Application of D-STATCOM to control Reactive Power in Distribution line for variable non-liner load

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Abstract

This paper presents reactive power compensation in distribution line using distribution static compensator (D-STATCOM). In order to reduce the reactive power burden and to diminish other adverse effects triggered by inductive load and non-liner load reactive power movement should be controlled in distribution line. There are four different control strategies to control the power flow. This paper illustrates methodology used for extracting reference compensating currents for reactive power compensation at PCC (Point of Common Coupling) for DSTATCOM. The voltage source converter (VSC) is used along with DC link capacitor as a DSTATCOM. The simulation has been carried out in MATLAB for various loading condition. A simulation result depicts the performance of DSTATCOM under different conditions.

Keywords: VSC, D-STATCOM, Distribution line, Reactive power control, Instantaneous symmetrical component theory, Variable inductive load, Non-liner load.

INTRODUCTION

Nowadays major power has been consumed in reactive loads such as fans, pumps, electric motors and non-linear loads. These are the load which draws lagging power factor currents and thus increases reactive power demand. Moreover, due to the presence of unbalanced non-linear loads this situation becomes much worse [1] . The excess demand of reactive power upsurges the feeder losses and thus reduces the active power flow capability of the distribution system, whereas unbalancing affects the working of transformers and generators. Many technical issues arises in distribution lines because many parameters got affected because of the reactive power flow. As these are very serious issues, reactive power compensation becomes very vital in distribution system. Conventional compensator has many drawbacks and they fail to compensate under varying loading conditions [2]. So Distribution static compensator (D-STATCOM) is one the most advance, versatile and suitable device that can be used for the compensation of reactive power in distribution system [1] .

Performance of D-STATCOM depends upon the control strategy used for the extraction of reference current components. Some of the algorithms used for this purpose are instantaneous reactive power (IRP) theory, instantaneous symmetrical component theory, synchronous reference frame (SRF) theory and current compensation using DC bus regulation [1] .

In this paper voltage source converter based D-STATCOM is used for the compensation of reactive power in distribution system. The instantaneous symmetrical component theory is being used for the generation of reference currents and hysteresis current control strategy has been used for the generation of gate pulses which are used for switching devices in VSC type D-STATCOM. D-STATCOM based on this methodology can provide compensation for different loading conditions.

STRUCTURE AND OPERATION OF DSTATCOM

Operation of D-STATCOM:

When the static compensator (STATCOM) is used in low voltage distribution lines it is termed as Distribution STATCOM (D-STATCOM). In general D-STATCOM is used to either generate or absorb the reactive power. D- STATCOM is a shunt connected power electronic device which consist of VSC, DC ESS, output filter and coupling transformer / interface reactor. The VSC is used to convert the DC voltage of capacitor storage device into balances three phase AC output voltages [3]. These generated voltages are in phase and interconnected to utility grid through coupling transformers. Fig. 1 illustrates the generalized connection of D-STATCOM with distribution line. Appropriate adjustment in magnitude and phase angle of output voltages of D-STATCOM ensures effective active as well as reactive power flow between D-STATCOM and distribution line.

If VI is same as Vpcc, there will be zero reactive power flow between D-STATCOM and distribution line which suggests that D-STATCOM neither absorbs nor generate reactive power as shown in Fig. 2(a). When V1 is greater than Vpcc, D-STATCOM acts as a capacitive reactance connected at its terminal as shown in Fig. 2(b).
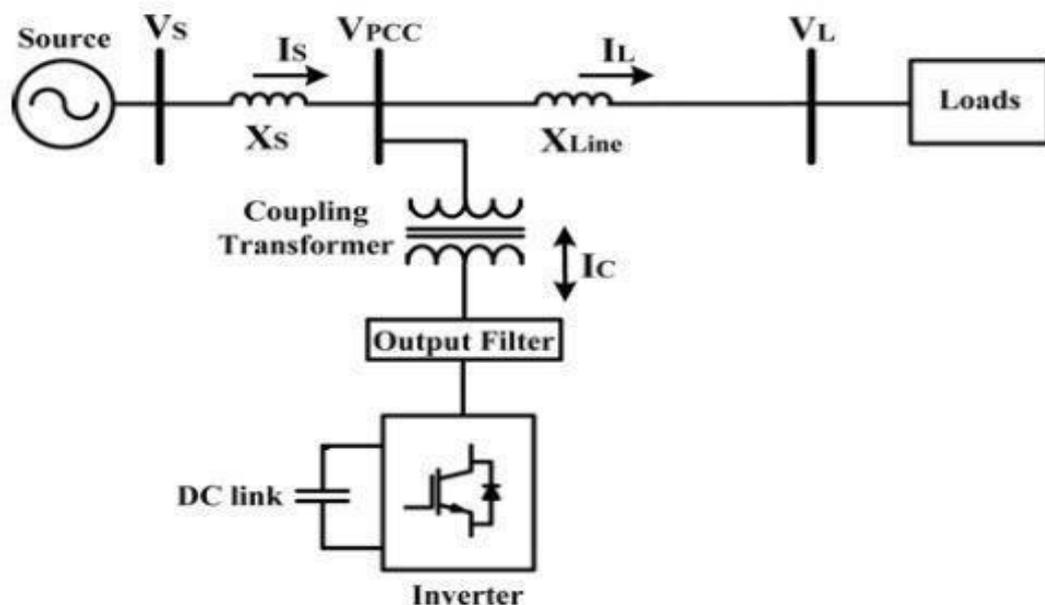

