

COMPARATIVE STUDY OF DSTATCOM, UPFC & DPFC WITH DIFFERENT SOURCE-LOAD CONFIGURATION

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ABSTRACT

The main objective of the presented work is to explore DSTATCOM, UPFC, and DPFC for mitigation of voltage sag/swell and improvement of power quality, to test their potential for single and multi-generator (power plant) system, effects of faults on adjacent lines in single generator system and multi-generator system. The high demand of electrical power distribution especially in India where it is targeted to have electrical power supply to every village, the non-linear load dynamics, extreme environmental conditions and increased harmonics simultaneously raised the demand for optimization in power losses, optimal power supply regulation, and mitigation of harmonic distortions. The integration of renewable energy sources on large scale and introduction of smart grids also needs transient state and steady state controllability enhancement and hence the work investigates the suitability and superior power electronic control for the power transmission and distribution systems. The presented work also investigates the impact of faults on adjacent lines, the dynamic instability due to integration of new power sources, future scope for integration of automation in power distribution and transmission system.

Keywords: AC, FACTS, SVC, DSTATCOM, UPFC, DPFC

1. INTRODUCTION

The increased demand of electricity, rapid industrialization, introduction of smart grids, instantaneous fault tolerance makes it necessary to use the advancements in power electronics. The following limitations have been observed under power distribution in a region or among multiple areas like steady state power transfer limit, transient and steady state stability limit, power system

oscillation damping limit, loop flow limit, thermal limit, short-circuit current limit [2].

There are various flexible alternating current power flow controllers were reported. Where, flexibility determines the capability of system to compensate changes in transmission line parameters while keeping steady state and transient state stability intact [3]. Where the transmission line is assumed as purely inductive, as shown in figure 1.1 [5]

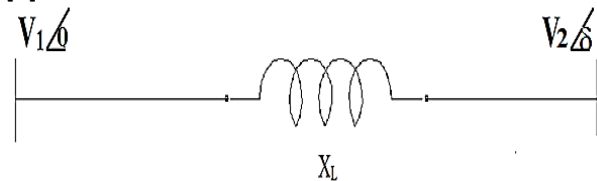


Fig 1.1 Basic FACTS representation

The power transfer through transmission line is defined by

$$P_{12} = \frac{V_1 V_2}{X_L} \sin \delta. \dots\dots\dots (1)$$

This determines that power transfer can be increase by increasing the V_1 , V_2 , controlling phase change and by decreasing transmission impedance [4]. The insertion of parallel impedance, segmenting the transmission lines or introducing a voltage source out of phase against the voltage drop due to transmission impedance are the possible options according to FACTS principle to enhance power transfer ratio [5]. DSTATCOM, UPFC, and DPFC already reported in the past. But, still the position of shunt series converter, optimization of gain of PI controllers used, the effect of faults on adjacent lines, the location of feedback tapping are rarely discussed. This paper concentrated on finding the superiority of

UPFC and DPFC FACTS controllers for single and multi-generator system.

2. BACKGROUND

2.1 DSTATCOM

It is a VSC based shunt convertor used to control the voltage sag/ swell through active and reactive power exchange. It also used external dc source to provide assistance to the transmission line power flow and maintain the line voltage. The static variable compensators (SVC) used shunt capacitor or reactor banks which is synchronously switched on and off to control the transmission line (variable) impedance. But, its slower response and limitation in capacitor switching limits its applications.

Feedback circuit consists a three-phase sequence analyzer to provide the voltage magnitude deviation into transmission lines, proportional-integral (PI) controller. A reference pulse is generated with the help of a PWM generator circuit which feedback to the universal bridge for controlling the dynamic voltage change of the transmission line connected. In order to change the reactive current, the condenser voltage is changed in controlled way. The reactive current is modeled as

$$I_R = \frac{1}{1+sT_L} I_{Ref} \dots\dots\dots (2)$$

Where, T_L is plant time constant and I_{ref} is reference current set by controller [7][8]. A static synchronous generator connected in parallel with the output (in-phase) and can be controlled independently of the AC voltage network [9]. The circuit diagram of DSTATCOM is shown below [10].

The DSTATCOM modeled with a DC source of 19KV, a high power condenser 750μF 19KV, high speed universal bridge, and a feedback circuit. The It is assumed that phase of source $\delta_s = 0$, then the power transfer with the network

$$P_{12} = \frac{P_1 P_2}{X_m} \sin \delta_{sh} \dots\dots\dots (3)$$

$$Q = \frac{V_1^2}{X_m} - \frac{P_1 P_2}{X_m} \cos \delta_{sh} \dots\dots\dots (4)$$

$$I_{sh} = \frac{V_m - V_1}{X_m} \dots\dots\dots (5)$$

The above equations represent active, reactive power and current to the network through the controller. The output voltage of Gate-Turn-Off thyristor for example IGBT, the shunt voltage V_{sh} is kept in phase with transmission line point voltage

V_t while the reactive current (I_q) is varied in accordance with the shunt voltage V_{sh} . The voltage V_t and V_{sh} determines the behavior of converter as inductive or capacitive.

