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Cascaded multilevel converter based superconducting magnetic energy storage system for frequency control

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ABSTRACT

The Super conducting magnetic energy storage (SMES), owing to high energy density and capacity, has been widely applied in different stages of power systems. One of these applications is the frequency control of the electric power systems. Frequency of a power system depends on the balance of produced and demanded energy in any instant of time. Subsequent to a sudden change in the system, which causes produced and demanded energy mismatch, frequency oscillates. According to standards, the permissible variation band of the frequency is very restricted. Larger swings of frequency may result in instability and undesirable trips. As a result, suitable frequency control mechanisms should be implemented in the system. SMES is well-suited for this application because of high energy density and fast response. SMES is attached to system by a power conditioning system (PCS) which include power electronic converters, mainly a dc–dc chopper and an inverter. This paper, studies the application of a cascaded H-bridge (CHB) multilevel converter for frequency control. As far as the authors' knowledge, such a study has not been done before. The design procedure of the converter is presented. Simulation results on a sample system are presented to verify the performance of the proposed PCS.

1. Introduction

Generation and distribution of electric energy with good reliability and quality is very important in power system operation and control. This is achieved by automatic generation control (AGC). In an interconnected power system, as the load demand varies randomly, the area frequency and tie-line power interchange also vary. The objective of load frequency control (LFC) is to minimize the transient deviations in these variables and to ensure for their steady state values to be zero. The LFC performed by only a governor control imposes a limit on the degree to which the deviations in frequency and tie-line power exchange can be minimized. However, as the LFC is fundamentally for the problem of an instantaneous mismatch between the generation and demand of active power, the incorporation of a fast-acting energy storage device in the power system can improve the performance under such conditions [1].

Superconducting magnetic energy storage (SMES) uses superconducting coils as an energy storage component. In an SMES unit, energy is stored in a magnetic field created by the DC flow in a superconducting coil. The system has very high efficiency, up to approximately 95%. One of the important advantages of the SMES is very short time delay during either charge or discharge process. The power output is available almost instantaneously and large capacity can be achieved. Due to self-requirement of power for refrigeration and high cost of superconducting wires, SMES systems are currently used just for short duration energy storage [2]. The most important advantages of SMES include: 1) high power and energy density with excellent conversion efficiency, and 2) fast and independent power response in four quadrants. When applied in power systems, SMES acts as a controllable active and reactive power source [3]. According to Ref. [4] the power rating of the SMES systems is between 0.01 and 10 MW. Its discharge duration is in the range of seconds, the gravity metric energy density is 0.5–5 Wh/kg, volumetric energy density is between 0.2 and 2.5 Wh/L, power density is 500–2000 W/kg, efficiency is 85–99%. Also the durability of the SMES in terms of years is over 20 years and in terms of cycles is over 100,000 cycles.

SMES efficiency and fast response capability have been exploited in different applications in all level of electric power systems. SMES systems have the capability of providing a) load leveling, b) frequency support (spinning reserve) during loss of generation, c)

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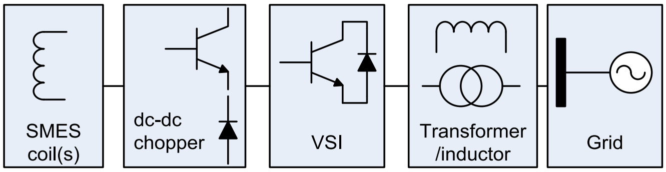

Fig. 1. A typical SMES system.

enhancing transient and dynamic stability, d) dynamic voltage support (VAR compensation), e) improving power quality, f) increasing transmission line capacity, thus overall enhancing security and reliability of power systems [5]. Therefore, SMES has been widely used in power systems at different levels. An overview of the SMES applications in power and energy systems could be found in Ref. [6].

Combination of flexible AC transmission systems (FACTS) and SMES has resulted in improved performance of these systems. Static synchronous compensator (STATCOM) and SMES combination has been reported and investigated in Refs. [7–9]. An SMES unit has the ability to follow system load changes almost instantaneously which provides for conventional generating units to operate at constant output. It has the capability to dampen out low frequency power oscillations and to stabilize system frequency as a result of system transients [10].

A comprehensive literature review of LFC can be found in Ref. [11]. This work reviewed different techniques for LFC. As one of the candidates, use of SMES for LFC in both conventional power system and the distributed generation systems has also been considered. In order to reduce the system frequency deviation to a mini- mum value, the storage system such as SMES or battery energy storage system (BESS) can be incorporated [11].

