Mitigation of Voltage Sag/Swell using Custom Power Devices with SMES System in Transmission Network

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Abstract— Any power problem noticed in voltage, current or frequency deviations that results in misoperation of customer or end user equipment. The new method of dynamic voltage restorer with SMES is proposed to protect consumers load from tripping. The DVR can effectively inject the voltage to the power lines. To improve the performance of DVR the superconducting magnet is selected as the energy storage unit. The compensation of the voltage sag, swell by short period of voltage injection. SMES based DVR has been used to improve the performance of power system. It is having high power rating with maximum efficiency than any other energy storage devices. It restores line voltage to its nominal value within few milliseconds. Most of the power quality problems are voltage sag, swell, interruption, transient, fluctuation, etc. Among those power quality problem voltage sag is severe one. So it is analyzing and mitigated using custom power device and SMES system using MATLAB SIMULINK in proposed system.

Keywords- Power quality, SMES, Dynamic Voltage Restorer (DVR), Voltage Source Converter (VSC), Voltage sag, PI controller.

I. INTRODUCTION

The term “power quality” refers to measure, analyses, and improvement of the bus voltage, usually a load bus voltage to maintain that voltage to be a ideal sine wave of rated voltage and frequency. Power quality is simply the interaction of electrical power with electrical equipment. The power quality is generally used to express the quality of the voltage. “Power quality deals with improvement of bus voltage in transmission and distribution side usually the load bus voltage to maintain that voltage to be sinusoidal at the rated voltage and its magnitude”. Most of the power quality problems are occurs due to non linear loads, like power electronics equipment, static UPS system, electronic ballasts for fluorescent lighting, switched mode power supplied in computer, medical test equipment, rectifier and filter so on.

The term “Power Quality” is associated with electrical distribution and utilization systems. The deviation of the electrical parameters like voltage, current, frequency etc… Non linear loads cause harmonic currents to change from a sinusoidal to nonsinusoidal waveform.

The most famous issues in power quality are voltage sag, swell, interruption transient, voltage imbalance and fluctuation [1]. Among this power quality problems the voltage sag in the electrical grid is not completely avoidable. So as to eliminate that severe problem for improvement of power quality. However, in practice power system especially the distribution system, have numerous non linear loads, which are significantly affect the quality of power supply.

IEEE 519-1992 and IEEE 1159-1995 describe the voltage sag/swell i.e., “IEEE recommended practice for monitoring electric power quality” as shown in Table (1).
In generally power quality consist of two approaches. (i) The first approach is on utility side and (ii) another approach is on customer side. The “line conditioning system” is considered in utility side for suppress the power system disturbance. The “load conditioning system” which ensure that the equipment is less sensitive to power disturbance.

So, providing the protection against the power quality problem using custom power device. Many kind of custom power devices are available, such as dynamic voltage restorer(DVR), battery energy storage system(BESS), superconducting magnetic energy storage devices(SMES), so on [1][2]. among the power quality problem voltage sag is severe problem in electrical grid which can be caused by fault on the line.

II. SYSTEM DESCRIPTION

2.1. Basic function of DVR

The injection transformer is connected series between the supply side and load side voltages. The series Voltage Source Inverter (VSI) can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. The energy storage consists of a capacitor which gives dc input to the inverter. The inverter is responsible for converting DC to AC.

The DVR is used to inject voltage only the missing part ie. sag or swell voltages. The injection (booster) transformer, a harmonic filter, a Voltage Source Inverter (VSI), DC charging circuit, control system and protection system are the major components of DVR. The basic block diagram represent in fig 1.

2.1.1. Injection transformer and filter.

The three phase injection transformer (Tr) is connected between three phase supplies to sensitive load. The voltage injected by the DVR through series injection transformer into the line. Filter components L and C are present in this transformer, it is used filter the ripples in the injected voltage on line. In most sag correction techniques, the DVR is required to inject active power into the distribution line during the period of compensation. It also ensures that only the swell or sag voltage
is injected to the injection transformer. During voltage sag, the DVR injects a voltage to restore the load supply voltages.

The DVR containing harmonics filter which helps to convert pulse width modulation to sinusoidal waveform. This filter can be placed either low voltage side or high voltage side of the voltage injection transformer. When the passive filter placed on the high voltage side, the secondary side transformer get higher order harmonics.

2.1.2. Voltage source inverter

Most of the power electronics equipment using voltage from 100 to 120V or any voltage from 210 to 240V. The voltage converter need for convert any voltage in one form to another form. Voltage source converter can be used in vehicle with 12V DC outlets. If more than required for high power device use switch mode power supply (SMPS).

VSC mainly used for power transmission for independent control of real and reactive power. In the voltage source converter, voltage supported combined with some energy storage system.

