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Performance Analysis of Three Phase VSC Based D-STATCOM for Three Phase Three Wire Distribution System

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Abstract: This paper deals performance analysis and operating principle of power electronics-based device called Distribution Static Compensator (D-Statcom) used to mitigate voltage sag, swell on a distribution network. The power circuit of the D-Statcom and the distribution network are modeled by specific block from the power system while the control system is modeled by Simulink blocks. A main feeder feeding the load is abruptly disturbed by the inclusion of sudden load thereby creating a voltage sag. This voltage sag is corrected by the static compensator. The dip in voltage is generally encountered during the variation of load. The model of D-STATCOM connected in shunt configuration to a three-phase source feeding dynamic loads is developed using Simulink of MATLAB software. Simulated results demonstrate that D-STATCOM can be considered as a viable solution for solving such voltage dip problems. In this, the three phase three wire disturbance create of three phase to two phase, two phase to single phase & single phase to two phase for Linear Load & three phase three wire disturbance is created for Non-Linear Load which is non sinusoidal and to prevent this unbalance system from being drawn from the D-STATCOM. This paper aims at performance analysis of three phase VSC based D-STATCOM for three phase three wire distribution system.

Keywords: FACTS, CPD, D-STATCOM, VSC, Mitigation, distortion, waveform.

I. INTRODUCTION

The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs, topology, and key operating parameters change continually. When subjected to a transient disturbance, the stability of the system depends on the nature of the disturbance as well as the initial operating condition. The disturbance may be small or large. With the development of FACTS technique, it becomes possible to increase the power flow controllability and enhance power system's stability. Recently, Flexible Alternative Current Transmission System (FACTS) controllers have been proposed to enhance the transient or dynamic stability of power systems. Basic application of FACT devices are Power flow control, Increase of transmission capability, Voltage control, Reactive power compensation, Stability improvement, Power quality improvement, Flicker mitigation, Interconnection of renewable and distributed generation and storages.

As the consumption of electricity increases there will be a serious shortage of power. The shortage may be due to the increase in the consumption or due to the malfunctioning of the equipment in the system. The ultimate way to decrease or overcome these shortages is to increase the power generation tremendously or to overcome the situations of malfunctioning. This paper presents a solution to overcome the later situation. To overcome these problems suitable measures are taken before, like circuit breakers, isolators etc., while taking these safety measures there may be conditions of switching on extra equipment or switching off of the present equipment. Due to this phenomenon there may be a reduction of reactive power or increase of reactive power in the system which leads to the active power change. There may be a sudden change in the load which for instant reduces or increases the active power which in turn leads to the voltage change and distorted waveforms. If any short circuit or open circuit in the line or phase occurs, the voltage value changes in the line. All of these issues which are related to problems occurring in the system disturbing the stability are called as power quality problems. Various power quality problems are like Voltage dip, voltage swell/overvoltage, Voltage flicker, Voltage and current harmonic distortion, Voltage and current transient, Short interruptions, Power frequency variation. If these problems are not eliminated by using a suitable control technique, the entire system may lose its stability. The term power quality describes by the magnitude and waveforms of the voltage and current in power system, for standard power quality means voltage should be within the limit and waveform should not be distorted. An electric distribution system can be defined as the link between the bulk power source and the utility. The non-standard voltage, currents affecting the end user equipment's which cause equipment outage and interrupting the optimum power flow through the system. The common problem relating with the voltage profile is sag and swell which ranges from 10%

to 90% of the nominal voltage level. Modern power systems are complex networks, where hundreds of generating stations and thousands of load center's are interconnected through long power transmission and distribution networks. Even though the power generation in most countries is fairly reliable, the quality of power is not so reliable. Power system especially distribution systems have numerous nonlinear loads, which significantly affect the quality of power supplies. Apart from nonlinear loads events like capacitor switching, motor starting and unusual faults could also inflict power quality problems. There are mitigation techniques for power quality problems in the distribution system and the group of devices is known by the generic name of Custom Power Devices (CPDs). The distribution static compensator (D-STATCOM) is a shunt connected CPD capable of compensating power quality problems in the load current. Some of the topologies of DSTATCOM for three-phase four wire system for the mitigation of neutral current along with power quality compensation in the source current are four-leg voltage source converter (VSC), three single-phase VSCs three leg VSC with split capacitors, three- leg VSC with zigzag transformer and three-leg VSC with neutral terminal at the positive or negative of dc bus. The voltage regulation in the distribution feeder is improved by installing a shunt compensator. There are many control schemes reported in the literature for control of shunt active compensators such as instantaneous reactive power theory, power balance theory, synchronous reference frame theory, symmetrical components based, etc. The synchronous reference frame theory is used for the control of the proposed D- STATCOM. In this paper, proposed control algorithm based on enhanced phase-locked loop (EPLL) scheme is implemented for compensation of reactive power, harmonics elimination, load balancing in power factor correction (PFC) and Zero Voltage Regulation (ZVR) modes of operation of DSTATCOM in three phase distorted voltage supply system under unbalanced nonlinear loads.

