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Simulation of Hybrid D-STATCOM for Commercial Load in Three Phase Four Wire Distribution System

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Abstract : The growth of electricity market has seen a change in the sense consumers perceive electricity. The electricity consumption can be roughly divided between three larger sectors — industry, household and commercial sector. This paper attempts to monitored and analyzed power quality (PQ) issues in commercial sector with a real case study for commercial load taken as educational building in Indore, India. The commercial or educational buildings major loads are computers, energy efficient lightings and official loads etc. This single phase loads within a building leads to a large amount of harmonics, mainly in neutral. A Hybrid distributed static compensator (D-STATCOM) is proposed to mitigate these harmonics. A hybrid D-STATCOM is combination of 3-phase D-STATCOM with small rating of 1-phase active power filter(APF) with T-connected transformer. The APF specially connected for third order harmonics in neutral. The proposed combination reduces harmonics, cost as well as size of the filters. The model of hybrid D-STATCOM is simulated in MATLAB with similar harmonics conditions. The results of simulation are satisfactory to mitigate most of the harmonics to meet the recommended standard of IEEE 519-2014.

Keywords –Commercial load, harmonics, Hybrid D-STATCOM,IEEE 519-2014, APF, Power quality monitoring, PQ, Power quality issue.

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I. INTRODUCTION

Power quality issues are becoming more significant day by day because of increase in the usage of modern equipment's which is having power electronic circuits for better control and energy saving. These type of load over heat the distribution transformer and degrade the quality of power. Hence, it is necessary to limit the harmonics to meet IEEE:519-2014 standard. Power quality is “the provision of voltages and system design so that the user of electric power can utilize electric energy from the distribution system successfully without interference or interruption”. Both end users and utilities are highly concerned of PQ as it is devastating the power system as well as the devices connected to it. The aim of this analysis is to determine the current situation of PQ in commercial buildings. In order to study the possibilities and limitations to implement different power quality measures with solutions harmonics analysis is required. Industries and commercial nonlinear loads are the main source of power quality issues. The PQ monitoring helps in understanding the behavior of power system with a goal to develop standards of power quality to upgrade the limits. PQ monitoring and analysis guides the electrical and electronic equipment designer to designed a product as per present and future trends, which can with stand adverse situations. In this paper, the results of power quality monitoring conducted in educational building, Indore, India for different load feeders. As per the literature survey, the APF mitigates the harmonics by generating anti harmonics into the system and thereby cancelling the harmonics present into the system. The single phase APF are generally available in low power ratings. They are suitable for retrofit applications, such as medical, small shops or educational buildings with computers and lighting loads where the current harmonics can be dealt with at the point of common coupling (PCC). The commercial type of load having main problem of 3rd harmonics, which is add with other triplen harmonics and the summation of these triplen harmonics flow into the neutral. For reducing the power rating of active filters many methods and combinations of active and passive filtering are used. The location of these filters also decide the cost and size of the filter. One of the several lower power filters can be connected on a given distribution site rather than using one large filter on incoming supply. Distribution Static Compensator (DSTATCOM) is a Voltage source inverter (VSI) based static compensator device (STATCOM, FACTS) to maintain bus voltage sags at the required level by supplying or receiving of reactive power in the distribution system. It is connected in shunt with distribution feeder with the help of coupling transformer.

Voltage THD: Total Harmonic Distortion of the voltage waveform. The ratio of the root-sum-square value of the harmonic content of the voltage to the root-mean-square value of the fundamental voltage.

$$THDv = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 \ldots .}}{V_1} \quad (1)$$

Current THD: Total Harmonic Distortion of the current waveform. The ratio of the root-sum-square value of the harmonic content of the current to the root-mean-square value of the fundamental current.

$$THDi = \frac{\sqrt{(I_2^2 + I_3^2 + I_4^2 \ldots .}}{I_1} \quad (2)$$

Current TDD: Total Demand Distortion of the current waveform. The ratio of the root-sum-square value of the harmonic current to the maximum demand load current.

$$TDDi = \frac{\sqrt{(I_2^2 + I_3^2 + I_4^2 \ldots .}}{I_L} \quad (3)$$

As per the guideline of IEEE 519-2014, the total harmonic distortion of voltage (THD_v) should be below 5%. For current distortions TDD must be less than 8% for the ratio of I_{sc}/I_L is in between 20 to 50. In this case the ratio for this building is in between 20 to 50.

