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Mitigation of fault current in DVR with SMES

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***Abstract*—Now a days power grid has been experiencing several disturbances in electric power generation, transmission, and distribution. Changing electric load and higher power transfer in a wide interconnected network leads to serious, security lack in power system operation. As energy storage appears to be beneficial to utilities since it can co-ordinate the instantaneous balance between demand and supply. Today, there is a demand for short term energy storage devices like flywheel energy storage, photovoltaic modules, battery energy storage and super capacitors. Since they are having less power and energy rating, they cannot be used for high power applications. So in order to minimize this problem, SMES has been used to improve power system performance as well as power quality as it has having high power rating with maximum efficiency. Super conducting magnetic energy storage (SMES) based dynamic voltage restorer (DVR) is introduced to protect consumers from the grid voltage fluctuations. In normal DVR based compensation, downstream fault current was not considered or the DVR was bypassed during that fault. But here along with voltage sag compensation, downstream fault current mitigation was also considered. Using MATLAB, the SMES based DVR is modelled, and the simulation tests are carried out to evaluate the system performance.**

Keywords—Downstream fault; DVR; SMES; Power Quality; Voltage Fluctuations

I. INTRODUCTION

As far as the equipments in world wide are taken into consideration, they are mostly electronic devices. They can be classified as programmable and non-programmble. But actually the problem arising is that whether it is programmable or non programmable they are very much sensitive to change in voltage or we can call it as fluctuations. Change in voltage can either be voltage sag or swell. From the previous studies it can be concluded that Voltage sags will be one of the most severe disturbance to the industrial devices. Compensation of these voltage can be done in different ways such as using shunt reactors, capacitors and by using different FACTS controllers. Voltage compensation at a load can be achieved by proper reactive power injection at the load point of common coupling. Shunt capacitors can be used in the primary side of the distribution transformer for the compensation of reactive power and thereby for voltage compensation. Using SCADA the mechanical switching can be done. There arises some drawbacks that is, high speed transients cannot be compensated. Some sags are not corrected within the limited time .Transformer taps can be used, but its costly when using on load. Another solution existing to the voltage regulation is the use of a dynamic voltage restorer (DVR). The Dynamic Voltage Restorer (DVR) is a custom power device utilized to counteract voltage sags. It injects controlled three-phase ac voltages in series with the supply voltage, subsequent to voltage sag, to enhance voltage quality by adjusting the voltage magnitude, wave shape , and phase angle.DVR operates in such a way that it injects a voltage corresponds to the fault level. The DVR are mainly used for sensitive loads that may be seriously affected by fluctuations in system voltage.

Voltage sags are becoming the most important power quality concern to electric utility customers with sensitive loads. Voltage magnitude between 0.1 to 0.9 Pu are said to be sags. As per the requirement, most of the utilities are interconnected. In such a way as the interconnection becomes complicated there induces severe fault and these dip in voltages are called voltage sags. The dynamic voltage restorer (DVR) is a series connected power electronics device which can compensate for both voltage sag and swell. Its primary function is to rapidly boost up the load side voltage in the case of a disturbance in order to avoid any power disruption to that load [7]. By using appropriate controllers it can also be used for downstream fault current mitigation. DVR is commonly meant for compensating fault that occurred in between the source and the DVR. In normal DVR based compensation, downstream fault current was not considered or the DVR was bypassed during that fault.Downstream fault current means the fault occurring in between DVR and load side. Here a controller is proposed for downstream fault current mitigation. So here a complete compensation of a transmission line is proposed. Different energy storage devices can be used along with DVR in order to increase its compensation capability. Here a superconducting magnetic energy storage device is used. A Superconducting Magnetic Energy Storage device consists power electronic converters that rapidly injects and/or absorbs real and/or reactive power and thereby controls power flow in an distribuition / transmission system. [2][5][7]

II. MODELLING OF THE DVR

Power quality concern is increasing now a days. Major power quality problems are voltage sag, voltage swells, harmonics, flickering etc. Voltage sag is the major problem that evolves among the consumers. Custom power devices are introduced from the earlier days as an effective solution for this. DVR is the main custom power device for this voltage sag mitigation. Other than voltage sags and swells compensation, DVR can also compensate for line voltage harmonics ,reduction of transients in voltage and fault current limitations.

A. Basic Configuration of DVR

The main components of the DVR consists of:

- Energy storage unit
- Filter unit
- Inverter circuit
- Series injection transformer

Energy storage unit

Whenever a fault occur, DVR needs to supply a voltage inorder to compensate for that voltage. So that it needs an energy storage device to supply that amount. We can either use stored energy or we can use energy directly from supply.

Inverter circuit

The incoming supply from an energy source is dc. So inorder to transmit it to the transmission line, there is a requirement of a inverter. Here it uses a voltage source converter to convert that dc voltage to ac.

