Original Article

ISSN: 2349 - 4891

International
Journal of Recent Research and Applied Studies
(Multidisciplinary Open Access Refereed e-Journal)

SMES Based DVR for Voltage SAG Compensation on Distribution System

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Received 16th February 2015, Accepted 20th April 2015

Abstract

DVR is an equipment which was connected in series and adjusting the loading voltage by feeding the voltage in system. The first installation was in 1996. Usually DVR installed between sensitive loads feeder and source in distribution system. The main duty is to fast support load voltage (by fast response energy storage device) during disturbance to avoid any disconnection. In this paper approaches to compensate for voltage sag as a common disturbance in voltage transmission and distribution networks is presented. Super conducting Magnetic Energy Storage (SMES) based DVR is proposed for fast response and effective sag compensation capabilities. The proposed method has the potential to bring real power storage characteristics to protect consumers from the grid voltage fluctuations. To evaluate the performance of the proposed design MATLAB/SIMULINK tool is used.

Keywords: Dynamic Voltage Restorer (DVR), Proportional Integral(PI), Pulse Width Modulation (PWM), SMES, Voltage Sag.

Introduction

Voltage disturbance may be caused by the fault of power systems, the starting of large loads, or the energizing of transformers.Voltage deviations, often in the form of voltage sags, can cause severe process disruptions and result in substantial economic loss [1]. Among the several novel custom power devices, the dynamic voltage restorers (DVR) for application in distribution systems are a recent invention [2]. Energy storage appears to be beneficial to utilities since it can decouple the instantaneous balancing between the demand and the supply.Therefore it allows the increased asset utilization, facilitates the penetration of renewable sources and improves the flexibility, reliability and efficiency of the grid.

Energy Storage Device

Energy storage devices can be classified into two different categories, depending on their application: short-term response and long-term response energy storage devices. Long-term response energy storage devices for power systems applications can usually absorb and supply electrical energy during minutes or hours and can specially contribute on the energy management, frequency regulation and grid congestion management. Short-term response energy storage devices are usually applied to improve power quality, particularly to maintain the voltage stability in power systems, through-out a contribution during transients (few seconds or minutes) [3].

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Voltage Sag

Voltage sags are usually caused by a short circuit current flowing into a fault on a transmission or distribution line. Voltage sags can interrupt system and shut down critical loads and processes. Over 90% of power quality related problems are from momentary (typically 0.1–2 s) voltage sags of 10–50% below nominal. Where the magnitude and phase of the faulted voltage during the sag are determined by the fault and supply impedances using the equation,

$$V_{sag} = E\frac{Z_f}{Z_f + Z_s} \qquad (1)$$

Where,

V_{sag} voltage during the sag;
E supply voltage;
Z_s supply impedance;
Z_f impedance at faulted line;

It should be noted that both a magnitude change and phase jump may be experienced as part of the voltage sag. The operating principle of a DVR is to inject the voltage in series with the supply to compensate for voltage sag and maintain an undisturbed load voltage. The sag duration varies depending fault type and location, but is generally linked to the protection system used in the grid system. Voltage sags can be symmetrical or nonsymmetrical. However, most voltage sags are nonsymmetrical, as identified in a recent Electric Power Research Institute (EPRI) survey [4]. Sags may be generated by: three-phase faults, three-phase faults with ground connection, two-phase faults, two-phase faults with ground connection, and single-phase faults. The different sag types do affect the basic DVR design fig.1

but the primary issues that influence the DVR rating for the different system topologies are the depth and duration of the voltage sags, as will now be discussed. Voltage sag can be defined as given in the following Table I.

Table I. Voltage sag Definition

Type of Disturbance	Voltage	Duration
Voltage sag	0.1-0.9 p.u.	0.5-30 cycles

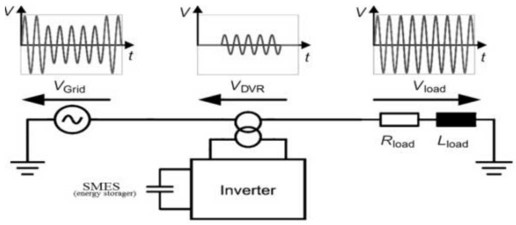

Figure I. DVR Operation during Voltage Sag

This paper is organized into V sections. The DVR location is presented in section II. Section III deals with the performance of SMES based dynamic voltage restorer in mitigating sags. Simulation results of the proposed method is described in section IV and section V presents the conclusion.

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently fig.2. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks.

