INVESTIGATIONS ON POWER QUALITY IMPROVEMENT IN DISTRIBUTION NETWORK USING DSTATCOM

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Abstract: A large number of single-phase linear and non-linear loads may be supplied from three phase ac mains with neutral conductor. They cause excessive neutral current, harmonics and reactive power burden and unbalance. A four wire DSTATCOM (distribution static compensator) is used for neutral current compensation along with reactive power compensation, harmonics elimination and load balancing. A novel control approach is proposed for the control of four wire DSTATCOM under non-ideal supply voltage conditions. A four-leg voltage–source converter (VSC) with a dc capacitor is used as a four wire DSTATCOM. The proposed control approach is based on synchronous reference frame (SRF) theory and an indirect current control technique. The switching signals for the voltage–source converter (VSC) of the DSTATCOM are derived from the estimated reference supply currents. The load balancing, harmonics elimination and the neutral current compensation are demonstrated along with unity power factor (UPF) and zero voltage regulation (ZVR) modes of operation. Simulation results based on MATLAB software with its Simulink and power system blockset (PSB) toolboxes are presented to validate the control strategy. The DSTATCOM is able to maintain the self-supported dc bus under various disturbances.

Keyword DSTATCOM, harmonic, synchronous reference frame

I. INTRODUCTION

Industrial and commercial consumers of electrical power are becoming increasingly sensitive to power quality problems. Reliability and quality are two important parameters in the field of power engineering. Electricity delivery is no exception. Combining today’s utility power with the ever increasing quantity of electrical sensitive load yields one of the major contributors to downtime in business and industries today. Issues of deregulation, standards and customer awareness (economics and legal) have brought forth a great deal of focus and motivation in these areas. Tremendous dedication from engineers as well as huge amounts of revenue has been spent to enhance the quality and reliability of electricity delivery. Power quality has become a very important issue recently due to the impact on electricity suppliers, equipment manufacturers and customers. Power quality is described as the variation of voltage, current and frequency in a power system. It refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location in the power system. Nowadays, there are so many industries using high technology for manufacturing and process unit. This technology requires high quality and high reliability of power supply. The industries like semiconductor, computer and the equipments of manufacturing unit are very sensitive to the changes in the quality of power supply. [10]. This power quality is essential for proper operation of industrial processes which involves a good protection to the system for being well and progressive for long usage. Power quality problems such as voltage sag, swell, harmonic distortion, unbalance, transient and flicker may have impact on customer devices which will cause malfunctions and loss of production. The last decade has seen a marked increase on the deployment of end-user equipment that is highly sensitive to poor quality controlled electricity supply. Several large industrial users are reported to have experienced large financial losses as a result of even minor lapse in the quality of electricity supply. Efforts have been made to remedy the situation, where solutions based on the use of the latest power electronic technologies prominently. Indeed, custom power technology, the low- voltage counterpart of the more widely known flexible ac transmission system (FACTS) technology, aimed at high-voltage power transmission applications, has emerged as a credible solution to solve many problems relating to continuity of supply at the end-user level. Both the FACTS and custom power concepts may be directly credited to EPRI (Electric Power Research Institute). Power quality problems in industrial applications concern a wide range of disturbances, such as voltage sags and swells, flicker, interruptions, harmonic distortions etc. Prevention of such phenomena is important particularly because of the increasing heavy automation in almost all the industrial processes. High quality in the power supply is needed, since failures due to such disturbances usually have a high impact on production costs. Voltage sag is the most important power quality problems faced by many industries and utilities. It contributes more than 80% of power quality (PQ) problems that exist in power systems . Voltage dips are one of the most happening power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problem and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in some cases for the utility. Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated. There are different ways to mitigate voltage dips, swells and interruptions in transmission and distribution systems. At present, a new generation of power electronics based equipment aimed at enhancing the reliability and quality of power flow in low voltage distribution network, so called custom power controllers are extensively used in compensating the voltage sag. PSCAD/EMTDC [16], a highly developed graphical user interface has been used by the researchers to perform the modeling and analysis of such controllers for a wide range of operating conditions.

