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POWER QUALITY IMPROVEMENT WITH ZIG-ZAG TRANSFORMER AND DSTATCOM

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ABSTRACT—

This paper proposes a topology consisting of Zig-Zag transformer for neutral current compensation and DSTATCOM for voltage sag compensation in the presence of unbalanced, non linear loads. The DSTATCOM is a shunt-connected device which takes care of the power quality problems in the load currents. There are different topologies for three-phase four-wire DSTATCOM, out of which a DSTATCOM with SVPWM switched VSC along with a zig-zag transformer is used for compensating power quality problems in the supply currents. The different voltages induced and currents flowing inside Zig-Zag transformer shows that Zig-Zag transformer provides low impedance path to zero sequence currents. The application of a zig-zag transformer for reduction of the neutral current is having an advantage due to passive compensation, rugged and less complex over the active compensation techniques. The new application of a zig-zag transformer is to connect in parallel to the load for filtering the zero-sequence components of the load currents. SVPWM technique offers several advantages like higher output voltage (15% more than conventional sine-triangle modulation technique and hence, better utilization of DC link), lower harmonics etc. As the neutral current (total zero sequence current) is being taken care by Zig-Zag transformer, a SVPWM switched DSTATCOM can be used for voltage sag compensation, load balancing. A detailed simulation study for the proposed scheme is carried out using MATLAB software.

I. INTRODUCTION

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. 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. 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. In addition to the above mentioned problems, the presence of unbalanced and non-sinusoidal currents in three-phase four- wire power distribution systems mainly used for supplying single-phase low voltage loads, leads to significant neutral current, overloading of neutral wire must be avoided because, the neutral current in the overhead distribution lines produces harmful induced voltages in the communication lines. Thus, neutral current in the source neutral wire should be ideally zero.

As a marked increase has been seen on the deployment of customer 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 solve the problems, where solutions mainly based on the use of the latest power electronic technologies. The custom power technology which is the low- voltage counterpart of the group known as flexible ac transmission system (FACTS) technology which is 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. This group of devices, custom power devices (CPDs) mainly includes the DSTATCOM (distribution static compensator), DVR (dynamic voltage restorer) and UPQC (unified power quality conditioner) which are used for compensating the power quality problems in the current, voltage and both current and voltage respectively.

This project deals with the formation of model of a distribution system with DSTATCOM (distribution static compensator) which is based on Voltage Source Converter which is going to be switched with the help of Space Vector Pulse Width Modulation Technique. The DSTATCOM, one of the CPDs, a shunt-connected device which takes care of the power quality problems in the load currents. There are different topologies for three-phase four-wire DSTATCOM, out of which in this project DSTATCOM with SVPWM switched VSC along with a zig-zag transformer is used for compensating power quality problems in the supply currents. The application of a zig-zag transformer for reduction of the neutral current is having an advantage due to passive compensation, rugged and less complex over the active compensation techniques. SVPWM technique used here offers several advantages like higher output voltage (15% more than conventional sine-triangle modulation technique and hence, better utilization of DC link), lower harmonics etc.

II. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

A. Basic Configuration and Operation of D-STATCOM

The DSTATCOM is a three phases, shunt connected power electronic based device. It is connected near the load at the distribution system. The major components of D-STATCOM is shown in the fig. 3.2 below

