Design and analysis of Passive Rectifier based front end converter topologies for Offshore Wind Turbine Systems.

Abstract:

Wind power has emerged to be one of the most feasible renewable sources of energy. The advancement in wind energy sector is not only characterized by the overall generation boost but also the increase capacity of individual wind turbines as well. Offshore wind power has inspired the fields of High Voltage Direct Current (HVDC) for advantages of high power transmission in long distance and dc-power collection has emerged to be a topic of industry interest. At high power, the power electronic operation for power conversion becomes complicated and challenging. Hefty wind generators are popularizing advanced multilevel converter topologies and parallel rectifiers due to their capability of accommodating higher power. In this study first a back to back grid connected neutral point clamped (NPC) based wind power system is analyzed along with integration of energy storage system (ESS).

The NPC converter control is implemented based on proportional resonant (PR) current controller for both rectifier and grid-tied inverter. The control of a bidirectional converter with integrated energy storage system at the dc-link is proposed. The dc/dc converter controls the dc-link voltage by injecting the difference between the extracted power from the permanent magnet synchronous generator (PMSG) and the output power of the grid-tied inverter, to the energy storage system. The controller of the dc/dc converter compensates the shortage of extracted active power from the PMSG during reduced wind speed condition. The proposed controller ensures the injection of constant power to the grid during normal grid operation. The WTS achieves grid-side fault-ride-through (FRT) capability and it can inject the reactive power to the grid in order to enhance the voltage of point-of-common-coupling (PCC) during voltage sags. The performance of the proposed controller is investigated under grid faults and wind speed variations. Further analysis suggests that with higher number of semiconductor switches involved the probability of faults rises. And the complexity of such system demands higher computational power which is again hard to achieve and maintain in offshore scenario. Thus moving forward the focus is shifted to dc-power collection which eventually eliminates the inverter requirement at the turbine nacelle. For rectifier topologies converters with lower number of switches are investigated.

The NPC topology discussed required twelve switches in the front end rectifier alone. Voltage source converter (VSC) topologies are made up of six switches but for high power application the it needs to be paralleled. Passive three phase diode rectifiers are sturdy, rugged and simple but when operated it produces high THD and low power factor for generator output. For similar power level alternate to VSC, an unity power factor rectifier (UPFR) topology with only three IGBTs can be used. In this study the parallel UPFR (PUPFR) is proposed and analyzed as a front end rectifier for dc-power collection.

The UPFR topology consist of three phase diode rectifier as its main rectifier and each phase is equipped with bidirectional switching blocks (BSB). The BSBs are composed of one active switch and four diodes. The IGBTs are exposed to only half of the rating of the dc-link voltage. During operation, only a small fraction of the total power is commuted through the bidirectional switches and thus the IGBTs are not stressed all through. Two UPFR are paralleled to create the PUPFR. The PUPFR is controlled with outer dc-link voltage control loop and the inner current control loop. The current control is achieved by hysteresis current control ensuring unity power factor operation and generator output current shaping. The current is divided in parallel branches. The operation of PUPFR is investigated for wind variations and grid side demand variations. Bringing in the diurnal behavior of varying wind speed into consideration a modular operation of the PUPFR is designed. The modular operation is realized by virtue of modular control algorithm and two zero voltage switching circuit breakers at two branches.

The PUPFR system is implemented in hardware prototype. It is designed and operated at 2 KW. Four case scenarios are validated in prototype experimentation. Control of the system is implemented in control-desk software interface. Activation of converter control enabled the system to refer to the defined reference dc-link voltage.

The reliability and economic feasibility of the proposed topology is also investigated. Failure rate determination methods of each power circuit components from Military Handbook (MIL HDBK 217F) is used to compare the reliability of the different front end converters. Calculation of failure rate of individual components quantified the overall converter failure rate, mean time between failure and availability. PUPFR is observed to be the better performing front end converter topology in terms of reliability and economic feasibility.

It is thus observed from the analysis that PUPFR is a promising front end topology for WTS. The modular operation further defends the claim of use of parallel rectifier topologies in regions of higher wind variation and PUPFR are more reliable as well. Further the study can be expanded in terms of the wind turbine synchronous generators. The impact of monopoly market of rare earth material, use of PMSG becomes questionable. Wound rotor synchronous generator becomes one of the alternatives for PMSG. The brushless WRSG is investigated for operation with the UPFR topology. The co-ordinated control of the generator field and PUPFR is a plausible future work. To add to it, alternative arrangement of passive rectifier based generator side power electronic circuits (e.g. FACTS devices) can be investigated as well.