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SIMULATION ANALYSIS OF DIFFERENT CONTROL TECHNIQUES FOR DVR AND DSTATCOM DEVICES FOR VOLTAGE PROFILE IMPROVEMENT

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Abstract: - Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at the smooth sinusoidal voltage at the ideal magnitude level and frequency but in practical power systems especially the distribution systems have numerous nonlinear loads which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems like voltage sag, voltage swell, distortion in waveform, harmonics, etc. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also under heavy load conditions, a significant voltage drop may occur in the system. The first one is a shunt device, which is commonly called DSTATCOM and the second one is a series device, which is commonly called DVR. These compensators can address other PQ issues, such as load voltage harmonics, source current harmonics, unbalancing, etc., under steady-state to obtain more benefits out of their continuous operation. There have been a variety of control strategies proposed for load voltage control using the aforementioned two devices. In this paper the role of DVR and D-STATCOM for voltage profile improvement validates using Matlab-Simulink.

Keywords: - DVR, D-STATCOM, Sag-Swell, PQ Isuues, THD, etc.

1. INTRODUCTION

Power quality phenomenon include all possible situations in which the waveform of the supply voltage (voltage quality) or load current (current quality) deviate from the sinusoidal waveform for all three phases of a three-phase structure at rated frequency with amplitude corresponding to the rated Root Mean Square (RMS) value. The adequate range of power quality disturbances covers sudden, short duration variations viz impulsive and oscillatory transients, voltage sags, short interruptions, as well as steady state deviations, such as harmonics and flicker. One can also differentiate, based on the cause, between disturbances associated to the quality of the supply voltage and those interrelated to the quality of the current taken by the load. In the latest time the most of the devices used in industries are mostly based on the Power Electronics devices and Controller types. But we know that it is sensitive to voltage disturbances and power quality (PQ) problems like voltage sag, swell, distortion etc. Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the ideal magnitude level and frequency but in practical power systems especially the distribution systems have numerous nonlinear loads which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems like voltage sag, voltage swell, distortion in waveform, harmonics, etc. Power quality phenomenon or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also under heavy load conditions, a significant voltage drop may occur in the system. Voltage sag and swell can cause sensitive equipment to fail, shutdown and create a large current unbalance.

USE OF POWER ELECTRONICS IN DISTRIBUTION SYSTEMS

At distribution level, power electronic controllers, also called custom power devices, have been established to pick up the quality of power distribution in industrial plants, in retort to growing demand from industries reporting production stops due to voltage disturbances, like short interruptions and voltage dips. These power quality phenomena are generally caused by clearing short-circuit faults in the power system and inspite of their very short duration, can impact the operation of low-power electronic devices, motor contactors and drive systems, where the sensitivity of electronic equipment to voltage disturbances can cause the stoppage of the whole facility. To solve this problem, different custom power devices have been proposed, many of which have at their heart a Voltage Source Converter (VSC) connected to the grid.

In PQ problems voltage sag, swell are major issues. So whenever we concern about the PQ in the industries as system are mostly considered the voltage sag, swell problems. In the power system for mitigation of voltage sag and swell Dynamic Voltage Restorer (DVR) has been used. After the use of DVR in the power system it will be work without any problem of voltage sag and swell. Voltage swell is not much important as voltage sag condition, because the voltage swell is very less in distribution system. Large inductive load switching or Energization of large capacitor bank creates the voltage swell problem in the system. The problem of voltage sag and swell is directly effects to the sensitive equipment of the system. Voltage sag and swell can cause sensitive equipment to fail, or shutdown, as well as create a large current unbalance that could blow fuses or trip breakers.

2. RESEARCH GAP & OBJECTIVES

The recent research indicates that 92% of all disturbances in the distribution system occur due to the voltage sag problem. For providing the protection against the voltage sag problem in the system DVR has been used in the system. The DVR has been connected between in series with the distribution line or with the sensitive loads for injecting the real and reactive power to mitigate the voltage sag problem in the system. The DVR output is always passing out from the L-C filter to remove the harmonics from the supply voltage. The filter has been designed according to parameters of system and depth of voltage to mitigate sag in the system.

