Performance Analysis of D-STATCOM and UPQC in Distribution System

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***Abstract*—Power supply in the distributed system is one of the most crucial tasks. Various methodologies are being used by the researchers to maintain the efficacious flow of supply. However, there are certain issues of power supply mechanism that affects the system performance. These issues include voltage sag, imbalance, flicker and also harmonic distortion in terms of current and voltage. A significant number of techniques have been proposed to deal with this problem. In the field of high power custom power devices, D-STATCOM and UPQC are two most preferred technologies among these that have been preferred rigorously in the distribution systems. This paper proposed implementation and comparison of these two devices based on synchronous reference frame theory in order to enhance the voltage and current stability by reducing the harmonic distortion in the distribution system. The results are based on the extensive simulations performed in the MATLAB environment.**

Keywords: D-STATCOM, UPQC, Power Supply, Distributive Generation.

I. Introduction

One of the main constraints is the provision of power requirements for the entire load while maintaining voltage range reasonable. The distribution systems feature two main traditional voltage control systems: series voltage control devices and shunt condensers. Traditional voltage series regulators are widely used in distribution system voltage regulations [1–3].

As the power electronics systems were improved in terms of current and voltage handling capacities to build the Flexible AC Transmission System (FACTS), various controller types could be used for effective shunt and serial compensation. FACTS devices should be taken into account when changing the network condition quickly. The FACTS definition for the transmission system was originally developed, but the same idea was introduced in distribution systems. Distribution STATCOM (D-STATCOM) is a source voltage converter connected with shunt and is basically used to compensate for certain problems with power quality, such as unbalanced load, voltage decrease, voltage fluctuations and voltage unevenness [4,5]. Dynamic Tensile Restorer (DVR) is a series-converter that addresses power quality issues such as voltage sag and voltage imbalance [6]. Although the performance of the D-STATCOM model is better than other systems, UPQC is one of the technologies available that can outperform the D-STATCOM performance. Unified power quality conditioner (UPQC) is an integrated series-and-shunt compensator that is utilized to enhance, decrease, and leading to the unbalance and flickering of voltages, improves harmonics, dynamic active and reactive power control [7-9]. UPQC is used for solving and increasing the power quality for both the voltage and current harmonic problems. This paper also includes the synchronous reference system theory for filter control on the computer.

A significant number of approaches have been designed in which authors have utilized UPQC. This section discussed some of the works done in this field.

Hosseini, et al [10] modeled UPQC in load flow calculations such that steady-state voltage could be compensated. A specific model was implemented to compute the load flows. A phasor diagram was designed to calculate and explain the model analytically and mathematically, along with the reactive injection direction needed in order to offset the voltage to the required amount (1 p.u). As the compensator's output varies when it exceeds its full power efficiency, UPQC modeling was extracted at its highest reactive power injection level. P. V. Kumar and R.Rajeswari, [11] suggested UPQC to enhance the issues related to the quality of power. SRF control strategy is used to simulate AUPQC combining the function of a series and shunt active power filter used at Specific Coupling Point (PCC) to boost the power quailty. A microcontroller (PIC18F877) UPQC prototype validates the algorithm. Raju Manuel,et al. [12] projected a model to alleviate harmonics compensation and power factor correction in a three-phase four-wire distribution system. The UPQC has a VSC converter and switching patterns are created by the use of Indirect PI and Synchronous Reference Frame controller. The whole system was built with the program MATLAB using its tool boxes for the stimulation of the control

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system. Pradeep Kumar et al [13] utilized DSTATCOM to alleviate the harmonics and power factor correction in a distribution system. Simulation was carried out to validate the model in terms of diode-rectifier and unbalanced R–L loads with a case study.Madhu et al. [14], In order to supply the sinusoidal current network, the UPQC shall be mounted in a distorted distribution line. This project proposed the placement of a UPQC for improving power quality in order to be evaluated in 33 bus radial distribution network.

In this paper, two techniques are designed such that the power quality issues can be resolved and the performance of the distributive generation is improved. Various techniques have been utilized to this end. The purpose of this model is to enhance the voltage and current stability. D-STATCOM and UPQC are two technologies that are utilized to reduce the total harmonic distortion in the power supply of distributive generation. The techniques are designed to assess their performance in terms of voltage and current distortion. With the help of these technologies, two systems are achieved and the performance analysis is performed to validate the higher efficacy. The proposed UPQC based model is scrutinized with and without UPQC. The same procedure is done for D-STATCOM model. The entire simulations are performed in MATLAB environment and the results achieved for each model are compared with each other in with respect to the supply current and the voltage.

