A power quality Improvement of Mitigating Neutral current for VSC Based DSTATCOM Using TIES

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ABSTRACT

Three-Phase four-wire distribution systems are facing severe power quality problems such as poor voltage regulation, high reactive power and harmonics current burden, load unbalancing, excessive neutral current, etc.This creates excessive neutral current both of fundamental and harmonic frequency and the neutral conductor gets overloaded. By integrating phase shifting into an extremely low zero phase sequence impedance transformer with single or multiple outputs, substantial reduction of triplen, 5th and 7th harmonics can be achieved. In this Paper the different TIES (Transformer connection) mitigate the neutral current and the VSC compensates Harmonic current, reactive power, and balances the load. TIES configuration for interfacing to a three-phase four-wire power distribution system and the required rating of the VSC is reduced. The insulated gate bipolar transistor (IGBT) based VSC is supported by a capacitor and is controlled for the required compensation of the load current. The DSTATCOM is validated using MATLAB software with its simulink and power system block set toolboxes.

Keywords **-** *Distribution Static Compensator (DSTATCOM), neutral current compensation, power quality improvement-connected transformer, voltage source converter (VSC),harmonic eimination.*

I. INTRODUCTION

Traditional electrical system design had very little need to deal with harmonics because the loads typically designed for were linear in nature [7]. Over the years, as more and more research and practical experience was gathered with linear loads, the design process became more and more predictable. Because in many cases a major portion of the loads today are nonlinear in nature, the loading due to harmonics created by these loads must also be taken into consideration.The synchronous reference theory is used for the control of the proposed DSTATCOM. The DSTATCOM is validated using MATLAB software with its simulink and Power system block set toolboxes for power factor correction, voltage regulation along with neutral current compensation, harmonic elimination, and load balancing with linear loads as well as non linear loads

II. SYSTEM CONFIGURATION AND DESIGN

Fig. 1(a) shows the single-line diagram of the shunt-connected DSTATCOM-based distribution system. The dc capacitor connected at the dc bus of the converter acts as an energy buffer and establishes a dc voltage for the normal operation of the DSTATCOM system. The DSTATCOM can be operated for reactive power compensation for power factor correction or voltage regulation.Fig. 1(b) shows the phasor diagram for the unity power factor operation.

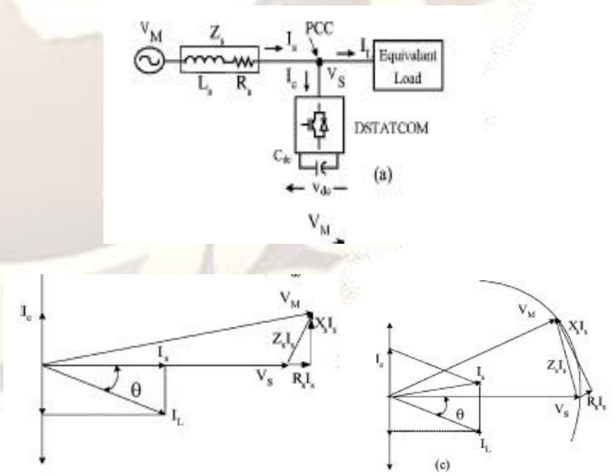

Fig 1(a) single-line diagram of the shunt-connected DSTATCOM (b) Phasor diagram for UPF operation. (c) ZVR operation.

The DSTATCOM injects a current *Ic* such that the source current is only *Is* , and this is in-phase with voltage.The voltage regulation operation of DSTATCOM is depicted in the phasor diagram of Fig. 1(b). The DSTATCOM injects a current *Ic* such that the voltage at the load (*VS*) is equal to the source voltage (*VM*).The Schematics of the proposed three-leg VSC with different TIES (connected transformers) based DSTATCOM connected in distribution system is figured out in fig.2,fig.3,fig.4.

