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An indirect current controller & PLL based DSTATCOM for harmonic elimination in distribution line

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***Abstract*— Now a days the power systems are of complex networks. Power distribution system should provide with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency to their customers.In this paper an indirect current control technique is implemented along with hysteresis current controller for control of output voltage of a VSC based static synchronous compensator called DSTATCOM connected at the point of common coupling (PCC) to a power system network for distribution of power. Also a voltage source converter using PLL is used in the control circuit of DSTATCOM for harmonic elimination in distribution line. A distribution static synchronous compensator (DSTATCOM) is used to improve the power quality in distribution line employing a hysteresis current controller to improve the voltage profile, correcting power factor, mitigate harmonicsetc. In this paper the indirect current controller interfaced with designed hysteresis current controller is also compared with PLL based controller for the VSC based STATCOM for harmonic elimination in distribution line.**

***Keywords*— DSTATCOM, Voltage source converter, Control circuit, Distributed Line. Phase locked loop.**

I. INTRODUCTION

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A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure-1,consists of a Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSCconverts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the acsystem. These problems are aggravated in harmonic environment, created by power electronics converters. The adverse effects of low power factor and unbalance loads are increased losses and overloading of one particular phase. These converters do not only corrupt the current but also distort the system voltage [1-3].The indirect current controller is presented in[1]. Performance of DSTATCOM system depends on the algorithm used for its control circuit along with current controller. There is various control algorithms used for detection of reference current for switching of VSC. Using Simulink's power system block set, simulation of DSTATCOM is done as [4].A control technique for Cascaded H-Bridge Converter based DSTATCOM is also performed as [5]. Nowadays, there are an increasing number of non-linear loads which inject harmonics into the system. A three-phase insulated gate bipolar transistor- (IGBT-) based current controlled voltage source inverter with a DC bus capacitor known as a DSTATCOM is used for power factor correction, harmonic compensation and for providing required reactive power to the load. Here the DSTATCOM employs an indirect current control technique with a hysteresis current controller. Hysteresis current control has desirable characteristics such as high stability, fast and accurate dynamic behaviour using relays & logic circuit. The relay based controller in the DSTATCOM has very fast dynamic response, is cheaper & easy to implement.

(II.A)GENERATION OF PULSES FOR TRIGGERING OF VSC IN INDIRECT CURRENT CONTROL TECHNIQUE

The fig1 (a) shows basic block diagram of DSTATCOM connected to a distribution line &fig1 (b) shows the realization of DSTATCOM by a voltage source converter using IGBT switches. For indirect current control method we have to compute first reference source currents. Thethree-phase reference source currents are computed using three-phase AC voltages (v_{ta}, v_{tb} and v_{tc}) and DC bus voltage (V_{dc}) of DSTATCOM. These reference supply currents consist of two components, one in-phase (I_{spdr}) and another in quadrature (I_{spqr}) with the supply voltages. The basic equations of control algorithm of DSTATCOM are as follows.

In-phase components of reference supply current
The instantaneous values of in-phase component of reference supply currents (I_{spdr}) is computed using one PI controller over the average value of DC bus voltage of the DSTATCOM (v_{dc}) and reference DC voltage (v_{dcr}) as

$$I_{spdr} = I_{spdr(n-1)} + K_{pd}\{v_{de(n)} - v_{de(n-1)}\} + K_{id} v_{de(n)} \quad \textbf{(1)}$$

where $v_{de(n)} = v_{dcr} - v_{dca(n)}$ denote the error in v_{dcr} and average value of v_{dc}, K_{pd} and K_{id} are proportional and integral gains of the DC bus voltage PI controller.
The output of this PI controller (I_{spdr}) is taken as amplitude of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents (i_{sadr}, i_{sbdr} and i_{scdr}) are computed using the in-phase unit current vectors (u_a, u_b and u_c) derived from the AC terminal voltages (v_{tan}, v_{tbn} and v_{tcn}), respectively.

