Design of FLC based Control Strategy for DSTATCOM for Power Quality Improvement with Balanced and Unbalanced Non-Linear Loads

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Abstract – *In this paper, a distribution static compensator (DSTATCOM) is introduced to reduce the issues related to power quality in an electrical network. The energy source connected to the DSTATCOM device injects the real power in the system and also reduces the effects of non-linear and unbalanced loads presented in the given system. The Proportional Integral (PI) controller in the control circuit is replaced with Fuzzy Logic Controller (FLC) and the performance of the electrical network under the PI and FLC are compared and presented. The proposed system is designed as well as simulated in MATLAB/Simulink software.*

Key Words: **Distribution static compensator, Real and Reactive power injection, Unbalanced load, PI control, FLC control, Harmonic Reduction.**

1. INTRODUCTION

The major occurring issue in the electrical network is voltage sag (reduction in RMS voltage occurs for a short duration of 10ms to 60s). The reduction in the magnitude of voltage ranges from 10% to 90% of the rated voltage of the system. It occurs mainly due to utility fault, fault at consumer end or sudden increase in load demand. In utility fault, due to short circuit, there is reduction in system voltage as high current starts flowing during the fault time period. The consumer end fault is due to the fault in the equipment, non linearity in loads, etc. Lightning is also one of the major causes for the occurrence of faults in transmission lines. If these faults occurred continuously, it causes major disadvantage in terms of service and also causes economic losses from repetitive maintenance, power outages and due to the replacement of faulty equipment etc. Voltage sag is the major occurring issue in the Power Quality among many others. There are no fixed solutions to mitigate this voltage sag occurrence but there are various methodologies presented so for compensation of the faults by injecting reactive as well as real power such as FACTS devices, capacitor banks, introducing DG units to the system, etc.

The Dynamic Voltage Restorer (DVR) and DSTATCOM are the most efficient devices for compensating such power quality problems. The control structures or strategies are based on various controllers in dealing with such issues like PI, PID, FLC, PR controllers. In this, PI controllers is one of the basic controllers which can be designed to inject real and reactive power based on system parameters such as Frequency, DC Voltage, AC Voltage etc. But it is difficult to design the PI controller for wide range of fault types and it is slower in response under transient conditions. Proportional Integral Derivative (PID) controller provides better response than that of PI controller but still it is inefficient to compensate the harmonic conditions. Proportional Resonant (PR) controller is suitable for harmonic reductions but in other issues such as short circuit faults, the performance is still needed to be improved. Hybrid controllers such as PI with PR or PID with PR are proposed and the complexity in design is increased.

In this paper, an indirect approach of current control is used to control the Voltage Source Converter (VSC) which combined with energy source formulates the DSTATCOM. The proposed system is tested under linear/non-linear loads and balanced/unbalanced load conditions. The ability of Power Factor Correction (PFC), Load Balancing and Harmonic Reduction of the proposed device is checked. The FLC replaces the present PI controller in the DC voltage control loop of DSTATCOM and the simulation results are compared.

2. HYBRID RENEWABLE ENERGY SOURCES BASED MICROGRID WITH BATERRY ENERGY STORAGE SYSTEM.

The proposed system is shown in figure 1, comprises of a VSC, a DC source, a coupling transformer in parallel to the distribution network. The three-phase grid supplying the power with 400V, 50Hz is as follows.

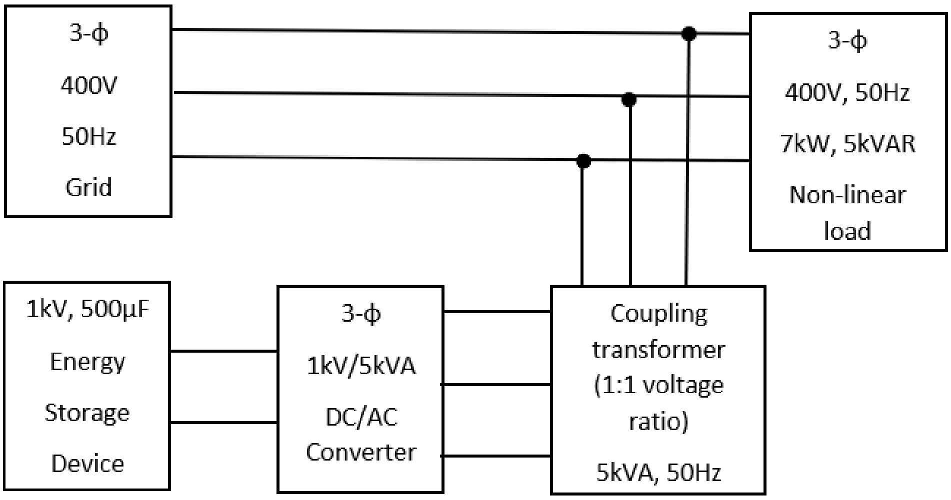

Fig 1 Distribution system with DSTATCOM

The voltage and current equations for the three-phase grid is as follows:

$$V_{i=}\begin{bmatrix}V_{sa}\\V_{sb}\\V_{sc}\end{bmatrix}=V_{im}\begin{bmatrix}\cos(\omega_i t)\\ \cos\left(\omega_i t-\frac{2\pi}{3}\right)\\ \cos\left(\omega_i+\frac{2\pi}{3}\right)\end{bmatrix} \qquad i_0=\begin{bmatrix}i_{oA}\\i_{oB}\\i_{oC}\end{bmatrix}=I_{om}\begin{bmatrix}\cos(\omega_o t-\emptyset_o)\\ \cos\left(\omega_o t-\emptyset_o-\frac{2\pi}{3}\right)\\ \cos\left(\omega_o t-\emptyset_o+\frac{2\pi}{3}\right)\end{bmatrix}$$

The VSC injects reactive power to the load.