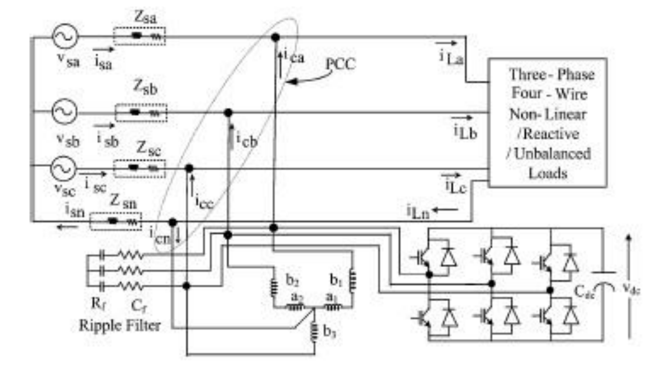

Fig. 2. Schematics of the proposed three-leg VSC with T-connected transformer- based DSTATCOM connected in distribution system.

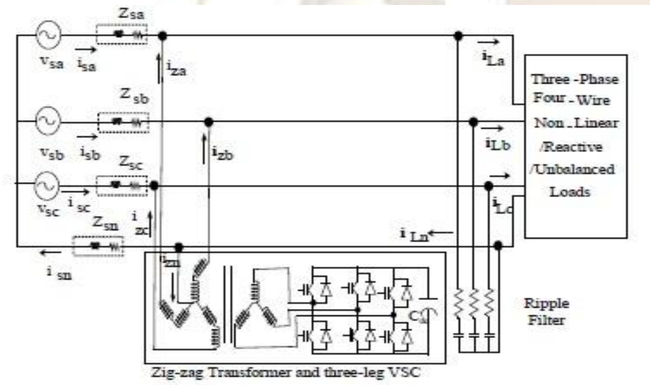

Fig.3. Schematics of proposed Integrated VSC with zig-zag
transformer based DSTATCOM connected distribution system.

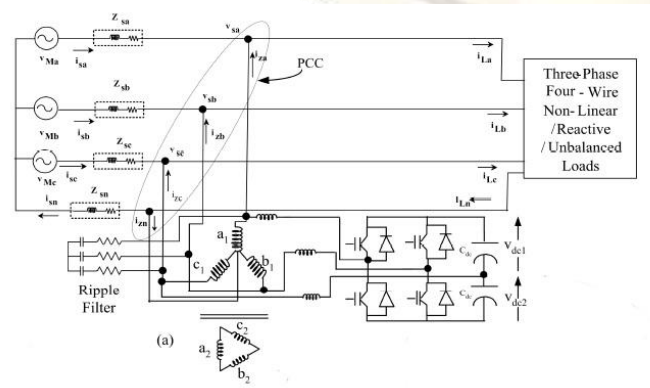

Fig.4 Schematics of proposed VSC with star/delta transformer based DSTATCOM.

The proposed DSTATCOM consisting of a VSC and different TIE connected transformers is shown in Fig. 2,3,4 where the TIE connected transformer is responsible for neutral current compensation. The windings of the T-connected transformer are designed such that the mmf is balanced properly in the transformer.

The selection of interfacing inductor, dc capacitor, and the ripple filter are done according their specifications [1].

III. DESIGN OF TIES

T-connected Transformer:

The connection of two single-phase transformers In T-configuration for interfacing with a three-phase four-wire system. The T-connected windings of the transformer not only provide a path for the zero-sequence fundamental current and harmonic currents but also offer a path for the neutral current when connected in shunt at point of common coupling (PCC). Under unbalanced load, the zero-sequence load-neutral current divides equally into three currents and takes a path through the T-connected windings of the transformer. The current rating of the windings is decided by the required neutral current compensation. The voltages across each winding are designed using the phasor diagram shown in Fig. 5.2 gives the following relations to find the turn's ratio of windings. If Va1 and Vb1 are the voltages across each winding and Va is the resultant voltage, then

Va1 = K1Va ----------- (1)
Va2 = K2va ----------- (2)

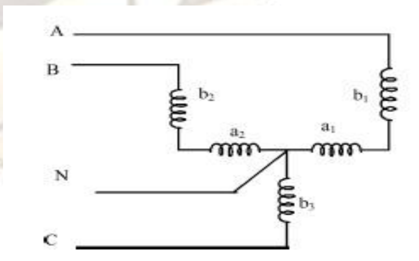

Fig 5.1 T-connected transformer and the VSC

Where *K*1 and *K*2 are the fractions of winding in the phases. Considering |*Va* | = |*Vb* | = *V* and *Va*1 = *Va* cos 30, *Vb*1 = *Va* sin 30.