II. D-STATCOM & CONTROL STRATEGY

D- STATCOM technology is considered the best technology to mitigate all the current-based power quality problems. D-STATCOMs are basically categorized into three types, namely, single-phase two-wire, three-phase three-wire, and three-phase four-wire configurations, to meet the requirements of three types of consumer loads on supply systems. Both current source converters (CSCs) with inductive energy storage and voltage source converters (VSCs) with capacitive energy storage are used to develop single phase D-STATCOMs. A major amount of AC power is consumed by three-phase loads. Many configurations and control strategies such as instantaneous reactive power theory, synchronous frame d–q theory, and synchronous detection method are used in the development of three-phase D-STATCOMs. One of the major factors in advancing the D-STATCOM technology is the advent of fast, self-commutating solid-state devices. In the initial stages, BJTs (bipolar junction transistors) and power MOSFETs (metaloxide semiconductor field-effect transistors) have been used to develop D-STATCOMs; later, SITs (static induction thyristors) and GTOs (gate turn-off thyristors) have been employed to develop D-STATCOMs. With the introduction of IGBTs (insulated gate bipolar transistors), the D-STATCOM technology has got a real boost and at present it is considered as an ideal solid-state device for D-STATCOMs. The improved sensor technology, especially Hall effect current and voltage sensors, has also contributed to the enhanced performance of D- STATCOMs. The next breakthrough in D-STATCOM development has resulted from the microelectronics revolution. This development in DSPs has made it possible to use different control algorithms such as PI (proportional–integral) controller, variable structure control, fuzzy logic control, and neural network control for improving the dynamic and steady-state performance of D-STATCOMs. With these improvements, the D-STATCOMs are capable of providing fast corrective action even with dynamically changing loads such as furnaces and traction.

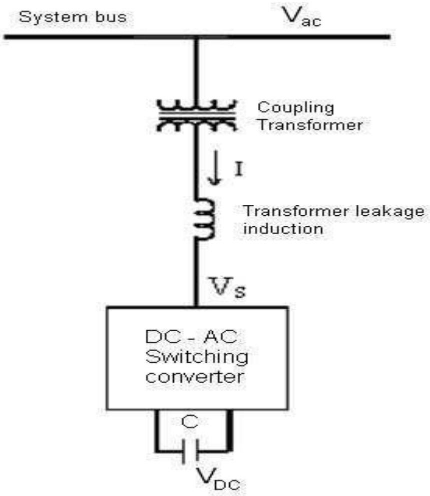

Fig. 1. D-STATCOM basic configurations

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A Distribution Static Synchronous Compensator (D-STATCOM) is a fast response, solid state power controller that provides flexible voltage control at a point connection to the utility distribution feeder for power quality improvement. It can regulate the bus voltage by absorbing or generating reactive power from system to the converter and converter to the system at a point of common coupling (PCC). The three basic operation modes of the D-STATCOM for the output current, I vary depending upon Vi. The controller of the DSTATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the DSTATCOM generates or absorbs the desired VAR at the point of connection. It operates in a similar manner as the STA- TCOM (FACTS controller), with the active power flow controlled by the angle between the AC system and VSC voltage and the reactive power controlled by the difference between the magnitudes of these voltages. The single line diagram is shown below in fig. no. 3. The D-STATCOM is a device which is considered as a current controlled source. The most fundamental purpose of a Voltage Source Inverter (VSI) is to generate AC voltages in sinusoidal forms with negligible harmonic disturbance occurring from a D.C. voltage source. The processes in D-STATCOM's operation are as mentioned:

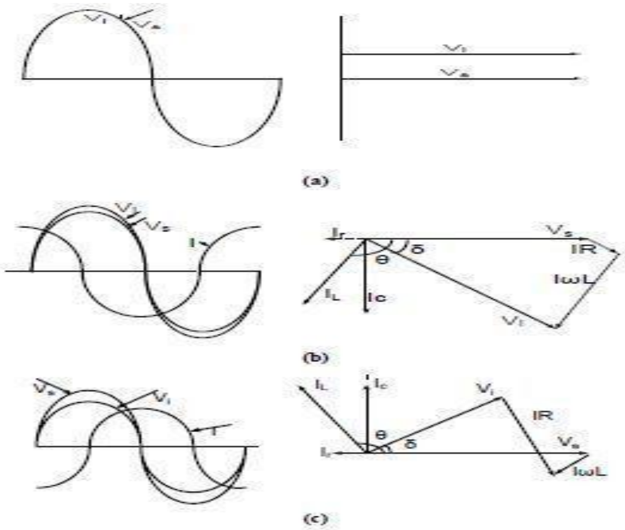

Fig. 2. Modes of D-STATCOM (a) No load mode(V_s=V_i), (b) Capacitive mode, (c) Inductive mode

