New Configurations of Power Converters for Grid Interconnection Systems

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***Abstract*—The increased penetration of renewable energy sources and other distributed energy sources has been seen nowadays. In this scenario power converters play a crucial role by providing the interconnection of these energy sources. This paper presents new configurations of power converters for grid interconnection systems. Several topologies are analyzed which are based on isolated ac-ac matrix converters.**

***Index Terms*—Grid interconnection, Power converters, Galvanic Isolation**

I. Introduction

According to the Energy Program 2014-2018 from the Chilean Minister of Energy [1], the technological and economical development of the country has lead to an increase in the energy demand in Chile. It is well known that energy resources based on fossil fuels are very limited in the country. Chile has little natural gas and oil resources and, at the same time, the extraction costs of coal are high. In addition, there is huge social opposition to the electrical development, because the perception of the community to this development is associated with environmental deterioration and social cost.

This has lead to higher generation costs and thus high electricity prices for the consumers. With all this what is needed is a "safe and efficient energy development, with reasonable prices, that take advantage of the renewable resources in a sustainable and non-polluting way".

In order to avoid the events experienced after the big earthquake and last huge storm in the north and central areas of the country (communication problems and thousands of people without electricity), recent initiatives from the government have been focused on electrical systems interconnection, to the promotion of using non-conventional renewable energies, and the installations of microgrids in isolated areas as well as the inclusion of redundancy and reliability of the interconnected system. In all of these initiatives, power converters play a critical role because they allow the integration to the electrical network of different kind of generation and distribution systems.

In the last years the concept of microgrids has become very popular. "A microgrid is a localized station with its own power resources, generation and loads, which is intended as a backup power or to bolster the main power grid during periods of heavy demand. Often, microgrids involve multiple energy sources as a way of incorporating renewable energy. Other purposes include reducing costs and enhancing reliability." [1]. In the last years it is possible to find different microgrid systems based on alternative renewable energies such as: solar (photovoltaic - thermal) [2]–[6], wind [7]–[12], ocean [12], micro-hydro [6], [10], [13], geothermal [14], [15], among others. Most of these microgrid clusters are working in islanded or grid interconnected modes.

In this context, power converters are critical, because they allow the integration to the electrical network with different kinds of generation and distribution systems. The most traditional power converters used in these applications are active front end rectifiers (AFE) [16], [17], two-level voltage source converters (2L-VSI) [18]–[20] and multilevel power converters such as the three-level neutral point clamped (3L-NPC) converters [21]–[23] and cascade H-Bridge topologies [24]. Modular multilevel converter technologies have emerged also as a suitable solution to the integration of renewable energy to the electrical grid [25]–[27]. As it can be reviewed, most of the power converters commonly used nowadays include storage elements which introduce size, weight and failure possibilities in the system.

An alternative to the converters with storage elements is the matrix converter (MC) which is shown in Fig. 1. The MC is a simple and compact power circuit that directly connects the AC-source with any arbitrary AC-load without the need for large storage elements, making this topology suitable for many applications where weight and size are important issues [28]–[30].

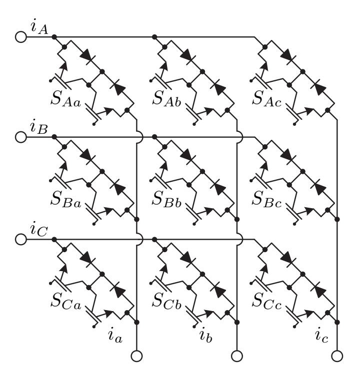

Fig. 1. Power topology of the conventional direct matrix converter.

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[1]http://www.minenergia.cl

With MC topologies the generation of output voltages of any different amplitude and frequency, sinusoidal input and output current waveforms, as well as operation with unity displacement power factor and regenerative capability are all possible. One of the challenges of MCs used to be the commutation of current between the bidirectional switches, but this issue has been solved with multi-step commutation techniques [31]. Due to these characteristics, in recent years MCs have shown continuous and fast development related to the development of new topologies and control methods, including industrial applications with standard units for high and medium voltage using cascade connections [32], [33].

The main goal of this paper is to contribute to the energy development of the country by proposing and studying new configuration of power converters based on multiport modular power converter structures.