Figure 1: Generalized Connection of D-STATCOM to Distribution Line

The compensating current flows through D-STATCOM and from that to distribution line where the device provides reactive power to distribution line. When Vpcc is greater than V1, D-STATCOM goes into inductive mode as shown in Fig 2(c). If voltage phase angle of D-STATCOM is kept leading than the Vpcc, it can supply real power to distribution line. The real power flow exchange can be used to mitigate the internal losses of inverter for maintaining the voltage across capacitor constant [3].

There are various controllers and control strategies are used for D-STATCOM for providing controlled power flow in distribution system under dynamic varying loading condition [1]. In this paper instantaneous symmetrical component theory is used to control the operation of D-STATCOM. Other controllers are also used in this paper which are Hysteresis current controller (for generating Gate pulses) and PI controller (for maintaining DC link voltage constant) [1].
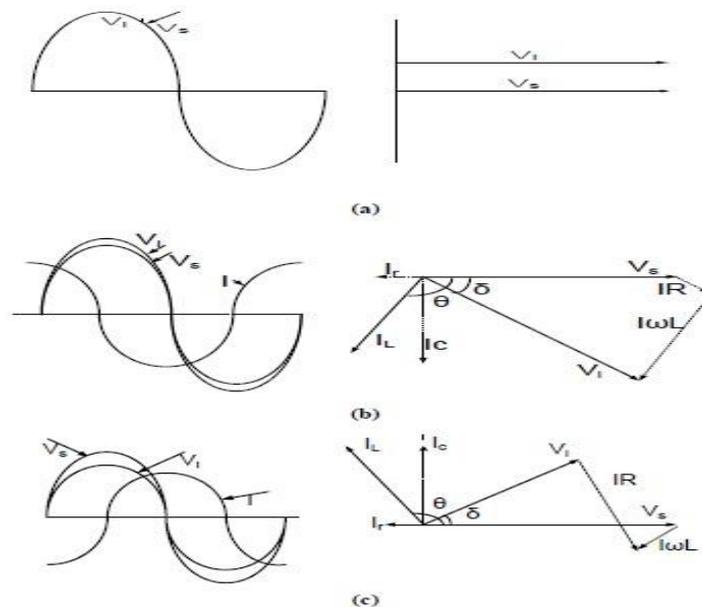

Figure 2: Operation of DSTATCOM (a) No Load Mode (Vs=Vi), (b) Capacitive Mode (c) Inductive Mode

Effect of Loads on various parameters of Distribution Line:

For analyzing the effects of different loads on distribution system, R & L type loads having different values are connected to the base system as shown in Fig 1. The effects of various loads on the parameters of the distribution line are simulated on the base system [1]. After observing the results it can be said that non-linear inductive loads increases the burden of reactive power in the distribution line and on the distribution transformer which leads to undesirable conditions like reduction in real power supplying capacity of the transformer, decline in real current carrying capacity of the line, poor power factor (PF), increased losses, voltage drop etc [1].

These effects are undesirable and they leads to economic losses. So, the power flow is necessary to be controlled by means of power and it is required to provide real power compensation in distribution line [1].