After surveying different works, this paper proposed a model that utilized UPQC for enhancing the different aspects such as current and voltage in the power quality. To this end, the simulation of the model is done with and without UPQC in MATLAB. The main purpose of this paper is to compare the effectiveness of the D-STATCOM and UPQC in distributive systems. Thus, for both the methods, control strategies are present and the comparison of the performance in terms of Current and voltage terminal is carried out to assess the proposed model.

II. DSTATCOM

DSTATCOM is a power device utilized for the removal of harmonic from the source current and also for balancing it in order to improve the power factor or to control the load bus voltage by providing power compensation. It has components that are based on a high-performance electronics technology.

The main component is voltage source converter (VSC). It comprises mainly of an IGBT, a control and a contact transformer DC voltage source behind self-commutated inverters. The IGBT inverter can be configured as a variable voltage source with a DC voltage source. It is also possible to model the electricity delivery network as a power source.

A. Control Strategy of D-STATCOM

DSTATCOM's output relies on the control algorithm used to extract current components of the reference. To this end, a variety of literature control schemes are mentioned, some of which include instantaneous reactive power theory (IRP), instantaneous symmetric components, a theory of synchronous reference frame(SRF), DC bus regulation, phase-based calculations, and neural network-based schematics [15-20]. SRF theory is most commonly used in this control system.

1. Synchronous Reference Frame (SRF) based Control Strategy

A block diagram of the control scheme is shown in the following figure 1. The PCC (point of common coupling) voltages (V_{qr}, V_{qy}, and V_{qb}), load currents (i_{La}, i_{Lb}, and i_{La}), and dc bus voltage (V_{dc}) of DSTATCOM are referred to as feedback signals.

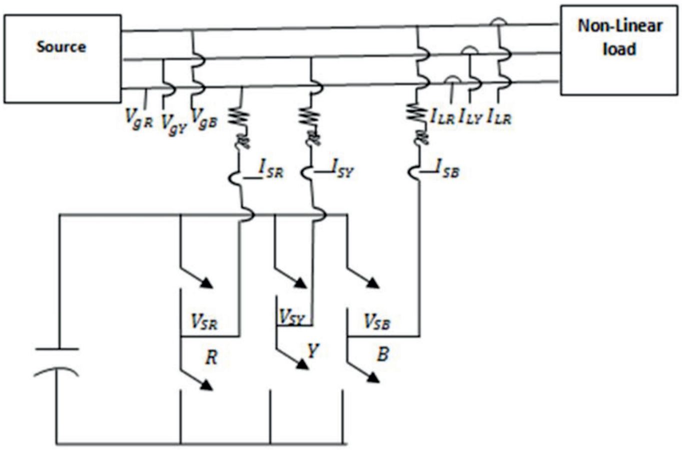

Fig. 1: Block Diagram of D-STATCOM

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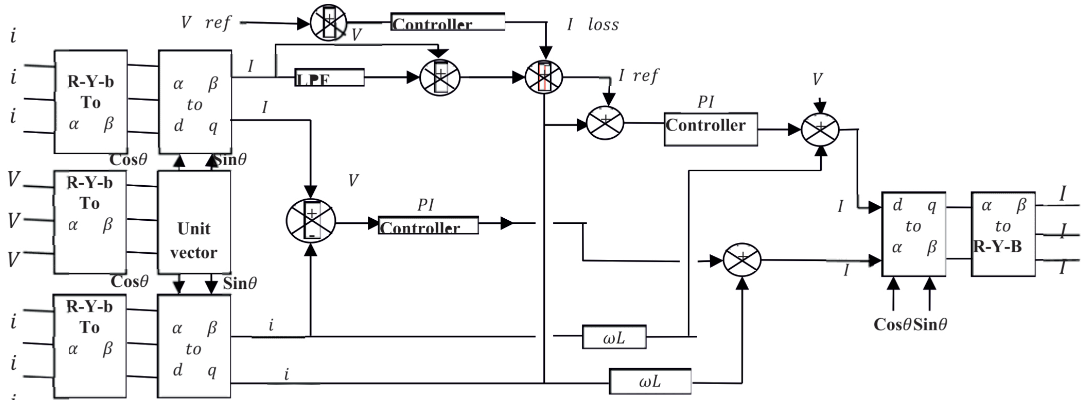