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$$u_a = v_{ta}/V_{tm}, u_b = v_{tb}/V_{tm}, u_c = v_{tc}/V_{tm} \quad \textbf{(2)}$$

Where V_{tm} is amplitude of the supply voltage and it is computed as

$$V_{tm} = [(2/3)(V_{tan}{}^2 + V_{tbn}{}^2 + V_{tcn}{}^2)]^{1/2} \quad \textbf{(3)}$$

The instantaneous values of in-phase component of reference supply currents (i_{sadr}, i_{sbdr} and i_{scdr}) are computed as

$$i_{sadr} = I_{spdr} u_a, i_{sbdr} = I_{spdr} u_b, i_{scdr} = I_{spdr} u_c \quad \textbf{(4)}$$

Quadrature components of reference supply current

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (V_{tm}) and its reference value (V_{tmr})

$$i_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\{V_{ac(n)} - V_{ac(n-1)}\} + K_{iq} V_{ac(n)} \quad \textbf{(5)}$$

where $V_{ac(n)} = V_{tmr} - V_{tm(n)}$ denotes the error in V_{tmnr} and computed value V_{tmnr} form Equation (3) and K_{pq} and K_{iq} are the proportional and integral gains of the second PI controller.

The quadrature unit current vectors $\mathbf{w_a}, \mathbf{w_b}, \mathbf{w_c}$ are derived from in-phase unit current vectors $\mathbf{u_a}, \mathbf{u_b}, \mathbf{u_c}$ as

$$\mathbf{w_a} = \{-\mathbf{u_b} + \mathbf{u_c}\}/\{(3^{1/2})\}$$

$$\mathbf{w_b} = \{-\mathbf{u_a}(3)^{1/2} + \mathbf{u_b} - \mathbf{u_c}\}/\{2(3^{1/2})\} \quad \textbf{(6)}$$

$$\mathbf{w_c} = \{-\mathbf{u_a}(3)^{1/2} + \mathbf{u_b} - \mathbf{u_c}\}/\{2(3^{1/2})\}$$

Three-phase quadrature components of the reference supply currents (i_{saqr}, i_{sbqr} and i_{scqr}) are computed using the output of second PI controller (i_{spqr})and quadrature unit current vectors (w_a, w_b, and w_c) as

$$i_{saqr} = I_{spqr}\mathbf{w_a}, i_{sbqr} = I_{spqr}\mathbf{w_b}, i_{scqr} = I_{spqr}\mathbf{w_c} \quad \textbf{(7)}$$

Total reference supply currents

Three-phase instantaneous reference supply currents (i_{sar}, i_{sbr} and i_{scr}) are computed by adding in-phase (i_{sadr}, i_{sbdr} and i_{scdr}) and quadrature components of supply currents (i_{saqr}, i_{sbqr} and i_{scqr}) as

$$\mathbf{i_{sar}} = \mathbf{i_{sadr}} + \mathbf{i_{saqr}}, \mathbf{i_{sbr}} = \mathbf{i_{sbdr}} + \mathbf{i_{sbqr}}, \mathbf{i_{scr}} = \mathbf{i_{scdr}} + \mathbf{i_{scqr}} \quad \textbf{(8)}$$

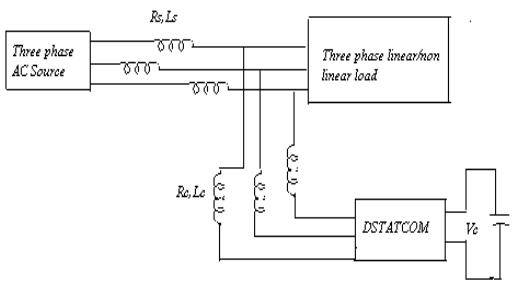


Fig. 1(a)Block diagram representation of DSTATCOM connected to distribution line

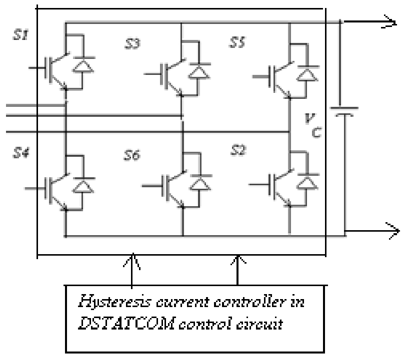


Fig. 1(b)The DSTATCOM realized by a IGBT based converter .

