Abstract

The growing concern towards the environment and encouragement through government policies by different countries have increased the installation of large-scale electric power using the renewable energy resources like wind and solar energy. Indian Govt. has a plan to integrate 70 GW of solar and 30 GW of wind energy by 2025. Due to the dependency on environmental conditions like wind velocity and solar irradiance, the nature of power generated by these generating units is stochastic in nature. The high-level penetration of these generating units into the existing ac network has shown the negative impact on the performance of existing grid by affecting the scheduling of conventional generating units, operation of transmission network and also affect the voltage and frequency stability margins of the ac grid. Besides this, the inertia of the grid reduces significantly with the increase of RES integration which is the main cause of concern for ramping up of RES installation. Thus, to improve the performance of renewable power dominated grids, different kinds of grid codes have been proposed by transmission system operators. Hence, various types of control techniques have been reported in the literature to improve the voltage regulation and frequency support at the Point of Common Coupling (PCC) of the Renewable Power Generating Systems (RPGS). But this haven't shown enough for the satisfactory operation of renewable power dominated grids.

Thus, it has necessitated to use a reactive power compensating device like STATCOM and an energy storage system to provide voltage, frequency, and inertia support. In reality, it doesn't require to support reactive and active power all times at the PCC of RPGS. Thus, a system which is having the ability to support active and reactive powers has been proposed in the literature. These kind of systems are termed as 'E-STATCOM' (i.e., Energy storage + STATCOM). An E-STATCOM can be formed by connected a storage system at the dc-link of STATCOM. But there are certain challenges to form the E-STATCOM like selection of appropriate power electronic converter and suitable storage system for providing the active power support. The conventional converter topologies like two or three level converters can be employed to form the E-STATCOM by integrating storage systems like battery and supercapacitor etc., at the dc-link. Here, the storage modules are connected in series to meet the required voltage level at the dc-link. These kind of configurations are vulnerable to reliability issues like failure or shutdown of any storage cell leads to complete outage of the storage system. The need of series connection of switching devices, larger foot-print due to passive filters, and higher losses are the other disadvantages of two/three level converters. Also, the conventional two/three level converters are not suitable for high voltage and high power applications.

Hence this thesis proposes modular multilevel converter (MMC) based E-STATCOM topologies to provide both active and reactive power support to integrate the large-scale RPGS. The MMC is a better topology in comparison to other multi-level configurations for high power and high voltage applications. A new topology of E-STATCOM using half-bridge MMC with distributed Battery Energy Storage System (BESS) at the dc-link. Associated control techniques have been developed for the operation of this configuration with desired performance. Here the MMC is employed to support reactive power while the distributed

storage system is used to support the required active power. The low voltage storage modules are distributed using the dc-dc converters which has the ability to transfer power in two directions i.e., from battery modules to MMC and vice-versa. Due to the use of BESS alone, this configuration may face difficulty for high power density applications.

To overcome the aforesaid issue, a new configuration with Hybrid Storage System (HSS) (i.e., battery + ultracapacitor) using MMC has been proposed for E-STATCOM application. The use of HSS in MMC has made this configuration suitable for high-power as well as high energy density applications. For the integration of hybrid energy storage system with MMC, two different topologies have been proposed. In the first configuration, battery modules are connected at the submodules using the dc-dc converter while the ultracapacitor modules are distributed at the dc-link of MMC. To distribute the active power among the battery and ultracapacitor modules, a power management algorithm has been discussed in this work. Though the configuration has the ability to support both high-power and high-energy density applications, but it has more component count and large foot-print. To overcome these shortcomings, the second configuration is proposed where the HSS modules are distributed only at the dc-link of MMC.

The proposed converters not only provide active/reactive power, but also supports various ancillary services that includes Low Voltage Ride Through (LVRT) operation and others. Various power quality issues have also been addressed by providing adequate reactive power support, negative sequence compensation, and harmonic filtering. Different control algorithms, e.g. P-Q control, capacitor voltage balancing, circulating current control, reduced dc bus operation, current/voltage mode control, etc. have been developed to make the E-STATCOM operational. Apart from this, a new algorithm has been proposed to balance the State-of-Charge (SoC) of the distributed energy storage modules. Finally, a comparison is made among all the proposed configurations using the efficiency analysis. The proposed converters along with their control have been simulated in PSCAD/EMTDC and the results show satisfactory performance.