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Design of the Pole Placement Controller for D-STATCOM in Mitigating Three Phase Fault

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Abstract--This paper presents the design of pole placement controller for D-STATCOM in mitigation of three-phase fault. The pole placement method is by shifting the existing poles to the new locations of poles at the real-imaginary axes for better response. This type of controller is able to control the amount of injected current or voltage or both from the D-STATCOM inverters to mitigate the three-phase fault by referring to the currents that are the input to the pole placement controller. The controller efficiency was tested in the different percentage of voltage sag that occurs during the three-phase fault. The controller and the D-STATCOM have been designed using SIMULINK and Power System Blockset toolbox that is available in MATLAB program. The simulation was done on an 11 kV distribution system having a three-phase fault. The results suggest that by using this type of controller, it is capable to mitigate the different amount of voltage sags.

Index Terms-- Pole placement, D-STATCOM, Three Phase Fault, MATLAB, SIMULINK, SPWM.

I. INTRODUCTION

The Distribution Static synchronous compensator (D-STATCOM) is a shunt-connected device that generates a balanced set of three phase sinusoidal voltages or current at the fundamental frequency [1]. The D-STATCOM consists of voltage source inverter such as Gate Turn Off (GTO) thyristor, a DC link capacitor and a controller [2]. It has been proven that the D-STATCOM is a device that is capable in solving the power quality problems at the distribution system.

One of the power quality problems that always occur at the distribution system is the three-phase fault that is cause by short circuit in the system, switching operation, starting large motors and etc. This problem happen in milliseconds and because of the time limit, it need the D-STATCOM that has continuous reactive power control with fast response [3].

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Due to this factor, various topologies for the controllers can be design such as Proportional Integration (PI), pole placement and Linear Quadratic Regulator (LQR) to give high response to the system and steady operating point. The PI controller refers to the reactive power and reference reactive power as the input to the controller for injecting the currents from the D-STATCOM that cause slow response to the controller [3]. For the pole placement method, the controller is based on a dynamic model rather than phasor diagram [3], which produces a high response to the system. The pole placement is also known as a discrete time control technique with close loop poles [4] and has meet the degree of stability on the operating points [5]. In LQR controller method, it is capable to response high by change of the system but the problem is in selecting the positive semi definite and positive definite matrix value to give a better performance.

In this work, the pole placement controller has been selected because it is operate in highly response, capable in controlling two outputs from the D-STATCOM and give better ride through system to the distribution system. The pole placement method is a combination of input–output feedback linearization and DQ transformations of the reference currents from the distribution system. Pole placement controller is used to shift the initial pole from the right to the left of the complex diagram, in order to increase the stability of the system and damping response [1] which makes the inverter in the D-STATCOM to inject voltage or current to compensate the three phase fault. This technique has been applied by [1, 4] and it shows it is suitable in D-STATCOM control. The different from the previous studies is the pole placement controller was design referring to signal flow diagram which consists only a branch, which represents the system and the nodes of the state space equation that obtained from the D-STATCOM circuit. In this pole placement controller the combination between DQ transformation of the current from the distribution has been applied to minimize of the D-STATCOM state space equation. This DQ transformation will give all information about three phase set, steady state unbalance, harmonic waveform distortions and transient components [6].

II. MODELING OF D-STATCOM

In designing the pole placement controller, the state space equations from the D-STATCOM circuit must be introduced. The theory of DQ transformation of currents has been applied in the circuit, which makes the d and q components as independent parameters. Fig.1 shows the circuit diagram of a typical D-STATCOM. The D-STATCOM

is connected in shunt with the power system and the capacitor in left hand side that used to supply the voltage to the inverter to solve the power quality problems.