Fig. 2: Control Strategy of D-STATCOM

This process involves the conversion of load currents from the a–b–c frame to the a– β frame and then to the d–q frame by applying the formulation given below:

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = {}^{2}/_{3} \begin{Bmatrix} 1 & -1/2 & --1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{Bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{Bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{Bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = 2/3 \begin{Bmatrix} \cos\omega t & \cos(\omega t-(2\pi/3)) & \cos(\omega t+(2\pi/3)) \\ \sin\omega t & \sin(\omega t-(2\pi/3)) & \sin(\omega t+(2\pi/3)) \end{Bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (3)$$

The output of low pass filters gives the average values of i_Ld and i_Lqthat is computed by using equation (4):

$$\begin{bmatrix} \overline{i_{Ld}} \\ \overline{i_{Lq}} \end{bmatrix} = G(s) \begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} \quad (4)$$

In eq. (4), G(s) is the selected as the transfer function of a second order Butterworth low pass filter.

With the help of the following mathematical equation, the conversion of the reference for the source current from the d-q frame to the α–β frame is performed and eventually a-b-c frame is achieved shown in

$$\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} = \begin{Bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{Bmatrix} \begin{bmatrix} i^*_{sd} \\ i^*_{sq} \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = {}^{2}/_{3} \begin{Bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{Bmatrix} \begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = {}^{2}/_{3} \begin{Bmatrix} \cos\omega t & \sin\omega t \\ \cos(\omega t-(2\pi/3)) & \sin(\omega t-(2\pi/3)) \\ \cos(\omega t+(2\pi/3)) & \sin(\omega t+(2\pi/3)) \end{Bmatrix} \begin{bmatrix} i^*_{sd} \\ i^*_{sq} \end{bmatrix} \quad (7)$$

III. Unified Power Quality Conditioner (UPQC)

UPQC is a method for compensating the voltage sag and voltage imbalances in the power grid. UPQC is the universal power quality conditioner. The voltage is thus entirely balanced on the load side, sinusoidal and well adjustable. The current at the source side is thus completely sinuous and free of distortion, which is often used for compensating load current harmonics.

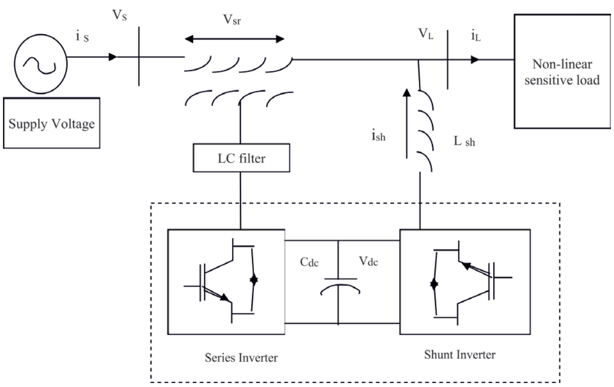

Fig.3: Block Diagram of UPQC

A Shunt and Series Active Power Filter together forms UPQC. In order to minimize the load current harmonics, Shunt Active power filter (APF) is utilized. The APF series helps to minimize voltage deformation and imbalance that is present on the load-side and to perfectly balance, regulate the voltage on. The shunt APF inverter is operated by an inverter with variable current source and APF is operated by an inverter with a variable voltage source. The shunt compensator control scheme is shown in Fig. 6. In addition to compensating for harmonics and unbalances in charges, the shunt compensator controls the DC bus voltage.

