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Compensation of Voltage Sag and Swell Using SMES Based Dynamic Voltage Restorer

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Abstract
Conducting Magnetic Energy Storage (SMES) is portrayed by profoundly proficient vitality storage. It has fast reaction and power controllability and is relied upon to add to brilliant intensity of the power grid. SMES innovation can possibly bring genuine power storage trademark and furthermore high power and vitality thickness for momentary reaction. This normal for SMES used to shield buyers from the network voltage variances like sag, swell and interference. This paper examinations the activity guideline of the SMES based DVR and its structure depends on basic PI control technique to repay voltage droops, swell and intrusion. Utilizing MATLAB/SIMULINK, the models of the SMES based DVR is set up, and the re-enactment tests are performed to assess the grid disturbances.

Keywords*: Superconducting magnetic energy storage (SMES); Dynamic Voltage Restorer (DVR); Voltage Sag, swell and interruption; Pulse-width modulated (PWM)*

INTRODUCTION

The inquires about on SMES for power quality enhancement for the most part have two strategies. One is using SMES as a uninterruptible power supply (UPS) to secure touchy burdens. The SMES-UPS needs to remunerate full power for the heap, which requires substantial limit converters and vitality stockpiling units. The other method is connecting SMES in parallel with the system and compensates system voltage fluctuation. By regulating the current on SMES coil the parallel compensation is carried out. Power systems have been experiencing good changes in electric power generations, transmissions, and distributions. For electrical load growth and higher power transfer in a largely interconnected network lead to complex and less secure power system operation. Power system engineers facing challenges seek solutions to operate the system in more a flexible and controllable manner. So role of energy storage devices play important role as Energy storage appears to be beneficial to utilities since it can decouple the instantaneous balancing between supply and demand. Therefore increased asset utilization is allowed, that facilitates the renewable sources Penetration and improves the Flexibility, Reliability and Efficiency of the grid. Voltage sags are caused by abrupt increases in loads such as faults or short circuits, starting of motors, or turning on of electric heaters or they are caused by abrupt source impedances is increase, which are caused by a loose connection. Power quality issues are divided into two categories voltage quality and frequency quality. Voltage quality issues are related with voltage sag, voltage swell, under voltage and over voltage while frequency quality issues are related with harmonics and transients. One of the most imperative power quality issues is voltage sag which is occur due to its usage of voltage sensitive devices. It has made industrials processes more susceptible to supply voltage sags. The typical compensation of voltage for sag and swell is given in the table 1.

Table 1: *Voltage sag and swell*

Disturbance	Voltage (PU)	Duration
Voltage Sag	0.1 – 0.9 p.u.	0.5 – 30 Cycles
Voltage Swell	1.1 – 1.8 p.u.	0.5 – 30 Cycles

Energy storage devices can be classified into two diff categories, depending upon their application: short term response energy storage devices and long-term response energy storage devices. Short term response energy devices which include flywheel, super capacitor, SMES whereas long term response energy storage devices are include compress air, hydrogen fuel cell, batteries, Redox flow.

Flywheel and super capacitor are having less power rating and energy rating so they cannot use for Short time high power application. To improve the efficiency of the compensation the energy storage device can be used in a transmission line.

Superconducting Magnetic Energy Storage system is a viable choice to bring solutions to some of the problems experienced in power systems. The power industry demand for high flexible, reliable and fast real power compensation, devices provides the ideal opportunity for SMES applications. Application of SMES for power conditioning with DVR is put forth. The dynamic response of the SMES based DVR on voltage sag and swell is evaluated using MATLABsimulation.

ENERGY STORAGEUNITS

The energy storage devices are split into two types direct energy storage and indirect energy storage.

1. Small categories (<10MW): Fly-wheel batteries, ultra capacitors &capacitors (combined with DG devices) are comes in smallcategories.
2. Medium categories (10MW < energy < 100MW): Large-scale batteries, lead-acid, NAS and Redox are come in medium categories.
3. Large categories (≥ 100MW): Compressed Air Energy Storage (CAES), Pumped Storage are comes in large categories.

Efficiency of storage devices is given by equation (1). Table.2 shows the applications of energy storage with respect to their storage capacity and discharging time period. Table.3 shows some factors.