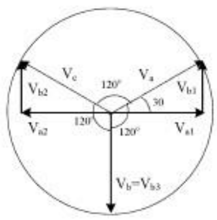

Fig.5.2 Phasor diagram

Zig-zag Transformer:

A Zigzag transformer is a special purpose transformer with a zigzag arrangement. It has primary windings but no secondary winding. One application is to derive an earth reference point for an ungrounded electrical system. Another is to control harmonic currents. The application of a zig-zag transformer for the reduction of neutral current is advantageous due to passive compensation, Rugged, and less complex over the active compensation techniques. A zig-zag transformer is a special connection of three single-phase transformer windings or three-phase transformers Windings. The zig-zag transformer in the past has been used to create neutral and to convert a three-phase three-wire system into a three-phase four-wire system. The new application of a zig-zag transformer is to connect in parallel to the load for filtering the zero-sequence components of the load currents. The phasor diagram of the zig-zag transformer is shown in Fig. 5.3. The currents flowing through the utility side of these three transformers are equal. Hence, the zig-zag transformer can be regarded as open-circuit for the positive-sequence and the negative-sequence currents. Then, the current flowing through the zig-zag transformer is only the zero-sequence component. An application of a zig-zag transformer alone in a three-phase, four-wire system has the advantages of reduction in load unbalance and reducing the neutral current on the source side. But there are inherent disadvantages such as the performance being dependent on the location of the zig-zag transformer close to the load. Moreover, when the source voltage is distorted or unbalanced, the performance of reducing the neutral current on the source side is affected to an extent. The Phasor Daigram of zigzag transformer [2] [8] and circuit connection for neutral current compensation are given below.

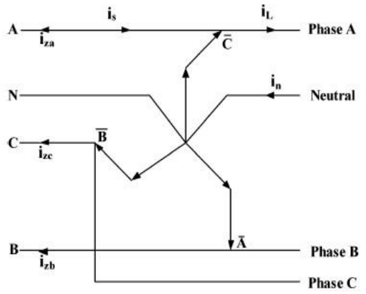

Fig.5.3 Diagram showing the flow of currents of zig-zag transformer for neutral current compensation.

Star-delta transformer:

Such connections are used principally where the voltage is to be stepped down, as for example, at the end of a transmission line. The neutral of the primary winding is earthed. In this system, line voltage ratio is 1/√3 Times of transformer turn-ratio and secondary voltage lags behind primary voltage by 30°. Also third harmonic currents flow in the to give a sinusoidal flux. The connection of the star/delta transformer [3] is shown in Fig.5.4 and Fig.5.5 shows the phasor diagram of the voltages. The current Io is the circulating current in the case of any zero sequence current in the load. The current rating of the transformer windings is based on this circulating current and the compensation current to be provided by the VSC. The primary winding voltage is

$$Va = VLL/3 \text{ --------- } (1)$$

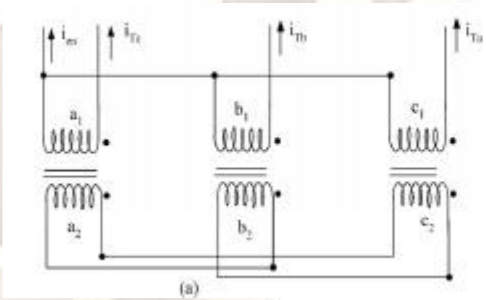

Fig. 5.4. Star/delta transformer windings

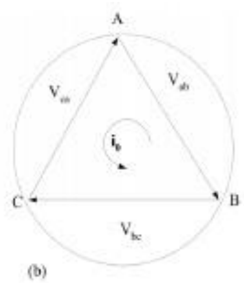

Fig.5.5.Phasor diagram.

The secondary line voltage is chosen for the same current to flow in the windings. The voltage ratio of the transformer is 1:1.

