International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 5, Issue 6 (month 2017), PP. 62-66

PERFORMANCE OF DISTRIBUTION STATIC COMPENSATOR IN LOW VOLTAGE DISTRIBUTION SYSTEM

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Abstract—**Distribution Static Compensator (DSTATCOM) is a device which can be used for compensation of harmonics present in source currents in distribution network. The performance and usefulness of DSTATCOM is examined for linear and non-linear load with source being non-stiff (weak). The presence of non-stiff source makes source currents and voltage at point of common coupling (PCC) unbalanced as well as disturbed. In this paper, a voltage source converter (VSC) based DSTATCOM is employed to eliminate above mentioned issues. For reference current generation of DSTATCOM, instantaneous symmetrical component theory (ISCT) method has been used. The distribution network is simulated with MATLAB / SIMULINK software and results are presented.**

Index Terms— **DSTATCOM, Non-stiff source, instantaneous symmetrical component theory, total harmonic distortion (THD).**

I. INTRODUCTION

Generation, transmission and distribution are the three stages of an electrical power system. The distribution system is the last stage of an electrical system in which power must be delivered to each consumer premises. Hence, quality of power mostly depends upon the state of distribution system. This is the reason why power quality (PQ) of distribution network is getting more attention now days [1]. The PQ issues can be eliminated in many fashions [2]-[4]. The DSTATCOM is nothing but newly developed distribution level STATCOM with different control algorithms used to improve PQ in low voltage distribution systems [5]-[7].

A DSTATCOM is shunt compensation type custom power device (CPD) used to eliminate PQ issues by injecting current into system at a point of common coupling (PCC). In this paper, the source is termed as 'non-stiff' source since the load is supplied by the feeder impedance because in practice load is remote distribution substation. The presence of non-stiff source makes source currents and PCC voltages unbalanced and disturbed [8].

The performance of DSTATCOM is verified for compensation of unbalanced and non-linear loads [9]. Various control methods are reported to exhibit the behavior of DSTATCOM [10]. It has also been observed that the voltage regulation and power compensation capability of DSTATCOM depends upon DC-link voltage rating [11].

The paper comprises of a three-phase, four-wire distribution system employed with DSTATCOM. The DSTATCOM uses three-legged VSC and two capacitors. The neutral of distribution system is connected between the two capacitors. This configuration is called as neutral clamped split capacitor arrangement. The performance of DSTATCOM and its control technique in distribution network is verified through simulation by using MATLAB / SIMULINK software.

This paper is arranged in following manner: (i) An overview of distribution system with DSTATCOM in section II, (ii) design of VSC in section III, (iii) control method for DSTATCOM in section IV and (iv) simulation of distribution system with and without DSTATCOM.

II. DISTRIBUTION SYSTEM WITH DSTATCOM

In this section, the equivalent circuit diagram of three-phase, four-wire distribution system with DSTATCOM is shown in Fig. 1. In this figure, V_{s_a}, V_{s_b} and V_{s_c} are the source voltages of phases a, b and c, respectively. Similarly, I_{s_a}, I_{s_b} and I_{s_c} are source currents in phases a, b and c, respectively. V_{ta}, V_{tb} and V_{tc} are the terminal voltages of phases a, b and c, respectively. The current in neutral leg is indicated by I_n. The load is comprised of both linear and non-linear load which may be balanced or imbalanced. L_f and R_f are interfacing inductance and resistance of filter respectively. The DC-link capacitors are termed as C_{dc1} (upper) and C_{dc2} (lower) whereas their respective voltages are maintained at V_{dc1} and V_{dc2}.

For better performance and effectiveness of DSTATCOM, the components of VSC are needed to be designed carefully. The complete design procedure for VSC is explained in next section.

