ISSN: 2278-4632
Vol-11 Issue-01 March 2021

# Controlling Power Flow in Distribution Line Using D-STATCOM

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***Abstract*—The application of the Distribution Static Compensator (D-STATCOM) to regulate power flow in the distribution line is presented in this study. Reactive power flow should be managed in the distribution line to lessen the load on reactive power and to alleviate other unfavourable impacts brought on by inductive type loads. Real power flow must also be managed in order to lessen the impact of voltage drop brought on by the distribution line's greater R/X ratio. In India, either no device is used in the distribution line to counteract the impacts indicated above, or traditional devices are utilised, which have various drawbacks. Power electronics-based sophisticated gadget D- STATCOM can be very helpful for managing power flow in the distribution line. In this study, the distribution line is connected to a voltage source converter (VSC) type D-STATCOM based on instantaneous symmetrical component theory to control the power flow. The D-STATCOM switching devices' gate pulses are produced via hysteresis current control. According to the findings, the D-STATCOM, which is based on instantaneous symmetrical component theory, effectively compensates for full or partial reactive power and also supplies real power assistance to distribution lines equipped with battery energy storage.**

***Index Terms*— Distribution Line, Reactive Power, Real Power, D-STATCOM, Instantaneous Symmetrical Component Theory**

## I. Introduction

The distribution transformer and distribution line must be used by the electrical power distribution network to deliver actual and reactive power to the associated loads. When the distribution network delivers actual and reactive power to the load, the various distribution line parameters must stay within allowable ranges. A significant amount of inductive type loads linked to the distribution network place a significant reactive power demand on the entire network [1]. Numerous distribution line parameters are impacted by the reactive power flow, which causes numerous technical problems. As a result of the technical difficulty of these

Importantly, the distribution line must be equipped with reactive power adjustment. The traditional compensating devices have numerous flaws and are unable to offer compensation in a variety of load settings [1]. Given that the distribution line has a somewhat larger R/X ratio, real power correction should also be offered [2] in order to mitigate the voltage drop brought on by the line's resistance. Consequently, it is necessary to manage both the reactive and actual power flows in distribution lines.

The constraints of typical compensating devices make it impossible for them to offer actual power compensation in distribution lines. The employment of power electronic-based devices to offer compensation in distribution lines is particularly beneficial [3,4]. One of the most cutting-edge, adaptable, and acceptable devices for usage in the distribution line to offer power flow control is the Distribution Static Compensator (D-STATCOM). With an energy storage facility, this shunt-connected device may provide the distribution line with real power while also compensating for reactive power [2-4].

In this study, power flow regulation in the distribution line is provided by D-STATCOM. The gate pulses for the switching devices of the VSC of D-STATCOM were produced using the hysteresis current control scheme [7,8] and the reference currents were produced using the instantaneous symmetrical component theory [5,6]. Under various load situations, the D-STATCOM with this control technique may deliver the appropriate power flow control.

## II. Power Flow Control in Distribution Line

In general, power flow in the distribution lines may be defined as the actual and reactive power flowing at a specific voltage level in the distribution line from the distribution transformer to the loads.

## III. *Base System*

Here, in this paper, a radial three phase distribution system as shown Fig.1 is considered as the base system. The system parameters of this base system are listed in Table I.

 ISSN: 2278-4632
Vol-11 Issue-01 March 2021

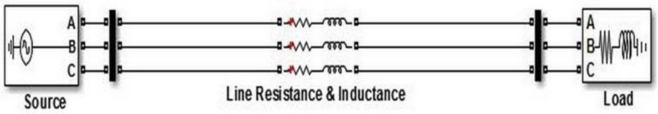



Fig. 1. Base System

TABLE I. PARAMETERS OF BASE SYSTEM

| | |
|---|---|
| **Source Voltage & Frequency** | 433V (Line to Line), 50Hz |
| **Total Resistance** | 0.1234Ω |
| **Total Reactance** | 0.045mH |
| **Load Connected** | Different Combinations of Resistive& Inductive (R-L) Loads |

*A. Effect of Loads on various parameters of Distribution Line*

The base system considered in Fig. is coupled with R & L-type loads of various values to demonstrate the impact of loads on the distribution line. 1. After observing these results, it can be concluded that both R&L type loads have an impact on values of the voltage received at the load end and flow of current through the distribution line, and that inductive loads have a negative impact on power factor. The effects of loads on the various parameters of the distribution line have been obtained after simulation of the base system are shown in Table III. The inductive loads connected to the distribution line add to the distribution line's and the distribution transformer's reactive power burden.All these effects are technically undesirable and also cause economic loss, so, the power flow is required to be controlled by means of power and real power compensation is required to be provided in the distribution line.

