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*Original Article*

# Control Algorithms for DSTATCOM Using ANN Controller

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***Abstract* — *Due to state-of-art technologies being implemented in today's power systems. The non-linear loads in the power system cause most of the problems in the electrical power system, such as burden on reactive power and unbalance. To solve these problems, using a distribution static synchronous compensator (DSTATCOM) is widely established. The compensating current for DSTATCOM is determined using two distinct methods in this paper. The instantaneous reactive power theory (p-q theory) and synchronous reference frame theory (d-q theory) are the methodologies that are compared using ANN controller. SIMULINK is used to simulate these two systems in a MATLAB environment. The performance of several strategies for controlling DSTATCOM is depicted in simulation results.*

***Keywords* — *ANN controller, Algorithms, DSTATCOM, p-q theory, d-q theory, PCC.*

## I. INTRODUCTION

Semiconductor technology has improved in recent years, as have power electronics equipment is with a wide range of voltage, current, and switching frequency. Uninterruptible power supplies, switching mode power supplies, electric drives, battery chargers, fans, pumps, and other devices consume the most electricity. Some of the loads take current with the lagging pf, producing a heavy reactive power demand in the distribution network. Furthermore, when there are uneven loads, the situation again worsens. Because of the non-linear nature of such loads, the majority of these power devices may face the issues like harmonics generation and reactive power. The presence of harmonic current and reactive current causes an increase in power losses and a decrease in power factor. In addition to that, the distribution system's active power flow capabilities will be reduced.

DSTATCOM is a shunt-configured power device used in the distribution network to provide compensation for harmonics, reactive power, PCC voltage, power factor correction, etc.

The control algorithms are the techniques for extracting current components and control procedure employed to generate the reference current. So many numerous control algorithms are documented in various kinds of literature. DSTATCOM is controlled primarily by time domain as well as frequency-domain techniques. Frequency domain algorithms are mostly sluggish and demand more processing burden, so that time-domain algorithms are preferred over frequency-domain algorithms.

This paper uses an ANN controller in DSTATCOM, which is controlled by the p-q and d-q theory algorithm for compensation of the source current harmonics and PCC voltage. Finally, the controller's performance is compared using these two algorithms. The algorithms that use ANN controller, which is accessible to implementation and requires minimal computational work. The reference current is extracted without phase shift using a least mean square (LMS) dependent reference current estimator. For the computation of weights, a neural network with LMS adaptive online evaluator approach has been used to estimate reference currents.

For these two DSTATCOM control approaches, a detailed MATLAB simulation is shown. The effectiveness of DSTATCOM's control algorithms with ANN controller to reduce harmonics available in the source current is also discussed. To generate firing pulses for DSTATCOM, hysteresis band control is used in this paper.

## II. SYSTEM CONFIGURATION

The DSTATCOM system's basic schematic diagram with a non-linear load having a lagging power factor coupled to a 3-phase 3-wire distribution system is shown in Figure 1. A three-phase universal diode bridge converter with Resistive inductive (R-L) loads provides the lagging power factor acts as a non-linear load. At the Point of Common Coupling (PCC), Six IGBT's using diodes in an anti-parallel position are used to create a 3-ϕ voltage source converter (VSC) that is realized as the DSTATCOM. On the AC side, interfacing inductors are mainly employed to filter out high-frequency terms in the compensation current. DSTATCOM provides compensating current $i_c$ so as to remove harmonic components present in source current and tries to maintain source current sinusoidal as well as inphase with source voltage in order to achieve source side power factor unity.