The application of SMES to improve the transient stability of power system has been presented in Ref. [12]. In this work, the current source converter has been used as the power conditioning system (PCS) of the SMES system. An improved controller of SMES system has been presented in Ref. [13] for system voltage regulation. The 48-pulse converter (obtained by special transformer arrangements) is used in this work as the PCS. Use of combined SMES and superconducting fault current limiters (SFCL) to enhance dynamic stability of power system has been reported in Ref. [14]. The use of SMES for power flow control and oscillation damping in wind farms has been investigated in Ref. [15]. In Ref. [16], the SMES system has been applied to improve frequency control of a power system including distributed generations (wing and diesel generators). Control of a microgrid including wind generation by use of

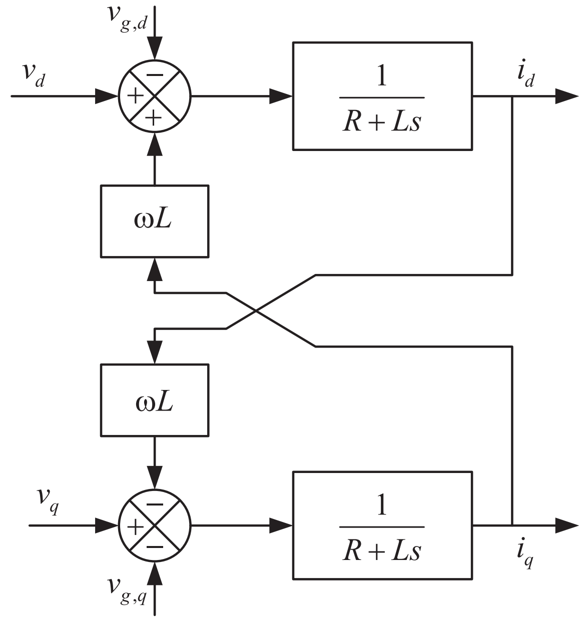

Fig. 3. Model of a grid-connected inverter in dq frame.

SMES system has been studied in Ref. [17]. The application of current source converter based SMES system for power quality improvement has been investigated in Ref. [18]. The design of state feedback control for current source power conditioning system of SMES has been studied in Ref. [3]. A multimodule current source converter based PCS has been presented for SMES system in Ref. [19]. In Ref. [20] the application of the SMES system for frequency control of a power system including several synchronous generators has been investigated. The converter used in this work, is a 48-pulse converter which is obtained by series-connected three-level NPC (neutral-point clamped) converters by different transformer arrangements. This structure is a suitable option for high-power applications; however, it uses relatively complicated structure of transformers. It is shown that in the 48-pulse converter the lowest-order considerable harmonics appear in the 47th and 49th order which are relatively easy to handle. The high-temperature SMES has been investigated in power fluctuation compensation in Ref. [21]. As the cooling requirement of the high-temperature SMES is lower, its capital costs may also be lower. In a power system with wind power penetration, both disturbances in power system and also generated power from the wing turbines have stochastic manner. Therefore, in Ref. [22], power system transient stability evaluation has been investigated using probabilistic methods. In an islanded power system with intermittent renewable power generation, the power fluctuation and frequency variations is a problem. A review of energy storage systems including the SMES for such systems has been done in Ref. [23]. In Ref. [10] the robust H-infinity LFC of hybrid distribute generation system consisting multiple kinds of DG units such as of wind turbine generator, diesel

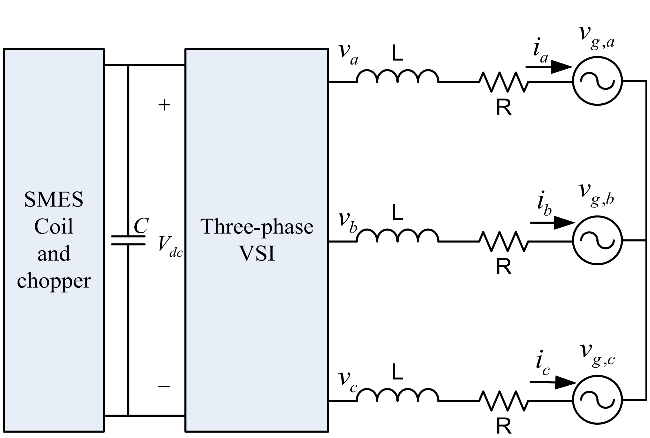

Fig. 2. A grid-connected inverter.

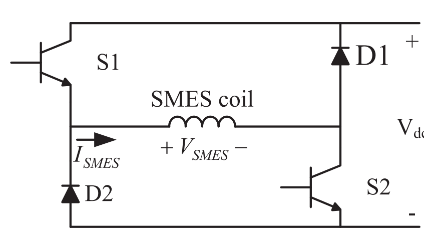

Fig. 4. dc chopper used in SMES system.

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