*B. Limitations of Conventional Compensating Devices*

To provide reactive power compensation in distribution lines, conventional compensating devices like synchronous condensers or capacitors may be used. However, because of their rotating parts, synchronous condensers have very slow response times, and capacitors can only provide fixed compensation, further limiting their use [1]. Furthermore, neither of the traditional compensating devices can actually support the distribution line's power supply. Due to all these restrictions, typical compensating devices cannot manage power flow in the distribution line.

## IV. D-STATCOM

A power electronic-based compensating device for use in the distribution line is called D-STATCOM. It works fundamentally as a distribution line-shunt coupled controlled current injector [1,3,4]. Figure 1 shows the design of a Fig. D-fundamental STATCOM, and step 3 [4] connects a Fig. A D-STATCOM to a three-phase distribution line. D-STATCOM and the distribution line can exchange reactive and real power. Reactive and actual power control of the distribution system can lower the magnitude & phase angle of the D–STATCOM voltage respectively [3, 4].

Fig. 2. Basic Construction of D-STATCOM

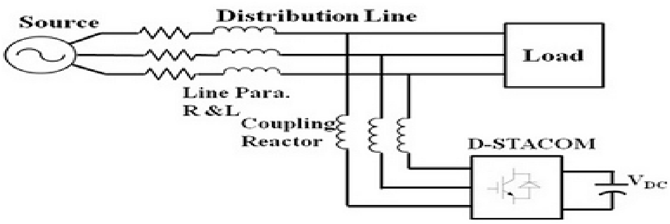



Fig. 3. Connection of D-STATCOM to 3-phase Distribution Line

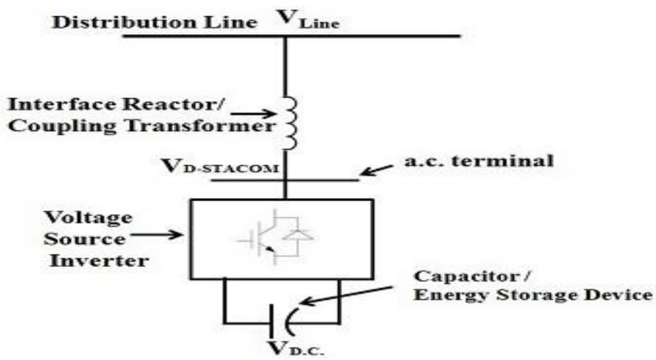
The D-STATCOM can offer reactive power to the distribution line if its voltage magnitude is maintained higher than that of the line, and it can provide actual power to the line if its voltage phase angle is maintained leading the line's voltage. The D-STATCOM must send the necessary component of compensating current to the distribution line depending on the type and degree of reactive/real power compensation required.

For D- STATCOM to offer the regulation of power flow in distribution lines under dynamic load fluctuating conditions, a variety of controllers and control algorithms are used [7].

Here in this paper, Instantaneous symmetrical component theory based control strategy has been used to control the functioning of D-STATCOM. The other controllers having been used here are Hysteresis Current controller (for Gate Pulse Generation) & PI Controller (for maintaining the voltage of Capacitor of VSC i.e. D.C. Link Voltage constant).

## V. CONTROL STRATEGY BASED ON INSTANTANEOUS SYMMETRICAL COMPONENT THEORY

Instantaneous symmetrical component theory is basically the symmetrical component theory (being applied to instantaneous voltages and currents [5]. The unbalanced voltages & currents can be converted into 3-set of balanced voltages & currents i.e. Positive sequence, negative sequence & zero sequence components by using this instantaneous symmetrical component theory. Equation (1) & (2) [1] represents the positive sequence component of Voltage & Current respectively where $V_{sa}$, $V_{sb}$ & $V_{sc}$ are source voltages and $i_{sa}$, $i_{sb}$ & $i_{sc}$ are currents of phase a, b & c respectively.



$$V_{sa1} = \frac{1}{\sqrt{3}}\left(V_{sa} + aV_{sb} + a^2 V_{sc}\right) \quad (1)$$

$$i_{sa1} = \frac{1}{\sqrt{3}}\left(i_{sa} + ai_{sb} + a^2 i_{sc}\right) \quad (2)$$

Here, his control strategy is used for D-STATCOM to generate the reference currents. The basic two objectives of this proposed control strategy are:

- To make supply currents balanced such that:

$$i_{sa} + i_{sb} + i_{sc} = 0 \quad (3)$$

- the source should supply only positive sequence component of power

Assuming that source current lags source voltage by an angle φ, then Positive sequence component of voltage would also lag the positive sequence component of current & Equation (4) [5] would be obtained

$$\left(V_{sb} - V_{sc} - 3\beta V_{sa}\right) i_{sa} + \left(V_{sc} - V_{sa} - 3\beta V_{sb}\right) i_{sb} + \left(V_{sa} - V_{sb} - 3\beta V_{sc}\right) i_{sc} = 0 \quad (4)$$

Where,

$$\beta = \frac{1}{\sqrt{2}} * \frac{\tan \Phi}{\sqrt{3}} \quad (5)$$

Now, if D-STATCOM is used to provide compensation & source should supply only average component of load power $P_l$, then the Equation (6) [1] is obtained.

$$V_{sa} i_{sa} + V_{sb} i_{sb} + V_{sc} i_{sc} = P_l \quad (6)$$

The power losses occurring in switches of VSI i.e. $P_{loss}$ would have to be supplied by the source itself, so equation (5) would get changed and equation (7) [5] is obtained.

$$V_{sa} i_{sa} + V_{sb} i_{sb} + V_{sc} i_{sc} = P_l + P_{loss} \quad (7)$$

The equations to calculate reference values of source currents are obtained as shown in Equations (8), (9) & (10) using Equations (4), (5) & (6) [5].

$$i_{sa} = \frac{V_{sa} + \left(V_{sb} - V_{sc}\right)\beta}{V_{sa}^2 + V_{sb}^2 + V_{sc}^2}\left(P_l + P_{loss}\right) \quad (8)$$

$$i_{sb} = \frac{V_{sb} + \left(V_{sc} - V_{sa}\right)\beta}{V_{sa}^2 + V_{sb}^2 + V_{sc}^2}\left(P_l + P_{loss}\right) \quad (9)$$

$$i_{sc} = \frac{V_{sc} + \left(V_{sa} - V_{sb}\right)\beta}{V_{sa}^2 + V_{sb}^2 + V_{sc}^2}\left(P_l + P_{loss}\right) \quad (10)$$

The equations of reference compensating currents to be provided by D-STATCOM would be as shown in equations (11), (12) & (13) [5,6].

$$i_{car} = i_{la} - \frac{V_{sa} + \left(V_{sb} - V_{sc}\right)\beta}{V_{sa}^2 + V_{sb}^2 + V_{sc}^2}\left(P_l + P_{loss}\right) \quad (11)$$

$$i_{cbr} = i_{lb} - \frac{V_{sb} + \left(V_{sc} - V_{sa}\right)\beta}{V_{sa}^2 + V_{sb}^2 + V_{sc}^2}\left(P_l + P_{loss}\right) \quad (12)$$

$$i_{cbr} = i_{lb} - \frac{V_{sc} + \left(V_{sa} - V_{sb}\right)\beta}{V_{sa}^2 + V_{sb}^2 + V_{sc}^2}\left(P_l + P_{loss}\right) \quad (13)$$

These reference currents $I_{car}$, $I_{cbr}$ & $I_{ccr}$ are then compared with actual currents $I_{ca}$, $I_{cb}$ & $I_{cc}$ respectively and by Using Hysteresis current control scheme, the gate pulses are generated for all the three legs of Inverter unit of D-STATCOM.

## VI. Simulation Results

The performance of D-STATCOM designed with instantaneous symmetrical component theory based control strategy to control power flow in distribution line has been checked using MATLAB-SIMULINK software. The Main simulation circuit is shown in Fig. 4, while the sub-circuits for control scheme and D-STATCOM used in the simulation are shown in Fig. 5 & Fig. 6 The values of various parameters of D-STATCOM considered are shown are listed in Table III.

TABLE II. Parameters of D-STATCOM

| | |
|---|---|
| **D.C. Link Capacitor** | 1000µF |
| **Reference D.C. Link Voltage** | 800V |
| **Coupling Inductance** | 2.2Mh |
| **Battery Energy Storage System (for Real Power Compensation only)** | 800V, 20Ah |

### *A. D-STATCOM operated for full reactive power compensation*

In this mode, for full reactive power compensation, the value of power factor is to be kept unity and so, value of β is set accordingly. In this case, almost all the reactive power demand of load is supplied by the D-STATCOM and source only needs to supply the real power. The results for this mode of operation of D-STACOM are shown in Table IV.