The functions of the DSTATCOM are provided below:

1. Regulation of load voltage and injection of real and reactive power.

2. Power Factor Correction and

3. Harmonic current reduction.

The relation for injected current I_{sh} is provided below,

$$I_{sh}=I_L-I_S=I_L-(V_{th}-V_{L)}/Z_{th}$$

The injected apparent power by D-STATCOM is provided below,

$$S_{sh}=V_L I_{sh}^*$$

The voltage is regulated by injecting the reactive power with the injected current is in quadrature with load voltage and the load regulation can also be done by injecting both real and reactive power in the system with minimum injected current.

The control strategy is as represented in the figure 2

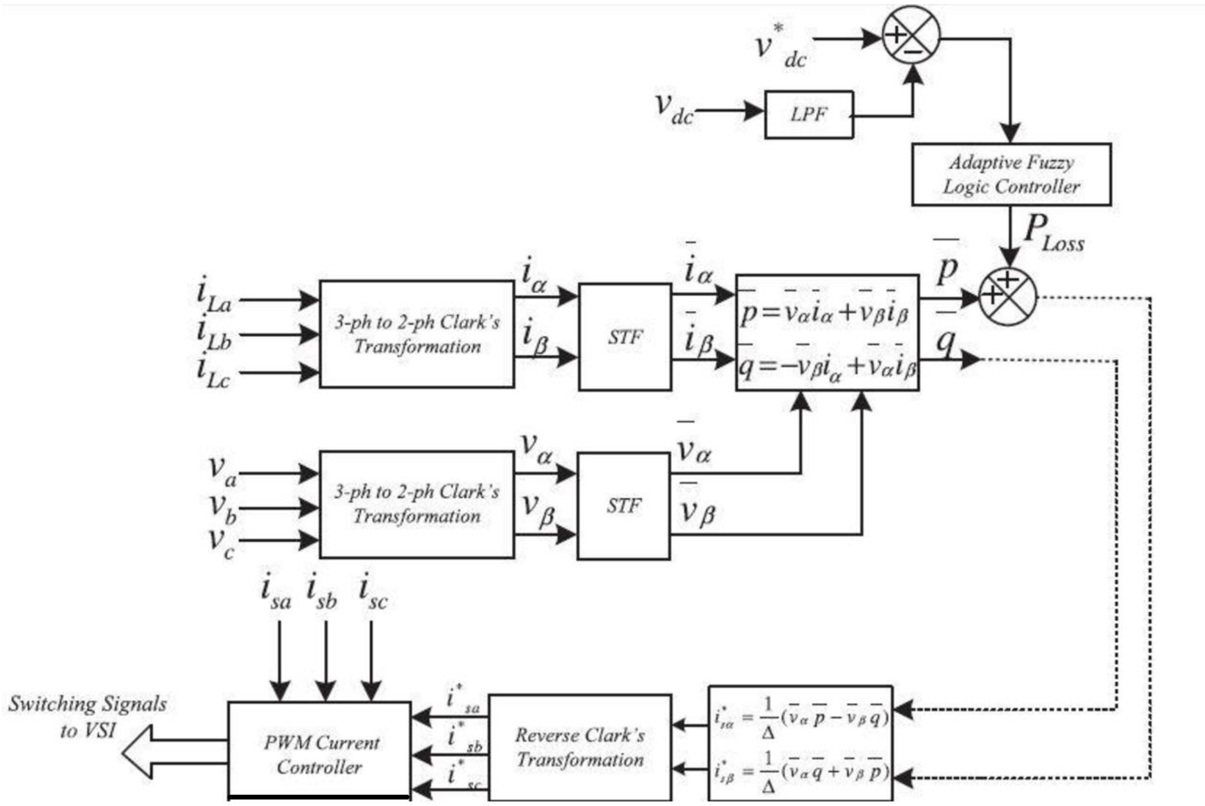

Fig 2 Control strategy of DSTATCOM

The DC voltage controller over the average value of DC bus voltage of the DSTATCOM (V_{dc}) and reference DC voltage (V_{dcr}) provides real power loss which will be added with measured power and it is combined with quadrature axes. The resultant reference current is compared with measured current and passed through hysteresis control. The hysteresis current controller generates the pulses for DSTATCOM.

3. DESIGN OF RLC FILTERS:

In RLC circuit, the function of R is to reduce the ripples present in the current waveforms. Here 1% of load current is taken as ripple limit and R=ΔI/I = 0.01Ω.

The inductor value is calculated as

$$L = \frac{R}{2 * \pi * Fc}$$

Where Fc is critical frequency for harmonic limits (100Hz) (below third order harmonic frequency).