The consideration of all these effects in system is very difficult for the customers. So the automatic calculation and analysis is provided for voltage sag & swell for PQ-assessment. The voltage dips problems are most common problem in the system. So the interest for research is focus on it. For calculation of time when the voltage dips signature has been measured from the comparison of waveforms of R.M.S phase voltage and phase to phase voltage. The DVR has the capability of absorbing and injecting the real & reactive power using control strategy of pulse width modulation (PWM) through the voltage source inverter (VSI). The voltage sag problem occurs in the power system due to the fault of single line to ground fault, line to line fault, etc. in the sensitive load or equipment of the system. The DVR device has the capacity to provide individual voltage to the system for restore and maintains the sensitive loads to its normal rated value.

The main objectives of the paper are to develop model for DVR and DSTATCOM for the enhancement of power quality in electrical power networks.

The following objectives have been laid down for this work:
1. Development of DVR with PI Controller and SRF based Hysteresis Controller simulation model and DVR performance analysis through simulation.
2. Development of DSTATCOM with PI Controller, SRF based Hysteresis Controller simulation model and DSTATCOM performance analysis through simulation.
3. Comparative analysis of both Device performance and THD analysis is carried out.

The effectiveness of the DVR and DSTATCOM, in solving the power quality problems has been proved through simulations, model development and analysis. Custom power devices transient performance observed. Control techniques developed to overcome the problems related to DC Link voltage deviations. Research has been carried out to achieve the above mentioned objectives of the paper.

3. POWER QUALITY

A Power Quality problem can be defined as deviation of magnitude and frequency from the ideal sinusoidal waveform. Good power quality is benefit to the operation of electrical equipment, but poor power quality will produce great harm to the power system. Most of the electronic equipment such as personal computers, telecommunication equipment, microprocessor and micro controller, etc. is responsible for power quality problems. Harmonics are defined as sinusoidal wave form having a frequency equal to an integer multiple of the power system fundamental frequency. It is a component of a periodic waveform. If the fundamental frequency multiple is not an integer, then we are dealing with inter harmonics .Most of the electronic equipment such as personal computers, telecommunication equipment, microprocessors, and microcontrollers etc.; are generally responsible to Power Quality problems. A poor power quality has become a more important issue for both power suppliers and customers. Poor power quality means there is a deviation in the power supply to cause equipment malfunction or may failure.

Voltage sags (dips) are short-duration reductions in rms voltage caused by short-duration increases of the current, typically at another location than where the voltage sag is measured. The most common causes of over currents leading to voltage sags are motor starting, transformer energizing and faults.

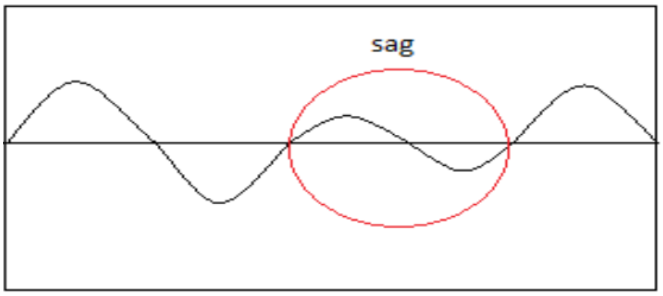

Fig.1 Voltage Sag or Dip

Voltage sags have been mainly associated with short circuit incidences. Fault occurrences elsewhere can generate voltage sags affecting consumers differently according to their location in the electrical system. Starting large motors can also generate voltage sags, although usually not so severe.

