

A Multifunctional DSTATCOM Operating Under Stiff Source

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Abstract: Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance for controlling the power flow for this industrial application requires Facts device, which is operated under distribution system is nothing but distributed compensation scheme. A DSTATCOM is capable of compensating either bus voltage or line current. If it operates in a voltage control mode, it can make the voltage of the bus to which it is connected a balanced sinusoid, irrespective of the unbalance and distortion in voltage in the supply side or line current. Similarly when operated in a current control mode, it can force the source side currents to become balanced sinusoids. Loads connected to a stiff source cannot be protected from voltage disturbances using a distribution static compensator (DSTATCOM). In this paper, a new control algorithm based multifunctional DSTATCOM is proposed to operate in voltage control mode under stiff source. This scheme provides fast voltage regulation at the load terminal during voltage disturbances and protects induction machine drive system. The simulation results are obtained using Matlab/Simulink software.

Keywords: DSTATCOM, Multifunctional, Power Factor, Stiff Source, Voltage Regulation.

I. INTRODUCTION

Large electric drives and utility applications require advanced power electronics converter to meet the high power demands. The evolution of power electronic devices, nonlinear loads, and unbalanced loads has degraded the power quality in the power distribution network [1]. The distribution static compensator is a shunt active filter, which injects currents into the point of common coupling (PCC) (the common point where load, source, and DSTATCOM are connected) such that the harmonic filtering, power factor correction, and load balancing can be achieved. In practice, the presence of feeder impedance and nonlinear loads distorts the terminal voltage (PCC) and source currents. The load compensation

using state feedback control of DSTATCOM with shunt filter capacitor gives better results [2]. The switching frequency components in the terminal voltages and source currents are eliminated by using state feedback control of shunt filter capacitor. in this situation, DSTATCOM should operate in CCM. However, due to grid faults, source voltage (stiff or non-stiff) can change at any time and then VCM operation is required. DSTATCOM regulates the load voltage by indirectly regulating the voltage across the feeder impedance. When a load is connected to nearly a stiff source, feeder impedance will be negligible[1]–[4]. Under these circumstances, DSTATCOM cannot provide sufficient voltage regulation at the load terminal [9].

This paper proposes a new control algorithm based DSTATCOM topology for voltage regulation even under stiff source. It is achieved by connecting a suitable external inductor in series between the load and the source point. Point of common coupling (PCC) will be the point where external inductor and source are connected. DSTATCOM, connected at the load terminal, provides voltage regulation by indirectly regulating the voltage across the external inductor. Proposed control algorithm to obtain variable reference load voltage is formulated as a function of the desired source current. This voltage indirectly controls the current drawn from the source for a permissible range of source voltage. Therefore, the control algorithm makes source currents balanced, sinusoidal, and in phase with respective source voltages during normal operation. During voltage disturbances, a constant voltage is maintained at the load terminal. Hence, proposed topology and control algorithm make compensator multifunctional so that it provides fast voltage regulation at load terminal and additionally provides advantages of CCM while operating in VCM.

II. DSTATCOM CONFIGURATION

A neutral point clamped voltage source inverter (VSI) topology is chosen as it provides independent control of each leg of the VSI [7]. A single phase equivalent circuit of DSTATCOM in distribution network is shown in Fig. 1. VSI represented by u V dc is connected to load terminal through an LC filter (L_f - C_{fc}).

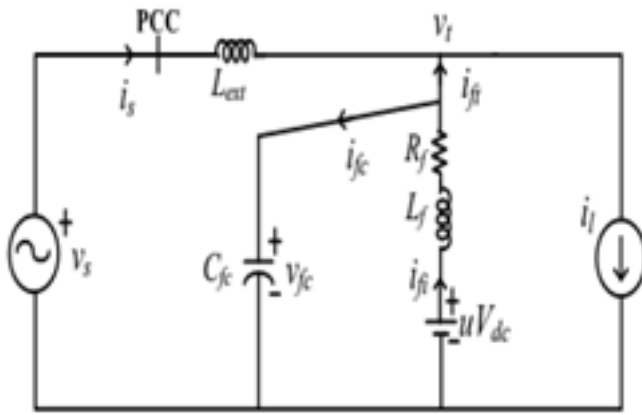


Fig1. Single phase equivalent circuit of DSTATCOM in distribution network.

