

8. CONCLUSIONS AND FUTURE WORK

8.1 CONCLUSIONS

This work has comprehensively addressed the issues of parallel three-phase PWM converters. The major accomplishments and some conclusions are summarized below.

- This work has developed a novel modeling approach for parallel three-phase converters. Instead of modeling the parallel converters as a whole, a generic functional switching unit is identified and averaged. The unit for the current-bidirectional converters is called a phase leg. The unit for the current-unidirectional converters is called a rail-arm. Functionally, the phase leg and rail arm are the most basic components in their converters. Based on the phase-leg or rail-arm averaging, the developed three-phase converters' model is not only equivalent to the conventional three-phase converters' model that is based on phase-to-phase averaging, but it also preserves common-mode information, which is critical in the analysis of the parallel converters.
- As part of the parallel models, a unique zero-sequence channel in both current-bidirectional and current-unidirectional converters has been explicitly shown. It is found that the zero-sequence current is governed by the difference of the common-mode voltages between the two converters. The common-mode voltage of one converter normally has no impact on the converter output except high-frequency common-mode noise, which is usually dealt with by filters. Because of the directly parallel operation, a zero-sequence current path is formed. As a result, the common-mode voltage has to be controlled so that the zero-sequence current can be minimized.
- This work has proposed a novel zero-sequence current control concept that uses varying zero-vectors in the pulse-width modulation of the converters. The principle of the control idea is to reject the zero-sequence current within an individual converter. Therefore, the control can be designed independently from the other

converters. It is also independent from the other loops' design within individual converters. The control concept greatly facilitates the expansion of a parallel system.

- The zero-sequence modeling and control concept has been generalized to any other multi-phase current-bidirectional PWM converters, such as full-bridge rectifiers and inverters, three-phase three-leg rectifiers and inverters, and three-phase four-leg rectifiers and inverters. These converters cover most medium- and high-power applications.
- This work has proposed a novel droop load-sharing method using a gain-scheduling technique. The method can achieve both good voltage regulation and good load sharing. Since it is a droop method, a modular design approach can be achieved.
- This work has presented a novel solution in the modulation and control of a new three-phase, four-leg inverter. With the proposed solution, the inverter can not only nearly eliminate high-frequency common-mode dv/dt noise, but it also can handle low-frequency common-mode components that occur due to unbalanced and nonlinear load.

8.2 FUTURE WORK

This work has practically established a foundation of modeling and control of parallel three-phase PWM converters. However, further studies are absolutely necessary. Some of the possible directions are identified below.

- Since the developed zero-sequence model is an averaged model, it cannot predict the peak of the zero-sequence current. Also, the proposed zero-sequence current control is an average current-mode control. It does not guarantee a low magnitude current peak, although the simulation and experimental results show the small current peak. Therefore, one possible future work is to quantify the peak current and to investigate a peak current-mode control for the zero-sequence current.
- The proposed four-leg inverter solution has some trade-offs between common-mode noise reduction and differential-mode ripple increase. A quantified trade-off study needs to be conducted.

8. CONCLUSIONS

- More experimental tests are needed in order to validate the proposed zero-sequence current control scheme under different practical conditions, such as transient, unbalanced source, high modulation index, and so on.

8. CONCLUSIONS