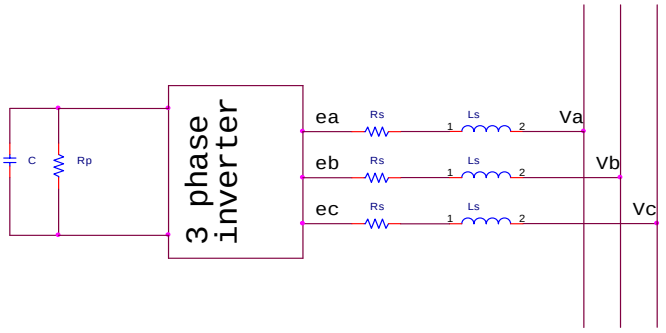

Fig.1. Equivalent circuit of STATCOM

The resistance 'Rs' in series with the inverter represents the sum of the transformer winding resistance losses and inverter conduction losses. The inductance 'Ls' represents the leakage inductance of the transformer. The resistance 'Rp' in shunt with the capacitor 'C' represents the sum of the switching losses of the inverter and power losses in the capacitor [1]. The inverter block represents an ideal transformer. The voltage 'ea', 'eb' and 'ec' are the inverter AC side phase voltage suitably stepped up. The circuit for the D-SATCOM without the capacitor in single line diagram is shown in Fig.2. The equation represents the circuit as follows,

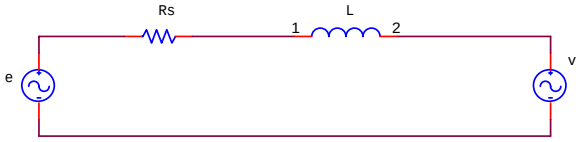

Fig.2. Single line diagram

The equation for single phase diagram can be written as,

$$R_s + L\frac{di}{dt} + v = e \tag{1}$$

$$L\frac{di}{dt} = e - v - R_s i \tag{2}$$

$$\frac{di}{dt} = \frac{e-v}{L} - \frac{R_s}{L} i \tag{3}$$

The loop equation for the circuit can be written in vector as,

$$\frac{d}{dt} i_{abc} = -\frac{R_s}{L} i_{abc} + \frac{1}{L}\left(e_{abc} - v_{abc}\right) \tag{4}$$

Equation 4, indicates of the D-STATCOM circuit without DQ transformation. After the DQ transformation and linearization process to Equation 4, the state space for D-STATCOM is shown in Equation 5 [6],

$$\frac{d}{dt}\begin{bmatrix} i'_d \\ i'_q \\ v'_{dc} \end{bmatrix} = [A_\nabla]\begin{bmatrix} i'_d \\ i'_q \\ v'_{dc} \end{bmatrix} + [B_\nabla]\begin{bmatrix} v' \\ \alpha \end{bmatrix} \tag{5}$$

where,

$$[A_\nabla] = \begin{bmatrix} \frac{-R'_s\omega_b}{L'} & \omega_b & \frac{\omega_b k}{L'}\cos(\alpha) \\ -\omega_b & \frac{-R'_s\omega_b}{L'} & \frac{\omega_b k}{L'}\sin(\alpha) \\ -\frac{3}{2}kC'\omega_b\cos(\alpha) & \frac{3}{2}kC'\omega_b\sin(\alpha) & \frac{-C'\omega_b}{R'_p} \end{bmatrix}$$

$$[B_\nabla] = \begin{bmatrix} \frac{-\omega_b}{L'} & \frac{-k\omega_b v'_{dc}}{L'}\sin(\alpha) \\ 0 & \frac{-k\omega_b v'_{dc}}{L'}\cos(\alpha) \\ 0 & \frac{3}{2}kC'\omega_b(i'_d\sin(\alpha) - i'_q\cos(\alpha)) \end{bmatrix}$$

The primed parameters indicate the p.u value. The D-STATCOM parameters (in p.u.) used in the following discussion are given as,

$\alpha = 0;\ V'_{dc} = 1.35;\ L' = 0.1;\ R'_s = 0.01$, k=1.273; $\omega_b = 314;$

$C' = 2.275;\ i'_d = 0.082;\ i'_q = -0.048$

Equation 5 shows the state space equation for the D-STATCOM. This equation will give the initial poles which are highly damp and has high frequency oscillation at the operating point and is shown in Fig.3. The initial poles of D-STATCOM are shown as,

$$S = \begin{bmatrix} -16 - 2356\ j \\ -16 + 2356\ j \\ -30.8 \end{bmatrix} \tag{6}$$