The capacitor value is calculated as

$$C = \frac{1}{2 * \pi * Fc * R}$$

4. DESIGN OF FL CONTROLLER

Fuzzy interference system, the main component of fuzzy logic system serves in decision making. The functional diagram of fuzzy logic controller is as shown in the figure 3.

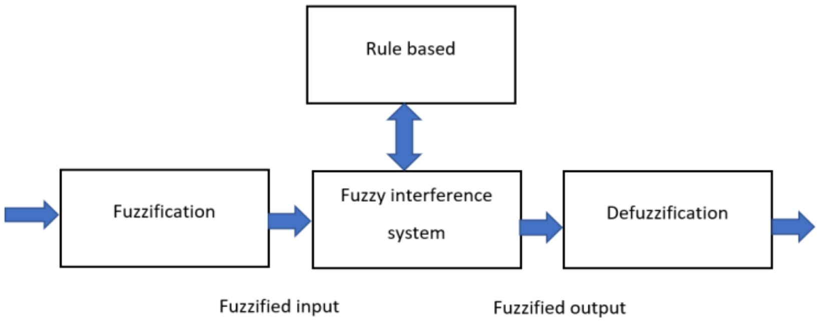

Fig 3 Functional block diagram of Fuzzy Logic Controller

Fuzzy inference system process comprises of following procedures:

- Input variables are processed and undergoes the Fuzzification step
- Applying the fuzzy operator (AND or OR) process as per the rules.
- Defuzzification of the fuzzy outputs

The rules provided for the FL controller is provided in Table I as shown below:

Table 1. FLC rule table

Enables	Output
Negative Very Low (NVL)	Positive Small (PS)
Negative Low (NL)	Positive Small (PS)
Negative Medium (NM)	Positive Small (PS)
Negative Small (NS)	Positive Small (PS)
Zero	Positive Medium (PM)
Positive Small (PS)	Positive Medium (PM)
Positive Medium (PM)	Positive Medium (PM)
Positive Low (PL)	Positive Low (PL)
Positive Very Low (PVL)	Positive Very Low (PVL)

5. SIMULATION SETUP AND RESULTS

The simulation circuit for the base system is provided in figure 4:

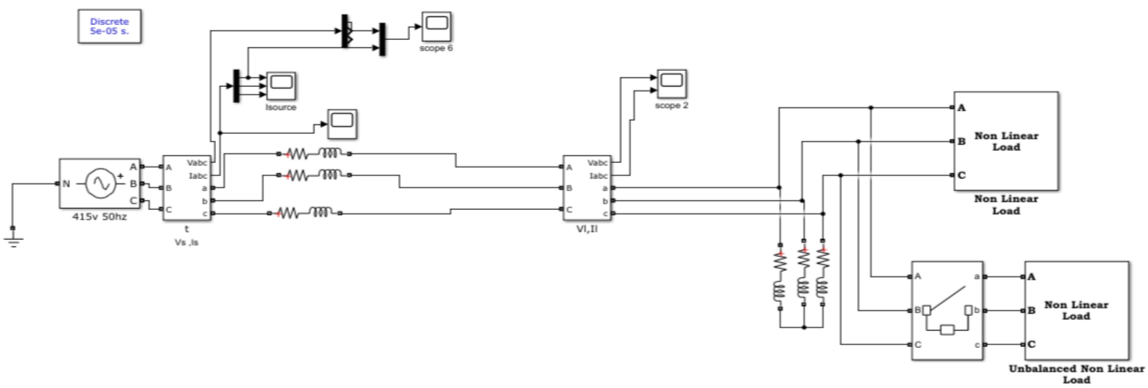

Fig 4 Simulation circuit of Distribution network without DSTATCOM

In this three-phase voltage supply of 415V, 50Hz is providing power to the loads connected (both linear and non-linear loads). An unbalanced load is connected to the system at t=0.6s.

The load voltage and current waveforms without DSTATCOM are provided in figure 5 along with the source voltage and current

