Application of a SMES to protect a sensitive load in distribution networks from two consecutive voltage sags

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***Abstract*- Nowadays, many electrical systems are practically sensitive to short power disturbances and voltage sags. Since three decades ago, many research of superconducting magnetic energy storage (SMES) system have been doing to improve power quality of sensitive electric systems. The objective of this paper is to present the modeling and analysis of a SMES to protect a sensitive load in Azarbayjan distribution network from consecutive voltage sags. The topology of the SMES system and its response to two consecutive voltage sags are described. Simulation results reveal the effectiveness of the proposed controller.**

Keywords SMES; voltage sag; sensitive load; Azarbayjan distribution network

I. INTRODUCTION

Power quality disturbances generally appear in the form of voltage sags, flickers, and harmonics [1]. From these categories of power quality problems, the most disturbances experienced by industrial customers are voltage sags. Voltage sags usually refers to instantaneous short-duration voltage reduction. The consequences of voltage sags to sensitive loads can be severe, such as production losses, and plant shutdown [2]. Many solutions have been proposed to compensate voltage sags. One of the attractive options to mitigate voltage sags is to use the superconductor magnetic energy storage (SMES) system [3-5].

A SMES is a device that stores energy in the magnetic field created through the flow of DC in a superconducting wire in a large magnet [6]. Depending on the control loop of its power converter unit including power electronic switches such as IGBT and GTO the total efficiency of a SMES system can be very high and also the SMES system can respond very rapidly. Consequently, SMES has naturally high storage efficiency, about or more than 90% [7]. Comparing with other storage devices, the SMES technology has a unique advantage in power system applications. A number of these applications have been proposed over the past last years [8-12]. The applications are mainly for power system load leveling [13], power system stabilizers [14], [15] and voltage support for critical loads [16].

In this paper, we want to use SMES technologies to maintain load voltage at one per-unit. The next section, power quality problem in Azarbayjan distribution network will be addressed. The third section will describe the SMES components including super-conducting magnetic energy storage system, DC/DC converter and inverter. Simulation results of the control of the SMES to protect a sensitive load in Azarbayjan distribution network will be described in section four. In the end, the paper is concluded in Section 5.

II. POWER QUALITY PROBLEM IN THE DISTRIBUTION NETWORK

A part of Azarbayjan distribution network including a sensitive load is shown in Figure 1. As you can see a 200 KW sensitive load is fed through a 20 KV voltage line.

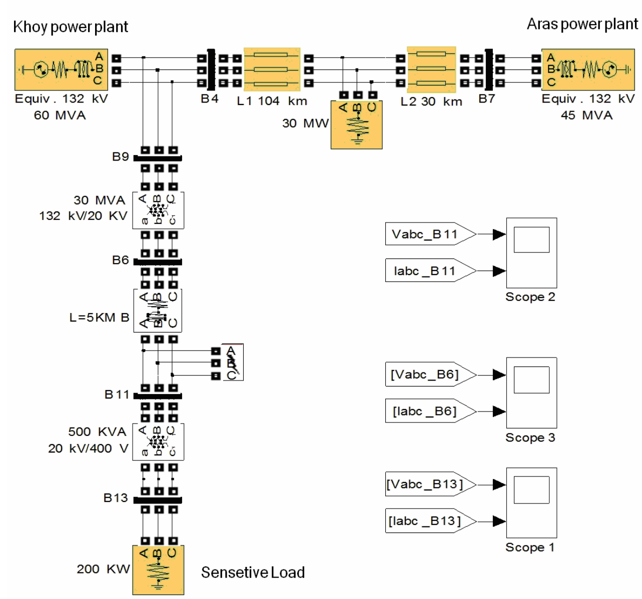

Fig 1. Azarbayjan distribution network with a sensitive load

In this system when a short time ground fault occurs, voltage sag happens on the sensitive load voltage (B13).