2.2 UPFC

This concept was developed by Gyugyi in 1991. It is obvious that the voltage and phase angle regulation involve real and reactive power exchange with transmission line. This exchange, therefore, required AC to DC converter and vice-versa, DC source & storage elements in addition to the controller. The unrestricted voltage and angle regulation required to operate in the complete $P + jQ$ complex plain. It has been achieved by using two voltage source converters one connected in shunt while other in series with the transmission line and the two converters also connected to each other through a dc link (capacitor). It provides control for voltage, phase angle, and transmission line impedance as well. It controls real and reactive power independently. Therefore, change in real power does not produce and unwanted change in reactive power and vice-versa [6, 11].

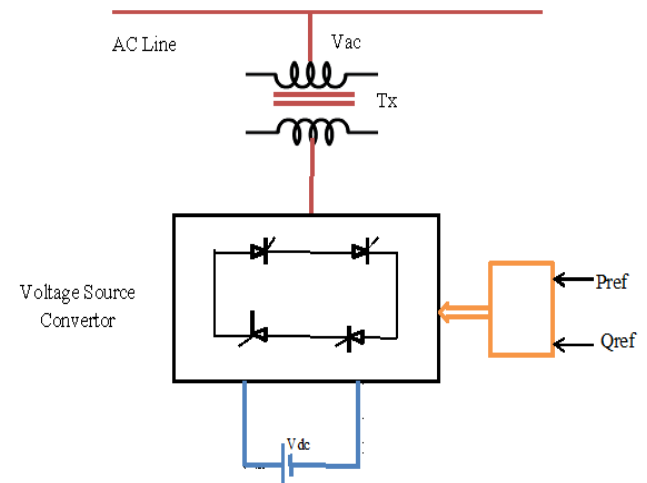


Fig. 2.1 Equivalent circuit of a DSTATCOM coupled to the network

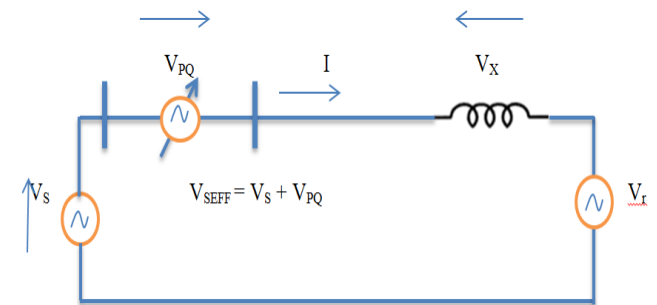


Fig. 2.2 Conceptual representation of the UPFC in a two-machine power system

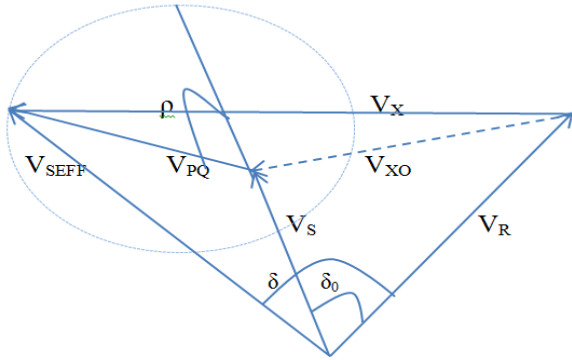


Fig. 2.3 Phasor representation corresponding to conceptual UPFC in a two-machine power system

The series voltage converter injects voltage $\vec{V}_{pq} = V_{pq}e^{j\rho}$ called synchronous voltage source in series with the transmission line via an insertion transformer. The power exchange derives through the series converter while the shunt converter provides ac/dc compensation with the help of link capacitor.

If $V_{pq} = 0$, then

$$P - iQ_r = V_r \left(\frac{V_s - V_r}{jX} \right)^* \dots\dots\dots (6)$$

The above equation determines the power flow of uncompensated line corresponding to two machine system. Therefore, real and reactive power can be represented as

$$P - iQ_r = V_r \left(\frac{V_s - V_r}{jX} \right)^* + \frac{V_r V_{pq}^*}{-jX} \dots\dots (7)$$

On solving equation (6) & (7) the real and reactive power can be given as

$$P_0(\delta, \rho) = P_0(\delta) + P_{pq}(\rho) = \frac{V^2}{X} \sin \delta - \frac{V V_{pq}}{X} \cos(\delta/2 + \rho) \dots\dots\dots (13)$$

$$Q_{0r}(\delta, \rho) = Q_{0r}(\delta) + Q_{pq}(\rho) = \frac{V^2}{X} (1 - \cos \delta) - \frac{V V_{pq}}{X} \sin(\delta/2 + \rho) \dots\dots\dots (14)$$

P_0, Q_{0r} are real and reactive power characterizing the power transmission of the uncompensated system at a given angle δ . Since angle ρ is freely variable between 0 and 2π at any given transmission angle $\delta (0 \leq \delta \leq \pi)$, it shows that P_0 , and Q_{0r} are controllable between $-\frac{V V_{pq}}{X}$ and $+\frac{V V_{pq}}{X}$ independent of angle δ . It improves the scope of voltage regulation, transient stability and power oscillation damping.