II. SYSTEM DESCRIPTION

The system is supplied with 33 KV incoming line via step down transformer of 3-phase, 50 Hz, 33 KV/440 V, 500 KVA with source impedance (Zs) of 4.5%. This commercial educational building having five different feeders to supply different types of loads as shown in figure 1.

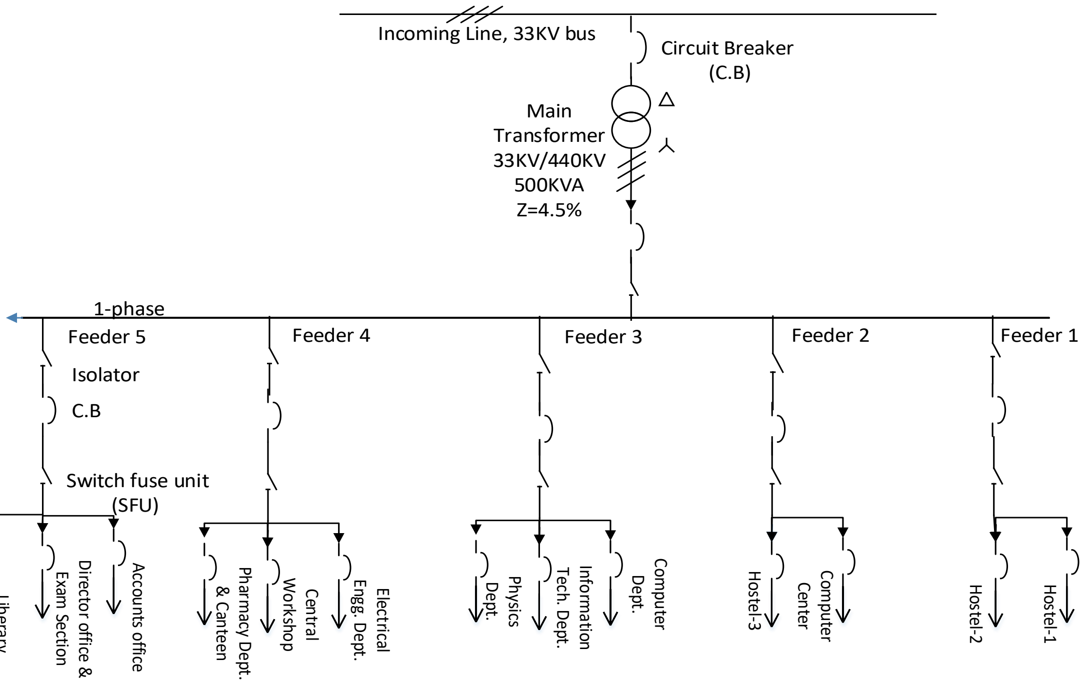

Figure. 1 Single line diagram of load feeders

III. POWER QUALITY MONITORING OF ALL FEEDERS

Detailed harmonic analysis has been done for identifying the source of high harmonics in all five feeders as shown in figure 2,3,4,5 & 6. In commercial building 3^{rd} harmonics is a big problem. As per the readings as shown in table 1, the feeder 3and 5 are most affected. The current harmonics at these feeder are not acceptable.

