ANALYSIS OF SINGLE PHASE TRANSFORMERLESS INVERTER FED GRID CONNECTED SOLAR PV SYSTEM

Ph.D. THESIS

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ABSTRACT

The efficiency of the commercial photovoltaic (PV) modules is very low and it is typically in the range of 15-20%. Therefore, PV generated power should not be wasted by employing inefficient power conversion systems. The PV inverters are the significant interfaces between the PV modules and the grid. PV inverters are generally classified into the galvanic isolation and non-isolation system. High-frequency (HF) compact transformers in the DC side or line frequency (LF) bulky transformers in the AC grid side are usually employed to provide the galvanic isolation. Line frequency transformers are heavy, bulky, and expensive, and these reduce the system efficiency because of power loss in windings. Significant reduction in size and weight can be achieved by using HF transformer. The efficiency of the entire system is still low due to multiple converter stages.

Regarding the size of grid connected power inverters, a change of paradigm has been observed in the last few years. Small size inverters are substituting large central inverters. They process energy supplied by one string or a small group of strings. Following this trend, there has been a remarkable proliferation of academic and industrial research on new solutions for single-phase grid-connected inverters in recent years.

Transformerless inverter topologies are introduced for small scale grid connected PV system due to their high efficiency, lower cost, and high power density. However, leakage current is the main concern in these inverters which needs to be addressed carefully. The leakage current increases the total harmonic distortion (THD) of the grid current, electromagnetic interference, and system losses, and it causes personal safety problems. These topologies are mainly classified on the basis of leakage current reduction methods: Galvanic isolation without- common mode voltage (CMV) clamping and with-CMV clamping. Nevertheless, the galvanic isolation alone cannot completely eliminate the leakage current due to the influence of junction capacitance of switches and parasitic parameters. Thus, the topologies based on galvanic isolation alone such as HERIC, H5 and H6 families generate higher leakage current due to oscillation of CMV during zero voltage states. Hence, these topologies are equipped with extra common mode filter (CMF) which increases cost and size of inverters. In addition, these topologies do not comply with IEEE-1547 standard and inject more than 5% grid current THD at low irradiance levels.

Moreover, the reactive power handling capabilities of single phase transformerless inverter topologies are not properly explored. These topologies are designed to operate at unity power factor. However, according to VDE-AR-N4105, the capability of reactive power

generation is essential for the inverters employed in grid-connected PV applications. Even though various single phase transformerless topologies with reactive power capability have been introduced, their modulation strategies and structures are complex which increase the cost, losses, and complexity of the design.

Thus, it is necessary to explore the performance of the single phase transformerless inverter fed grid connected PV systems under different conditions. The topologies and modulation strategies should be designed such that CMV remains constant throughout the inverter operation and they exhibit high efficiency. Considering the fast growth of grid-connected PV systems, it is better for the next generation transformerless PV inverters to be capable of low voltage ride through (LVRT) with reactive power injection.

In this study, recently introduced single phase transformerless grid connected PV inverter topologies are analyzed. The performances of the topologies are evaluated in terms of CMV, leakage current, semiconductor device losses, efficiency, and THD. It is observed that leakage current generation is highly dependent on CMV, especially, high frequency components. The topologies are also analyzed for reactive power generation capability.

Several recently published topologies such as H5, HERIC and H6 families are analyzed for reactive power generation and LVRT capability. There is no path for current flow for the negative power transfer during freewheeling periods. Therefore, zero voltage states cannot be achieved during negative power flow. As a result, current is distorted and PV inverters inject current with high THD into the grid. These topologies with their conventional modulation strategy are not suitable for reactive power applications and LVRT capability.

Various improved modulation strategies are presented for the existing topologies. With improved modulation strategies, reactive power generation and LVRT capability are achieved in inverter topologies without any alteration to converter structures. Improved modulation techniques provide path for current to flow in order to generate zero voltage states during negative power flow. The injected grid current THD are within specified limit which is less than 5%.

An improved CMV clamped topology with improved modulation strategy is proposed which can eliminate leakage current and is capable of injecting reactive power into the grid. The proposed topology has less conduction losses compared to H5 and other H6 families as only two switches are in conduction state at positive grid voltage.

The proposed topology can eliminate leakage current and is capable of injecting reactive power into the grid. The CMV of the topology remains constant throughout inverter operations and it eliminates the requirement of extra CMF. THD analysis of the topology is carried out at various irradiance levels and the results comply with IEEE-1547 standard.