DVR Location

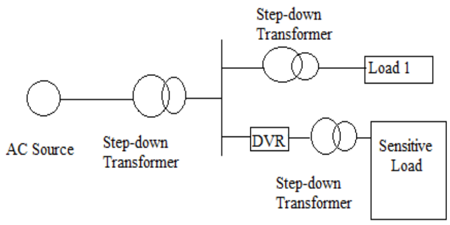

Figure II. DVR location

Note that the DVR capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of DVR is very short and is limited by the power electronics devices and the voltage sag detection time [14]-[16]. The predictable response time is about 25 milliseconds, and which is much less than some of the traditional methods of voltage correction such as tap-changing transformer [17].

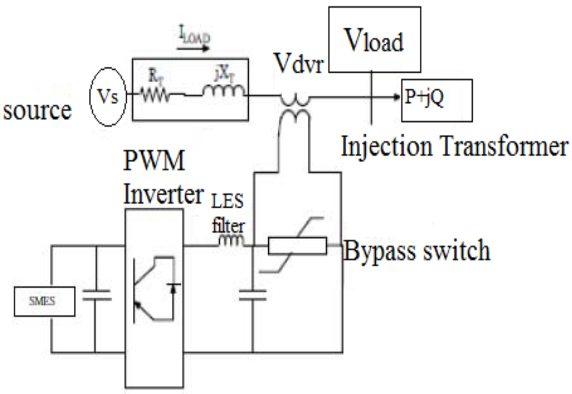

Figure III. SMES Based DVR

DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC) as shown in fig.3 [5],[6]. Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

SMES Based Dynamic Voltage Restorer

The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

$$V_A = Sin(\omega t + \delta) \quad (2)$$

$$V_B = Sin\left(\omega t + \delta - \frac{2\pi}{3}\right) \quad (3)$$

$$V_C = Sin\left(\omega t + \delta + \frac{2\pi}{3}\right) \quad (4)$$

An advantage of a proportional plus integral controller is that 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. The output of error detector is,

$$V_{ref} - V_{in} \quad (5)$$

V_{ref}equal to 1 p.u. voltage

V_{in}voltage in p.u. at the load terminals. This paper analyses the operation principle of the SMES based DVR and its design is based on simple PI control method to compensate voltage sags.

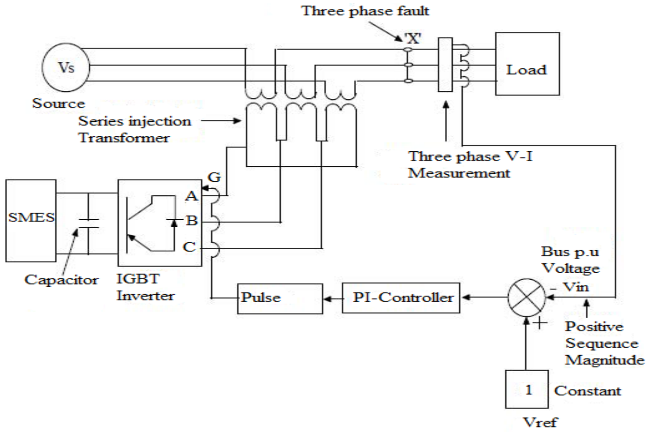

Figure IV. Circuit Model for SMES Based DVR

Using MATLAB SIMULINK, the models of the SMES based DVR is established, and the simulation test are performed to evaluate the system performance. For voltage sag compensation, the dynamic voltage restorer (DVR) which acts as series-connected topology is a more cost-effective solution. In this paper, a super conducting magnetic energy storage (SMES) unit is introduced as the energy storage unit of the DVR[4].

SMES for the Proposed System

The simulation diagram of the proposed system is shown in the fig.6.The circuit shows the SMES model for proposed system.

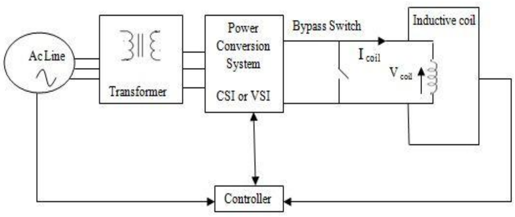

Figure V. Component of SMES

It's the energy released circuit model has the following operating states.

1) Energy-charging state
2) Energy-storing state
3) *Energy discharging state*

During charging cycle, inductance coil is place across DC source. When certain amount of energy stored in the coil then DC source removed & inductance coil is shorted through super conductor material. So current continuously flow through coil without decay & energy is stored in inductance coil. For discharging of inductance coil energy, negative voltage applied across the coil[7]-[10].