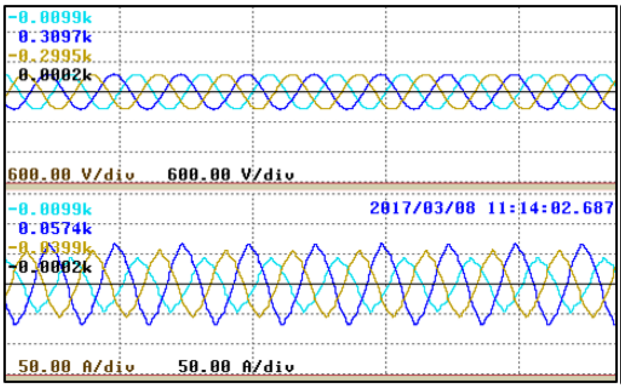

Fig. 2 Voltage and current waveform of Feeder 1

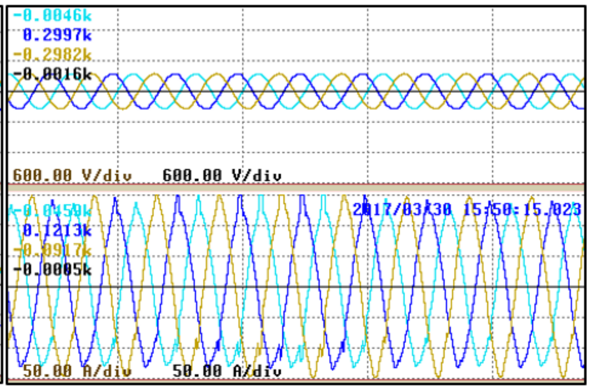

Fig. 3 Voltage & current waveform of feeder 2

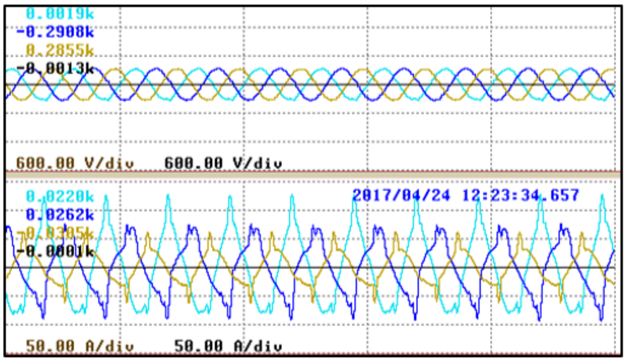

Fig. 4 Voltage & current waveform of Feeder 3

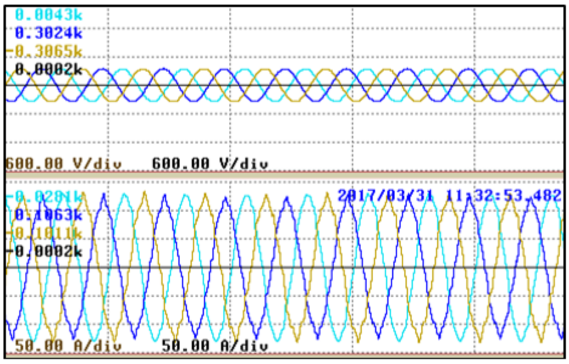

Fig. 5 Voltage and current waveform of Feeder 4

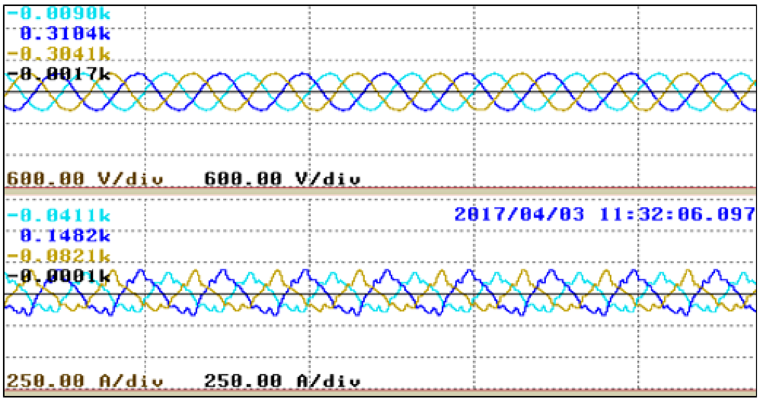

Fig. 6 Voltage and current waveform of Feeder 5

Table 1.Detail of Total harmonic distortions (THD) in all five feeders

	Feeder 1		Feeder 2		Feeder 3		Feeder 4		Feeder 5	
S.N	THD_i	THD_v	THD_i	THD_v	THD_i	THD_v	THD_i	THD_v	THD_i	THD_v
CH1	8.18	2.07	7.33	1.34	11.89	1.44	4.80	1.93	17.82	2.90
CH2	6.25	2.07	6.91	1.44	15.71	1.42	6.11	1.71	19.67	2.50
CH2	6.91	2.07	6.65	1.44	10.67	1.48	5.33	1.87	23.61	2.52

