Abstract

The superconducting magnetic energy storage (SMES) systems have the quality of higher energy storage efficiency and higher energy charging and discharging speeds than conventional energy storage systems (ESS), like pumped hydroelectric, compressed air energy storage and battery. Also, SMES has the maximum longevity than other ESS. SMES increases stability in power systems and improves power quality. In micro-grid systems, SMES can store the unpredictable and irregular power from renewables like solar and wind which can be used later for power applications whenever needed. The SMES can also be used for storing solar power during the day for use at night. Additionally, SMES can store more energy from high wind at night than daytime in absence of solar power. Based on the working principle, various types of SMES systems, such as solenoidal and toroidal type systems have been developed in many countries.

SMES device is a combination of three technologies namely Superconductivity, Cryogenics and Power Electronics. Superconducting coil is the heart of SMES. Electrically it is a pure inductor (no internal resistance) and DC current can flow through it without any ohmic (I^2R) loss. As a result, superconducting coil can persist current or energy (0.5 LI^2) for years with energy density as high as 100 MJ/m^3.

Numerous researches in material science, design, application and control aspects are under process to minimize the cost of SMES coil and to optimize its operation towards power system. Though the design and development of SMES in a high range may be commercially possible in next years, it is a challenge to connect it to the grid in the best and proper way for solving the necessary problems. The optimum design of converter and the best control strategy are required to use an SMES device properly. There are many research groups working on it and many new ideas are revealed, but the best way of connectivity is still not found.

An SMES magnet design requires some preliminary data, like the amount of stored energy in HTS coil, operating temperature, operating current, cooling method and available maximum length of superconducting tape suitable for the design. The

proposed research is planned to apply the Finite Element Method (FEM) method first and then an independent calculation method to understand the performance of SMES coil clearly. Energy density of SMES device plays very important role in cost effective power applications such as UPS, load levelling, voltage stability etc. These applications require high storage capacities (0.5 LI^2) as well as high energy densities of SMES coil. Both energy density and cost depend on the volume of the superconducting coil. In this thesis, high Tc superconducting pancake type solenoid coil dimensions are optimized with different Inner Diameters (IDs) to fulfil the maximum energy density. A minimum volume criterion is developed from the relation between shape factor and the coil volume. The tape length is automatically constrained with the coil volume. This results in a number of coil dimensions satisfying the minimum volume criteria within the specified available tape length. The FEM is adopted for electromagnetic and electromechanical analysis of these coils. The optimum dimension is then suggested with the maximum energy density.

Power electronics converter, interfacing the coil to the AC line is generally called Power Conditioning System (PSC). Proper control of PSC is required according to power system requirements and superconducting coil protection. At numerous conditions to maintain the power quality and reliability, it needs to release very high power with high di/dt rate. On the other hand, reduced di/dt is preferred from the ac loss point of view to prevent the quenching of superconducting coil. Further, high capacity SMES coil with high di/dt increases the lethal voltage risk. For voltage sag and swell, primary frequency stability and load frequency control, SMES converter with low di/dt is required.

In this thesis, the voltage source converter is used as PSC. The Type – D dc-dc converter is proposed for chopper circuit. To control VSC based SMES (SMES-VSC), Fuzzy Logic, Artificial Neural Network and Neuro-Fuzzy are used, as these controllers have better handling and adaptability than conventional Proportional (P), Proportional-Integral (PI) controllers.

After designing the optimum coil and artificial intelligent controllers, the SMES-VSC unit is proposed as a stability enhancer for wind power generating system (WPGS) integrated to power system. SMES can decrease the output power fluctuation of WPGS and enhance its performance in sharing power demand with the conventional generating systems of power grid. As an ancillary device, SMES provides economic impact on WPGS. A proper location of SMES makes the performance of WPGS cost effective. In a variable speed WPGS consisting of doubly fed induction generators (DFIG), there are two possible locations of SMES, i.e. inside DFIG conversion system and at point of common coupling (PCC) with grid. The later location is more cost effective for SMES for levelling the power fluctuations of WPGS.

When a fault occurs at the connected grid, WPGS is required to be isolated. As this disturbance in power system suddenly increases the demand, the WPGS becomes unstable and may get damaged due to sudden increase in electromechanical torque in the rotor circuit. With isolation of WPGS, the grid becomes overloaded and unstable due to reduction of supply. A properly controlled SMES can reduce the impact of sudden occurrence of fault and enhance the fault ride through (or low voltage ride through) capability of WPGS. A properly designed Artificial intelligent controller can increase the fast charging and discharging capabilities of SMES to overcome the demand created during fault, thereby enhancing the dynamic stability of WPGS and increasing its connectivity with power grid.