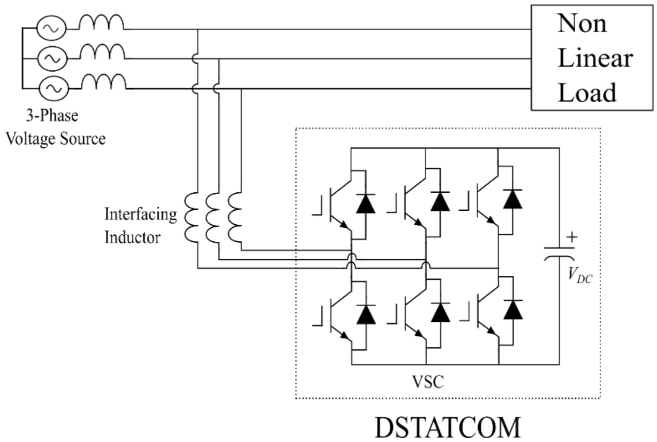


**Fig. 1 DSTATCOM Schematic**

## III. CONTROL ALGORITHMS

Control strategies are used to produce the compensating reference currents for VSI of DSTATCOM. This paper presented algorithms with new ANN controller-based approaches for obtaining the reference signal, which is an essential factor in DSTATCOM control.

### *A. Instantaneous Reactive Power Theory (IRP)*

Professor Akagi first introduced the instantaneous reactive power theory, generally named the p–q theory, in 1983. In the α-β transformation, 3-ϕ voltages, as well as load currents, are converted into 2-ϕ terms. α-β transformation is employed to compute instantaneous active and reactive power. Also, Reverse Clark's transformation is used to convert reference current in α-β transform to ABC transform.

$V_a$, $V_b$, $V_c$ are three-phase voltages and $i_{La}$, $i_{Lb}$, $i_{Lc}$ are three-phase load currents. These voltages and currents transform into $the\, \alpha-\beta$ frame using Clark's transform given below:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} \mathrm{i}_\alpha \\ \mathrm{i}_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} \mathrm{i}_{la} \\ \mathrm{i}_{lb} \\ \mathrm{i}_{lc} \end{bmatrix}$$

Here $\alpha$ and $\beta$ represent the orthogonal coordinates. In three-phase circuits, instantaneous active power and instantaneous reactive power are written as:

$$p_i = v_\alpha i_\alpha + v_\beta i_\beta$$
$$q_i = v_\alpha i_\beta - v_\beta i_\alpha$$

Instantaneous active power $p_i$, as well as reactive powers $q_i$, are given in matrix forms as follows:

$$\begin{bmatrix} p_i \\ q_i \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Here active as well as reactive power decomposed as:

$$p_i = \tilde{p} + \bar{p}$$
$$q_i = \tilde{q} + \bar{q}$$

In this decomposition, the average ($\bar{p}$) part of active and average ($\bar{q}$) part reactive power along with and oscillatory ($\tilde{p}$) part of active and oscillatory ($\tilde{q}$) part of reactive power shown. Reference source currents $i^*{}_{sa}$ , $i^*{}_{sb}$ compensate for the oscillatory part of instantaneous active power and the instantaneous reactive power. Matrix form of Reference source currents represented as:

$$\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix}$$

Where $\Delta = v_\alpha^2 + v_\beta^2$

By using the method of reverse Clark's transform reference source currents $i^*{}_{sa}$ and $i^*{}_{sb}$ transform in the a-b-c frame for calculating reference values of currents into a-b-c coordinates:

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} 0 \\ i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix}$$

These reference current values further given to hysteresis current controller for generation of switching pulses for IGBTs of DSTATCOM**.**

### *B. Synchronous Reference Frame Theory (SRF)*

The control approach for SRF theory is built upon transforming the current in the synchronously rotating d-q-0 frame. PLL process sensed voltage signals $V_a$, $V_b$, $V_c$ to generate sine (sinθ) and cosine (cosθ) signals. Current values are sensed, converted into a d-q frame, and then filtered. The filtered currents are reverse transfer to an a-b-c frame for switching pulse generation then supplied to a hysteresis band control. Figure 2 presents the SRF algorithm in detail.