Result Analysis

When we creating the three phase balanced fault, the voltage will be decreased to approximately 30% of its normal value for a duration of 0.2sec from t=0.3 till t=0.5as show in the output figure. The proposed DVR responds to this sag within one cycle (20milliseconds), and injects the appropriate amount of missing voltage during the sag event. On detection of voltage recovery, the DVR switches off to keep conduction losses to minimum.

Simulations and Results

The first simulation was done with no DVR and a three phase fault is applied to the system at point with fault resistance of 0.44Ω for a time duration of 200 ms. The second simulation is carried out at the same scenario as above but a DVR is now introduced at the load side to compensate the voltage sag occurred due to the three phase fault applied. Following simulation results shows the rms voltage and a three phase faultat load point when the system operates with no DVR is applied to the system. When the DVR is in operation the voltage interruption is compensated almost completely and the rms voltage at the sensitive load point is maintained at normal condition. Figure VI firing pulse generated by discrete PWM generator.

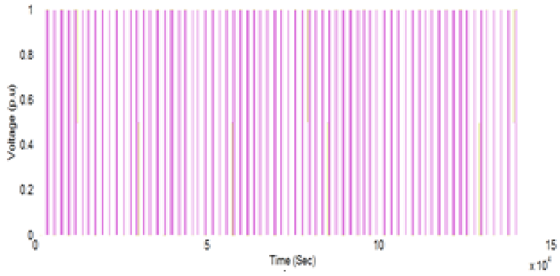

Figure VI. Firing Pulse Generation

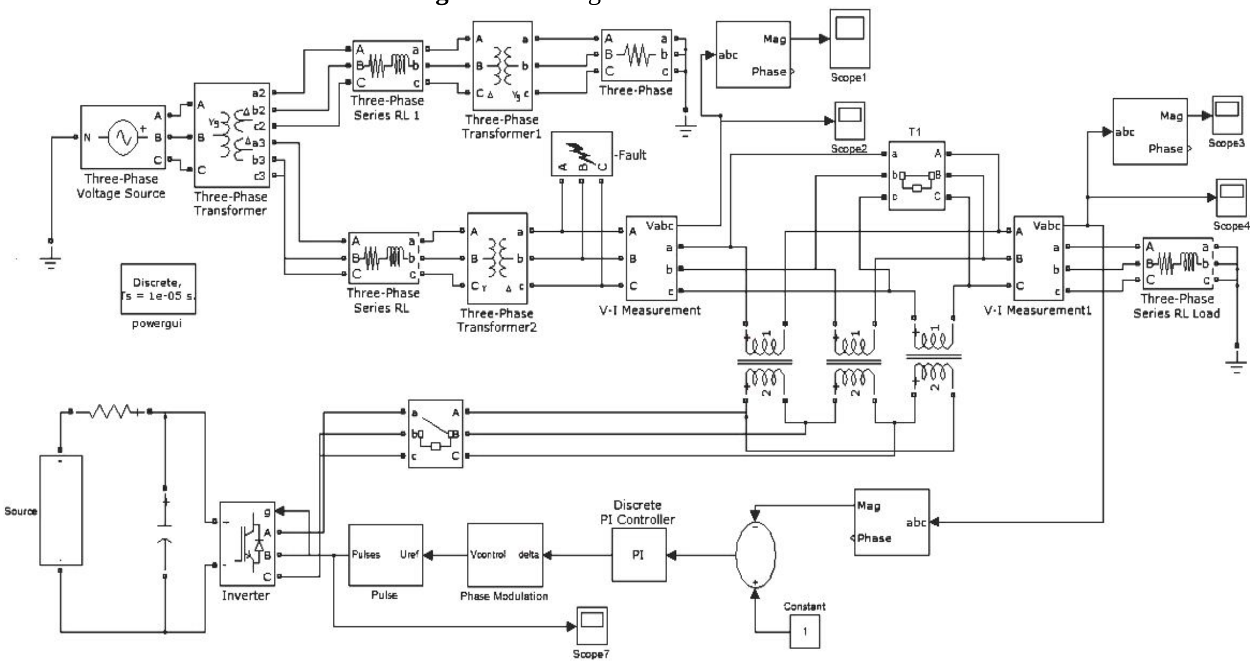

Figure VII. Overall Simulation Diagram

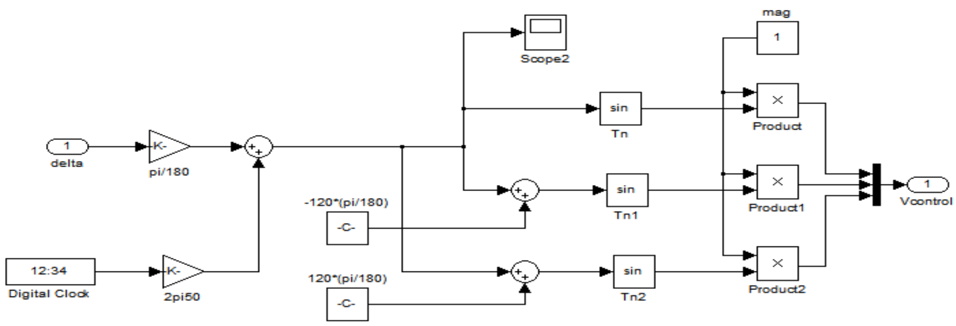

Figure VIII. Phase Modulation Control

Voltage Sag Compensation without SMES Based DVR

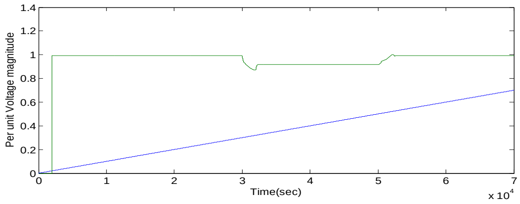

Figure IX. (a) Per Unit Voltage Magnitude at Load Point without SMES based DVR

The simulation was carried out without SMES based DVR and a three phase to ground fault is applied to the system at point with fault resistance of0.44Ω for time duration of 200 ms which result voltage sag as shown in Figure IX(a)

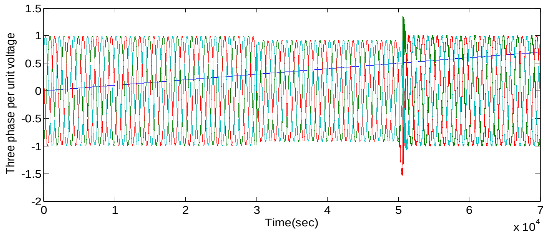

Figure IX.(b) Three Phase, Phase-Phase Per Unit Voltage without SMES based DVR