A. Synchronous Reference Frame Control Strategy for UPQC

This process involves the conversion of load currents from the a–b–c frame to the a– β frame and then to the d–q frame by applying the formulation given below:

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = {}^{2}/_{3} \begin{Bmatrix} 1 & -1/2 & --1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{Bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (8)$$

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$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{Bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{Bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (9)$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = 2/3 \begin{Bmatrix} \cos\omega t & \cos(\omega t-(2\pi/3)) & \cos(\omega t+(2\pi/3)) \\ \sin\omega t & \sin(\omega t-(2\pi/3)) & \sin(\omega t+(2\pi/3)) \end{Bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (10)$$

With the help of the following mathematical equation, the conversion of the reference for the source current from the d-q frame to the α–β frame is performed and eventually a-b-c frame is achieved shown in eq. (12). low-pass filter is used to remove dc quantities from the SRF controller and, thus, the non-dc quantity (harmonics) is isolated from the reference signal. As a proportional controller, the DC voltage controller is built. The current i_{Cd} is called the output of the proportional (P) controller at the dc bus voltage.

$$\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} = \begin{Bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{Bmatrix} \begin{bmatrix} i^*_{sd} \\ i^*_{sq} \end{bmatrix} \quad (11)$$

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = {}^{2}/_{3} \begin{Bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{Bmatrix} \begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} \quad (12)$$

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = {}^{2}/_{3} \begin{Bmatrix} \cos\omega t & \sin\omega t \\ \cos(\omega t-(2\pi/3)) & \sin(\omega t-(2\pi/3)) \\ \cos(\omega t+(2\pi/3)) & \sin(\omega t+(2\pi/3)) \end{Bmatrix} \begin{bmatrix} i^*_{sd} \\ i^*_{sq} \end{bmatrix} \quad (13)$$

Further, the source current vector $(i^*_{sa}, i^*_{sb}, i^*_{sc})$ is determined and the desired compensator currents $(i^*_{Ca}, i^*_{Cb}, i^*_{Cc})$ are computed by attaining the difference between the load and the source currents. This computation is performed on synchronous reference frame (SRF) theory.

$$i^*_{Ca} = i_{La} - i^*_{Sa} \quad i^*_{Cb} = i_{Lb} - i^*_{Sb} \quad i^*_{Cc} = i_{Lc} - i^*_{Sc}$$

In eq.15, ω is the supply frequency with the units radians/sec. phase-locked loop (PLL) is used to attain unit vectors cos ωt and sin ωt. PLL is locked to the PCC voltage. The schematic shown in figure 7 represents the control strategy of the series compensator.

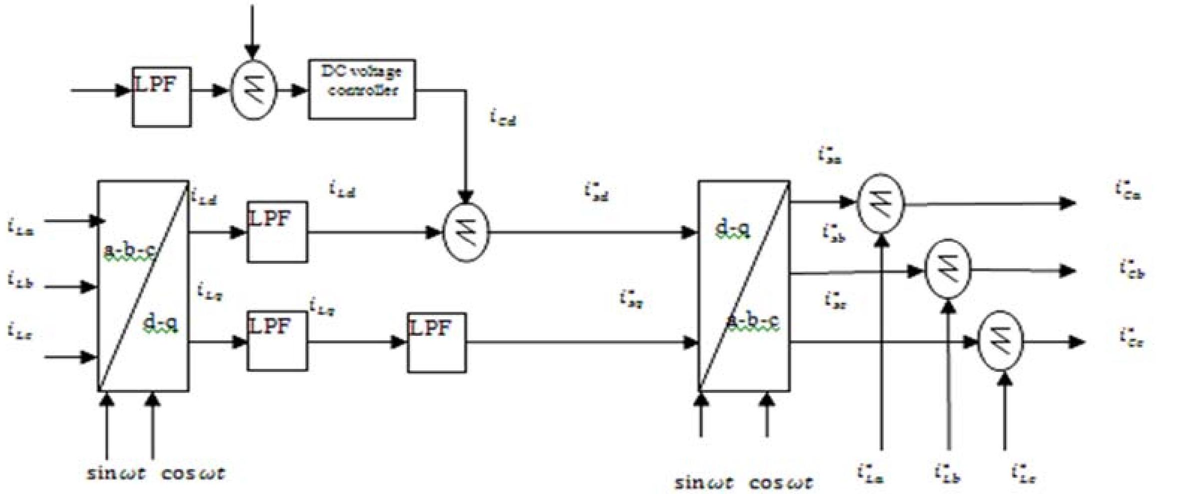


Fig. 4: Shunt Compensator Control Scheme For Generation Of Reference Compensator Currents