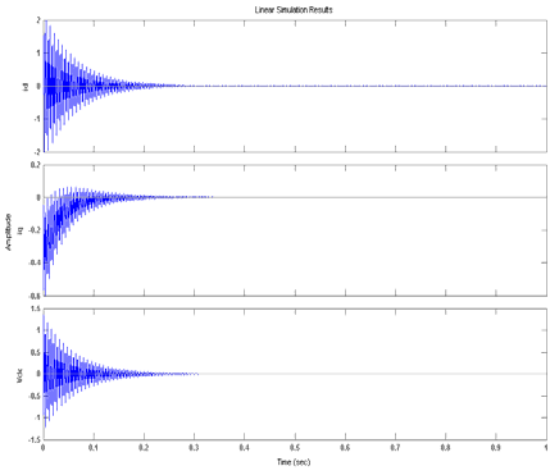

Fig.3. Initial poles response of D-STATCOM

In Fig.3, it shows large oscillations in i_d and i_q during 0 to 0.2 sec and the V_{dc} value gives zero output where means it will be no supply voltage from the V_{dc} to the inverter.

III. POLE PLACEMENT CONTROLLER DESIGN

In designing the pole placement controller, the new poles must satisfy a few conditions stated below,

- the oscillations in i_d, i_q and V_{dc} must respond less than one period of cycle due to system frequency which is 50 Hz [3],
- the overshoot of i_d and i_q must be improved,
- the voltage of the capacitor (V_{dc}) should be kept constant [4,7] by control of the controller, and
- i_d must give zero output because it represents the active power [1].

The new poles locations were selected according to [4] which one of the poles locations is needed to be at the origin for fulfill the requirements stated above. The controller block diagram was been designed using SIMULINK-MATLAB application after the new poles locations were found based on Fig.4. Fig.4 shows the pole placement controller for D-STATCOM applications. It shows that the block consists of Equation 5 with a feedback loop from Kp block which are the values of the gain of the pole placement controller that was found from the locations of new poles. This feedback gain also used to minimizing the error between the references value with the Kp gain. The control block diagram using the new poles locations of the D-STATCOM and the reference currents are shown in Fig.4.

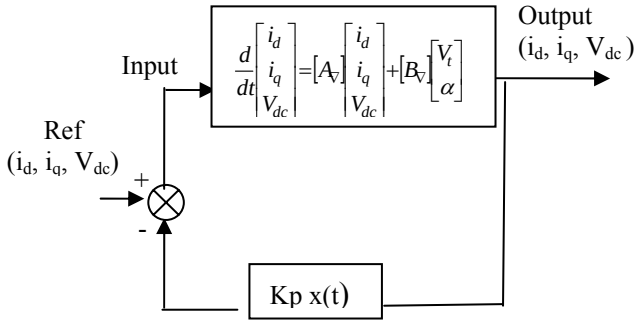

Fig.4. Pole Placement controller block

In designing the signal flow diagram, the flow of the nodes and the branches of the signal flow diagram are referring to Fig. 4 which include Equation 5. To design the controller, it needs a separation between the Kp block and Equation 5 block before combining it to a complete block diagram.

The locations of new poles was found using a program that written in M-File format in the MATLAB. This program is needed to determine the outputs for i_d, i_q and V_{dc} which satisfy the requirement stated when the poles locations was selected. The selection of the poles locations was been done in try and error method with referring to point [3]. Different poles locations determine different system performance. The program flow in M-File Format is shown in Fig.5.

