PFC Rectifier for High Power Quality and High Efficiency Domestic Induction Heating Appliances

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***Abstract*—Domestic induction heating technology is present in most of buildings due to the advantages of induction cooktops such as fast heating, efficiency, safety, and cleanness. However, the latest trends in this technology have brought new challenges due to the control restrictions to fulfill EMC standards, and due to the required high power, efficiency, and power density, while keeping a cost-effective implementation. This paper proposes the use of a front-end PFC rectifier in order to address these challenges and get a high power quality and high efficiency solution. A review the state of the art of PFC rectifier is presented, and the main advantages of its application to domestic IH appliances are described.**

Keywords—induction heating, home appliances, power factor correction, PFC rectifier, multi-phase.

I. INTRODUCTION

Most of electronic devices connected to the electric distribution of buildings are composed of non-linear loads. These may produce main voltage distortion due to the harmonic content of the current and low power factor, leading to low power quality and low efficiency. In order to avoid these drawbacks, Power Factor Correction (PFC) techniques are widely used.

Induction Heating (IH) is a heating technology that uses electromagnetic fields to increase the temperature of conductive materials. The first developments were applied to industrial metal melting in the early 1900s, and this technology was quickly developed during WWII to reach accurate and fast processes of metal hardening. Later, it was extended to automotive and aircraft industries. Currently, it is used in a wide variety of applications, such as manufacturing processes, medical treatments, and domestic applications, among others.

Since the late 80's, domestic applications were able to take the advantage of this technology due to the advances in power semiconductors, especially with the introduction of the insulated-gate bipolar transistor (IGBT). This improved technology enabled developing compact, reliable and cost-effective solutions. The main domestic application of IH are the IH cookers, that get not only an improved heating times and efficiency compared with classical cookers, but also more safety and cleanness due to the lower surface temperatures [1].

The elements of a typical domestic IH system (Fig. 1) can be classified in three main groups according to its functionality: the inductor-load system, the power electronics, and the control electronics. Each block has to be optimally and coordinately designed to get a good performance, efficiency, and cost-effective final product. Besides, flexible surfaces improve further this experience because of the bigger coils with several concentric windings or fully active surfaces, enabling the use of any pan or pot, regardless the selected size, shape, or position.

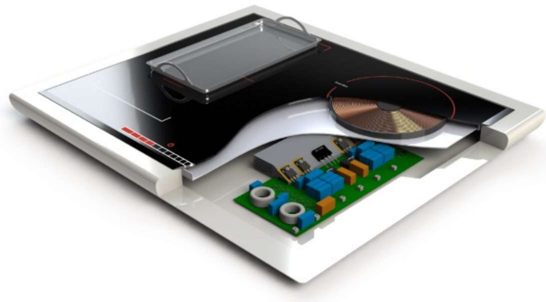

Fig. 1. Typical induction cooktop with flexible surfaces.

The remainder of this paper is organized as follows. Section II presents the main challenges of domestic IH appliances and the main drawbacks of current technology. In Section III, PFC rectifiers are introduced as a solution to improve the performance of cookers, and the state of the art for passive and active rectifier systems is presented. In Section IV, the advantages of using a PFC rectifier applied to domestic IH are discussed. Finally, Section V summarizes the main conclusions of this paper.

II. CURRENT CHALLENGES OF DOMESTIC IH TECHNOLOGY

Currently, IH cooktops are usually composed of two isolated electronic boards powered from two mains phases in certain regions, where the maximum phase current in domestic installations is usually limited to 16 A. However, there are different installation limitations in other regions where only a single-phase mains connection exists, but limited to 25 A, or areas where three-phase mains connections can be used. Moreover, the design specifications of flexible surfaces are more restrictive because of the control constraints, higher output power, higher efficiency, the required power density to fit the electronic system into a built-in implementation, EMC restrictions, power coupling issues between mains phases, and, last but not least, the cost.

In this context, using a front-end power stage that allows separating the mains from the IH inverters has been recently identified as a key research because it will allow partially overcoming these limitations, obtaining a good Electro-Magnetic Compatibility (EMC) performance, efficiency and avoiding the control restrictions over downstream inverters. Furthermore, developing a front-end stage that allows merging different mains phases in a common bus voltage will avoid the use of several isolated electronic boards as it is now, leading to a significant cost reduction among other additional advantages to domestic IH [2].