Table 2: *Classification of stored capacity*

Application	Stored Capacity	Discharge Period
Power Grid Leveling	11 MJ-201 GJ	Few Sec. - Few Days
Power Quality	0.11-11 MJ	Few Sec.
Custom Devices	0.11-11 MJ	Few Cycle

Table 3: *Efficiency of storage devices*

S. No.	Technology	Efficiency %	Energy Density [W-h/kg]	Power Density [kW/kg]	Sizes [MW-h]
1.	Pumped hydro	75	.27/100 m	Low	5000-20000
2.	Compressed gas	70	0	Low	250-2200
3.	SMES	90 +	0	high	20 MW
4.	Batteries	74-84	30-50	0.2-0.4	17- 40
5.	Flywheels	90 +	15-30	1-3	0.1-20 kwh
6.	Ultra capacitors	90 +	2-10	high	0.1-0.5 kwh
7.	Fuel cell	<70	300-600	1.06-2.50	250 mwh

Although SMES systems may not be cost effective, at the present time, they have a positive cost and environment impact by reducing fuel consumption and emissions. SMES' efficiency and fast response capability has been and can be further exploited in different applications in all level of electric power systems which have been characterized in Table 4 below.

Table 4: *Characterized Application of SMES*

Field	Application	Discharge time required
Generation	Load Leveling	Hours
	Dynamic Response	Hours
	Spinning Reserve	Minutes
	Frequency Control	Seconds
Transmission	Load Leveling	Minutes/Hours
	Stabilization	Seconds
	Voltage/VAR Control	Cycles
Distribution	Load Leveling	Minutes/Hours
	Power Quality	Seconds
	Custom Power	Cycles

SMES WITHDVR

The basic structure of a DVR based on Super Magnetic Energy Storage is shown in Fig.1. It consists of super conducting magnetic energy storage, capacitors bank, voltage source inverters (VSI), low pass filter and a voltage injection transformer.