The load terminal is connected to the PCC through an external series inductance L_{ext} . V_{dc} is the voltage maintained across the each dc capacitor and u is a control variable which can be +1 or -1 depending upon switching state. If i_s , i_{ft} , and i_{fc} are currents through VSI, DSTATCOM, and C_{fc} respectively. V_s and V_t are source and load voltages respectively. Loads have both linear and nonlinear elements with balanced or unbalanced features. Load and source currents are represented by I and i respectively.

III. CONTROL STRATEGY

Control strategies of DSTATCOM can be classified as either current controlled or voltage controlled. In voltage control there is natural regulation of both voltage magnitude and v_{PCC} harmonics, nevertheless there is not natural current (i_{L_f}) limitation, decreasing converter robustness during transients. There are techniques to protect indirectly the converter against overloads but they need foreknowledge of grid's equivalent impedance or even they need insertion of extra series impedance between grid and converter. This paper prioritizes robustness of this application hence it uses current control, where even under large v_{PCC} variations L_f -inductor current (i_{L_f}) is kept limited by simply limiting current references. Harmonic-mitigation strategies can be classified as load current detection, source-current detection or voltage detection. This paper uses the voltage-detection method once MVQR is enabled to compensating voltage harmonics only near the source of harmonics, because this source may not be easily detected by a distribution company (see Fig1). This scenario turns the harmonic mitigation through current detection unfeasible. Harmonic mitigation using v_{PCC} detection can be implemented through emulation of resistances for harmonics, actively damping harmonics, but this method does not envisage complete elimination of harmonics. Emulation of tuned active filters was done by; however these filters can resonate with non-foreseen loads. With similar features to voltage controlled converters, but current controlled, there are solutions that use non-linear and adaptive techniques, but some of them have chattering

problem and they aggregate higher complexity comparing with linear techniques.

In this paper is not expected the compensation of non-periodic v_{PCC} distortions and those techniques do not become attractive. Harmonics can be mitigated using internal-model based controllers as resonant and repetitive structures, which are also applied in current control because of their good reference tracking and good rejection of periodic disturbances. This paper uses resonant controllers for harmonic compensation, acting only in chosen frequencies, not acting in zero and fundamental frequencies. The used control strategy is presented in Fig. 2, being similar to but differentiating by addition of harmonic loops and by consideration of parametric variation of grid's model in controller designs. The v_{PCC} sampling circuit has anti-alias filters (f_{aa}). For the generation of sinusoidal references, effective v_{PCC} values and i^*_h signals there are conventional types of digital analog signal converters (DAC) and types that use Pwm with high frequency filters f_{DA} . Sinusoidal references are provided by a Phase-Locked-Loop (PLL) scheme. Control was done using abc coordinates, facilitating controllers' designs for acting under unbalanced loads once they are simply replicated to the three loops. Current loops have high bandwidth (BW) (8 kHz), uses proportional-integral controllers and the three are identical. Current references i^*_{ref} are composed by four components:

TABLE I. MVQR SPECIFICATIONS

Parameter	Value
Nominal converter power	$S_{conv} = 30 \text{ kVA}$
Grid voltage	$V_{gd,ph} = 220 \text{ Vrms}$
dc-link total voltage	$V_{total} = 800 \text{ V}$
dc-link total capacitance	$C_B = C_b/2 = 7050 \text{ } \mu\text{F}$
Filter inductance	$L_f = 560 \text{ } \mu\text{H}$
Filter capacitance	$C_f = 47 \text{ } \mu\text{F}$
Current-sensor gain	$K_i = 0.068$
Voltage-sensor gain	$K_v = 0.01$
Triangular peak voltage	$V_t = 11 \text{ V}$
Grid frequency	$f_{gd} = 60 \text{ Hz}$
Switching frequency	$f_s = 20 \text{ kHz}$
Sampling frequency	$f_a = 20 \text{ kHz}$
Shunt resistance	$R_{shunt} = 1 \text{ k}\Omega$
L_f inductor series resistance	$r_{L_f} = 0.1 \text{ } \Omega$

i^*_{dc} Continuous component used in unbalance compensation of dc-link differential voltage ($V_{b+} - V_{b-}$).

i^*_{0} Direct component synchronized with v_{PCC} , where converter consumes needed active power for regulation of dc-link total voltage V_{total} .

i^*_{90} Quadrature component synchronized with v_{PCC} , which is needed for reactive power circulation between converter and grid, promoting v_{PCC} -magnitude regulation.

i^*_h Harmonic content, which are needed to complement non-linear load currents, hence reducing harmonic content echoed at v_{PCC} .