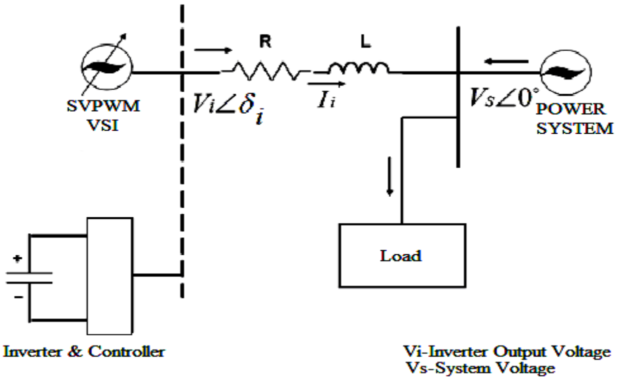


Fig. 1 Basic building blocks of D-STATCOM

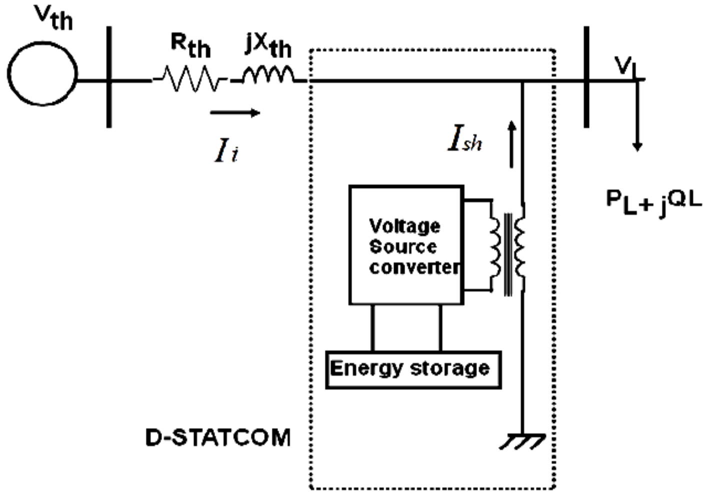
It consists of a dc capacitor, three phase inverter usually a GTO or an IGBT, ac filter (coupling transformer) and a control strategy. The basic electronic block of the D-STATCOM is the voltage sourced inverter that converts input dc voltage into a three phase output voltage at fundamental frequency.

The D-STATCOM employs an inverter to convert the dc link voltage Vdc on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage controlled source. The D-STATCOM can also be seen as a current controlled source.

Fig.1 above shows the inductance L and resistance R which represents the equivalent circuit elements of the step down transformer and the inverter are the main components of D-STATCOM. The reactive power output of D-STATCOM can be either inductive or capacitive depending on the operation mode of D-STATCOM.

Referring to the Fig. 2 above the controller of D-STATCOM 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 D-STATCOM generates or absorb the desired VAR at the point of connection. The phase of the output voltage of the thyristor based inverter Vi is controlled in the same way as the distribution system voltage Vs.

Here, as we can see from the figure 3.3 below, the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Xth.



The value of the shunt current Ish can be controlled by adjusting the output voltage of the converter. The shunt injected current Ish can be written as:

$$Ish = IL - Ii \qquad (1)$$

$$Ish = IL<-\theta-Vth/Zth<(\delta-\beta)+Vl/Zth<-\beta \qquad (2)$$

The complex power injection of the D-STATCOM can be expressed as

$$Ssh = VL\ Ish^{*} \qquad (3)$$

Here, the effectiveness of the D-STATCOM in correcting voltage sag depends upon the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with VL, the desired voltage correction is achieved without injecting any active power into the system. On the other hand when the value of Ish is minimized the same voltage correction can be achieved with minimum apparent power into the system.

III.PROPOSED METHODOLOGY

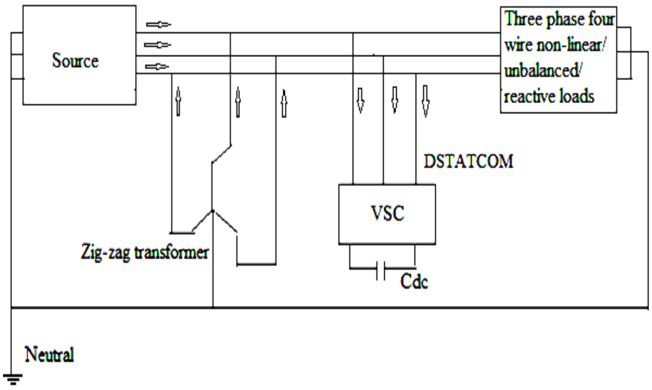


Fig. 4 Three-leg VSC-based DSTATCOM and zig-zag transformer

Above figure illustrates the proposed methodology of power quality improvement. In this DSTATCOM is used for improvement of voltage profile and by ssuitable 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.

In a DSTATCOM, the voltage source is normally controlled with hysteresis or ramp comparison type current regulated PWM inverter. The hysteresis and ramp comparison type current regulated PWM inverter can be implemented with conventional analog and digital circuit. The PWM switching pattern for DSTACOM can also be generated by comparing phase shifted reference voltage signal generated PLL and associated circuitry with triangular carrier wave. The application of SVPWM for DSTACOM is not explored fully. SVPWM technique offers several advantages like higher output voltage (15 % more than conventional sine - triangle modulation technique and hence, better utilization of DC link), lower harmonics contents and suitability for complete digital implementation with new generations DSPs. This methodology is a DSTATCOM with SVPWM technique for generation of PWM pattern. The suitability of SVPWM technique for reactive power management in DSTATCOM has been verified by simulation by using SimPower System of MATLAB and Simulink.