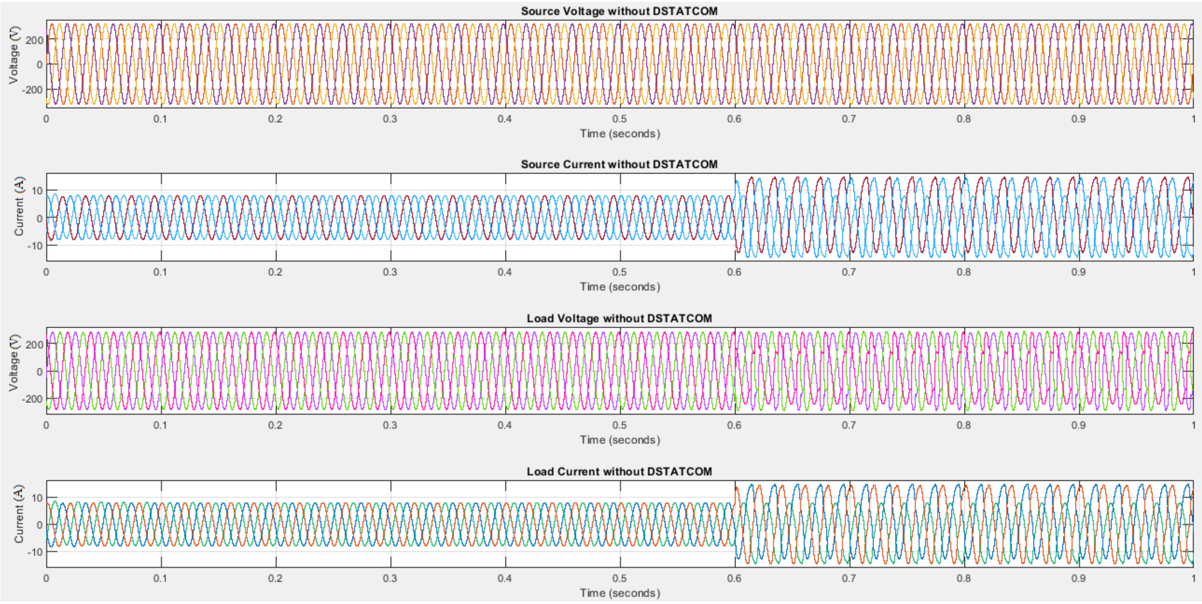

Fig 5. Load voltage and current without DSTATCOM

The voltage is around 300V and the current is around 10A initially and when the unbalanced load is connected at t=0.6s, the unbalanced current increases to 20A.

The simulation circuit of the base system with DSTATCOM is provided in fig 6:

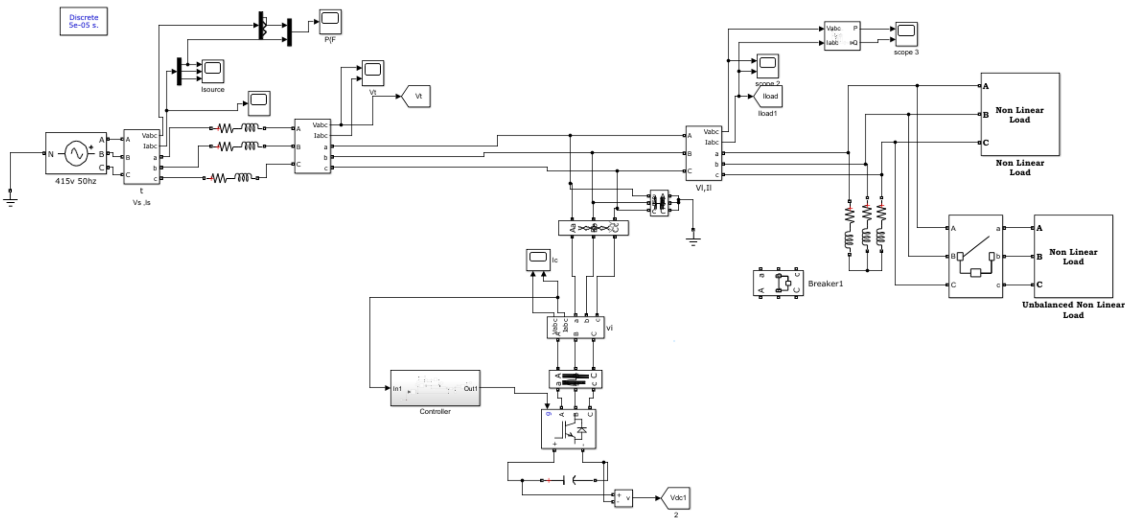

Fig 6 Simulation circuit of Distribution network with DSTATCOM

In this, the DSTATCOM is connected to the base system through coupling transformer of power 5000VA, voltage of 450V/450V. An RLC filter is also connected in between the Point of Common Coupling (PCC) and Voltage Source Converter (VSC) device.

The supply voltage and current of the proposed system with PI controller is provided below in figure 7 along with the load voltage and current waveform. In this, the source voltage is around 440V and source current is around 40A. The load voltage is around 460V and load current is around 13A. Here, unlike the base system, there is no unbalance between the phases even though the unbalanced load is connected.

