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A T, Star-Delta and Zigzag Connected Transformer Connections of 5-Level and 7-Level VSC Based DSTATCOM for Power Quality Improvement

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Abstract: In this paper, a new three-phase four-wire Distribution Static Compensator (DSTATCOM) based on a T-connected transformer and a three-leg Voltage Source Converter (VSC) is proposed for power quality improvement. The T-connected transformer connection mitigates the neutral current and the three-leg VSC compensates harmonic current, reactive power, and balances the load. Two single-phase transformers are connected in T-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 DC bus voltage of the VSC is regulated during varying load conditions. The DSTATCOM is tested for power factor correction and voltage regulation along with neutral current compensation, harmonic elimination, and balancing of linear loads as well as nonlinear loads. The performance of the three-phase four-wire DSTATCOM is validated using MATLAB software with its Simulink and power system block set toolboxes.

Keywords: D-STATCOM, Harmonics, Inverter Transformer, Power Quality.

I. INTRODUCTION

D-STATCOM is a solid state, three phase inverter-based power controller which is connected in shunt to a distribution feeder through a coupling transfer that matches the inverter ac output voltage to the distribution system voltage [1]. Thus, D-STATCOM is used to protect the distribution system from power quality disturbances [2]. The main components of the D-STATCOM are the inverter using either GTO or IGBT, dc capacitor, coupling transformer and control system [3]. It can be regarded as an active energy exchanging device because it utilizes the passive energy storage component to realize the energy storing and exchanging and the switches to control the reactive power flow between different phases of a distribution system [4-6].The reactive power provided by the D-STATCOM is either capacitive or inductive depending on whether the magnitude of the D-STATCOM output voltage is larger or smaller than the magnitude of the system voltage [7]. In recent years, D-STATCOM has been extensively studied in which many papers in the literature have discussed its theory, modeling, control and applications (4,8-10). The conventional D-STATCOM is controlled at low switching fundamental frequency of the inverter based on the control of the phase angle of the fundamental switching pattern [11]. In recent years Electrical Power Quality had obtained more attention in power engineering. In present day's power distribution systems is suffering from severe power quality problems. These power quality problems include high reactive power burden, harmonics currents, load unbalance, excessive neutral current etc.

II. PROPOSED SYSTEM

Instantaneous real-power theory based cascaded multilevel inverter based DSTATCOM is connected in the distribution network at the PCC through filter inductances and operates in a closed loop. The DSTATCOM system contains a cascaded inverter, RL-filters, a compensation controller (instantaneous real-power theory) and switching signal generator (proposed triangular-sampling current modulator) as shown in the Figure 1. The three-phase supply source connected with non-linear load and these nonlinear loads currents contains fundamental and harmonic components. If the active power filter provides the total reactive and harmonic power, is (t) will be in phase with the utility voltage and would be sinusoidal. At this time, the active filter must provide the compensation current therefore; active power filter estimates the fundamental components and compensating the harmonic current and reactive power.

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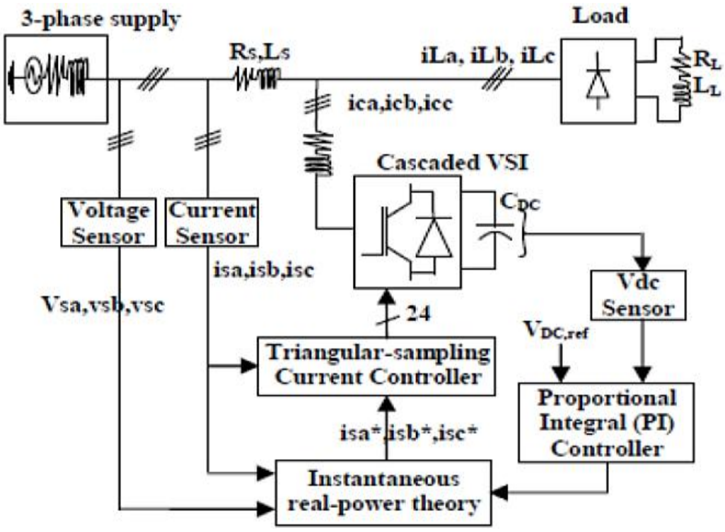

Fig 1: Schematic diagram of DSTATCOM

III. DESIGN OF THE T-CONNECTED TRANSFORMER

The figure shows the connection of two single-phase transformers in T-configuration for interfacing with three-phase four-wire system. The T- connected transformer not only provides a path for the zero-sequence fundamental current and harmonic current when connected in shunt at Point of Common Coupling (PCC).