Control Strategy

Instantaneous symmetrical component theory is basically symmetrical component theory that is being applied to instantaneous voltages and currents [1]. Using instantaneous symmetrical component theory unbalanced voltages and currents can be transformed into 3 sets of balance voltages & currents i.e. Positive sequence, Negative sequence and Zero sequence components [1].

The control strategy used here is for generating reference currents. Two basic objectives of this proposed scheme are:

1) The source should supply only the positive sequence component of power supply

2) To make supply currents balanced such that…

$$i_{sa} + i_{sb} + i_{sc} = 0 \tag{1}$$

As we are assuming that source current lags voltage by angle φ, then positive sequence component of voltage should also lag the positive sequence component of current and thus we obtain the equation

$$(V_{sb} - V_{sc} - 3\beta V_{sa})i_{sa} + (V_{sc} - V_{sa} - 3\beta V_{sb})i_{sb} + (V_{sa} - V_{sb} - 3\beta V_{sc})i_{sc} = 0 \tag{2}$$

Where, $\beta = \dfrac{1}{\sqrt{6}}\tan\varphi$

If D-STATCOM is used to provide compensation for reactive power then source should only average component of load power (P_l) and the losses occurring in switches of VSI, this means that P_{loss} has to be supplied by source itself. So equation (3) is obtained as follows

$$V_{sa}i_{sa} + V_{sb}i_{sb} + V_{sc}i_{sc} = P_1 + P_{loss} \tag{3}$$

Calculation of source reference current:

The equation for calculating reference value of source currents are obtained in following equation (4), (5) and (6)by using equation (2)

$$i_{sar} = V_{sa} + (V_{sb} - V_{sc})\beta(P_1 + P_{loss})/(V_{sa}^2 + V_{sb}^2 + V_{sc}^2) \tag{4}$$

$$i_{sbr} = V_{sb} + (V_{sc} - V_{sa})\beta(P_1 + P_{loss})/(V_{sa}^2 + V_{sb}^2 + V_{sc}^2) \tag{5}$$

$$i_{scr} = V_{sc} + (V_{sa} - V_{sb})\beta(P_1 + P_{loss})/(V_{sa}^2 + V_{sb}^2 + V_{sc}^2) \tag{6}$$

Calculation of compensating reference current:

The reference compensating current equation to be provided by D-STATCOM would be as shown in following equation (7), (8) and (9)

$$i_{rca} = i_{la} - i_{sar} \tag{7}$$
$$i_{rcb} = i_{la} - i_{sbr} \tag{8}$$
$$i_{rcc} = i_{la} - i_{scr} \tag{9}$$

These compensating reference current irca, ircb , ircc are then compared with actual currents ica, icb & icc respectively and then hysteresis current controller is used to produce gate pulses of three legs of Inverter unit of D- SATACOM.

Hysteresis Current Controller:

When the value of error is greater than +h, pulse generation takes place for the lower switches S2 of phase 'a' leg and when the value of error is less than –h, pulse generation takes place for the upper switch S1 of phase 'a' leg of the VSC [2]. The whole scheme is applicable for the remaining two phases i.e. phase 'b' & phase 'c'.

SIMULATION AND RESULTS

To control the reactive power flow in distribution lines, the design of D-STATCOM with symmetrical component theory has been carried out in MATLAB SIMULINK software. The system is implemented

with 3-phase programmable voltage source with configuration of 415 V, 50 Hz. PCC voltage is considered as 415 V, which is nearly 340 V per phase.

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. The magnitude of various parameters of base system and D-STATCOM considered are shown are listed in Table 1 and 2 .

Table 1: *Parameter of Base System*

Reference D.C. Link Voltage	800 V
D.C. link capacitor	3000μF
Coupling Inductance	0.025H
Pi Controller Constant	Kp = 0.85 , Ki = 5

Table 2: Parameter Of D-STATCOM

Source voltage & frequency	415 V (Line to Line) , 50Hz
Total line resistance	0.1234Ω
Total line reactance	0.045mH
Non-Linear Load	Three-Phase rectifier with 50 ohm
Active Power for Main Load	20kw
Active power for switching load	15kw
Reactive Power for Main Load	20kvar
Reactive power for switching load	25kvar