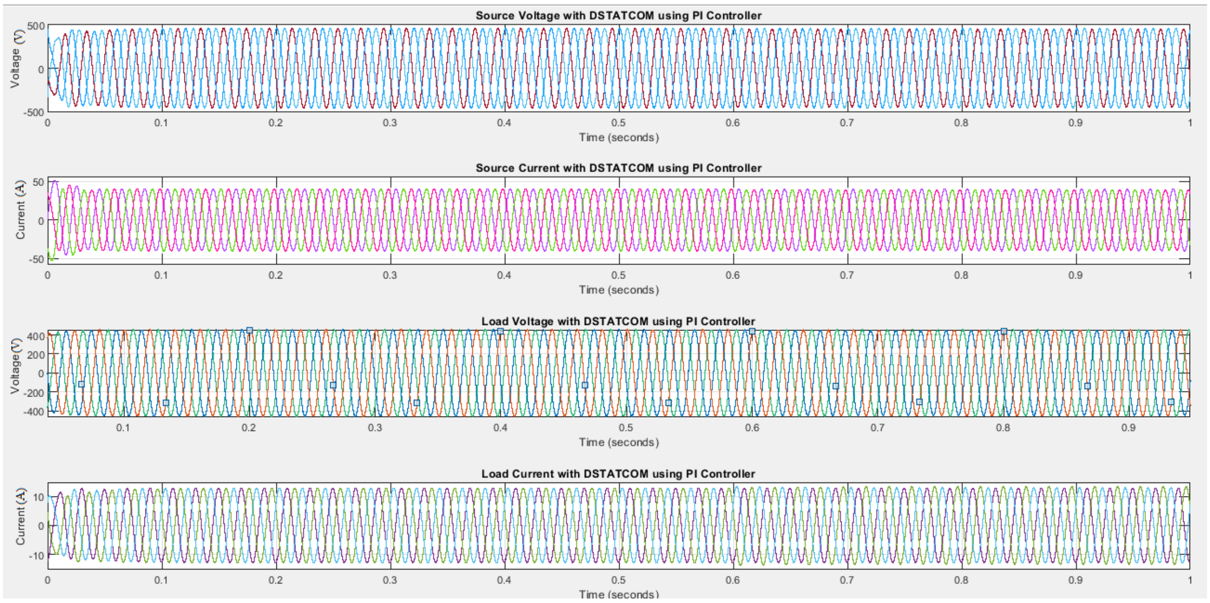

Fig 7. Waveforms for source voltage and current along with load voltage and current with DSTATCOM using PI Controller

The fuzzy controller replaces the PI controller in DC voltage control loop so that the overall performance of the system is improved. Similar to the PI Controller, the source voltage is also around 440V and source current is around 40A. The load voltage is around 460V and load current is also around 13A. Here too, unlike the base system, there is no unbalance between the phases even though the unbalanced load is connected. The waveforms are as shown in the figure 8.

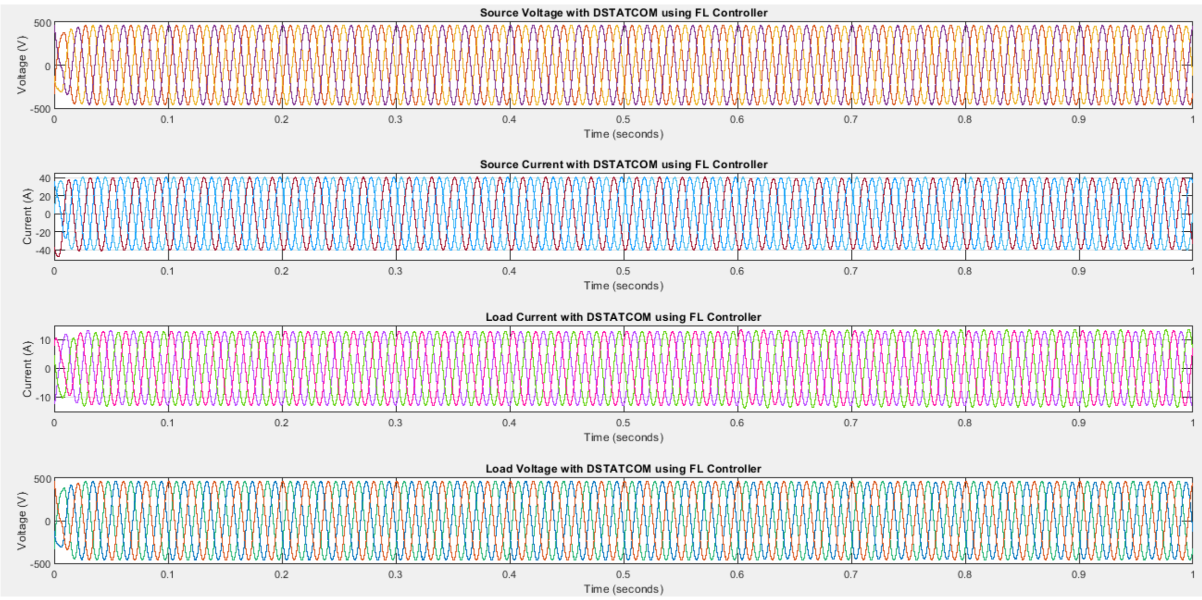

Fig 8. Waveforms for source voltage and current along with load voltage and current with DSTATCOM using FL Controller

The difference in phase angle between voltage and current is 48.6 degrees (0.0027s in terms of time period) in the base system without DSTATCOM. On using the PI controller, the difference in phase angle between voltage and current is zero degrees (0s in terms of time period) i.e., both voltage and current are in phase with each other. Similar waveforms are observed when FL controller is used in the DSTATCOM. This can be seen in the figure 9.