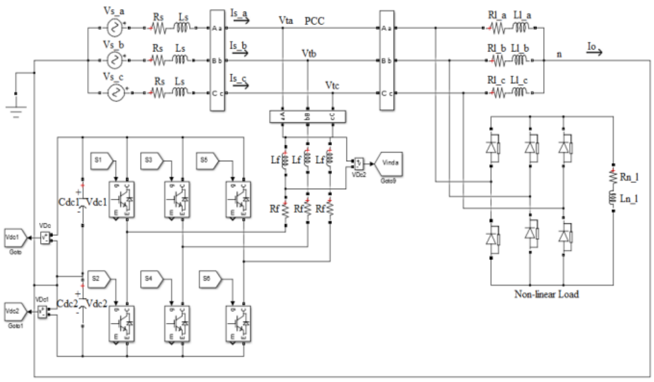


Fig.1: Schematic diagram of distribution system with DSTATCOM

III. DESIGN OF VSC FOR DSTATCOM

The parameters that need to be designed carefully for better performance of DSTATCOM are DC-link voltage (V_{dc}), DC-link capacitor (C_{dc}), interfacing inductance (L_f) and switching frequency (f_{sw}). The procedure to design these parameters is explained as follows:

A. Selection of DC-link voltage (V_{dc}):

For good tracking performance, V_{dc} need to be designed properly. In [12], it is observed that for neutral clamped split capacitor arrangement the reference DC-link voltage should be between 1.6 and 2 times of peak source voltage. In this paper the DC-link voltage is taken as 1.6 times peak value of system voltage (V_m). Hence, the DC-link voltage which is to be maintained across DC-link capacitor is calculated as:

$$V_{dc} = 1.6 * V_m = 1.6 * \sqrt{2} * 230 = 520\ V \qquad (1)$$

B. Selection of DC-link capacitor (C_{dc}):

The selection of DC-link capacitor is next important step once the DC-link voltage is obtained. Instantaneous energy during transient period available across DSTATCOM is one of the factors for deciding the value of DC-link capacitor. It is chosen as [13]:

$$C_{dc} = \frac{2(2K - K/2)nT}{(1.8V_m)^2 - (1.4V_m)^2} \qquad (2)$$

Where, K = KVA rating of the system
V_m = Peak value of source phase voltage
n = Number of cycles
T = Time period of each cycles.

Substituting the values of, $V_m = \sqrt{2} \times 230$ V, K = 15 kVA, n= 0.5 and T = 0.02 sec in equation (2)., C_{dc} is calculated as 3322 µF. In simulation studies, C_{dc} is taken as 3300 µF.

C. Selection o interfacing inductance (L_f):

For tracking of reference currents, the interfacing inductance is selected from a trade-off which provides higher switching frequency and sufficient rate of change of filter current. The interfacing inductance is given by,

$$L_f = \frac{1.6\ V_m}{4\ h\ f_{swm}} \qquad (3)$$

Where, h = hysteresis band

Maximum switching frequency (f_{swm}) of IGBT is around 20 kHz. In this paper it is assumed to be 10 kHz and h=0.5. L_f is calculated to be 26mH.

IV. REFERENCE CURRENT GENERATION FOR DSTATCOM

The main aim of a particular control method is to generate reference currents required for DSTATCOM. The control strategy required for the DSTATCOM mainly includes: (i) reference current extraction method and (ii) control of extracted currents. In this paper, the reference currents for DSTATCOM are generated using instantaneous symmetrical component theory (ISCT) and the control of extracted currents is done through hysteresis band current controller (HBCC) [14], [15].

