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COMPARATIVE STUDY ON VOLTAGE SAG/SWELL MITIGATION BY MODELLING AND SIMULATION OF DVR AND DSTATCOM

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Abstract: The electrical energy is one of the easily used forms of energy. It can be easily converted to other forms of energy. With the advancement of technology, the dependency on the electrical energy has been increased greatly. Computer and telecommunication networks, railway network banking, post office, life support system are few application that just cannot function without electricity. At the same time these applications demand qualitative energy. However, the quality of power supplied is affected by various internal and external factors of the power system. The presence of harmonics, voltage and frequency variations deteriorate the performance of the system. In this paper the frequently occurring power quality problem- voltage variation is discussed. The voltage sag/dip is the most frequently occurring problem. There are many methods to overcome this problem. Among them the use of FACT devices is an efficient one. This paper presents an overview of the FACT devices like- DVR, D-STATCOM, in mitigating voltage sag. Each one of the above device is studied and analyzed. And also the control strategies to control these devices are presented in this project. The proposed control strategies are simulated in MATLABSIMULINK environment and the results are presented in this paper. A comparative study based on the performance of these devices in mitigating voltage sag is also presented.

I. INTRODUCTION

Overview:-
Power quality is one of the major concerns in modern power system. It has become important especially with the introduction of sophisticated devices, whose performance is very sensitive to the power quality problems. In modern industries, load equipment uses electronic controllers which are sensitive to poor voltage quality and will shut down if the supply voltage is depressed and may mal-operate in other ways if harmonic distortion of the supply voltage is excessive. Power quality problems is an occurrence manifested as non-standard voltage, current or frequency, the result in failure or miss operation of end user equipment. Much of this modern load equipment itself uses electronic switching devices which then can contribute to poor network voltage quality. The introduction of competition into electrical energy supply has created greater commercial awareness of the issues of power quality while equipment is now readily available to measure the quality of the voltage waveform and so quantify the problem. The quality of the power is affected if there is any deviation in the voltage and frequency values at which the power is being supplied. This affects the performance and life time of the end user equipment. Whereas, the continuity of the power supplied is affected by the faults which occur in the power system. So to maintain the continuity of the power being supplied, the faults should be cleared at a faster rate and for this the power system switchgear should be designed to operate without any time lag

The power quality is affected many problems which occur in transmission system and distribution system. Some of them are like- harmonics, transients, sudden switching operations, voltage fluctuations, frequency variations etc. These problems are also responsible in deteriorating the consumer appliances. In order to enhance the behaviour of the power system, these all problems should be eliminated.

To full fill consumer requirement many efforts have been taken by utilities, some consumers require a level of power quality higher than the level provided by modern electric networks. This implies that some Measures must be taken in order to achieve higher levels of power quality. The FACTS devices and Custom power devices are introduced to electrical system to improve the power quality of the electrical power. DVR, STATCOM/DSTATCOM, ACTIVE FILTERs, AUTOTRANSFORMER, UPQC etc are some of the devices used to improve the power quality of the voltage and current. With the help of these devices we are capable to reduce the problems related to power quality. The power quality is affected many problems which occur in transmission system and distribution system. Some of them are like- harmonics, transients, sudden switching operations, voltage fluctuations, frequency variations etc. These problems are also responsible in deteriorating the consumer appliances. In order to enhance the behaviour of the power system, these all problems should be eliminated.

II. POWER QUALITY PROBLEMS

Introduction:
Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbance and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage s wells, and harmonics. A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries

that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy

Power Quality

The quality of electric power delivered is characterized by two factors namely- "continuity" of supply and the "quality" of voltage. As indicated by IEEE standard 1100, Power Quality is characterized as- "The idea of controlling and establishing the touchy supplies in a manner that is suitable for the operation of the gear."

Power quality Problems

There are many reasons by which the power quality is affected. The occurrence of such problems in the power system network is almost indispensable. Therefore, to maintain the quality of power care must be taken that suitable devices are kept in operation to prevent the consequences of these problems. Here an overview of different power quality problems with their causes and consequences is presented.

The distortion in the quality of supply power can be introduced /enhanced at various stages; however, some of the primary sources of distortion can be identified as below:

Introduction to voltage sag:

Voltage sag/swell that occurs more frequently than any other power quality phenomenon is known as the most important power quality problems in the power distribution systems. IEEE 519-1992 and IEEE 1159-1995 describe the voltage sags /swells as shown in Fig.Voltage sag is defined as a sudden reduction of supply voltage down from 90% to 10% of nominal. According to the standard, a typical duration of sag is l0 ms to 1 minute. On the other hand, voltage swell, is defined as a sudden increasing of supply voltage up1l0% to 180% in rms voltage at the network fundamental frequency with duration from 10 ms to 1 minute. Voltage sag/swell often caused by faults such as single line-to-ground fault, double line-to-ground fault on the power distribution system or due to starting of large induction motors or energizing a large capacitor bank.