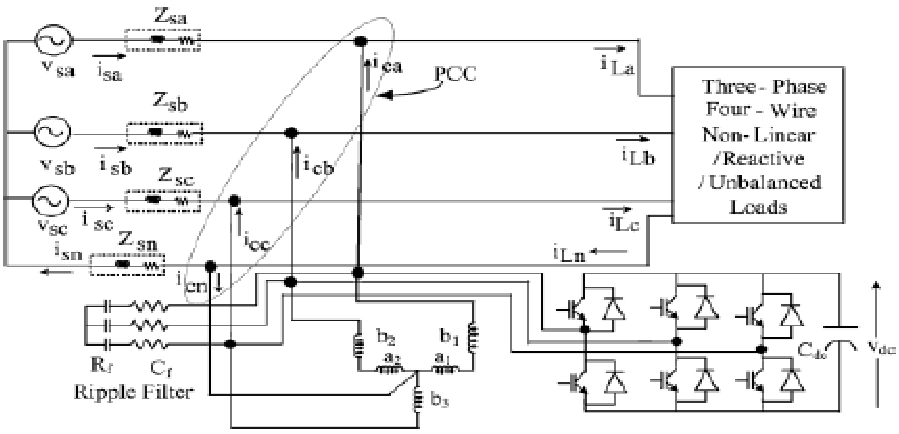

Fig 2.Schematics of the proposed three-leg VSC with T-connected transformer-based DSTATCOM connected in distribution system.

The T-connected transformer is used in the three-phase distribution system for different applications [6]–[8].But the application of T-connected transformer for neutral current compensation is demonstrated for the first time. Moreover, the T-connected transformer is suitably designed for Magneto Motive Force (mmf) balance. The T-connected transformer mitigates the neutral current and the three-leg VSC compensates the harmonic current and reactive power, and balances the load. The IGBT based VSC is self-supported with a dc bus capacitor and is controlled for the required compensation of the load current. The DSTATCOM is designed and simulated using MATLAB software with its Simulink and Power System Block set (PSB) toolboxes for power factor correction and voltage regulation along with neutral current compensation, harmonic reduction, and load balancing with nonlinear loads.

IV. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig. 1 and consists of Voltage Source Converter (VSC), a DC energy storage device, a coupling transformer connected in parallel to the distribution network through a coupling transformer. Necessary adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power which transfers between the D-STATCOM and the AC system. Such configuration allows the device to absorb or generate controllable active and reactive power flows. [7].

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The D-STATCOM commonly utilized mainly for regulation of voltage, correction of power factor and elimination of current harmonics. Such a device may be employed to provide continuous voltage regulation using an indirectly controlled converter. In this paper, the D-STATCOM is used to regulate the voltage at the point of common connection. The control technique is based on sinusoidal PWM and requires the measurement of the rms voltage at the load variation.

The shunt injected current I_{SH} can be written as,

$$I_{SH} = I_L - I_S$$

Where $I_S = \frac{V_{TH} - V_L}{Z_{TH}}$

Therefore

$$I_{SH} = I_L - I_S = I_L - \frac{V_{TH} - V_L}{Z_{TH}}$$

Or

$$I_{SH}\angle\eta = I_L\angle-\theta - \frac{V_{TH}}{Z_{TH}}\angle(\delta-\beta) + \frac{V_L}{Z_{TH}}\angle-\beta$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{SH} = V_L\, I_{SH}$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage variations depends on the value of ZTH or fault level of the load bus. When the shunt injected current ISH is kept in quadrature with VL, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of ISH is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

V. REFERENCE CURRENT CONTROL STRATEGY

The control scheme of the shunt active power filter must calculate the current reference signals from each phase of the inverter using instantaneous real-power compensator. The block diagram as shown in Figure.3, that control scheme generates the reference current required to compensate the load current harmonics and reactive power. The PI controller is tried to maintain the dc-bus voltage across the capacitor constant of the cascaded inverter. This instantaneous real-power compensator with PI-controller is used to extracts reference value of current to be compensated. To enhance the performance of distribution system, D-STATCOM was connected to the distribution system. D-STATCOM to be designed using MATLAB - SIMULINK R2010a 7.10 version [6].

