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SAG MITIGATION IN DISTRIBUTION SYSTEMS USING DVR

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ABSTRACT

This paper deals with dynamic voltage restorers in order to mitigate voltage sags in power distribution systems symmetrical fault and unsymmetrical fault conditions. Here the DVR is used to generate the controllable phase voltage. The load voltage vector of magnitude and angle are used to desire phase angle and magnitude of dynamic injected the voltage during sag event, to restore the load voltage to pre-sag conditions. A control technique based on a proportional–integral (PI) controller is used. This novel controller scheme simulated and, analyzed in MATLAB SIMULINK.

KEYWORDS *- DC Energy Storage, Dynamic Voltage Restorer, Voltage Sag.*

1. INTRODUCTION

Now-a-days electrical power system (AC electric power) is generated, transmitted and distributed in the form of alternating current. When the AC power is generated it possesses certain electrical properties that allow electrical system to function in their intended manner i.e. it can energize all electrical equipment equally and satisfactorily. But power travels long distances through wires. Due to various pieces of equipments or due to any abnormal conditions in the network, the quality of the power changes and thus it becomes less suitable for any further application. Voltage magnitude is one of the major factors that determine the quality of electrical power. Hence it is necessary to improve the quality of power before it is used to energize any load. Though the transmission system and the distribution system are similar for man's circulatory system, in present scenario power quality directly related to distribution system. The reason is that distribution system locates at the end of the power system and is directly connected to the customer. The distribution system can be defined as that part of power system which distributes electrical power to the consumer for utilization.

Voltage magnitude, waveform, and frequency are the major factors that dictate the quality of a power supply. Voltage disturbance is the common power quality problem in industrial distribution systems. The voltage disturbance mainly includes voltage sags, voltage swells, voltage harmonics, voltage flicker and voltage unbalance. Voltage sags are now one of the most important power quality problems in the distribution system. Power Quality problems include a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions. A voltage sag is a momentary decrease in the RMS AC voltage (10%-90% of the nominal voltage), at the power frequency, of duration from 0.5 cycles to a few seconds. Voltage sags are normally caused by short-circuit faults such as a single-line-to-ground fault, line to line fault, double line ground fault, in the power system or by the starting up of induction motors of large rating current flow through the induction machine and also damaged the machine life time. Voltage sags may cause the malfunction of voltage-sensitive loads in factories, buildings, and hospitals. Voltage swells are not as important as voltage sags because they are less common in distribution systems. Voltage sag and swell can cause sensitive equipment (such as found in semiconductor or chemical plants) to fail, or shutdown, as well as create a large current unbalance that could blow fuses or trip breakers. These effects can be very expensive for the customer, ranging from minor quality variations to production downtime and equipment damage.

There are many different methods to mitigate voltage sags and swells, but the use of a custom Power device is considered to be the most efficient method. Switching off a large inductive load or Energizing a large capacitor bank is a typical system event that causes swells. Earlier the prime focus for power system reliability was on generation and transmission system but now-a-days distribution system receives more attention. Because most of the electrical distribution network failures account for about 90% of the average customer interruptions and if any disturbance occur in the distribution system a huge amount of financial losses may happen with the consequent loss of productivity and competitiveness. Power distribution systems, should ideally provide their customers with an uninterrupted flow of energy with a smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially distribution systems, have numerous nonlinear loads, which significantly affect the quality of the power supply. As a result of these nonlinear loads, the purity of the supply waveform is lost in many places. This ends up producing many power quality problems. An important percentage of all power quality problems are of the voltage-quality type where what matters is the deviation of the voltage waveform from its ideal form. The best known disturbances of the voltage waveform are voltage sags and swells, harmonics, inter harmonics and voltage imbalances.