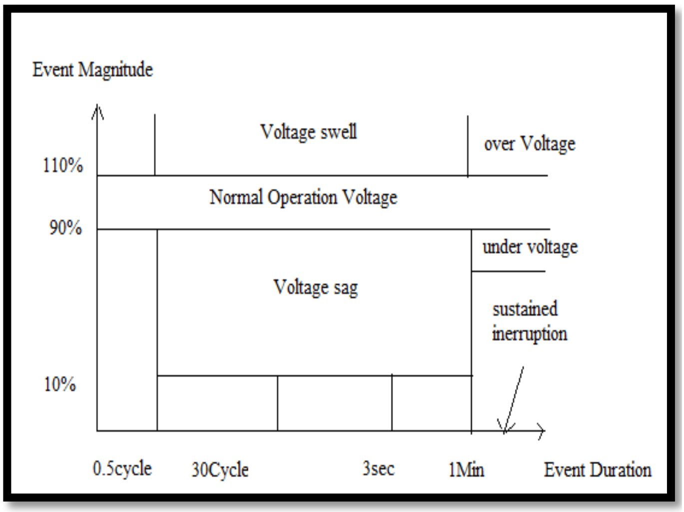


Fig- Voltage Reduction Standard of IEEE std.1159-1995

Causes of voltage sag:

Starting of Large Induction Motors

Voltage sags typically are due to starting on large loads, such as an electric motor or an arc furnace. Induction motors draw starting currents ranging between 600 and 800% of their nominal full load currents. The current starts at the high value and taper off to the normal running current in about 2 to 8 sec, based on the motor design and load inertia.

Due to Arc furnaces

Arc furnaces are another example of loads that can produce large voltage sags in electrical power system.

Equipment Failure:

If electrical equipment fails due to overloading, cable faults etc., protective equipment will operate at the sub-station and voltage sags will be seen on other feeder lines across the utility system.

Bad Weather:

Thunderstorms and lightning strikes cause a significant number of voltage sags. If lightning strikes a power line and continues to ground, this creates a line to ground fault. The line to ground fault in turn creates voltage sag and this reduced voltage can be seen over a wide area.

Animals & Birds:

Animals particularly squirrels, raccoons and snakes occasionally find their way on to power lines or transformers and can cause a short circuit either phase to phase or phase to ground. Large birds, geese and swans, fly into power lines and cause similar faults. While the creature rarely survives, the protective circuit breaker operates and voltage sag is created on other feeders.

Vehicle Problems:

Utility power lines frequently run alongside public roads. Vehicles occasionally collide with utility poles causing lines to touch, protective devices trip and voltage sags occur.

POWER QUALITY MITIGATION TECHNIQUES

There are different solutions to mitigate Power Quality problems.

- Passive harmonic filter
- Surge Arrester
- D-statcom
- DVR

III. STUDY OF DVR AND DSTATCOM FOR VOLTAGE SAG MITIGATION

Dynamic Voltage Restorer (DVR)

The DVR is a power quality device, which can protect these industries against the bulk of these disturbances, i.e. voltage sags and swells related to remote system faults. A DVR compensates for these voltage excursions, provided that the supply grid does not get disconnected entirely through breaker trips. Modern pulse-width modulated (PWM) inverters capable of generating accurate high quality voltage waveforms form the power electronic heart of the new Custom Power devices like DVR. Because the performance of the overall control system largely depends on the quality of the applied control strategy, a high performance controller with fast transient response and good steady state characteristics is required. The main considerations for the control system of a DVR include: sag detection, voltage reference generation and transient and steady-state control of the injected voltage. The typical power quality disturbances are voltage sags, voltage swells, interruptions, phase shifts, harmonics and transients. Among the disturbances, voltage sag is considered the most severe since the sensitive loads are very susceptible to temporary changes in the voltage.

Operating principle of DVR:-

The basic principle of operation of the DVR is that by injecting a voltage of required magnitude and frequency in the system restored the load side voltage to desired amplitude frequency as shown in figure.3.1 DVR injects a controlled voltage generated by a forced commuted converter in a series to the bus voltage by means of an injecting transformer. A DC to AC inverter regulates this voltage by sinusoidal PWM technique. All through normal operating condition, the DVR injects only a small voltage to compensate for the voltage drop of the injection transformer and device losses. However, when voltage sag occurs in the distribution system, the DVR control system calculates and synthesizes the voltage required to preserve output voltage to the load by injecting a controlled voltage with a certain magnitude and phase angle into the distribution system. Figure 4.3a shows the phasor diagram in which DVR injects the missing voltage between sag voltage and pre-sag voltage.

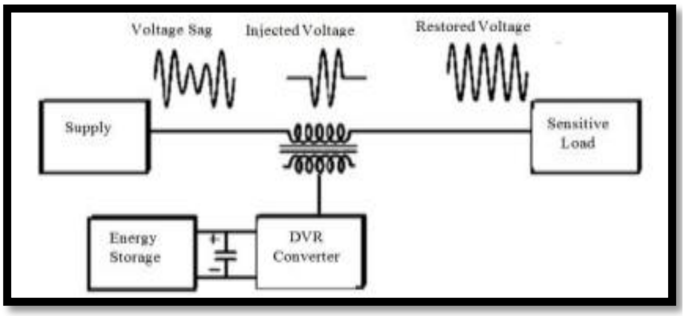


Fig-3.1 Principle of Operation of DVR System

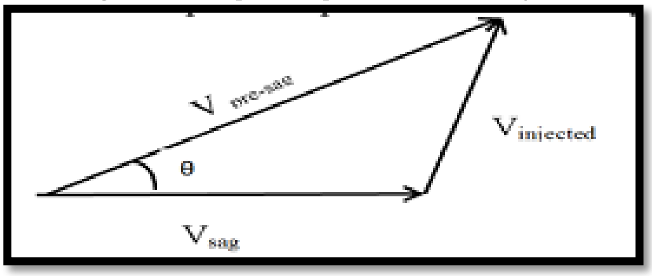


Fig-3.1 (a) Vector Diagram of Operating Principle of DVR

Control Strategy:

Control theory introduces feedback loop to overcome the limitations of the open-loop controller. A closed-loop controller uses feedback loop to control outputs of dynamic system. Closed-loop controllers have the following advantages over open-loop controllers:-

- Provides disturbance rejection.
- When the model structure does not match perfectly the real process and the model parameters are not exact, guaranteed performance can be obtained even with model uncertainties.
- Sensitivity will be reduced to parameter variations.
- Unstable processes can be able to stabilize.