A. Instantaneous symmetrical component theory (ISCT):

The block diagram of ISCT control method is shown in Fig. 2. The three-phase reference currents calculated for DSTATCOM with ISCT method are given as follows:

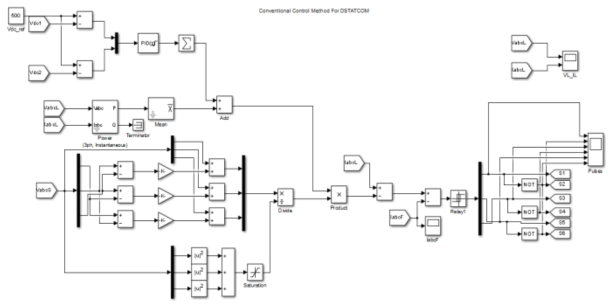


Fig.2: Instantaneous symmetrical component theory

$$I_{filter\_a}^{*} = I_{L\_a} - I_{s\_a}$$
$$= I_{L\_a} - \frac{V_{ta_1}{}^{+} + \alpha\left(V_{tb_1}{}^{+} - V_{tc_1}{}^{+}\right)}{\left(V_{ta_1}{}^{+}\right)^2 + \left(V_{tb_1}{}^{+}\right)^2 + \left(V_{tc_1}{}^{+}\right)^2}\left(P_{avgl} + P_{swloss}\right)$$
$$I_{filter\_b}^{*} = I_{L\_b} - I_{s\_b}$$
$$= I_{L\_b} - \frac{V_{tb_1}{}^{+} + \alpha\left(V_{tc_1}{}^{+} - V_{ta_1}{}^{+}\right)}{\left(V_{ta_1}{}^{+}\right)^2 + \left(V_{tb_1}{}^{+}\right)^2 + \left(V_{tc_1}{}^{+}\right)^2}\left(P_{avgl} + P_{swloss}\right)$$
$$I_{filter\_c}^{*} = I_{L\_c} - I_{s\_c}$$
$$= I_{L\_c} - \frac{V_{tc_1}{}^{+} + \alpha\left(V_{ta_1}{}^{+} - V_{tb_1}{}^{+}\right)}{\left(V_{ta_1}{}^{+}\right)^2 + \left(V_{tb_1}{}^{+}\right)^2 + \left(V_{tc_1}{}^{+}\right)^2}\left(P_{avgl} + P_{swloss}\right)$$
(3)

P_{avgl} = load average power.
P_{swloss} = Switching losses in compensator
And,

$$\alpha = \tan\left(\frac{\mu}{\sqrt{3}}\right)$$

In the presence of non-stiff source, PCC voltages get distorted and unbalanced. Basically, it is not possible to draw sinusoidal currents with this compensation technique if these voltages are unbalanced and distorted. Hence, by extracting fundamental positive sequence PCC voltages as shown in equation (3), this limitation overcomes.

B. Hysteresis Band Current Controller (HBCC):

To control the reference currents the three-phase generated currents are given to the hysteresis band current controller. The switching commands for IGBTs are generated with HBCC by comparing the actual source currents with the generated reference current by the respective control algorithm. The switching logic for VSC is generated as follows:

$$u = hys\left[-K\{y - y_{ref}\}\right] \quad (4)$$

Where, u has values ±1 depending upon inverter switching and the hysteresis function 'hys' is defined by,

If h ≥ + 0.5 then hys (h) = −1, lower switch is turned ON whereas the upper switch is turned OFF.

If h ≤ - 0.5 then hys (h) =1, upper switch is turned ON whereas the lower switch is turned OFF.

The switching devices are turned ON and OFF in a complementary manner. HBCC is the fastest control method and its implementation is very simple. But, the switching frequency of converter depends upon ac voltage. This is the main drawback of this method.

V. SIMULATION RESULTS AND DISCUSSION

Simulation studies are carried out to validate the performance of DSTATCOM in distribution system. The simulation study is divided into two sections: (i) distribution system without DSTATCOM and (ii) distribution system with DSTATCOM.

A. Distribution system without DSTATCOM:

The performance of low voltage distribution system is verified with linear and non-linear load. The system parameters for simulation study of distribution system are given table I. The simulation of distribution system without DSTATCOM is shown in Fig.3.