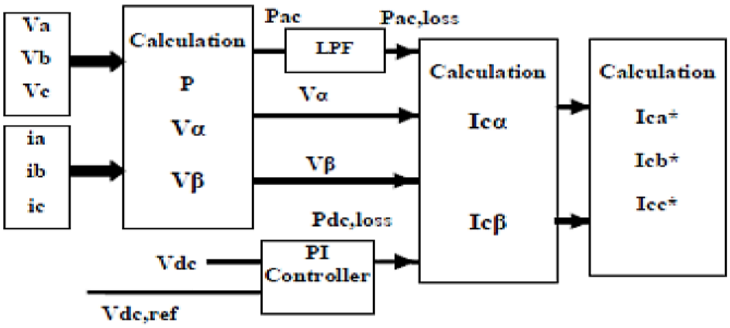

Fig 3: Reference control strategy for instantaneous real-power theory

D-STATCOM Simulations and Results for THD Total harmonic distortion, which is the summation of all harmonic components of the Voltage or current waveform compared against the fundamental component of the voltage or current wave.

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Simulation model and results:

DSTATCOM for mitigating power quality problems like voltage variations with load balancing in 3-phase 4-wire distribution network. Four leg inverter is used for the compensation purpose and .synchronous reference frame theory based controller is used with the control of DSTATCOM.

Here the simulation is carried out by Seven cases:

1. Non-linear load Without DSTATCOM and APF
2. Non-linear load with APF
3 Non-linear load with DTSATCOM and APF
4. Non-linear load with DSTATCOM, PI Controller and five-level cascaded multilevel.
5. Non-linear load with DSTATCOM, PI Controller and seven-level cascaded multilevel.
6. Non-linear load with DSTATCOM, PI Controller and five-level cascaded multilevel, with T and PI connections.
7. Non-linear load with DSTATCOM, PI Controller & seven-level cascaded multilevel, with T and PI connections.

Three-phase Transformer Line Voltage and Current

Configuration	Line Voltage	Line Current
Delta – Delta	$V_L \Rightarrow nV_L$	$I_L \Rightarrow \frac{I_L}{n}$
Delta – Star	$V_L \Rightarrow \sqrt{3}.nV_L$	$I_L \Rightarrow \frac{I_L}{\sqrt{3}.n}$
Star – Delta	$V_L \Rightarrow \frac{nV_L}{\sqrt{3}}$	$I_L \Rightarrow \sqrt{3}.\frac{I_L}{n}$
Star – Star	$V_L \Rightarrow nV_L$	$I_L \Rightarrow \frac{I_L}{n}$

Where: n equals the transformers "turns ratio" (T.R.) of the number of secondary windings N_S, divided by the number of primary windings N_P. (N_S/N_P) and V_L is the line-to-line voltage with V_P being the phase-to-neutral voltage.

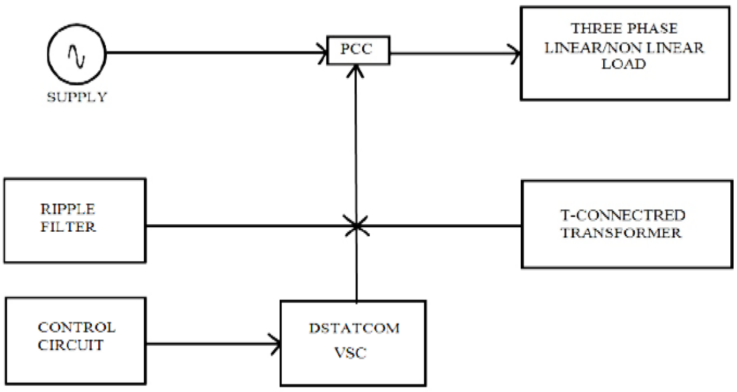

Fig 4. Block Diagram of T-connected VSC DSTATCOM

The block diagram representation of the proposed Three-Phase Four-Wire DSTATCOM and T-connected Transformer based distribution System is as shown in fig 2.1. It consists of three phase linear/nonlinear load block, ripple filter block, control circuit block and shunt active filter block. The T-connected Transformer block is used for neutral current compensation and it reduces the rating of three leg voltage source converter. The control circuit consists of DSATATCOM with Three leg Voltage Source Converter. This block is used to compensate the harmonic current and reactive power and load balancing. Also The DSTATCOM is tested for power factor correction and voltage regulation. The three leg VSC is used as an active shunt compensator along with a T-connected transformer. The ripple filter block is used to reduce the high frequency ripple voltage in the voltage at **Point of Common Coupling (PCC)**. High frequency ripple is due to switching current of the VSC of the DSTATCOM. All the blocks should be connected at PCC.