IV. PROPOSED METHODOLOGY

The selection of proper compensation technique is depends on

1. Power rating and speed of response in compensated system,
2. Power circuit configuration
3. Control techniques employed

The power rating of the compensated system and its speed of response play a major role in deciding the control technique to implement the required filter. The cost of any particular system is proportional to the required speed of the response. As per the monitoring results, the feeder 3 and 5 are affected by the harmonics. In this paper, a hybrid D-STATCOM has been proposed, which is consist of mainly 3-phase non isolated DSTATCOM connected at 3-phase side of main transformer secondary, and 1-phase APF with T-connected transformer connected specially for 3rd harmonics in neutral of feeder 3 and 5 as shown in table 1.

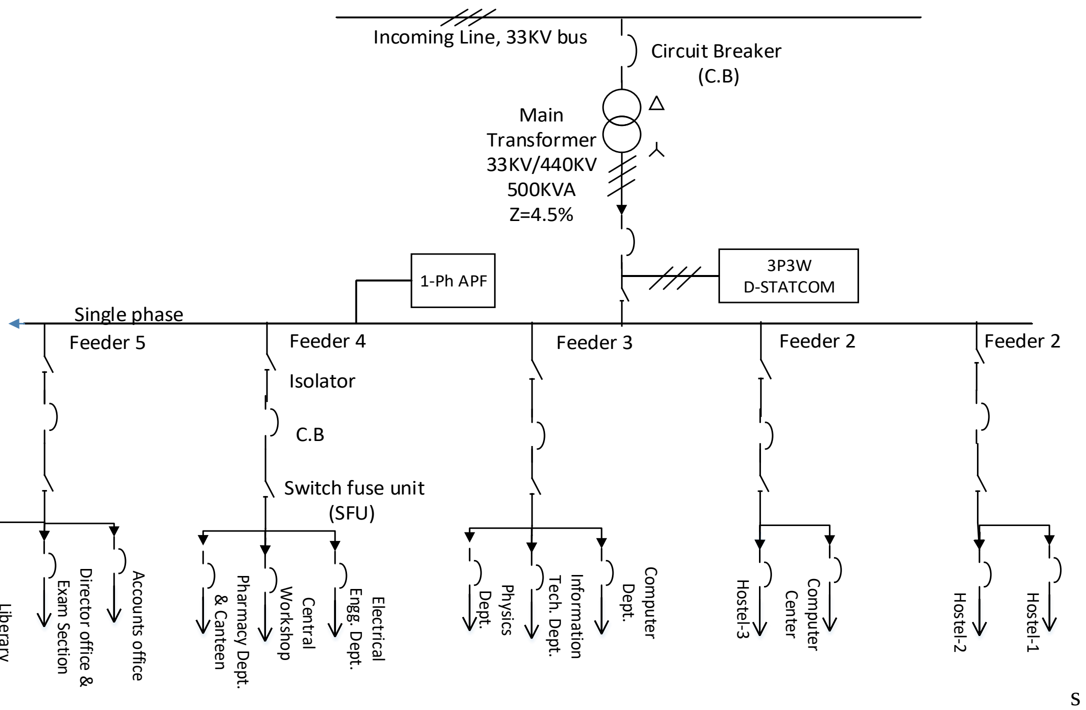

Fig. 7. Location of Filters

4.1 D-STATCOM

A static synchronous compensator (STATCOM) with or without a coupling transformer, an inverter, and energy storage devices used in distribution system is called D-STATCOM. D-STATCOM include voltage source converter (VSC), DC bus capacitor and ripple filter. The D-STATCOM. The main function of D-STATCOM is to supply reactive power to regulate the voltage at point of common coupling. Active power can also be supplied if storage is connected at DC side.

4.2 APF

Active power filters (APF) is an instantaneous voltage source converter. APF mitigates the harmonics generating anti harmonics into the system and thereby cancelling the harmonics present into the system.

4.2.1 **T-Type Transformer**

T type transformer is small in floor space, low in height and with lower in weight. It uses two single phase transformers which make core economical and easy to assemble it can be regarded as open circuit for the positive and negative sequence currents hence the current flowing through the transformer is only zero sequence current.