In presence of non-linear load and feeder impedance, source currents and terminal voltages get disturbed and become non-sinusoidal. Fig. 4 (a) and Fig. 4 (b) shows uncompensated terminal voltage and source current respectively.

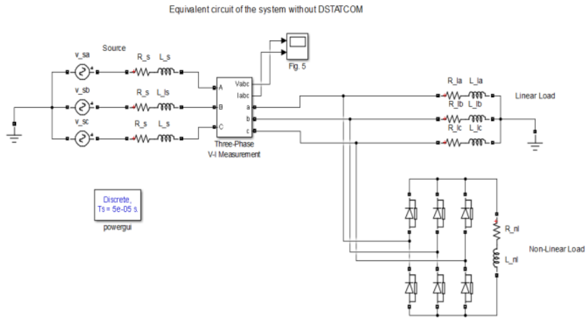
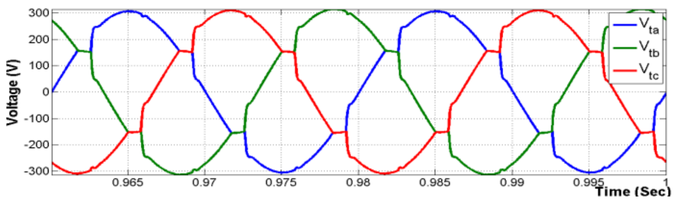


Fig.3: Simulation of distribution system without DSTATCOM

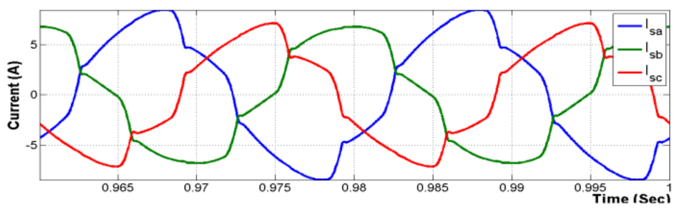
TABLE I

SYSTEM PARAMETERS FOR DISTRIBUTION SYSTEM

Sr. No.	**Parameters**		**Values**
1.	Grid Parameters	Supply Voltage	Vs = 230v, 50 Hz
		Feeder Impedance	Z_s= 1+ j 3.141 Ω
2.	Load Parameters	Linear Load	Z_{l_a} =34+ j 47.5 Ω Z_{l_b} 814+ j 39.6 Ω Z_{l_c} =31.5+ j 70.9 Ω
		Non-linear Load	3-Ø Full Bridge Rectifier Load with R_{n_l}=150 Ω & L_{n_l}=300mH



(a)



(b)

Fig. 4: (a) Uncompensated terminal voltages (b) Uncompensated load currents

B. Distribution system with DSTATCOM

To provide compensation in distribution network, DSTATCOM is used as shown in Fig. 5. The system parameters required for simulation study are listed in table II.

TABLE II

SYSTEM PARAMETERS FOR DISTRIBUTION SYSTEM WITH DSTATCOM

Sr. No.	Parameters	Values
1.	VSC Parameters	V_m= 520 V C_{dc}= 3300 µF V_{dc}=520 V L_f = 26 mH, R_f = 0.1Ω
2.	Voltage controller (PI) gains	K_p=2, K_i=0.5
3.	Hysteresis Band	h= ±0.5

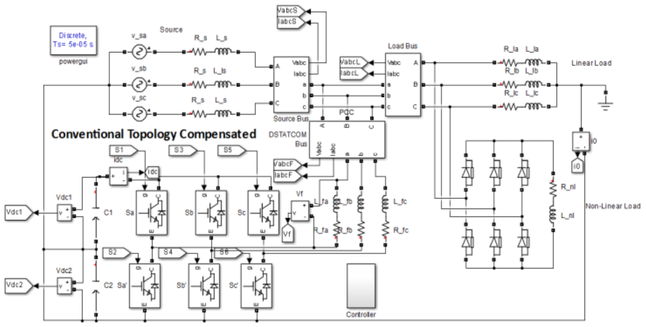
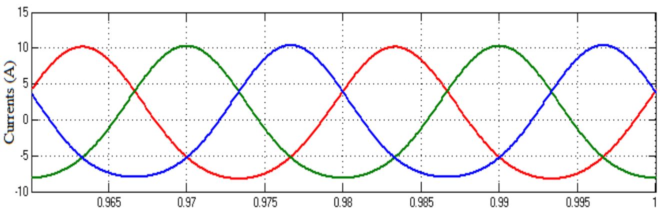