Suppose there is an interconnected power system with two or more independently controlled areas and any disturbance may cause a change in frequency of power system which results in instability. In addition the power interchange between the control areas cannot be constant. PI controller design has been implemented to maintain constant voltage at the sensitive load in this report. The PI controller design demand to find out the characteristic equation of the simulation model. It proves to be an effective and efficient method to control the settling time and maintain the stability of the system.

In the simulation model, the two feeder line had been taken to demonstrate the operation of the Dynamic voltage restorer. Dynamic voltage restorer is successful in compensating voltage sag and voltage swell type of power quality problems. For maintaining constant magnitude at the sensitive load end, the PI controller is designed Precisely. In the designing of PI controller, the stability and the step response is checked firstly to ensure about the stability. But the transfer function of the model shows the stability of the system and as its denominator term does not contain any sign change. If there is any sign change then the system will be unstable according to the number of sign changes i.e. if sign changes two times then there will be two roots on the R.H.P of S-plan. If there is no any sign change then the system is having all the roots on L.H.P of S-plan. Thus the characteristic equation of the model plays a very significant role in designing the PI controller.

IV. INTRODUCTION OF DSTATCOM:

Voltage sags 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. Various methods have been applied to reduce or mitigate voltage sags. The conventional methods are by using capacitor banks, introduction of new parallel feeders and by installing uninterruptible power supplies (UPS). However, the PQ problems are not solved completely due to uncontrollable reactive power compensation and high costs of new feeders and UPS. The D-STATCOM has emerged as a promising device to provide not only for voltage sags mitigation but a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction and harmonic control. The D-STATCOM has additional capability to sustain reactive current at low voltage reduce land use and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage. Distribution Static Compensator is in short known as D-STATCOM. It is a power electronic converter based device used to protect the distribution bus from voltage unbalances. It is connected in shunt to the distribution bus generally at the PCC.

4.14.1Basic Structure:

D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in Fig. 4.14.1. It consists of a dc capacitor, three-phase inverter, ac filter, coupling transformer and a control strategy. The basic electronics block of the D STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency.

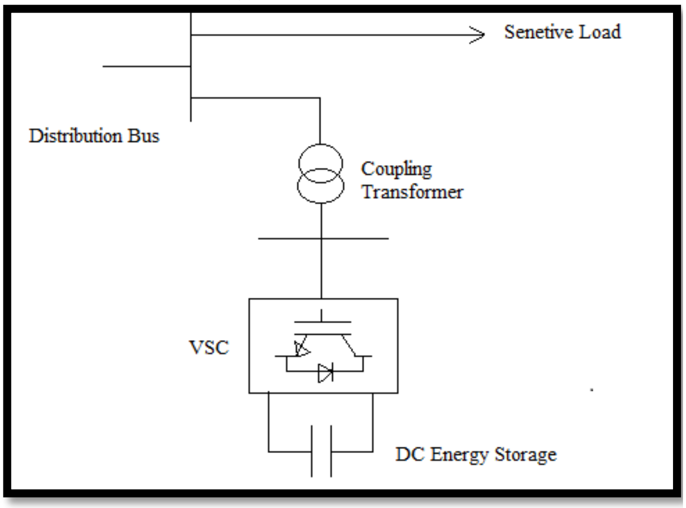


Fig-3.3 DSTATCOM

Voltage Source Converters (VSC)

Converter used here is a voltage source inverter (VSI). It is a power electronic device consisting of IGBTs and a DC storage unit. VSI is used to generate three phase AC voltage at any required magnitude, phase and frequency to compensate the load voltage at the required value.

Lc Filter

An LC filter is used for decreasing harmonics and matching inverter output impedance to enable multiple parallel inverters to share current. The LC filter is selected as per the type of the system and the harmonics present at the output of the inverter.

DC-Energy storage:

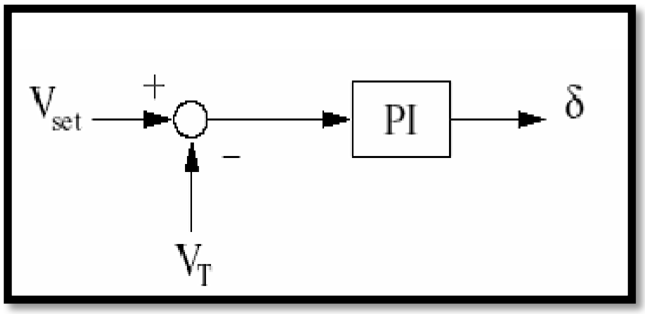
The function of this part is to supply the necessary energy to the VSC for converting DC to AC signal. Batteries are most widely used DC storage unit. The amount of voltage which has to be compensated determines the capacity of the battery.

Coupling Transformer:

It is used to couple the VSC to the distribution line. The high voltage side is normally connected in shunt with the distribution network while the power circuit of the DSTATCOM is connected to the low voltage side [13]. The DSTATCOM inject the current which is required for the compensation from DC side of the inverter to the distribution network through the injection transformer. It also isolates the line from the VSC.

Control Strategy:

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favoured in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. 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. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.



