Voltage Compensation in Distribution Networks

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Abstract: *Due to the rapid technological progress, theconsumption of electrical energy increases continuously.In this paper the frequently occurring power quality problemvoltage variation has been 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 and D-STATCOM in mitigating voltage sag. Each one of the above device has been studied and analyzed along with the control strategies to control these devices. The proposed control strategies have been simulated in MATLAB Simulink platform and the results are presented. A comparative study based on the performance of these devices in mitigating voltage sag has been presented.*

Keywords: *PI Controller,DVR, D-STATCOM, Sag/Swell. Static Var Compensator, Voltage Compensation*

1. INTRODUCTION

Electrical energy is the most efficient and popular form of energy and the modern society has been heavily dependent on the electric supply. This considerably affects the power quality delivered. Transmission systems should be flexible to respond to generation and load patterns. Solving the problem of increasing power demand is either by building more generating and transmission facilities which is not very economical or environmentally friendly or the use of Flexible Alternating Current Transmission System FACTS devices [4]. FACTS device ensure effective utilization of existing equipment. These devices are not capable to generate reactive power and by its operation only force the source to generate reactive power.

Flexible AC Transmission Systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin. Shunt FACTS devices play an important role in reactive power flow in the power network [1, 2]. In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances.

The life cannot be imagined without the supply of electricity. At the same time the quality and continuity of the electric power supplied is also very important for the efficient functioning of the end user equipment. Most of the commercial and industrial loads demand high quality uninterrupted power. Thus maintaining the qualitative power is of utmost important [3]. 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 affects 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 [4]. In order to enhance the behavior of the power system, these all problems should be eliminated. With the recent advancements in power electronic devices, there are many possibilities to reduce these problems in the power system. One of them is the use of Flexible AC Transmission System FACTS devices [5]. The connection of these devices in the power system helps in improving the power quality and reliability.

In this paper the mitigation of voltage sag using FACTS devices has been studied and analyzed with Voltage compensation in Distribution Networks for the power quality improvement in distribution system. Different cases have been considered with these loads to analyze the operation of voltage compensation to improve the power quality in distribution system.

2. DYNAMIC VOLTAGE RESTORER

It is a power electronics converter based device used to protect the distribution bus from voltage unbalances. It is connected in series to the distribution bus generally at the Point of Common Coupling (PCC). It injects a set of three-phase AC output voltages in series and synchronism with the distribution feeder voltages [6].

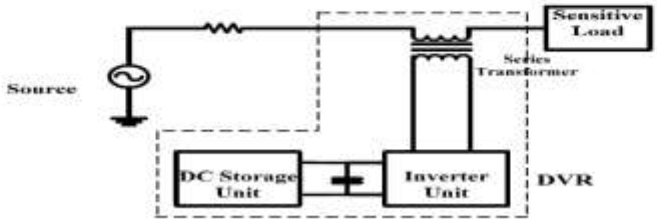

Fig. 2.1 Basic Structure of DVR

The dynamic voltage restorer (DVR) is one of the most efficient and economic devices to compensate voltage sags. The DVR is basically a voltage–source converter in series with the ac grid via an interfacing transformer, conceived to mitigate voltage sags and swells [7]. For low-voltage applications, DVRs based on two-level converters are normally used and, therefore, much of the published literature on DVRs deals with this kind of converter [8]. Nevertheless, for higher power applications, power-electronic devices are usually connected to the Medium-voltage (MV) grid the use of two-level voltage converters becomes difficult to justify owing to the high voltages that the switches must block.

- Voltage Source Inverter (VSI)
- DC storage unit
- Series Transformer

2.1.1Voltage Source Inverter (VSI): The VSI consists of solid state switches like IGBT's or GTO's used to convert the DC input to AC. It is used to inject the AC voltage to compensate the decrease in the supply voltage. The switches of the VSI are operated based on the pulse width modulation (PWM) technique to generate the voltage of required magnitude and frequency [11].

