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# Flexible Control of Wind Farm Based DSTATCOM Using External Inductor for Better Performance

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## ABSTRACT

*Distribution compensator (DSTATCOM) is utilized for load voltage control and its execution essentially relies on the feeder impedance and its tendency (resistive, inductive, stiff, non-stiff). Be that as it may, a review for examining voltage regulation execution of DSTATCOM relying on system parameters is not all around characterized. This paper expects to give a exhaustive investigation of design, operation, and adaptable control of a DSTATCOM working in voltage control mode. A point by point investigation of the voltage direction capacity of DSTATCOM under different feeder impedances is exhibited. At that point, a benchmark design methodology to figure the estimation of external inductor using advanced controller is exhibited. A dynamic reference regulation voltage era plot is additionally created which enables DSTATCOM to adjust load reactive power amid typical operation, notwithstanding giving voltage bolster amid unsettling influences.*

## 1.INTRODUCTION

Faults in far reaching power system and also exchanging of vast burdens make voltage unsettling influences, for example, hang and swell in a conveyance system [1]. This power quality (PQ) issues altogether debase the execution of sensitive loads like process-control industry, devices types of equipment, customizable drives, and so on. Traditionally, static var compensator (SVC) is utilized to manage Voltage regulation, compensation reactive current, and make strides transient solidness. Be that as it may, the SVC causes issues like harmonic current infusion in the system, harmonic enhancement, also, conceivable reverberation with the source impedance [2]. Appropriation static compensator (DSTATCOM) has been proposed to beat the constraints of SVC [3]–[9]. A DSTATCOM is a standout amongst the best answers for control the loadl voltage. It gives regulation voltage direction by providing major reactive current into source [5], [10]–[12]. In any case, the vast majority of the regular DSTATCOMs utilized

for voltage direction consider exceedingly inductive and additionally altogether vast feeder impedance [11]. This is generally not valid in a dispersion system where feeder impedance used to be resistive in nature. In this situation, the DSTATCOM will have little voltage direction capacity critical issue is the era of reference load voltage. In customary DSTATCOM application for voltage direction, reference regulation voltage is set at 1.0 p.u. At this load voltage, VSI dependably trades receptive power with the source with driving force calculate. This causes constant power misfortunes in the feeder and VSI. Likewise, an ordinary DSTATCOM requires high current rating voltage source inverter (VSI) to give voltage bolster [11]. This high current prerequisite builds the power rating of the VSI and delivers more misfortunes in the switches and in addition in the feeder.

The voltage control execution of DSTATCOM basically relies on the feeder impedance and its tendency (resistive, inductive, stiff, non-stiff). For voltage control mode (VCM) operation of DSTATCOM as well as matrix associated inverters, the thought of embeddings an external inductor in line has been accounted. Be that as it may, in these plans, just the idea has been presented leaving adequate

degree for further examination what's more, understanding into the plan points of interest.

## 2. DSTATCOM IN POWER DISTRIBUTION SYSTEM

Fig. 1 shows power circuit diagram of the DSTATCOM topology associated in distribution system.  $L_s$  and  $R_s$  are source inductance and resistance, individually. An external inductance,  $L_{ext}$  is incorporated into arrangement amongst load and source focuses. This inductor causes DSTATCOM to accomplish regulation voltage direction capacity even in most exceedingly bad system conditions, i.e., resistive or hardened matrix. From IEEE-519 standard, point of regular coupling (PCC) ought to be the point which is available to both the utility and the client for direct estimation. Consequently, the PCC is the point where  $L_{ext}$  is associated with the source. The DSTATCOM is associated at the point where load and  $L_{ext}$  are associated. The DSTATCOM utilizes a three-stage four-wire VSI. An inactive LC channel is associated in each eliminate to channel high recurrence exchanging segments. Voltages crosswise over dc capacitors,  $V_{dc1}$  and  $V_{dc2}$ , are kept up at a reference estimation of  $V_{dcref}$ .