Equivalent circuit of DSTATCOM

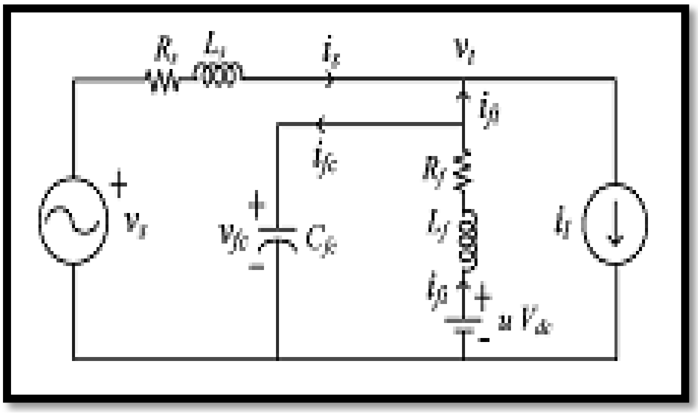


Fig. 3.4 Single-phase equivalent circuit of DSTATCOM

Fig. 2 shows the single-phase equivalent circuit. Variable u is a switching function, and can be either+1 or -1 depending upon switching state. Filter inductance and resistance are Lf and Rf, respectively. Shunt capacitor Cfc eliminates high-switching frequency components

Operating Principle of DSTATCOM

A D-STATCOM is capable of compensating either bus voltage or line current. It can operate in two modes based on the parameter which it regulates [4]. They are-

Voltage Mode Operation:

In this mode, it can make the bus voltage to whichit is connected a sinusoid. This can be achieved irrespective of the unbalance or distortion in the supply voltage.

V. MODELLING AND SIMULATION

General:-

In modern engineering work, computer programming is used for developing software. Previously in order to develop software, toolbox or standalone applications, one had to rely on C, C++, Visual basic, or Java. For a computer science or information technology student it is easy to program in these environments but for other science and engineering students this pose a problem since they are not familiar with these programs and may not have excellent programming expertise. Nevertheless MATLAB also has very nice inherent GUI development environment called as GUIDE that allows creation of GUI so that the code becomes more user friendly.

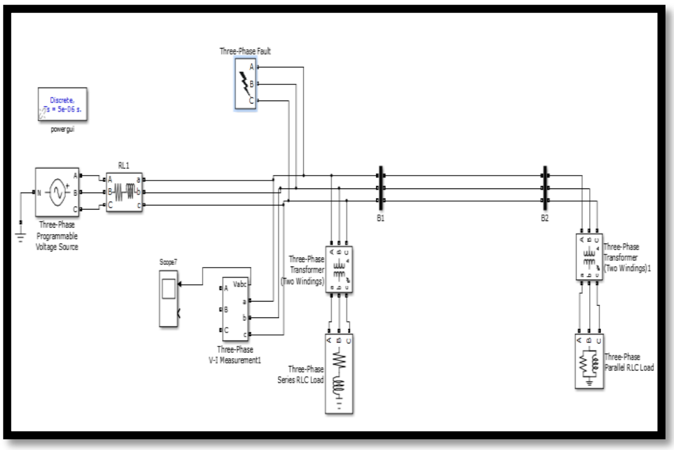


Figure 4.1: simulation circuit for voltage sag and swell without DVR and d-statcom

The system consists of voltage of 1 pu, 50 Hz source with 10kw 3-phase RLC load shown in fig 5.1. voltage sag is occurred at 0.05 sec to 0.015 sec and voltage swell occurred 0.05 sec to 0.15 sec. Fig: 5.2 shows three phase voltage waveform under fault condition without DVR. As shown fig 5.1, sag occurs at 0.5sec to 0.15 sec. Now the function of DVR would be to inject a compensating voltage, which would result in fairly constant voltage across the load terminal. With the use of the fast acting power electronics converters, DVR is capable to inject voltage for such a small duration of few cycles.

Sr. No	System quantities	Standards
1	Source	3-phase,415V,50HZ
2.	PI controller	K_p=60,K_i=1400,Sampling Time=50µs
3.	RLC load	Active power=10kw,Ind reactive p=50KVAR
4.	3Ø Linear Tr,- 12 Terminal	P=10?⁶ VA, F=50HZ
5.	DC V Source	500V