II. D-STATCOM AND METHODOLOGY

Distribution Static Compensator (D-STATCOM) also known as shunt voltage controller consists of a two level voltage source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network and associated control circuit [13] as shown in the fig below. The VSC converts the dc voltage across the storage device into a set of three phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allow effective control of active and reactive power exchanges between the D-STATCOM and ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

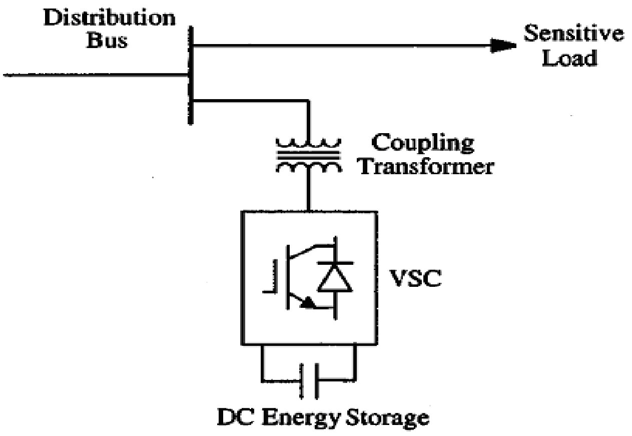

Figure 1: Basic Structure of DSTATCOM [13]

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes.

a) Correction of power factor.

b) Voltage regulation and compensation of reactive power.

c) Elimination of current harmonics.

The DC voltage across the storage device will be converted by VSC into a set of three phase AC output voltages. Several adjustments have to be made to the phase and magnitude of the D-STATCOM output voltage in order for the active and reactive power exchanges between the AC system and the device controlled effectively.

Current-controlled PWM for generating gating pulses:

In a current controller, the sensed and reference supply currents are compared and a proportional controller is used for amplifying current error in each phase before comparing with a triangular carrier signal to generate the gating signals for six switches. The gating signals for the other two switches in the fourth leg of VSC of the DSTATCOM are obtained from the error signal by comparing sensed (isn) and reference (isn) neutral current.

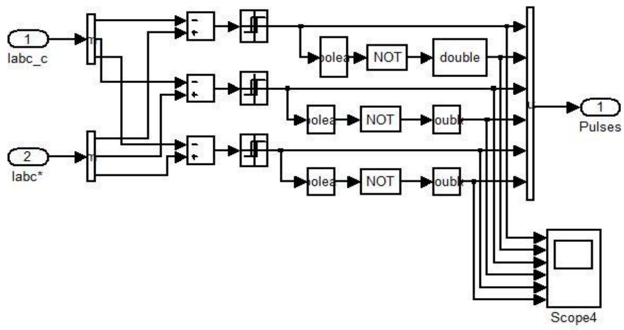

Figure 2: Pulse generation

III. MODELLING OF DSTATCOM

A block diagram of the control scheme equipped with the function of voltage regulation is shown in Fig. 4.6 and Fig.4.7. Two PI controllers are used for the purpose of control of dc bus voltage of DSTATCOM and ac voltage at PCC. The compensation current should lead or lag by 90_ from the voltage. The DSTATCOM draws a lagging current to reduce the line-voltage amplitude, when the load injects capacitive reactive power. In other words, the DSTATCOM acts as an inductor. The compensating current produces a voltage drop and then, the line-voltage amplitude is kept at its reference value. In the case, when the load is an inductive, the DSTATCOM operates as a capacitor. Along with reactive current control, the control of DSTATCOM consists of the following control functions: harmonic elimination, load balancing and neutral current compensation.

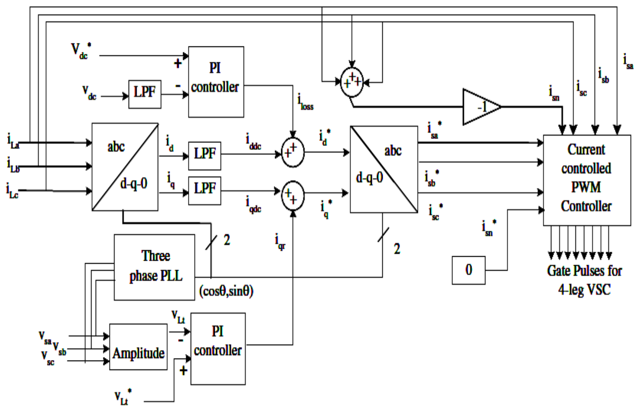

Figure 3: Control algorithm for the operation of DSTATCOM [1]