2.3 DPFC

Distributed power flow controller is obtained by removing dc link between shunt and series

converter as shown in figure 2.4 [12]. Now each converter in DPFC therefore, is an independent compensator and has their individual dc capacitor. The shunt and series converters communicated through single link and it is transmission line itself at third harmonic frequency. Here, the large rated series converters are replaced by several one dimensional series converters [13].

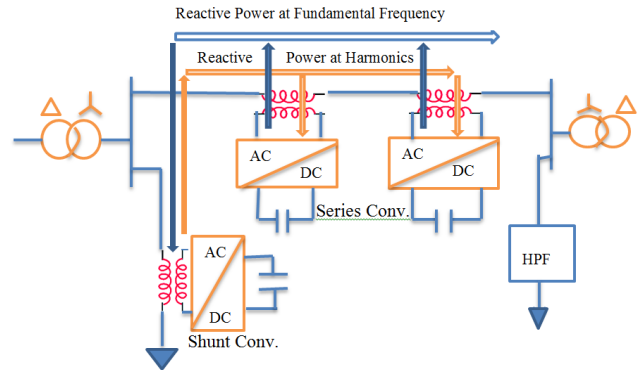


Fig. 2.4 Active power exchange between DPFC converters

The presence of third harmonic frequencies enables the DPFC system to work without DC source at converters. This is due to capability of converters to generate active power at one frequency and absorbing it at other frequencies. The distributed series converters make it possible of active power exchange through transmission line through ac link.

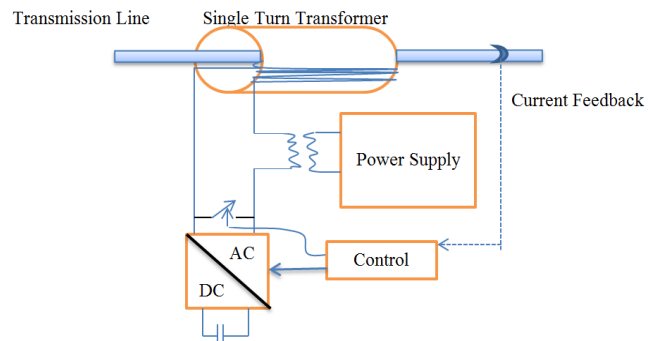


Fig. 2.5 Distributed series unit converter

The active power due to non-sinusoidal voltage and current generated through switching of controllers is expressed as $P = \sum_{i=1}^{\infty} V_i I_i \cos \phi_i \dots (15)$

Where V_i and I_i are i^{th} harmonic components. "The shunt converter can absorb active power from the grid at the fundamental frequency and inject the current back into the grid at harmonic frequency. This harmonic current will flow through the transmission line. According to the amount of required active power at the fundamental frequency, the DPFC series converters generate a voltage at the harmonic frequency, thereby absorbing the active

power from harmonic components. Assuming a lossless converter, the active power generated at fundamental frequency is equal to the power absorbed from the harmonic frequency” [13].

3. MODELING AND SIMULATION

The basic simplified model of uncompensated network, network with STATCOM, UPFC and DPFC are modeled using MATLAB Simulink. All the Models are tested for single bus that is single source module. STATCOM, UPFC and DPFC are incorporated individually with uncompensated network to observe the comparative response of different modules. All these modules have been subjected to a fault of short-circuiting in order to analyze voltage regulation. The three phase-input Source of Voltage 240KV which further step down to 25 KV for distribution, transmission angle $\delta = 0$, fundamental frequency of transmission, $f = 60\text{Hz}$, transmission line inductance $L = (0.06 * ((25e3)^2)/250e6)/(2 * \pi * 60)$ H, and two loads of impedance $0.5 + j181.25 \Omega$. The models are shown in figures 3.1 to 3.4. Double generators FACTS have also been modeled and results are compared.

