Analysis, Control and Applications of Active Phase Converters for Single-Phase Power Grids

Anil Kumar Adapa,
Thesis Advisor: Prof. Vinod John,
Department of Electrical Engineering,
Indian Institute of Science, Bangalore, India.

Abstract

Single-phase distribution is a preferred approach for setting up microgrids or supplying power to rural and remote locations due to its lower infrastructure costs when compared to a three-phase grid. On the other hand, three-phase induction machines exhibit smooth torque-speed characteristics, offer better starting torque, have higher power density and are of lower cost compared to their single-phase counterparts. Due to the modernization of the technologies used in agriculture and mechanization of production processes, the demand for electrical energy on single-phase distribution grid has increased considerably in the past decade. However, the sole availability of single-phase power limits the usage of three-phase induction motors in certain applications such as auxiliary services in railways, pumps or mills in the agricultural sector and in small urban and rural industries. Conventionally, power electronics based double-conversion drive systems are available that power three-phase machines with single-phase supply. However, inexpensive and low-efficiency power conversion solutions are often adopted to achieve cost benefits at the expense of performance and power quality.

In this context, there is a need for power electronic phase converters that facilitate the use of three-phase induction machines on the single-phase grid while offering high performance at low cost.

This work investigates reduced switch-count active phase converters (APC) that serve three-phase loads from a single-phase grid. Specifically, the focus is on topologies that process only a fraction of the load power while still maintaining the quality of power at the grid and load ends. An auxiliary capacitor based active phase converter (AC-APC) topology is shown to have reduced current stress in the switching devices and the dc-link capacitors. At the rated load of 3.3 kVA/0.8 pf, the total VA processed by the semiconductor devices of the conventional topology is 180% of the load VA. Whereas the semiconductor VA of the APC and AC-APC in the experimental prototype are 88% and

40% respectively. Analytical power loss evaluation shows that the device power loss at rated conditions for the APC and AC-APC are 46% and 18% respectively, of that of a conventional double conversion configuration. Moreover, 50% reduction in the double frequency dc-link ripple is observed in the experimental prototype of AC-APC when compared to that of a standard APC at rated load.

The proposed control structure allows asymmetric control of the three legs of the APC. It also facilitates independent selection of optimized components for higher order filters, to meet the independent design requirements at the grid and the load. The control to generate modulation signals for the APC with a shared leg is implemented as two decoupled single-phase converter controllers. A method for soft-starting an induction motor is incorporated in the APC. Moreover, the bidirectional power flow capability of the APC also facilitates injection of power to a single-phase grid. A common-mode filter and its design method are presented for the asymmetric APC, which significantly reduces the effects of common-mode voltage in the system. All the methods proposed in this work are validated on an experimental 5 kVA laboratory converter prototype.