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Full Length Article

Analysis of enhancement in available power transfer capacity by STATCOM integrated SMES by numerical simulation studies

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ABSTRACT

Power system researches are mainly focused in enhancing the available power capacities of the existing transmission lines. But still, no prominent solutions have been made due to several factors that affect the transmission lines which include the length, aging of the cables and losses on generation, transmission and distribution etc. This paper exploited the integration of static synchronous compensator (STATCOM) and superconducting magnetic energy storage (SMES) which is then connected to existing power transmission line for enhancing the available power transfer capacity (ATC). STATCOM is power electronic voltage source converter (VSC) which is connected to the transmission system for shunt reactive power and harmonics compensation. SMES is a renowned clean energy storage technology. Feasibility of the proposed power system can control the real as well as reactive power flow independently between the transmission lines and STATCOM-(SMES) units. Complete proposed power system is implemented in numerical simulation software (Matlab/Simulink) and its performance is validated based on obtained investigation results.

1. Introduction

Today's demands in power sector lies on proper planning which improve the Available Power Transfer Capacity (ATC) of the existing transmission lines and avoid drastic blackouts. In such congestion management, the Flexible AC Transmission System (FACTS) controllers play a vital role. Among the FACTS controllers, STATCOM (static compensator) is the most prominent choice for reactive power flow and harmonic control in the transmission grid system [1–3]. It consists of a three-phase voltage source converter (VSC) connected in shunt with the transmission line through a step-up transformer and a dc link capacitor as shown in Fig. 1. Shunt connected VSC (STATCOM) inject current vector into the transmission line in such a way to maintain the voltage across the dc capacitor which is always constant. It means that the continuous reactive power compensation had been done with limited real power compensation [2–4].

The integration of an electrical energy storage system and the power system security improved by storing excess energy during the off-peak load periods [5]. Even though the super conducting phenomena was developed in 1911, the application in electric energy storage system was proven by adequate research articles from 1970. Energy storage systems such as Pumped Storage Hydroelectric System (PSHS), Battery Energy Storage System (BESS) and Superconducting Magnetic Energy Storage (SMES) are available. Among these topologies the SMES finds attraction due to its fast response and highly efficient performances (95%) [6]. The main limiting factor of SMES is its operating temperature, which decides the cost and operating conditions of the superconductor. The SMES unit may add a tremendous amount of spinning reserve capacity with low cost when it is connected to the power system. Under the circumstance, when SMES is disconnected by the breaker switch, still it is possible to provide continuous rated capacity of VAR to the power system by the STATCOM operation alone [7–11] with increased security level. Nowadays due to the availability of Low Temperature Superconductors, research is moving towards the development of High Temperature Superconductor (HTS). The SMES unit adds a tremendous amount of spinning reserve energy flow capacity to the grid through VSCs at low cost. But the main limiting factor of SMES

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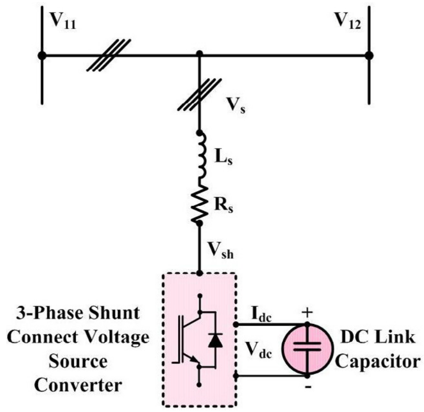

Fig. 1. Schematic circuit of static compensator (STATCOM) showing shunt compensation voltage source converter (VSC) integrated with transmission line.

is its operating temperature, which decides the cost and operating conditions by the superconductors [7,9,10].

Considering the above facts, this research work develops ATC system based on integration of STATCOM and SMES to increase the power transfer capacity for the grid security and controlled operation shown in Fig. 2. The paper work is organized as follows: the basic concepts and operating principle of STATCOM with SMES integration are explained in section 2. Real power control compensation and enhancement of power system security are developed using numerical simulation software (Matlab/Simulink) which is given in section 3. Set of numerical simulation results are provided and explained in section 3 to validate the proposal of ATC. Finally, the conclusion of this paper work is presented in section 4.