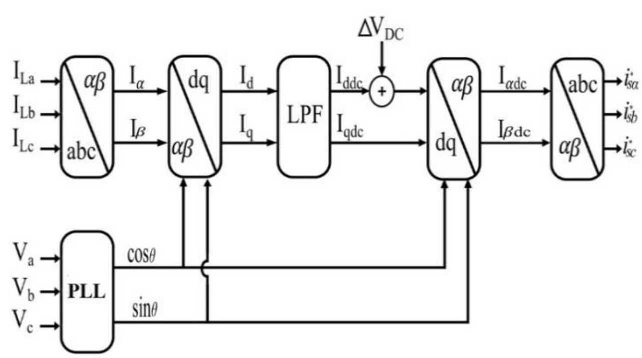


**Fig. 2 SRF algorithms**

With the help of Park's transformation, all currents generated in $\alpha-\beta$ coordinates are transferred to *the d-q* frame using θ as transformation angle:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

$i_{ddc}$ is DC components of $i_d$, and $i_{qdc}$ is DC components of $i_q$ extracted using the LPF. These currents transformed back into $\alpha-\beta$ coordinates using reverse Park's transform:

$$\begin{bmatrix} i_{\alpha dc} \\ i_{\beta dc} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{ddc} \\ i_{qdc} \end{bmatrix}$$

To produce 3-ϕ reference source currents in the a-b-c frame, these currents mainly translated as follows:

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

Without considering the source voltages, the current reference quantity is mainly borrowed from load currents, one of the essential features of this algorithm. This is a significant benefit because the reference signals are not impacted by voltage imbalance or voltage distortion, resulting in increased flexibility and effectiveness of compensation.

### *C. ANN Controller*

The DSTATCOM with ANN controller is developed to increase DSTATCOM's dynamic performance. With non-linear load conditions, Conventional PI controllers fail to obtain satisfactory results. So, that ANN network comprises two layers, each with its own set of neuron interactions. In the input layer, a '1' neuron takes the inputs—the middle layer, which consists of ten neurons that receive the input after processing. The output layer uses a single neuron, which is output taken into consideration for reference current calculation. Activation transfer functions are allocated to every layer individually to train it. The input layer uses activating function, which is the hyperbolic tangent sigmoidal transfer function, whereas the output layer's activating function is the identity transfer function. Figure 3 depicts the proposed ANN controller scheme.

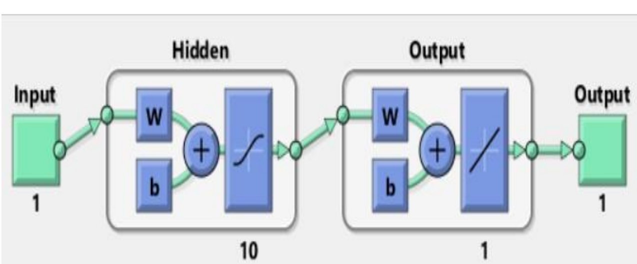


**Fig. 3 Internal block of the proposed neural network controller**

#### *a) Training Algorithm for ANN Controller*

- Obtain DC link voltage for different intervals and saved it in the MATLAB workspace.
- Enter 'nftool' in the workspace; it will start ANN fitting app.
- Select input and target data from the workspace
- Enter the number of hidden neurons required
- Choose the training algorithm as Levenberg-Marquardt backpropagation.
- Train the ANN model for a particular input and output.
- Generate the simulation diagram for the trained neural network.

## IV. SIMULATIONS

Using the above technique, a Neural Network with fixed multiple neurons in every layer is generated. The difference between the $V_{DC}$ and the reference value is given to the artificial neural network controller's input. Harmonics mitigation is the result of ANN's output.

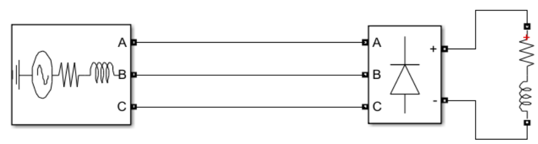


**Fig. 4 Uncompensated 3-ϕ system**

### *A. Uncompensated System*

Fig. 4 shows a simulation schematic for a 3-Phase, 3-wire distribution system supplied to a non-linear load coupled with a three-phase voltage source. 3-Phase bridge rectifier used with R-L load act as non-linear load in this case. In an uncompensated system, there is no presence of DSTATCOM in the system. Figure 5 displays the source current and load current waveforms in an uncompensated system. The load current waveform in an uncompensated system is non-sinusoidal with harmonics mainly because of a non-linear load; also, because of an uncompensated system, the identical waveform is reflected on the source site.