Filter unit

Mostly all of the semiconductor devices consists of non linear characteristics. Non linear characteristics causes distorted waveforms that contain harmonics. So inorder to avoid that disturbance at the end here it uses a filter unit so that the output is purely sinusoidal. Filter unit is an urgent requirement of a dynamic voltage restorer.

Series injection transformer

Whenever a fault occur, DVR needs to supply a voltage inorder to compensate for that voltage. That voltage must be injected through a series injection transformer. Series injection transformer means transformer windings are connected in series.

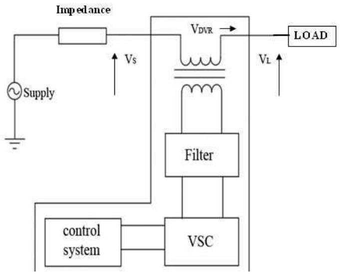

Fig. 1 Components of DVR

B. Mathematical model of DVR

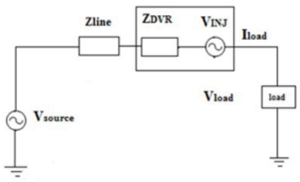

Fig. 2 Equivalent Circuit of DVR

Fig 2 shows the equivalent circuit of DVR. The series injected voltage of the DVR can be written as

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

$$V_{DVR} < 0 = V_L < 0 + Z_{TH} < (\beta - \theta) - V_{TH} < \delta \quad (2)$$

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

$$S_{DVR} = V_{DVR} I_L \quad (3)$$

$$\theta = tan^{-1}(\frac{\theta_L}{P_L}) \quad (4)$$

The load current I_L is given by,

$$I_L = \frac{[P_L + j\,Q_L]}{V} \quad (5)$$

III Superconducting Magnetic Energy Storage(SMES)

SuperconductingMagneticEnergyStorage(SMES) system store energy in the magnetic field created by the flow of direct current in a superconducting coil. An SMES system consists of three parts: a superconducting coil, power conditioning system and a cryogenically cooled refrigerator.

Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. This is the main property of SMES.

Discharging of coil allow SMES to releases the stored charge. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient and is greater than 95%.Due to the high cost of superconducting wire, SMES is currently used for short duration energy storage. Therefore, SMES is most commonly meant to improve power quality.

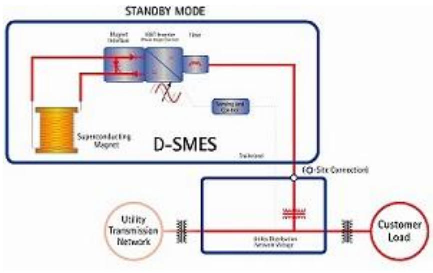

Fig. 3 Schematic diagram of SMES

The magnetic energy stored by a coil of an SMES is given by

$$E = \frac{1}{2} L I^2 \qquad (6)$$

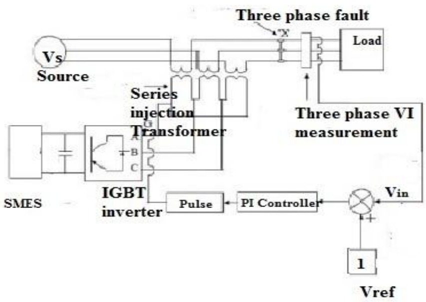

Fig. 4 Schematic diagram of SMES based DVR

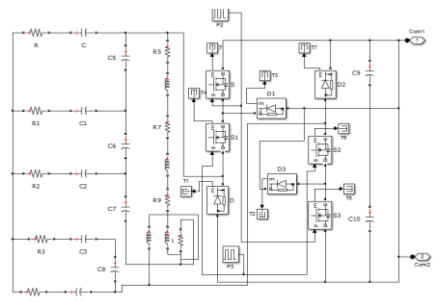

Fig.5 Equivalent circuit of SMES

IV.PROPOSED CONTROL CIRCUIT

In normal DVR based compensation, downstream fault current was not considered or the DVR was bypassed during that fault. But here along with voltage sag compensation downstream fault current mitigation was also considered. The control scheme for the mitigation of downstream fault current is given below.

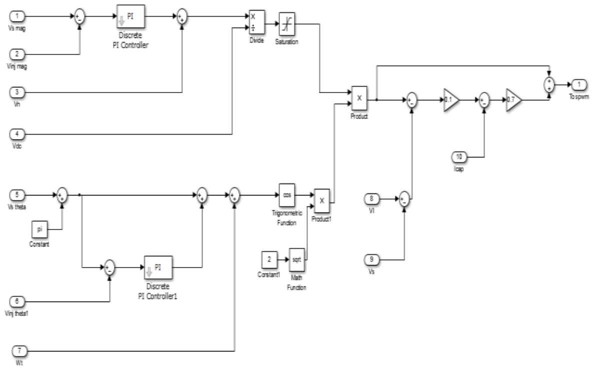

Fig. 6 Control block diagram of mitigation of fault current

The DVR is conventionally bypassed during a downstream fault to prevent potential adverse impacts on the fault and to protect the DVR components against the fault current. A technically elaborate approach to more efficient utilization of the DVR is to equip it with additional controls and enable it also to limit or interrupt the downstream fault currents. A control approach to enable a DVR to serve as a fault current limiter is proposed earlier .The main drawback of this approach is that the dc-link voltage of the DVR increases due to real power absorption during fault current-limiting operation and necessitates a switch to bypass the DVR when the protective relays, depending on the fault conditions, do not rapidly clear the fault.