### *B. D-STATCOM operated for partial reactive power compensation*

Practically it might not be economical to utilize the D-STATCOM mode to provide full reactive power compensation because this would require a D-STATCOM having a very large rating and hence having a very high cost. So, it would be more beneficial l to utilize D-STATCOM in partial reactive power compensation mode. The simulation results, when D-STATCOM is used for partial compensation as per desired value of power factor are shown in Table IV.

### *C. D-STATCOM operated for real power compensation*

By using an energy storage device & modifying the equations & circuit of this proposed control strategy, the D-STATCOM might also be used to provide real power support to distribution line. In order to provide real power support, the capacitor is replaced by a battery energy storage system. Some other modifications are also made in equations of the control strategy. The simulation results obtained for this mode of operation of D-STATCOM are illustrated in Table-IV.

ISSN: 2278-4632
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TABLE III. EFFECT OF LOAD ON VARIOUS PARAMETERS OF DISTRIBUTION LINE

| Sr. No | Source Voltage (V) | Power Demand | | Power Supplied By Source | | Power Received By Load | | Load Voltage (V) | Current (A) | Source Power Factor |
|---|---|---|---|---|---|---|---|---|---|---|
| | | P (kW) | Q (kVAR) | P (kW) | Q (kVAR) | P (kW) | Q (kVAR) | | | |
| 1 | 433 | 20 | 20 | 19.93 | 19.48 | 19.42 | 19.42 | 426.7 | 37.17 | 0.511 |
| 2 | 433 | 30 | 20 | 29.58 | 19.27 | 28.76 | 19.17 | 427 | 47.07 | 0.702 |
| 3 | 433 | 40 | 30 | 39.35 | 28.53 | 37.8 | 28.35 | 420.9 | 64.81 | 0.655 |