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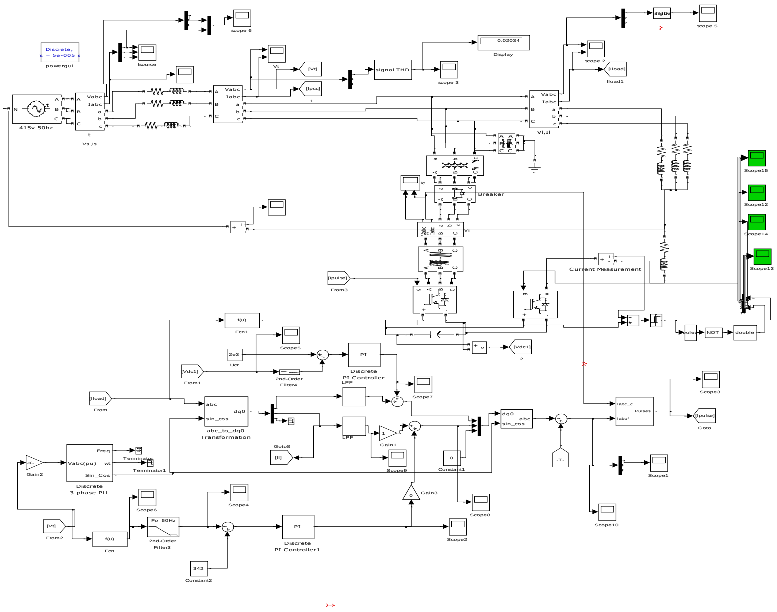