Transfo-rmer	winding Voltage (V)	winding Current (A)	kVA	Number of Transformers	Total kVA
Zig-zag	140/140	10	1.4	3 Nos	4.2
Star/ Delta	240/240	10	2.4	3 Nos	7.2
T-connected	240/120/120 208/208	10	2.4 2.08	1 Nos 1Nos	4.48

Table 1. Comparison of rating of transformer connections for neutral current compensation.

IV. CONTROL OF DSTATCOM

The control approaches available for the generation of reference source currents for the control of VSC of DSTATCOM for three-phase four-wire system are instantaneous reactive power theory (IRPT), synchronous reference frame theory (SRFT). The reference current are drawn through SRF Theory in this paper. From here the transformation can be made to obtain three phase reference currents in a-b-c coordinates using

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \text{--- (1)}$$

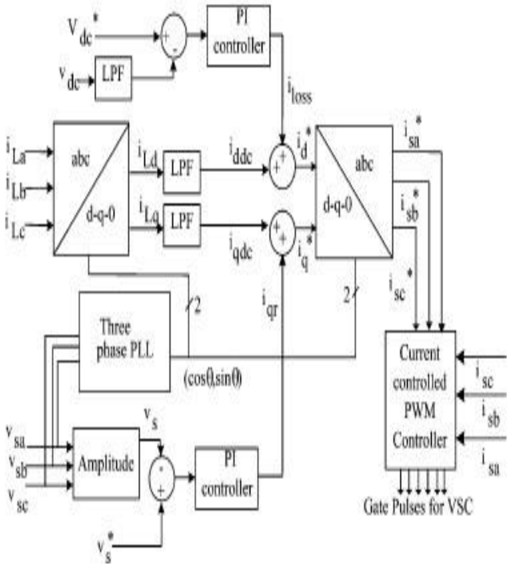

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Fig.6 Control algorithm for the VSC-based DSTATCOM in a three phase four-wire system.

The UPF operation,ZVR operations,Current controlled PWM techniques are explained in [1] [11].

V. SIMULATIONS AND RESULTS

Simulation studies are carried out to analyze the performance of Voltage source converter based DSTATCOM with various TIES for neutral current compensation, voltage regulation, power factor correction conditions in a distribution system. Here we consider a distribution line with a source voltage of 415v, 50 Hz. The TIES mitigates the Excess neutral current problem by specific design.

The Test System Parameters:

Line impedance	Rs = 0.01 Ω, Ls = 2 mH
Loads	1) linear: 20 kVA, 0.80 pF lag 2) Nonlinear: Three single-phase bridge rectifiers with R = 25 Ω and C = 470 μF
Ripple filter	Rf = 5 Ω, Cf = 5 μF
DC bus voltage of DSTATCOM	700 V
DC bus capacitance of DSTATCOM	3000 μF
AC inductor	2.5 mH
DC voltage PI	Kpd = 0.19, Kid = 6.25
PCC voltage PI controller	Kpq = 0.9, Kiq = 7.5
AC line voltage	415 V, 50 Hz
PWM switching frequency	10 kHz
T-connected transformer	Two single-phase transformers of rating 5 kVA, 240 V/120 V/120 V and 5 kVA, 208 V/208 V.
Zig-zag and star-delta transformer	Zig-zag transformer: three numbers of single-phase transformers of 5 kVA, 150/150 V. Star-delta transformer: Three single-phase transformers of rating 2.4kVA, 240V/240V.

1.) MATLAB model of the T-connected transformer and the VSC-based DSTATCOM connected system.