When we creating the three phase balanced fault, the voltage will be decreased to approximately 30% of its normal value for a duration of 0.2sec from t=0.3 till t=0.5sec as show in the output figure IX(b).

Voltage Sag Compensation with SMES Based DVR

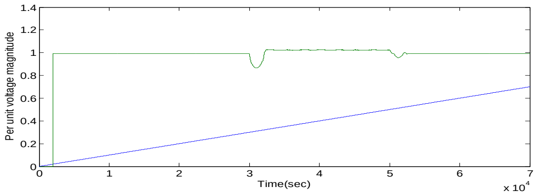

Figure X. (a) Per Unit Voltage Magnitude at Load Point with SMES based DVR

The second simulation is carried out at the same scenario as above fig .6(a) & (b) but now in this case SMES based DVR is introduced to compensate the voltage sag occurred due to the three phase to ground fault which is as shown in Figure X(a)

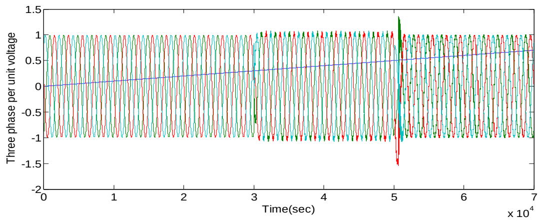

Figure X.(b) Three Phase, Phase-Phase Per Unit Voltage with SMES based DVR

The proposed DVR responds to this sag within one cycle (20milliseconds), and injects the appropriate amount of missing voltage during the sag event t=0.3 to t=0.5 as shown in Figure X(b).

Conclusion

To carry out any investigation in the power quality improvement it needs a thorough knowledge of nature of the power quality issues over the particular location of transmission lines and complete understanding of the energy storage device is necessary. SMES based dynamic voltage restorer for compensating voltage sags has been developed. The SMES based dynamic voltage restorer (DVR) technology has the ability for good compensation characteristics. The compensation strategy is capable of mitigating up to 50% severe voltage sags and can have an important role for power quality improvement compared to conventional methods.

Table II. Parameter Specification

S.no	System Quantity	Specification
1	Transmission Line Parameter	R=0.001Ohms, L=0.005Henry
2	Inverter Specifications	IGBT Based,3 Arms,6 Pulse, Carrier Frequency=1080Hz, Sample time=5µsec
3	PI Controller	K_P = 0.5, K_i = 50, Sample time=50µsec
4	SMES Fault resistance	0.44Ω
5	TRANSFORMER Three winding transformer Two winding transformer	 13/115/115 KV 115/11 KV

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