltage control, modulus optimum criterion, static synchronous compensator, symmetric optimum criterion, voltage source converter.

NOMENCLATURE

MO	Modulus optimum
PCC	Point of common coupling
SO	Symmetric optimum
VSC	Voltage source converter
V_{LL}	PCC line-line voltage
i_{abc}	Three-phase source current
V_{dc}	DC capacitor voltage
L	AC inductor
R	Resistance of AC inductor
K_{pi}	Proportional gain of current PI controller
K_i	Integral gain of current PI controller
T_i	Integral time constant of current PI controller
K_{po}	Proportional gain of DC voltage PI controller
K_{io}	Integral gain of DC voltage PI controller
T_o	Integral time constant of DC voltage PI controller

I. INTRODUCTION

The power quality has always been a matter of concern for any electrical distribution system. It involves the consideration not only from the source side but also from the load side. Since last few decades, the use of power electronic interfaces has been increased to a great extent that allows the consumer to use the power in the required way. The use of such interfaces distorts the system waveforms and causes a poor power quality. The IEEE 100 (authoritative dictionary of IEEE standard terms) acknowledges the definition of the power quality [1]. IEEE 519-1992 standards prescribe the power practices and requirements for limiting the harmonics in the power system [2]. Reactive power arises due to the energy storing elements *viz.* inductor and capacitor in the electrical network and refers to the portion of power which does not contribute to the energy conversion / transformation but circulates back and forth in each cycle in the power system [3–4]. It is primarily responsible for maintaining the voltages for the normal operation of the electrical power system and is required for the magnetization of the electric machines as well [5]. With the reactive load connected in the electrical network the power factor becomes worsen. As a consequence, the reactive power demanded by the load from the source should be kept a minimum.

It is possible to improve the power factor by means of a compensator which generates the reactive power equal and opposite to the load reactive power and does not affect the active power of the load. Active compensators based on the custom power devices are nowadays common in industry applications for both reactive power compensation (power factor correction) as well as harmonic mitigation. However, the reactive power compensation should be provided as close as possible to the consumer / load point.

The STATCOM is the second generation shunt connected FACTS device that works as a static VAR compensator. The choice of STATCOM lies behind its property of faster and better transient / dynamic responses, and enhanced capability to exchange power [6]. However, the proper working of the STATCOM is dependent on the switching signals generated by its controller [7]. This paper basically focuses on the design of a controller for STATCOM.

Many literatures [7–12] have already proposed the designing of controller for STATCOM. Singh *et al.* [7] presented control algorithm based on correlation and cross correlation function approach for power quality improvement. Schauder *et al.* [8] presented two advanced static VAR compensator inverter for control of the output voltage magnitude and phase angle. Chen *et al.* [9] presented a novel STATCOM controller with a fixed modulation index reference to minimize the voltage and current harmonics. Cheng *et al.* [10] presented an integrated model of energy storage system and STATCOM. Escobar *et al.* [11] presented a passivity-based controller for a STATCOM for the compensation of reactive power and harmonics. Ledwich *et al.* [12] presented a paper where a discussion on voltage and current control of STATCOM is given.

In this paper, a brief description of the STATCOM system and its control scheme is discussed. The control scheme is developed such that the controller forces the source current to be sinusoidal. The performance results of the control scheme are shown with the help of the harmonic spectra and waveforms.

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II. SYSTEM DESCRIPTION AND PROPOSED CONTROLLER SCHEME

The configuration of the system is represented as shown in Fig.1. An AC supply is acting as a source of magnitude *V* and frequency *f*. Here, the STATCOM is represented as a three-phase VSC empowered by a large DC capacitor.