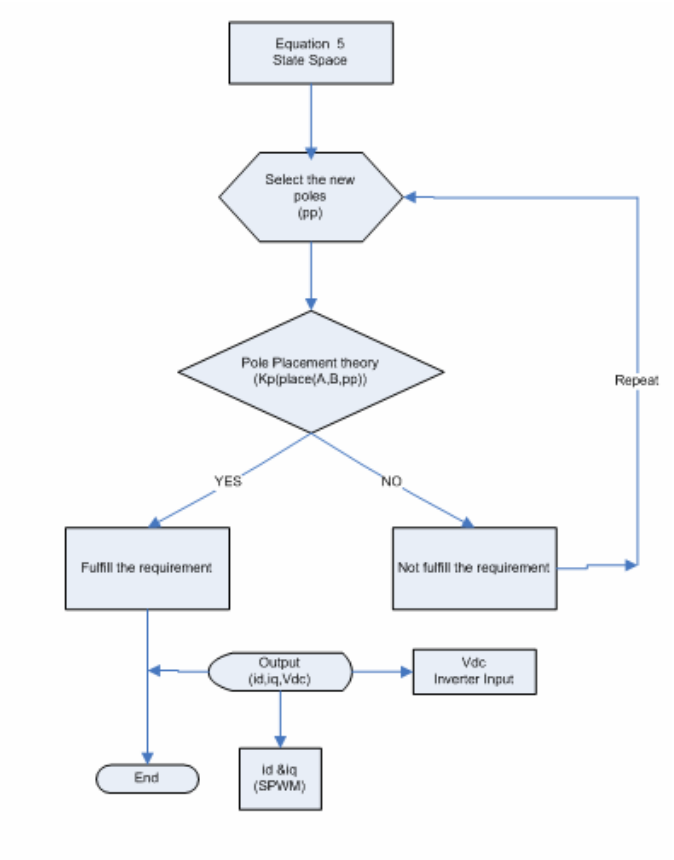

Fig.5. Flow chart of M-File program

From Fig.5, the outputs are i_d, i_q and V_{dc}. Outputs of i_d and i_q will be the input to generate reference signal for SPWM technique while the V_{dc} will be the input to the inverter. Fig.6 shows the response of the outputs when the poles was selected at (-5000± 2346j, 0). It shows that the value for V_{dc} is in constant during the simulation, the overshoot of i_d and i_q have been reduced and the id output give zero value because it represents the active power.

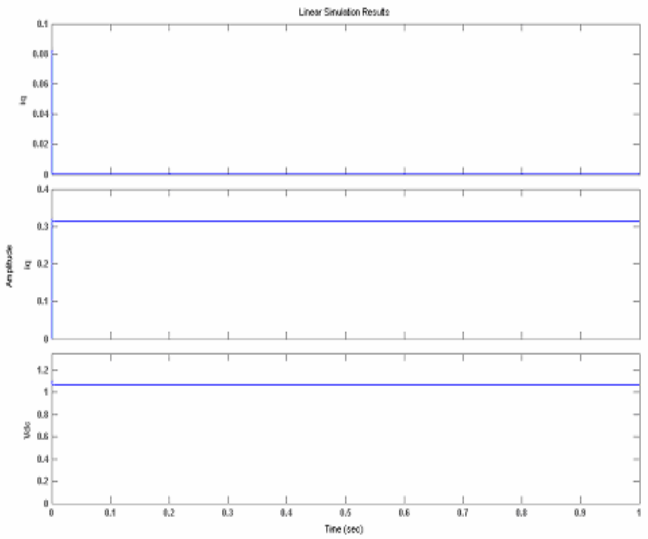

Fig.6. Outputs at poles (-5000± 2541j, 0),

The gain values of (Kp) are stated in equation 7 where,

$$Kp = \begin{pmatrix} -1.600 & -0.3847 & -1.1892 \\ -1.1393 & 0.9138 & -0.2703 \end{pmatrix} \quad (7)$$

After the values of Kp were found the pole placement controller was designed in SIMULINK block referring to Fig.4 and the signal flows concepts. The complete block diagram of pole placement controller is shown in Fig.7.