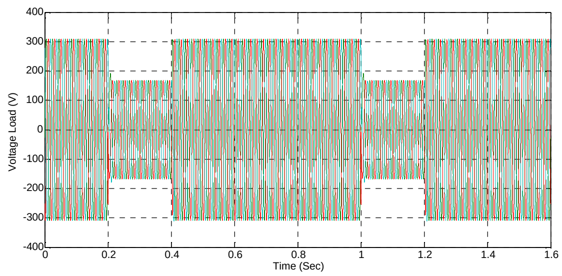

Fig. 2. voltage on the load including the voltage sags without compensating

Figure 2 shows the sensitive load voltage when two ground faults create two voltage sags. Here to compensate voltage load a SMES system will be designed. The position of SMES in the distribution network is shown in Figure 3.

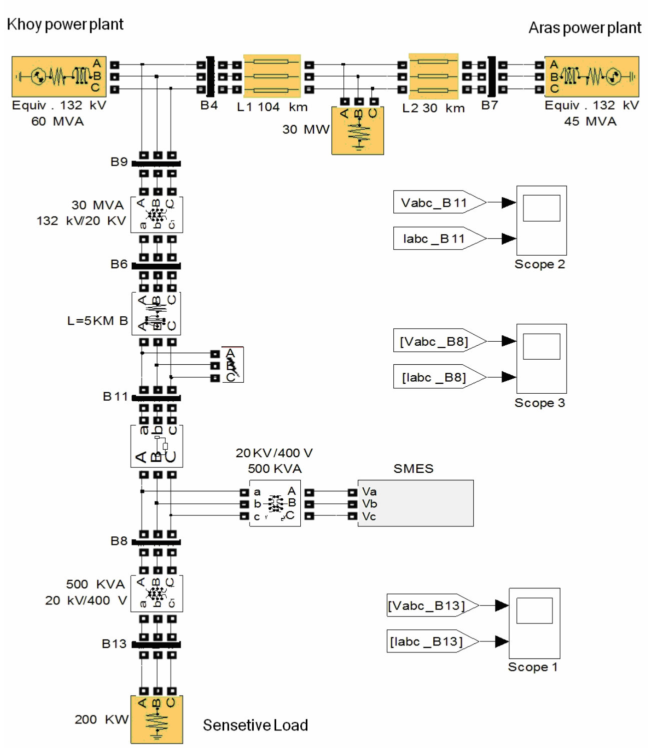

Fig. 3. Azarbayjan distribution network with a sensitive load with SMES system

For the SMES system, three operating conditions should be considered. Two conditions could be the operation when load demand reaches its power via grid. Under this operation, the SMES works on the standby mode or coil charging mode. Standby mode is a state that SMES don't exchange any power with grid and coil charging mode is a state that SMES is charged by absorbing power from the distribution network.

Another situation could be when there is no supply from the power system. Under this condition, SMES system will then provide all the load demand and acts as a backup power supply. This situation is coil discharging. Where there is a severe voltage sag in the supply system, a static switch will be activated to disconnect the supply system so that the SMES can provide the necessary backup supply.

III. SMES COMPONENTS

A SMES system consists of the some major items. As it can be seen in Figure 1 superconducting coil, dc-dc chopper and voltage source converter are the main components.