2.1.2 DC Storage Unit: The storage unit may consist of batteries, capacitors, flywheel, or super magnetic energy storage (SMES). For DVR with internal storage capacity, energy is taken from the faulted grid supply during the sag. This configuration is shown in Fig. 2.1; here a rectifier is used to convert the AC voltage from the grid to DC voltage required by the VSI.

2.1.3 Series Transformer: A series transformer is used to connect the DVR with the distribution feeder. In case of three phase system, three single phase transformers are used to connect the DVR with the power network.The main operation of the DVR is to inject voltage of required magnitude and frequency when desired by the power system network. During the normal operation, the DVR will be in stand-by mode. During the disturbances in the system, the nominal or rated voltage is compared with the voltage variation and the DVR injects the difference voltage that is required by the load.

2.1.4 D-STATCOM: A 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 Point of common coupling PCC.

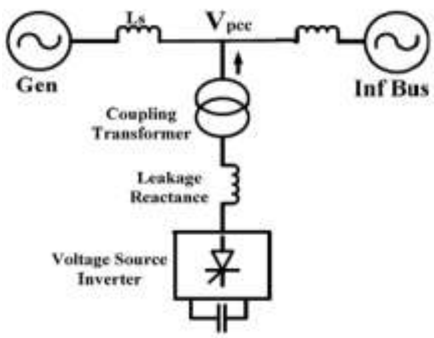

Fig.2.2 Schematic Diagram of D-STATCOM

In this model, D-STATCOM is capable of injecting active power in addition to reactive power. Since energy storage has a capacity limit, it is not capable to inject active power for a long term for voltage regulation purpose. Therefore, for the steady-state application, D-STATCOM consists of a small dc capacitor and a voltage source converter and the steady-state power exchange between D-STATCOM and the ac system is reactive power DC Capacitor [4]. This exchange is done much more rapidly than a synchronous condenser and improves the performance of the system.

3. RELATED WORK

The main aim of the control strategy implemented to control a DVR and D-STATCOM used for voltage mitigation is to control the amount of reactive power exchanged between the FACTS device and the supply bus. When the PCC voltage is less than the reference (rated) value then the DVR andD-STATCOM generates reactive power and when PCC voltage is more than the reference (rated) value then the FACTS device absorbs reactive power. To achieve the desired characteristics, the firing pulses to PWM VSI are controlled. The actual bus voltage is compared with the reference value and the error is passed through a PI controller. The controller generates a signal which is given as an input to the PWM generator. The generator finally generates triggering pulses such that the voltage imbalance is corrected. The block diagram of the control circuit is shown in Fig. 3.1.

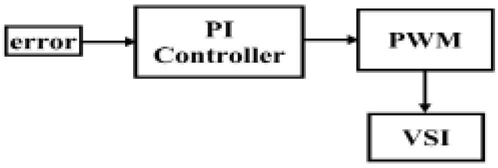

Fig.3.1 Block Diagram of the Control Circuit of DVR

4. PARAMETERS USED FOR DVR

The test system employed to take out the simulations regarding the DVR actuation. This system is composed by a 33Kv, 50 Hz generation system, represented by a Thevenin's equivalent, feeding two transmission lines feed two transmission lines through a three winding transformer connected in $Y/\Delta/\Delta$ 33/115/115 Kv. Such transmission lines feed two distribution networks through two transformers Δ/Y of 115/11 Kv.

Table-4.1 System parameters used for DVR and D-STATCOM simulation

SI NO.	QUANTITIES	PARAMETER
1	Source Voltage	33 kv
2	Series Transformer ratio	1:1
3	DC Voltage Source	1.5 kv
4	Line inductance	15.4×10^{-3}H
5	Line Resistor	0.605 Ohm
6	Inverter Parameters	IGBT based, 3 arms, 6 pulse, carrier frequency=1080, Sample time=50µs
7	PI Controller	Kp=0.5, Ki=50, Sample time=50µs
8	Line Frequency	50 Hz
9	Load Active Power	1 KW
10	Inductive Reactive Power	500 VAR

4.1 Single Line Diagram of the DVR and D-STATCOM Test System

In this test system we have a generating unit of 11kv, 50 Hz. The test system employed to carry out the simulations concerning the DVR actuation. The output from generating unit has been fed to the primary of the three winding transformer.Further two parallel feeders of 11 kv each are drawn.