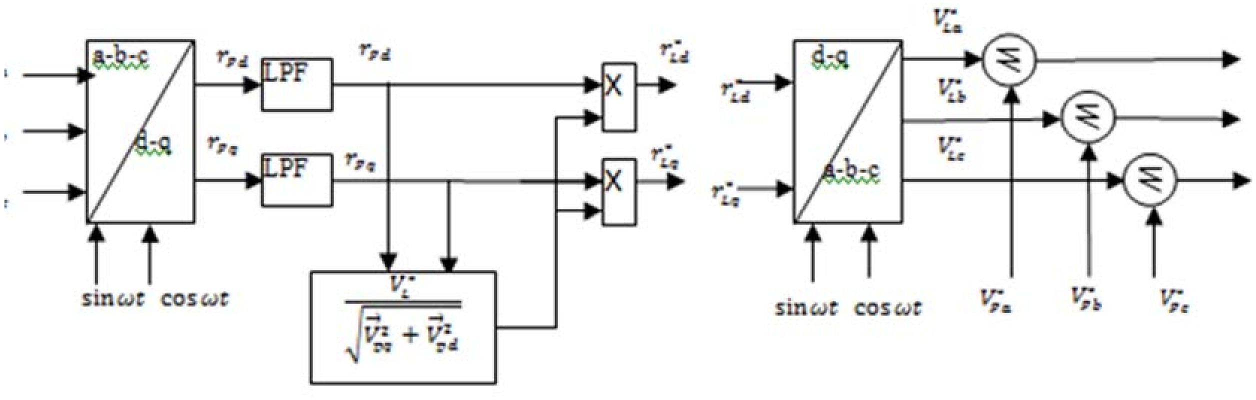


Fig. 5: Series Compensator Control Scheme

The transformation of PCC voltage (V_{Pa}, V_{Pb}, V_{Pc}) is performed into d-q components by implementing a-b-c to α-β and then α-β to d-q frames:

$$\begin{bmatrix} V_{P\alpha} \\ V_{P\beta} \end{bmatrix} = {}^{2}/_{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{Pa} \\ V_{Pb} \\ V_{Pc} \end{bmatrix} \tag{14}$$

$$\begin{bmatrix} V_{Pd} \\ V_{Pq} \end{bmatrix} = \begin{bmatrix} \cos\omega_o t & \sin\omega_o t \\ -\sin\omega_o t & \cos\omega_o t \end{bmatrix} \begin{bmatrix} V_{P\alpha} \\ V_{P\beta} \end{bmatrix} \tag{15}$$

Where $\omega_o\ t$ is the operating system frequency Moreover, A low pass filter is utilized to extract the DC components (V_{Pd} and V_{Pq}). Equation 14 is use to compute the components $\bar{V}_{Pd}$ and $\bar{V}_{Pq}$ in and G(s) is the transfer function of the filter.

$$\begin{bmatrix} \bar{V}_{Pd} \\ \bar{V}_{Pq} \end{bmatrix} = G(s) \begin{bmatrix} V_{Pd} \\ V_{Pq} \end{bmatrix} \tag{16}$$

Subsequently, to obtain the required load, following formulae are used:

$$V_{Ld}^{*} = \bar{V}_{Pd} \left(V_L^{*} \Big/ \sqrt{\bar{V}_{Pq}^{\ 2} + \bar{V}_{Pd}^{\ 2}} \right) \tag{17}$$

$$V_{Lq}^{*} = \bar{V}_{Pq} \left(V_L^{*} \Big/ \sqrt{\bar{V}_{Pq}^{\ 2} + \bar{V}_{Pd}^{\ 2}} \right) \tag{18}$$

To obtain the load voltage using and V_{Lq}^{*} and V_{Ld}^{*} in phase coordinates of a-b-c components, the conversion of d-q to α-β frame and then α-β to a-b-c conversion is performed as show in below:

$$\begin{bmatrix} V_{L\alpha}^{*} \\ V_{L\beta}^{*} \end{bmatrix} = \begin{bmatrix} \cos\omega_o t & \sin\omega_o t \\ -\sin\omega_o t & \cos\omega_o t \end{bmatrix} \begin{bmatrix} V_{Ld}^{*} \\ V_{Lq}^{*} \end{bmatrix} \tag{19}$$

$$\begin{bmatrix} V_{La}^{*} \\ V_{Lb}^{*} \\ V_{Lc}^{*} \end{bmatrix} = {}^{2}/_{3} \begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{L\alpha}^{*} \\ V_{L\beta}^{*} \end{bmatrix} \tag{20}$$