Harmonic controller is arranged using a sum of four resonant filters centered at 3rd, 5th, 7th and 9th harmonics, which concentrate large amount of harmonic energy. Controller C_{vh} receives the feedback from v_{PCC} and produces the harmonic-current reference (i_h^*) that mitigates harmonic voltages. Exclusively this controller was digitally implemented. V_{total} is controlled using a PI controller (C_{total}) with BW around 6 Hz, not responding to natural oscillations of V_{total} . C_{total} controller's signal I_0 is multiplied by the PLL component that is in phase with v_{PCC} , producing i_0^* . Differential dc-link voltage ($V_{dif} = V_{b+} - V_{b-}$) is controlled using a PI controller (C_{dif}) with 2 Hz BW, blocking signals which has grid's and upper frequencies. Controller C_{dif} produces the continuous-current reference i_{dc}^* . PCC-voltage effective value (v_{PCC_rms}) is controlled using a PI controller (C_{rms}) with around 1 Hz BW, cutting off signals with grid's frequency. C_{rms} controller's signal is multiplied by the PLL component in quadrature with v_{PCC} , producing i_{90}^* . MVQR parameters are presented in Table I. Once the design of the controllers C_{total} , C_{dif} and C_{rms} are very similar to those implemented in, they are not discussed. These controllers are presented in Table II.

TABLE II. CONTROLLERS C_{total} , C_{dif} AND C_{rms}

Controller	Transfer Function
$C_{total}(s)$	$-6 \frac{s/2\pi 6 + 1}{s^2/2\pi 60 + s}$
$C_{dif}(s)$	$3.3 \frac{s/2\pi 2 + 1}{s^2/2\pi 20 + s}$
$C_{rms}(s)$	$3100 \frac{s/2\pi 2 + 1}{s^2/2\pi 13 + s}$

A. Boundary Conditions

This paper was based in a branch of a real distribution grid. The branch is 277 meters long from the transformer

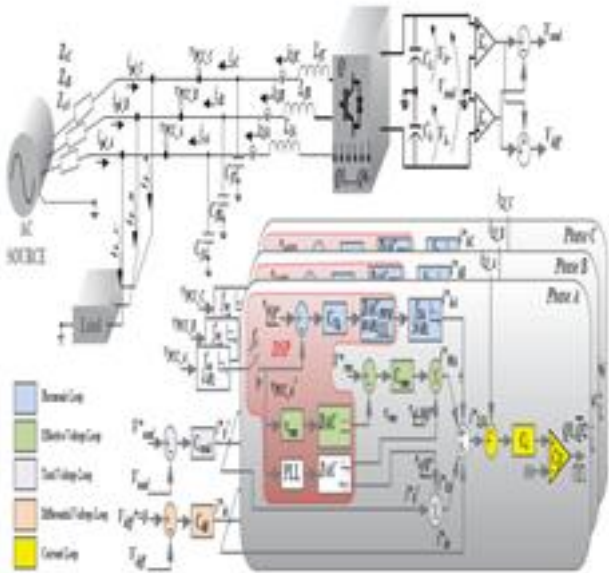


Fig2. General Diagram of control loops.

IV. RESULTS

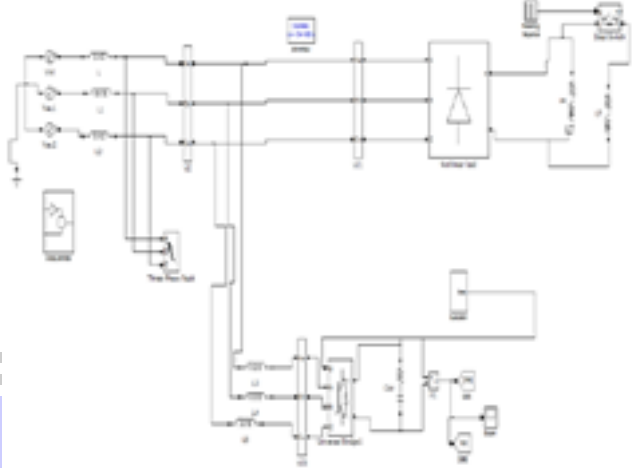


Fig3. Matlab/Simulink Model of Proposed DSTATCOM Topology for PQ Improvement Features

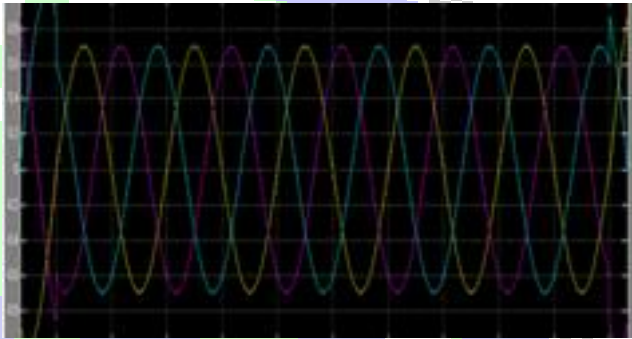


Fig4. Load Change of Phase a waveform before, during and after load change.