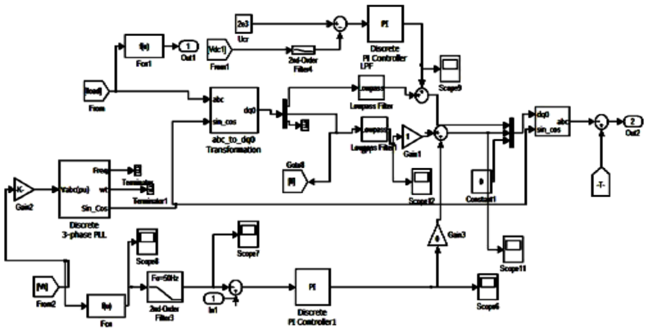

Figure 4: Matlab Simulink of the control scheme for the case-I

IV. WORKING OF PI CONTROLLER BASED SCHEME FOR PHASE MODULATION UNIT OF THE CONTROL ANGLE Δ

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller the output is the angle δ, which is provided to the PWM signal generator.

The sinusoidal signal Vcontrol is phase-modulated by means of the angle

i.e., VA = Sin (ωt +δ)

VB=Sin (ωt+δ-2π/3)

VC = Sin (ωt +δ+2π/3).

The modulated signal Vcontrol is compared against a triangular signal in order to generate the switching signals for the VSC. The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller the output is the angle δ, which is provided to the PWM signal generator. The sinusoidal signal Vcontrol is phase-modulated by means of the angle

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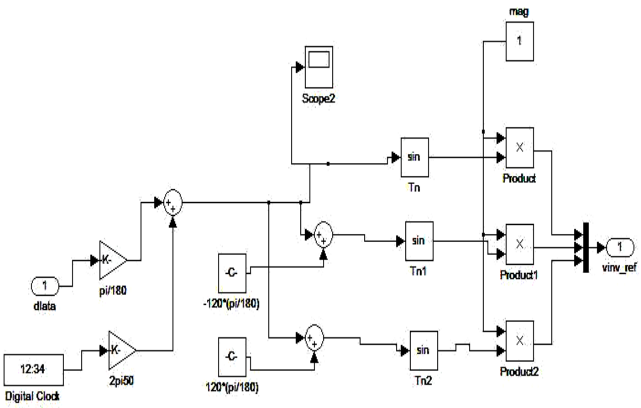