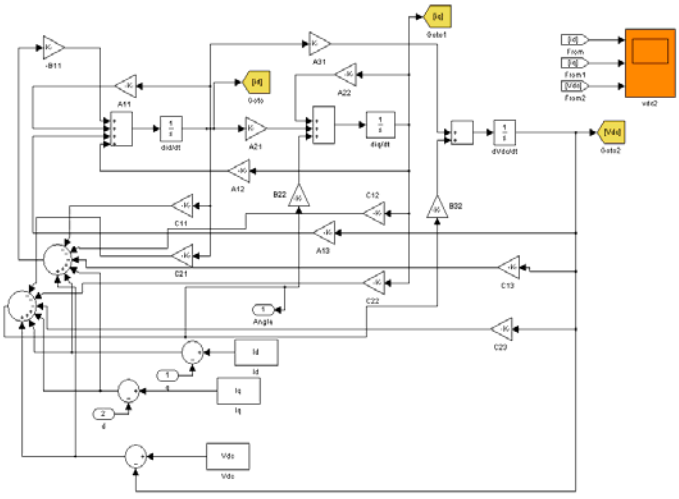

Fig.7. Complete block diagram of pole placement controller

IV. SPWM TECHNIQUE

SPWM technique has used to generate the pulses signals to the GTO. This is done by comparing the references signal with the carrier frequency. The reference signals come from the outputs of the pole-placement controller which are i_d and i_q signals. These signals will flow first to dq / abc transform block to convert back to ia, ib and ic signals. After the transformation, these signals will act as references to signal pulse generator which can be found in PSB library. The magnitude of the reference sine waveform must be in range [-1 to 1] for highly switching. From Fig.6 it shows that the value for i_d and i_q are between the range and it prove that it has highly response. The carrier frequency is set at 2 kHz. The block of SPWM technique with the i_d and i_q inputs are shows in Fig.8,

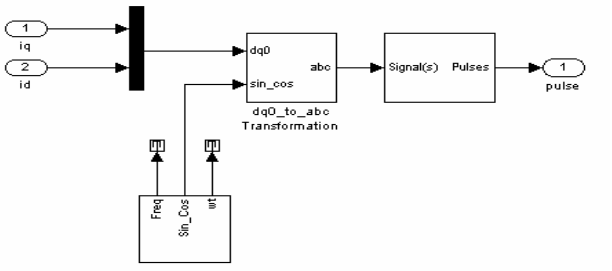

Fig.8. Complete block diagram for SPWM technique

V. D-STATCOM CONFIGURATION FOR THREE PHASE FAULT SIMULATION

The system shown in Fig.9 was simulated using MATLAB software. The system parameters and the transformer data chosen for the simulation studies are given in Table 1,

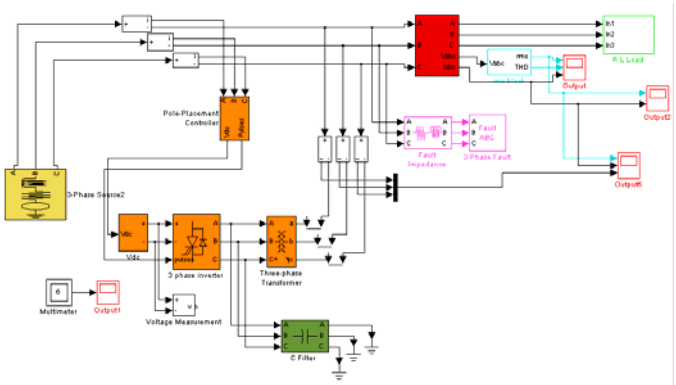

Fig.9. D-STATCOM in distribution system

Table 1: System Data

System Quantities	Values
Source Voltage	11 kV
System frequency	50 Hz
Source impedance	1+8jΩ
Load impedance	72.6+35.1618jΩ
Fault impedance	20+35.796jΩ/50
Fault time	0.1 sec to 0.3 sec
Rated transformer	2/11kV
Transformer impedance	0.01+31.4jΩ

The simulation of the D-STATCOM in fault condition was done by using three phase fault. The duration of the fault is set for about 0.2 sec and the total simulation time is 0.4 sec.

VI. SIMULATION RESULTS

The simulation was done in three phase fault that was introduced in the 11kV distribution system. Fig.10 shows the simulation results when the D-STATCOM is not applied to the distribution system. In Fig.9a it is shown the output on the RMS voltage. From the graph, the percentage of voltage sag during the fault can be calculated and it is about 16% sag. In Fig.9b it is shown that the amount of current at load was drop during the fault period when three phase fault was been applied. The amount of current drop is between 105A to 88A.

