Abstract of PhD Thesis

"Design and Control of High-Power Grid Interfaced Solar PV System with BES"

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In this thesis work, high-power grid interfaced solar PV plants and battery energy storage (BES) systems utilizing fundamental frequency switching (FFS) modulated different multipulse and multilevel voltage source converters (VSCs) topologies are investigated in detail. Investigations are made on 52MWp grid interfaced solar PV plant based on multipulse VSCs utilizing FFS modulated two-level converters with different switching phase displacement angles and star-delta medium voltage (MV) transformers. The transformers primary sides (HV side) are series connected to electro-magnetically add the converters generate voltage for direct integration to the 33kV grid. The investigations are also made on a 100MWp grid interfaced solar PV plant based on 48-pulse VSCs utilizing star-delta MV transformer and FFS modulated three-level neutral point clamp converters (NPCs). Two different MV transformer configurations are used, one with delta-star and another with delta-delta transformer configurations. The transformer secondary delta open windings are separated phase-by-phase, and the primary star and delta windings are series-connected. In this multipulse VSC configuration, the harmonics mitigation is achieved by operating the NPCs with different switching phase displacement angles and fixed voltage dead-angle. The VSC dead-angle is optimally selected, and VSC works as equivalent to a 96-pulse VSC for harmonics mitigation. The VSC output voltage amplitude control is realized with two sets of NPCs operated with leading and lagging voltage angles to provide lagging, leading, and unity power factor operation. Grid interfaced 40MWp solar PV plant configured with FFS modulated three-level-NPC and different phase-shifted 12-pulse transformers is investigated in detail. In this, the FFS modulated NPCs generated lower order current harmonics and are mitigated by utilizing different phase-shifting transformer windings located at different pooling locations inside the solar plant. The plant generates low current harmonics similar to a 48-pulse converter at the 33kV grid connection. Investigations are made on grid interfaced solar PV plant of capacity 240MWp with DC coupled BES of 120MW/720MWh configured with high-power 72-pulse VSC. The 72-pulse VSC is configured with NPCs with suitably selected switching angles and MV transformer with different phase-shifted zigzag secondary windings and series-connected star primary winding. The NPCs are divided into two groups, Group-A NPCs are connected with the line side of zigzag windings, and Group-B NPCs are connected with the neutral side of the zigzag windings. The NPCs dead angle (β) is controlled to control the VSC output voltage amplitude. The multi-MPPT technique is applied to this single-stage VSC for optimal solar power generation. In the large solar PV plant area, the BES is deployed along with the solar PV array and locally stores the excess solar PV energy and dispatches the stored energy during nighttime when the solar PV array is not generating. A 225MWp solar PV plant based on 54-pulse VSCs is also investigated. The 54-pulse VSC is developed with identical three sets of 18-pulse VSCs, each configured with two-level converters (TLCs) and a step-up transformer with series-connected star and different phase-shifted zigzag primary windings, and delta-connected secondary windings. The 54-pulse VSC operation is realized with suitably selected TLCs switching phase displacement angles and 18-pulse VSC transformer configuration. A 112.5MW/450MWh BES is DC coupled at the VSCs DC terminals for storing surplus solar energy and supply to the grid during non-solar hours. Investigations are also made on grid interfaced 480MWp solar PV plant based on 96-pulse modular VSC. Four sets of modular 24-pulse VSC having identical power circuit configurations are utilized to develop the 96-pulse VSC. Each 24-pulse VSC is configured with three-level converters and transformers with delta open LV-windings and series connected different phase-shifted zigzag HV-windings. The solar PV plant is integrated to the 66kV grid. The 96-pulse VSC lower order harmonic elimination is realized with the multipulse transformer (MPT) configuration, and higher order harmonics are eliminated with the suitably selected converters switching angles based on selective harmonics elimination (SHE) techniques. The MPPT DC-DC boost converter is used with each PV string for optimum solar generation. A battery energy storage system (BES) is connected in the field with the PV sub-array to provide the grid Round-the-Clock Power (RTC) supply. Investigations are made on high-power grid interfaced solar PV plants based on multilevel converters (MLCs). Fundamental frequency switching selective harmonic elimination (SHE) modulated eleven-level cascaded H-bridge (CHB) VSC is utilized in MLC applications. The eleven-level CHB VSC configuration and control algorithms with the capacitor voltage balancing method are presented in detail. Investigations are also made on BES based on 13-level CHB VSC utilized to mitigate 20MW solar PV plant power fluctuation and energy time shifting/peak shifting applications. A hybrid smoothing method is presented, suitable for sunny and cloudy weather conditions and optimizing the battery energy uses and sizing. The battery state of charge (SOC) control and VSC area equalization modulation strategy (AEMS) is presented in detail. The design, modelling, control, and real-time implementation of the various plant configurations of high power grid interface solar PV, and BES systems as discussed above have been carried out, and their steady-state, harmonic, and dynamic performances, STATCOM operation, are evaluated under varying solar irradiance levels and change in grid voltages.