The zig-zag connection is the most widely used grounding transformer because the geometry of the Zig-Zag connection is useful to limit circulation of third harmonics. Furthermore, the Zig-Zag transformers are provides grounding with a smaller in size than a two winding Wye-Delta transformer providing the same zero sequence impedance. During undisturbed system operation with balanced (symmetrical) voltages and under balanced current on the systems. The three phase voltage equal in magnitude but 120° out of phase with each other, are applied to the three terminals of grounding transformer, the currents in the two windings in the same limb of the core flow in opposite directions because of the special Zigzag winding connections. As the fluxes oppose but the ampere turns in the windings cannot cancel so the zig-zag transformer takes a very small current as the magnetizing current during normal condition .But when single line to ground fault occurs on any phase of the system, zero sequence component of the earth fault current flows in the earth and returns to the electrical power system by way of earth star point of the grounding transformer. It gets divided equally in all the three phases. Hence, the currents in the two windings in the same limb of the core flow in opposite directions. And therefore the magnetic flux set up by these two currents will oppose and neutralize each other. As there is no increase in flux due to fault current, there is no extra (***dφ /dt***) means no extra voltage induced across the winding and no choking effect occurs to impede the flow of fault current. So it can be concluded like that, the zigzag type grounding transformer maintains the rated supply voltage at normal current as well as when a solid single line to ground fault current flows through it. The ground fault current is only limited by a Neutral Grounding Resistor (NGR), and the small reactance of the Zigzag.

The main features of Zig-zag grounding transformers are:

1. Winding has much lower impedance to zero sequence currents.
2. Can be used with three phase system without secondary winding.
3. Avoidance of undesirable stresses in the insulation.
4. Can be used with either delta or star connected winding to feed desired load.
5. It keeps zero sequence impedance constant even when auxiliary winding under load.
6. Fault current is not reflected on to the secondary side (auxiliary winding).

From the above, it is very clear that the Zig-Zag winding can be utilized either as grounding transformer or power transformer, or in combination depending upon the requirement.

A. Controlling of DSTATCOM

The control block diagram of DSTATCOM in reactive power generation mode is shown in Fig. 4.2.

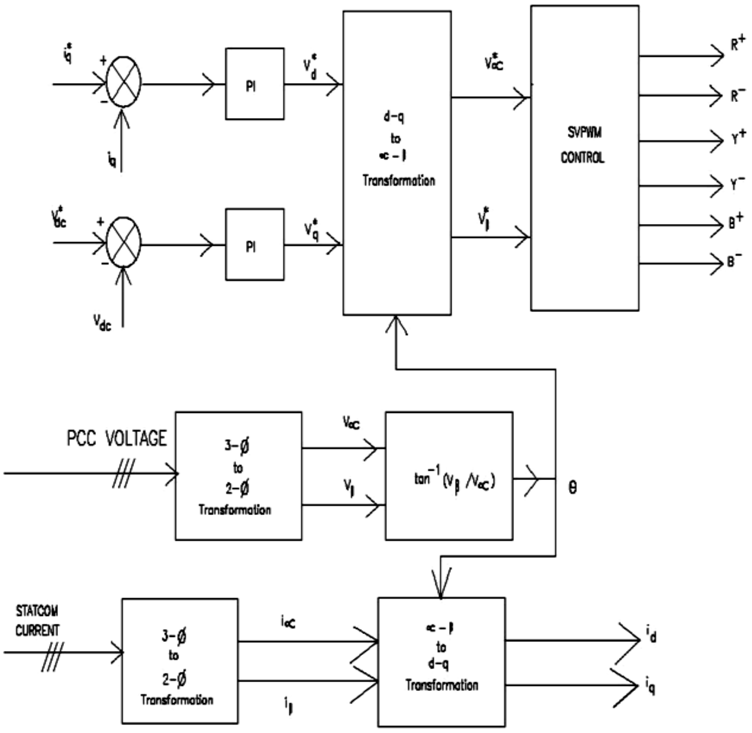


Fig. 5 Control block diagram of DSTATCOM

The three-phase PCC voltages (vsa, vsb vsc) and source currents (isa, isb, isc) are measured. These three-phase voltage and current signals at control level are converted into equivalent α-β axis (two axis stationary reference frame) components (isα, vsα, isβ, vsβ). The current or voltage signals in α-β (two-axes stationary) frame are converted to d-q (two-axes synchronously rotating reference) frame. In synchronously rotating reference frame, the direct axis current component is proportional to active power and quadrature axis current component is proportional to reactive power.