Swells

Swell is an RMS increase in the AC Voltage, at the power frequency, for duration from a half a cycle to a few seconds. Voltage can rise above normal level for several cycles to seconds. Voltage swells can originate internally in building wiring or externally on power lines. Voltage swells are the least frequent of the power line problems representing only about 2 to 3% of all power problems occurring to industry studies

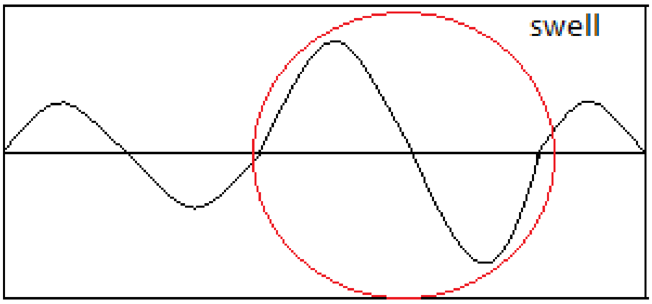

Fig. 2 Voltage Swell

Voltage swells will normally cause damage to lighting, motor and electronic loads and will also cause shutdown to equipment. With electronically controlled equipment, voltage above 6 to 10% above normal may result in damage.

Solutions to voltage swells for motor loads include motor phase protectors, electronically controlled devices that shutdown motors before damage occurs. For sensitive computer and electronic loads, solutions include Uninterruptible Power Supplies, Voltage Regulators, Power Conditioners, Energy Storage Devices and Static Switches.

4. DVR and D-STATCOM

BASIC CONFIGURATION OF DVR

The common configuration of the DVR consists of the following necessary units.
1 An Injection/ Booster transformer
2 A Harmonic filter
3 Storage Devices
4 A Voltage Source Converter
5 DC charging circuit
6 A Control and Protection system

Injection/ Booster Transformer
The Injection / Booster transformer is a particularly designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its major tasks are given below.

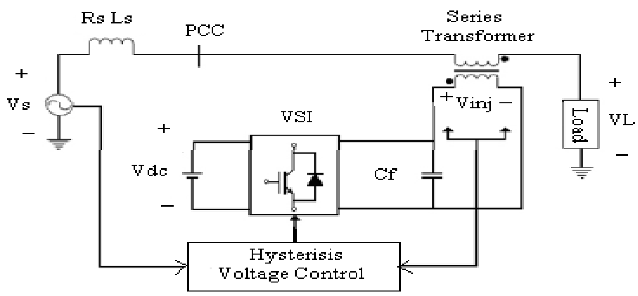

Fig. 3 Schematic Diagram of DVR

1. It connects the DVR to the distribution network using the HV-winding of the transformer and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.
2. In addition, the Injection / Booster transformer serves the function of isolating the load from the system (VSC and control mechanism).

Voltage Source Converter
A VSC is a power electronic system consists of a storage device and switching equipment, which can produce a sinusoidal voltage at any necessary frequency, magnitude and phase angle. In the DVR application, the VSC is used to momentarily replace the supply voltage or to produce the part of the supply voltage which is missing. The purpose of storage devices is to supply the necessary energy to the VSC using a DC Link for the generation of injected voltages. The different kinds of energy storage devices are superconductive magnetic energy storage (SMES), batteries and capacitance.

DC Charging Circuit
The dc charging circuit has two main tasks.
1 The first task is to charge the energy source after a sag compensation event.
2 The second task is to maintain DC Link voltage at the nominal DC Link voltage.

Equations related to DVR
The load impedance Zth depends on the fault level of the load bus. When the system voltage (Vth) drops, the DVR injects a series voltage VDVR through the injection transformer so that the desired load voltage magnitude VL can be maintained. The series injected voltage of the DVR can be written as

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \quad \text{............... (1)}$$

Where
VL: The desired load voltage magnitude
ZTH: The load impedance.
IL: The load current
VTH: The system voltage during fault condition