Table-4.1 Simulation parameters

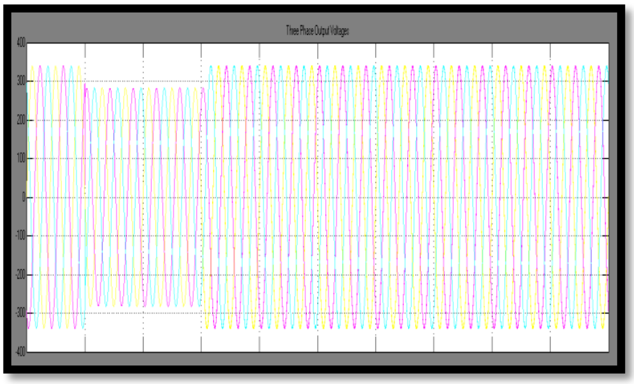


Figure 4.2: simulation result for voltage sag without DVR

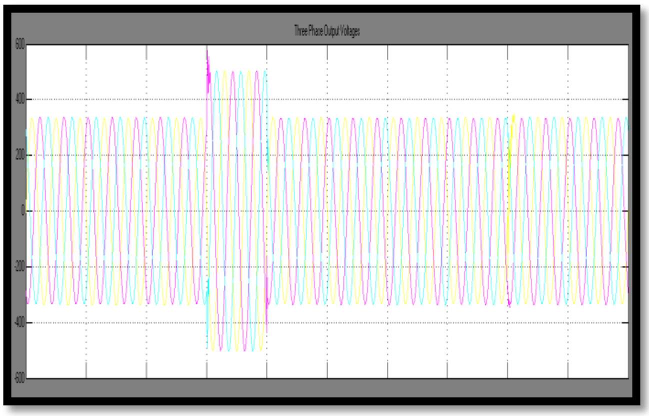


Figure 4.3: simulation result for voltage swell without DVR

Simulation for voltage sag with DVR

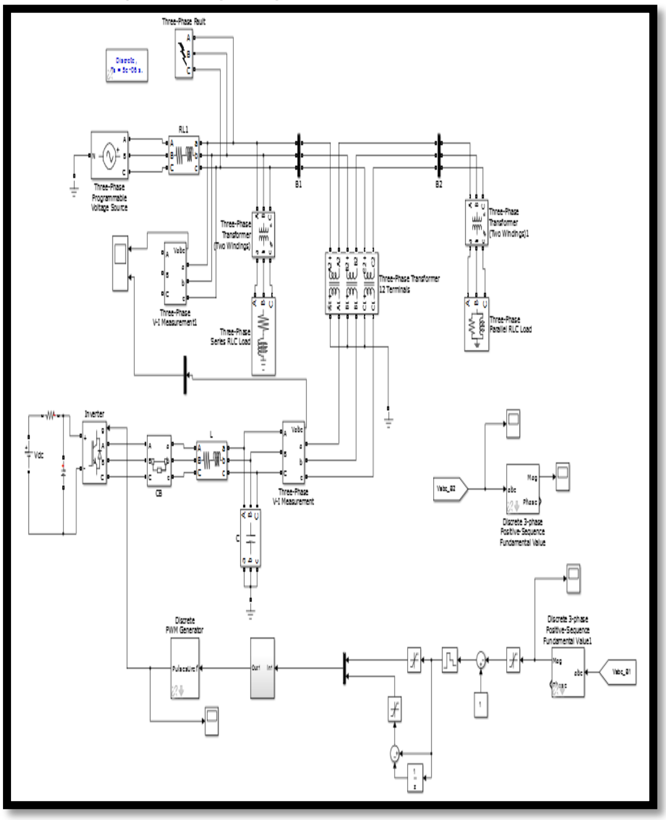


Fig 4.4- simulation for voltage sag with DVR