Power quality (PQ) is an issue which is gaining significant interest to both electric utilities and end-users. Lack of PQ causes huge economical losses all over the world which makes it more important. Voltage quality is the most important part of PQ from the viewpoint of sensitive load. Voltage disturbances mainly include voltage sags, voltage swells and voltage harmonics. Different power-electronic based techniques can be used to mitigate PQ problems. They can be divided into two groups, series and shunt compensators. Series compensators are usually used for voltage quality improvement where shunt compensators are well suited for current quality improvement. There are various series compensators in distribution voltage levels which are similar to each other from the viewpoint of hardware circuit configuration. Series active filters are used to compensate voltage harmonics. DVRs and also static series compensators are mainly used for voltage sags and swells compensation. DVR is considered as a suitable and economical device to compensate the voltage disturbances such as voltage sags and swells. In a DVR, it is possible to take the required compensation power from an energy storage element (battery, super-capacitor, etc.) or from the incoming supply by a rectifier. The energy storage based Topologies have the advantage of helping the faulted supply by injecting stored energy in the energy storage. But the energy storage elements have so high cost that limited the application of DVRs.

Moreover, the energy storage elements have limited capacity so that the DVR might fail to operate suitably under long term voltage sags. In the DVRs that employ ac/dc/ac conversion, it is required to use a large capacitor in the dc link to smooth the dc link voltage. Hereafter these topologies are called conventional DVRs. A considerable amount of technical works has been done on the conventional DVRs concerning both hardware circuit topology, control strategy and voltage disturbances detection methods. The topologies of DVRs vary from both viewpoints of how to connect to the system and the used inverter topology in the DVR structure. The DVRs can operate in both low voltage and medium voltage distribution systems. Application of multilevel inverters in the conventional DVRs has been presented as a solution to handle high voltage and high power by the DVRs. Beside the voltage sag and swell compensation, the DVR has been successfully used for voltage harmonic compensation and downstream fault current limitation . Unlike the conventional DVRs, a little attention has been paid to the application of direct ac/ac converters in the DVR topologies. However some works can be found in which the direct ac/ac converter operates as a series voltage compensator. In, a series active power filter has been presented for voltage sag compensation. This topology needs a UPS system in addition to an ac chopper. In, a voltage regulator which uses direct ac/ac conversion and can compensate voltage sags has been presented. The used control method is based on the RMS method leading to delay in detection and compensation of voltage sags. In three phases topology has been presented in which an ac/ac converter is used and consequently does not require dc-link. This topology applies four bidirectional switches and is able to compensate voltage sags and swells with 25% and 50% magnitudes, respectively. A three phase direct converter based DVR has been presented in which improves the sag/swell compensable range. A sag corrector topology has been presented in which is able to compensate both balanced and unbalanced voltage sags without using energy storage. However, this topology cannot compensate voltage swells and harmonics.

2. VOLTAGE SAGS

The different types of faults increase the severity of balanced and unbalanced voltage sags. If the phase voltages during the sag have unequal magnitudes or phase relationship other than 120, the sag is considered to be unbalanced. The voltage sags experienced by three- phase loads can be classified into seven types denoted as A, B, C, D, E, F and G. Type A is balanced sag and the other types are unsymmetrical sags. Figure 1. Shows the phasor diagrams of voltage sag types

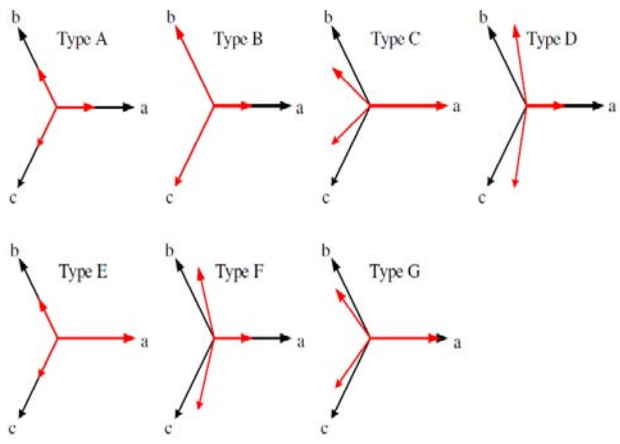

Figure 1: Voltage sag types

Type A sag generally occurs on the end user devices. It is rarely occurred in the distribution systems. The power requirement is the same for each of the three phase devices.