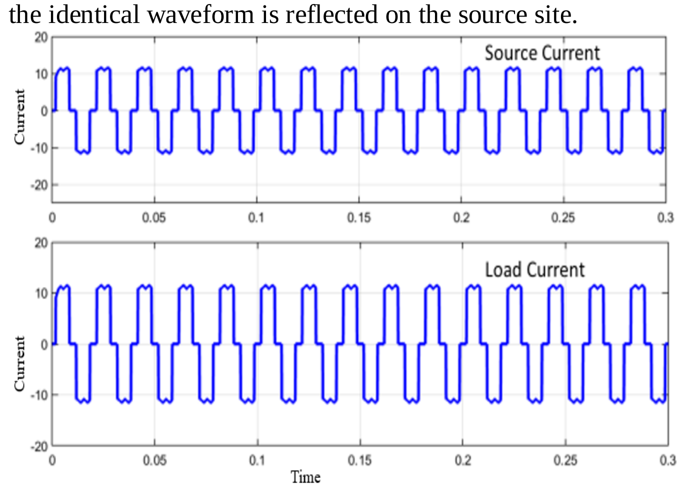


**Fig. 5 Simulation outcomes of uncompensated system**

Total harmonics present in the source current is near about 29.87 %, as shown in figure 6. To minimize the presence of harmonics in the current, system must compensate.

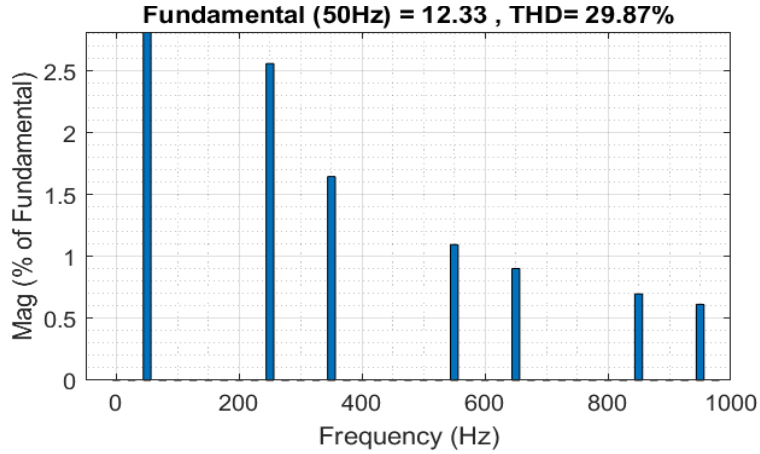


**Fig. 6 THD in source current for uncompensated system**

### *B. Compensated System*

Simulation circuit of DSTATCOM with p-q theory with ANN controller shown in the figure. 7