2. Principle operation of STATCOM and SMES integration

The block diagram of STATCOM with SMES unit is shown in Fig. 2. STATCOM is controlled by standard synchronous reference controller, where the reference signal is obtained by comparing the *d* and *q* axis voltages, which are derived through the PI controller process on the *d* and *q* axis component of the line currents [12–14]. The required current vector is determined by comparing V_{dc} (dc link voltage) and V_s (system source voltage) with V_{dcref} (dc reference voltage) and V_{sref} (system reference voltage at the point of connection) respectively. The real power flow which is transferred from the sending end to receiving end (assuming $V_s = V_r$,) is given by the equation below [12,15,16]:

$$P_{s_1} = \frac{V^2}{X_L}\sin(\delta) \tag{1}$$

where,

Vs is the magnitude of sending end voltage,
V_r is the magnitude of receiving end voltage,
V_c is the compensation voltage of the converter,
δ is the phase difference between the sending and receiving end voltages.

If the phase angle between the sending end and receiving end are ±δ/2, then there is no absorption or generation of active power but merely reactive power is compensated. For instance, if the phase difference is not equal to δ/2, for small interval of time the STATCOM compensates the real power flow. Now, the power transferred to the receiving end is given by the equation below [12,15,16]:

$$P_{s_2} = \frac{2V^2}{X_L}\sin\left(\frac{\delta}{2}\right) \tag{2}$$

From Eqs. 1 and 2 with STATCOM, the real power transferred from sending to receiving end is improved to a great extent, since $2\sin\left(\frac{\delta}{2}\right)$ is always greater than $\sin(\delta)$ and where δ range between 0 and 2π. Therefore, the maximum real power and reactive power at receiving end are given by:

$$P_{r_1} = \frac{V^2}{X_L}\sin(\delta) \tag{3}$$

$$Q_{r_1} = \frac{V_R V_S}{X_L}\cos n(\delta) - \frac{V_R^2}{X} \tag{4}$$

Suppose, when the real and reactive power is constant, then power flow is the function of *V*, *X* and power angle alone, which is the phase difference between sending end and receiving end voltages. Meanwhile, if the sending end voltages and receiving end voltages are equal, then the power flow control is governed only by the δ phase angle. To ensure good voltage profile with stability, reactive power should be compensated i.e.:

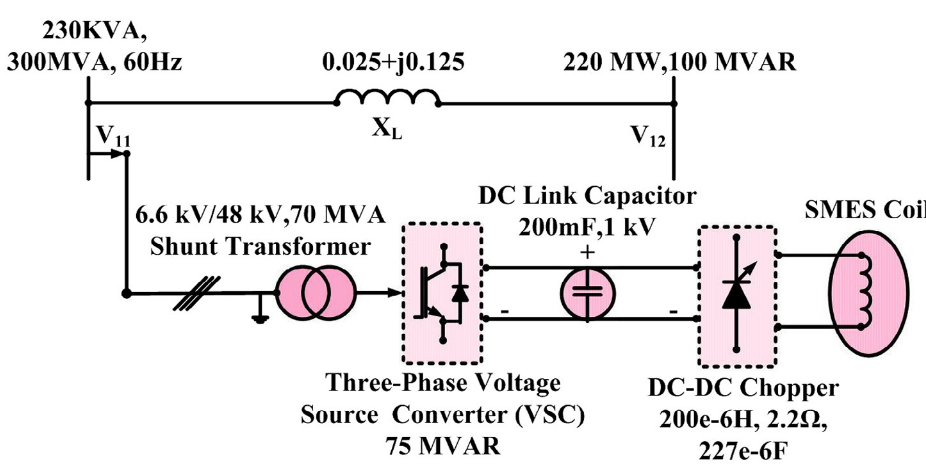

Fig. 2. Schematic circuit of proposed power system with available power transfer capacity enhancement by integrating STATCOM and SMES.