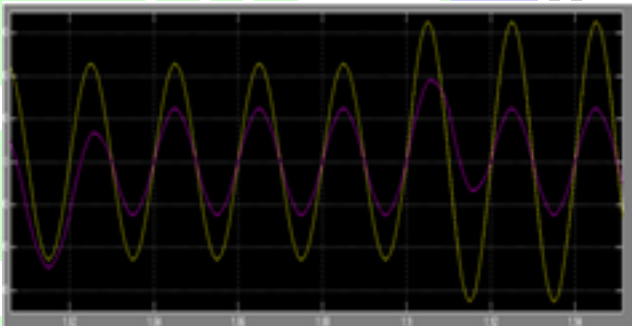


Fig5. Phase a waveform of source voltage and source current before and after Sag.

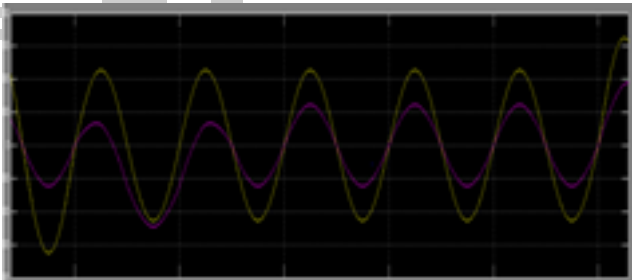


Fig6. Phase a waveform of source voltage and current before during and after load change.

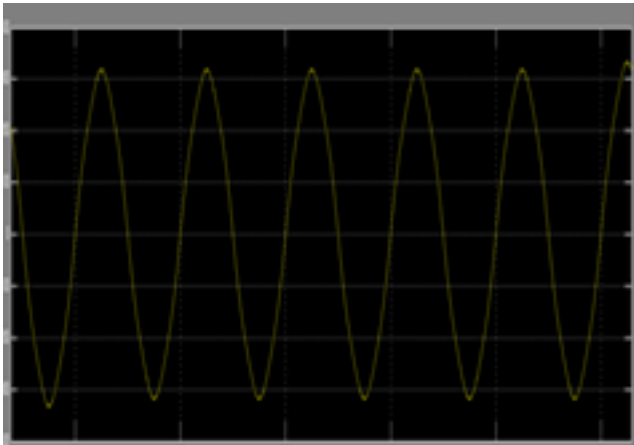


Fig7. Phase a waveform before & after during sag of load voltage.

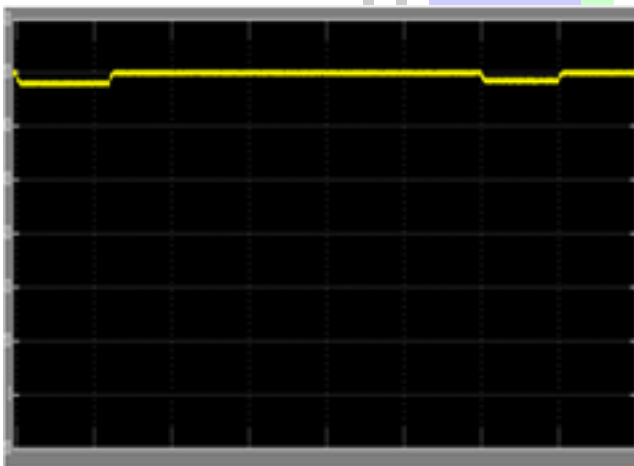


Fig8. Voltage Across DC Bus.

V. CONCLUSION

In this paper, a new converter topology has been proposed which has superior features over conventional topologies in terms of the required power switches and isolated dc supplies, control requirements, cost, and reliability with a new control algorithm based multifunctional DSTATCOM is proposed to protect the load from voltage disturbances under stiff source. It has been achieved by placing an external series inductance of suitable value between the source and the load. In addition, instantaneous reference voltage is controlled in such a way that the source currents are indirectly controlled and advantages of CCM operation are achieved while operating in VCM for permissible range of source voltage. Moreover protects the Induction machine drive through DSTATCOM under power quality concerns with near to optimal features with efficient operation.

VI. REFERENCES

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