2.1.2.1. VSC control and protection

The VSC contains two major control and protection schemes, one is station control and another one is monitoring system (SCM).

From the station control, two control functions are adopted such as (i) human machine interface and data storage (ii) control and protection. In human machine interface through online, local and remote operation work station. Online access to operation status, control protection system and to diagnosing the event list, alarm list, fault list, disturbance recording of the control and protection system. The other control and protection methods are functioning under computers, using microcontroller, DSP and also by recording multiple transient fault.

2.2. Compensation techniques of DVR

DVR power rating, different types of voltage sag/swell, various conditions of load, those limiting factors depends to dynamic voltage restorer compensation techniques. Compensation achieved by injecting real and reactive power into the line. For compensating the voltage sag, swell the following techniques is (a) In-phase voltage injection. (b) Pre-sag compensation technique. (c) Energy compensation techniques. The given phase diagram representing the various compensation method,

2.2.1. Pre-sag condition

In the re-sag compensation technique is recommended for the non linear load which needs to compensate the voltage magnitude, phase angle. Fig (a) describes the pre-sag compensation method he DVR supplies the difference between pre-sag voltage and sag voltage, it restore the voltage magnitude and its frequency. The supply voltage is continuously tracked and the load voltage is compensated to the pre-sag condition. The supply voltage directly proportional to load voltage when sag is absence, i.e. $V_s = V_2 = V_3$. The DVR injects a voltage $V_{\text{inj}}$ to compensate the supply voltage into the line.
2.2.2. In-phase compensation

The voltage injected by the DVR is always in phase with the supply voltage regardless of the load current and the pre-sag voltage. These control strategies results are only compensate the voltage magnitude.

In figure (b) represents the phase shift between the voltage before sag and after the sag and in fig (c) represents the energy optimization method, \( \text{Vinj} \) denotes the injected voltage in quadrature with the current, when \( \text{Vinj} \) is in quadrature with the load current, DVR supplies only reactive power. When the magnitude of \( \text{Vinj} \) is not constrained the minimum value of \( \text{Vinj} \) that still allows full compensation is

\[
\text{Vinj}_{\text{min}} = \frac{\text{Vo}}{\cos \varnothing}
\]

where Vo is the required magnitude of the load bus voltage, Vs is minimum value of supply voltage.

III. PROPOSED MODULES

In the new proposed topology deals with Superconducting Magnetic Energy Storage System (SMES) as an active energy storage device, attractive energy storage device, very high number of charging/discharging cycle. In this system increasing the level of voltage injection through superconducting coil.

The DVR can effectively inject the voltage to the power lines. To improve the performance of DVR the superconducting magnet is selected as the energy storage unit.

The PI controller has been implemented for controlling the function of VSC. The compensation of the voltage sag, swell by short period of voltage injection. SMES based DVR has been used to improve the performance of power system. It is having high power rating with maximum efficiency than any other energy storage devices. So it is analyzing and mitigated using custom power device and SMES system using MATLAB SIMULINK in proposed system.

3.1. Developing topology for SMES.

SMES systems are a developing technology which utilizes the properties of superconducting material to store energy in magnetic fields. SMES systems have very fast charge and discharge times which make them an attractive energy storage system for sag mitigation. Another advantage of SMES systems is the very low losses due to the superconducting characteristics. It consists of superconducting magnetic energy storage unit, capacitor bank, VSI, low pass filter and voltage induction transformer.

3.1.1. Characteristics of SMES.

The main characteristics of SMES are, providing high energy power density, infinite number of charge and discharge cycle, very high productivity in energy conversion; it is superior to 95%.
SMES systems are a developing technology which utilizes the properties of superconducting material to store energy in magnetic fields. Another advantage of SMES systems is the very low losses due to the superconducting characteristics. In order to compensate the voltage sag/swell, SMES based DVR has been used to improve the performance of power system.

The control system of a DVR plays an important role, with the requirements of fast response in the face of voltage sags and variations in the connected load. The block diagram of proposed module is shown in figure 2,

![Block diagram of proposed module.](image)

In the paper established the new storage device SMES, the function of the block diagram represented. The DVR with SMES as a superconducting magnetic energy storage device fed between supply side and load side. This storage device gets energy from the supply side. The coil must be superconducting otherwise the energy is dissipated in the form of heat by “joule effect” in a few milliseconds.

When the voltage interruption occurs due to internal or external fault suddenly SMES storage device discharging the voltage to the electrical grid. During the voltage sag/swell - By supplying the real power from the energy storage device together with the reactive power, the DVR injects the voltage under various methods.

The MATLAB based model of DVR with SMES is shown below, in this simulation model completely analyzed and mitigated using custom power device and SMES system using MATLAB SIMULINK in proposed system was shown in fig (3).,
IV. CONTROL TECHNIQUES

Generally, two control schemes are used in DVR applications, namely, open-loop controller and closed-loop controller.