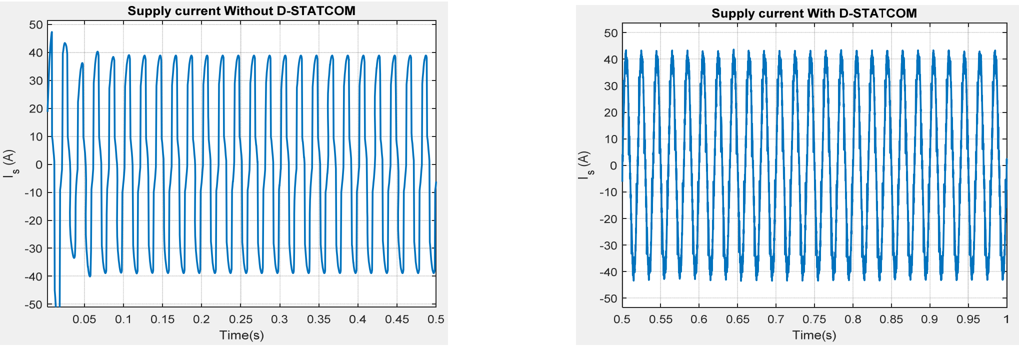
Ultimately, by using the following equations, compensated voltage is achieved:

$$V_{Ca}^{*} = V_{La} - V_{Pa}^{*} \qquad V_{Cb}^{*} = V_{Lb} - V_{Pb}^{*} \qquad V_{Cc}^{*} = V_{Lc} - V_{Pc}^{*}$$

Through the above formulation, the implementation of the proposed model is performed and the results are achieved.

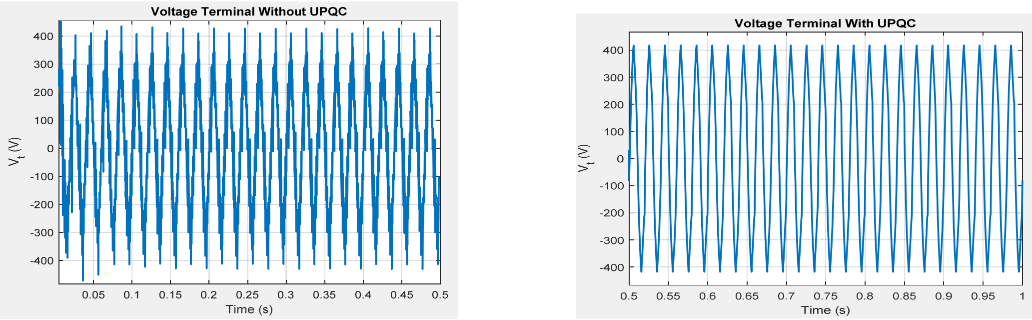
IV. Results and Discussion

The simulation of existing D-STATCOM based model and proposed model is carried out in the MATLAB environment. The results of the proposed system were obtained with UPQC and without UPQC. A comparison with the previously proposed scheme that was analyzed with and without D-STATCOM is performed to scrutinize the efficacy of the UPQC based model.



(A) (B)

Fig. 6: Supply Current Without D-STATCOM and with D-STATCOM



(A) (B)

Fig. 7: Voltage Terminal Without UPQC and with UPQC

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The above graph displayed the supply current without D-STATCOM. The close examination of the graph in Fig 6(a) shows the current with respect to time. The current was irregular in the beginning and it become regular after 0.1 seconds. The values are recorded for 0.5 seconds. The Fig 6(b) exemplifies the current obtained by the D-STATCOM based model. The graph shows after 0.5 sec when harmonics is clear from the current and that the current is regular no disturbance is experienced. The value of current accounted to -40A to 40 A for before 0.5 seconds and after 0.5 seconds when D-STATCOM enter into the system.

