Chapter 5

Control for the Contactless Series Resonant Energy Converter

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ABSTRACT

This chapter presents control methods applied in the operation of the series loaded series resonant (SLSR) power converters in a most efficient operation zone. The choice of the control method is affected by the objective to guarantee suitably the efficiency, being this method in the same time, relatively easy to apply. The first part of the chapter compares three basic principles of regulation: frequency mode (FM), pulse width mode (PWM), and their combination (PWM/FM). Finally, a new method for instantaneous regulation is developed. The proposed technique consists of a simplified observation of a state variable value to limit each portion of supplied energy, depending on the requirement for power in each half period. The result of this regulation is comparable to the current mode (CM) control applied to the hard-switching power converters. The viability of this new regulation method is demonstrated by simulations of its analogue circuit implementations and experimentally proved. The circuit is also prepared for the changes in the magnetic coupling (contactless energy transfer).

1. INTRODUCTION

This chapter presents control methods, applied in the effort to maintain the operation of the Series Loaded Series Resonant (SLSR) power converters in their most efficient operation mode, including wireless energy transmission. This is not an exhaustive study of all possible techniques of SLSR converter control but rather a demonstration of the possibility to achieve high efficiency operation, following the principles and ideas suggested in previous publications, e.g. Valtchev and Klaassens (1990). The choice of the control method is affected by the objective to guarantee a suitably efficient contactless conversion of energy, being this method in the same time, relatively easy to apply.

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The present chapter starts with a comparison of three basic ways of regulation for SLSR converters: frequency mode (FM), pulse width mode (PWM), and their combination (PWM/FM). Finally, a separate, new method for instantaneous regulation of the energy delivered to the resonant circuit, is presented. The proposed technique is based on a direct measurement of the instantaneous value of a state variable. Based on simple calculations, the switching is commanded, to regulate each one portion of supplied energy, sent through the resonant circuit. In this way, the necessary energy is decided and sent in each individual half period. The result of this regulation may be compared to the effect produced by the current mode (CM) control applied to the hard-switching power converters. The viability of this new regulation method is demonstrated by simulations of scaled in time analogue circuit implementations, and by measured results. The circuit is provided with another feedback that permits the changes in the magnetic coupling to be compensated for. This allows the operation of the contactless power converter to be commanded correctly and the power switches to be protected accordingly.

2. THE CONTROL OF THE SLSR AND CONTACTLESS CONVERTERS

Several control methods are known to have been developed during the last 30-35 years and many of them are already considered classical, implemented in factory-made resonant converters, e.g. Hewlett-Packard (1982). The problem of the resonant converter physics is that the energy is flowing from magnetic to electric and vice versa, so the instantaneous control is extremely difficult. It is not possible to cut off the process in the right moment. The difficulty is even greater if contactless energy is to be transferred through a loosely coupled magnetic transmitter/receiver, in which case the reaction should be fastest, to avoid damaging the power switching devices. In the effort to maintain the operation of the SLSR converter stable and efficient and especially, to keep the contactless converter in the best efficiency operation region, the modes of operation were considered, and some graphical methods are already in use, e.g. (Jovanovic, Liu, Oruganti, & Lee, 1987). The safe behaviour of the SLSR converter, especially the transmitting part, is very important for the mass inclusion of the wireless energy in the electric vehicle charging technology (Valtchev, Jorge, Craciunescu, & Brandisky, 2012) and some initial ideas are discussed in (Medeiros, Valtchev, & Valtchev, 2012).

2.1. The Regulation Methods and the Difficulties Up to Now

The above mentioned graphical, state-plane method looks reasonable, but its implementation rises some concern. There are methods that include calculation of normalized phase-plane trajectory as in Nguyen and Dhyanand (1987), Nguyen, Dynand, and Thollot (1986), and Rosetto (1992). Those calculations are complicated and need multiple points of real-time measurements. In the works of Jovanovic et al. (1987), Souesme et al. (1989), Kim et al. (1991), etc. many measurements are also required as an input for the calculation of the instantaneous conditions (phase-plane graphics), to recalculate the moments of necessary commutations. Since the beginning of their work on the SLSR power converter, the intention of the authors was to find a simple and reliable solution. The beginning is maybe in the simplification of the TLO problem (Klesser, & Klaassens, 1986), a heavy problem from the thyristor times and still existing in the super-resonant converter when the resonant could provoke a back-discharge (Valtchev, 1990). In more recent publications, e.g. (Amghar, Darcherif, Barbot, & Boukhetala, 2014), the modelling of the converter is complex. The calculations of Lyshevski (2000) are even more com-
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