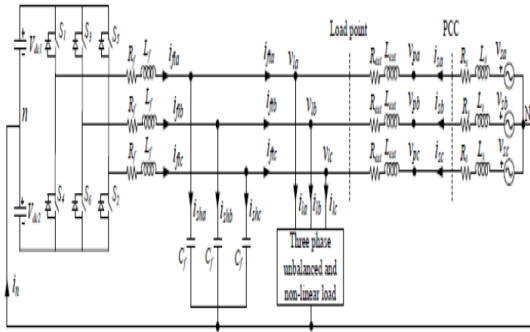
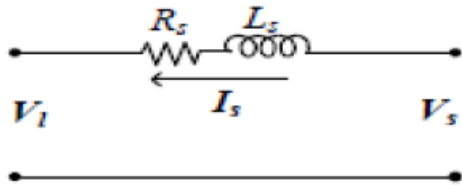


Fig. 1. Three phase equivalent circuit of DSTATCOM topology in distribution system

### 3. EFFECT OF FEEDER IMPEDANCE ON VOLTAGE REGULATION



To show the impact of feeder impedance on voltage control execution, a proportionate source-regulation show without considering external inductor is appeared in Fig. 2. The current in the circuit is given as

$$I_s = \frac{V_s - V_l}{Z_s} \quad (1)$$

where  $V_s = V_s \angle \delta$ ,  $V_l = V_l \angle 0$ ,  $I_s = I_s \angle \phi$ , and  $Z_s = Z_s \angle \theta_s$ , with  $V_s, V_l, I_s, Z_s, \delta, \phi$ , and  $\theta_s$

are rms source voltage, rms load voltage, rms source current, feeder impedance, load angle, power factor angle, and feeder impedance angle,

respectively. The three phase average load power (Pl) is expressed as

$$P_l = \text{Real} [3V_l I_s] \quad (2)$$

Substituting  $V_l$  and  $I_s$  in (2), the load active power is

$$P_l = \frac{3V_l^2}{Z_s} \left[ \frac{V_s}{V_l} \cos(\theta_s - \delta) - \cos \theta_s \right] \quad (3)$$

Rearranging (3), expression for  $\delta$  is computed as follows:

$$\delta = \theta_s - \cos^{-1} \left[ \frac{V_l}{V_s} \left( \cos \theta_s + \frac{P_l Z_s}{3V_l^2} \right) \right] \quad (4)$$

For power exchange from source to load with stable operation in an inductive feeder, additionally, every one of the terms of the second piece of (4), i.e., inside  $\cos^{-1}$ , are amplitude and will positive. Along these lines, estimation of the second part will be between  $0$  to  $\pi/2$  for the whole operation of the load I. Therefore, the load I point will lie between  $\theta_s$  to  $(\theta_s - \pi/2)$  for the whole operation of the load I. Therefore, the load I point will lie between under any load I operation, and in this manner, greatest conceivable load point is s. The vector expression for source voltage is given as takes after

$$V_s = V_l + I_s Z_s \angle (\theta_s + \phi) \quad (5)$$

A DSTATCOM directs the loadl voltage by infusing central reactive current. To exhibit the