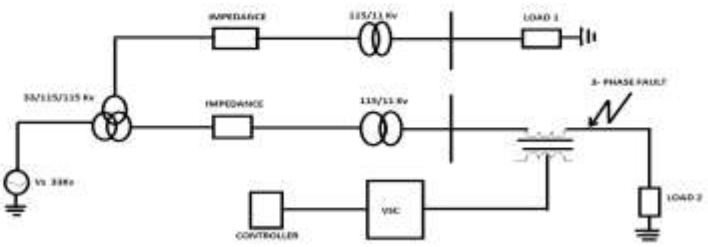

Fig.4.1 Block diagram of the DVR system

In one of the feeder DVRhas been connected in seriesand other feeder has been kept as it is. For this system two different loads have been considered one by one with different fault conditions. The two loads are sensitive load. PI controller has been used for the control section [9]. D-STATCOM is same as DVR only D-STATCOM has been connected in shunt and DVR has been connected in series.

4.2 Simulink Model of the DVRand D-STATCOM Test System

In this simulink model we have a system in which two parallel feeders are shown. In both the feeders further loads has been also connected in parallel. In one feeder FACTS devices has been connected in series and shunt with line and the other feeder has been kept as it is[10]. PI controller has been used for control purpose. Here FACTS devices system has been connected to the distribution system using an injected transformer.