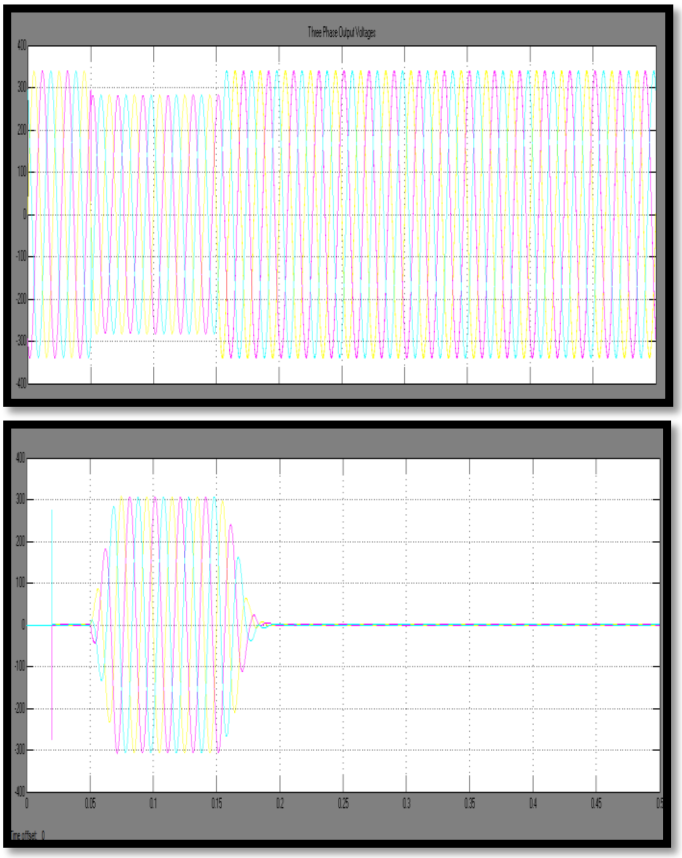


Fig-4.5 Simulation result for voltage sag with DVR

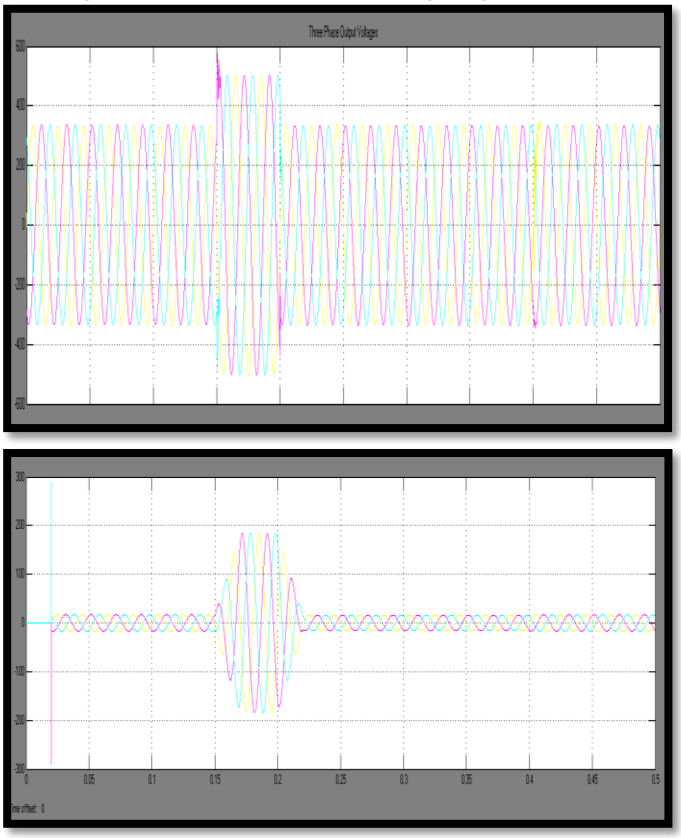


Fig-4.6 Simulation result for voltage swell with DVR

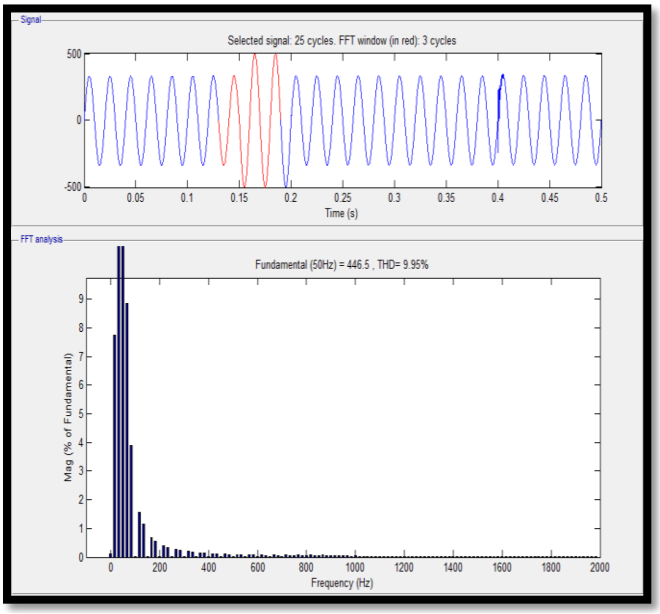


Fig-4.7 FFT analysis for voltage swell condition without DVR

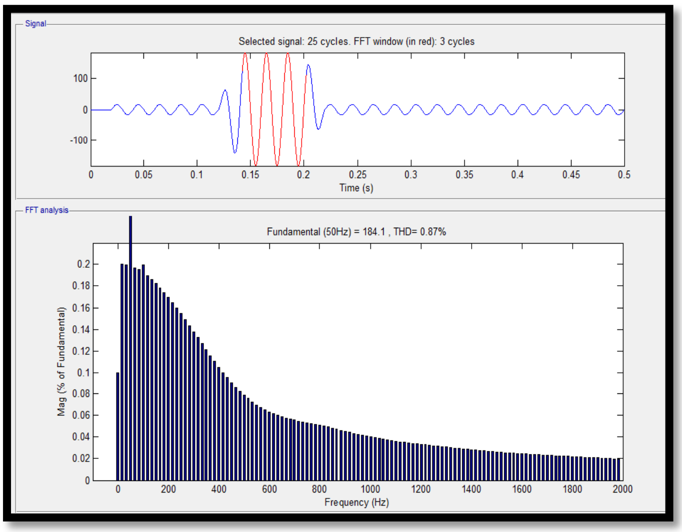


Fig-4.8 FFT analyses for voltage swell condition with DVR