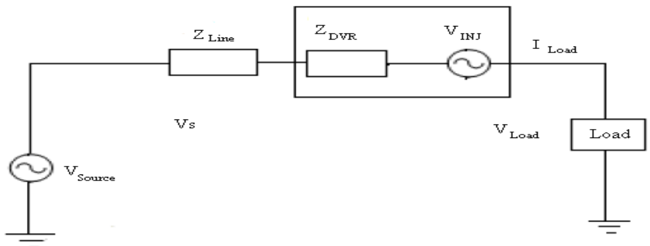

Fig. 4 Equivalent Circuit Diagram of DVR

The load current IL is given by,

$$I_L = \frac{[P_L + jQ_L]}{V_L} \quad \text{..................... (2)}$$

When VL is considered as a reference equation can be rewritten as,

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{TH}\angle(\beta - \theta) - V_{TH}\angle$$

………………… (3)

α, β, δ are angles of VDVR, ZTH ,VTH respectively and is Load power angle

The complex power injection of the DVR can be written as,

$$S_{DVR} = V_{DVR} I_L^*$$

………………… (4)

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

BASIC CONCEPTS OF DSTATCOM

A distribution static compensator is a voltage source converter based power electronic device. Usually, this device is supported by short term energy stored in a dc capacitor. The DSTATCOM filters load current such that it meets the specifications for utility connection. The DSTATCOM can fulfil the following points.

- The result of poor load power factor such that the current drawn from the supply has a near unity power factor.
- The result of harmonic contents in loads such that current drawn from the supply is sinusoidal.
- The result of unbalanced loads such that the current drawn from the supply is balanced.
- The dc offset in loads such that the current drawn from the supply has no offset.

One of the main features of DSTATCOM is the generation of the reference compensator currents. The compensator, when it tracks these reference currents, injects three-phase currents in the ac system to cancel out disturbances caused by the load. Therefore, the generation of reference currents from the measurements of local variables has fascinated wide attention. These methods carry an inherent assumption that the source is stiff (i.e., the voltage at the point of common coupling is tightly regulated and cannot be influenced by the currents injected by the shunt device). This however is not a valid assumption and the concert of the compensator will reduce considerably with high impedance ac supplies. The operation of VSI is supported by a dc storage capacitor with appropriate dc the transient response of the voltage across it. The transient response of the DSTATCOM is very significant while compensating AC and DC loads.

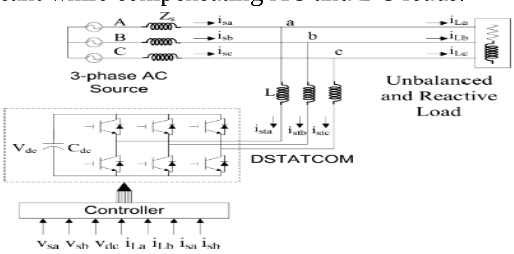

Fig. 5 Basic Circuit Diagram of the DSTATCOM System

A static synchronous compensator (STATCOM) is one of the most operative solutions to regulate the line voltage. The STATCOM consists of a voltage source converter connected in shunt with the power system and permits to control a leading or lagging reactive power by means of correcting its ac voltage. A STATCOM for installation on a distribution power system called DSTATCOM, has been researched to clear voltage fluctuations and voltage flickers. A shunt active filter intended for installation on a power distribution system, with emphasis on voltage regulation capability. Theoretical investigation as well as computer simulation provides the dynamic performance of harmonic damping and voltage regulation. As a result, harmonic damping has the capability to improve the stability of voltage regulation. Thus, modification of the feedback gains makes it possible to decrease voltage fluctuation in transient states, when the active filter has the function of combined harmonic damping and voltage regulation. The simulation results are shown to verify the effectiveness of the active filter capable of both harmonic damping and voltage regulation.

The system scheme of DSTATCOM is shown in Figure 5. These are briefly described as follows:

A. Isolation transformer: It connects the DSTATCOM to the distribution network and its main purpose is to maintain isolation between the DSTATCOM circuit and the distribution network.

B. Voltage source converter: A voltage source converter consists of a storage device and devices of switching, generating a sinusoidal voltage at any required frequency, magnitude and phase angle. In the DSTATCOM application, this temporarily replaces the supply voltage or generates the part of the supply voltage which is absent and injects the compensating current into the distribution network depending upon the amount of unbalance or distortion. In this work, an IGBT is used as the switching device.