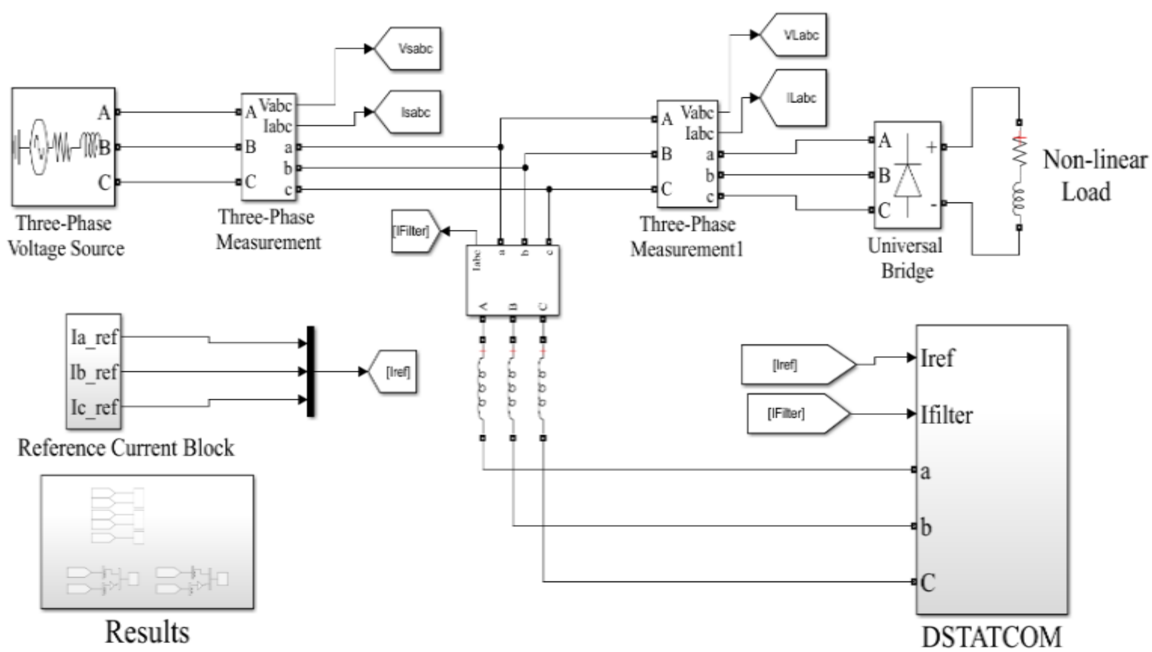


**Fig. 7 Simulation circuit of DSTATCOM with p-q theory**

**Table 1 . Parameters used for simulation**

| | |
|---|---|
| Source Voltage | 415 Volts, 50Hz |
| Source Impedance | 0.1mH |
| Load | R=50 ohm, L= 50mH |
| Active filter inductor | 4.25 mH |

Fig. 8 depicts the simulation outcomes of the p-q theory with the ANN controller. When a compensated system is compared to an uncompensated system, the time lag is reduced, and the waveforms become sinusoidal with minimal distortions in source current. It was also discovered that injecting the capacitor current eliminates source current harmonics because the voltage across the capacitor is constant.