Fig 5. Simulation model of Five-level MLI with T-connected VSC DSTATCOM

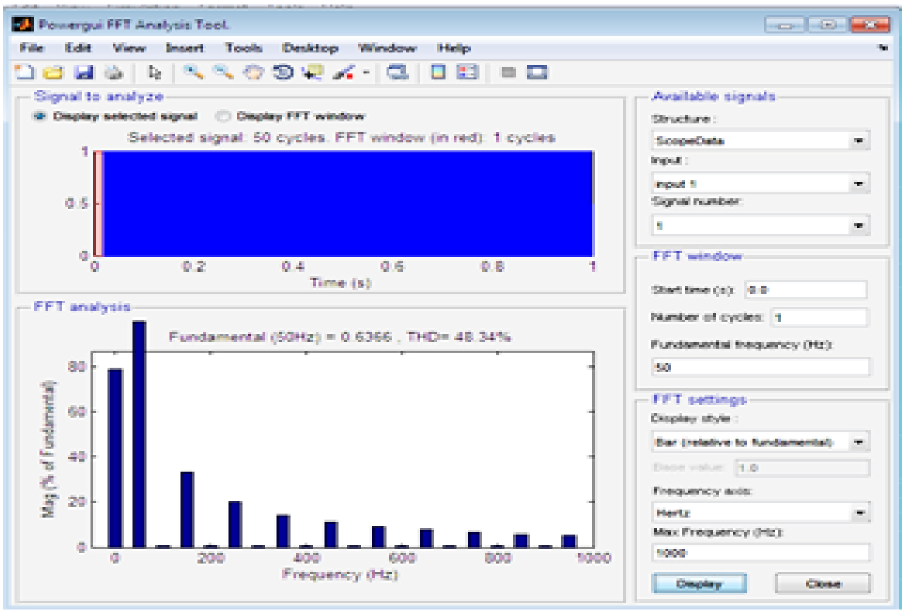

Fig 6. THD of Five-level MLI with T-connected VSC DSTATCOM

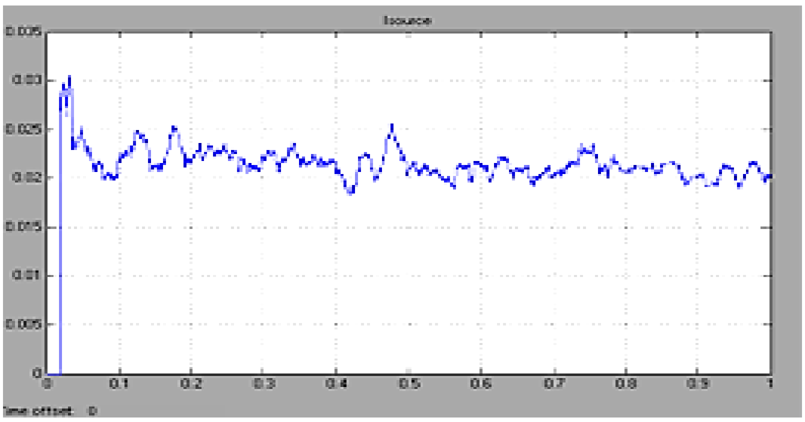

Fig 7. THD (load side) of Five-level MLI with T-connected VSC DSTATCOM

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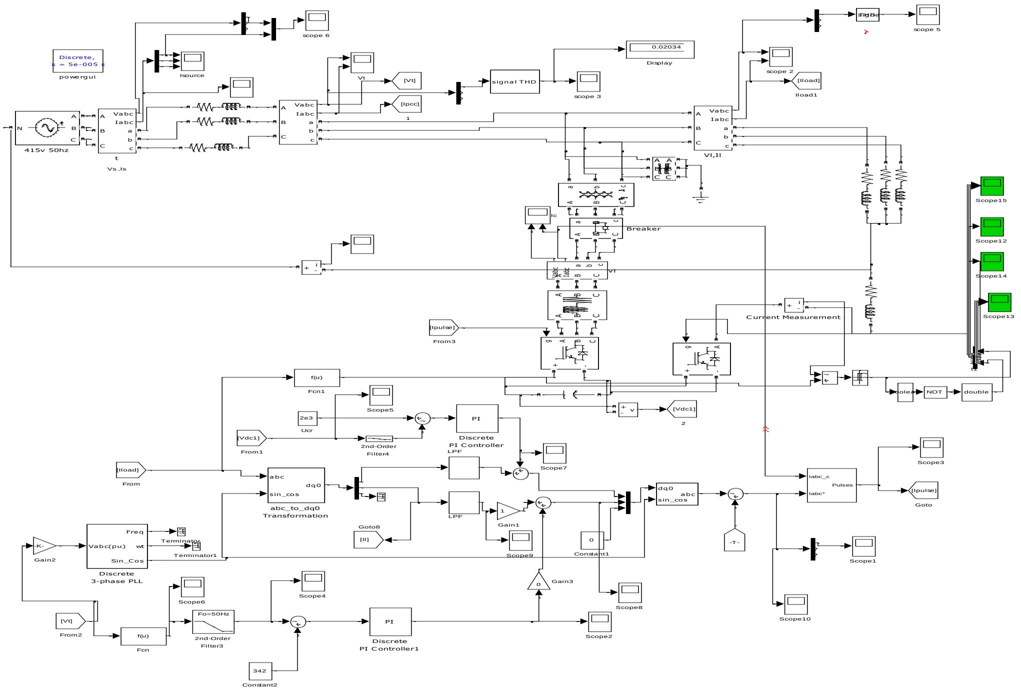