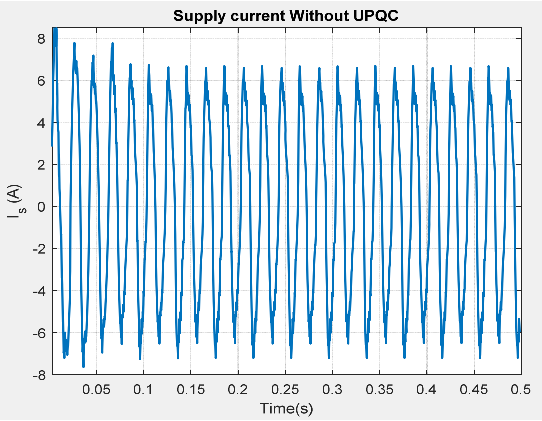
This section presents the results obtained by the proposed model with and without UPQC. In Fig 7(a), the graph represents the relation between the voltage and time achieved for the model without UPQC. it is observed that in the beginning the voltage value is irregular and it becomes stable at 0.1 seconds. It went up to 400 v in the initial stage. The values are recorded when harmonics are present in the system(before 0.5 seconds) and after when harmonics are eliminated from the system (after 0.5 seconds) This graph in the Fig 7(b) demonstrates the result obtained from the model with UPQC. The graph clearly demonstrates that the voltage achieved is steady and continuous. No interactions are observed and this value is less than that of the model without UPQC. Moreover, the values for voltage terminal with UPQC accounted to 400 to -400 V. The results of the supply current achieved for system with and without UPQC are discussed in the subsequent section.

In Fig 8(a) the graph explains the current attained without UPQC. The graph designs the current with respect to time. Irregular values are observed in the beginning which continues till 0.1 second further they become stable. The highest value in the beginning is 8 amperes which decreases and becomes constant at nearly -6 A to 6A. This ensures that the system has an effective supply of current except in the initial stage. Further this system performance is evaluated and results for current achieved by the system with UPQC are obtained and displayed in the graphical view. The graph in Fig 8(b) reveals that no disruptions are experienced at any stage. For 0.5 seconds the values of supply current are recorded which constituted to almost -6A to 6 A.

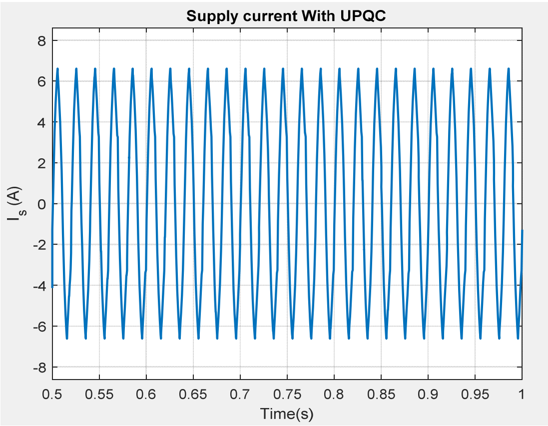
Table 1: Total Harmonic Distortion Of Current And Voltage

Non-linear Load	Without UPQC	With UPQC	Without D-STATCOM	With D-STATCOM
Current THD	29.66	3.75	29.41	7.08
Voltage THD	41.20	3.96	-----	-----

Finally, total harmonic distortion of the current is recorded in table 1. The value achieved for D-STATCOM based model is almost one fourth of the value attained without D-STATCOM i.e. 7.08. Similarly, the proposed model is evaluated with and without UPQC in terms of THD of current and voltage. The effectiveness of the proposed model as the current THD with UPQC is 3.75 and without UPQC is 29.66. In addition, the voltage is also considered as the parameter for comparing the efficacy of the model. A great difference is observed in the values. The total harmonic distortion of voltage with UPQC is only 3.96 whereas without UPQC it is 41.20.



(A)



(B)

Fig. 8: Supply Current Without UPQC Figure and without UPQC

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V. Conclusion

To resolve the issues of power supply such as distortion in voltage and current achieved while operating the distributive system, two techniques are proposed. One of them is designed using D-STATCOM and the other implements UPQC. These techniques are designed using mathematical formulation and the simulation is performed in MATLAB. The comparison of the obtained results of both the techniques ensured the efficacy of the UPQC model as it is capable of reducing the total harmonic distortion of current and voltage. UPQC model diminishes the current distortion. The output of both the models is observed to be stable but UPQC gave more effective results in terms of both the voltage and current.

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