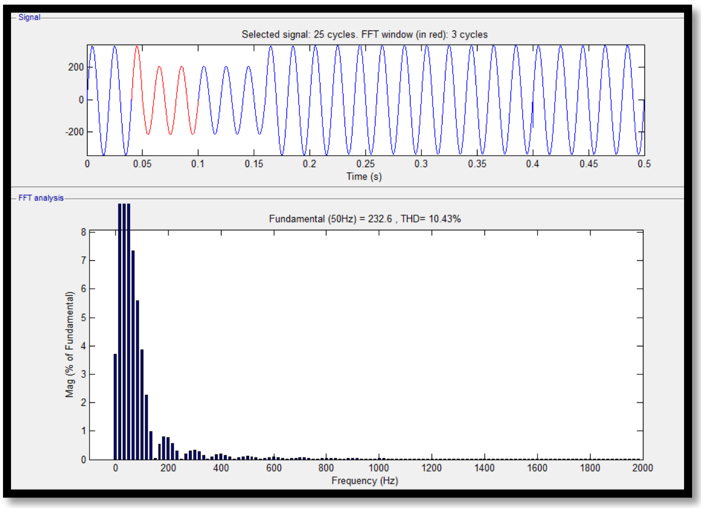


Fig-4.9FFT analysis for voltage sag condition without DVR

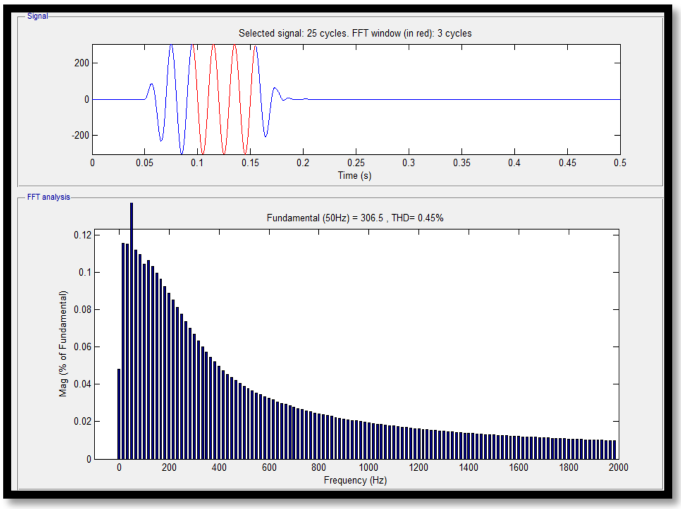
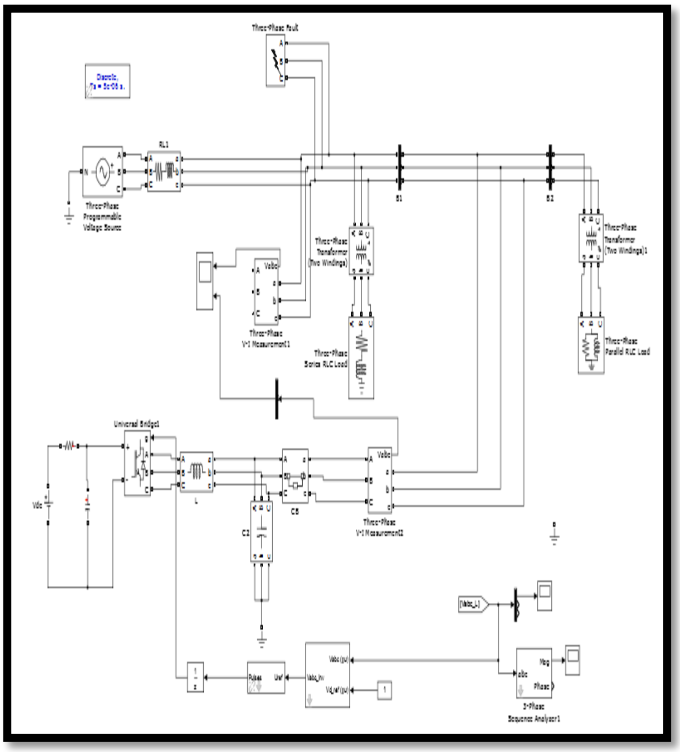


Fig-5.10FFT analysis for voltage sag condition with DVR



4.11 Simulation for voltage sag with DSTATCOM

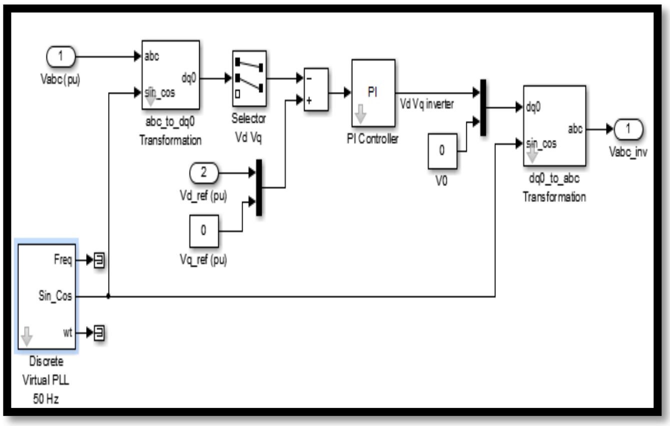
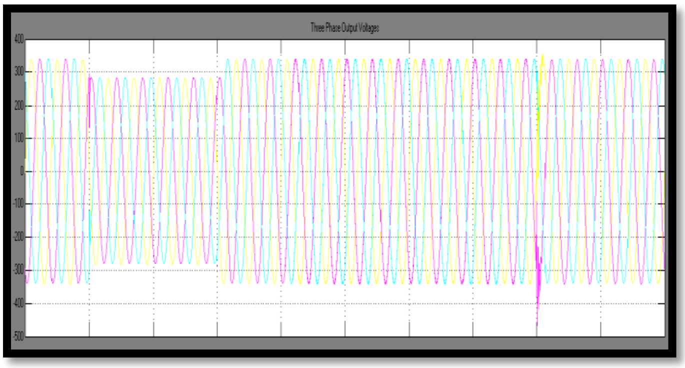