Figure 5: Matlab Simulink of Phase modulation unit of the control angle δ

V. SIMULATION OF D-STATCOM

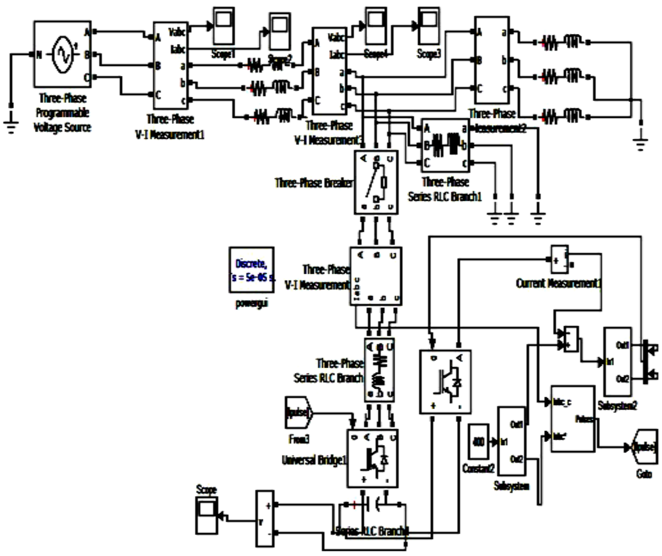

Figure 6: Case-I Unbalanced load condition

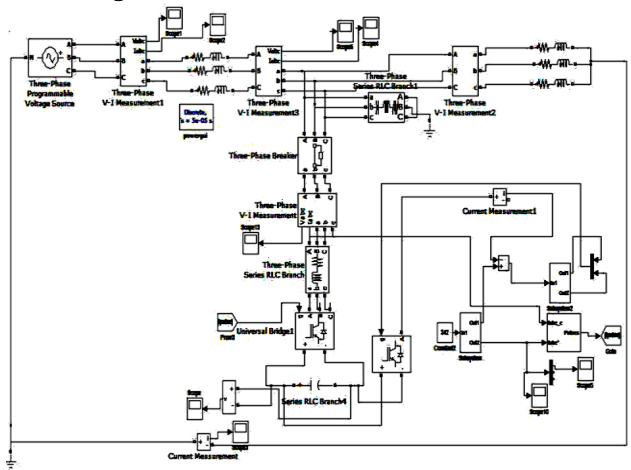

Figure 7: Simulink model of test System for CASE-II (3ph 4wire)

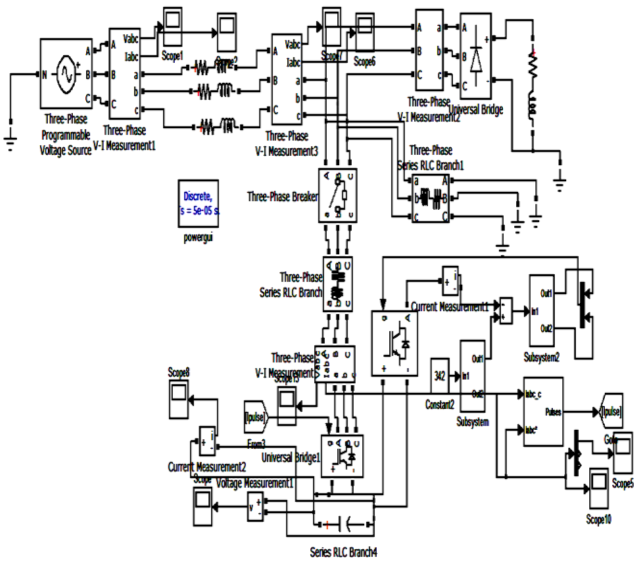

Figure 8: Matlab Simulink model of the case-III (3phase 3 wire)

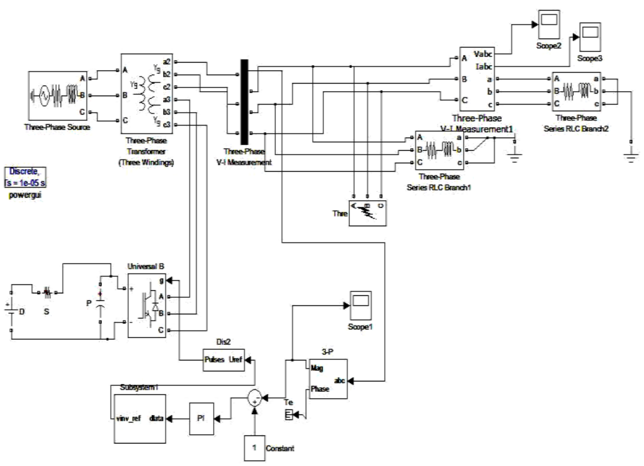

Figure 9: Matlab Simulink model of sag voltage mitigation.

VI. SIMULATION RESULTS

All results are performed on Matlab simulation. Following are the data which are filled in linear load unbalance model. Many results are observed which are described below. Results are observed based on synchronous reference frame theory.

Table no.1 Data for unbalanced load condition

System parameter	**Value of parameter**
Source voltage	415V(vrms ph-ph)
Source resistance and inductance	Rs=0.01 Ω Ls= 2mH
Unbalanced linear Load	Ra=75 Ω ,La=240mH Rb=35 Ω ,Lb=130mH Rc=50 Ω ,Lc=190mH
DSTATCOM	Vdc=680V Cdc=500e-6F Rf=1Ω Lf=35mH