The equations involved for phase transformations are well known

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = [C] \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \tag{4}$$

$$[C] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \sin(\theta) \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \sin(\theta) \end{bmatrix} \begin{bmatrix} v_d \\ v_q \end{bmatrix} \tag{7}$$

Where

Vsa, Vsb, Vsc : Source voltages

V, V : Voltages in two-axes stationary frame

Vd, Vq : Voltages in two-axes synchronously rotating frame

In reactive power control loop, the reference, reactive power is compared with the actual reactive power generated by the DSTATCOM and the error in reactive power is processed by the PI controller to give the direct axis component of converter reference voltage. The DC link voltage of the DSTATCOM should be selected such that the converter can deliver the rated reactive power in the desired range of grid voltage. The reference DC link voltage is compared with actual DC link voltage and the error in DC link voltage is processed by the PI controller to give quadrature axis component of converter reference voltage. The direct axis and quadrature axis reference voltages are transformed to two axes stationary reference frame and fed to SVPWM block. The SVPWM block receives the reference voltages in oc-f frame and generates PWM switching signals. Depending on the magnitude and phase angle of the reference voltage space vector, the duration of the adjacent switching state vectors are calculated and accordingly the PWM switching signals are generated by internal compare registers. The PWM switching signals generated by the DSP are given to IGBTs of VSC through respective gate drives.

B. Working of Zig-Zag transformer

The Zig-Zag transformer has been used to attenuate the neutral current and zero sequence harmonic currents on the utility sites in recent years due to the advantages of low cost, high reliability and simplified circuit analysis.

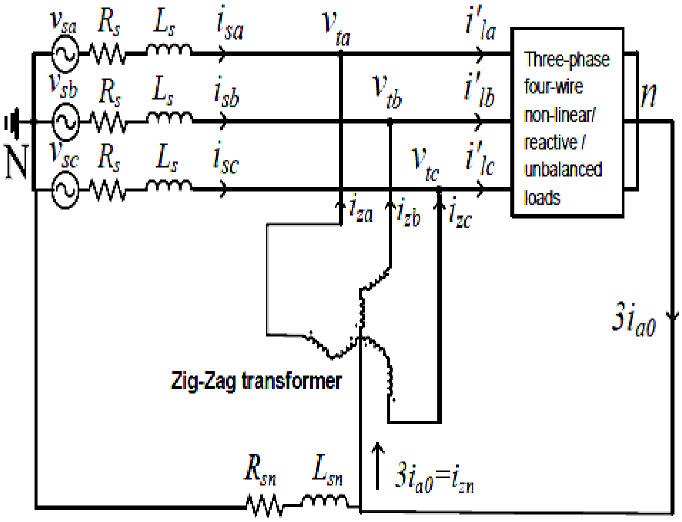


Fig. 6 Neutral current compensation using Zig-Zag transformer

Fig.6 shows the circuit connections of the same configuration. In this figure, Rs and Ls represent feeder resistance an inductance respectively, (which are generally very low). At the same time, Rsn and Lsn represent resistance and inductance inserted in the source neutral wire to ensure significant neutral current flow through Zig-Zag transformer. The zero-sequence equivalent circuit for the system is shown in Fig. 7 considering balanced as well as unbalanced supply voltages.

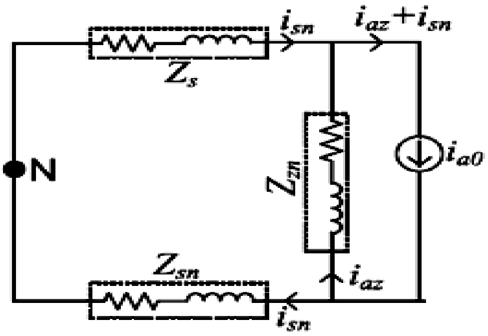


Fig. 7 Zero sequence circuit for neutral current compensation using Zig-Zag transformer for balanced utility condition

From Fig. 6.5 it can be concluded that to the degree Zsn is greater than Zzn, to that degree better neutral current compensation is achieved.