DSTATCOM voltage direction capacity at various supply voltages for diverse  $R_s=X_s$ , vector design utilizing (5) are attracted Fig. 3. To draw graphs, voltage regulation VI is taken as reference phasor having the ostensible esteem OA (1.0 p.u.). With point of making  $V_l = V_s = 1.0$  p.u., locus of  $V_s$  will be a half circle of range VI. Since, the greatest conceivable load edge is 90 in an inductive feeder, phasor  $V_s$  can be anyplace inside bend OACBO. It can be seen that the estimation of  $\theta_s + \phi$  must be more prominent than 90 for zero voltage control. Furthermore, it is conceivable just when power element is driving at the load terminal as  $s$  can't be more than 90 Fig. 3(a) demonstrates the restricting situation when  $R_s/X_s = 1$ , i.e.,  $\theta_s = 45^\circ$ . maximum value of angle,  $\theta_s + \phi$ , can be  $135^\circ$  when is  $90^\circ$ . Hence, the limiting source current phasor OE, which is denoted by  $I_s$  limit, will lead the load voltage by  $90^\circ$ . Lines OC and AB demonstrate the constraining vectors of  $V_s$  and  $I_s Z_s$ , separately with D as the crossing point. Subsequently, range under ACDA demonstrates the working district of DSTATCOM for voltage control. The point D has a constraining estimation of  $V_s$  limit =  $I_s Z_s = 0.706$  p.u. In this way, greatest conceivable voltage control is 29.4%. Nonetheless, it is difficult to accomplish

these two breaking points all the while as and - can't be most extreme at a similar time. Again if  $Z_s$  is low at that point source current, which will be practically inductive, will be sufficient to be acknowledged by a DSTATCOM.

Fig. 3(b) considers situation when  $R_s=X_s = p$  3 i.e.,  $s = 30$  The region under ACDA recoils, which demonstrates that with the expansion in  $R_s=X_s$  from the restricting quality, the voltage direction ability diminishes. For this situation the constraining esteems of  $V_s$  limit and  $I_s Z_s$  are observed to be 0.866 and 0.5 p.u., separately. Here, greatest conceivable voltage direction is 13.4%. Nonetheless, because of high current prerequisite, a reasonable DSTATCOM can give little voltage control. Voltage control execution bends for more resistive matrix, i.e.,  $s = 15$  as appeared in Fig. 3(c), can be drawn likewise. Here, range under ACDA is immaterial. For this case, barely any voltage direction is conceivable. In this manner, more the feeder is resistive in nature, lesser will be the voltage direction ability. Consequently, it is gathered that the voltage direction capacity of DSTATCOM in a circulation system for the most part relies on the feeder impedance. Because of resistive nature of feeder in a Distribution system, DSTATCOM voltage regulation ability is restricted. In addition, high current is required to alleviate little voltage unsettling influences which brings

about higher rating of IGBT switches and also expanded misfortunes. One more point worth to be noted is that, in the resistive feeder, there will be some voltage drop in the line at ostensible source voltage which the DSTATCOM may not be capable compensate to look after load voltage at 1.0 p.u. indeed, even with a perfect VSI..

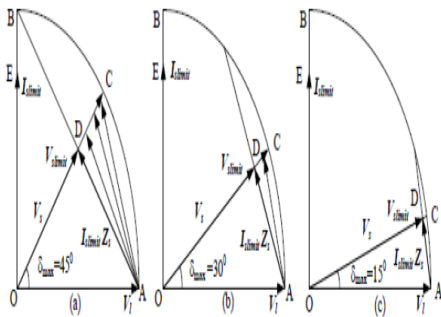


Fig. 3. Voltage regulation performance curve of DSTATCOM at different  $R_s=X_s$ . (a) For  $R_s=X_s = 1$ . (b) For  $R_s=X_s = p3$ . (c) For  $R_s=X_s = 3.73$

#### 4. SELECTION OF EXTERNAL INDUCTOR FOR VOLTAGE REGULATION IMPROVEMENT AND RATING REDUCTION

This segment exhibits a summed up system to choose External inductor for development in DSTATCOM voltage control ability while lessening the present rating of VSI. Fig. 4 indicates single stage comparable DSTATCOM circuit design in distribution system. With adjusted voltages, source current will be

$$I_s = \frac{V_s \angle \delta - V_l \angle 0}{(R_s + R_{ext}) + j(X_s + X_{ext})} = \frac{V_s \angle \delta - V_l \angle 0}{R_{sef} + jX_{sef}} \quad (6)$$

where  $R_{sef} = R_s + R_{ext}$  and  $X_{sef} = X_s + X_{ext}$  are effective

feeder resistance and reactance, respectively.  $R_{ext}$  is equivalent series resistance (ESR) of external inductor, and will be small. With  $\theta_{sef} = \tan^{-1} \frac{X_{sef}}{R_{sef}}$  and  $Z_{sef} = \sqrt{R_{sef}^2 + X_{sef}^2}$  as effective impedance angle and effective feeder impedance, respectively, the imaginary component of  $I_s$  is given as effective impedance angle and effective feeder impedance, respectively, the imaginary component of  $I_s$  is given as