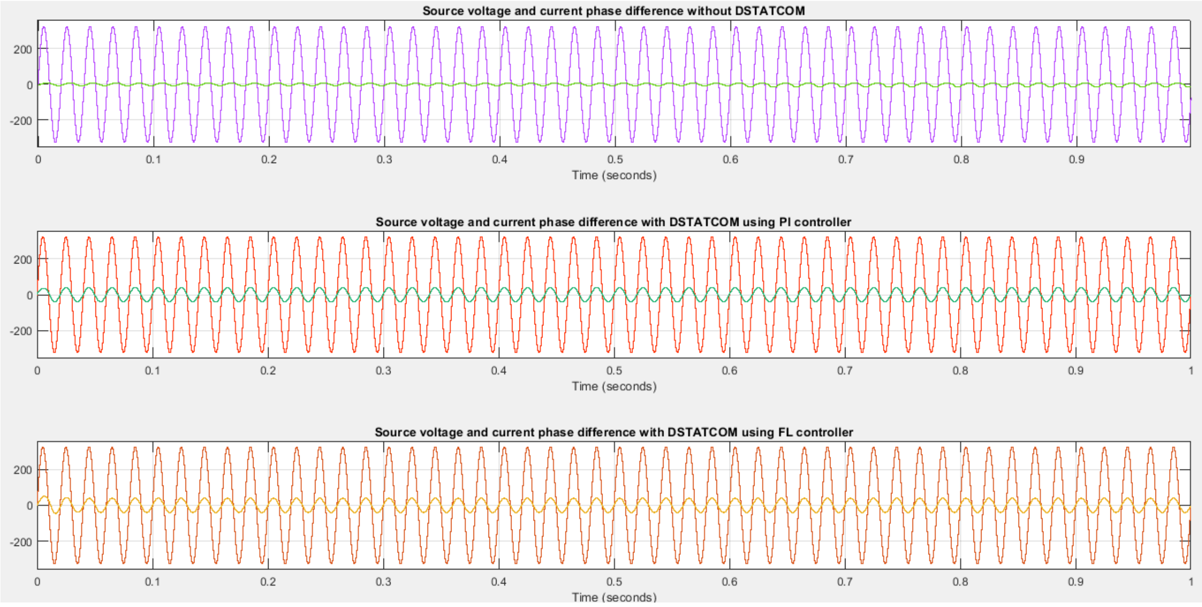

Fig 9 Phase difference between voltage and current

The DC link voltage of DSTATCOM is provided in Fig 10. For both the PI controller as well as FL controller, the DC link voltage is around 1KV as the reference dc voltage is provided as 1KV. Here the overshoots in FL controller are removed compared to PI controller where the peak overshoot is around 1053V.

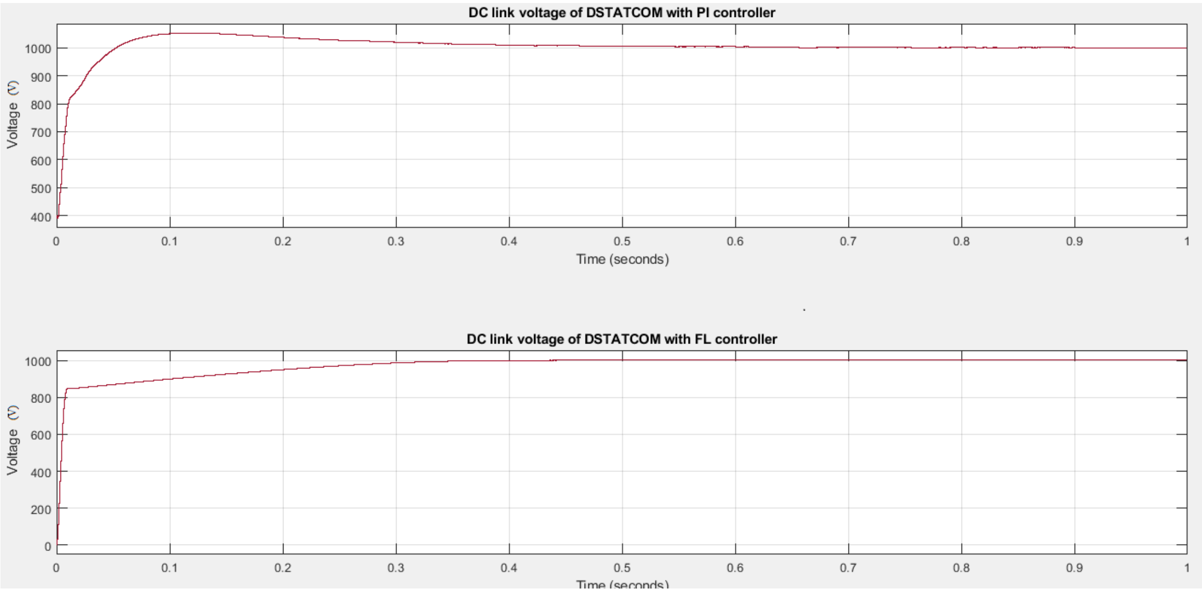

Fig 10 DC link voltage of DSTATCOM using PI controller and FL controller

The real power is around 6.8KW and reactive power is around 5.8KVAR when DSTATCOM using PI controller is employed. The real power is around 6.9KW and reactive power is around 5.7KVAR when DSTATCOM using FL controller is used. Due to the unbalanced load connected at t=0.6s, there are ripples present in both real and reactive power for DSTATCOM using PI controller as well as FL controller.