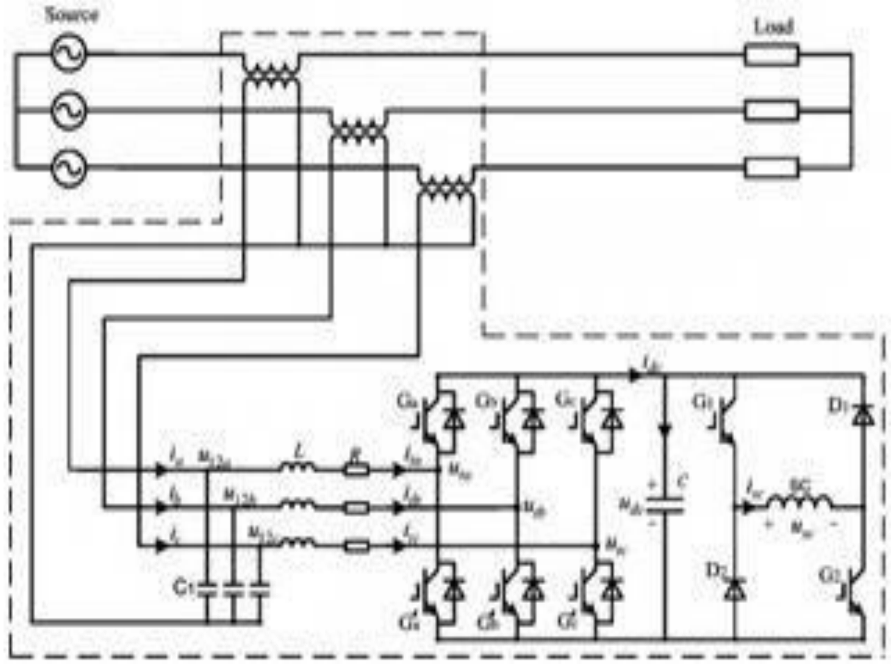

Figure 1: Basic structure of DVR based on SMES

Its energy released circuit model is as shown in Fig.2

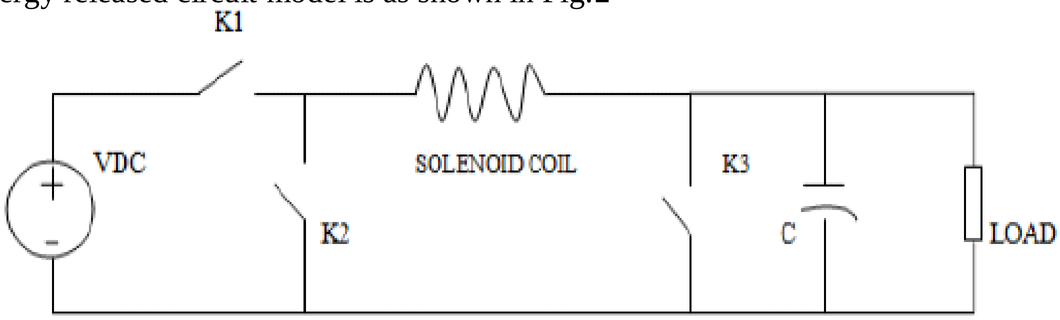

Figure 2: *SMES energy released circuit there are three operating states in the circuit model*

1. Energy-charging state (close $K_1$and K_3, openK_2);
2. Energy-storing state (close $K_2$and K_3, openK_1);
3. Energy discharging state (close K_2, open K_1andK_3).

The current is continuously flow though coils without decay & energy is stored in solenoid coil. For discharging of solenoid coil energy, negative voltage applied across thecoil.

In order to mitigate the simulated voltage sag in practical application, a discrete Pulse Width Modulation-Based control scheme is implemented, with reference to DVR as shown in Fig 3. The aim of the control scheme is under the system disturbance to maintain a constant voltage magnitude at the sensitive load point, Voltage sag, swell and interruption is created at load terminals by a various phase fault as shown in Fig.3. The PI controller is controls the IGBT to maintain 1 per unit voltage at the load terminals that is considered as base voltage=1per unit.

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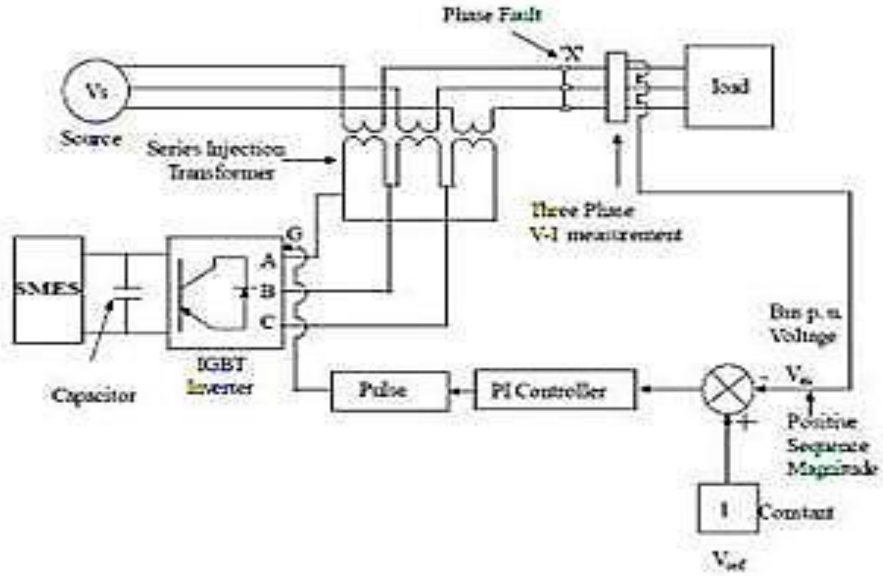

Figure 3: DVR with SMES (SMES based)

$$VA = \sin(\omega t + \delta)$$

$$VB = \sin(\omega t + \delta - 2\pi/3)$$

$$VC = \sin(\omega t + \delta + 2\pi/3)$$

The input for PI controller is an actuating signal which is the difference between the *Vreference* and *Vinput.* The controller block output is of the form of an angle δ, in the three phase voltages which introduce additional phase-lag/lead. The error detector output is

Vref - Vin.

Vref equal to 1 p.u. voltage. *Vin*voltage in p.u. at the load terminals. The controller output when compared at Pulse Width Modulation signal generator results in the desired firing sequence.