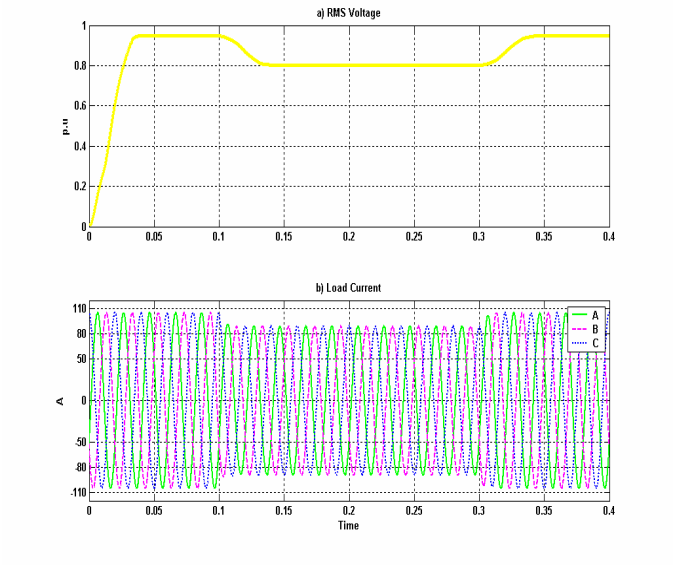

Fig.10. a) RMS Voltage, b) Current at load

Fig 11 shows the outputs when the D-STATCOM was connected to the distribution system. In Fig.11a it is shown that, the voltage sag was been mitigated and maintain at 1.0 p.u during the simulation. From Fig.11b it is shown the current load was increased to 110A to its nominal value because of the D-STATCOM has injected the current to the distribution system that shows in Fig.11c. The amount of injected current during fault period is higher from no fault period because it is used to compensate the voltage sag. The amount of injected current is about during the fault period is about 2350A.

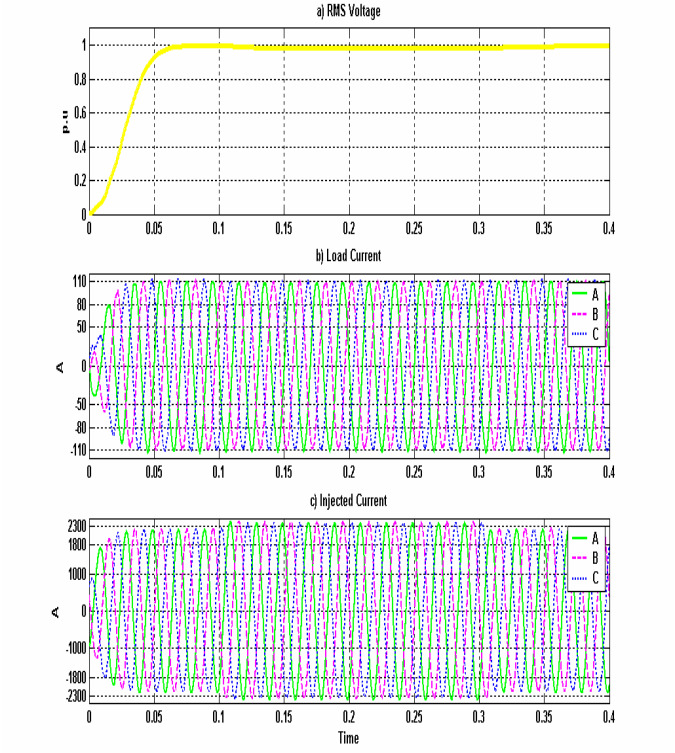

Fig.11. a) RMS Voltage, b) Current at load, c) injected current

The simulation for three phase fault was done again but in different amount of voltage sag. The different amount of voltage sag can be introduced by changing the fault components in the fault system or by increase the fault resistance. From Fig.12 it is shows that the amount of sag voltage is smaller than in the Fig.10a. The percentage of voltage sag can be calculated and it is about 10% sag. Fig 12b shows the current profiles at the load and during the fault period the current are reduced from 105A to 96A.

