EMI Filter Design and Optimization for Three-Phase Motor Drive Systems

by

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ABSTRACT

Electromagnetic interference (EMI) is a common problem in power electronics systems. Pulse-width modulation (PWM) control of semiconductor devices in a power converter circuit creates discontinuity in voltage and current with rich harmonics over a broad frequency range, creating both conducted and radiated noise. The increase in switching speed enabled by new power semiconductor devices helps to reduce converter size and reduce switching losses, but further exacerbates the EMI problem. Complying with regulatory EMI emission limits requires the use of EMI filters in almost all power converter designs, and EMI filters are often the dominant elements for system volume, weight, and cost. This is particularly true for motor drives used in an aircraft environment, where filtering of both input and output conducted EMI may be necessary.

The traditional approach to EMI filter design requires measurements of unattenuated EMI emission of a converter, which cannot start until a complete system prototype has been built and tested. This “EMI-last” approach results in sub-optimal solutions at best and often results time-consuming and costly redesign of part or the entire system. To solve this problem and to enable a “concurrent EMI design” approach, EMI modeling of motor drive systems is studied first in this work. Piece-wise linear behavioral models are used to model different components of a typical motor drive system, such as semiconductor devices, passive components, interconnects and cables, and motors. Such behavioral models can be established in parallel with motor drive circuit and control design, thereby providing a means to evaluate different design options in terms of system EMI performance and to optimize EMI filter design without requiring prototype measurement results.

The second part of this work deals with new methods to reduce EMI emission from motor drive systems. One technique proposed is to reduce system common-mode (CM) EMI emission by inserting passive components around the CM voltage source to create a balanced Wheatstone impedance bridge where the CM current generated through one path is cancelled by that in another path, significantly reducing CM current emission at the input or output terminals that needs to be attenuated. The inserted passive components carry only the CM current, hence can be much smaller than traditional CM filter compo-

nents which have to carry the full input or output current. The second technique, which is effective in reducing both CM and differential-mode (DM) EMI, is by phase-shifting the PWM signals of parallel converter modules. In particular, asymmetric interleaving, in which the phase-shift angle is varied from module to module is applied to optimize the cancellation of harmonics that otherwise drive the EMI filter size.

The third part of this work deals with damping of EMI filters. It is known that peaking in the output impedance of an EMI filter due to parallel resonance of the filter inductor and capacitor may create an intersection point with the input impedance of the converter, causing degradation in converter control performance or even instability of the filter-converter system. In this work, we demonstrate that dipping in the input impedance of an EMI filter due to series resonance of filter inductor and capacitor can also cause intersection with the source output impedance and lead to source-filter system instability. Optimal damping of EMI filter input impedance to avoid interactions with the source output impedance is studied. Closed-form analytical results are developed for optimal design of different damping circuits. The optimization method is further extended to multi-stage LC filters.