SMES SIMULATIONMODEL

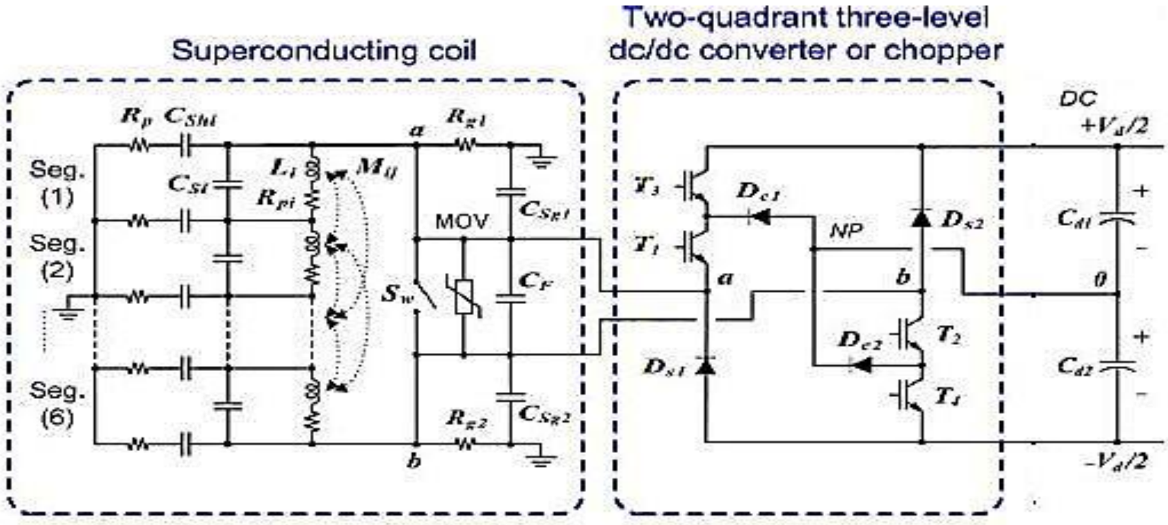

Figure 4: *Detailed model of the proposed SMES system*

Table.5. shows three-level chopper output voltage vectors and their corresponding igbt switching states. Fig.4.shows Matlab model and Fig.9,10 shows the corresponding SMES charging and discharging outputs.

Table 5: *Three-level chopper output voltage vectors and their corresponding IGBT switching states*

States	T_1	T_2	T_3	T_4	V_{ab}
1	1	1	1	1	$+V_d$
2	0	0	0	0	$-V_d$
3	0	1	0	1	*0*
4	1	0	1	0	*0*
5	1	1	0	0	*0*
6	1	1	0	1	$+V_d/2$
7	1	1	1	0	$+V_d/2$
8	1	0	0	0	$-V_d/2$
9	0	1	0	0	$-V_d/2$