Fig 8. Simulation model of Five-level MLI with star-delta connected VSC DSTATCOM

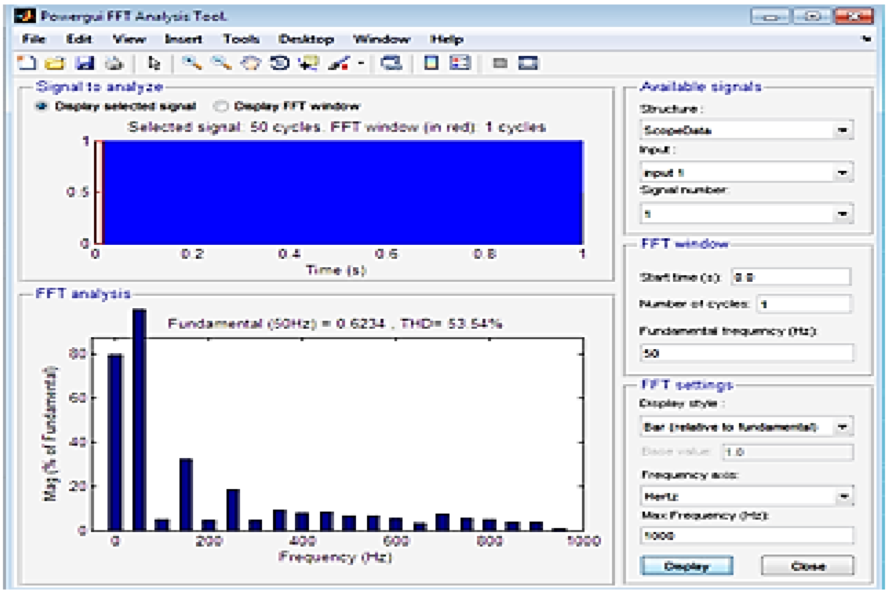

Fig 9. THD of Five-level MLI with Star-Delta connected VSC DSTATCOM

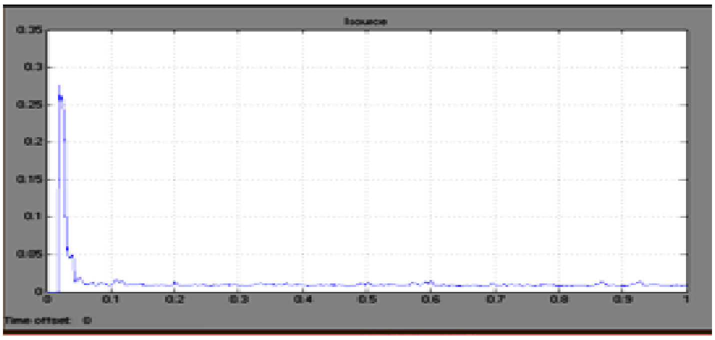

Fig 10. THD (Load side) of Five-level MLI with Star-Delta -connected VSC DSTATCOM

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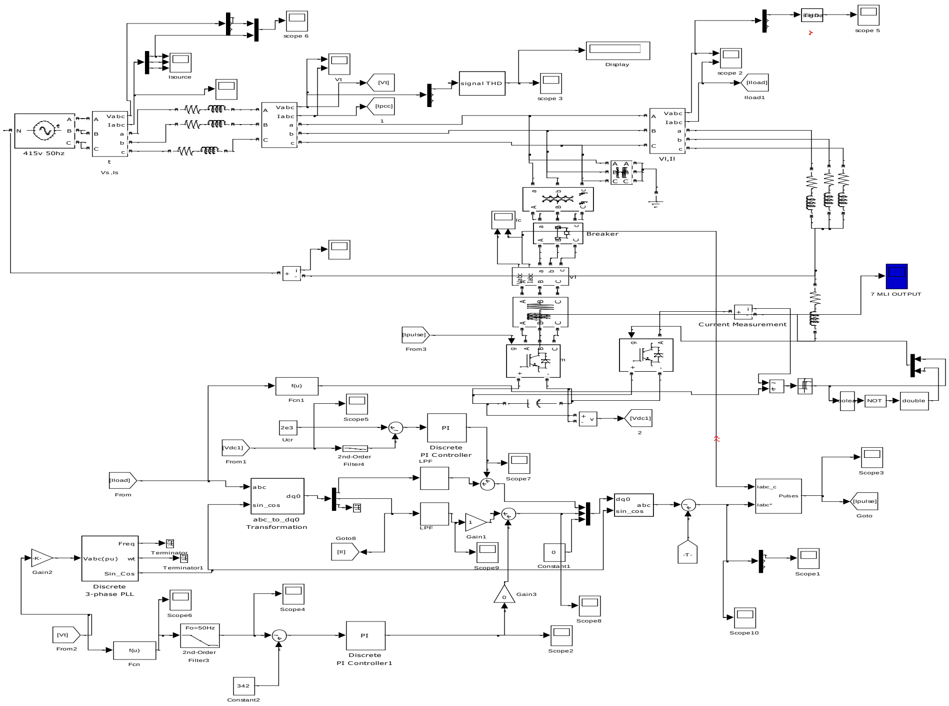