The proposed methodology implement the **PI controller** is used for response of the VSC. The schematic diagram of DVR with SMES is shown in fig. (4). shown below,

Figure 3 The schematic diagram of DVR with SMES.
The schematic diagram of DVR with SMES is shown. In a PI controller is used in a DVR system to voltage sags, harmonic voltages, and voltage imbalances. It has a wide range of applicability, a fast transient response and ensures zero error in steady state.

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error.

In order to maintain the dc bus voltage of the self-supported capacitor, a PI controller is used at the dc bus voltage of the DVR.

4.1. PI controller

The proportional integral (PI) algorithm computes and transmitting the control output (Co) signal every sample time (t). The PI control algorithm is influenced by the controller tuning parameters and control error e(t). PI controllers contain two tuning parameters to adjust. Many tuning method are available some of them are, manual tuning, Ziegler Nicholas tuning, PID tuning so on. The tuning parameter Kp and Ki of PI controller values depending on the operating condition of the system.

4.1.1. PI algorithm

The combination of proportional and integral terms is important to increase the speed of the response and it also to have no steady state error. The proportional integral (PI) controller block diagram as shown in figure 4.

The proportional and integral terms is given by,

\[ u(t) = K_P e(t) + K_I \int e(t) dt \]

Where Kp and Ki are the tuning parameter, are adjusted to obtain the desired output.

![Figure. 4 control functional block of PI controller](image)

The integral mode of the controller function is to integrate sum the controller error e(t), over time. The reset time tuning parameter provides a separate weight to the integral term so the influence of integral action can be independently adjusted, increase the influence of integral term and also it has units of time so it is always positive. The proportional term of the PI controller Kc.e(t), adds or subtracts from controller bias based on the size of controller error e(t). The transfer function of PI controller denoted as Gc(s) = K( 1+1/TiS). In the proposed methodology the PI output is delta, the gain block helps to multiple the input by a constant value. The power electronic device as IGBT is used, it controlled with PI regulator in order to maintain a p.u. voltage value.
V. SIMULATION VERIFICATION

In order to explore the performance of the system is analyzed for compensating voltage sag with SMES with custom power device, and also shown the simulation result for absence of SMES. The most common fault are, (i) phase to phase fault, (ii) line to line fault, (iii) line to ground fault, due to this faults the system become unbalanced, all the condition of I and V in all three phases are no longer symmetrical, such fault are solved by symmetrical component analysis. The simulation result of absence of SMES device with its magnitude as shown in figure 5.

![Figure 5 instantaneous voltage sag for 3ϕ fault without storage device](image)

The mitigation of voltage sag/swell using custom power device has been demonstrated in this proposed methodology. The three phase voltage source generate as 13KV with frequency of 50Hz, the amplitude (Vrms ph-ph) the output voltage is defined as, \( Vo = \frac{\sqrt{2}}{\sqrt{3}} V_{\text{line – rms}} \), the Vline – rms is rms phase to phase voltage.

Therefore, \( V_a = V_o \cdot \sin (2\pi ft + \phi) \); \( V_b = V_o \cdot \sin (2\pi ft + \phi - 120^\circ) \); \( V_c = V_o \cdot \sin (2\pi ft + \phi + 120^\circ) \); where \( V_a, V_b, V_c \) are phase voltage. Then 13kv step up into 135kv through three phase transformer by using three single phase transformer. Thus, 135kv supply given to grid 1 and grid 2 through star-delta connection of transformer to three phase RLC branch. The R, L, C are uniformly distributed in transmission line, we have to calculate positive (+ve) sequence and zero sequences in per unit for inductance H/km, resistance in \( \Omega /\text{km} \), capacitance in F/km with line length. Here manually created three phase fault is applied to grid line 2, it can create voltage sag. under this fault condition, the inductor deliver the voltage to DVR ,then it injects the voltage into grid line 2, performance of SMES has been simulated and its results represents the compensation of voltage as shown in figure 6.
VI. CONCLUSION

The new method of dynamic voltage restorer with SMES is proposed to protect consumers load from tripping. The DVR can effectively inject the voltage to the power lines. A design of superconducting magnetic energy storage module as a dc voltage source to mitigate voltage sags and enhance power quality of a distribution system based on DVR has been presented. Among the power quality problem voltage sag is severe one. So it is analyzed and mitigated using custom power device and also analyses the principle of SMES system. It can be analyzed and compensation achieved by attractive storage device used as SMES is established. The results of simulation tests are performed to evaluate the system performance has been demonstrated. This proposed system design analyses the performance of SMES using MATLAB SIMULINK.

REFERENCES


