CONTROL TECHNIQUES FOR MULTI-PHASE PERMANENT MAGNET MOTOR DRIVES UNDER OPEN CIRCUIT FAULTS AND MULTI-PHASE DC-DC POWER CONVERTER

by

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ABSTRACT

In electric motor drive applications, where high reliability is demanded, it is crucial to continue the drive operation under fault conditions. The multi-phase machines are advantageous over the conventional three-phase machines for fault-tolerant operation. This is because in a multi-phase machine, when faults occur in one or more number of phases, the machine can still continue its operation by using the remaining healthy phases. In this work, at first, the fault-tolerant control of multi-phase permanent magnet (PM) motor drives in the time domain is presented. An optimum open circuit fault-tolerant control technique for general *n*-phase PM machines, which can be applied for both sinusoidal and non-sinusoidal back-EMFs, is proposed. The fault-tolerant control technique is developed based on the instantaneous power balance theory. Closed form expressions are derived to calculate the excitation currents in the healthy phases which can produce the desired output torque under various open circuit fault conditions with zero torque pulsations, zero neutral current, and minimum stator ohmic loss. In the next part of this work, fault-tolerant control techniques for multi-phase PM machine drives in the frequency domain are presented. A theory of mirror symmetry is proposed to correlate the phase angles and amplitudes of the currents in the healthy phases, based on their spatial symmetry with respect to the fault in the motor drive. Utilizing the mirror symmetry in the healthy phase currents, a general fault-tolerant control approach is proposed for the multi-phase PM machines. The proposed approach is applied to derive fault-tolerant control techniques for five-phase PM machines with sinusoidal back-EMF and trapezoidal back-EMF. Optimum solutions for the fault-tolerant currents are obtained to operate the PM machines under single-phase and double-phase fault conditions. The proposed control techniques can successfully operate the multi-phase PM machines under different fault conditions with low torque pulsations and high output torque.

In the final part of this work, a high efficiency and high step-up non-isolated multi-phase DC-DC converter is proposed. The proposed converter can be used as an interface between the low voltage sources and the output loads, which are operated at much higher voltages. Examples of such applications are: interfaces between the low voltage distributed energy storage components (batteries, fuel cells, and ultracapacitors used in

the Hybrid Electric Vehicles, Electric Vehicles and Fuel Cell Vehicles) and the high voltage motor drive bus, High Intensity Discharge (HID) lamp ballasts, photovoltaic (PV) cells etc. The conventional boost converter is not suitable for such high voltage step-up application, as it can not be optimally designed to operate at a high efficiency. In the proposed converter circuit, coupled-inductor boost converters are interleaved. The leakage inductance, present in a practical coupled-inductor boost converter, causes high voltage stress on the switch and significant losses in the converter circuit. In this work, a common active clamp circuit is proposed to limit the voltage stresses on the switches of the interleaved converters to a lower level. The leakage energies of the interleaved converters are collected in a single capacitor and recycled to the output. The proposed multi-phase converter achieves high efficiency because of the recycled leakage energies, reduction of the switch voltage stress, mitigation of the output diode's reverse recovery problem, and interleaving of the coupled-inductor boost converters.