Fig 11. Simulation model of Seven-level MLI with T-connected VSC DSTATCOM

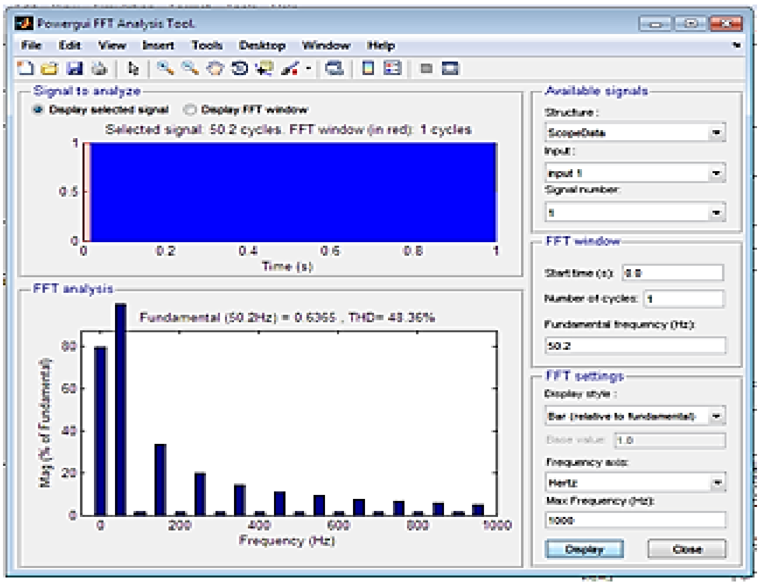

Fig 12. THD of Seven-level MLI with T-connected VSC DSTATCOM

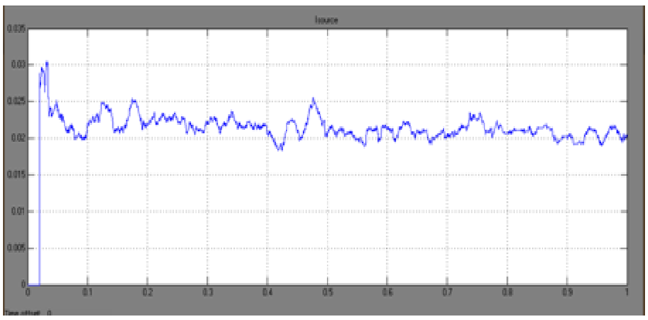

Fig 13. THD (load side) of Seven-level MLI with T-connected VSC DSTATCOM

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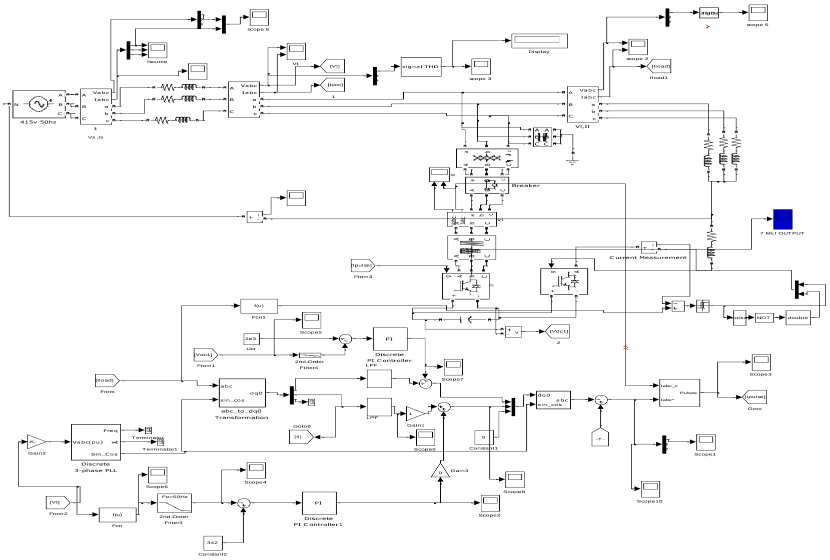

Fig 14. Simulation model of Seven-level MLI with star-delta connected VSC DSTATCOM