C. DC charging unit: This unit charges the energy source after a compensation event and also maintains the dc link voltage at the nominal value.

D. Harmonic filters: The main function of harmonic filter is to filter out the unwanted harmonics generated by the VSC and hence, keep the harmonic level within the permissible limit.

E. Energy storage unit: Energy storage units like flywheels, batteries, superconducting magnetic energy Storage (SMES) and super capacitors store energy. It serves as the real power requirements of the system when D-STATCOM is used for compensation. In case, no energy source is connected to the DC bus, then the average power exchanged by the D-STATCOM is zero assuming the switches, reactors, and capacitors to be ideal. Figure 5 represents the schematic scheme of D-STATCOM in which the shunt injected current I_{Sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{Th} and value of I_{Sh} can be controlled by altering the output voltage of the converter.

5. MODELLING AND SIMULATION

Voltage Sag Mitigation Using DVR

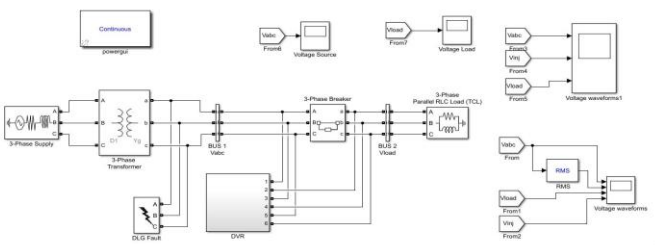

Fig 6-Voltage Sag Mitigation System Using DVR

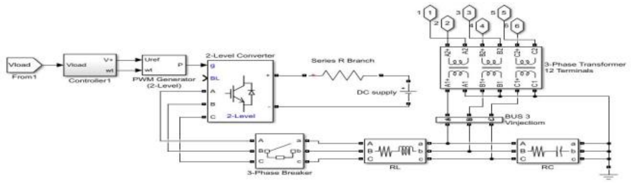

Fig 7- DVR Subsystem

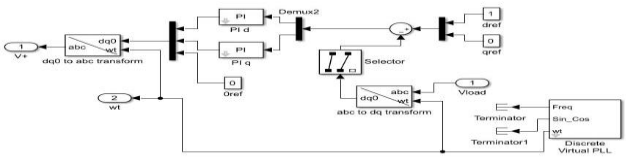

Fig 8- DVR Controlling Subsystem

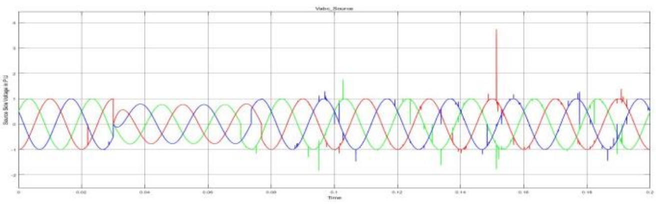

Fig 9- Source Side Voltage in P.U

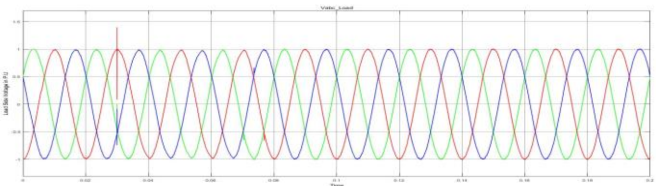

Fig 10- Load Side Voltage in P.U

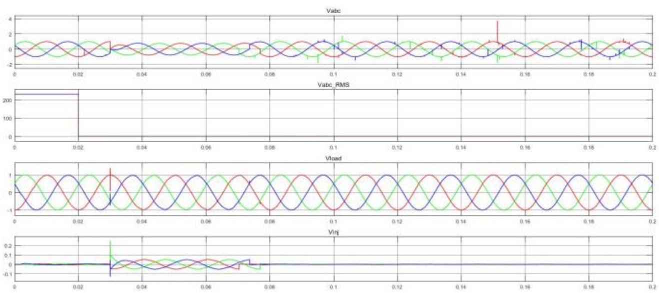

Fig 11- DVR All Parameters Results

Voltage Swell Mitigation Using DVR

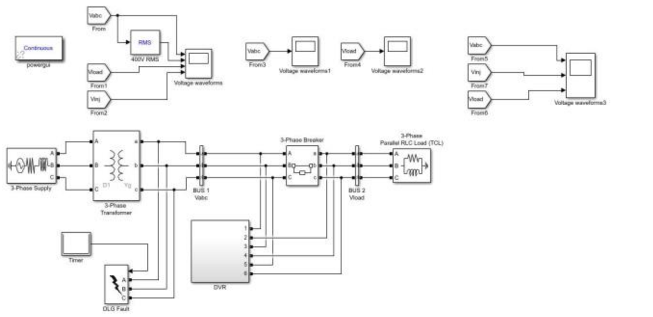

Fig 12-Voltage Swell Mitigation System Using DVR

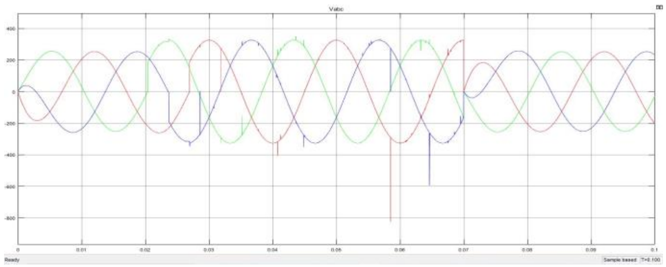

Fig 13- Source Side Voltage for swell condition

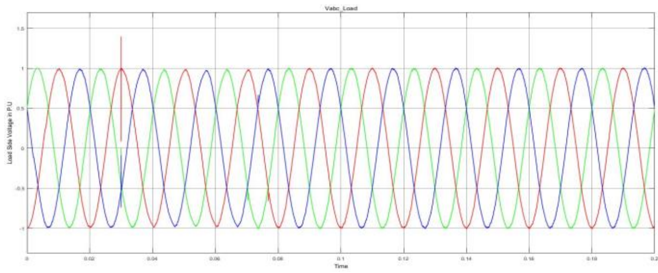

Fig 14- Load Side Voltage in P.U for swell mitigation

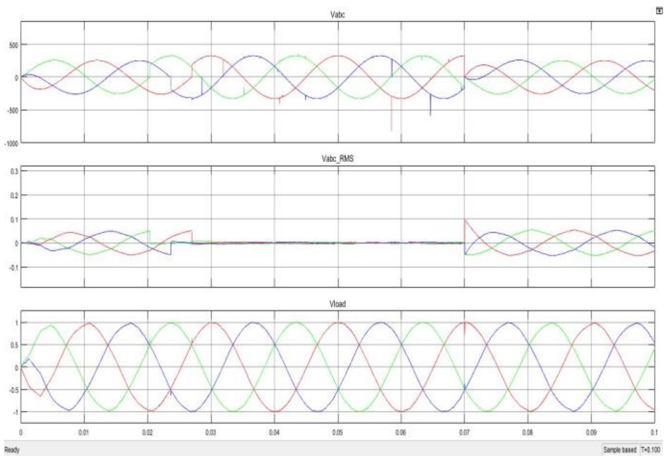

Fig 15- Voltage at Source Side, DVR Injecting and Load Side

Voltage Sag Mitigation Using DSTATCOM

The voltage sag mitigation using PI controller is easily done. The MATLAB- SIMULINK model of voltage sag mitigation using PI Control Strategy is shown in fig below:-