The DSTATCOM has IGBT switches which are controlled by a gate driver circuit employing an indirect current control technique associated with a relay based hysteresis current regulator.

(II.B).DESIGN OF HYSTERESIS CURRENT CONTROLLER

A relay based current regulator with logic circuit is employed over the reference (i_{sar}, i_{sbr} and i_{scr}) and sensed supply currents (i_{sa}, i_{sb} and i_{sc}) to generate gating pulses for IGBTs of DSTATCOM.The main purpose here is to force the ac line current to follow a given reference. The status of the power valves S_1 and S_4 are changed whenever the actual $i_a$current goes beyond a given reference $i_{a(ref)}$(+/-)$\Delta i/2$. Figure 2(a)shows the hysteresis current controller for phase a. Identical controllers are used in phase b and c. Finally, although the ac load currents add up to zero, the controllers cannot ensure that all load line currents feature a zero dc component in one load cycle.

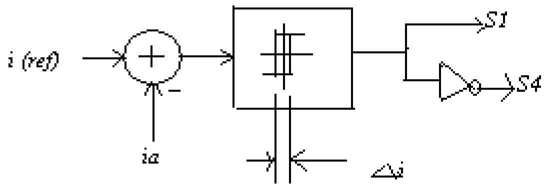


Fig. 2(a). 1-ϕ hysteresis current controller

There are many considerations involved in the correct selection of a control relay for a particular application. These considerations include factors such as speed of operation, sensitivity, and hysteresis. Although typical control relays operate in the 5 ms to 20 ms range, relays with switching speeds as fast as 100 us are available. In comparison with the other schemes, the hysteresis current control yields a continuously varying output spectrum contents which is dependent on the derivative ofthe reference current, the variation of input voltage, and the load parameters.Upper and lower bounds are set for the load current as $|i| > |i_{max}|$,no output, $|i| < |i_{min}|$ output is obtained, $|i_{min}| < |i_{max}|$,no change

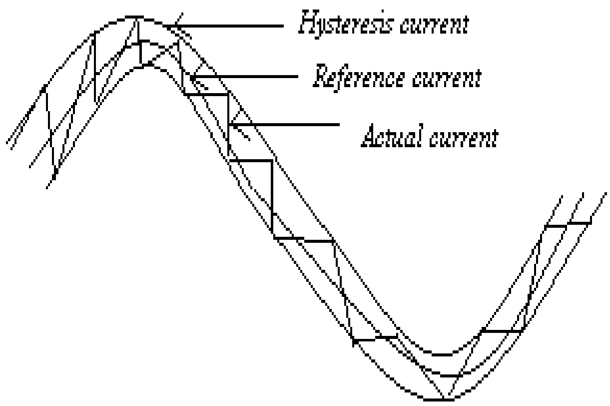


Fig. 2(b). Band of hysteresis current controller

Among the conventional current-controlled schemes, the hysteresis current control provides a simple and robust current control performance with good stability; very fast response and an inherent ability to control peak current.

The output of PI controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, ahysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of DSTATCOM. The controller controls the DSTATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as DSTATCOM. A DSTATCOM is a capable of compensating either busvoltage or line current.

(II.C).MODELLING OF INDIRECT CURRENT CONTROLLER

The fig2(c) shows Simulink block diagram for power circuit of compensated line with VSC based DSTATCOM. &fig2 (d) shows the control circuit with indirect current control technique.