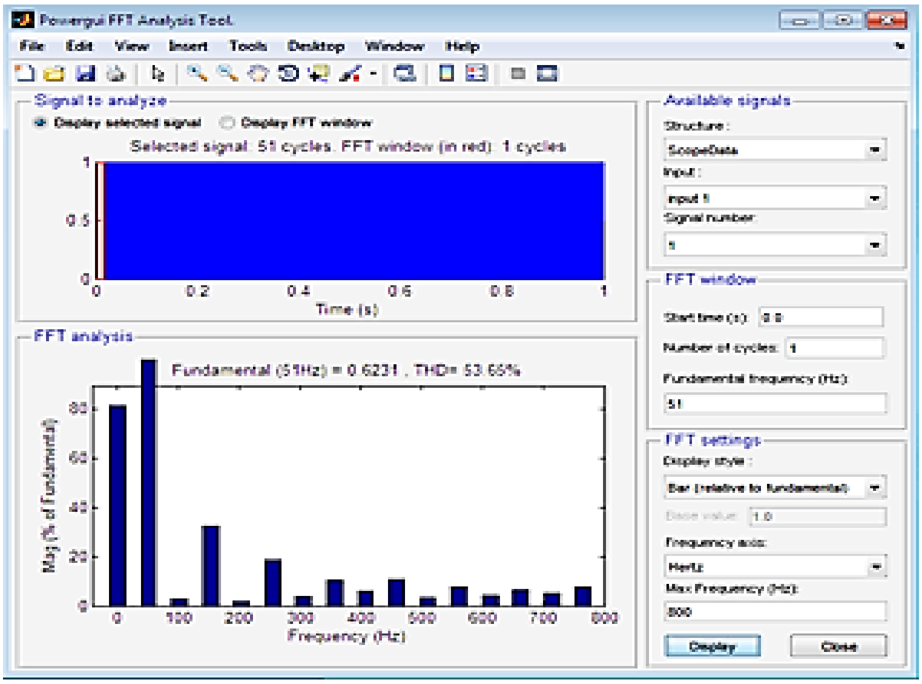

Fig 15. THD of Seven-level MLI with Star-Delta connected VSC DSTATCOM

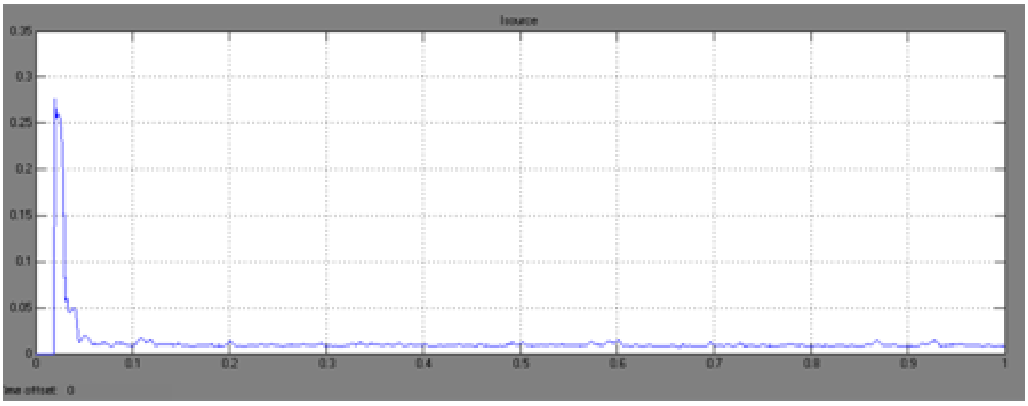

Fig 9. THD(Load side) of Seven-level MLI with Star-Delta connected VSC DSTATCOM

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Table 1: Comparison Table of THD for five-level and seven –level with different transformer connections

Voltage (THD)	Five-level (%)		Seven-level(%)	
	Star-star	Star-Delta	Star-star	Star-Delta
	48.34	53.54	48.36	53.65

Table 2: System Specifications

S.No	System Parameters	Rating
1	voltage	415v,50Hz
2	inductance	2e-3 h
3	resistance	0.01ohm
4	Load	R=30,L=70e-3
5	Inverter parameters	DC Link voltage=14kv

VI. CONCLUSION

A seven level cascaded multilevel voltage source inverter based DSTATCOM using instantaneous real power controller is found to be an effective solution for power line conditioning. A new three phase four wire DSTATCOM using T-connected transformer has been proposed for Three-Phase Four-wire DSTATCOM system to improve the power quality. The performance of three-phase four-wire distribution system with and without controller circuits for Non-linear load was discussed in the above section and following observation is obtained. Two single phase transformers are used for the T-configuration of the transformer to interface with a three-phase four-wire system. The total kilovolt amperes rating of the T-connected transformer is lower than a star/delta transformer for a given neutral current compensation. From the above discussion, the proposed technique is very efficient one for power quality improvement of Three-phase Four-wire distribution system compared to other techniques (Using star-delta and etc).

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