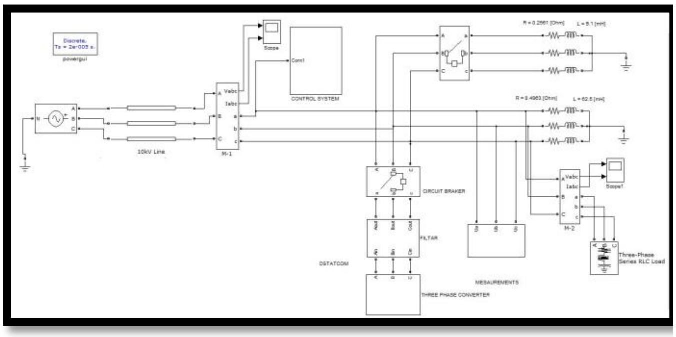

Fig 16 - Voltage Sag mitigation Using DSTATCOM

The PI controller based DSTATCOM is provided for comparison and relation development between the reference value and running condition value. The control block system is shown in fig 17 below.

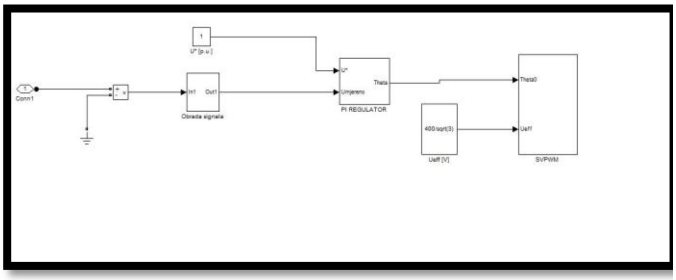

Fig 17- Controlling system for DSTATCOM

The control system includes PI Controller and SVPWM topology for PWM control in VSC Converter.

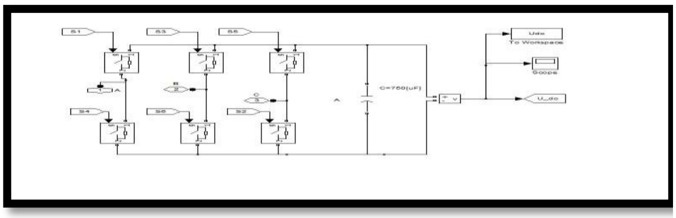

Fig 18 VSC Converter for DSTATCOM

After applying the PI control Strategy and VSC Converter of DSTATCOM, the voltage sag condition is mitigated as shown in fig below: -

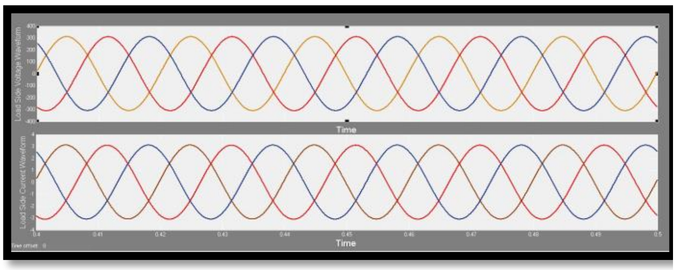

Fig 19- Voltage sag mitigated sinusoidal load side voltage waveform

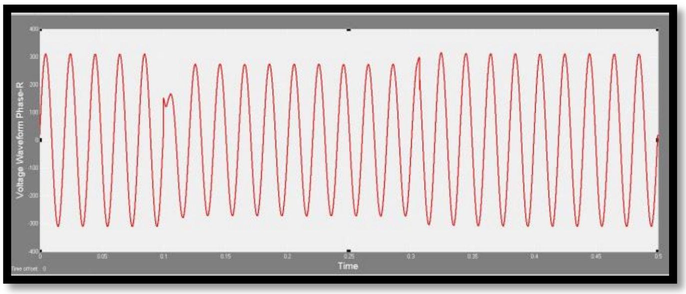

Fig 20- Voltage Sag mitigation in Phase-R waveform

Fig 21- R.M.S value of Load side mitigated voltage sag condition waveform in P.U value

Voltage Swell Mitigation Using DSTATCOM

The voltage sag mitigation using PI controller is easily done. The MATLAB- SIMULINK model of voltage Swell mitigation using PI Control Strategy is shown in fig below:-