V. SIMULATION OF HYBRID D-STATCOM

A simulation of hybrid D-STATCOM is performed as shown in figure 8. The combination of D-STATCOM at secondary of main transformer and 1-phase APF is known as Hybrid D-STATCOM

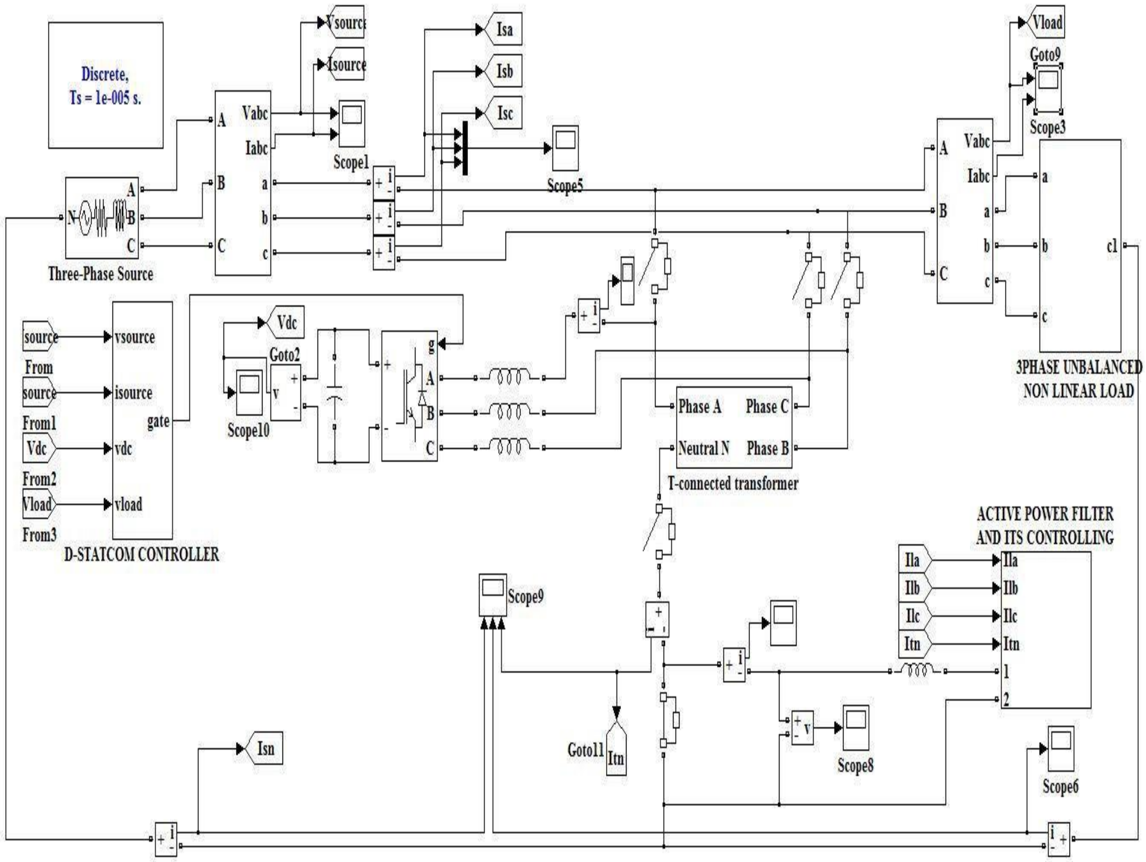

Fig. 8. Simulation of Hybrid D-STATCOM

5.1 Three-Phase Three-Wire (3P3W) D-STATCOM

A three-leg, two level pulse width modulated (PWM) voltage source inverter (VSI) is used as the D-STATCOM in this configuration. The VSI is realized by using insulated-gate bipolar transistor (IGBT) switches and operated through a three-leg, PWM switching scheme.

5.1.1 Control of 3P3W D-STATCOM

The PWM signals are generated by a suitable control scheme for which reference and sensed D-STATCOM currents are the input signals. Several control schemes have been reported in the literature for extraction of load harmonic and reactive currents and they are based on instantaneous reactive power (IRP) theory, power balance theory, synchronous reference frame theory, symmetrical components based theory and etc. In this paper synchronous reference frame (SRF) theory is used to generate control signals.

