6. Conclusions and Future Work

This dissertation addresses the issues related to Power Electronics Building Blocks and System Integration. It consists of four parts: development and design considerations of PEBB modules, modeling a PEBB-based distributed power system, interaction analysis of the integrated system, and dc bus conditioning. The research was carried out with multi-level modeling, analysis and simulation of a PEBB-based power system, and the construction and experimentation of the PEBB-based power system testbed.

The dissertation identified the basic power electronics building block (PEBB) structures for a wide variety of applications. The PEBB module, as a multi-terminal device, is expected to have superior switching performance: low switching loss and insensitivity to system integration. In reality, however, the PEBB module exhibits a strong parasitic oscillation at the turn-on and turn-off. Using INCA (Inductance Calculator) and circuit simulation software, the dissertation revealed the microscopic correlation between the physical packaging layout conductor traces and equivalent circuit elements. The dominant packaging inductance was identified. The complicated electrical, magnetic, and mechanical interactions inside the wire-bond power module were revealed. The PEBB module based on the advanced packaging techniques was characterized in comparison with the wire-bond packaging technique. Different soft-switching techniques were evaluated for PEBB application in smoothing the switching transient waveform and reducing the switching loss. The zero-current-transition (ZCT) was proved better for PEBB application after a comparative analysis with the zero-voltage-transition (ZVT), because the parasitics along the power flow path are absorbed into the resonant soft-switching operation. This makes the PEBB modules insensitive to integration.

The dissertation presents three-level models for the PEBB-based power system: the discrete model, the large signal model, and the small signal model. A novel large signal average model is developed based on the build block concept. Firstly, the PEBB module is modeled as a duty cycle controlled voltage and current source. Secondly, the SVM is modeled based on the averaged concept, which provides the duty cycle information to PEBB modules. There is something very special about the SVM model. The duty cycle is calculated in a way that it calculates the duty cycle at least once at the beginning of each switching cycle. Therefore, the discontinuity and common mode component of the SVM are captured. Using these averaged models, the computer models of a large-scale system can be constructed easily the same as the hardware. No dq/abc and abc/dq transformations are needed. Even though the system is a time-varying system, these models still allow for small signal analysis by looking at the transfer functions on rotating dq coordinates. Therefore, this modeling approach significantly simplifies the large-scale system simulation. The time domain simulation speed is very fast. Even though the system is modeled based on the modularized concept on ABC coordinates, the small signal transfer functions on the DQ coordinates still can be obtained. The analysis also reveals how a small-signal perturbation is propagated in the time-varying three-phase systems.

The dissertation also demonstrates the system-level interactions in the PEBB-based power system and some of the mitigation methods. Three interaction scenarios are presented: (1) the zero-sequence circulation current in paralleled three-phase rectifiers caused by the interleaved discontinuous SVM, (2) the load and source interactions caused by unbalance load and impedance overlap, and (3) the combined common mode noise caused by both front-end PWM rectifiers and load inverters. The phenomena (1) and (3) are analyzed and tested on a 400 V dc bus PEBB system test-bed, and the design considerations are implemented on the test-bed.

Finally, a dc bus conditioner is proposed in the dissertation. The dc bus condition is a novel concept for dc distributed power system. A bi-directional dc/dc converter is used for the bus conditioner, which shunts the large signal ac current, which is otherwise on the dc bus, into an isolated energy storage component, so that the dc bus and source converter are free from its contamination. It decouples the ac dynamic load from the dc bus. It also improves the transient performance of the dc bus, actively shapes the input impedance of the regulated converter or the output impedance of the source converter, and provides more stability margins to distribution systems. The dc bus conditioner was constructed; and preliminary tests were carried out at low power level.

The following research areas are of interest of future work.

(1) The parasitic packaging inductance is a function of packaging techniques and thermal management. Thermal management, layout design, packaging parasitics, and device switching characteristics are coupled in a module. Further integrated designs with considerations of thermal management and layout design would benefit overall module's performance.

(2) The dc bus conditioner has been tested at low power level. It was shown that inductor current of the bus conditioner can follow the given reference. High power testing is needed in a large-scale system.