IV. MODEL SIMULATION AND RESULTS

A. System without fault

This is the normal system without any fault in the system. In this model generator source of 11kv is used and which is then connected to step down transformer of rating 2.5 MVA, 11kv/440v, 50 Hz, which is connected to the feeder.

In this we have calculated voltages and currents at point of common coupling, also active and reactive powers. The simulated model of the normal system with load is as shown below.

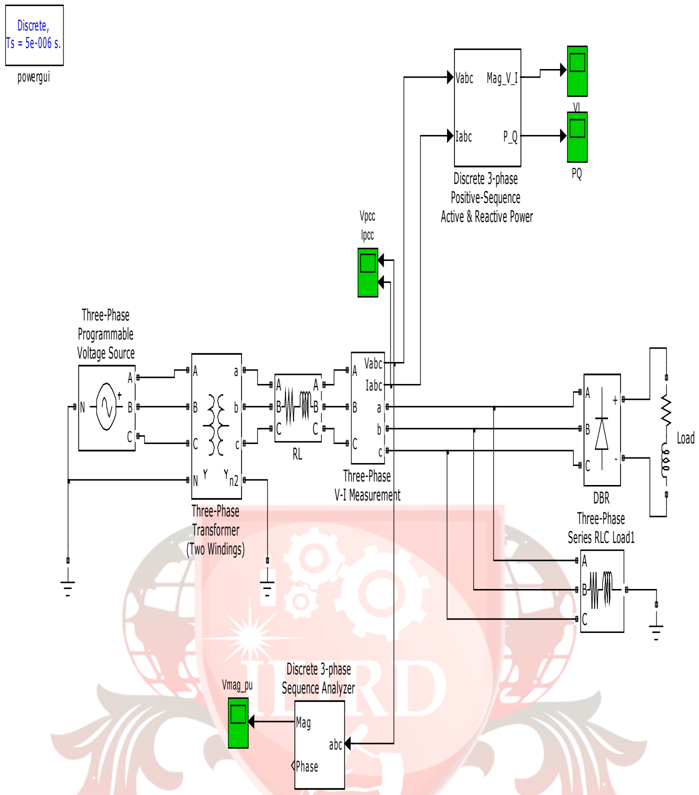


Fig.8 Model showing normal system without fault

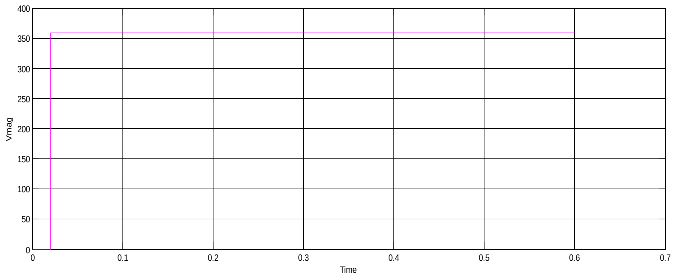


Fig. 9 Waveform for magnitude of voltage at PCC

B. System with Fault

Here, three phase fault with ground resistance 0.001 ohm for 0.2 sec to 0.3 sec is introduced in the system and effect of fault is observed. The simulated model and respective waveforms are shown below. The waveforms shows that as the fault is introduced in the system for 0.2 to 0.3 sec, the voltage sag is created which is near about 50 % of the total value of voltage. It is called as instantaneous sag as the r.m.s voltage decreases to between 0.1 and 0.9 per unit for time duration of 0.008333 second to 0.5 second.