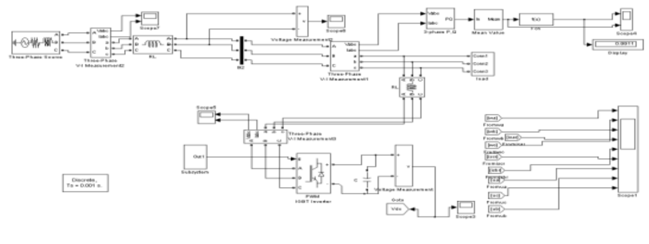


Fig. 2(c). Power circuit of compensated line

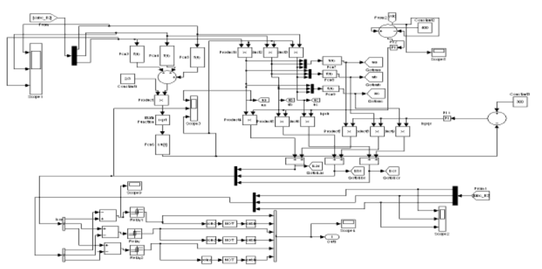


Fig2(d).Control circuit of DSTATCOM along with hysteresis current controller

III.A.PULSE GENERATION FOR VSC IN STATCOM USING PLL & dq0 TRANSFORMATION.

The block diagram shown in fig3 (a) shows a VSC based DSTATCOM which employs phase locked loop &dqotransformation.Fig3 (b) shows a basic phase locked loop block diagram.

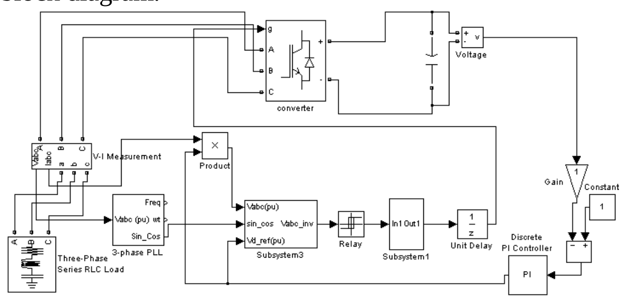


Fig3(a).Block diagram of basic voltage source converter

PHASE LOCKED LOOP

The phase locked loop (PLL) is used to synchronise the converter control with the line voltage and also to compute the transformation angle used in the *d-q* transformation. The PLL block measures the system frequency and provides the phase synchronous angle *Θ* for the d-q transformations block.

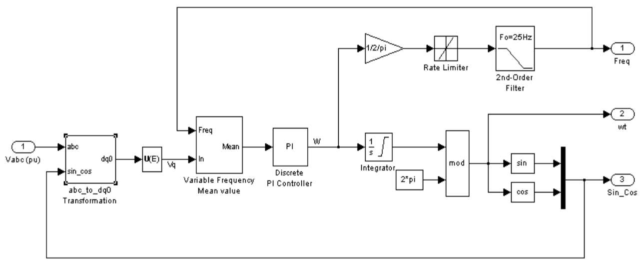
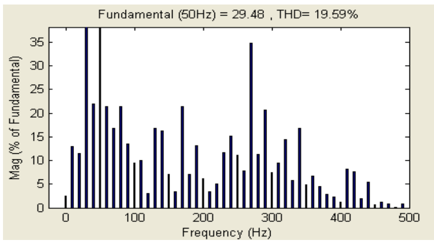
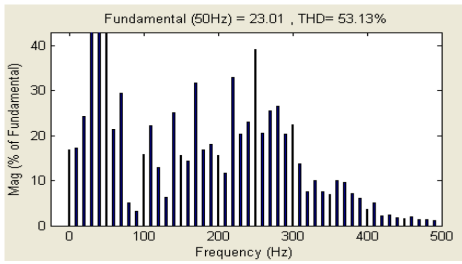


Fig3(b).Basic phase locked loop

IV.RESULTS.

Harmonics in load current before compensation by DSTATCOM is shown in fig-4.