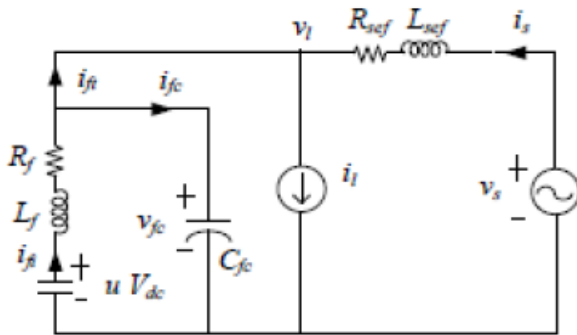
$$I_s^{im} = \frac{V_l \sin \theta_{sef} + V_s \sin (\delta - \theta_{sef})}{Z_{sef}} \quad (7)$$

With the addition of external impedance, the effective feeder impedance becomes predominantly inductive. Hence,  $Z_{sef} \approx X_{sef}$ . Therefore, approximated  $I_{ims}$  will be

$$I_s^{im} = \frac{V_l \sin \theta_{sef} + V_s \sin (\delta - \theta_{sef})}{X_{sef}} \quad (8)$$

DSTATCOM Power rating (Svsi) is given as follows [21]:

$$S_{vsi} = \sqrt{3} \frac{V_{dc}}{\sqrt{2}} I_{vsi} \quad (9)$$



**Fig.4.** Single phase equivalent circuit of DSTATCOM topology with external inductor in distribution system. Compensator current used for voltage regulation (same as  $I_{ims}$ ) is obtained by subtracting  $I_{im1}$  from  $I_{vsi}$  and given as follows

$$I = I_{vsi} - I_l^{im} = \frac{\sqrt{2}S_{vsi}}{\sqrt{3}V_{dc}} - I_l^{im}. \quad (10)$$

Comparing (8) and (10) while using value of  $\_$  from (4), following expression is obtained

$$X_{sef} = \frac{V_l \sin \theta_{sef} - V_s \sin \left[ \cos^{-1} \left[ \frac{V_l}{V_s} \left( \cos \theta_{sef} + \frac{P_l X_{sef}}{3V_l^2} \right) \right]}{\frac{\sqrt{2}S_{vst}}{\sqrt{3}V_{dc}} - I_l^{im}} \dots$$

The above expression is utilized to process the estimation of external inductor. Plan case of

external inductor, utilized for this work, is given in next area .

## 5. FLEXIBLE CONTROL STRATEGY

This areas shows an adaptable control technique to move forward the execution of DSTATCOM in nearness of the external inductor  $L_{ext}$ . Right off the bat, a dynamic reference voltage regulation based on the planned control of theload basic current, PCC voltage, and voltage over the external inductor is figured. At that point, a corresponding necessary (PI) controller is utilized

to control the heap point which helps in managing the dc bus voltage at a reference esteem. At last, three stage reference voltages regulation are created. The square graph of the control procedure is appeared in Fig. 5.