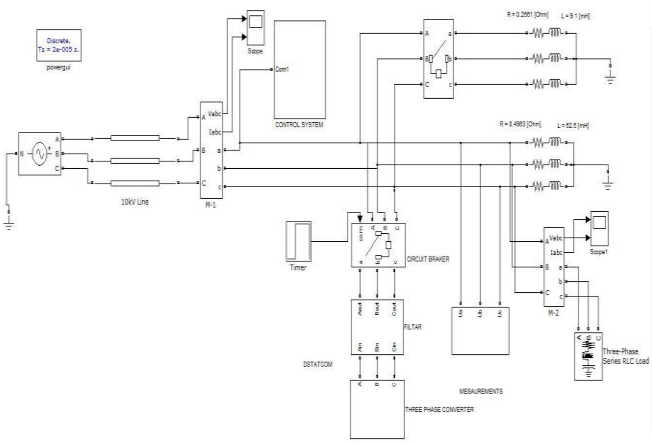

Fig 22- Voltage Sag mitigation Using DSTATCOM

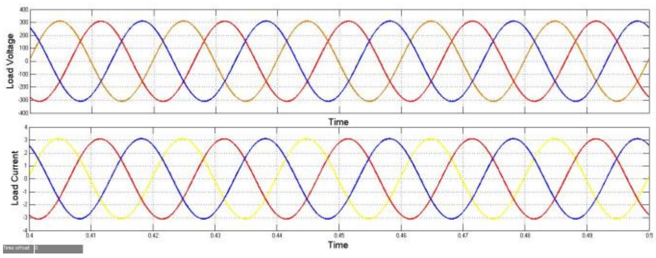

Fig 23- Voltage Swell mitigated sinusoidal load side voltage waveform

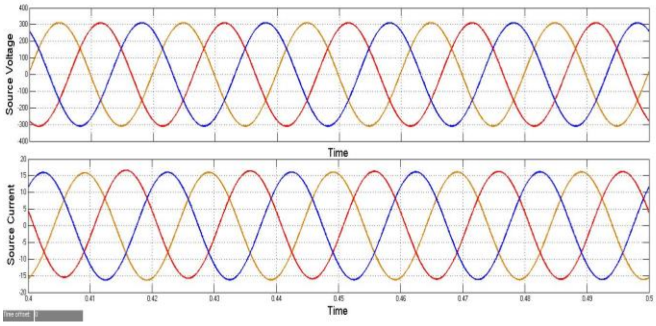

Fig 24- Voltage Swell mitigation in Source Side Parameters

THD Comparative Analysis

Parameters	Using DVR THD %	Using D-STATCOM THD %
Voltage Sag	10.32 %	7.90 %
Load Voltage (PI Controller)	11.40 %	4.99 %
Voltage Swell	17.77 %	4.83 %
Load Voltage (Hysteresis Controller)	10.30 %	3.35 %

6. CONCLUSION

This paper presents a modified control scheme to compensate a distribution feeder loading with non-linear loads. The D-STATCOM operation consists of three main objectives that are regulation of real powers delivering to loads, regulation of DC link voltage to ensure PWM converter operation Correction of Voltage Profile. Modification of the control scheme made in this paper is to add the reactive power regulation into the control loop. The proposed controlling mitigates the voltage sag condition using DSTATCOM as shown in the simulation results. As a result, the modified control scheme can regulate voltage deviation using D-STATCOM. The Matlab Simulation of DVR and D-STATCOM is successfully implemented for Voltage Sag Mitigation. The MATLAB Simulation of DVR and D-STATCOM for Swell problems mitigation. The performance comparison of DVR and D-STATCOM for Voltage Sag and Swell Problems is solved using PI controller and Hysteresis Controller. Both the controller give the effective performance for Voltage Profile improvement. The THD analysis of DVR and D-STATCOM for Voltage profile improvement shows that the D-STATCOM device gives better performance compare to conventional DVR device.

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