II. The Use of Matrix Converters for Grid Interconnection Systems

Different modulation and control methods for MCs can be found in the literature [34]–[37]. These methods have different implementations and different levels of complexity, but all have dynamic behavior which is acceptable in a variety of applications. As reviewed in [38], the most used techniques are Venturini, carrier-based pulse width modulation (PWM), space vector modulation (SVM) and direct torque control (DTC) [38]–[43]. Other methods that have been applied to MCs in specific applications are fuzzy control, neural networks and genetic algorithms [44]–[46]. Predictive control has shown to be a very interesting alternative for control MCs because the use of the discrete nature of power converters and its simplicity for implementation and intuitive approach [36], [37], [47].

Matrix converters have emerged as a flexible and efficient alternative to manage energy in specific applications such as military, aerospace, wind generation systems among others. However, they have not been deeply studied in applications for grid interconnection of microgrids, generation systems and/or loads. The work done in [48] has considered a modified matrix converter topology for grid integration of two AC sources to the utility, demonstrating that “this converter is very suitable to integrate two AC type power sources into the utility grid” [49], [50].

In order to use the matrix converter in high power applications, new multilevel topologies have appear in the last years. These new configurations allow “high power quality, high-voltage capability, low switching losses and low EMI issues” [51]. In [52], a multimodular matrix converter for wind power generation applications is proposed. The same idea has been presented in [33] and [53] for other applications such as blowers, pumps, extruders, mixers, kilns, etc., where the basic block of the modular matrix converter is a three-input one-output module with six bidirectional switches. This structure allows the use of low voltage power semiconductors, with low switching frequency and also the generation of high-quality output waveforms. The common modulation and control strategies developed for these topologies are PWM and SVM techniques.

III. Power Converter Topologies with MF/HF Isolation for Grid Interconnection Systems

It is well known that the most of the present Chilean architecture network is only in one direction: the electricity is generated from the power stations and transmitted to the users through high voltage transmission systems. Recent initiatives of the Chilean government and recent research have focussed on “providing a more flexible and modular power electronics interface able to connect different kind of sources and loads including medium voltage electrical networks, renewable energy sources, and energy storage systems”, such as the one illustrated in Fig. 2 which requires a flexible power management control in order “to ensure proper and secure operation of the networks” and bidirectional power flow [54].

Some requirements for the future electricity network are:

- Galvanic Isolation.
- Multi-directional power flow capability.
- Flexibility and scalability.
- Easy maintenance and low cost.
- Compact power conversion and low weight.
- High efficiency and reliability.

The general structure for grid interconnection shown in Fig. 2 can be formed by two different configurations:

1) Two AC/DC stages and a DC/DC stage with isolation medium or high frequency (MF/HF) transformers. In this case single phase H-bridge converters are used (Fig. 3).
2) Two AC/AC stages with isolation MF/HF transformers. In this case single phase matrix converters are used (Fig. 4).

Both configurations use the advantages of multimodular structures based on single phase power converters (shown in Fig. 5) in a cascade connection to provide a more flexible and modular power electronic interface to connect different types of microgrids and generation systems including medium voltage electrical networks, renewable energy sources and energy storage systems. Some characteristics of both architectures are:

- Both configurations are modular structures, allowing easy replacement of the cells in case of failure.
- Both configurations have the same number of semiconductor devices. In each cell of the first architecture there are four H-bridges, which implies 16 semiconductor devices. In the second configuration, there are two single phase matrix converters, which have also 16 semiconductor devices.
- Both configuration schemes are able to operate with multi-directional power flow.
- Different from the first configuration structure, the second alternative topology does not include energy storage elements, reducing the weight and size.
- Because the second configuration architecture does not include energy storage elements, there is no need for DC-link controllers and the potential for failure is reduced.

Recent investigations have been focused in to propose microgrid clusters and generation systems based on different power converter configurations when used for non-conventional renewable energies. Such configurations must ensure an optimal active and reactive power flow control

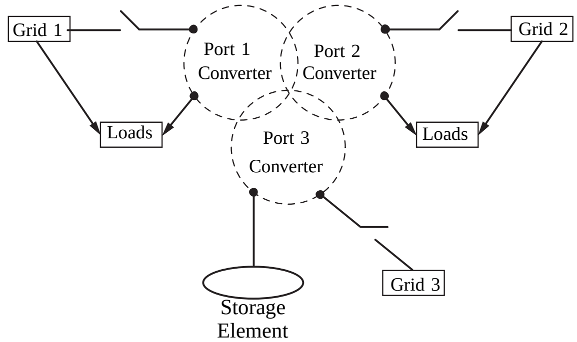

Fig. 2. General structure of the universal and flexible model for grid interconnection.