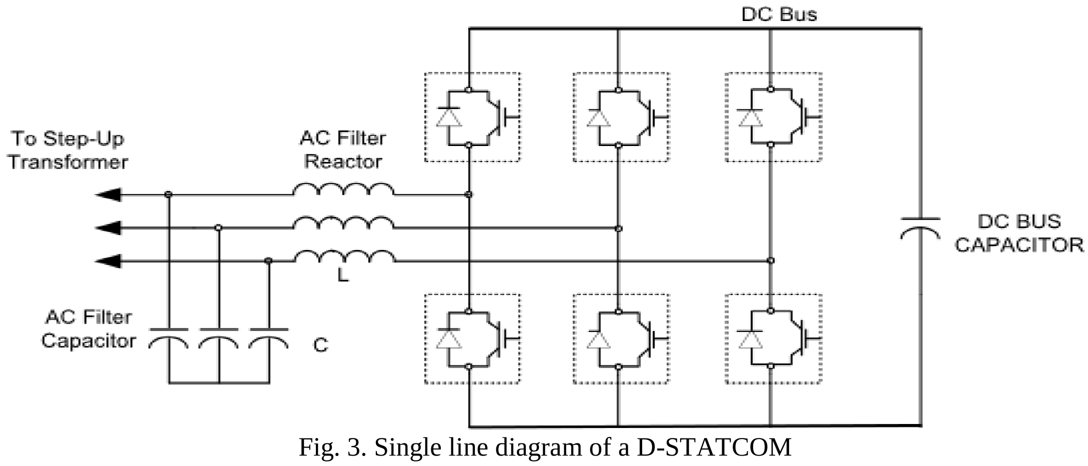

Fig. 3. Single line diagram of a D-STATCOM

AC bus voltage system's voltage (Vs.) is first matched with voltage of the VSI voltage. The DSTATCOM acts as an inductance connected to terminals of the AC system, when (V_c) voltage of the VSI is lower than that of the AC bus voltage. Or else the AC system sees the DSTATOM as a capacitance connected to its terminals i.e.AC bus voltage magnitude<V_c. There will be no exchange of reactive power is both the voltages Vc and AC bus voltage are equal. The DSTATCOM supplies real power to the distribution system from its available DC or energy source. This is accomplished by calibrating the AC power system's phase angle with the DSTATCOM's phase angle."When phase angle of the AC power system leads the VSI phase angle, the DSTATCOM absorbs the real power from the AC system, if the phase angle of the AC power system lags the VSI phase angle, the DSTATCOM supplies real power to AC system"(Kumar.S et al, 2011).

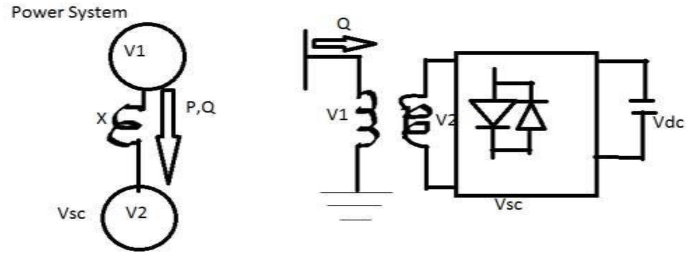

Fig. 4. D-STATCOM principle of Operation

D-STATCOM is to suppress voltage variation and control reactive power in phase with the system voltage. It can compensate for inductive and capacitive currents linearly and continuously. The D-STATCOM consist mainly of a PWM inverter connected to a net- work through a transformer. The DC link voltage is provided by capacitor C which is charged with power taken from the network. The control system ensures the regulation of bus voltages and the DC link voltage. The D-STATCOM function is to regulate the bus voltage by absorbing or generating reactive power to the network like a thyristor static compensator.

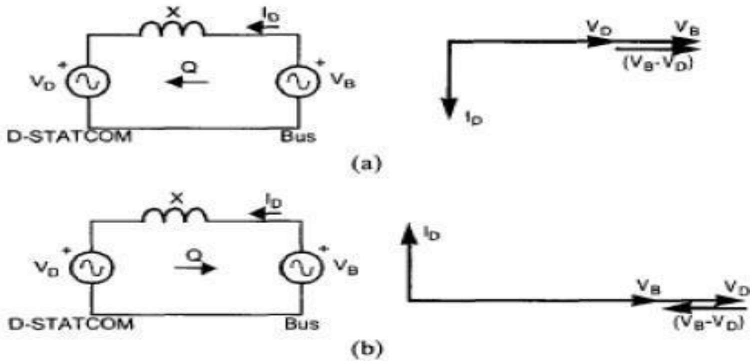

Fig. 5. D-STATCOM Operation(a) Inductive Operation (b) Capacitive Operation

The reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary voltage in phase with the primary voltage (network side). This voltage is provided by a voltage source PWM inverter. When the secondary voltage VD is lower than the bus voltage VB, the D-STATCOM acts like an inductance absorbing reactive power from the bus. When the secondary voltage VD is higher than the bus voltage VB, the D-STATCOM acts like a capacitor generating reactive power to the bus. In steady state, due to inverter losses the bus voltage always leads the inverter voltage by a small angle to supply a small active power. The D-STATCOM has a several advantages as compared to the conventional Static VAR Compensator (SVC) using thyristor. It is faster can produce reactive power at low voltages.