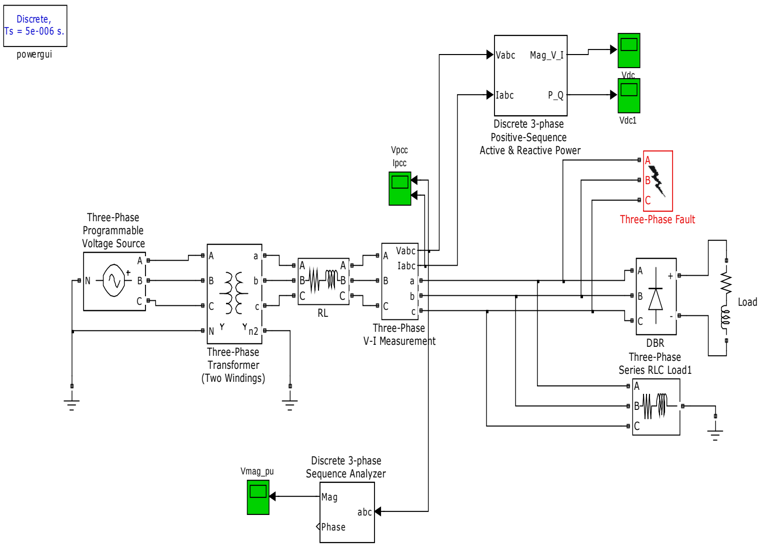


Fig. 10 Model showing system with fault

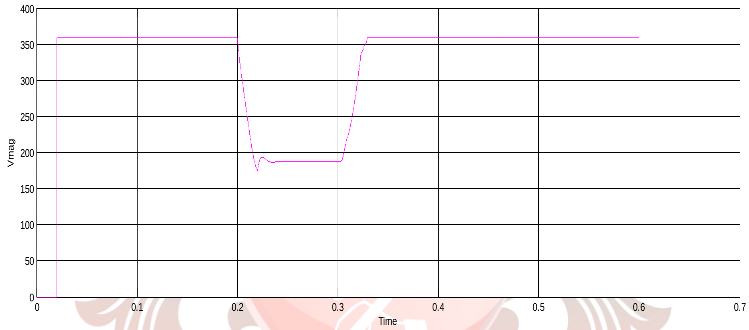


Fig. 11 Waveform for magnitude of voltage at PCC

C. System with Fault and DSTATCOM

To mitigate the sag created by fault, DSTATCOM is introduced in the system. The basic parts of DSTATCOM are 3 phase, 6 pulse voltage source converter, storage capacitor of 3000µF, coupling inductor of 3.3mH and DC source voltage of 680 V. Respective waveforms are plotted. From the waveform of voltages and currents at PCC, it is observed that voltage which was reduced between 0.2 to 0.3 sec duration is now raised to the normal value and the sag is now reduced to less than 6%.

Also the neutral current in the system is plotted after introduction of fault and it is found to be very high, hence, compensation of neutral current is required.

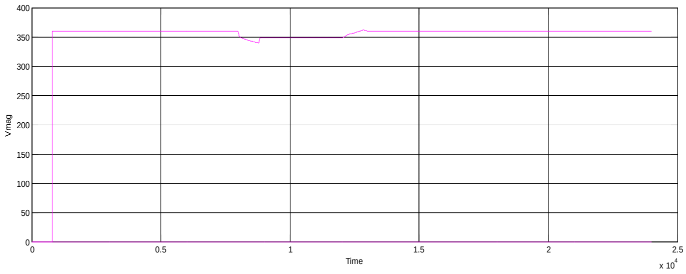


Fig. 12 Waveform for magnitude of voltage at PCC

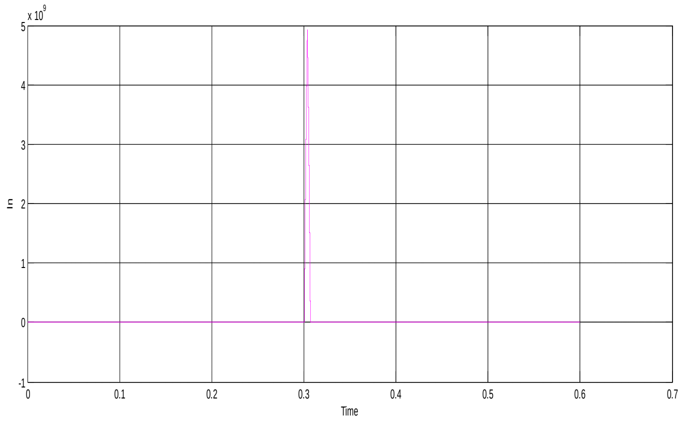


Fig. 13 Waveform for neutral current

D. System with zig-zag transformer

Here, zig-zag transformer of 0.5 MVA, multiple winding, 50 Hz is introduced in the system for neutral current compensation. From waveform of neutral current, it is seen that the value of current is reduced greatly.