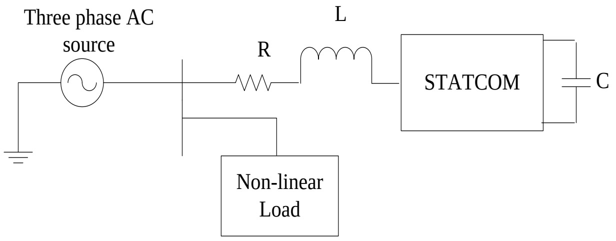


Fig.1. The configuration of the proposed system.

The proposed control schematic for the STATCOM is illustrated in Fig.2. The objective of the controller is to generate the switching pulses in such a way so that it could compensate the non-linear load and force the source currents to be sinusoidal. It is achieved by voltage oriented control wherein two loops (*viz.* inner current control loop and outer DC voltage control loop are involved) and the source quadrature component is forced to be zero so that only real power is supplied by the source to the non-linear load.

For the conversion from the *a-b-c* reference frame to synchronously rotating *d-q* reference frame, two transformations are required. Clark’s transformation is used to convert three-phase AC quantities from *a-b-c* reference frame into *α-β* reference frame and Park’s transformation is applied for converting *α-β* reference frame into *d-q* reference frame. The reason behind choosing *d-q* reference frame is its ability to decouple both the real and reactive powers and making them independent of each other.

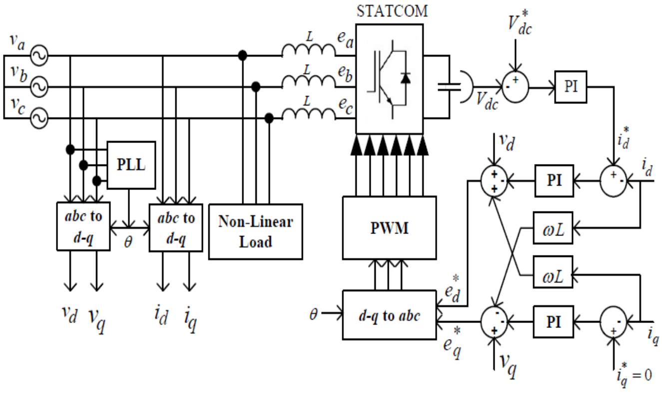


Fig.2. Proposed control schematic for STATCOM.

The involved PI controllers can be tuned by means of different tuning methods. However, tuning of the PI controller parameters is always a challenging job to engineers because of uncertain plant. Every tuning method has its own constraints and limitations as thoroughly discussed in [13]. The ‘modulus optimum (MO)’ and ‘symmetric optimum (SO)’ criteria are identified as one of the straightforward optimum PI tuning criteria offering satisfactory set-point response of the closed-loop system without requiring complete plant model [13–14]. In order to make the inner current control loop work faster and oscillation free, the tuning of the inner loop current PI controller is carried out with the MO criterion wherein, the dominant pole of the plant is cancelled with the controller zero. On the other hand, the tuning of the outer-loop DC voltage PI controller is carried out with the SO criterion [15] in order to achieve optimum regulation and system stability along with better rejection to the disturbance and maximized phase margin. A modus operandi is presented in the upcoming sub-sections so as to calculate the PI controller gains for the inner current as well as outer DC voltage control loops.

A. Current control loop

The block-diagram of the current control loop is shown in Fig.3. The PWM converter acts as a transformer with a time-lag converting the reference voltage to a different voltage level. The average time-lag T_w for the control delay and PWM converter blocks as shown in Fig.3 is 1.5 times the sampling time T_{sample} of the current control loop [13].

$$T_w = 1.5\ T_{sample} \tag{1}$$

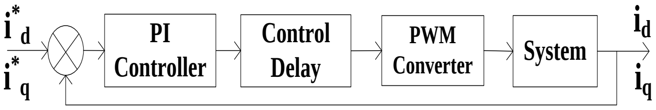


Fig.3. Block-diagram of the inner current control loop.