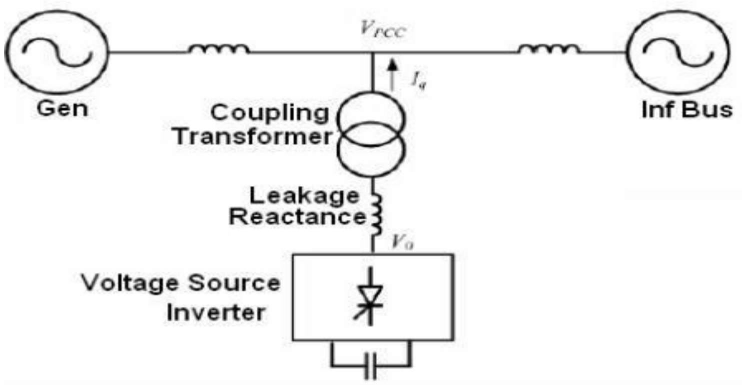

Fig. 6. Schematic Configuration of D-STATCOM

D-STATCOM is based on the principle that a voltage source inverter generate a controllable AC voltage source behind a reactance so that the voltage difference across the reactance produce active and reactive power exchange between the D-STATCOM and the transmission network line in a similar manner of a synchronous condenser, but much more rapidly.

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III. VOLTAGE SOURCE CONVERTER

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable speed drive. It can used to either completely replace the voltage or to inject the missing voltage. The "missing voltage" is the difference between the nominal voltage and the actual voltage. It also converts the DC voltage across storage devices into a set of three phase AC output voltages. DSTATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltage, DSTATCOM is to be in capacitive mode. There for, it will compensate the reactive power through AC system and regulates missing voltages. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronic converter is switched to get desired output voltage. Normally the VSC is not only used for voltage sag mitigation, but also used for other power quality issues such as flicker, unbalance and harmonics.

IV. METHODOLOGY

Synchronous Reference Frame (SRF) Theory- Based Control Algorithm of D-STATCOMs: A block diagram of the control algorithm is shown in Figure 7. The load currents (*i*La, *i*Lb, *i*Lc), PCC (Point of Common Coupling) voltages (*v*sa, *v*sb, *v*sc), and DC bus voltage (*v*DC) of the DSTATCOM are sensed as feedback signals.

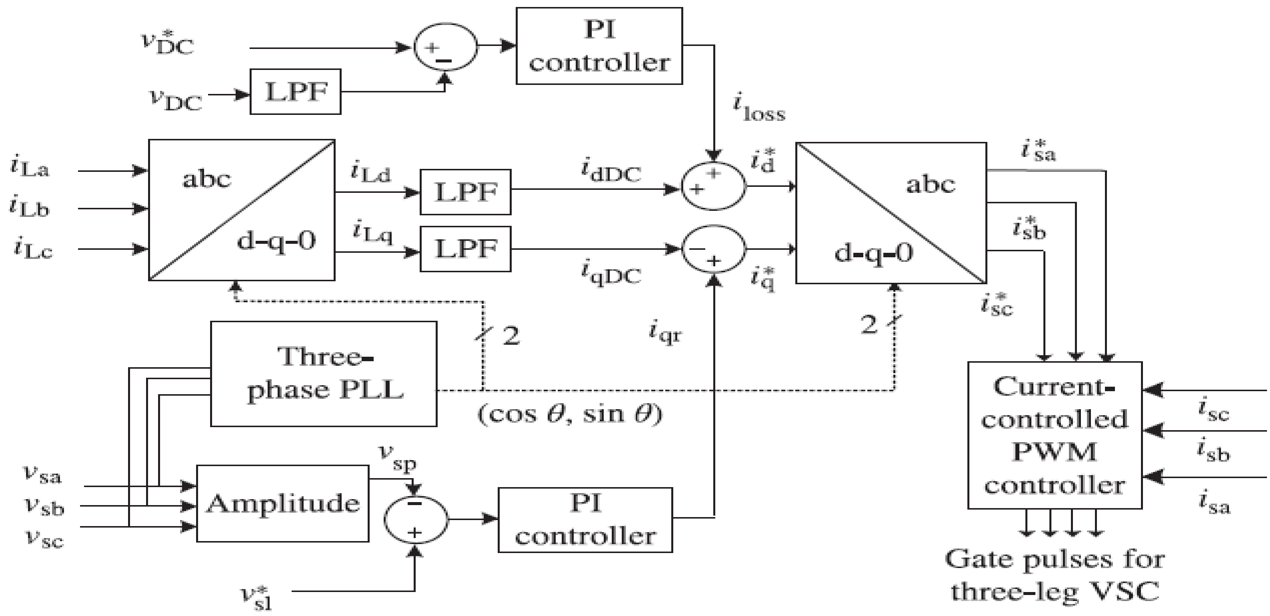

Fig. 7. Block diagram of SRF theory-based control algorithm of D-STATCOMs

The control strategy for reactive power compensation, the supply must deliver the DC component of the direct-axis component of the load current (*i*dDC) along with the active power component for maintaining the DC bus and meeting the losses (*i*loss) in the DSTATCOM. The output of the PI controller at the DC bus voltage of the DSTATCOM is considered as the current (*i*loss) for meeting its losses:

$i_{loss}(n)= i_{loss}(n-1) +k_{pd} \{v_{dl}(n)-v_{de}(n-1)+k_{id}v_{de}(n)$

where $v_{de}(n)=v^*_{de} - v_{DC}(n)$ is the error between the reference .v^*_{DC}. and the sensed (v_{DC}) DC voltage at the *n*th sampling instant, and *K*pd and *K*id are the proportional and integral gain constants of the DC bus voltage PI controller, respectively. $i^*d=idDC+iloss$. The reference supply current must be in phase with the voltage at PCC but with no zero- sequence component.

V. RESULT AND DISCUSSION

This chapter will focus on the results gained in simulation. The result consists of the simulation of the distribution system without insertion of Distribution Static Compensator (D-STATCOM) scheme and with installation of D-STATCOM system.

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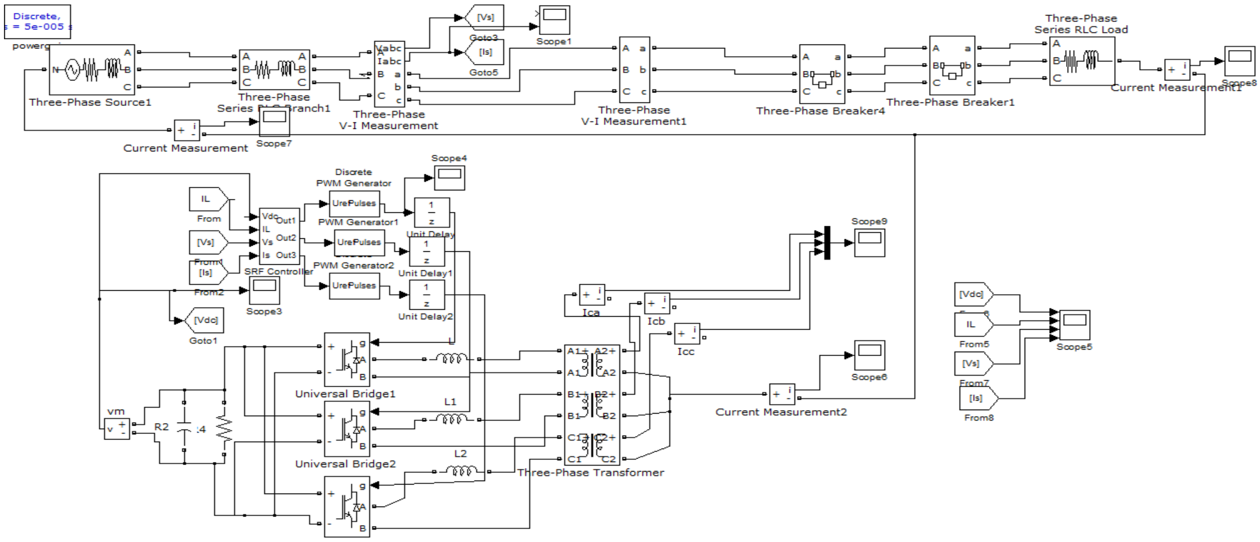

Fig 2.1 Simulink model of the three phase three wire disturbance create of three phase to two phase, two phase to single phase & single phase to two phase for Load 16kW, 0.8 power factor of without D-STATCOM