5.1.2 SRF Theory-Based Control Algorithm of D-STATCOM

A block diagram of the control algorithm is shown in Figure. 9. The load currents (i_{La}, i_{Lb}, i_{Lc}), point of common coupling (PCC) voltages (v_{sa}, v_{sb}, v_{sc}), and DC bus voltage (V_{DC}) of the DSTATCOM are sensed as feedback signals. The load currents in the three phases are converted into the dq0 frame using the Park's transformation. A three-phase PLL (phase locked loop) is used to synchronize these signals with the PCC voltages. These d–q current components are then passed through a low pass filter (LPF) to extract the DC components of i_{Ld} and i_{Lq}. The d-axis and q-axis currents consist of fundamental and harmonic components. A SRF controller extract DC quantities by a LPF and hence the non DC quantities are separated from the reference signals.

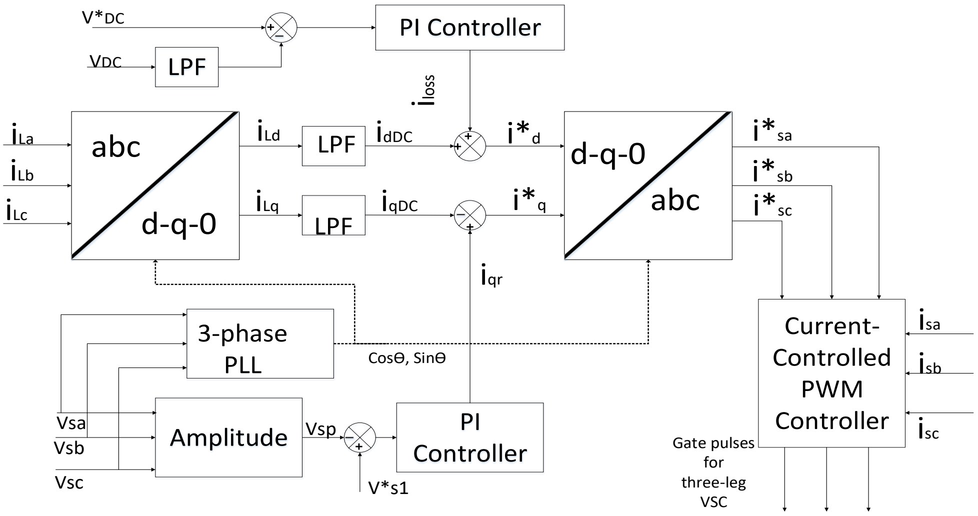

Fig9. Block diagram of SRF theory-based control algorithm of D-STATCOM'

5.2 APF with T-Connected transformer

The rating of the APF is very small due to the low voltage drop across the T-connected transformer neutral and the utility neutral (V_{Tn}). This voltage is primarily determined by the sum of the voltage drops across the leakage impedance of the T-connected transformer and filter inductor due to the compensating current of the source neutral. However, under sustained unbalanced/distorted utility voltage conditions or fault conditions, V_{Tn} can be very high. This makes it necessary to protect the single-phase APF and T-connected transformer by means of a protective device. For better compensation under nominal unbalanced and/or distorted conditions, the dc side voltage of the single-phase inverter is kept at three times the peak voltage drop between the T-connected and utility neutrals with ideal utility voltage.

5.2.1 Operation and control of single-phase APF

When T-connected transformer only acts as compensator (Switch closed) then the transformer provides a low impedance path for the zero-sequence currents to flow between the load and the T- connected transformer. However, the effectiveness of the compensation is strongly dependent upon the location of the compensator and impedances of the T-connected transformer, and the system. When switch (S) is open, the single-phase APF comes into the operation and produces the desired current for compensating source neutral current and injects the same through the neutral of the T-connected transformer. This current splits equally and flows through each of the T-connected windings of the transformer such that the APF circulates the neutral current to the load via the T-connected transformer. Therefore, the effectiveness does not depend on the zero-sequence impedance of the T-connected transformer and its location and hence a special design for a T-connected transformer for low zero-sequence impedance is not necessitate.