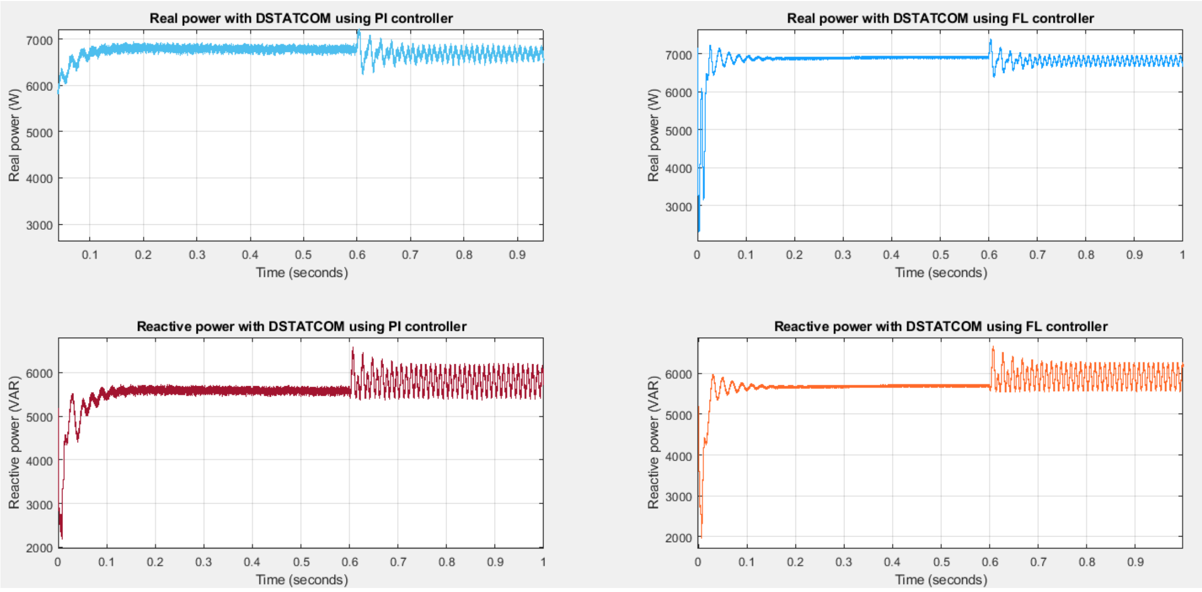

Fig 11 Real and Reactive power with DSTATCOM using both PI and FL controller

The % Total Harmonic Distortion (THD) of load current in the base system is around 10.50% as depicted in figure 12.

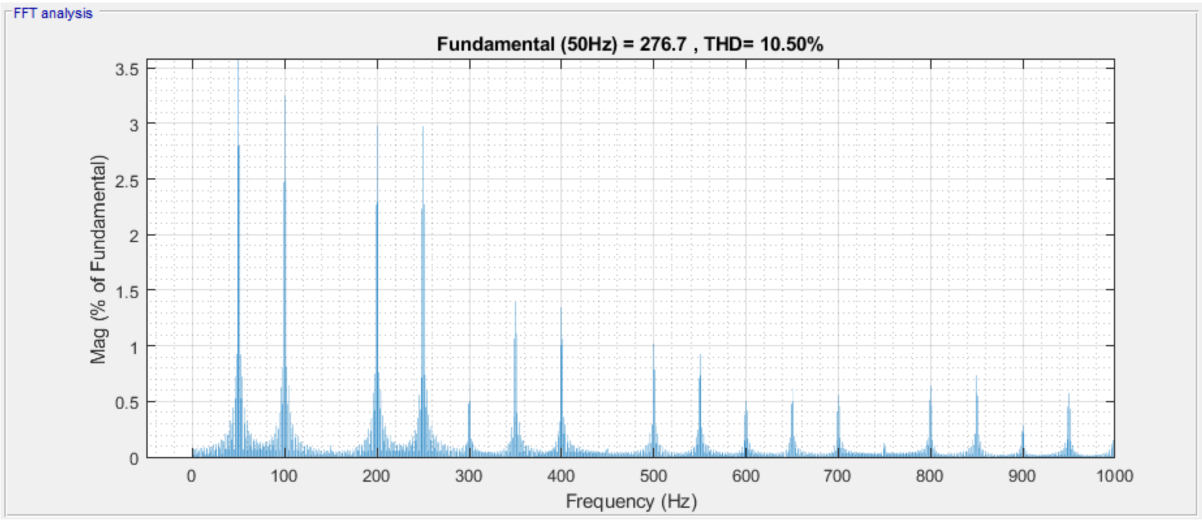

Fig 12 %THD of Load current without DSTATCOM

Harmonics can be even (2,4,6,8,10,12 etc) or odd (3,5,7,9,11 etc). Expressed as a percent of the fundamental, the Total Harmonics Distortion is defined as the ratio of the root mean square of the harmonic content, including the harmonic components up to the 50^{th} order. To meet the IEEE 519 standards, the THD limit for voltage up to 1kV is 8%. The design of DSTATCOM using PI controller yields around 4.06% THD as shown in figure 13 and that of FL controller yields around 2.11% THD as depicted in figure 14.