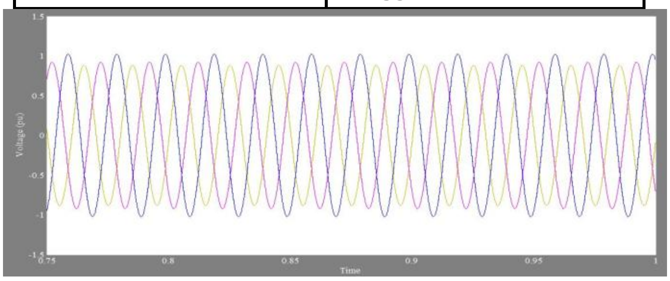

Figure 10: PCC voltage of the system without compensation

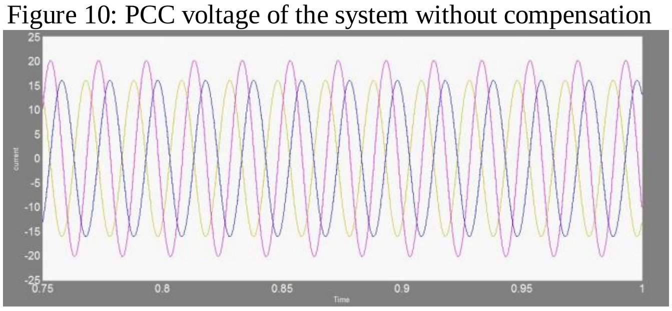

Figure 11. Source current without compensation

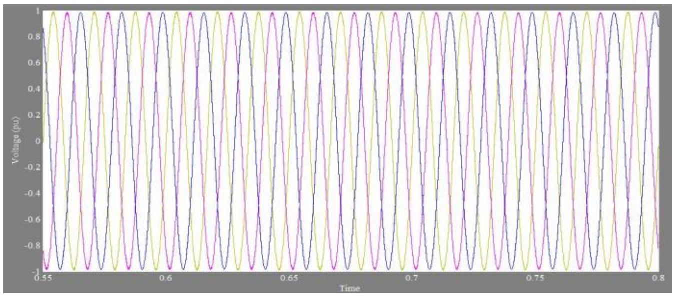

Figure 12. PCC voltage of the system with compensation

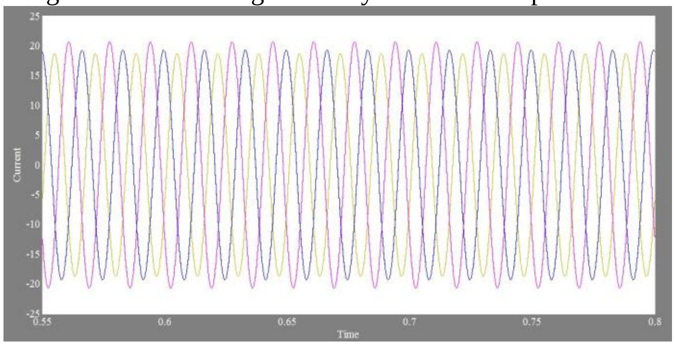

Figure 13: Source current with compensation

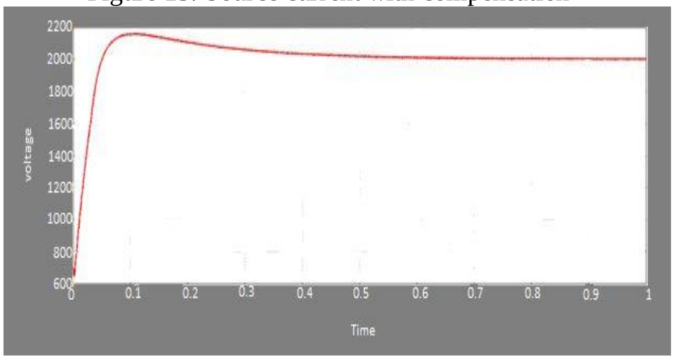

Figure 14: DC link voltage across capacitor

In figure 10 describe voltage unbalance of PCC at the time of unbalance load condition.3 phase are unbalance due to unbalance load. In figure 11 describe Current unbalance at the time of linear load unbalance condition. This is also in p.u. system. Figure 12 and 13also described voltage at PCC and source current after compensation. It shows balanced voltage at PCC and current. In figure 14 the voltage across capacitor is maintained at nearly to its reference value under all disturbances.

VII. SIMULATION RESULT OF DSTATCOM 3 PHASES 4 WIRE SYSTEM FOR NEUTRAL CURRENT COMPENSATION

All results are performed on Matlab simulation. Following are the data which are filled in linear load unbalance model. Many results are observed which are described below. Results are observed based on synchronous reference frame theory. In figure 15 show source current without compensation and it indicate 3 phases are also unbalanced due to 3 phases 4 wire system. After compensation source current is also balanced in 3 phases 4 wire systems. These results are also performed based on synchronous reference frame theory.