### A. Derivation of Dynamic Reference Voltage Magnitude ( $V_l^*$ )

In traditional VCM operation of DSTATCOM, the reference Voltage regulation is kept up at a consistent estimation of 1.0 p.u. [10]–[12]. Source currents can't be controlled in this reference era plot. Along these lines, control element will not be solidarity and source trades reactive power with the system even at ostensible supply. To beat this constraint, an adaptable control procedure is created to produce reference load voltage. This scheme allows DSTATCOM to set different reference

voltages during various operating conditions. The scheme is described in the following

**1). Normal Operation:** It is characterized as the condition when Voltage regulation lies between 0.9 to 1.1 p.u. For this situation, the proposed adaptable control technique controls voltages regulation such that the source currents are adjusted sinusoidal and VSI does not trade any reactive power with the source. Subsequently, the source supplies just major positive succession current segment to bolster the normal load power and VSI misfortunes. Reference current source ( $i_{sj}$  where  $j = a; b; c$  are three stages), registered utilizing momentary symmetrical segment hypothesis, are given as

$$i_{sj}^* = \frac{v_{pj1}^+}{\Delta_1^+} (P_l + P_{loss}) \quad (12)$$

where  $\Delta_1^+ = \sum_{j=a,b,c} (v_{pj1}^+)^2$ . The voltages  $v_{pa1}^+, v_{pb1}^+, v_{pc1}^+$  are fundamental positive sequence components of PCC voltages. Average load power ( $P_l$ ) and VSI losses ( $P_{loss}$ ) are calculated using moving average filter (MAF) as follows:

$$P_l = \frac{1}{T} \int_{t_1-T}^{t_1} (v_{la}i_{la} + v_{lb}i_{lb} + v_{lc}i_{lc}) dt \quad (13)$$

$$P_{loss} = \frac{1}{T} \int_{t_1-T}^{t_1} (v_{la}i_{fta} + v_{lb}i_{ftb} + v_{lc}i_{ftc}) dt. \quad (14)$$

The reference source currents must be in phase with the respective phase fundamental positive sequence PCC voltages for achieving UPF at the PCC. Instantaneous PCC voltage and reference source current in phase-a can be defined as follows:

$$v_{pa1}^+ = \sqrt{2}V_{pa1}^+ \sin(\omega t - \varphi_{pa1}^+), \quad i_{sa}^* = \sqrt{2}I_{sa}^* \sin(\omega t - \varphi_{pa1}^+) \quad (15)$$

where  $V_{pa1}^+$  and  $\varphi_{pa1}^+$  are rms voltage and angle of fundamental positive sequence voltage in phase-a, respectively.  $I_{sa}^*$  is the rms reference source current obtained from (12). With external impedance, the expected load voltage is given as follows:

$$V_{la} = V_{pa1}^+ - I_{sa}^* Z_{ext}. \quad (16)$$

From (15) and (16), the load voltage magnitude will

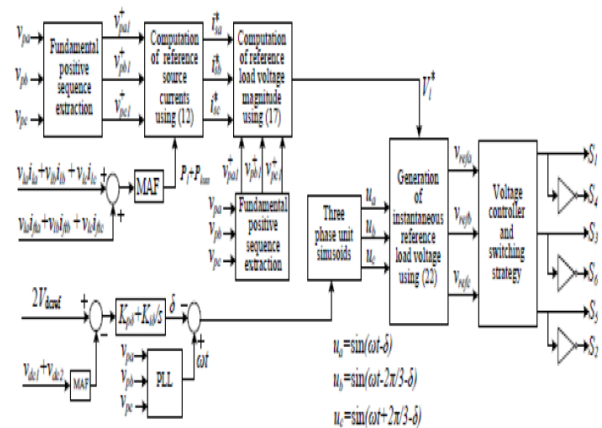


Fig.5. Block diagram of proposed flexible control strategy

$$V_{la} = \sqrt{\left[ (V_{pa1}^+ \cos \varphi_{pa1}^+ - I_{sa}^* Z_{ext} \cos(\theta_{ext} - \varphi_{pa1}^+))^2 + (V_{pa1}^+ \sin \varphi_{pa1}^+ - I_{sa}^* Z_{ext} \sin(\theta_{ext} - \varphi_{pa1}^+))^2 \right]} \quad (17)$$