Type B and D are the sags of single-line faults and they are the most common types in the distribution systems, it has an occurrence percent of 70% among all sags. In Type B sag, the system is solidly rounded so the non-faulted phases are kept healthy. In Type D sag, the system is grounded through the impedance. The non faulted phases experience voltage change because the zero sequence differs from positive and negative impedance of the system. Type C and E are the sags of double-line faults. These voltage sags have an occurrence of percentage of 20% among all types of sags that happen in distribution systems. Type C and E sags have common properties except for the angle between the sagged phases. Type F and G are the sags of double-line ground faults. The worst case scenario for this type of sag is that the system is grounded through impedance. In that condition, the zero sequence voltage drops is increased drastically, so it is expected to have voltage change in non-faulted phases. The voltage changes in non-faulted phases occur because the zero sequence voltage drop increases effectively.

3. ANALYSIS OF DYNAMIC VOLTAGE RESTORER

The power circuit topology of the proposed DVR consists of a centre-tapped transformer, dc/ac converter, a low-pass filter, an injection transformer and a bypass switch. The transformers used in the proposed topology are considered linear devices without saturation effect as it is usually considered in the literature. However, when the saturation occurs, the waveform of voltage becomes distorted and the compensation will not be completed. The direct ac–ac converter used in the proposed topology consists of two bidirectional switches. Several structures are available for bidirectional switches. In this paper, the common emitter structure is used. To generate both in-phase and 180 degrees phase shifted voltage from the grid voltage, a centre-tapped transformer with the turn's ratio of 1:n1 is used which makes it possible to access two voltage levels. It is clear that these switches cannot be turned on simultaneously. By continuous high frequency switching between the two available voltage levels, it is possible to generate the output voltage between primary sides to secondary side. Clearly the resulting secondary side contains high order harmonics which should be filtered before being injected to the grid. To filter out the high order harmonics from *v*o(t) an LC filter issued. The resistance Rf indicates the resistance of the filter inductance (Lf) and it can be used to damp the transients of the filter in passive damping schemes. The filtered voltage is injected to the grid through an injection transformer.

The injection transformer has the turns ratio of 1:n2. As mentioned, two transformers are used in the proposed topology, the centre-tapped and the injection transformer. The transformers can have different turns ratios. For example, the centre-tapped transformer can be a step-down transformer and the injection transformer can be a step-up transformer. In this case, the switches can operate in lower voltage level while the grid voltage is higher. Therefore, the proposed topology can operate in higher voltage distribution systems with lower voltage rating switches which can be IGBTs instead of thyristor and GTOs. The thyristor and GTOs (as high voltage switches) have some problems regarding the commutation process. The thyristor need auxiliary commutation circuits. The commutation circuits are composed of passive elements capacitances, inductances, resistances. Beside the cost of the commutation circuits, they may introduce some problems like power losses, electromagnetic noises, delay in commutation, disturbances, etc. Both thyristors and GTOs have considerable delay in the commutation process. This results in distorted output waveform so that they are not suitable for applications like DVRs where high quality of output voltage is needed. Application of two transformers in the proposed topology makes it possible to use IGBTs even if the voltage level is higher and therefore, it eliminates the problems regarding the commutation circuits such as additional costs, losses, electromagnetic noises, turn on/off delay time and distortions in the output waveform. The compensation capability and the voltage ratings of the switches are dependent on the turn's ratios of the transformers.