5.2.2. Operation of under unbalance/distorted utility voltages

The performance of the only T-connected transformer (S closed) also depends upon the utility voltage conditions. Under unbalanced and/or distorted source voltage conditions, a zero- sequence voltage may exist which provides a low impedance path for the zero-sequence current to flow between the utility and the T-connected transformer. Therefore, the source neutral current becomes larger than the load neutral current and which will have an adverse effect on the performance and may result in the burn down of the transformer or the neutral conductor. But, with single-phase APF, the compensating source neutral current forcibly injects through the neutral of the T-connected transformer and hence its effectiveness of compensation of neutral current does not depend on utility voltage conditions.

VI. RESULTS

The results of simulated model with FFT analysis is shown in fig 10,11 and 12. The figure 10 shows analysis and waveform without compensation and having total THD is of 19.63. when D-STATCOM is connected the FFT analysis shows the reduced THD of 8.46% as shown in fig 11. The FFT analysis with combination of D-STATCOM and APF reduces the THD below 2%.

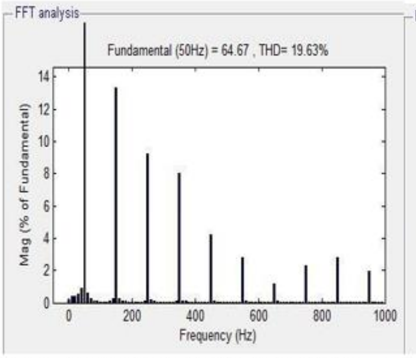

Fig.10. Results without Compensation

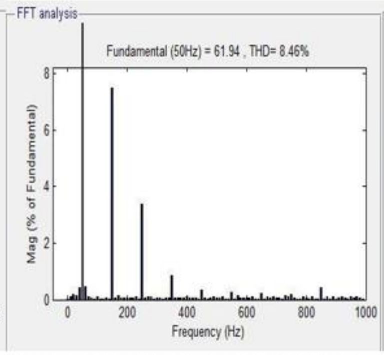

Fig. 11. Results with D-STATCOM

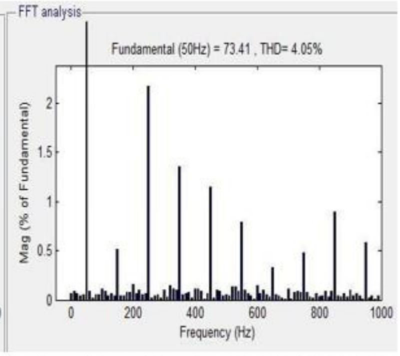

Fig.12. Results with DSTATCOM & APF

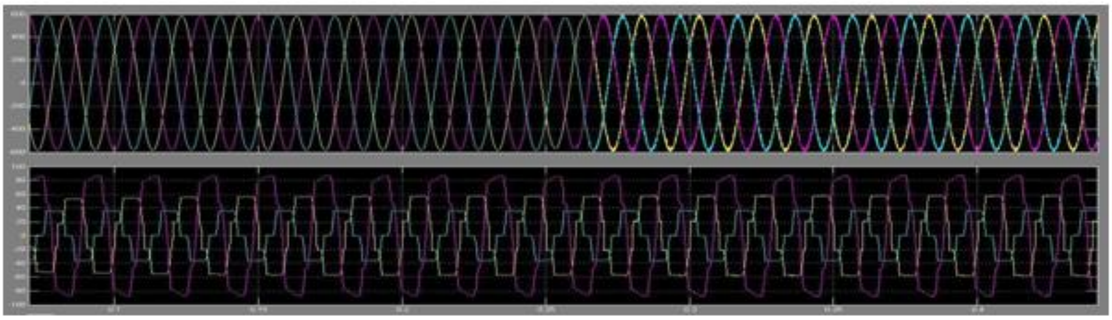

Fig.13 Distortion in Supply currents

6.2 Results with only D-STATCOM

As the result shows that, alone D-STATCOM reduced THD till 8.7% from 20%. The 3rd harmonics reduces from 13% to 9%, 5th harmonics reduces from 10% to 3%, 7th harmonics reduces from 8% to 1%and all higher harmonics are reduced below 0.5%.

6.3 Results with D-STATCOM and APF

When D-STATCOM and APF are connected together, the performance of the system is improved. The 3rd harmonics reduces to 0.5% and all remaining harmonics reduced to below 2% or acceptable limits.