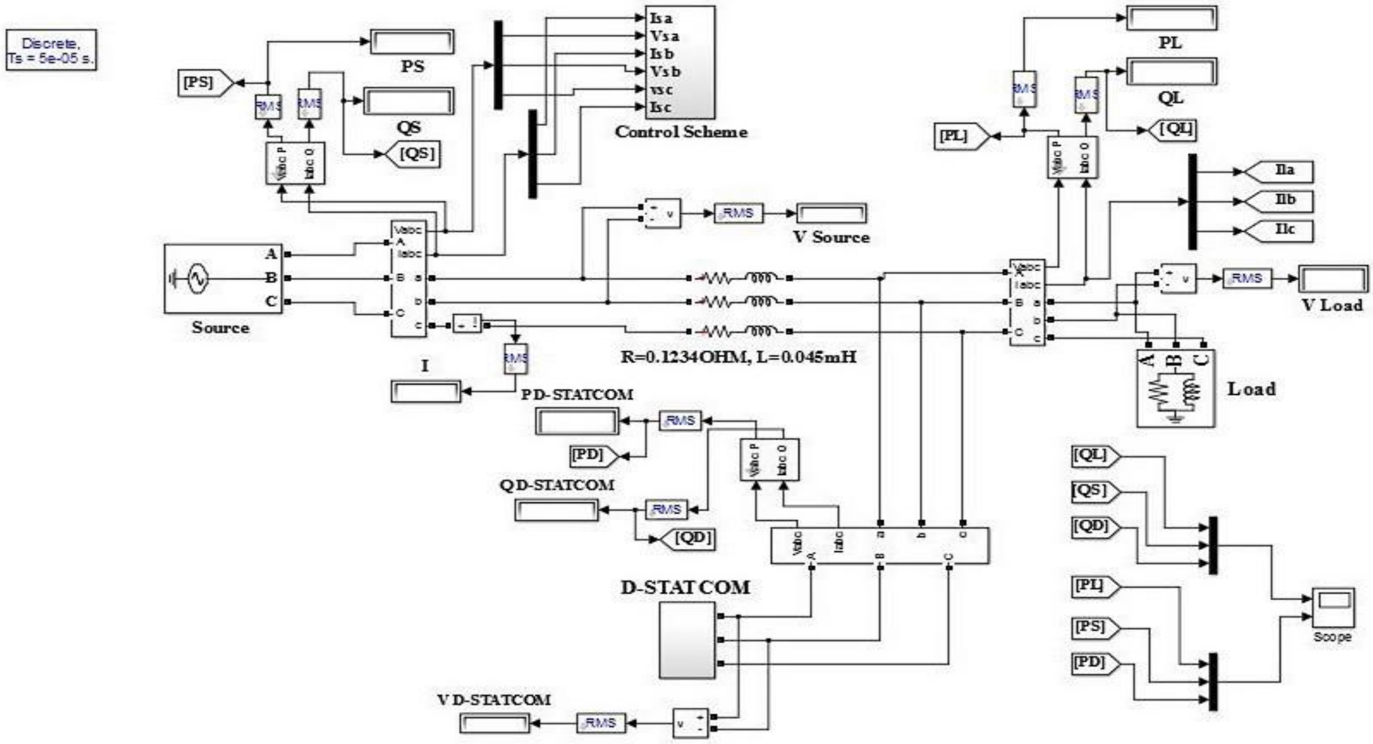


Fig. 4. Main Simulation Circuit

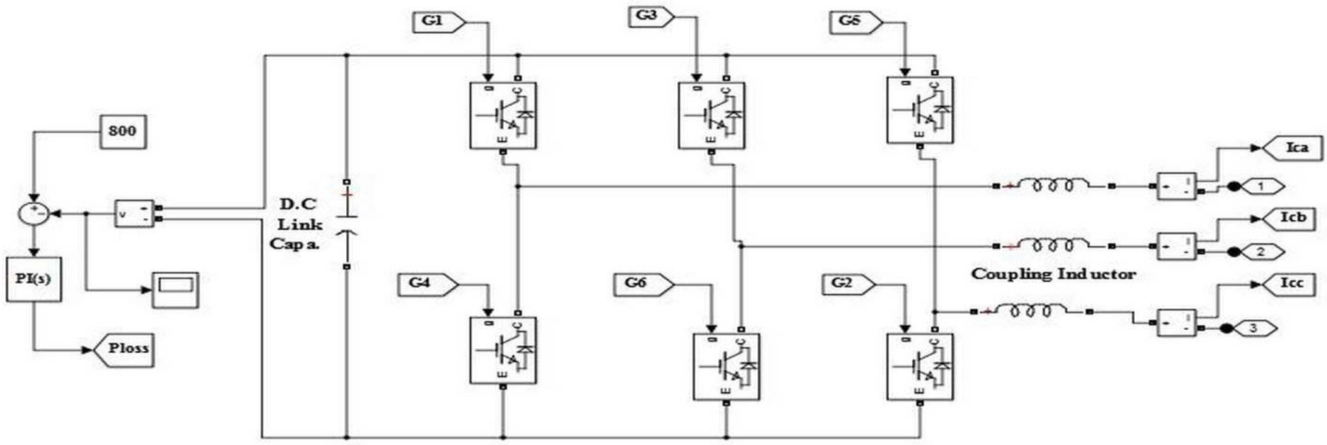


Fig. 5. Sub-circuit of D-STATCOM

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TABLE IV. SIMULATION RESULTS

| Case | Source Voltage (V) | Power Demand | | Power Supplied By Source | | Power Supplied By D-STATCOM | | Power Received By Load | | Load Voltage (V) | Current (A) | Source Power Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P (kW) | Q (kVAR) | P (kW) | Q (kVAR) | P (kW) | Q (kVAR) | P (kW) | Q (kVAR) | | | |
| Before Compensation | 433 | 20 | 20 | 19.93 | 19.48 | 0 | 0 | 19.42 | 19.42 | 426.7 | 37.17 | 0.511 |
| After Full Reactive Power Compensation | | | | 20.07 | 3.35 | 3.38 | 20.03 | 19.51 | 19.5 | 427.4 | 26.93 | 0.973 |
| Before Compensation | 433 | 30 | 20 | 29.58 | 19.27 | 0 | 0 | 28.76 | 19.17 | 424 | 47.07 | 0.702 |
| After Full Reactive Power Compensation | | | | 29.79 | 3.48 | 3.33 | 19.58 | 28.88 | 19.24 | 424.6 | 39.91 | 0.987 |
| After Partial Reactive Power Compensation | | | | 29.87 | 9.17 | 3.08 | 11.52 | 28.82 | 19.21 | 424.3 | 41.45 | 0.914 |
| After Partial Reactive Power Compensation | | | | 29.64 | 11.88 | 2.59 | 8.82 | 28.82 | 19.2 | 424.3 | 42.51 | 0.862 |
| Before Compensation | 433 | 40 | 30 | 39.35 | 28.53 | 0 | 0 | 37.8 | 28.35 | 420.9 | 64.81 | 0.655 |
| After Full Reactive Power Compensation | | | | 39.31 | 3.51 | 3.15 | 28.33 | 38 | 28.48 | 422 | 53.05 | 0.992 |
| After Partial Reactive Power Compensation | | | | 39.12 | 15.94 | 3.4 | 13.48 | 37.93 | 28.42 | 421.5 | 56.31 | 0.858 |
| After Partial Reactive Power Compensation | | | | 39.24 | 19.53 | 34 | 9.98 | 37.89 | 28.4 | 421.3 | 58.03 | 0.801 |
| After Full Reactive + Partial Real Power Compensation | | | | 30.77 | 3.65 | 9.19 | 29.45 | 38.45 | 28.82 | 424.3 | 40.94 | 0.986 |
| After Partial Reactive + Partial Real Power Compensation | | | | 29.54 | 11.77 | 10.30 | 18.19 | 38.44 | 28.81 | 424.3 | 42.2 | 0.863 |