Following figures depicts the simulation outcomes of active and reactive power of source and load without D-STATCOM.
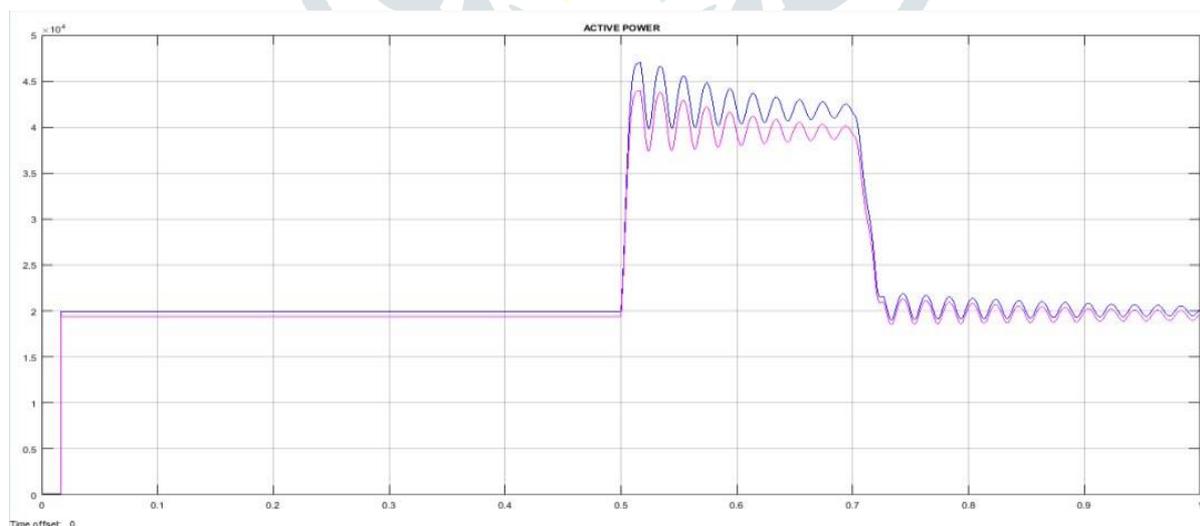

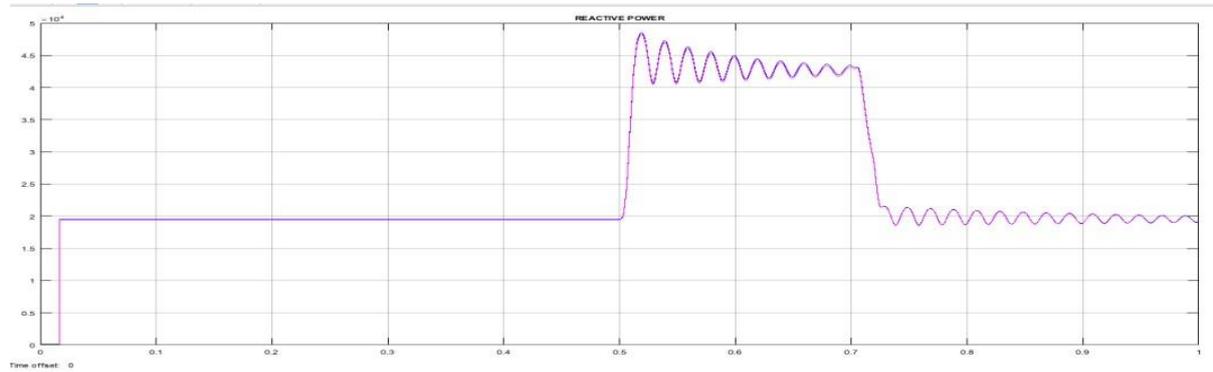**Figure 3:** Active Power of Source and Load without D-STATCOM

Figure 4: Reactive power of source and load without D-STATCOM.

Power supplied by source	:	_____
Power received by load	:	_____
Power supplied by D-STATCOM	:	_____

Obtained results shows that whatever the requirement of reactive power by inductive loads (R-L parallel) and switching non-linear loads are fulfilled by source only. This puts a huge burden of reactive power on system which decreases the voltage as well as it results in poor power factor.

To tackle this problem, D-STATCOM is connected at load side in the distribution system. VSC type D-STATCOM based on instantaneous symmetrical component theory is employed for this purpose.