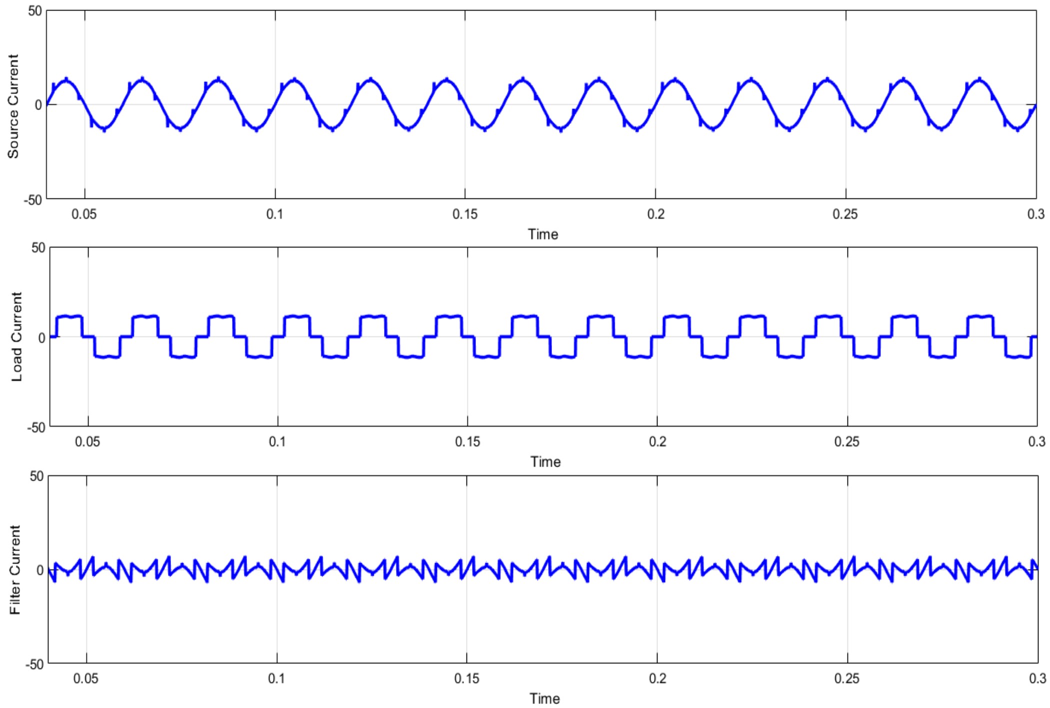


**Fig. 8 Simulation outcomes of p-q theory with ANN**

DSTATCOM with p-q theory using ANN controller mainly reduces the fewer distortions in source current and makes it sinusoidal. Here is a compensated system with ANN controller, THD in source current reduces from 29.87% to 5.51%, as depicted in figure 9

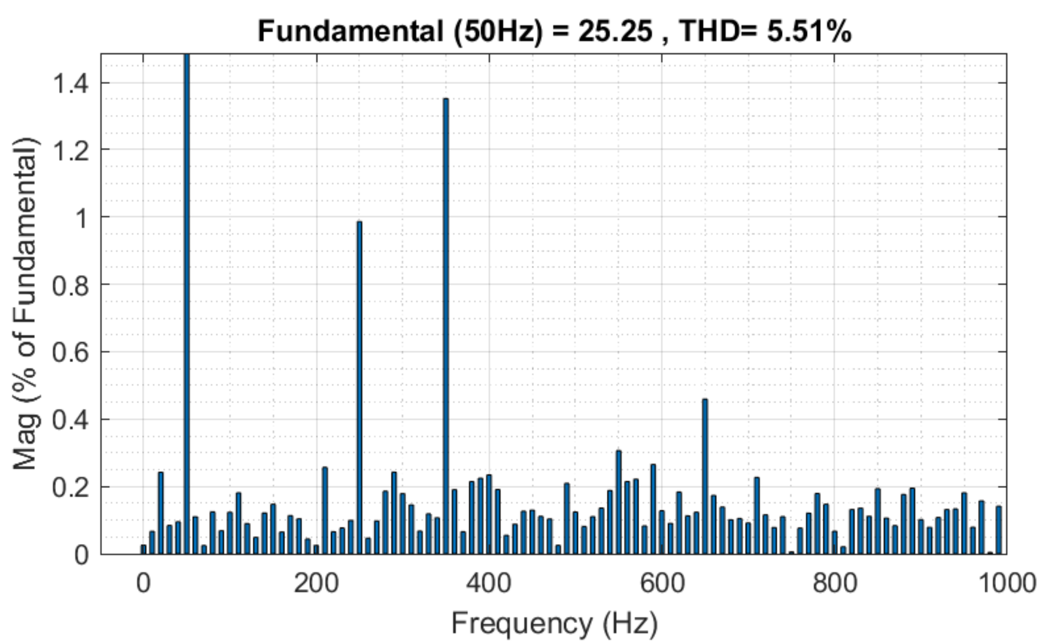


**Fig. 9 sources current THD for PQ theory with ANN controller**

In this case, the voltage across the capacitor takes 0.01 sec to achieve a steady-state with the help of the ANN controller. The voltage across capacitor response depicts in figure 10.