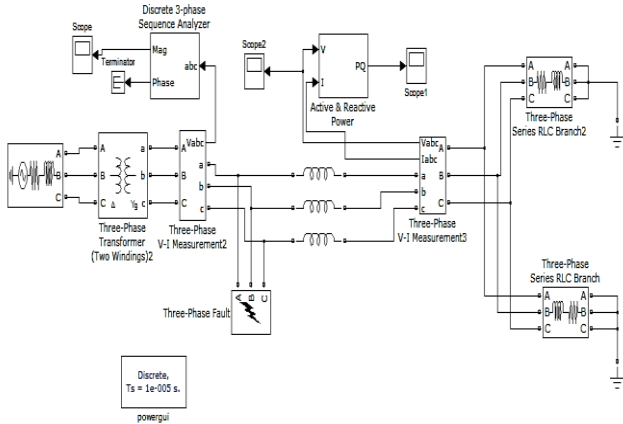


Fig.3.1 Uncompensated Power Distribution Network

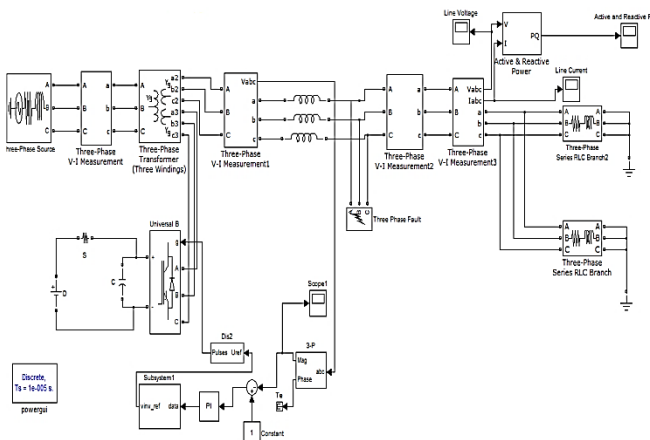


Fig. 3.2 DSTATCOM Based Power distributions Network

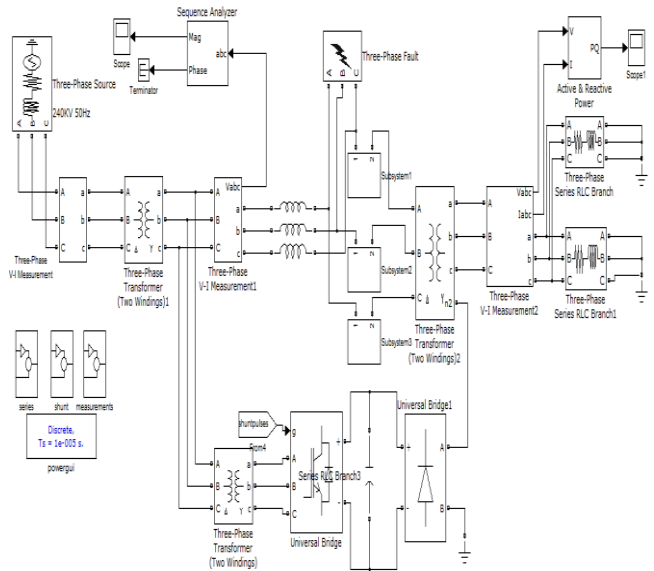


Fig. 3.3 UPFC Based Power Distribution Network

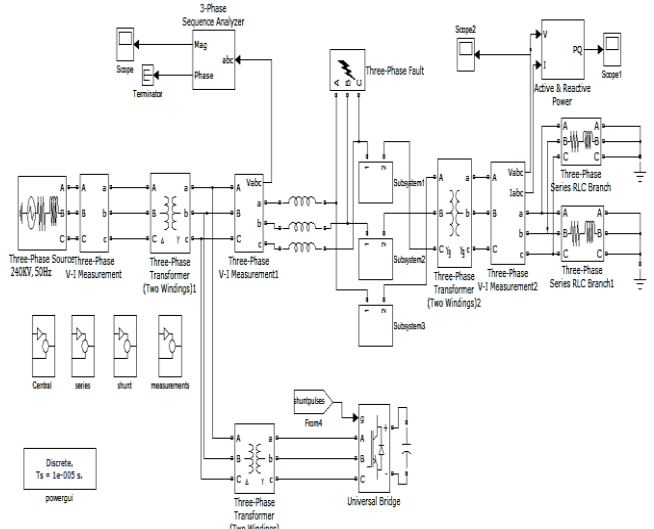


Fig. 3.4 DPFC Based Power Distribution Network

4. RESULTS

The FACTS devices are integrated into the three models. A fault is applied after 0.2 second of switch-on the system and it is removed at 0.3 second. All the loads are in place from time of switch-on the system. The significant voltage sag observed in uncompensated line. The voltage sag reduced significantly with STATCOM controller which further improved with UPFC controller in terms of power quality. Some fluctuations due to harmonics have also observed. These fluctuations increased at source end if more sources are present in the network. The next model was simulated with DPFC where the similar results of DPFC are found except the step response series current. The series current in adjacent branch has decreased with single source as

no backup available while it is balanced if more sources are present. The other generators in the network worked as a backup here while it created oscillations with UPFC. The significance of using DPFC is to reduce the cost of the system, fluctuations due to harmonics has also been reduced.