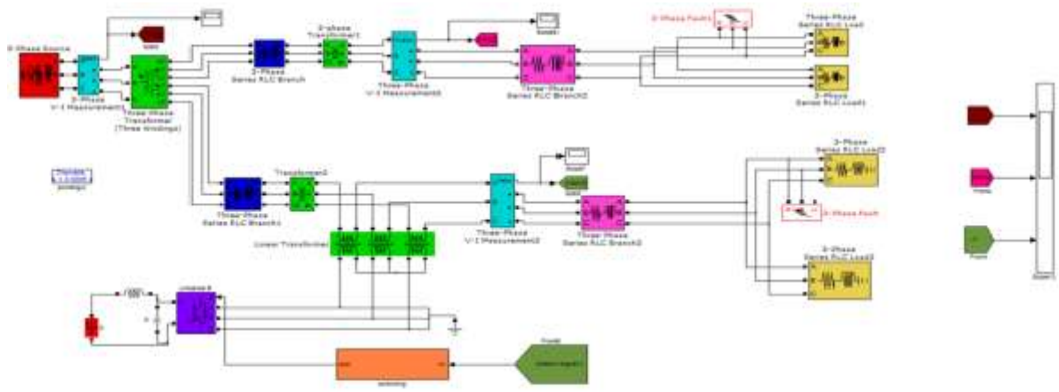

Fig.4.2 Simulink model of DVR

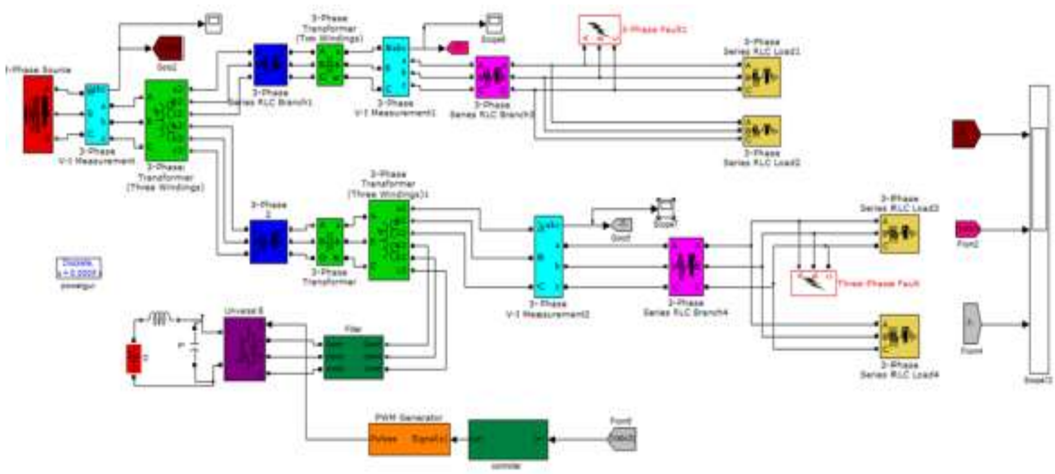

Fig.4.3 Simulink model of D-STATCOM

5. SIMULATION RESULTS

The output voltage for both the conditions with DVR and without DVR is difference. The first wave shapes in Figure 5.1 represent uncompensated load voltage with respect to time. The last wave shape is compensated load voltage where DVR is connected

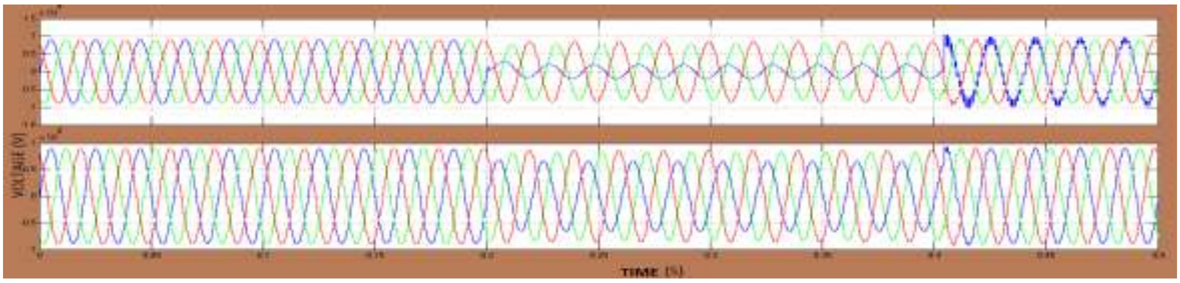

Fig.5.1Singe phase fault simulation Results Using DVR (a) Fault Voltage (b) Compensation Voltage