Table no.2: Data for 3 phases 4 wire system condition

s System parameter	**V Value of parameter e**
Source voltage	230*sqrt(3)V(vrms ph-ph)
Source resistance and inductance	Rs=0.01 Ω Ls= 2e-3 H
Unbalanced linear Load	Ra=75 Ω ,La=240e-3H Rb=35 Ω ,Lb=130e-3H Rc=50 Ω ,Lc=190e-3H
DSTATCOM	Vdc=2000V Cdc1=500e-6F, Cdc2=500e-6F Rf=1Ω Lf=35e-3H

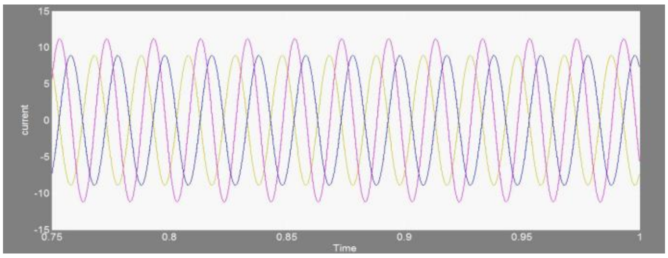

Figure 15 Source current without compensation in 3phase 4 wire system

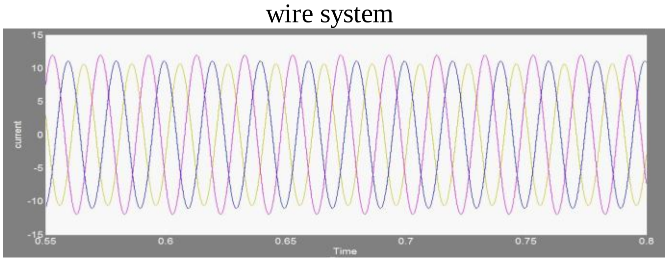

Figure 16: Source current after compensation in 3phase 4 wire system

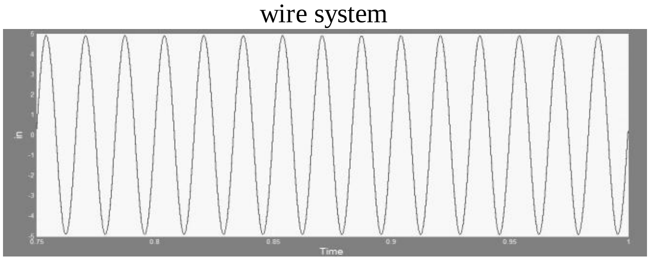

Figure 17 Neutral current without compensation in 3phase 4 wire system

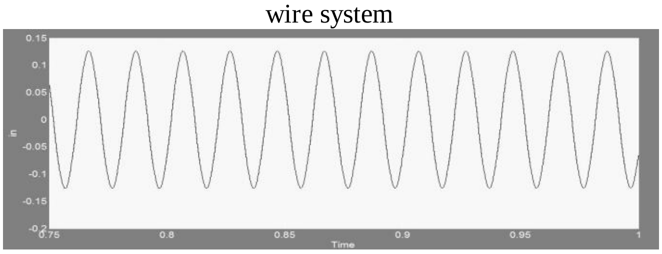

Figure 18 Neutral current after compensation in 3phase 4 wire system

In figure 17 shows the neutral current without compensation and it will somewhat larger than neutral current after compensation. It is shown in figure no. 18.

VIII. SIMULATION RESULT OF DSTATCOM 3 PHASES 3 WIRE SYSTEM BALANCED LOAD CONDITION.

All results are performed on Matlab simulation. Following are the data which are filled in linear load unbalance model. Many results are observed which are described below. Results are observed based on synchronous reference frame theory. In figure 19 shows source current without compensation under balanced load nonlinear condition. So THD is 41.66% due to harmonic current distorted on source side. It is very large so it is necessary to keep as small as possible using D-STATCOM. It is also shown in figure 20.