III. STATE OF THE ART OF PFC RECTIFIERS

In an electric power system, a load with a low power factor draws more current than a load with a high power factor

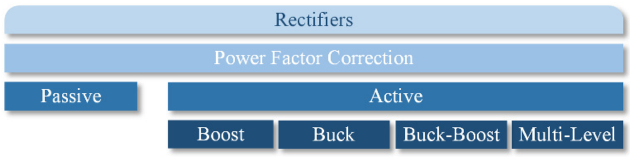

Fig. 2. Classification of the PFC rectifiers.

for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor.

PFC technique reduces the harmonic content with the consequent increases of the power factor of a load, improving efficiency for the distribution system to which it is attached. Linear loads with low power factor, such as induction motors, can be corrected with a passive network of capacitors or inductor. Non-linear loads, such as rectifiers of domestic IH, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise the power factor (Fig. 2). On the one hand, passive methods include the use of tuned LC filters and avoid the control elements, what represents a robust solution. On the other hand, active methods come as a more efficient solution by using controlled solid-state switches in association with passive elements such as resistors, inductors, and capacitors [3, 4].

A. *Passive PFC rectifiers*

In the simplest case, conventional rectification systems along with inductances and capacitors for filtering may be used in order to get low complexity power factor correctors. The main advantage is the high robustness because control, sensors, or auxiliary supplies are not necessary. However, larger magnetic components are usually required for filtering, resulting in increased size, weight, and volume converters. Besides, the passive filter may not respond adequately if the load power factor comes to vary. Moreover, the output voltage is not regulated and depends directly on the mains voltage level.

B. *Active PFC rectifiers*

Active PFC rectifies are able to reach Total Harmonic Distortion of the current (THD_i) smaller than 3% and a higher power density at the cost of a more complex control [5]. In fact, the closed-loop operation of the static power converter dedicated to PFC assures satisfactory performance with high input PF and regulated dc output voltage over a wide operating range. However, the drawback of this rectification method is the increased complexity and reduce robustness in comparison with passive PFC rectification systems.

IV. Active PFC Rectifier Applied to Domestic IH

A multi-phase boost active PFC rectifier provides significant advantages to domestic IH. Firstly, higher power can be delivered to the pots, e.g. typically 3.6 kW systems can be easily rescaled to 11 kW, decreasing significantly the heating times in bigger pots. EMC issues are isolated from the IH design, decreasing the filter size and avoiding the use of complex jitter strategies when non-linear loads are powered. The control hardware can be also simplified, i.e. a single control unit is able to control both the PFC stage and the multi-phase outputs, removing isolated measurements and auxiliary power supplies for each phase.

Secondly, the IH system control is improved because of the controllable bus voltage, allowing an easier and more accurate power control in several IH load scenarios, enabling also the operation closer to the resonant frequencies, improving the IH inverter efficiency. Furthermore, power coupling issues between different mains phases when multiple inductors are activated in multi-coil IH systems are avoided because a single inductor can be powered from several mains phases.

Finally, the higher the bus voltage is, the lower the required current through the switching devices and coils, decreasing the conduction losses. The inherent higher and low-ripple voltage of the proposed systems enables also a better usage of the switching devices, leading to potential cost reductions in the inverter stage. All these benefits motivate and justify the application of a multi-phase PFC stage to domestic IH in order to achieve a good tradeoff between efficiency, power quality, and cost, improving the energy management of buildings.

V. Conclusions

This work has proposed the use of PFC rectifiers to improve the performance of current domestic IH appliances, keeping a cost-effective implementation. A review of the state of the art of PFC rectifiers using passive and active methods has been presented in order to find the most effective solution for this application. Finally, the main advantages of a multi-phase boost active rectifier system have been highlighted, such as high power, good EMC performance, and high efficiency. The final version will be completed with an exhaustive comparative of the different state-of-the-art alternatives that improve the current implementation, and the experimental results of the selected alternative will be presented.

Acknowledgment

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