be with UPF at the PCC, the voltage over the external inductor will lead the PCC voltage by 9°. Ignoring ESR of external inductor, it can be watched that the voltage over External inductor enhances the load voltage contrasted with the PCC voltage. This highlights another favorable position of external inductor where it helps in enhancing the load voltage. As long as  $V_{la}$  lies between 0.9 to 1.1 p.u., same voltage is utilized as reference terminal voltage ( $V_{l1}$ ), i.e.,

$$\text{if } V_{la} \in [0.9 - 1.1 \text{ p.u.}], \text{ then } V_l^* = V_{la}. \quad (18)$$

**2) Operation During Sag:** Voltage sag is considered when value of (17) is less than 0.9 p.u. To keep filter current minimum, the reference voltage is set to 0.9 p.u. Therefore,

$$V_{l1}^* = 0.9 \text{ p.u.} \quad (19)$$

**3) Operation During Swell:** A voltage swell is considered when any of the PCC phase voltage exceeds 1.1 p.u. In this case, reference load voltage ( $V_{l1}$ ) is set to 1.1 p.u. which results in minimum current injection. Therefore,

$$V_{l1} = 1.1 \text{ p.u.} \quad (20)$$

**B. Calculation of Load Angle ( )** Normal real power at the PCC ( $P_{pcc}$ ) is total of normal load power (PI) and VSI misfortunes (Ploss). The real power  $P_{pcc}$  is taken from the source contingent on the point between source and load voltages, i.e., load point In the event that DSTATCOM dc bus capacitor voltage is directed to a reference esteem, at that point in consistent state condition P loss is a steady esteem and structures a small amount of P pcc. Thus, is likewise a steady esteem. The dc connect voltage is directed by producing a reasonable estimation of The normal voltage crosswise over dc capacitors ( $V_{dc1} + V_{dc2}$ ) is contrasted and a reference voltage and blunder is passed through a PI controller. Yield of PI controller,  $\delta$ , is given

$$\delta = K_{p\delta} e_{vdc} + K_{i\delta} \int e_{vdc} dt \quad (21)$$

where  $e_{vdc} = 2V_{deref} - (V_{dc1} + V_{dc2})$  is the voltage error.  $K_p$  and  $K_i$  are relative and vital additions, individually.

**C. Generation of Instantaneous Reference Voltage** Choosing appropriate reference regulation voltage magnitude and processing load point from (21), the three stage adjusted sinusoidal reference load voltages are given as takes after:



$$\begin{aligned}
 v_{refa} &= \sqrt{2}V_l^* \sin(\omega t - \delta) \\
 v_{refb} &= \sqrt{2}V_l^* \sin(\omega t - 2\pi/3 - \delta) \\
 v_{refc} &= \sqrt{2}V_l^* \sin(\omega t + 2\pi/3 - \delta).
 \end{aligned}
 \tag{22}$$

These voltages are realized by the VSI using a predictive voltage controller.