Table no.3 Data for balanced load condition

System parameter	**Value of parameter**
Source voltage	415V(Vrms ph-ph)
Source resistance and inductance	Rs=0.01 Ω Ls= 2e-3H
linear load	R=15 Ω L=50e-3H
Non –linear rectifier load	R=100 Ω L=40e-3H
DSTATCOM	Vdc=2000V Cdc=500e-6F Rf=1Ω Lf=35e-3H

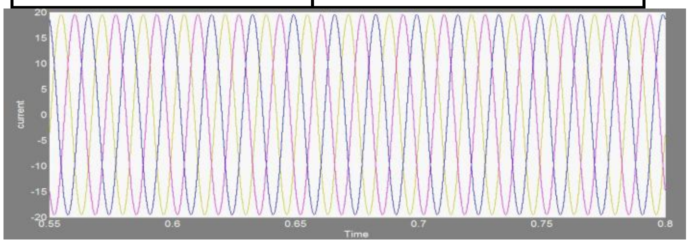

Figure 19 Source current without compensation balanced and non-linear load condition

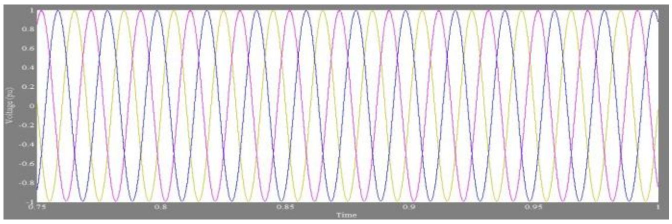

Figure 20 PCC voltage without compensation balanced and non-linear load condition

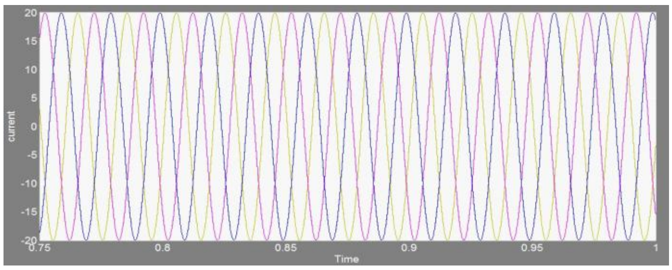

Figure 21 Source Current with compensation balanced and non-linear load condition

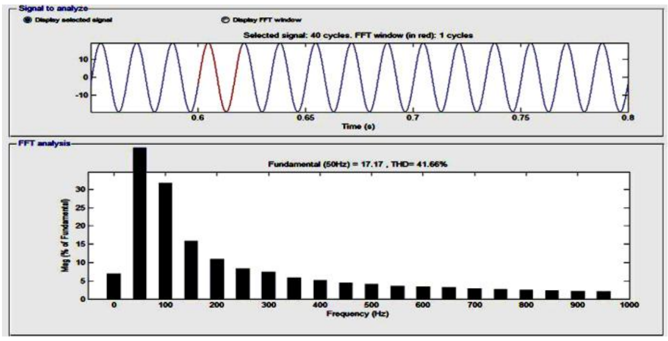

Figure 22 THD without compensation

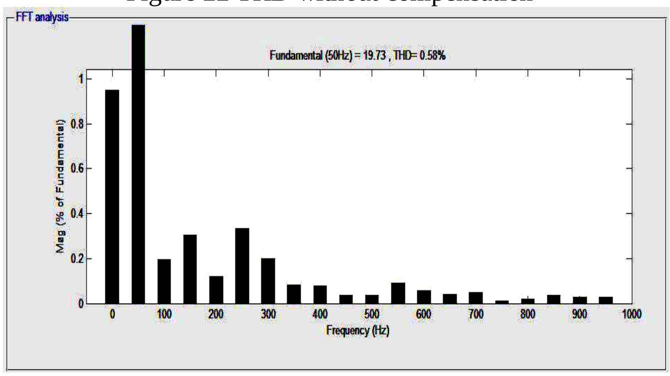

Figure 23 THD with compensation

So after compensation THD reduce to 0.58% with the help of D-STATCOM. Voltage at PCC without compensation and after compensation is also described in figure 22 and 23.

IX. SIMULATION RESULT OF DSTATCOM FOR SAG VOLTAGE MITIGATION.

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller the output is the angle δ, which is provided to the PWM signal generator. All results are performed on Matlab simulation. Following are the data which are filled in simulation model.