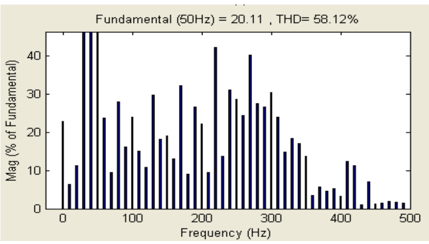
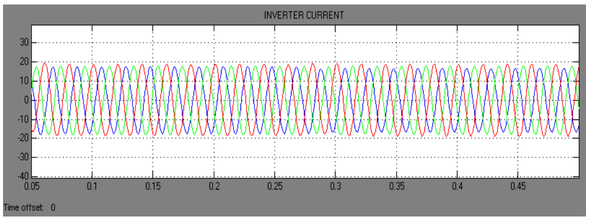
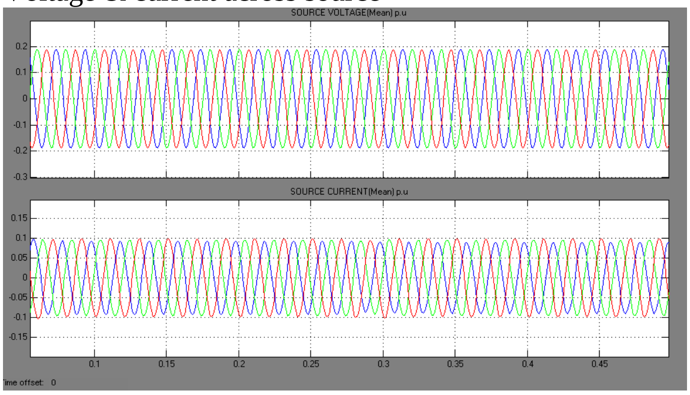


Fig. 4. HARMONICS IN SOURCE /LOAD CURRENTS (before compensation)



IV.A.RESULTS FOR INDIRECT CURRENT CONTROL TECHNIQUE

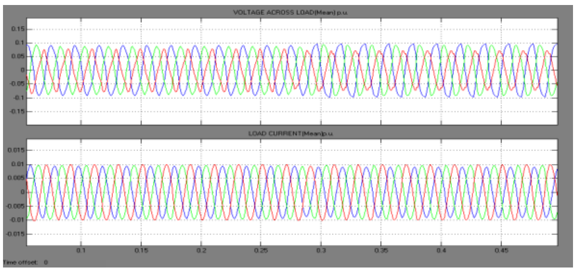
Voltage & current across source

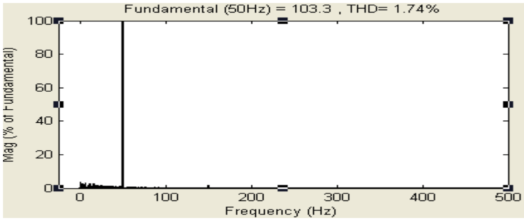


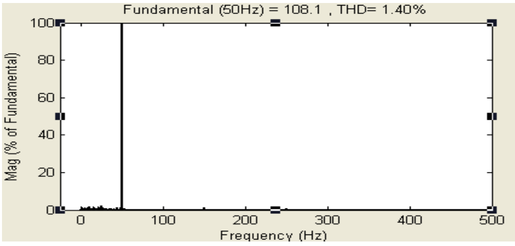
Voltage & current across load

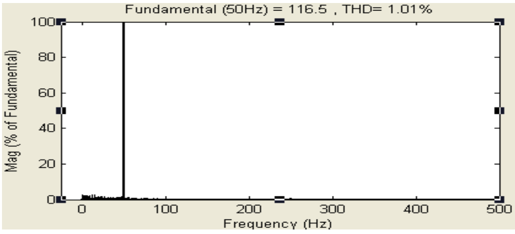
Inverter output current

Harmonics in load current after compensation for nonlinear load by indirect current control technique.