The open-loop transfer function for the current control loop is given as

$$G_{C,OL}(s) = \frac{i_d}{i_d^*} = \frac{i_q}{i_q^*} = K_{pi}\cdot\left(\frac{1+T_i s}{T_i s}\right)\cdot\left(\frac{1}{1+T_w s}\right)\cdot\frac{1}{R}\cdot\left(\frac{1}{1+\tau s}\right) \tag{2}$$

where, $T_i = (K_{pi}/K_i)$ and $\tau = L/R$.

In order to make the current control loop work faster and oscillation free, tuning of the PI controller is carried out with MO criterion. After applying the MO tuning criterion, the closed-loop transfer function of the current control loop is found to be as

$$G_{C,CL}(s) = \frac{1}{2T_w^2.s^2 + 2T_w.s + 1} \tag{3}$$

It can easily be deduced from the transfer function mentioned above that the damping ratio is $\xi = 0.707$. The estimated values of the proportional and integral gains of the current PI controller are

$$K_{pi} = \frac{\tau R}{2T_w} \quad \text{and} \quad T_i = \tau \tag{4}$$

B. DC voltage control loop

The block-diagram of the DC voltage control loop is shown in Fig.4. The open-loop transfer function of the outer control loop may be given as

$$G_{O,OL}(s)=\frac{K_{po}.K}{sT}\left(\frac{1+T_0 s}{T_0 s}\right)\left(\frac{1}{1+T_e s}\right) \tag{5}$$

where, $K=v_d/V_{dc}$ and $T=2C/3$ $T_e=2T_w+10T_{sample}$.

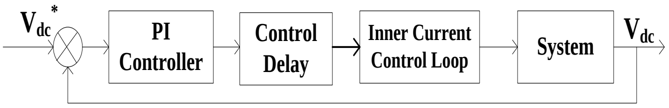


Fig.4. Block-diagram representation of the outer DC voltage control loop.

The tuning of the DC voltage control loop is carried out with SO criterion. After applying the SO tuning criterion, the closed-loop transfer function for the DC voltage control loop is given as

$$G_{O,CL}(s)=\frac{1+a^2.T_e.s}{(a.T_e.s+1)(a^2.T_e^2.s^2+a.(a-1).T_e.s+1)} \tag{6}$$

The estimated values of the proportional and integral gains of the DC voltage PI controller are

$$K_{po}=\frac{T}{a.K.T_e} \quad \text{and} \quad T_o=a^2.T_e \tag{7}$$

where, the value of parameter 'a' may vary from 2 to 4 [13]. The calculated values of the controller parameters are listed in Table–1.

Table.1: System parameters

Parameters	Value	Controller Parameters	Value
V_{LL}	415 V	K_{pi}	26.06
V_{dc}^*	800 V	K_i	12000
R	1.8Ω	K_{po}	2.5829
L	3.91 mH	K_{io}	445.3274

III. SIMULATION RESULTS

An unbalanced non-linear inductive load is connected at the PCC. The non-linear loads drawing harmonic currents from the AC source result in the distortion in the voltage waveforms at the PCC, the magnitude of which mainly depends on the source impedance [16]. However, in this paper, the stiff AC supply system with negligible (almost zero) impedance is considered between the AC source and the PCC. In simulation model, three single-phase diode bridge rectifiers connected in delta configuration and feeding the impedances of values 12+j120e-3, 24+j12e-3 and 36+j1.2e-3, respectively at the DC side constitute an unbalanced non-linear load connected at the PCC.