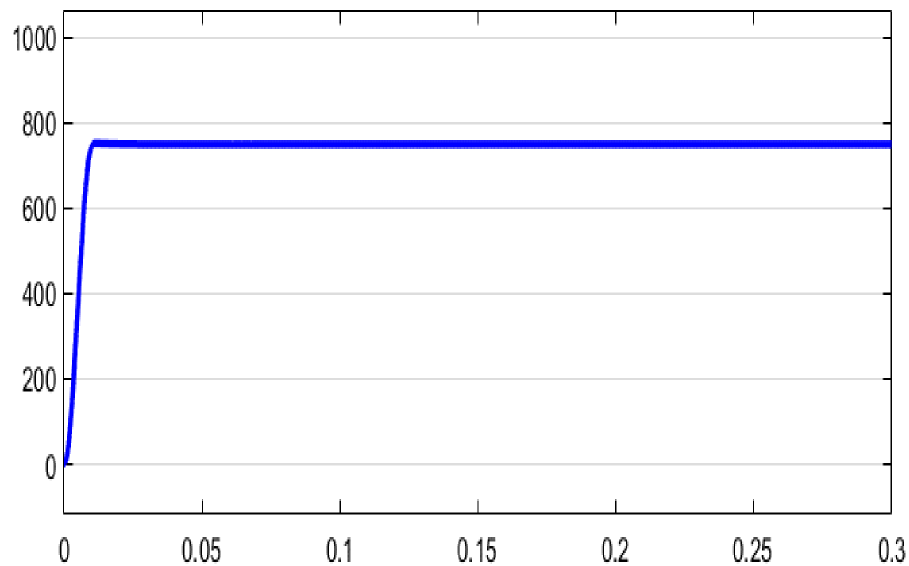


**Fig. 10 Voltage across the capacitor in IRP theory**

Figure 11 gives the simulation results of synchronous reference frame theory with ANN controller used.with this theory source current get more sinusoidal than IRP theory also it achieve source power factor to near to unity.

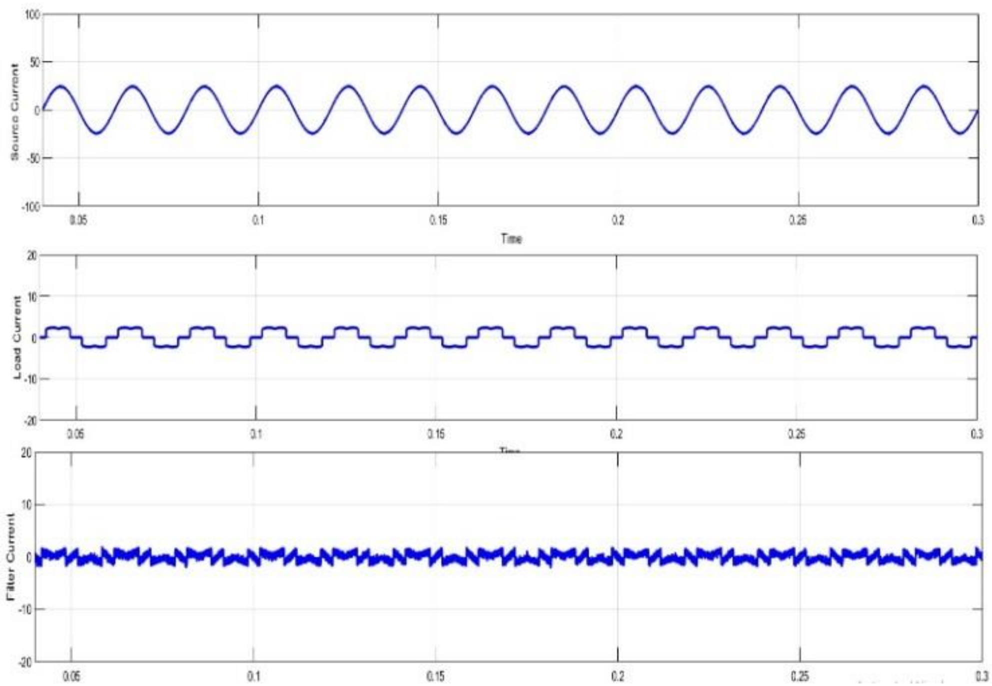


**Fig. 11 Simulation outcomes of SRF theory with ANN controller**

Here in figure 12, also due to the ANN controller, it takes 0.011 seconds for voltage across the capacitor to attain a steady-state value.