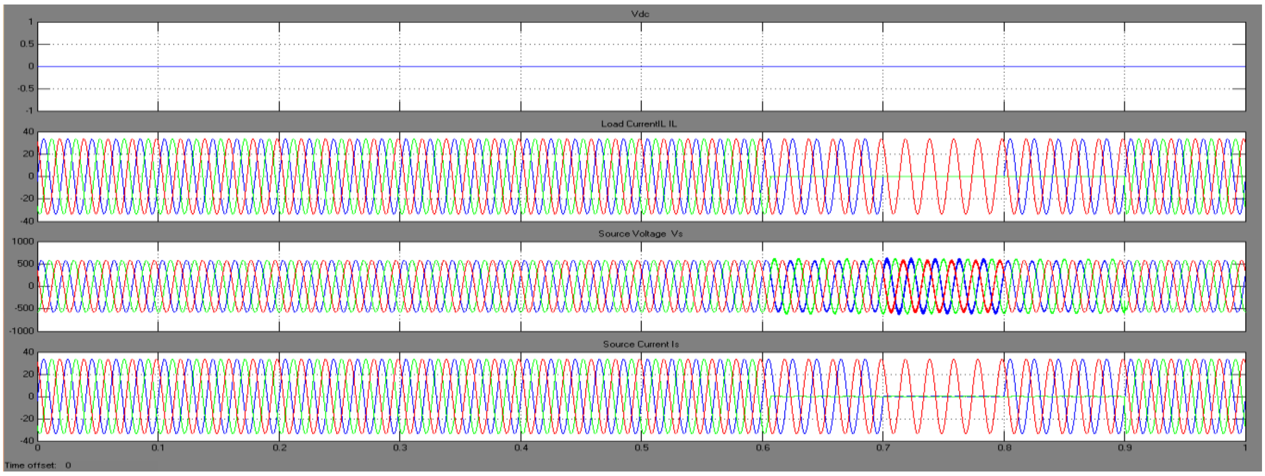

Fig 2.2 Waveform of Simulink model of the three phase three wire disturbance create of three phase to two phase, two phase to single phase & single phase for Load 16kW, 0.8 power factor to two phase of without D-STATCOM

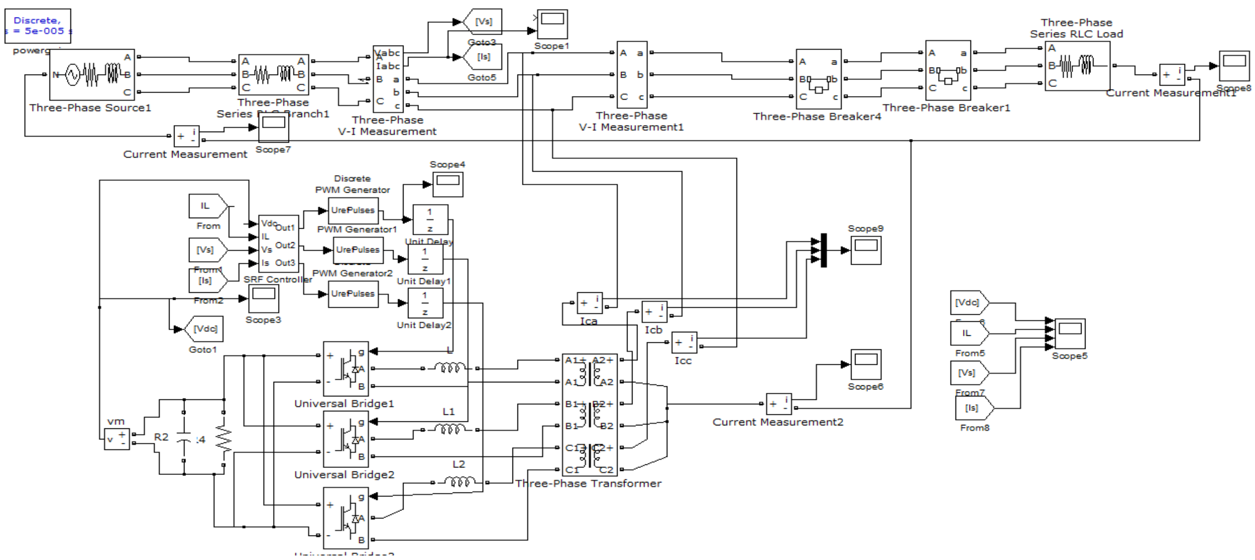

Fig 2.3 Simulink model of the three phase three wire disturbance create of three phase to two phase, two phase to single phase & single phase to two phase for Load 16kW, 0.8 power factor of with D-STATCOM

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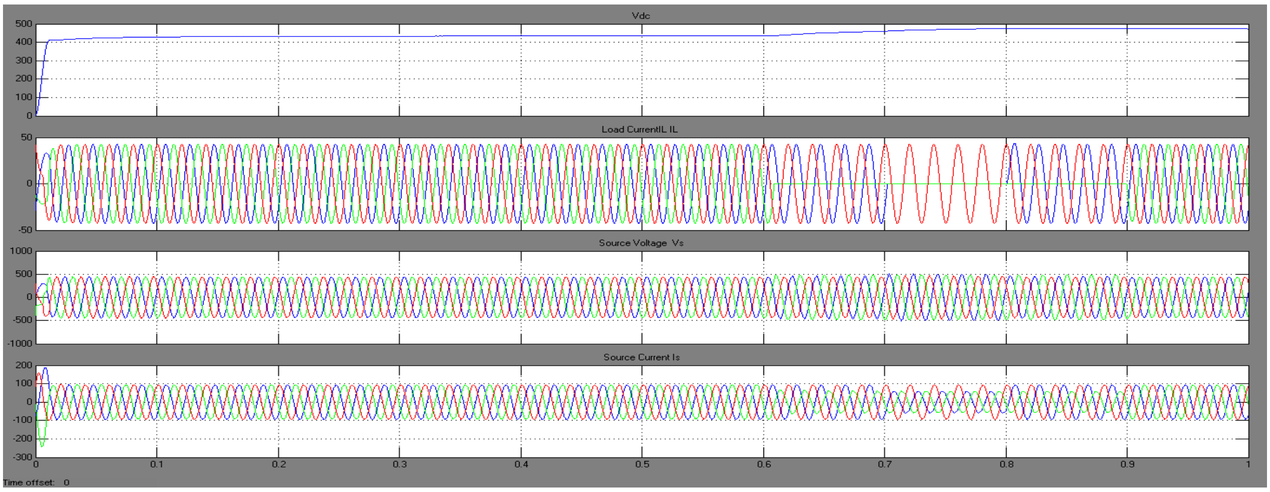