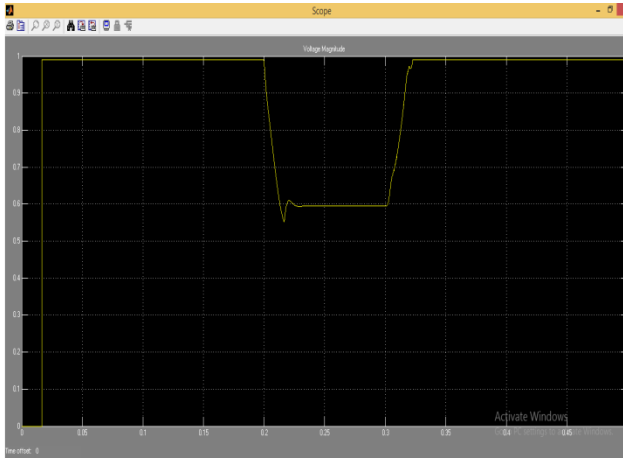


Fig. 4.1 Uncompensated line voltage sag for single generator

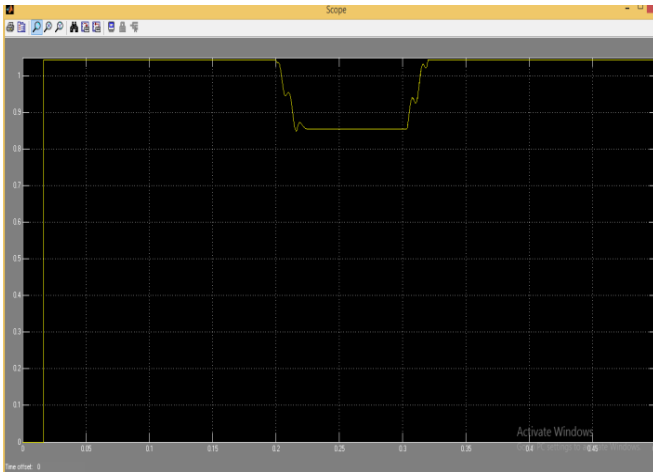


Fig. 4.2 Uncompensated line voltage sag for double generator

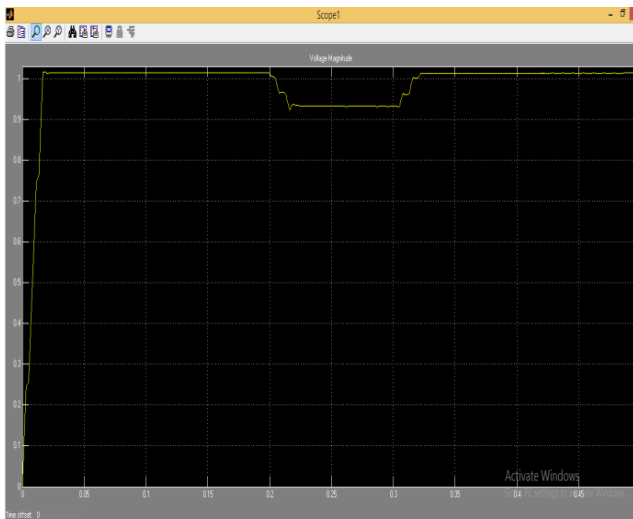


Fig. 4.3 Voltage sag with DSTATCOM for single generator

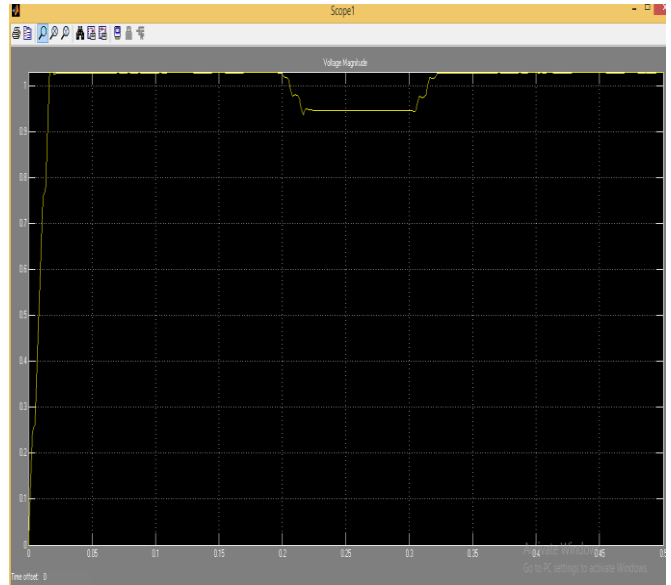


Fig. 4.5 Voltage sag with DSTATCOM for double generator

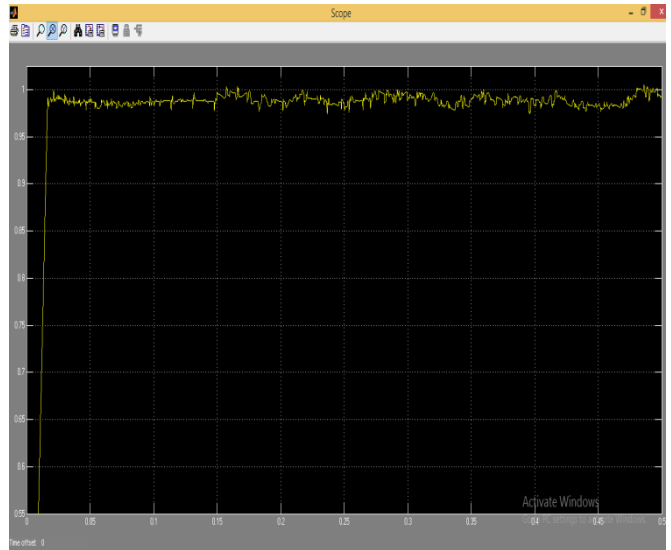


Fig. 4.6 voltage sag with UPFC for double generator

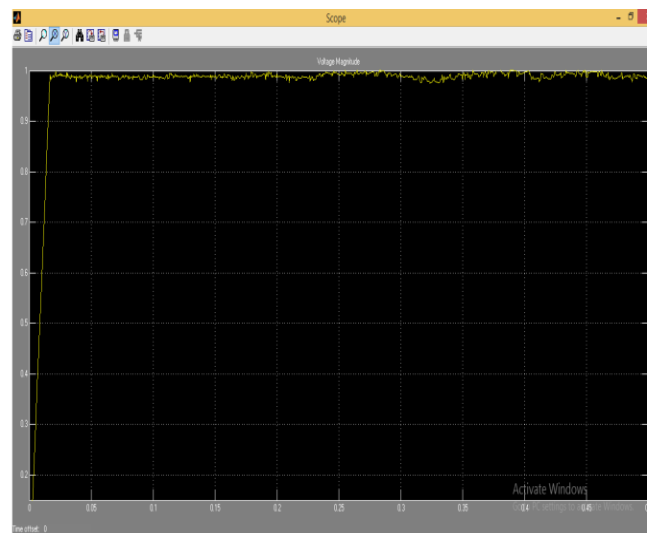


Fig. 4.7 voltage sag with UPFC for single generator

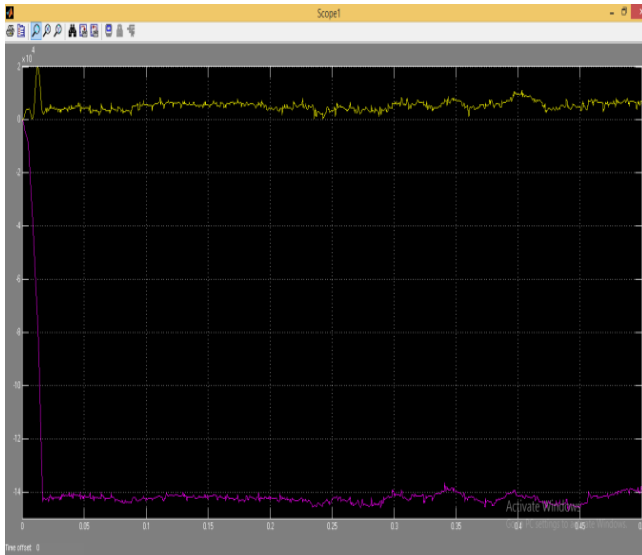


Fig. 4.8 Active and reactive Power (P.U) with UPFC for single generator

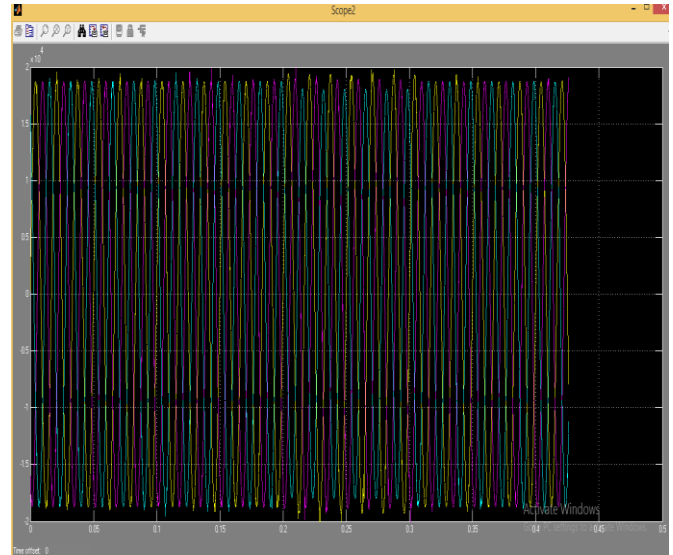


Fig. 4.11 Voltage sag with DPFC for single generator

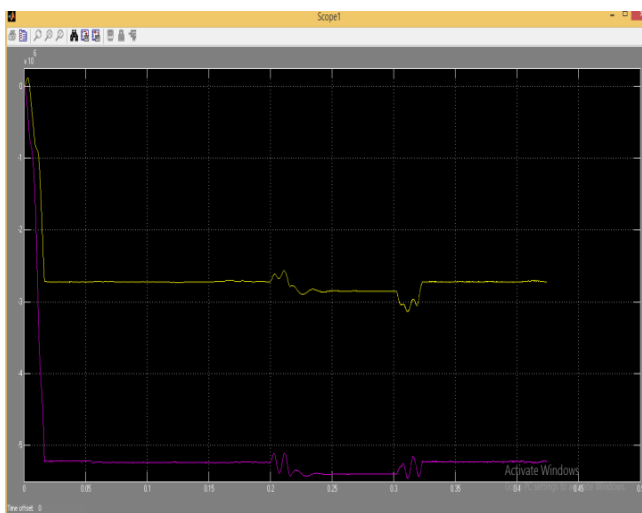


Fig. 4.9 Active and reactive Power (P.U) with UPFC for double generator