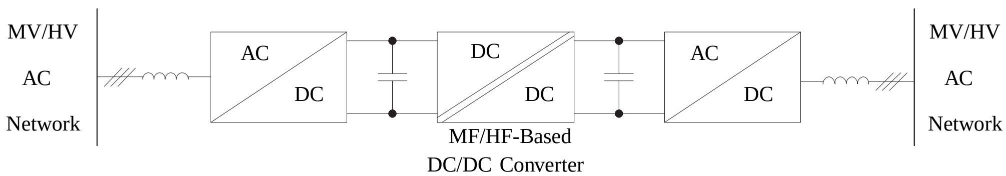

Fig. 3. Basic schematic block of the first configuration: two AC/DC stages and a DC/DC stages with isolation MF/HF transformers based on H-bridge converters.

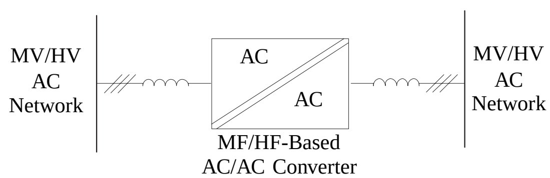

Fig. 4. Basic schematic block of the second configuration: two AC/AC stages with isolation MF/HF transformers based on single phase matrix converters.

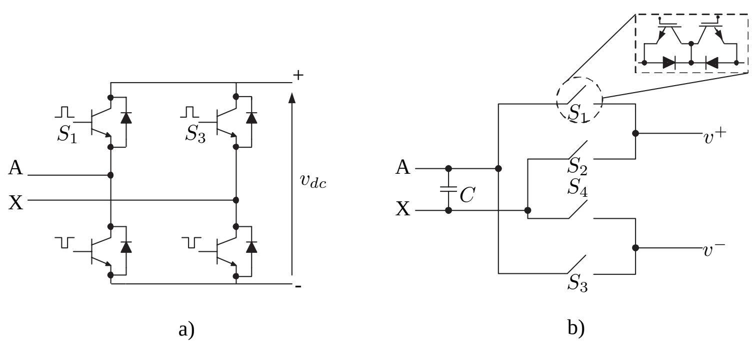

Fig. 5. Basic topologies: a) H-bridge; b) single phase matrix converter.

and flexibility to be adapted to different load/users/grid conditions such as parameter variations, load changes, voltage imbalances, harmonic content, resonances and others. In order to achieve all these requirements, different modulation and control strategies have been proposed in the literature. Among them, pulse width modulation (PWM), space vector modulation (SVM), fuzzy control, predictive control and others, are currently the most popular [55], [56]. But, despite the several advances in new technologies and control strategies for microgrids and generation systems when working in standalone mode or grid interconnected, there is still need for novel improvements to make them more reliable, smart, cooperative and an open system to the inclusion of new generation systems.

A. Modulation of single phase AC/MF/AC

A Dual-CBM configuration for AC/MF/AC solution is shown in Fig. 7. In Dual-CBM, a low frequency input voltage is modulated to a medium/high frequency voltage waveform and then it is demodulated to low frequency output voltage as shown in Fig. 8. The shown solution works well when demanded frequency is equal to input frequency i.e. fi=fo and is a good alternative in this case for grid interconnection applications. Due to the single phase nature of the solution, output voltage frequency is limited to only integral multiples of the input voltage frequency. For instance, with an input voltage at 60Hz, it is only possible to generate 30Hz, 20Hz, 15Hz and so on. This constraint can be formulated as:

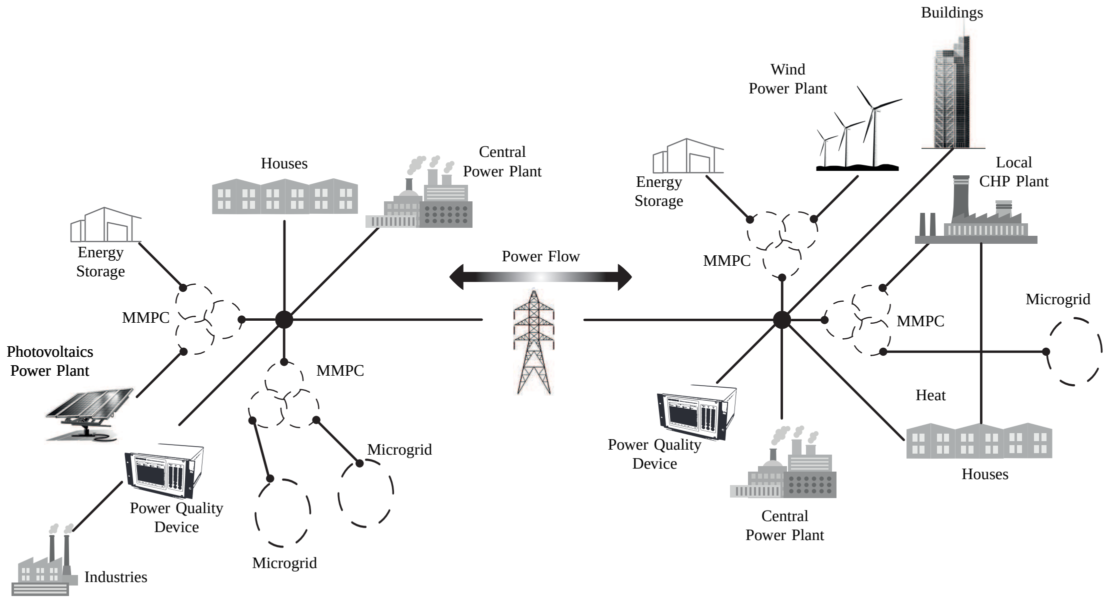

Fig. 6. Microgrid clusters and generation systems based on multiport modular power converter (MMPC) structures with fully integrated network management.

$$f_o = \frac{f_i}{n}, \quad \forall\, n \,\epsilon\, Z^+, \quad Z^+ = 1, 2, 3... \tag{1}$$

Some countries are utilizing 60Hz while others are utilizing 50Hz as grid frequency and the interconnection of said grids via Dual-CBM is not feasible as 50 is not an integral multiple of 60, therefore violating the constraint. This can be validated Fig. 9, when 50Hz output is generated from a 60Hz input. Furthermore, it is important for the converter in MMPC to be fully able to generate any frequency at the output.

B. New AC/MF/AC topology for grid interconnection systems

Now, it is clear that the single phase solution has some drawbacks as:

- Its failure in the applications interconnecting two systems at different frequencies e.g. interconnection of 60Hz and 50Hz grid.