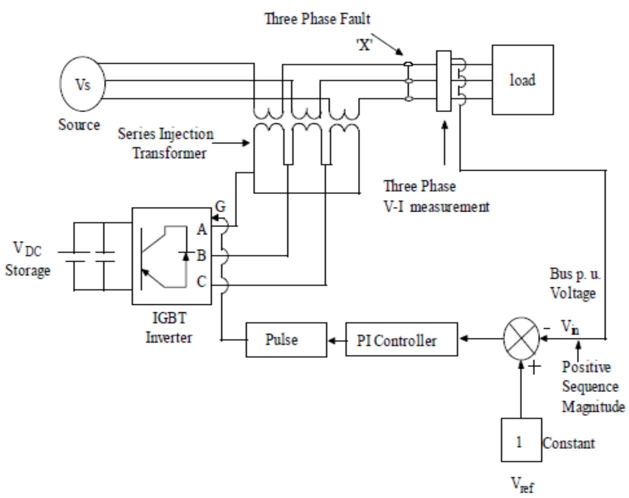

Figure 2: Circuit Model of DVR Test System

4. SPECIFICATION AND OPERATION OF DVR

Among the power quality problems like sag, swell, harmonic, transients etc, voltage sag i.e. sudden voltage dip is the most severe disturbance in the power system, generally caused by faults. It last for duration ranging from 3 cycles to 30 cycles. Starting of large induction motors can also result in voltage sag as it draws a large amount of current during starting. In order to mitigate this problem DVR is one of the efficient and effective custom power devices. DVR injects voltage into the system in order to compensate the voltage dip in the load side and maintains the load voltage at nominal magnitude. DVR is a solid state power electronic switching device which is connected in series to the power system. It comprises of the following components: Energy storage device, Voltage source Inverter Injection transformer, Control unit, harmonic filter.

Energy storage unit is responsible for the energy storage in DC form. Flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices. It will supply the real-power requirements of the system when DVR is used for compensation.

The Injection / Booster transformer has two purposes. It connects the DVR to the distribution network via the HV-winding and transforms and couples the injected compensating voltages generated by the voltage source converter (VSC) in series with the incoming supply voltage. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

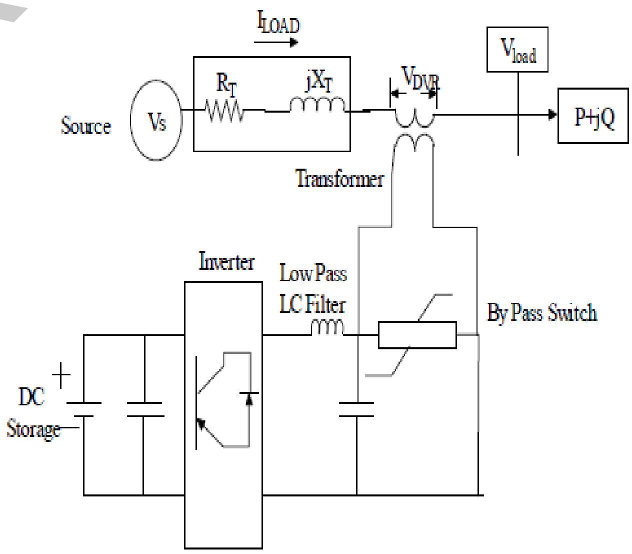

Figure 3: Basic Structure of Dynamic Voltage Restorer.

Voltage Source Converter is a power electronic system consisting of switching devices like: Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Gate Turn-Off-Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT), which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle [23].The output voltage does not need to be of a single frequency. Voltage source converters are widely used in Variable-speed drives (VSD), but can also be used to mitigate voltage dips. The VSC is used to either completely replace the supply voltage or to inject the „missing voltage". The „missing voltage" is the difference between the nominal voltage and the actual one. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics. The main task of the harmonic filter is to keep the harmonic voltage content generated by the voltage source converters (VSC) below the permissible level. (i.e. eliminate high-frequency switching harmonics)