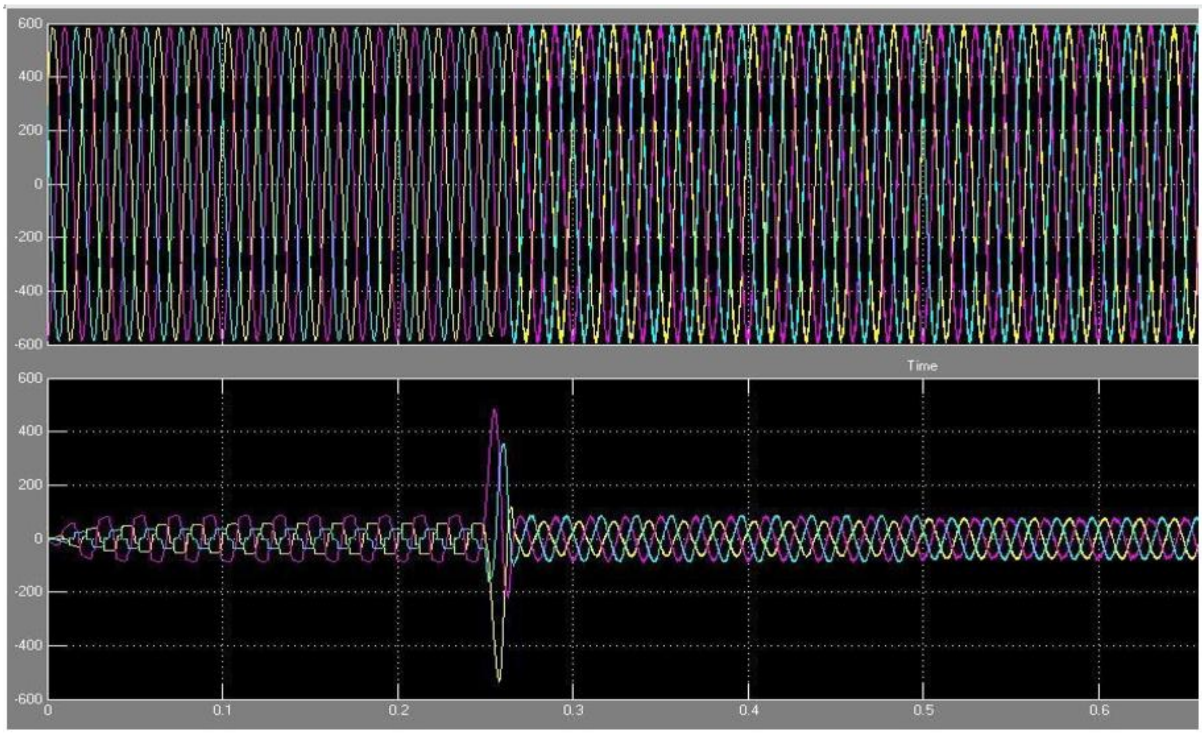

Fig. 14. Compensation in current waveform due to STATCOM and Active power filter

VII. CONCLUSION

The proposed methodology uses the combination of 3-phase D-STATCOM in main line of transformer secondary and single phase APF with T connected transformer in feeder. This combination make the size of D-STATCOM is of small and having low KVA rating. This hybrid D-STATCOM is economical by cost, small in size and simultaneous compensate reactive power, load current harmonics and source neutral current. The APF with T-connected transformer has an advantage of using standard two single-phase transformers and consequently, the cores are economical to build and occupy low space. The performance of the proposed D-STATCOM has been investigated through simulation in MATLAB. It is observed that the proposed scheme completely compensated the source current harmonics, reactive power and neutral current. The proposed D-STATCOM has better performance under unbalance/ distorted utility voltage conditions and also it does not need a special design for T-connected transformer for low zero-sequence impedance. The single phase APF are generally available in low power ratings and suitable for medical, small shops or educational buildings with computers and lighting loads, where the current harmonics are dominated. To reduce the cost, several lower power filters can be connected at affected feeder rather than using one large filter on incoming supply or at PCC. Therefore, the proposed DSTATCOM topology will have reduced weight, cost, rating, size with improved efficiency and current compensation capability compared with the traditional topology. The effectiveness of the proposed DSTATCOM topology over traditional topologies is validated through simulation.

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