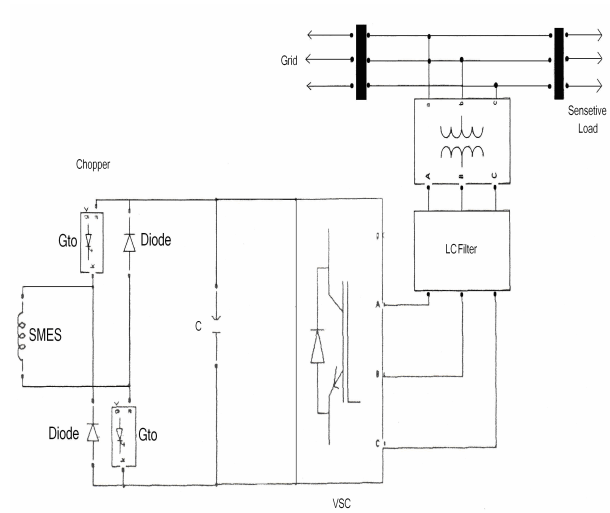

Fig. 4. Overall SMES configuration

SMES system works in three modes, coil charging, coil discharging and standby. When voltage sag occurs SMES system goes to coil discharging and in this mode SMES injects power to the sensitive load during the presence of voltage sag. After removing the voltage sag SMES system works in coil charging mode and then it goes to standby mode.

All mentioned components are described in the following subsections.

A. *Superconducting coil*

A superconducting coil stores energy in its magnetic field created by flowing dc current.

For this system, the inductively stored energy can be expressed as follows:

$$W = \frac{1}{2} L I_{dc}^2 \quad (1)$$

Where L is the inductance of the coil, I_{dc} is the dc current flowing through the coil.

B. Voltage source converter (VSC)

The VSC is designed to operate as either an inverter when discharging the superconducting coil or as a rectifier when charging. Voltage and current ratings of the converter must be taken into account in the design of the control system. In this system, VSC should work in two states, voltage control or power control. It works in voltage control mode when voltage sag occurs and SMES begins to compensate voltage. In this mode the voltage load should recover to one per-unite again. In other SMES modes the inverter works on power control.

C. DC/DC chopper

The chopper is used to maintain a constant dc voltage across the capacitor. The chopper controller is designed with tradeoff between the superconducting reactance, the dc capacitor and the maximum deviation for the dc voltage. Here two hysteresis control is considered to control dc link voltage and coil current.

IV. Simulation Results

The basic concept of is demonstrated by simulation. In this section the power electronics devices are modeled using the power system block set in MATLAB/SIMULINK. Then the proposed controller to exchange energy during the critical load management is evaluated by simulation. For simulation the system parameters shown in Table 1 are used.

TABLE I
SYSTEM PARAMETERS

System parameters	Value
Load PF	0.9
Load	200KW
Gris and SMES frequency	50 Hz
DC link voltage	1000 v
SMES coil inductance	0.5 H
Inverter Inductance	0.7 mH
Inverter capacitor	0.3 mF

Now, in order to confirm the performance of the designed system, two sudden ground faults in the time region of 0.2<t<0.4 and 1.0<t<1.2 were assumed and compensated by SMES system. The total simulation time is 1.6 sec.

Figure 5 and 6 show the line voltage waveforms when two consecutive voltage sags occur. These figures show that voltage is sustained instantly.

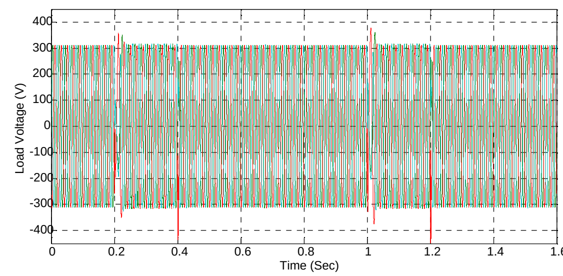

Fig. 5. Voltage on the load during of including the voltage sags with SMES compensating

The enlarged figure of the load voltage is shown in Figure 6. It turns out that the system voltage falls with the generation of the instantaneous voltage sags and the compensation start is carried out after instantaneous voltage sags detection.

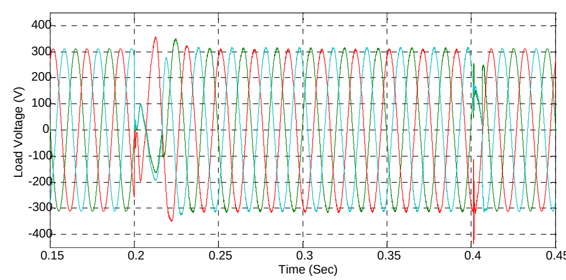

Fig. 6. Enlarged figure of the voltage on the load during of the first voltage sag occurrence with SMES compensating

The rms voltages for all 3 phases are drawn in Figure 7. As you can see these voltages the compensation is completed in 30 to 40 ms.