Voltage sag is created at load terminals by a three-phase fault as shown in Fig.3. Load voltage is sensed and passed through a sequence analyzer. The magnitude is compared with reference voltage (*Vref*). Pulse width modulated (PWM) control technique is applied for inverter switching so as to produce a three phase 50 Hz sinusoidal voltage at the load terminals. Chopping frequency is in the range of a few KHz. The IGBT inverter is controlled with PI controller in order to maintain 1 p.u. voltage at the load terminals i.e. considered as base voltage =1p.u. A proportional-integral (PI) controller (shown in Fig. 2) drives the plant to be controlled with a weighted sum of the error (difference between the actual sensed output and desired set-point) and the integral of that value. An advantage of a proportional plus integral controller is that its integral term causes the steady-state error to be zero for a step input. PI controller input is an actuating signal which is the difference between the *Vref* and *Vin.* Output of the controller block is of the form of an angle δ, which introduces additional phase-lag/lead in the three-phase voltages.

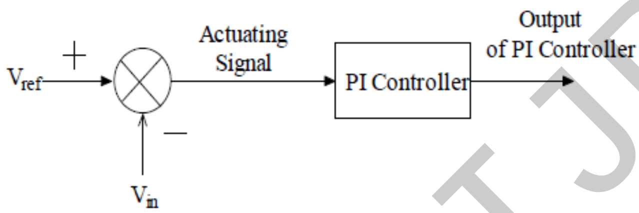

Figure 4: Schematic of a typical PI Controller.

The controller output when compared at PWM signal generator results in the desired firing sequence. MATLAB Simulation diagram of the test system is shown in Fig.1. System comprises of 13 kV, 50 Hz generator, feeding transmission lines through a 3-winding transformer connected in Y/Δ, 11KV/ 0.42 kV.

5. ANALYSIS OF SIMULATION RESULTS

Detailed simulations are analysed on the DVR test system using MATLAB SIMULINK. System performance is analysed for compensating voltage sag with different DC Storage capacity so as to achieve rated voltage at a given load. Various cases of different load condition are considered to study the impact DC storage on sag compensation. These various cases are discussed below:

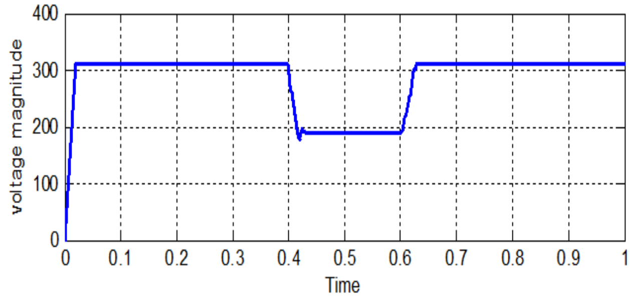

Figure 5: Voltage at the Load Point without DVR System

Case I: A three-phase fault is created resistance of 4Ω which results in a voltage sag of 38.85%.Transition time for the fault is considered from 0.4 sec to 0.6 sec as shown in Fig. 5.

The simulation results without DVR compensation technique are shown in Fig. 6 on normal basis. Here line voltage sag with 39% of supply voltage and line current increased to compensate the load requirement shown in fig.6

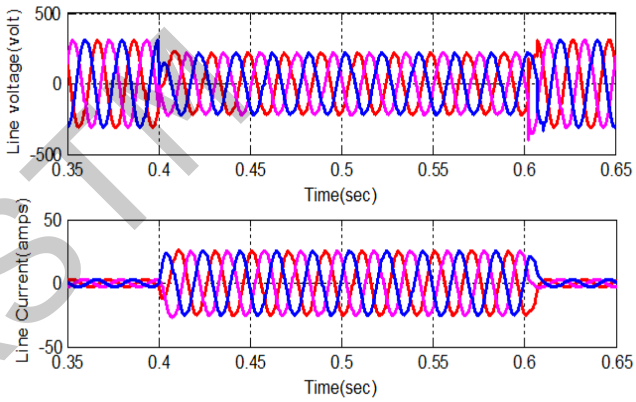

Figure 6: Waveform of load voltage with three phase fault

Case 2: The effectiveness of the DVR under unbalanced conditions is shown in figure 6, in figure 6 also shows the occurrence of 38% three phase voltage sag on a utility grid. Through simulation the supply voltage with three phase voltage dropped down to 62% as shown in Figure 6.