V. SIMULINK MODEL AND RESULTS

Using MATLAB, the model of DVR is established, and the simulation tests are conducted. A fault is given for a period of 0.4-0.8s. At 0.5s the circuit breaker gets opened and closes on 0.9s. Without using DVR, from the fig. it is clear that, when a fault is applied voltage gets reduced. With DVR when the circuit breaker gets opened, DVR is automatically connected and injects appropriate voltage in proportion to the reduction in voltage and hence get compensated.

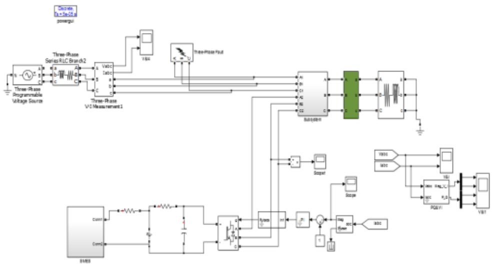

Fig. 7 SMES based DVR

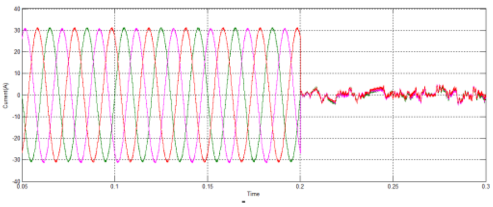

Fig.8 Downstream fault mitigation

The proposed DVR is a multifunctional DVR that is it can mitigate for both voltage sag and downstream fault current .Thus, the mutual effects of these modes on each other must be evaluated. At 15 ms, the system is subjected to a phase-A to phase-B fault with the resistance of 0.8 ohm at 90% of the line length from source side. The fault causes 87% voltage sag at the PCC. At 55 ms, another fault with the resistance of 0.3 on phase-A at 10% length of the cable at load side.

The upstream fault is cleared by relays at 93 ms. The system is subjected to a three-phase short circuit with a negligible fault resistance at 0.2 ms . Prior to the fault inception, the DVR is inactive (in standby mode) (i.e., the primary windings of the series transformers are shorted by the DVR).

During the fault if the DVR is bypassed, the voltage at VI Measurement 1 drops to 0.77 p.u. and the fault current increases to about 17 times the rated load current . Fig. 8 shows the performance of the proposed DVR control system during the fault. Fig. 8 illustrates that the proposed FCI method limits the maximum fault current to about 2.5 times the nominal value of the load current and interrupts the fault currents in less than 1 cycles.

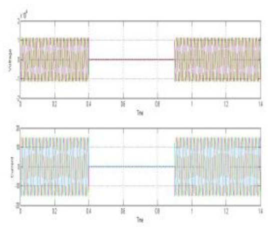

Fig. 9 Simulation results without DVR

In fig.9 we can observe that ,a three phase short circuit fault is occurred at 0.4 sec. But without any compensating device,the fault remains uncompensated.

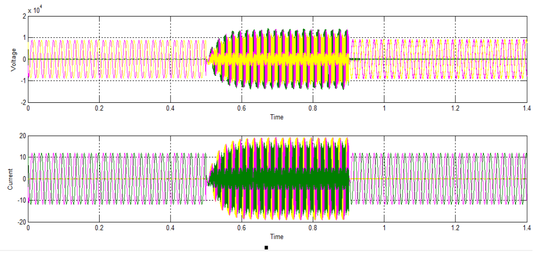

Fig. 10 Simulation results with SMES based DVR

But in fig.10 it can be seen that fault fully gets compensated due to the presence of SMES based DVR.

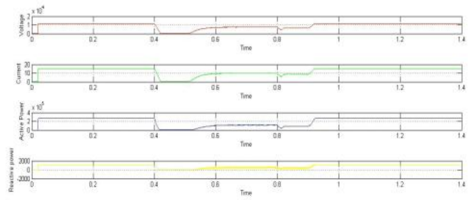

Fig. 11 Active and Reactive power

V. CONCLUSION

Due to the characteristic of high energy density and quick response, a superconducting magnet is selected as the energy storage unit to improve the compensation capability of DVR. In addition to that, an auxiliary control strategy for the interruption of downstream fault current in transmission line is introduced. The compensation capability of DVR can be further be improved by using fuzzy controller as feedback controller.

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Appendix

Table I System Parameter

Parameters	Specification
Source Voltage	11 KV
Three winding Transformer	11/110KV
Three phase fault Transition time	0.4- 0.8 sec
Circuit Breaker Transition Time	0.5-0.9 sec
DC link capacitor	450μF