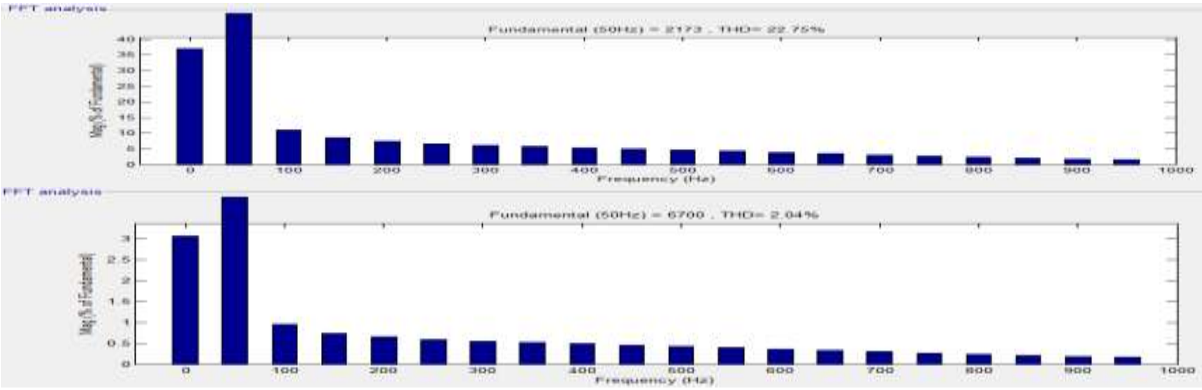

Fig.5.2 THD of single phase fault voltage and compensate voltage using DVR

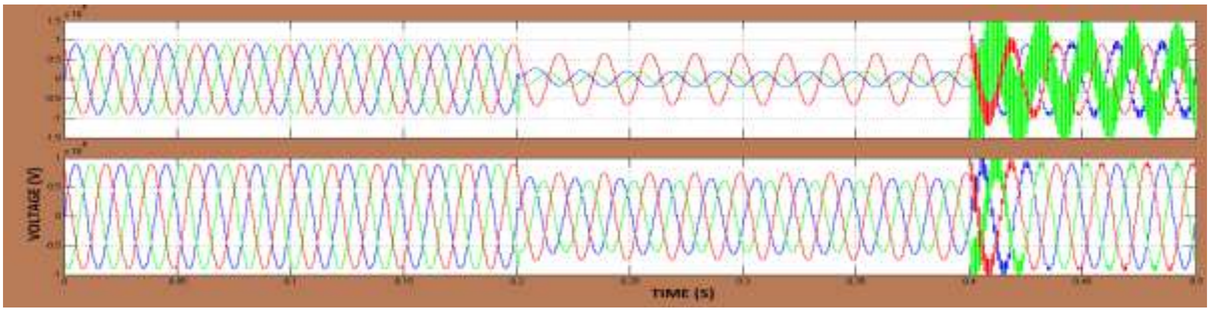

Fig.5.3Double phase fault simulation Results Using DVR (a) Fault Voltage (b) Compensation Voltage

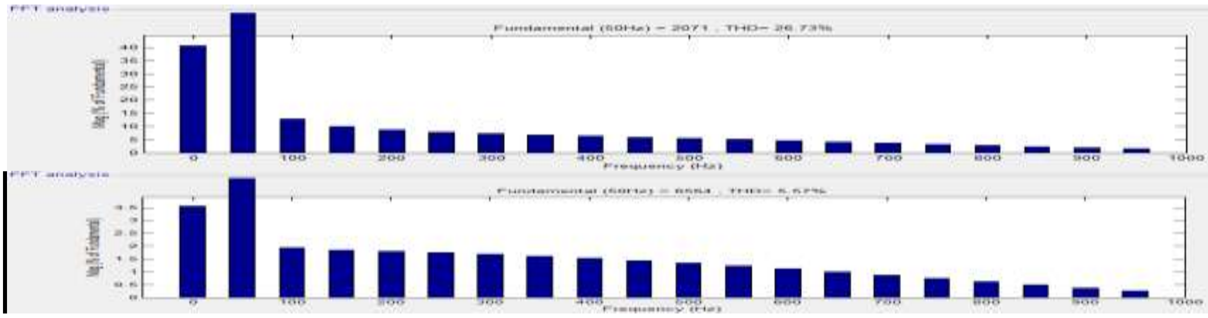

Fig.5.4 THD of Double phase fault voltage and compensate voltage using DVR

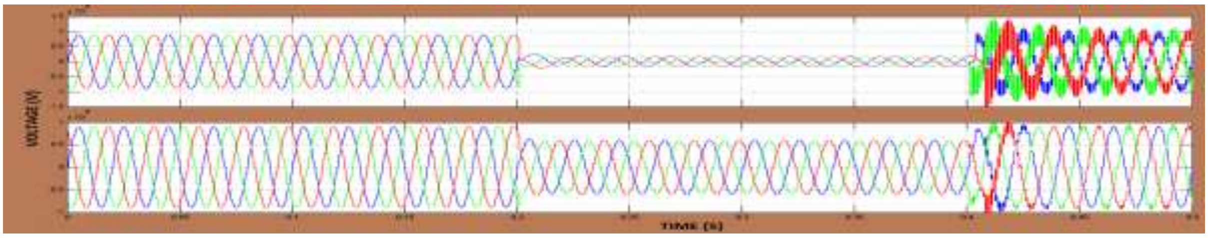

Fig.5.5Three Phase fault simulation Results Using DVR (a) Fault Voltage (b) Compensation Voltage