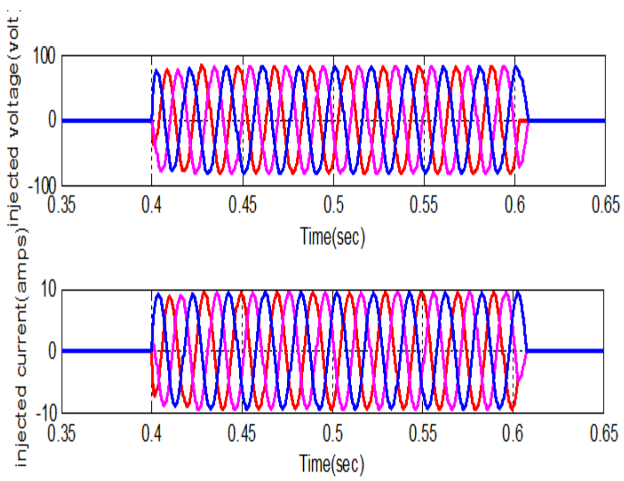

Figure 7: Waveform of injected voltage and current with three phase fault

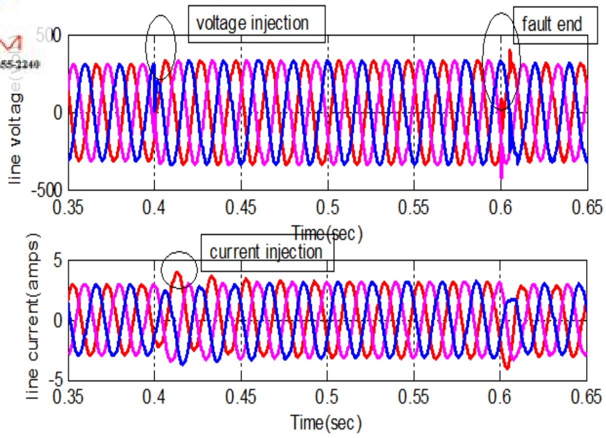

Figure 8: Waveform of load voltage and current with DVR

The simulation is done with the same parameters but connecting the DVR at the load side. Fig.8 shows the waveform of the load voltage with DVR. Thus it is seen that voltage dip occurring in the three phases are compensated to a great extent. Fig. 8 Waveform of load voltage with line to line fault and with DVR It is observed from the above figures that due to fault the load voltage reduce to a very low value. If we compare the waveforms of load voltage with and without DVR, we observed that when the DVR is in operation the voltage dip is compensated almost completely and the RMS voltage at the sensitive point is maintained at normal condition. The DVR is designed to supply the sag voltage until the fault is removed from the network.

6. CONCLUSION

Investigations were carried out for various cases of load at 420V feeder. The effectiveness of a DVR system mainly depends upon the rating of DC storage rating and the loads. In the test system it is observed that after a particular amount of load increases on 420V feeders, the voltage levels at the load terminal decreases. Here harmonic filters are designed to convert the inverted PWM waveform into a sinusoidal waveform. This is achieved by eliminating the unwanted harmonic components generated VSI action. Higher orders harmonic components distort the compensated output voltage. Filter inductance L_f=2mH, capacitance C_f=250µF

The pre-sag method tracks the supply voltage continuously and if it detects any disturbance in that voltage it will inject the difference voltage between the sag or voltage at the PCC and the ideal pre-fault condition. In this way, the load

Voltage can be restored back to the pre-fault conditions. Here 40% Compensation of voltage sags in both phase-angle and an amplitude sensitive load has to be achieved by pre-sag compensation method. In this method, the active power injected by the DVR cannot be controlled and it is determined by external conditions such as the type of faults and the load conditions.

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