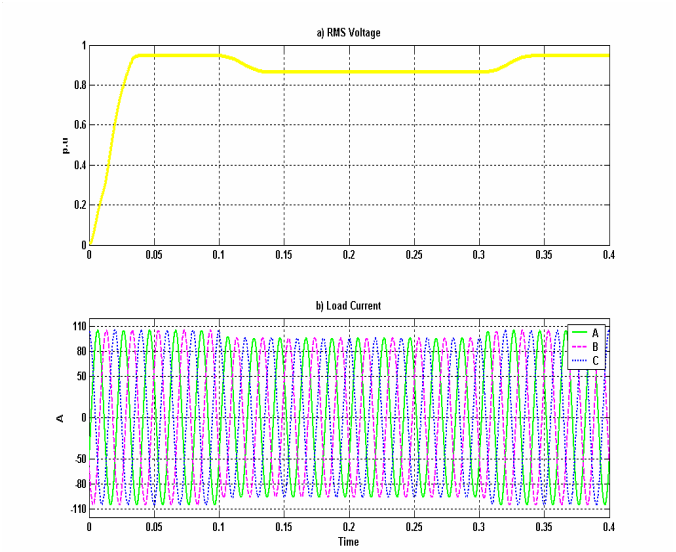

Fig.12. a) RMS Voltage, b) Current at load

When the D-STATCOM was connected to the distribution system the outputs are shown in Fig.13.

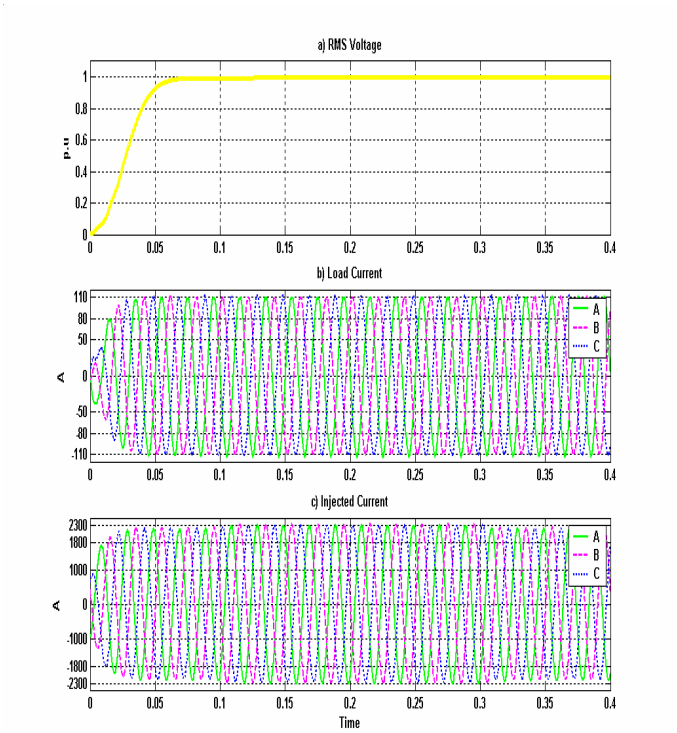

Fig.13. a) RMS Voltage, b) Current at load, c) injected current

From Fig.13a it shows that the voltage sag has been improved to it normal value and in Fig.12b it shows the current has been improved to 110A. Its explained that the D-STATCOM was injected the current to the distribution system. The injected current from the D-STATCOM is about 2300A during the fault period.

VII. CONCLUSION

The modeling of a pole placement controller for the D-STATCOM is presented in this paper. The pole placement controller in the D-STATCOM has been applied in the distribution system that having three phase fault to investigate the efficiency. From the analysis of the pole placement controller, it shows that it is capable to control the inject current from the D-STATCOM to the distribution system for three phase fault correction. The different amount of injected current from the D-STATCOM is used to mitigate the different percentage amount of voltage sag which is shown in Fig.11c and Fig.3c.. Due to this advantage the pole placement controller can be one promising device that can be used in other types of custom power families in solving power quality problems.

VIII. REFERENCES

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