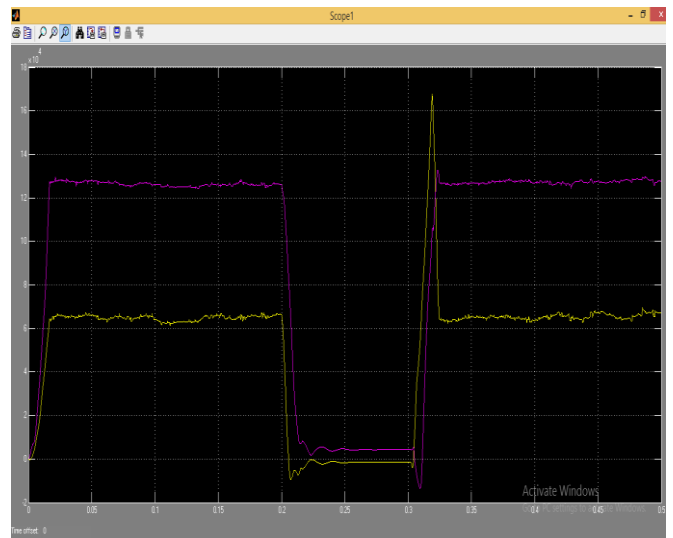


Fig. 4.12 Active and reactive Power (P.U) with DPFC for single generator

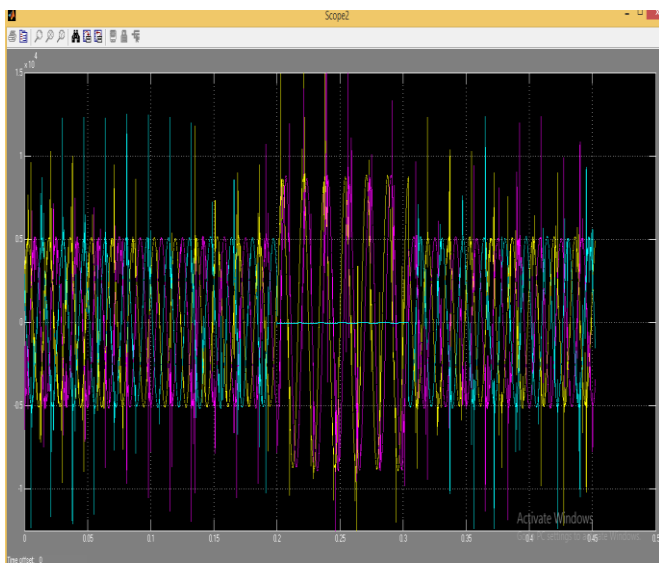


Fig. 4.10 Voltage sag with DPFC for single generator

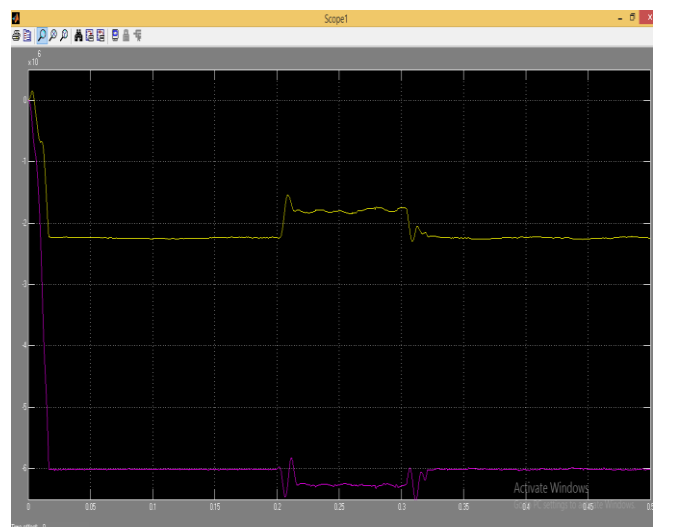


Fig. 4.13 Active and reactive Power (P.U) with DPFC for double generator

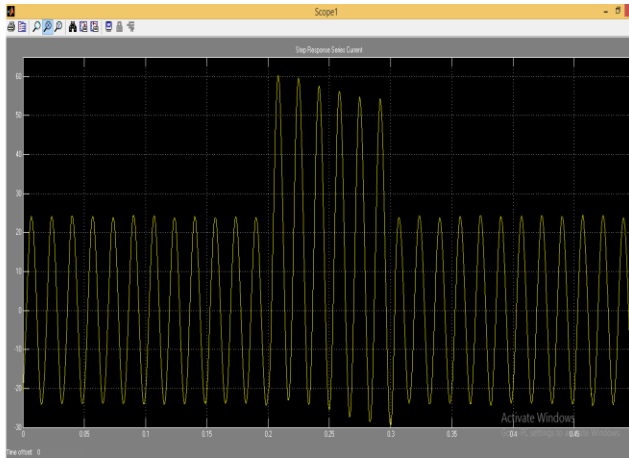


Fig. 4.14 Step Response of Line Current using DPFC for single generator

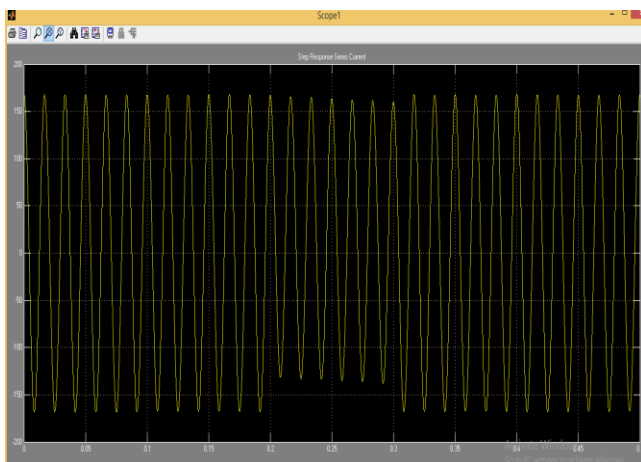


Fig. 4.15 Step Response of Line Current using DPFC for double generator

CONCLUSION

The simulation has been done with three phase system. DSTATCOM, UPFC and DPFC were modeled and simulated using MATLAB Simulink. It is found that DSTATCOM provides poor voltage regulation and quality factor as compared to UPFC and DPFC. There is approximately 10% of voltage sag present. UPFC is more accurate and best possible solution with enhanced system cost due to requirement of DC energy sources and high isolation at series voltage converters.