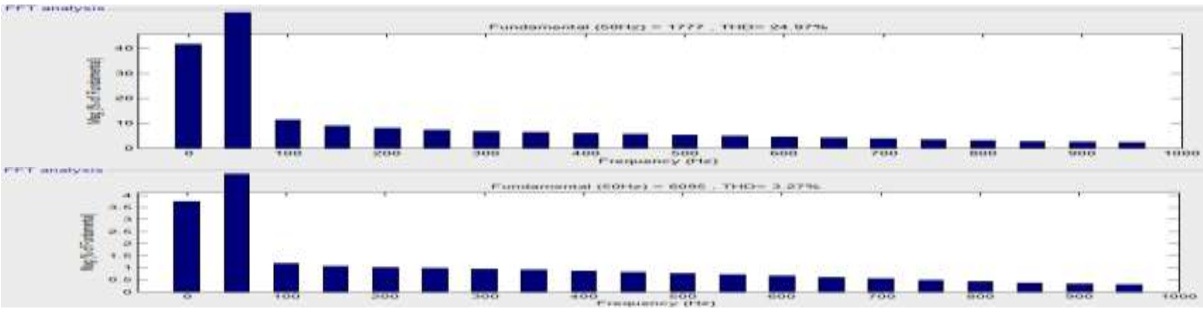

Fig.5.6THD of Three phase fault voltage and compensate voltage using DVR

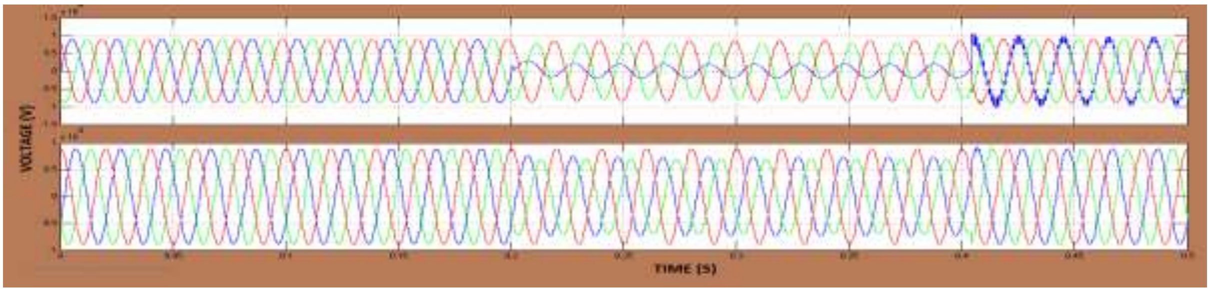

Fig.5.7Singe phase fault simulation Results Using D-STATCOM (a) Fault Voltage (b) Compensation Voltage