Table no.4 Data for balanced load condition

System parameter	Value of parameter
Source	3-phase, 230KV ,50Hz,
Three phase three winding transformer	230MVA Y/Y/Y230KV/11KV/11KV
RL load	Load 1 – 1MW,5MVAr Load 2 - 20MW,10MVAr
Inverter parameters	IGBT based,3 arms ,6Pulse, Carrier Frequency=1080 Hz , Sample Time= 5 µs
Fault resistance	0.66ohm

In system fault resistance is 0.66 ohm and fault is created between 0.4s to 0.6s. At that time output voltage for load without compensation and with compensation as shown in figure 24 and figure 25. Voltage magnitude without compensation and with compensation is shown in figure 26 and 27 respectively.

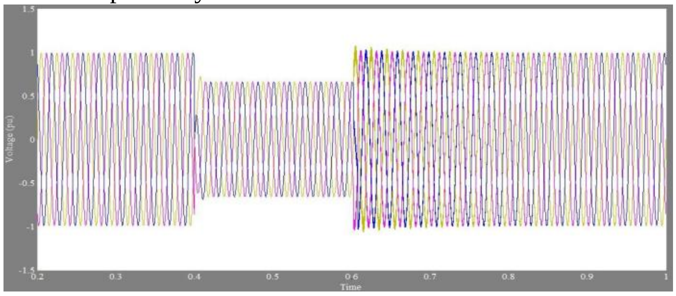

Figure 24Load voltage under the fault condition without compensation

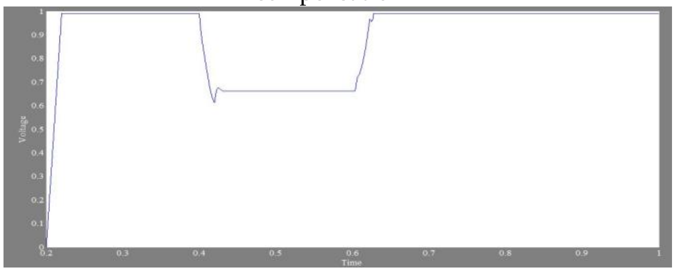

Figure 25 Voltage magnitude under fault condition without compensation

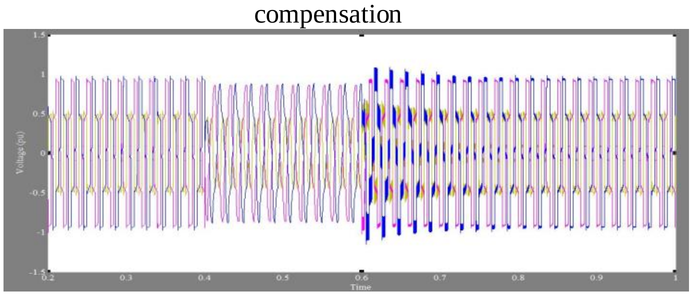

Figure 26 load voltage under fault condition after compensation

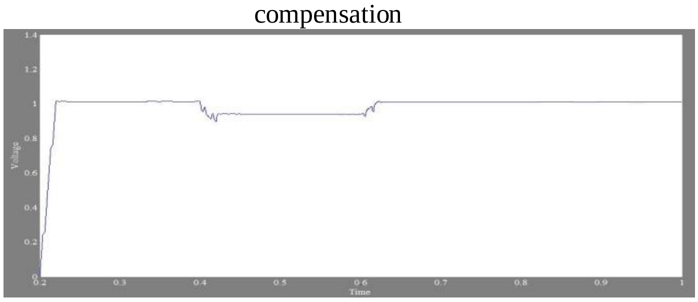

Fig.ure 27 Voltage magnitude under fault condition after compensation

X. CONCLUSION

In this work, the investigation on the role of DSTATCOM is carried out to improve the power quality in distribution networks with linear and nonlinear loads.

This paper present three load condition in which unbalanced source current and PCC voltage are balanced using DSTATCOM in unbalanced load condition using SRF theory. In balanced load condition THD is 41.66% without compensation and after reactive current compensation it is 0.58% using DSTATCOM. In 3 phase 4 wire system neutral current is large without compensation and it reduced using DSTATCOM with compensation. Voltage sags mitigation during Fault condition using phase modulation unit for control angle with the help of DSTATCOM

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