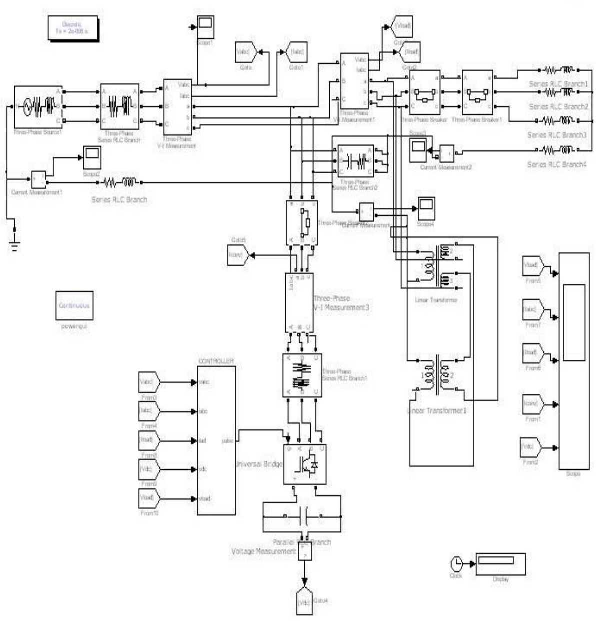


Fig 7.1 MATLAB model of the T-connected transformer and the VSC-based DSTATCOM connected system.

Result:

Fig.7.2 Neutral current compensation for T-connected transformer DSTATCOM-connected system.

In fig.7.2 graph between source neutral current (In) and time in sec is observed. The source neutral current shown in the fig.7.2 is observed as nearly zero, and this verifies the Proper compensation. Thus the neutral current compensation is done.

Fig.7.3 MATLAB model of the three-phase four wire DSTATCOM and zig-zag transformer for neutral current compensation.

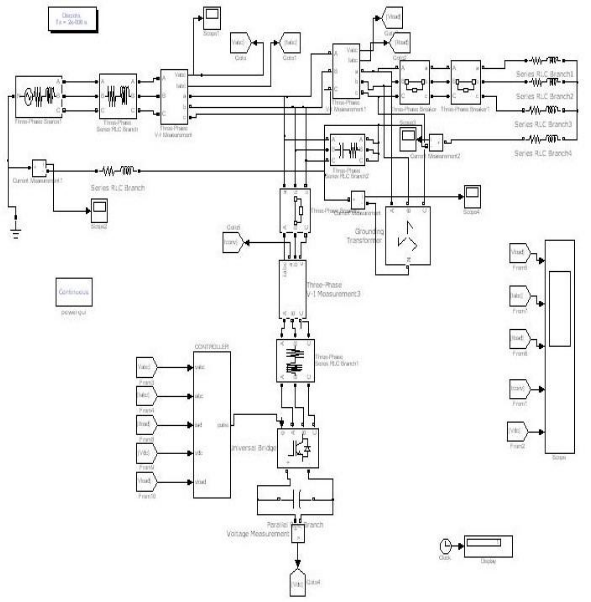


Fig 7.4.MATLAB model of the three-phase four wire DSTATCOM and zig-zag transformer for neutral current compensation.

Result :

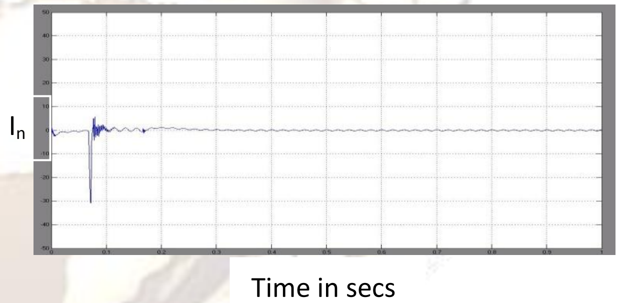


Fig.7.4 Neutral current compensation for zig-zag transformer and the VSC-based DSTATCOM-connected system.

In fig.7.4 graph between source neutral current(In) and time in sec is observed .The source neutral current shown in the fig.7.4 is observed as nearly zero, and this verifies the Proper compensation. Thus the neutral current compensation is done. The zig-zag transformer provides a low impedance path for the zero-sequence currents and, hence, offers a path for the neutral current when connected in shunt and, hence, attenuates the neutral current on the source side. When a zig-zag transformer is used alone as a neutral current compensator, the rating of the zig-zag transformer depends on the amount of imbalance and harmonic content.

Fig.7.5 MATLAB model of the three-phase four wire DSTATCOM and star-delta transformer for neutral current compensation.