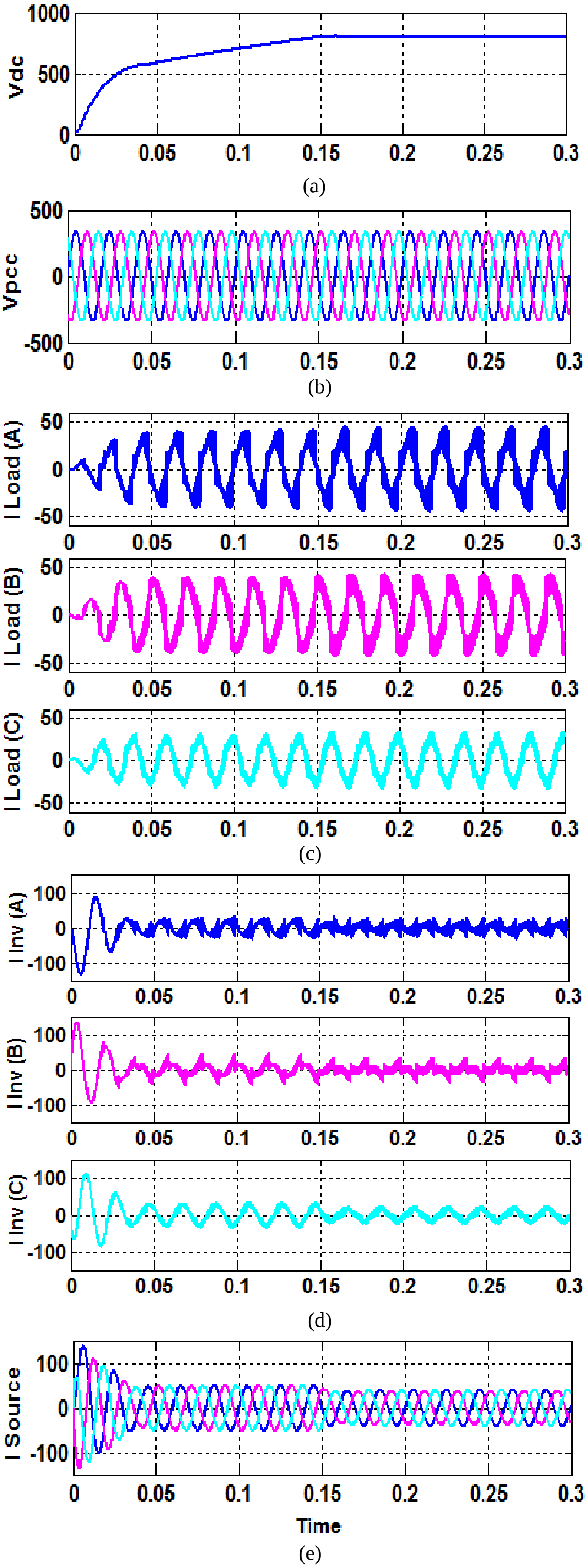
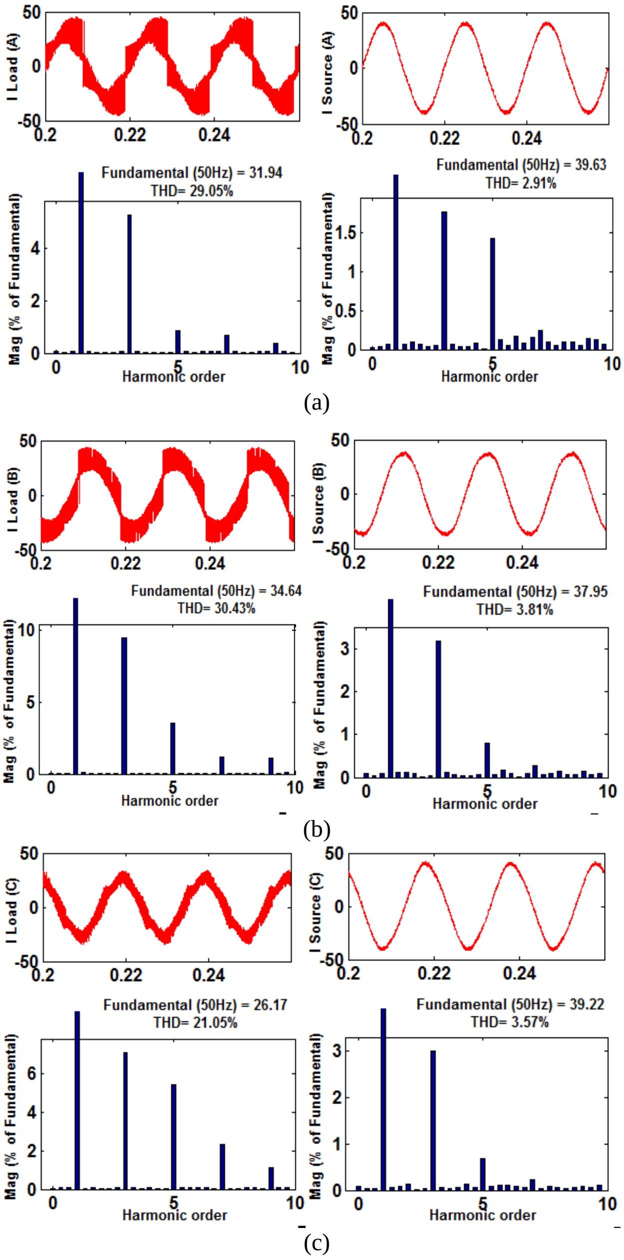