Fig-4.12 D-statcom control Subsystem



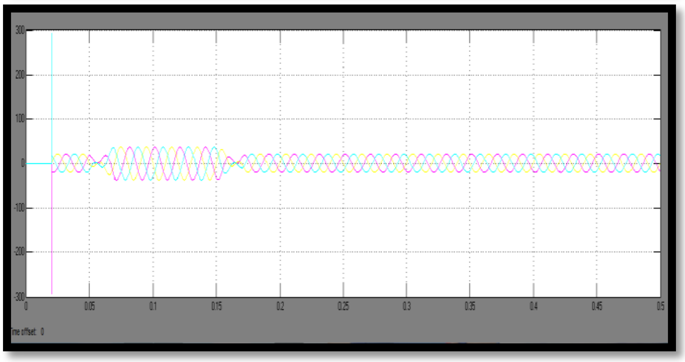


Fig-4.13 Simulation result for voltage sag with DSTATCOM

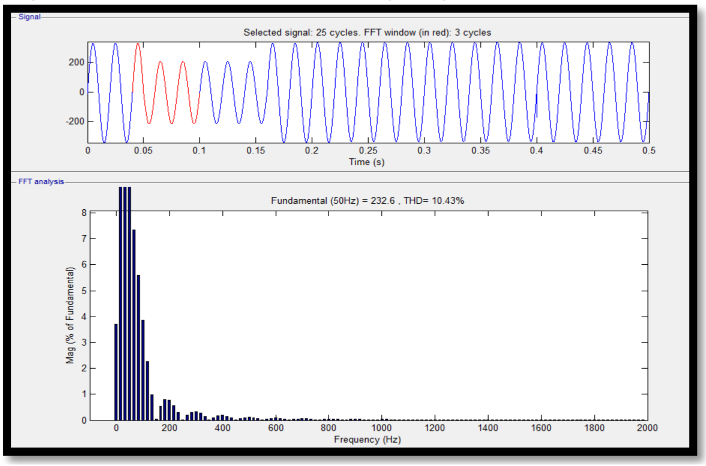


Fig-4.14FFT analysis for voltage sag condition without DSTATCOM

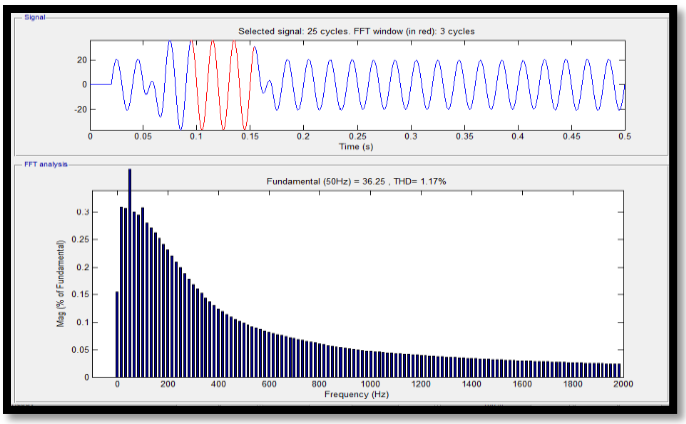


Fig-4.15FFT analysis for voltage sag condition with D-STATCOM

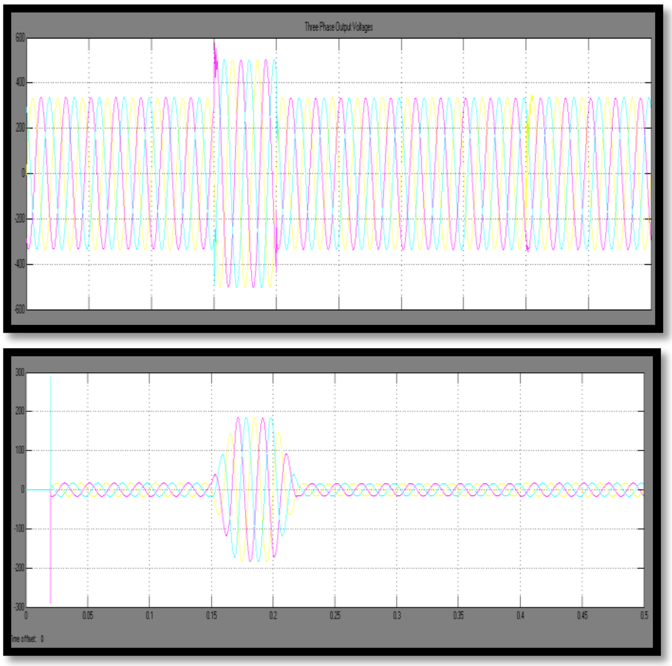


Fig-4.16 Simulation result for voltage swell with DSTATCOM

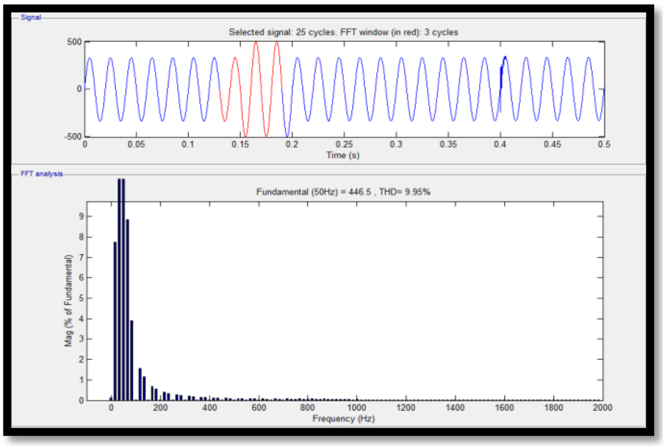


Fig-4.17 FFT analysis for voltage swell condition without DSTATCOM

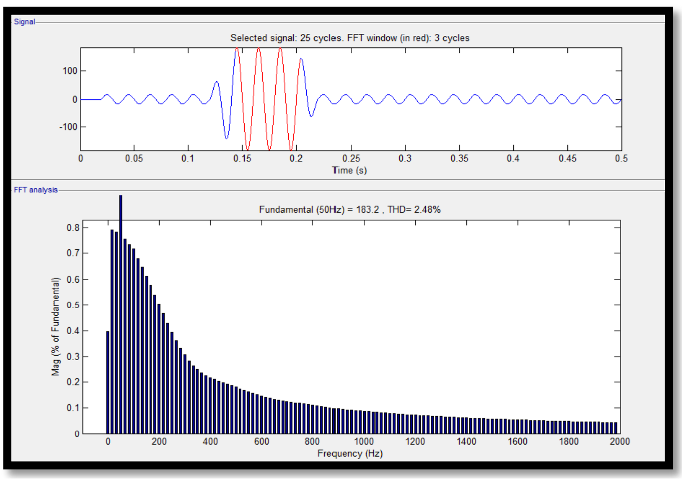


Fig-4.18 FFT analyses for voltage swell condition with DSATCOM

Table-2 Comparison tables for D-STATCOM and DVR

(a) THD comparison

Sr. No.	Condition	THD (%) without any Device	THD (%) using D-STATCOM	THD (%) using DVR
1	Sag	10.43	1.17	0.45
2	Swell	9.95	2.48	0.87

(b) Behavior vise comparison

Sr.No.	Device	Behaviour
1	D-STATCOM	Sluggish
2	DVR	Dynamic

VI. CONCLUSION

In this paper the main objectives for the utilization of the studied equipment to mitigate the voltage sag and voltage swell. In order to protect critical loads from more sever fault in distribution network. The facility available in MATLAB/SIMULINK is used to carry out extensive simulation study.

By simulating DVR and FFT analysis of Voltage, it can be concluded that, it can give better performance than D-STATCOM because it's dynamic response against voltage sag and swell.

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