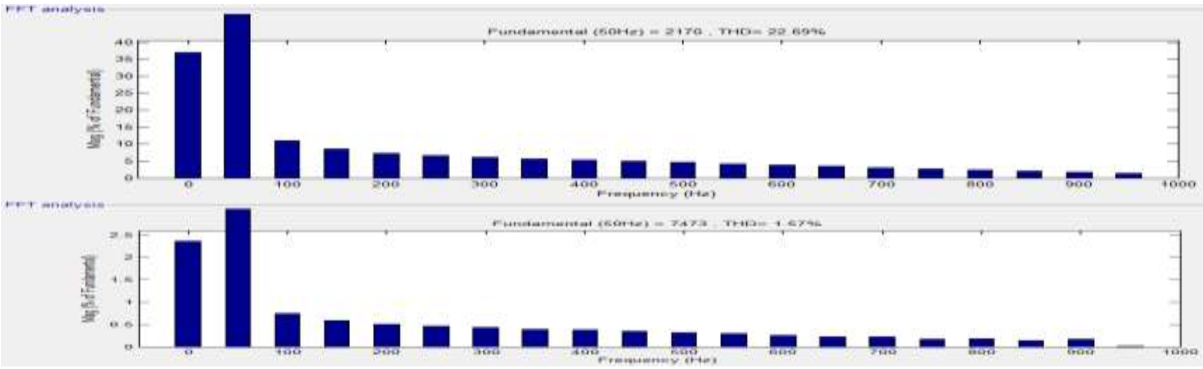

Fig.5.8 THD of single phase fault voltage and compensate voltage using D-STATCOM

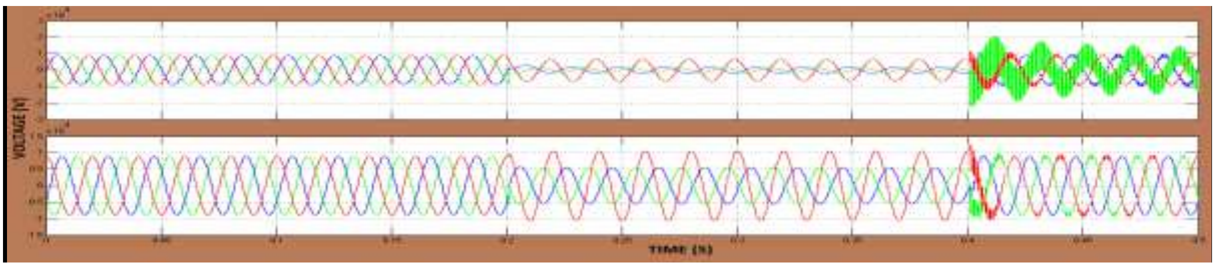

Fig.5.9Double phase fault simulation Results Using DVR (a) Fault Voltage (b) Compensation Voltage

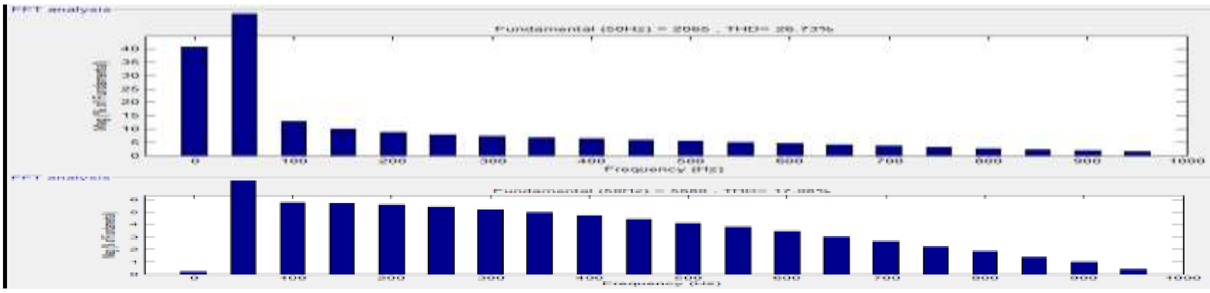

Fig.5.10 THD of single phase fault voltage and compensate voltage using D-STATCOM

