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Bidirectional Switch Commutation with a New Multiple-Output Resonant Matrix Converter Topology Applied to Domestic Induction Heating

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Abstract

This paper describes a bi-directional switch commutation strategy for a resonant matrix converter loaded with a contactless energy transmission system. Most of the ac-ac converters used in home-appliances are based on single-output dc-link inverters, which provides a cost-effective and straight-forward solution. However, this two stage power conversion decreases power density and efficiency. Direct ac-ac conversion has been thoroughly studied in the past. However, the complex control scheme and higher cost has prevented it from being used in low-cost applications, such as home appliances. This paper proposes the direct ac-ac conversion by means of a multiple-output resonant matrix converter applied to multiple-inductive load systems. Due to the different application compared to classical 3 phases to 3 phase matrix converters supplying induction machines a new investigation of possible commutation principles is necessary. The paper therefore compares the full bridge series-resonant converter with the 3 phase to 2 phase matrix converter. From the commutation of the full bridge series-resonant converter, conditions for the bi-directional switch commutation are derived. One of the main benefits of the derived strategy is the minimization of commutation steps, which is independent from the load current sign Most of the ac-ac converters used in home-appliances are based on single-output dc-link inverters, which provides a cost-effective and straight-forward solution. The proposed topology reduces significantly the number of devices and complexity, leading to an efficient, versatile and cost effective solution. The analytical and simulation results have been verified by means of a prototype applied to a novel total-active-surface induction heating appliance.

Keywords: Induction heating, resonant power conversion, matrix converter, digital control.

Introduction

An efficient high-speed bi-directional data transmission scheme for isolated AC-DC and DC-DC switched mode power converters is presented. The bi-directional scheme supports fast, efficient and reliable transmission of digitally encoded data across the isolation barrier and enables primary side control, allowing effective start-up and a simple interface to system controllers. Another key feature is that the bi-directional communication is independent of coupler gain and degradation and only the minimum number of couplers is required. The digital interface can also be used to transmit auxiliary signals between both sides. For test purposes, the scheme has been implemented on FPGAs and verified using a custom-built SMPC board. Many electronic-fed home appliances are based on dc-link inverters which provide frequency adjustable Excitation required for motors, air conditioning systems, or induction heating device. This architecture provides a straight forward implementation, but also implies a two-stage power conversion which decreases power density and efficiency. Direct ac-ac conversion has been thoroughly studied in the past in order to provide an efficient and compact solution with no energy storage elements. These converters have been compared to other alternatives and successfully applied to drives aerospace applications, or power supplies. Matrix converters have also been applied to series resonant loads for 3-phase systems in . Considering the induction heating application, several resonant matrix converters featuring MOSFETs (Nguyen-Quang et al. 2006; Nguyen- Quang et al. 2007) or RB-IGBTs (Gang et al. 2008; Sugimura et al. 2008) have been proposed. All the proposals previously described show some common positive points including improved power factor and harmonic distortion, increased power density, and reduction of electrolytic bus capacitors. However, the main drawback is the use of additional switching devices to implement the matrix converter, which lead to increased control complexity and cost. This issue becomes critical for certain cost-oriented applications. This may be the main reason A New Multiple-Output Resonant Matrix Converter Topology Applied To Domestic Induction Heating for the low percentage of use of matrix converters compared to classical dc-link inverters some areas as the home appliances segment. the aim of this paper therefore is to propose a new multiple-output resonant matrix converter topology based on the series resonant multi-inverter (O. Lucía et al. 2010) to modify traditional power conversion based on a dc-link inverter (Fig. 1 (a)). The proposed multiple output resonant matrix converter (Fig. 1 (b)) combines the advantages of matrix converters with the improved cost and power control of the series resonant multi-inverter. Since the matrix converter block is shared with a high number of induction loads, the overall cost is significant reduced, and the proposed topology can target the home appliances market.

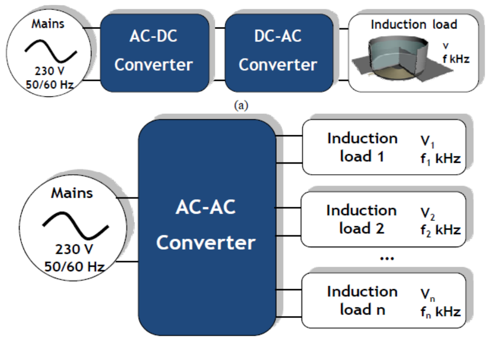
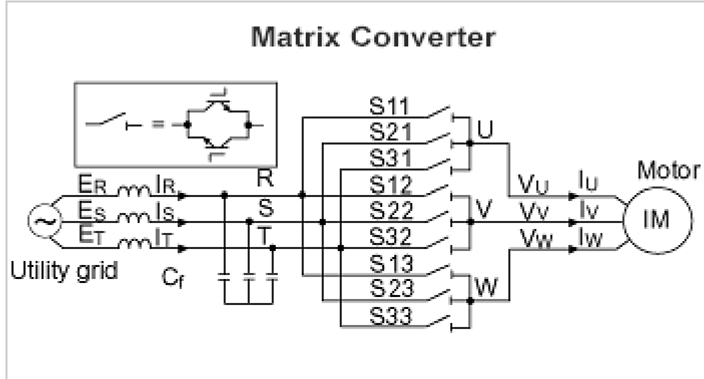


Fig 1.0 Introduction of heating system

Matrix Converter

The matrix converter directly converts AC to AC rather than AC to DC to AC as in conventional voltage source PWM AC Drives. Matrix converters have capability to regenerate power and suppress input current harmonics and noticed as optimum drives for applications ranging from cranes, elevators and centrifuges where regeneration occurs, to air-conditioning fans and feed-water pumps where high harmonic countermeasures are required. Figure 2 shows main circuit configurations of the matrix converter and the conventional voltage source PWM AC Drive. The main circuit of the matrix converter consists of small input filters, which consist of reactors and capacitors, and 9 bi-directional switches. The bi-directional switches consist of the combination of IGBTs shown in Fig.1. On the other hand, the voltage source PWM AC Drive consists of a power AC Drive circuit with the combination of a rectifying circuit on the input side, a smoothing circuit with capacitors on the intermediate part, and IGBTs on the output side.