There is dynamic instability (small fluctuations) observed with UPFC though the system is costly and provides better power quality while it presented in less amount in case of DSTATCOM and DPFC.

As voltage source is present with UPFC for power or energy exchange, still fluctuations with multi-bus system or network with more than one generator. On other hand DPFC does not require any

DC source with converters and so could not provide stability for single bus or generator system. DPFC provides greater stability with reduced system cost for multi bus or multi generator system. It is found satisfactory on compensating the real power through reactive power generation with help of other generators. While the voltage regulation and power quality is same as of UPFC.

The heavy fault is also tested in comparison with the single phase fault. In which, it has been seen that, if there is fault in single line then there is similar impact on adjacent line (phases) irrespective of single generator or multi generator systems. But, with heavy fault (all the lines are shorted) caused power blackout with negligible jitters.

The DPFC with some modification might be proved excellent which is yet to be investigated. These are (1) use of multiple combinations of series-shunt converter, (2) auto tuning of PI controller, (3) providing a bypass with series converters and (4) optimization for shunt placements for a power distribution network.

Table 5-3

Comparisons of DSTATCOM, UPFC and DPFC for double sources

Parameters	DSTATCOM	UPFC	DPFC
% Voltage Sag	<5%	1-3%	<1%
Harmonics/Fluctuations	Negligible	Present within limit	Negligible
%Change in reactive power	9.9%	<1%	<0.1
% Change in active power	9.3%	<1%	<0.1
Cost	High	Higher	Low

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