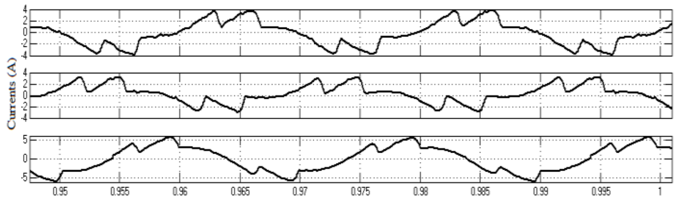
Fig.5: Simulation of distribution system with DSTATCOM

Simulation results of distribution system with DSTACOM are depicted in Fig. 6. Fig. 6 (a) and Fig. 6 (b) depicts the source currents and filter currents after compensation respectively. Voltage across each capacitor is maintained at 520 V as calculated from equation (1). It is portrayed in Fig. 6 (c). The terminal (PCC) voltages are shown in Fig. 6 (d).

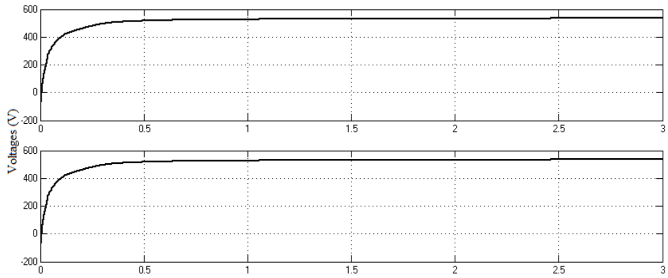
From Fig. 6 it can be observed that after compensation of distribution system with DSTATCOM, the source currents and terminal voltages are sinusoidal and balanced. But is has components of inverter switching. A summary of THD values of source currents and terminal voltages before and after compensation are listed in table III.



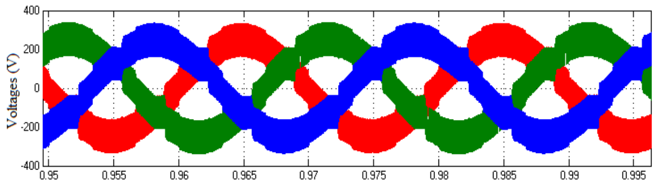
(a)



(b)



(c)



(d)

Fig. 6: (a) Source currents after compensation (b) Filter currents after compensation (c) DC-link capacitor voltage (d) Terminal voltages after compensation

TABLE III

THD OF TERMINAL VOLTAGES AND SOURCE CURRENTS

Sr. No.	Parameters	% THD	
		Without DSTATCOM	**With DSTATCOM**
1.	V_{ta}	7.49	3.61
2.	V_{tb}	7.2	4.51
3.	V_{tc}	7.49	3.46
4.	I_{s_a}	11.11	1.52
5.	I_{s_b}	12.48	1.67
6.	I_{s_c}	13.64	1.97

VI. CONCLUSION

The performance and usefulness of DSTATCOM with ISCT control method is demonstrated for low voltage distribution system in this paper. The design procedure for components of VSC is explained in detail. The comparative study of distribution system with and without DSTATCOM has been made. The results indicate that DSTATCOM in low voltage distribution system provides better compensation at PCC as well as the THD values of source currents and terminal voltages are reduced.

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