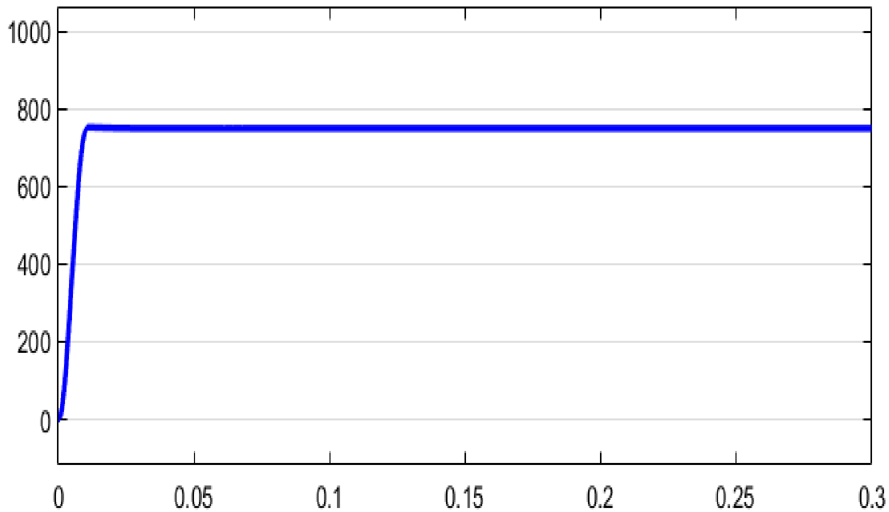


**Fig. 12 T source current THD for SRF theory using ANN Controller**

From figure 13, it is mainly verified that the source current THD minimized to 2.41% from 29.87%.

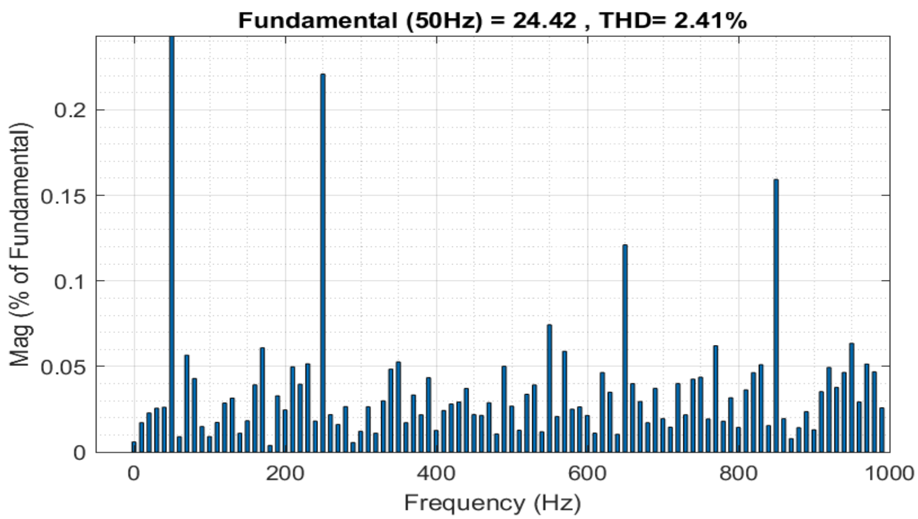


**Fig. 13 THD in source current for SRF theory using ANN**

Table 2 represents the comparison results of the simulation performed in MATLAB Simulink.

**Table 2. Summary of results**

| | UnCompensated System | p-q Theory | d-q theory |
|---|---|---|---|
| **THD** | 29.87 | 5.51 | 2.41 |
| **Time for $V_{DC}$ to settle in Sec.** | -- | 0.11 | 0.11 |

## V. CONCLUSION

A complete analysis of a DSTATCOM using p-q and d-q theories with ANN controller is recommended in this paper to minimize harmonics in three-phase distribution systems. The obtained results demonstrate the proposed ANN controller's simplicity and effectiveness under non-linear load situations. Total harmonic presence in source current is reduced better using ANN controlled DSTATCOM, according to the results. The modelling and simulation study reveal that the new ANN controller method is simple to compute and execute, but it is also very successful at minimizing harmonics.

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