## 6. SIMULATION RESULTS

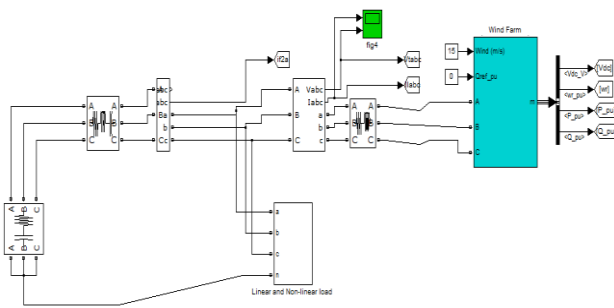


Fig 6. Simulation circuit of Windfarm based Without dstatcom

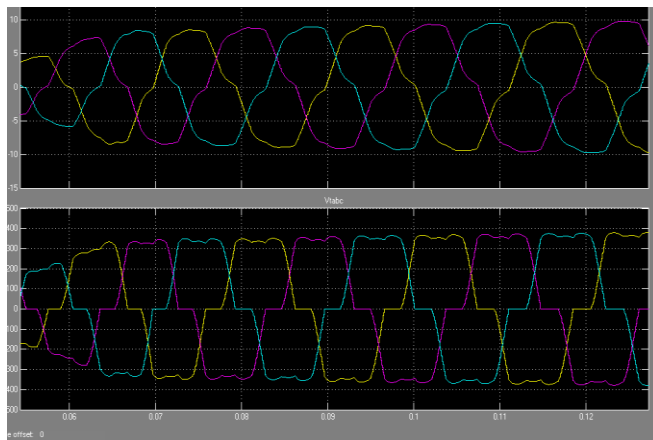


Fig 7. Source current & Load voltage

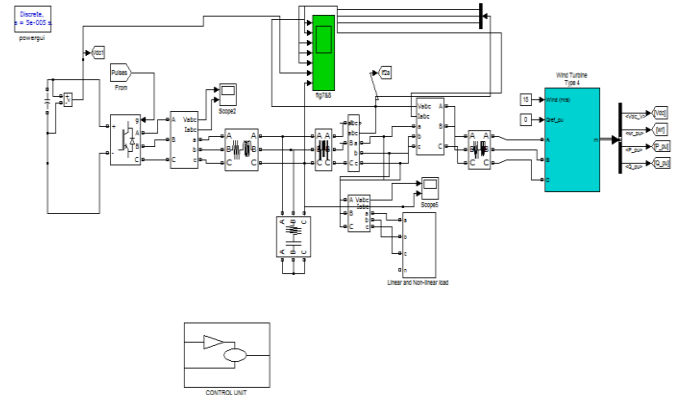


Fig 8. Wind farm based With dstatcom

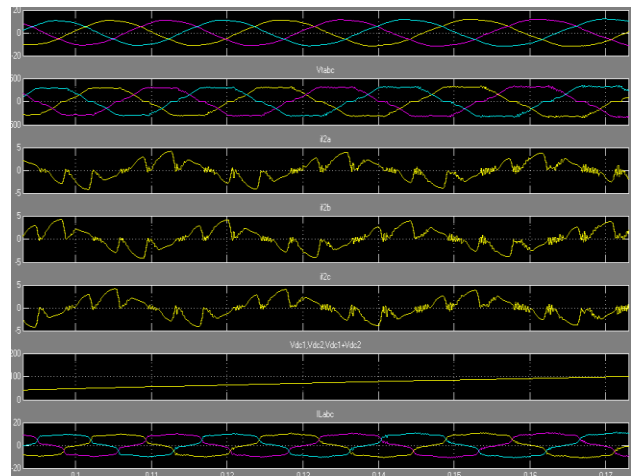


Fig 9. Source current, Load voltage, dstatcom currents (a,b,c), Vdc, Load Current

## 7. CONCLUSION

This paper has introduced external, operation, and control of a Windfarm based DSTATCOM working in voltage control mode (VCM). Subsequent to giving a nitty gritty investigation of voltage control capacity of DSTATCOM under different feeder situations, a benchmark outline method for choosing

appropriate estimation of external inductor using fuzzy logic controller is proposed. A calculation is defined for dynamic reference regulation voltage size generation. The DSTATCOM has enhanced voltage control capacity with a decreased current rating VSI, lessened misfortunes in the VSI and feeder. Additionally, dynamic reference regulation voltage era conspire enables DSTATCOM to set diverse steady reference voltage amid voltage unsettling influences. Reenactment and test comes about approve the adequacy of the proposed arrangement. The external inductor is an exceptionally basic and shabby arrangement for enhancing the voltage direction, be that as it may it remains associated all through the operation and ceaseless voltage drop crosswise over it happens. The future work incorporates operation of this settled inductor as a controlled reactor with the goal that its impact can be limited by differing its inductance.

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