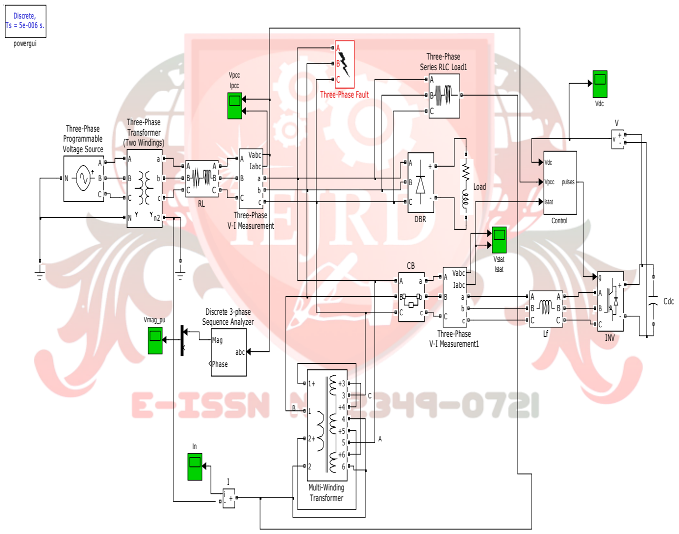


Fig. 14. Model showing system with DSTATCOM & zig-zag transformer

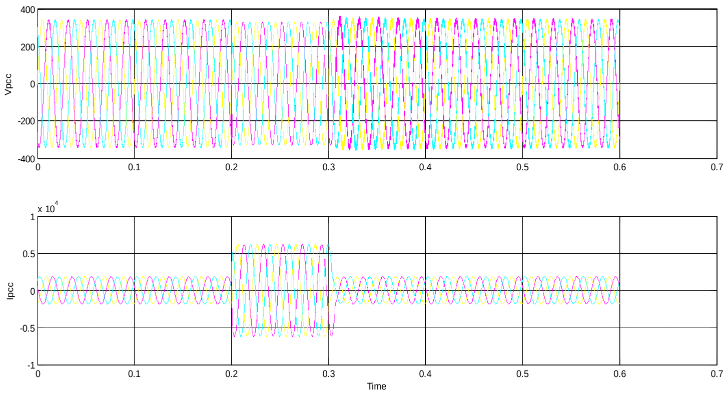


Fig. 15. Waveforms of voltages and currents at PCC

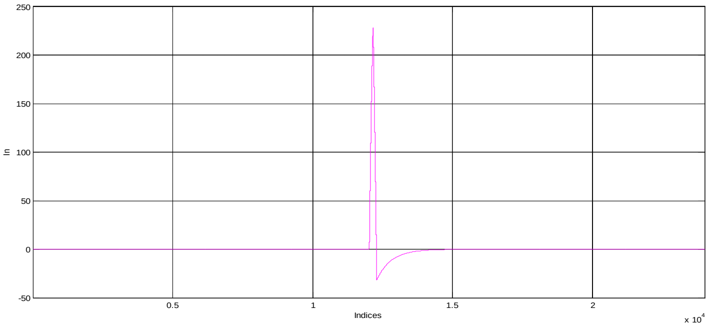


Fig. 16 Waveform for neutral current

Parameters used for System

Sr. no.	System quantities	Values
1	3phase Voltage source	11kV, 50 Hz
2	3phase (two winding) step down transformer	0.5 MVA, Y/Y type, 11kV/440V, 50 Hz
3	Line Inductance	0.03 mH
4	Line Resistance	0.001 ohm
5	Three phase fault with ground resistance	0.001 ohm
6	DC source	680V
7	Capacitor	3000 µF
8	Circuit Breaker	Ron=0.001 ohm, Rp=1 Mohm
9	Inductor	Lf=3.3 mH
10	Inverter	3phase, 6 pulse, IGBT inverter
11	Zig-zag transformer parameters	5 kVA, multiple winding transformer, 50 Hz
		Winding nominal voltages= 150 V

Table 1. Parameters used for system

V. CONCLUSION

In this thesis, causes, standards, and mitigation techniques of voltage sag and the excessive neutral current have been investigated in the three-phase four-wire distribution system. A step-by step modelling and simulation of systems without and with faults has been demonstrated for voltage sag and neutral current compensation. To mitigate them a system with DSTATCOM and zig-zag transformer is developed and simulated and respective results are obtained. Results obtained shows that the generated 50% sag in the system is reduced to less than 6% after compensation. These results shows that SVPWM switched DSTATCOM with zig-zag transformer has been observed as an effective option for overall compensation.