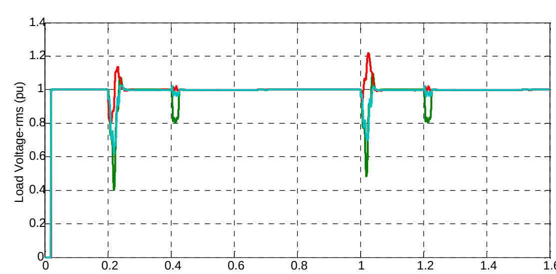

Fig. 7. Load rms voltages with SMES

The injected active and reactive powers are depicted in Figure 8. The figure shows that the SMES could supply the sensitive load.

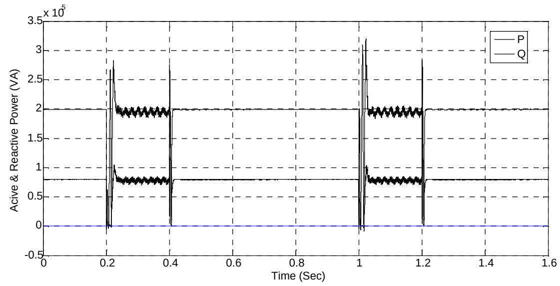

Fig. 8. Delivered active and reactive power to the load by the SMES and power system

Figure 9 shows that the DC current of the SMES coil recovers slowly to its reference level after the sags.

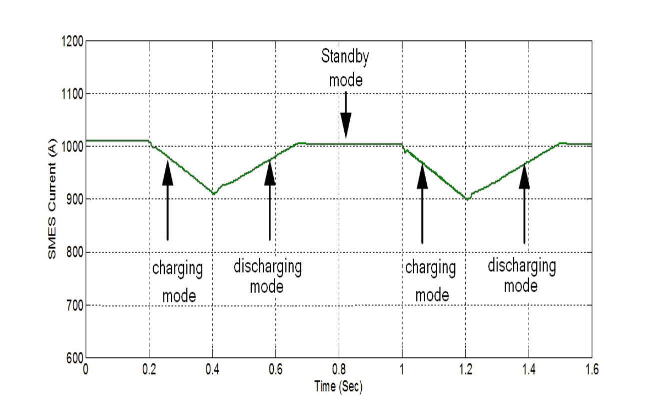

Fig. 9. SMES coil current and constant voltage control.

The dc bus reference voltage is set to 1000 V. The hysteresis tolerance on it is varied from 1 to 4 V i.e., from 0.1% to 0.4%. The dc bus voltage is presented in Figure 10.

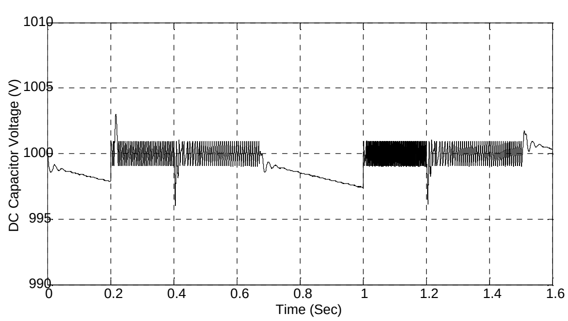

Fig. 10. DC bus voltage (V) under hysteresis control

V. Conclusions

Power Quality is an important factor in maintaining production output in every industrial facility. The most common power quality problems in power systems are voltage sags. In this paper, a SMES is designed to protect a sensitive load in Azarbayjan distribution network from consecutive voltage sags. This SMES system was simulated under the two short time voltage sags, it was showed that the short time power interruption was successfully compensated using the stored energy in the SMES system.

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