Fig 2.4 Waveform of Simulink model of the three phase three wire disturbance create of three phase to two phase, two phase to single phase & single phase to two phase for Load 16kW, 0.8 power factor with D-STATCOM

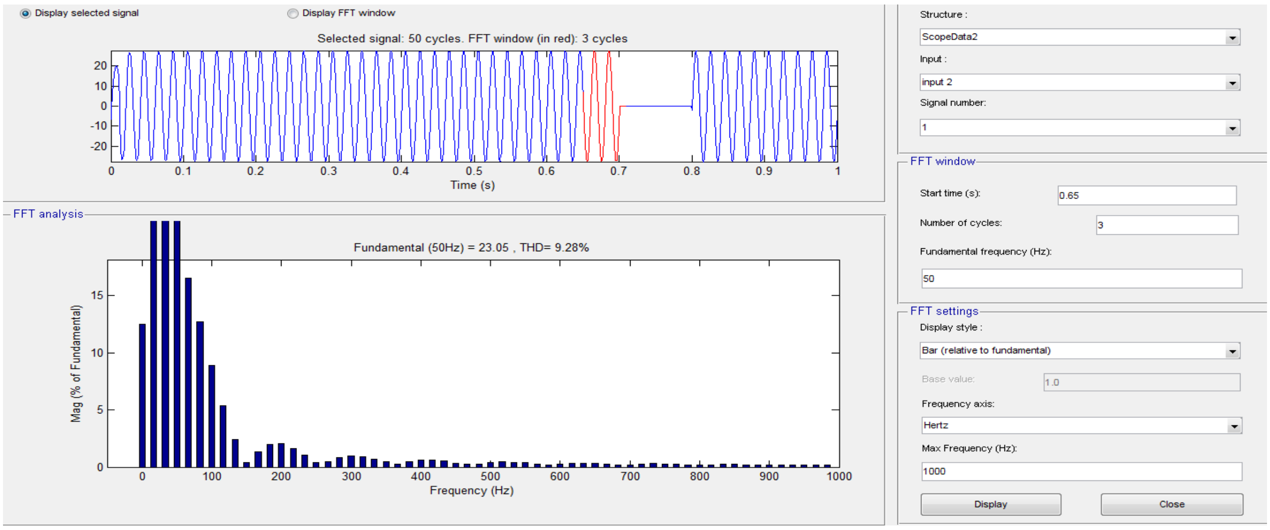

Fig 2.5 Total Harmonic Distortion of Without D-STATCOM for Load 16kW, 0.8 power factor

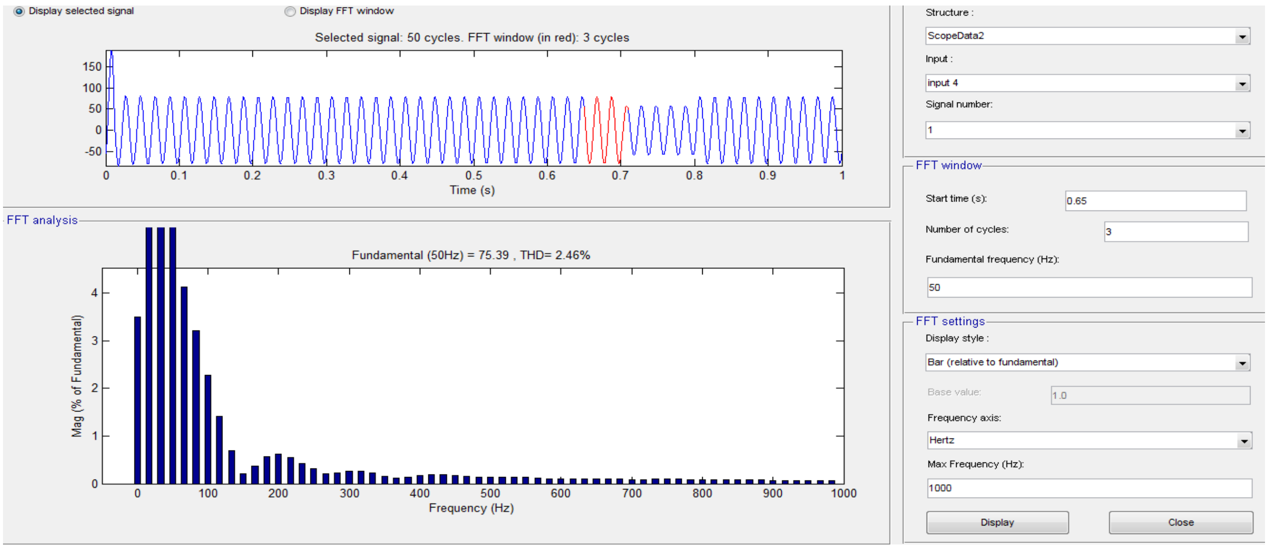

Fig 2.6 Total Harmonic Distortion of With D-STATCOM for Load 16kW, 0.8 power factor.