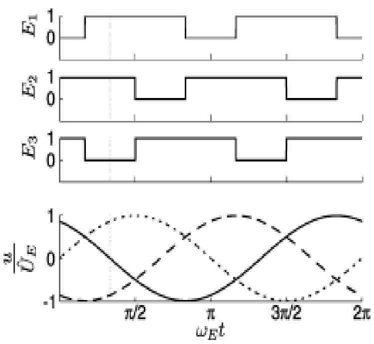


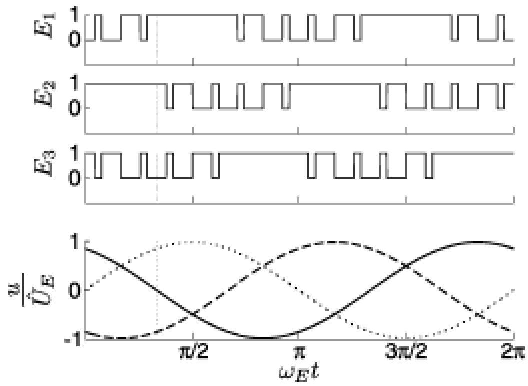
Matrix converter circuits offer the following effects comparing to conventional AC Drive circuits.

1. Suppression of power harmonics Realizes less than 7% THD of input current and more than 98% input power factor without any specific measures taken.
2. Longer operating life The main circuit does not have endurable parts such as an electrolytic capacitor. This makes the operating life of the main circuit longer and the maintenance interval longer.
3. Elimination of derating With the elimination of current constriction on any specific device, the reduced operation during low-frequency operation is unnecessary.
4. Power regeneration Unique bi-directional switches for directly connecting the power supply and loads enable continuous regeneration.
5. High-efficiency Only the bi-directional switches are used to connect the power supply and loads, allowing higher-efficient operation than as in conventional AC Drives.

Current Commutation

Though several commutation strategies have been introduced over the years , a new investigation of the commutation process is necessary because the topology and the control of the three-phase to two-phase matrix converter differs from that of the known three-phase to three-phase matrix converters. Moreover, previous work deals with three-phase to two-phase matrix converters, e.g., suggested four-step approaches for fixed resonant frequency , which are not always practicable. If we neglect the commutation strategy called basic current commutation





that breaches the basic switching rules as mentioned before and soft-switching techniques by the use of additional resonant component leads, a separation in current-direction-based strategies voltage-magnitude-based strategies and combined strategies becomes obvious. For the current direction- based strategy, it is necessary to determine the direction of the load current. With this information, a unidirectional current path can be switched. Voltage magnitude strategies are based on the detection of the signs of the mains phases. The commutation paths are switched in such a way that there are no short circuits between the input phases and the load current will not be interrupted.

Switching State Machine

For simulation and experimental verification, a state machine that performs and controls the commutation, being dependent on a superior controller, the combination of the high-frequency and the low-frequency pulse patterns, and the wanted high frequency output voltage is required. The demand of commutating not only between the main states of one interval but also between the main states of adjacent intervals first makes a general view of all possible commutations—fulfilling the conditions mentioned before—necessary.

A. Deriving All Possible Commutations

As it becomes clear from Table I, a direct two-step commutation between the two main states of one interval, e.g., not possible at any time due to only a unidirectional connection of the load during the commutation. So, a direct commutation between the two normal main states can be done only by using the base main state as an intermediate state. Furthermore, possible commutations between the main states and base main states of adjacent intervals as they are required when a new interval becomes active are dependent on the active switches of the individual source and target state. Commutation from IE to IIB is possible, but not from IE to IIC. Analyzing the switching state table led to the result that a commutation possibility between states of the same or an adjacent interval is not given if one of the following two conditions becomes true.

Conclusion

Direct ac-ac conversion has proven to be a convenient technique which can be extended to the ubiquitous dc-link inverters present in most household appliances. It combines higher power density with a reduced number of conversion stages and energy-storage elements. However, the higher number of switching devices and complex control scheme has prevented it from being widely used. In this paper, a multiple-output resonant matrix converter has been proposed. This paper has presented a two-step commutation policy for a three-phase to two-phase matrix converter, which supplies series resonant loads. With the investigation of the main switching state conditions, it was shown that current-direction-based commutation strategies are not suitable due to the demanded high output frequencies above 100 kHz. Instead, the presented method is very similar to a special two-step method presented in and . This strategy allows only direct commutations between the base main states and the normal main states. Due to the used low-frequency pulse pattern of the input phases, an additional reduction of necessary commutation steps is feasible. The developed switching state machine becomes less complex. Simulations and measurements on a prototype prove the operation of the two-step commutation policy. No short circuits of the input phases and no breaks of the output current are occurring. Further, with the use of the proposed commutation strategy—which forces a bidirectional connection of the load at any instant—the individual operating point influences the load current path but not the sequencing of the switching state machine. The commutation is therefore independent of the

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individual resonant frequency, which, in practice, may vary for some applications.

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