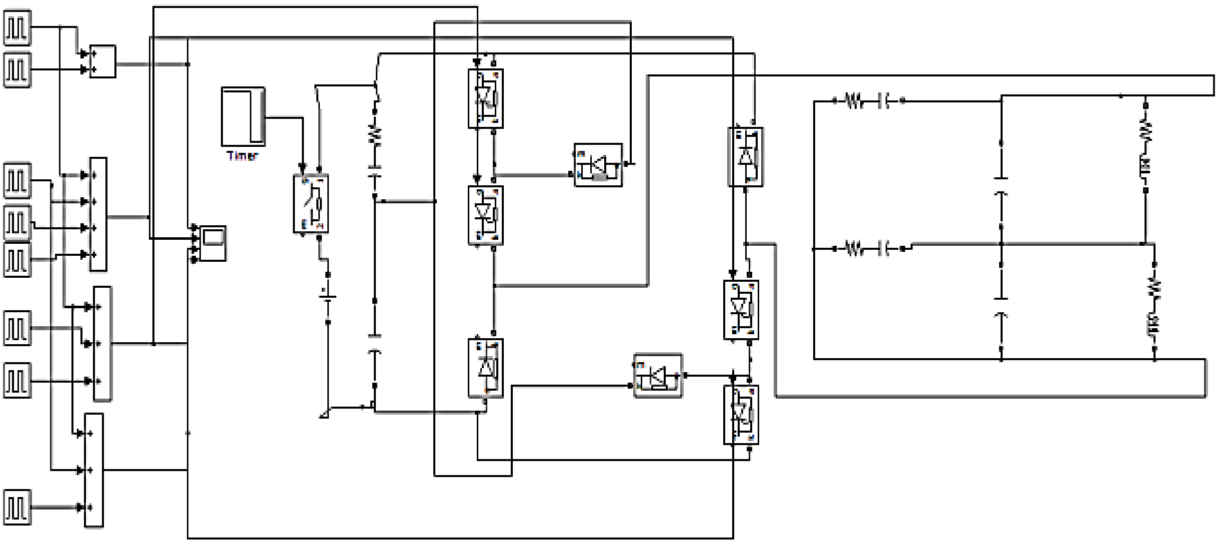

Figure 5: *MATLAB/SIMULINK diagram of SMES model*

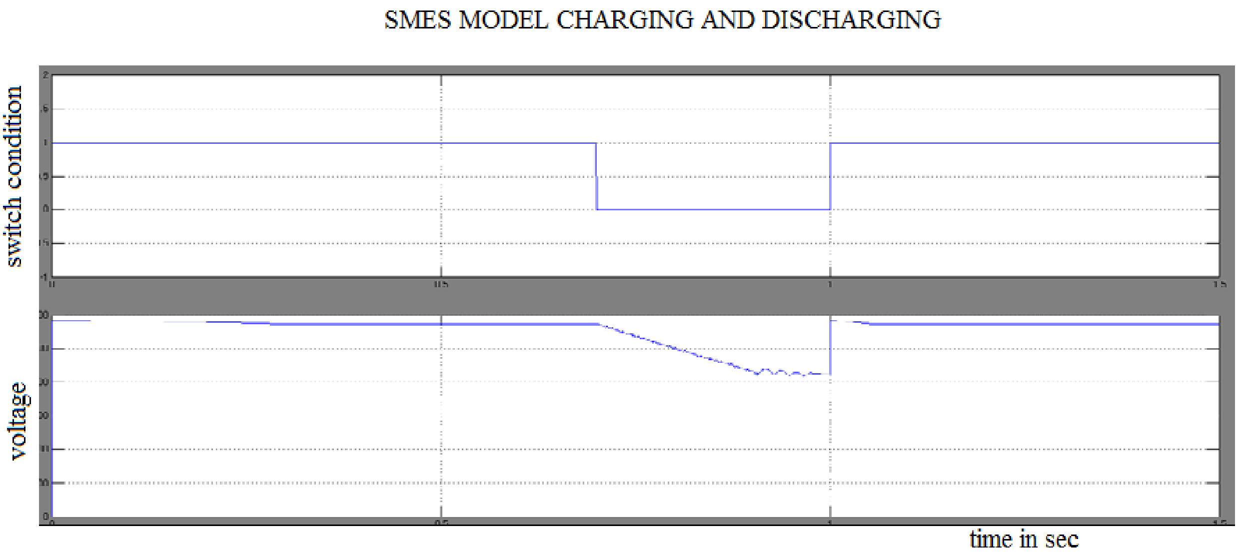

Figure 6: *Output waveform for SMES model and discharging*

SMES BASED ON DVR TESTSYSTEM

Single line diagram of the test system 13 kV composes DVR Based on SMES, 50 Hz generation system, feeding two transmission lines through a 3- winding transformer. It verify the working of DVR for voltage compensation at 0.44 ohms fault resistances for fixed time duration of 200 ms. While take SMES with 588KA current flowing through it, for analysis of system performance i.e. voltage sagcompensation.

Fig.17 is MATLAB/SIMULINK diagram of SMES based DVR for voltage sag compensation. The first 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 of 0.44Ω for time duration of 200 ms which result voltage sag as shown in Fig.5. The second simulation is carried out at the same scenario as above but now in this case SMES based a DVR is introduced to compensate the voltage sag occurred due to the three phase to ground fault which is as shown in Fig. 6. For that SMES carrying 588KA current circulating through solenoid coil used. While Fig.7 to Fig.13 are P. U. Load voltage profile without & with SMES based DVR.