Fig.5. Performance of the proposed STATCOM control—(a) DC capacitor voltage (b) voltages at PCC, (c) load currents for phases a, b and c, respectively (d) inverter (STATCOM) currents for phases a, b and c, respectively (e) source currents.

The waveforms for the different currents and voltages are presented along with current harmonic spectra as shown in Figs. 5–6. From Fig.5 (a) it can be seen that the DC voltage is settled at its reference value of 800 volts. Fig.5 (b) shows the voltages at the PCC which is completely sinusoidal. The load currents profile is shown in Fig.5 (c). The inverter (STATCOM) current compensation is shown in Fig.5 (d) and the three-phase source currents are shown in Fig.5 (e). Further, Fig.6 shows the harmonic spectra of the load and the source currents for all three phases. The THDs of the load and the source currents are listed in Table–2.



(a)

(b)

(c)

Fig.6. Load and source current waveforms and their harmonic spectra—(a) phase ‘*a*’ (b) phase ‘*b*’ (c) phase ‘*c*’.

It is worth noticeable that for a standard single-phase bridge rectifier (which is used here in constituting the non-linear load), the number of pulses $p = 2$ in one cycle of the line frequency and, therefore, the characteristic harmonics are $h = 2n \pm 1$ *viz.* 1 (fundamental), 3, 5, 7, 9, 11… *etc.* wherein, the lower order harmonics such as 3rd, 5th and 7th are dominant [17]. This is also apparent in the current harmonic spectra shown in Fig.6. It can be concluded that the STATCOM controller forces the source current to be sinusoidal by compensating the non-linearity in the load-currents. Further, the THDs of the source currents are within 5% as per IEEE-519 standard.

Table.2: THDs of the source and load currents

Phase	**Source Current**		**Load Current**	
	Magnitude (A)	**THD (%)**	**Magnitude (A)**	**THD (%)**
a	39.63	2.91	31.94	29.05
b	37.95	3.81	34.64	30.43
c	39.22	3.57	26.17	21.05

IV. CONCLUSIONS

A simple control of a three-phase VSC based STATCOM was presented and studied. For obtaining oscillation and delay free response, two different tuning criteria *i.e.* MO and SO were applied. These tuning criteria were found to be responding very well. The voltage and current waveforms corresponding to the case of unbalanced non-linear load were observed and the controller was found functioning well. The THDs of the source currents were found to be under the limit of 5% as per IEEE-519 standard.

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BIOGRAPHIES

Prakash Ji Barnawal was born in Bhadohi, India in 1991. He completed his B.Tech. degree from Galgotias College of Engineering & Technology, (U.P.), India in the year 2014 and M.Tech. degree in Power Electronics & Drives from Kamla Nehru Institute of Technology, (U.P.) India in the year 2016. His fields of current interest include power quality, power electronics and electric drives.

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