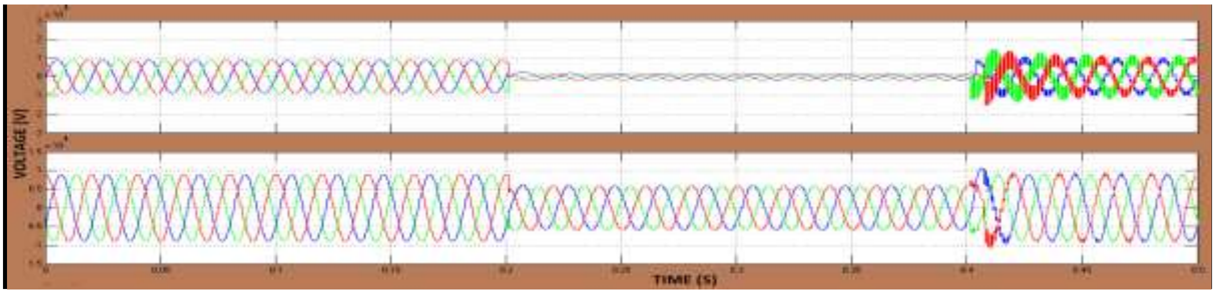

Fig.5.11 Three Phase fault simulation Results Using D-STATCOM (a) Fault Voltage (b) Compensation Voltage

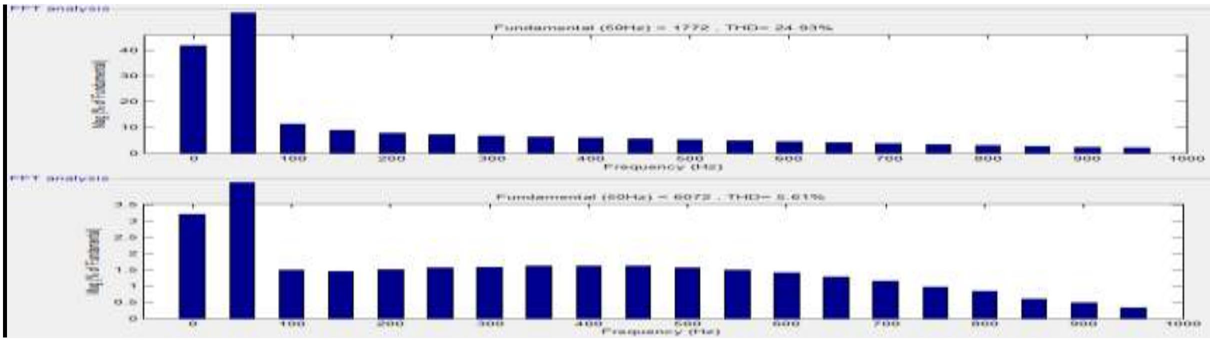

Fig.5.12 THD of single phase fault voltage and compensate voltage using D-STATCOM

5.1 Comparison Simulations and Analysis of the Results

A comparative study has been made between two above discussed devices for mitigating voltage sag. The comparative study has been based on the THD of the load voltage and is shown in Table-5.1. From this study it has been clear that the DVR is more efficient in mitigating the voltage sag. Among DVR and D-STATCOM, DVR is better in terms of Total Harmonic Distortion and voltage sag compensation.

Table:5.1 Simulations and Analysis of the Results

S. no	Custom devices	THD of Single Phase	THD of Double Phase	THD of Three Phase
1	Without Compensator	22.75%	26.73%	24.97%
2	DVR	2.04%	5.57%	3.27%
3	D-STATCOM	2.57%	17.08%	5.61%

CONCLUSIONS

In this paper two FACTS devices namely DVR and D-STATCOM have been proposed to compensate the voltage sag in distribution networks. Simulation has been done by using MATLAB SIMULINK. Various results have been obtained and analyzed causing due to three different types of faults. The controlling of DVR and D-STATCOM has been done with the help of PI controller. The results obtained have been compared. From obtained results, the following conclusions have been made:-

1. It has been observed that voltage level of any power distribution system without compensator become very low during fault condition. This problem can be solved by the use of different kinds of Flexible Alternating Current Transmission System (FACTS) devices.
2. In this paper DVR and D-STATCOM, FACTS devices have been used and their results have been compared. On analysis of results, it has been concluded that distribution power system with DVR compensator has better result in comparison to D-STATCOM.
3. In this paper Total Harmonics Distortion (THD) has been also analyzed with compensator and without compensator. It has been observed that THD level is also better in case of distribution power system with DVR compensator over with D-STATCOM.

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