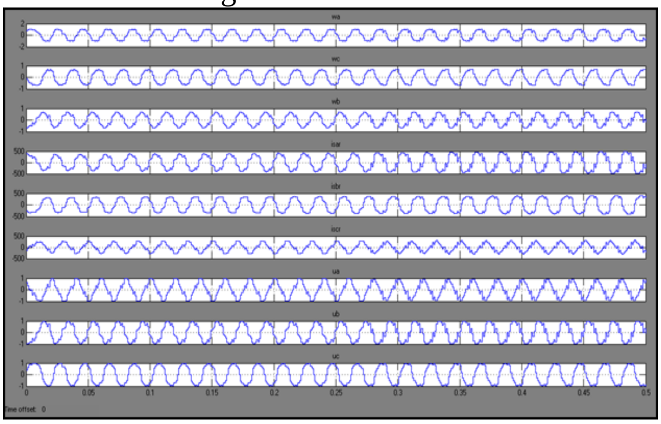






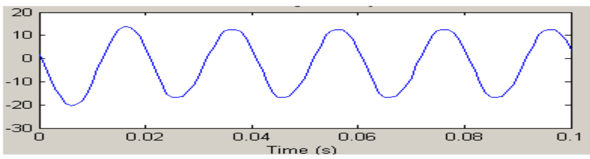


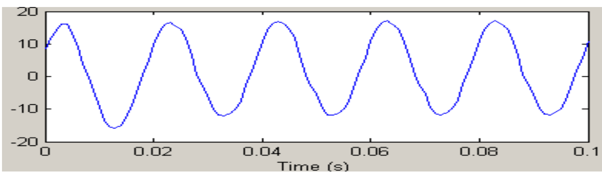
Control circuit signals of indirect current controller



IV.B.RESULTS FORPLL BASED VSC CONTROLLER IN DSTATCOM

Output load currents with THDs of 26.02%, 10.37%&16.9%





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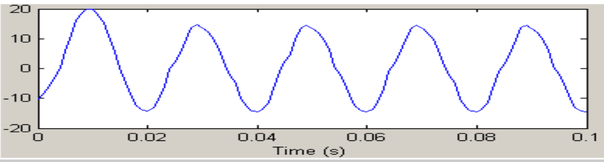
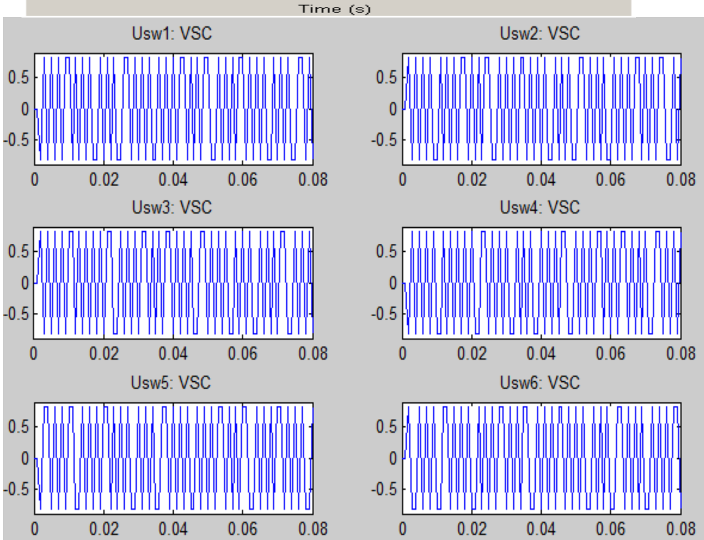
Harmonics in load current after compensation for nonlinear load by PLL based voltage source converter in DSTATCOM .

Synchronizing voltagesfor PLL based VSC in DSTATCOM





V.Conclusions

An indirect current control algorithm is suitably applied to the controller circuit of VSC based STATCOM interfaced with the hysteresis current controller. It is capable of providing a controlled output voltage at PCC of the VSC based STATCOM.It can also be used for mitigation of harmonics, correction of power factor & voltage regulation. The control algorithm of DSTATCOM has an inherent property to provide a self-supporting DC bus of DSTATCOM. The DSTATCOM controller is also realized by conventional control scheme by PLL &dqotransformation. It is concluded that the harmonic content in the load current by indirect current control technique is superior ,but complicated as compared to PLL based controller presented here.

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