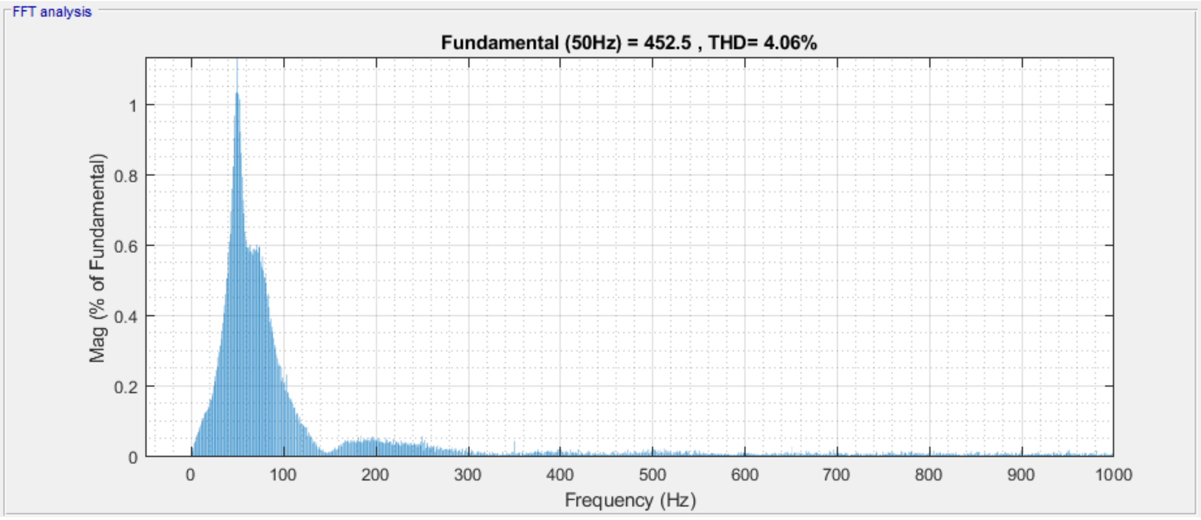

Fig 13 %THD of Load current with DSTATCOM with PI controller

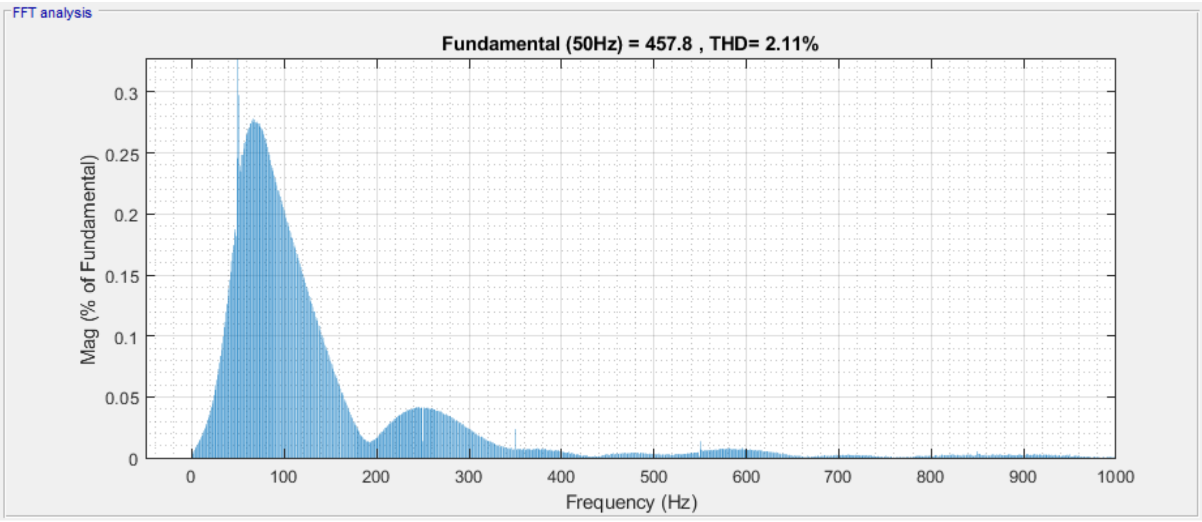

Fig 14 %THD of Load current with DSTATCOM with FLC controller

The comparison of different parameters with and without DSTATCOM (both PI & FL converters) is summarized in the table below.

Table 2. Comparison of parameters with and without DSTATCOM.

Parameters	Without DSTATCOM	With DSTATCOM using PI controller	With DSTATCOM using FL controller
Phase angle between voltage and current	48.6 degree	Zero degree	Zero degree
Power factor correction	0.66	0.99 ≈ 1	0.99 ≈ 1
% THD	10.50	4.06	2.11

6. CONCLUSION

In this paper, a distribution network is subjected to non-linear and unbalanced loads and the disturbances are included. The DSTATCOM is introduced into the system with PI and FL controllers separately and the performance of the system under these controllers are presented. The PI controller based DSTATCOM gives better power factor correction and %THD is reduced from 10.50 to 4.06 and also the load voltage is regulated. The FL controller improves the performance by reducing the power oscillations and improves the power injection by reducing the overshoot in DC link voltage. It brings down the %THD to 2.11 from the initial value of 10.50. The %THD is found to be much improved with FL compared to PI controller.

7. ANNEXURES

The simulation parameters are provided in the following table

Table 3. Simulation Parameters

Parameters	Values
Supply Voltage	415V
Frequency	50Hz
Load Parameters	R=30Ω, L=70mH
Non-Linear load parameters	R=60Ω, L=0.15mH
Coupling Transformer Parameters	V1/V2=450V/450V Frequency=50Hz Power=5kVA
Filter parameters	R=0.01Ω L=16μH C=0.32mF

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