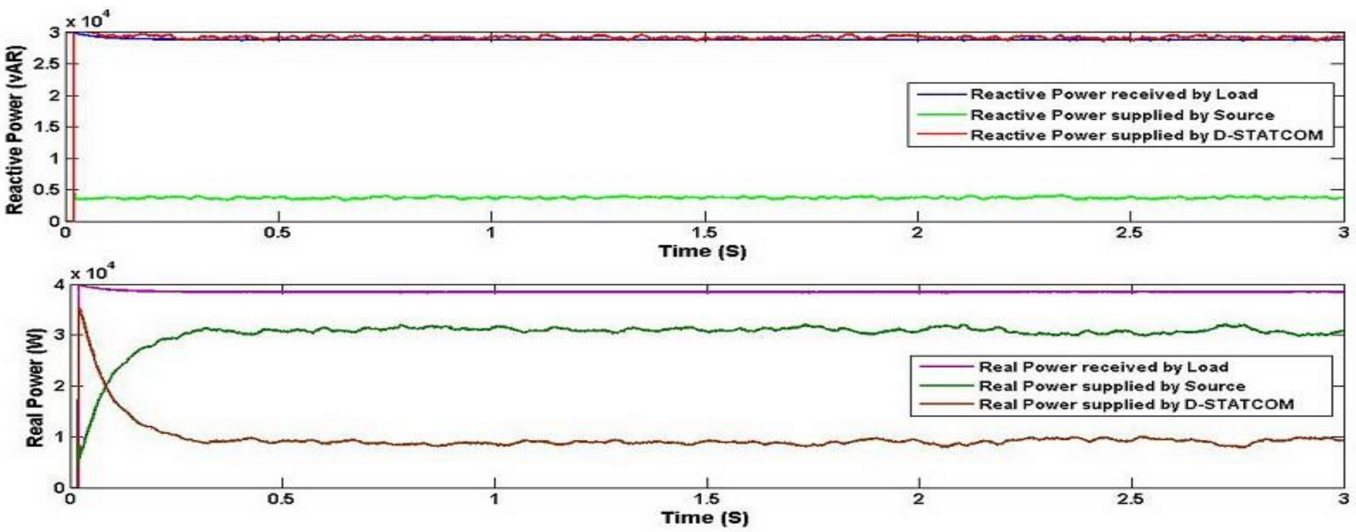


Fig. 6. Results of Power Flow for Source, Load and D-STATCOM

ISSN: 2278-4632
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## VII. CONCLUSION

D-STATCOM with the instantaneous symmetrical component theory based control strategy is proposed to control power flow in the distribution line. The simulation results show that the D-STATCOM based on the proposed power flow control strategy provides full or partial reactive power compensation to the distribution line. It is observed that when the D-STATCOM is operated to provide full reactive power compensation, the source almost supplies no reactive power and source power factor improves to 0.98. The compensator with a reduced rating is used to provide partial reactive power compensation with compromised source power factor value of 0.8 to 0.9. When the energy storage is used, the D-STATCOM provides real power support in addition to the reactive power support. The real power support capability depends on the size of energy storage; however, here the D-STATCOM has been used to provide partial real power support only. The results prove that the D-STATCOM is better than conventional compensator for reactive and real power compensation under the dynamic condition. The overall performance of distribution network gets improved with combined real and reactive power compensation.

## ACKNOWLEDGEMENT

Authors acknowledge support and guidance obtained from Prof. (Dr.) S.N. Pandya & other faculty members of Department of Electrical Engineering, Lukhdhirji Engineering College, Morbi.

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