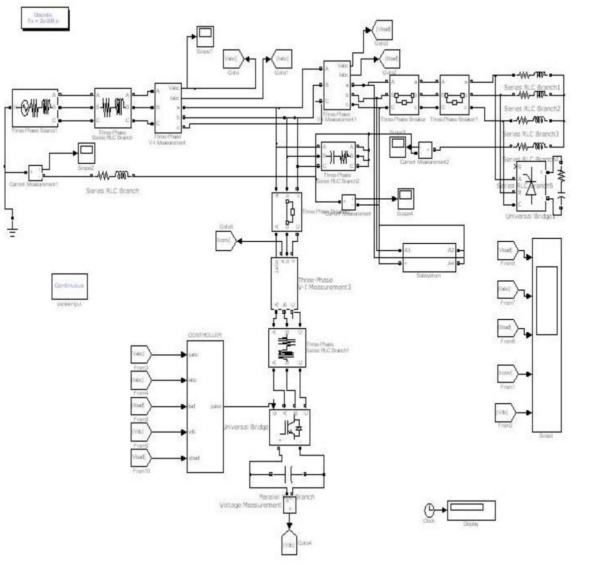


Fig 7.5. MATLAB model of the three-phase four wire DSTATCOM and star-delta transformer for neutral current compensation.

Result :

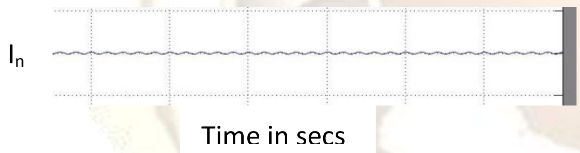
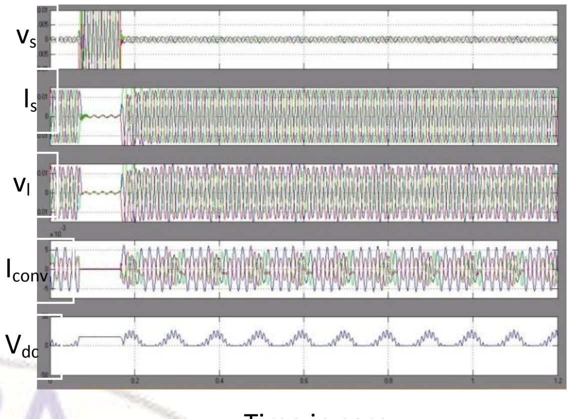


Fig.7.6. Neutral current compensation for star-delta transformer and the VSC-based DSTATCOM-connected system.

In fig.7.6 graph between source neutral current(In) and time in sec is observed. The source neutral current shown in the fig.7.6 is observed as nearly zero, and this verifies the Proper compensation. Thus the neutral current compensation is done.The Performance of VSC based DSTATCOM for one of the TIE Connection is below figure.



The PCC voltages (v_s), source currents (i_s), load currents (i_L), compensator currents (iC), source neutral current (iSn), load-neutral current (iLn), compensator neutral current (iCn), dc bus voltage (vdc), and amplitude of voltage (VS) at PCC of non-linear loads for T-connected VSC based DSTATCOM are depicted at above graph between source voltage, source current, load current, compensator current and dc voltage and time in sec is observed. The dynamic performance of the DSTATCOM with nonlinear and unbalanced load is given in above figure. It is observed that the source currents are balanced and sinusoidal. At 0.8 s, the load is changed to two-phase load and to single-phase load at 0.9 s. The loads are applied again at 1.0 and 1.1 s, respectively. The source currents are still balanced and sinusoidal even when the load current in a phase is zero. This shows the Current balance and proper compensation has done. The dc bus voltage of DSTATCOM is maintained at nearly its reference value under all load disturbances.

VI. CONCLUSION:

The performance of a new topology of three-phase four-wire DSTATCOM consisting of VSC with a TIE connected transformers has been demonstrated for neutral current compensation along with reactive power compensation, harmonic elimination, and load balancing. The transformer TIE connection has mitigated the source-neutral current. The voltage regulation and power factor correction modes of operation of the DSTATCOM have been observed and are as expected. The dc bus voltage of the DSTATCOM has been regulated to the reference dc bus voltage under all varying loads. The total kilovolt amperes rating of the T-connected transformer is lower than a star/delta transformer for a given neutral current compensation. The experimental results on a prototype have verified that the T-connected transformer has been effective in compensating the zero sequence fundamental and harmonics currents.

VII. REFERENCES

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