Fig 4 shows the main circuit with D-STATCOM in MATLAB Simulink. There is two controller used to control the D-STATCOM. Hysteresis Current controller is being used for tracking the reference compensating current. The error signals of reference and actual (instantaneous) compensating current are compared with small hysteresis band generally 1-5% of current level. The logic is if isa more than isa*-hb then upper switch of VCS is turn ON & lower switch is OFF.so in this way, it generate Gate Pulse & PI Controller is used for maintaining the voltage of Capacitor of VSC i.e. D.C. Link Voltage constant.
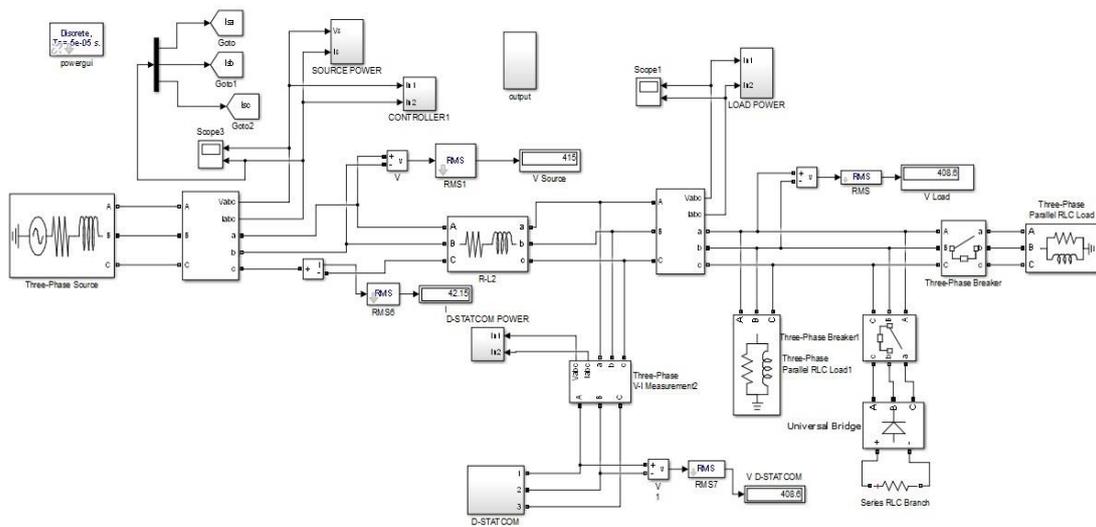

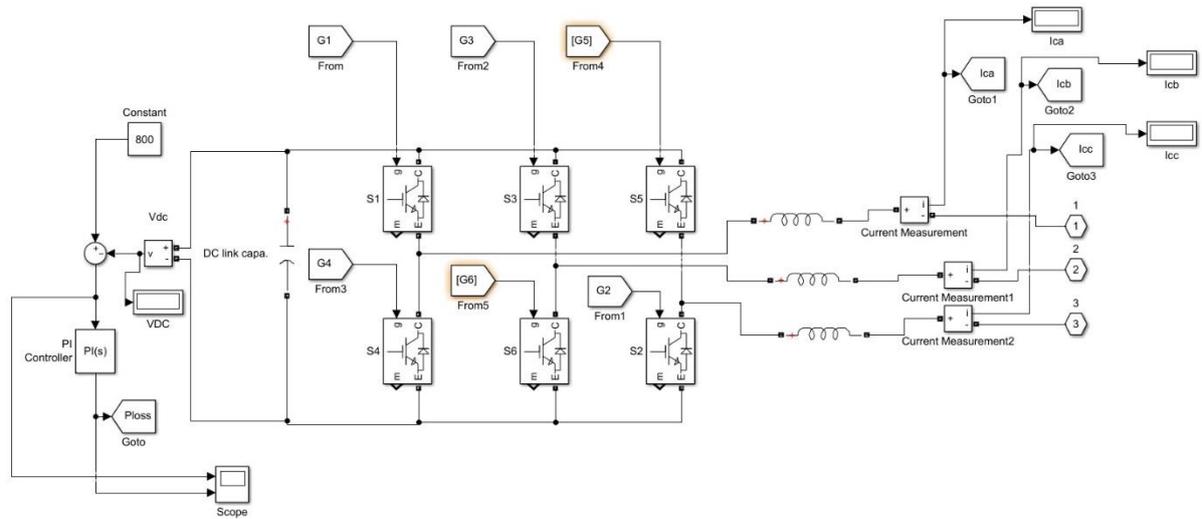**Figure 5:** *Main Circuit of System with D-STATCOM*