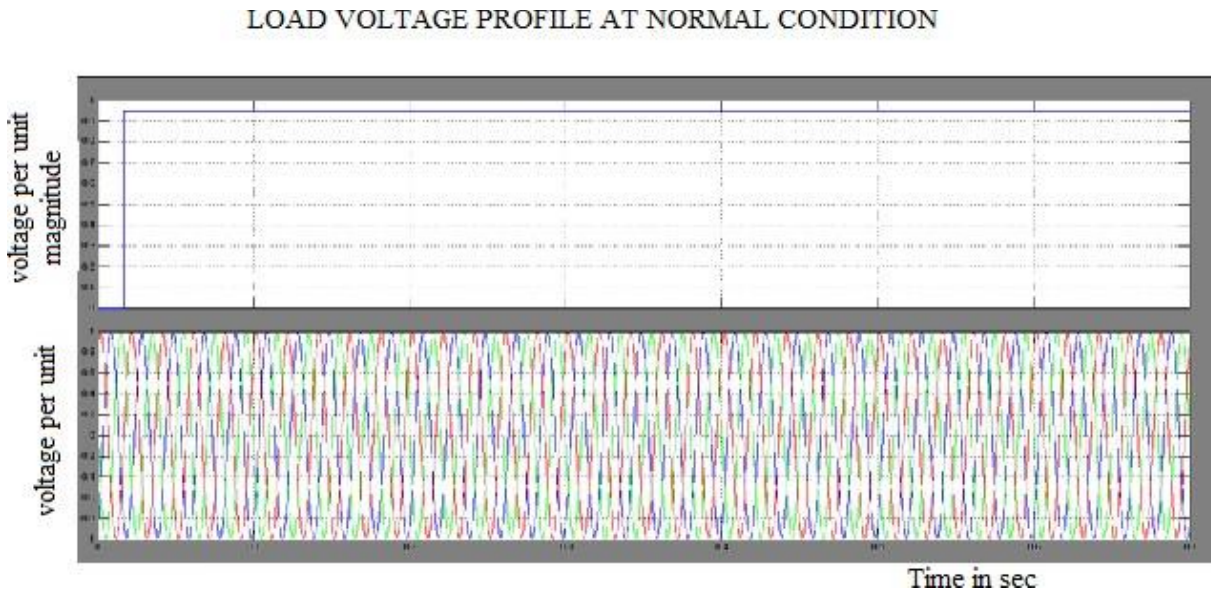

Figure 7: *Phase-phase voltage without any fault*

Figure 8: *Single line fault, phase-phase voltage without SMES based DVR*

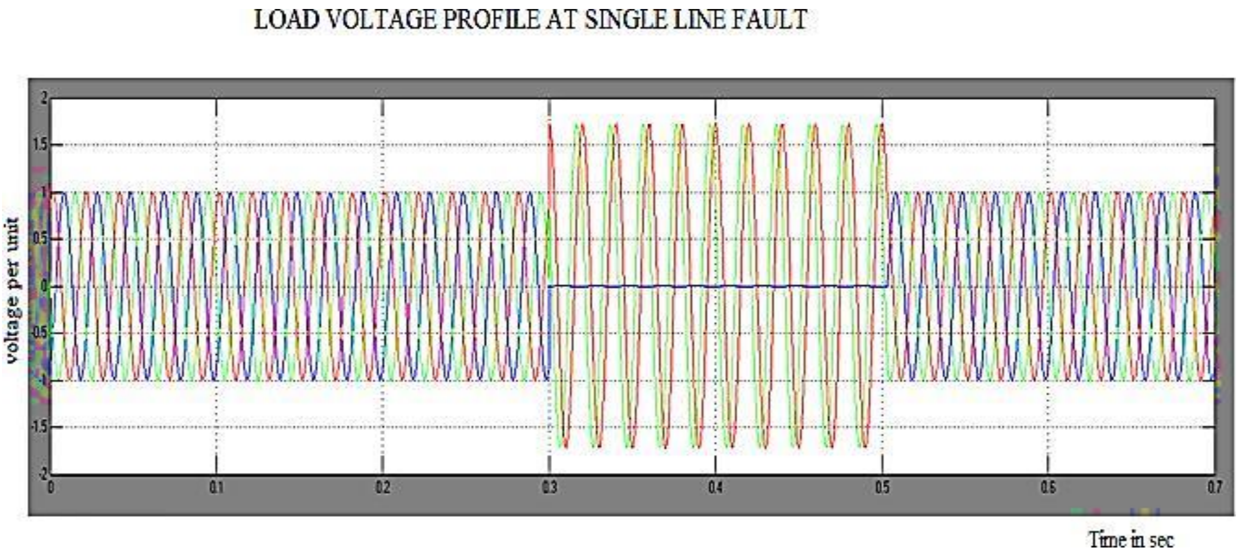

Figure 9: *Line- line fault, phase-phase voltage without SMES based DVR*

Figure 10: *Three phase fault, phase-phase voltage without SMES based DVR*

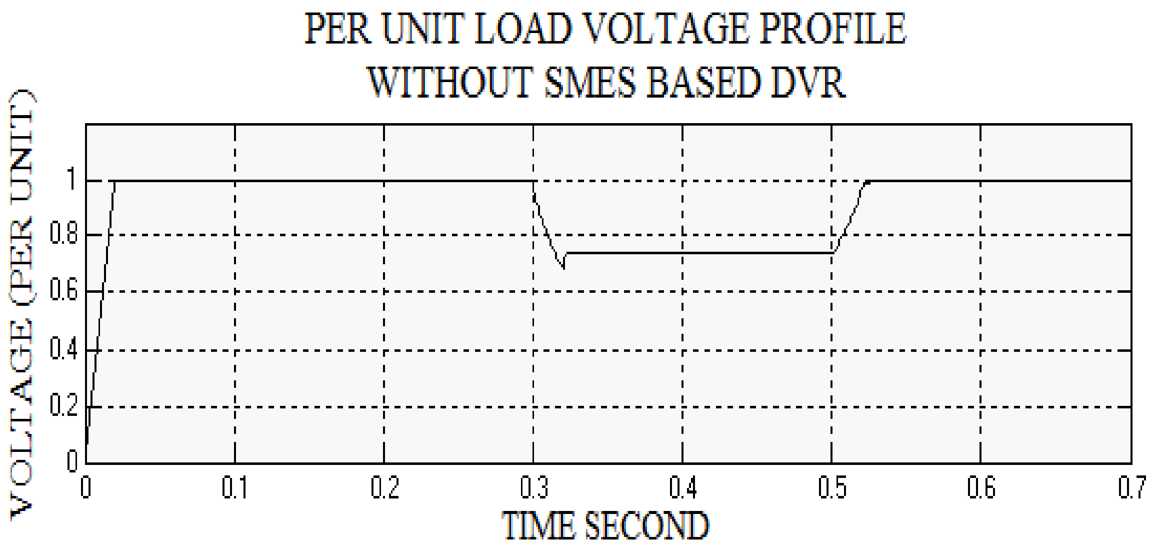

Figure 11: *Voltage P.U at load point without SMES based DVR*

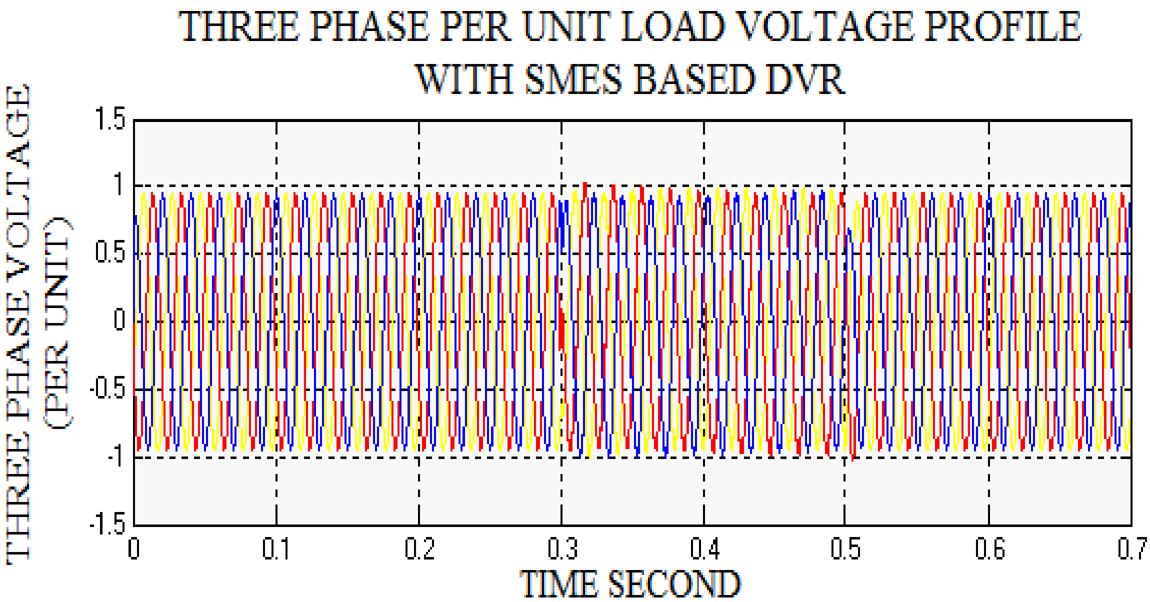

Figure 12: *Three phase P.U. voltage at the load point with SMES based DVR*

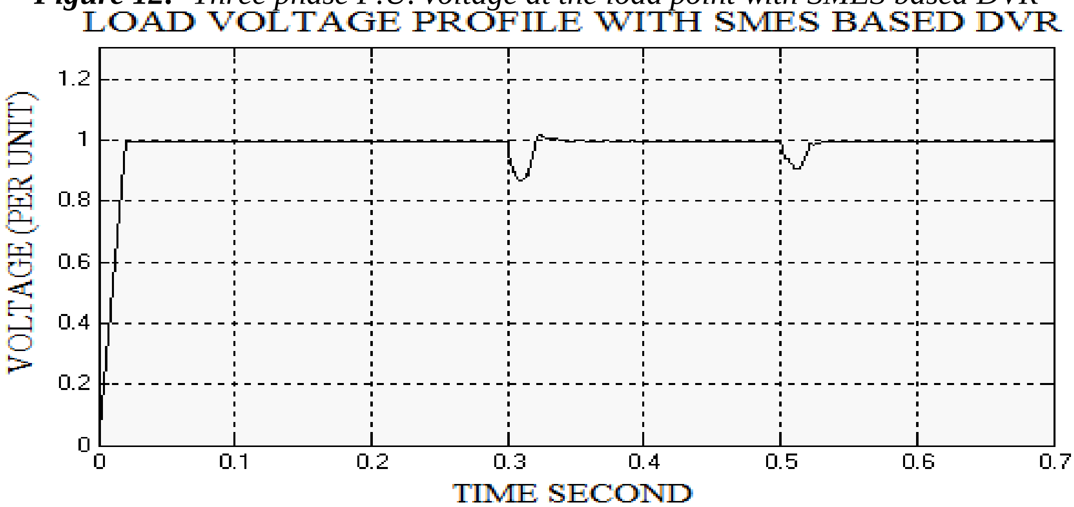

Figure 13: *Voltage P.U. at the load point with SMES based DVR*

CONCLUSION

A new design which incorporates a superconducting magnetic energy storage module as a DC voltage source to mitigation voltage sag, swells and enhances power quality of a distribution system based on DVR has been presented. The proposed strategy is utilized for ID of the voltage list and is fit for placation of the list by keeping and keeping up the size of burden voltage at the voltage which is wanted and THD inside breaking points. The proposed technique is extremely straightforward and is dependable, has been utilized just for one exchanging per stage. Consequently the framework is simple, straightforward, yet requires vitality stockpiling gadget as contrasted with normally utilized DVR or STATCOM. The working execution of the proposed gadget is checked by hypothetical results and is observed to be agreeable. This is the best control system for non-straight loads which can't withstand for stage edge hops is pre-hang remuneration. For least voltage infusion, in-stage infusion remuneration is the best. For least vitality addition by the DVR, stage advance remuneration is ideal however requires more voltage infusion.

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