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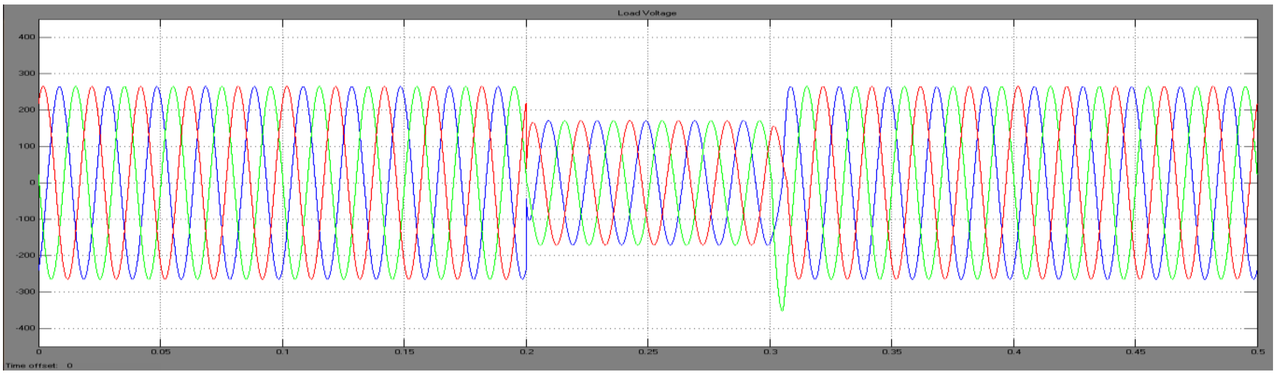

Fig. 2.7 Waveform of Simulink model of Voltage Sag without D-STATCOM

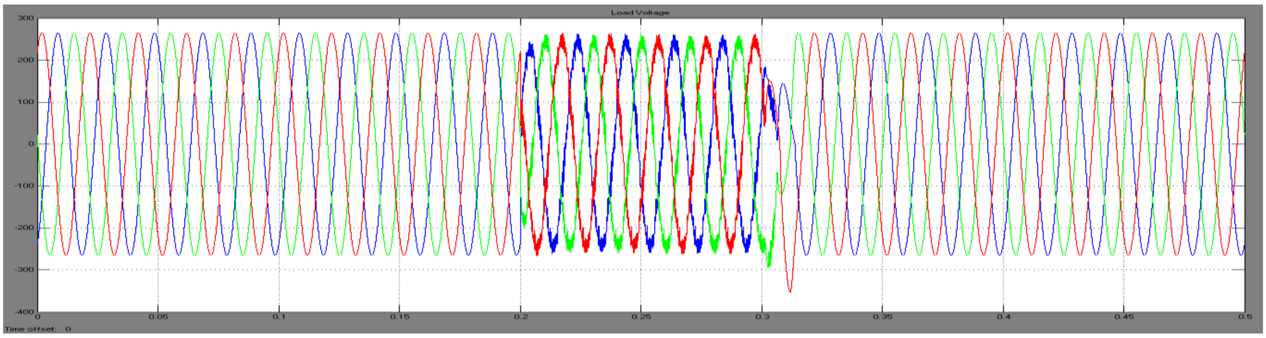

Fig. 2.8 Waveform of Simulink model of Voltage Sag improved with D-STATCOM

VI. CONCLUSION

From this study, it is known that one of the methods to improve the voltage sag (dip) is by using Distribution Static Compensator (D-STATCOM). In order to show or examine whether voltage sags can improve by using D-STATCOM or not, MATLAB/Simulink was chosen so as to perform simulation for the distribution scheme and improve the voltage sag (dip). Based on the outcome and simulation that has been completed, it can prove and verify that D-STATCOM device can be capable to overcome the voltage sags problem. Although the scheme cannot compensate 100 percent of voltage during sag, it is an acceptable because the output voltage after compensation still in range of the nominal value. The simulation was executed by using the distribution system. In this case, the fault only takes place at the distribution system and D-STATCOM has a superior effectiveness because it is deal with distribution system only. Since Distribution Static Compensator, D- STATCOM is deal with a power electronic device that is IGBT. In this, the three phase three wire disturbance create of three phase to two phase, two phase to single phase & single phase to two phase for Linear Load and to prevent this from being drawn from the distribution bus, a shunt compensator, also called D-STATCOM, is used & three phase three wire disturbance is created for Non-Linear Load which is non sinusoidal and to prevent this unbalance system from being drawn from the D-STATCOM. It ensures that the currents drawn from the D-STATCOM are sinusoidal.

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