Figure 6: Sub Circuit of D-SATACOM

Figure 7 & 8 shows the result of active and reactive power of source and load of main circuit with D-STATCOM. By observing the result we can say that the reactive power essential by load is compensated by D- STATCOM and reactive power provided by source is negligible so voltage is also increased and power factor improved.
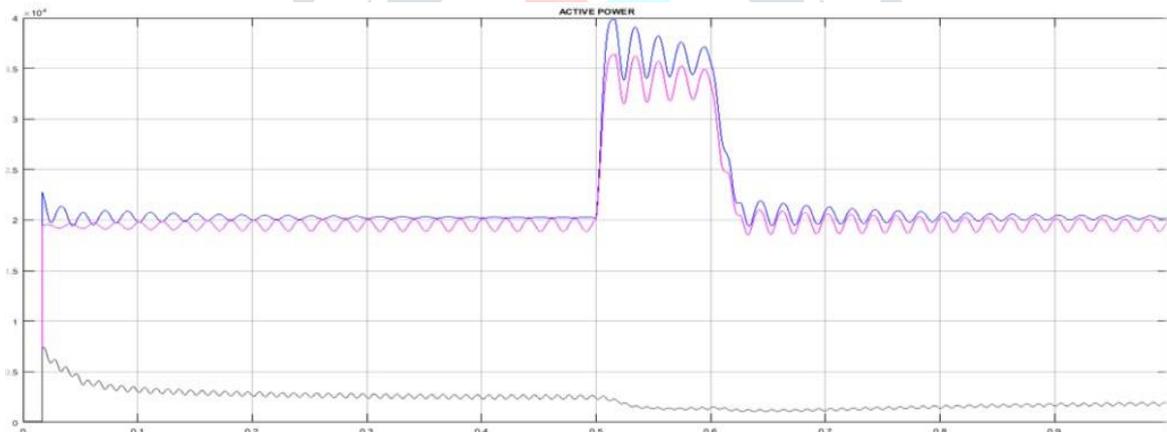

Figure 8: Active Power of Source, Load and D-STATCOM (Main Circuit with D-STATCOM)
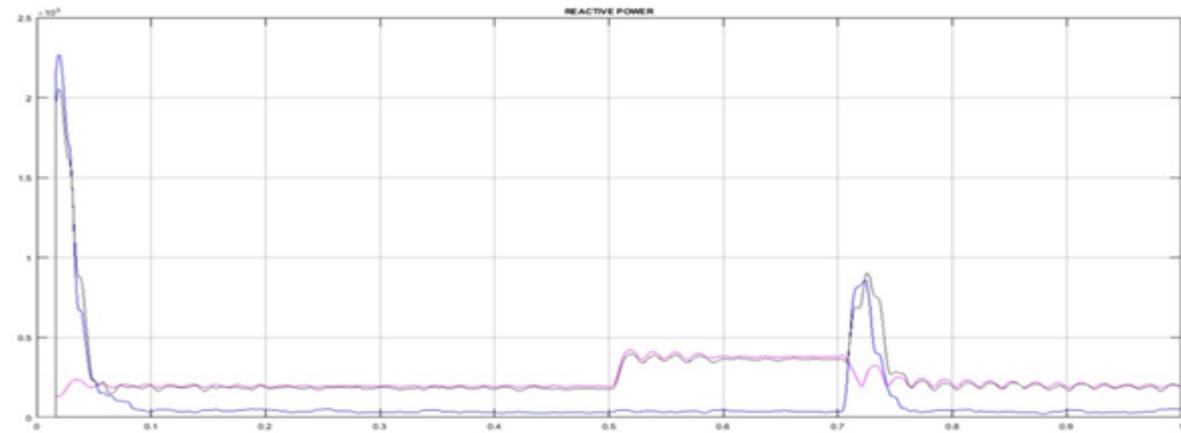

Figure 7: Reactive power of source, load and D-STATCOM (Main circuit with D-STATCOM)

CONCLUSION

For compensation of reactive power in distribution line, VSC based D-STATCOM is used based on Instantaneous symmetrical component theory. Hysteresis current controller is implemented in this proposed scheme for providing gate pulses to switching device. The 415 volt distribution line with switching of heavy non-liner loads is simulated using MATLAB Simulink software. The simulation results shows that D-STATCOM based on the proposed strategy provides compensation for reactive power in distribution line with variable non-liner loading condition & the source supplies almost negligible reactive power, hence source power factor improves.

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