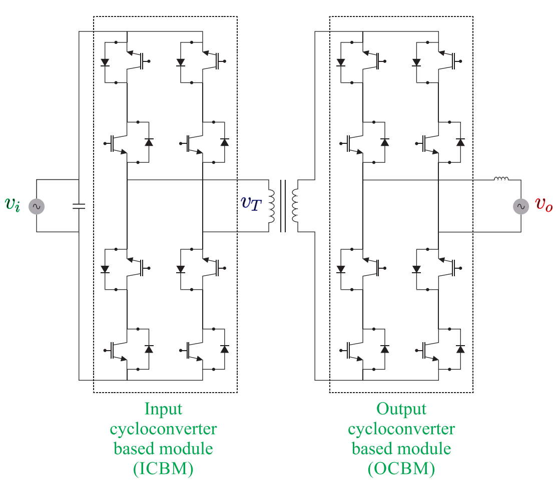

Fig. 7. Dual-CBM configuration

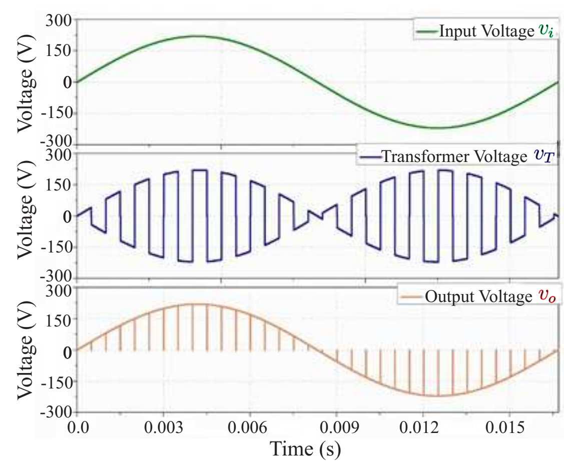

Fig. 8. Voltages in the dual CBM

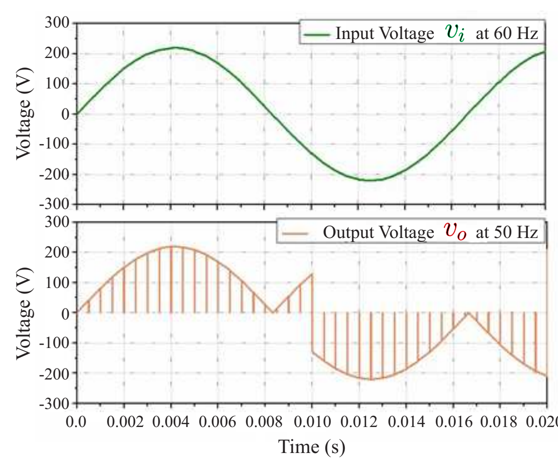

Fig. 9. Voltages in the dual CBM when $f_o < f_i$

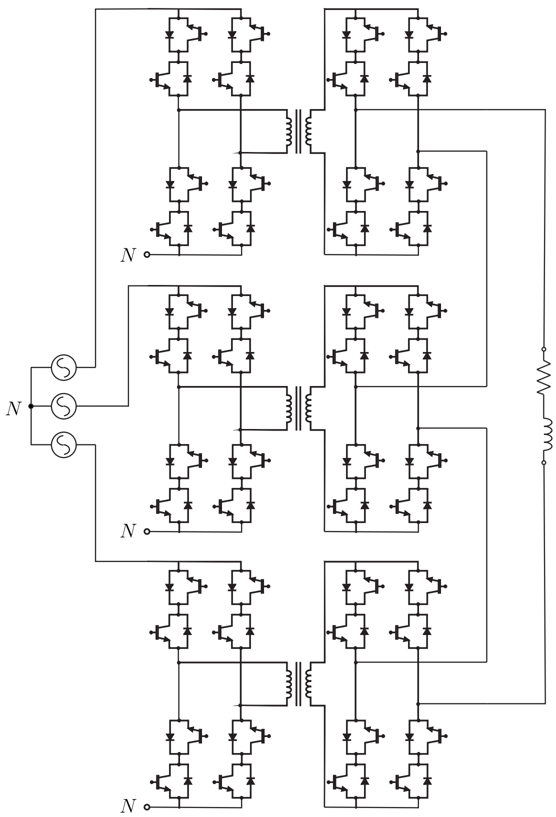

Fig. 10. A new 3-phase to 1-phase isolated AC/AC topology using three Dual CBMs

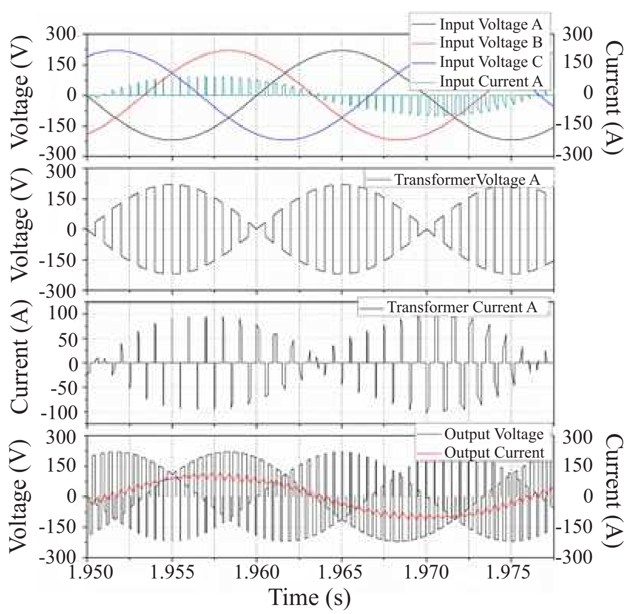

Fig. 11. Systems behavior for an input of 50 Hz and a output of 40 Hz

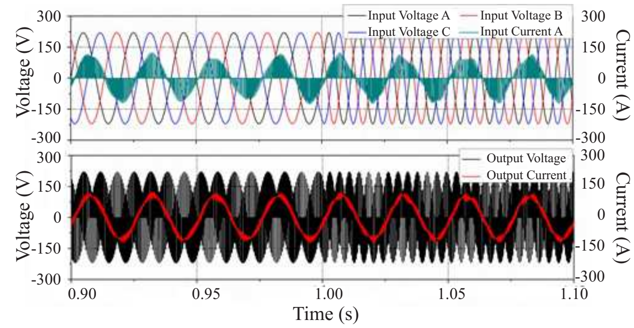

Fig. 12. Systems behavior for a changing input

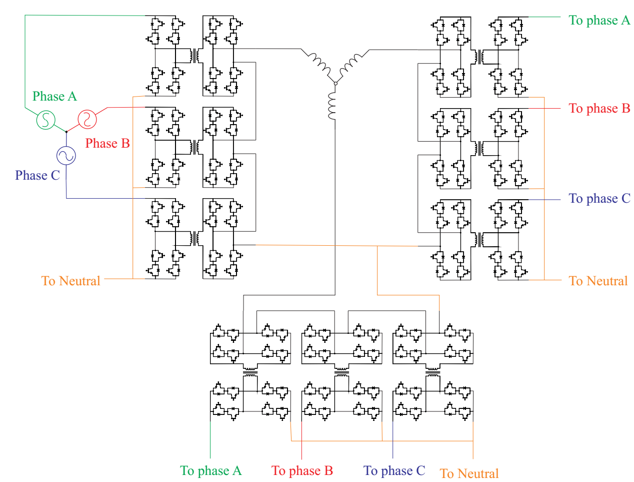

Fig. 13. A new 3-phase to 3-phase isolated AC/AC topology

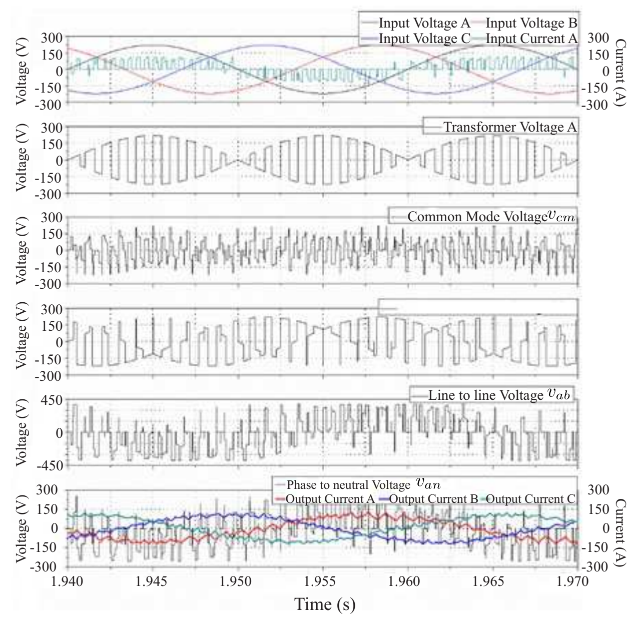

Fig. 14. Voltages and currents in the three-phase to three-phases interconnection proposal.

- It is not a viable solution for the applications requiring frequency regulation e.g. v/f control of drives.

The reasons of mentioned drawbacks are that converter has single phase input i.e. output is limited to single phase input in terms of selection. A possible solution for this limitation consist of increasing the input options of the converter i.e. utilizing the concept of matrix converters. The topology can be modified to Fig. 10 therefore, utilizing three-phase input in a way to have three input options at any time and at the same time also providing modularity, galvanic isolation, bi-directional power capability etc. With the new topology of Fig. 10, it is possible to generate, at the output, the non-integral multiples of the input i.e. 40Hz output voltage is generated from 50Hz input voltage as shown in Fig. 11. Not only that but the new topology also provides excellent output grid frequency regulation even when validated with an exaggerated variation in input grid frequency i.e. 50Hz to 86Hz at t=1s as shown in Fig. 12. Eventually, a three phase to single phase AC/AC isolated converter system can be extended to three phase to three phase system as shown in Fig. 13. It is important to mention that the input and output voltage and currents of the three phase to three phase topology, shown in Fig. 14, are similar to that of classical matrix converters. This new converter topology can be a step forward, considering the utilizing of bi-directional switch based converters, in the grid interconnection applications.

IV. Conclusions

The growing technological development has increased the demand of more available energy. It is necessary a safe and efficient energy development, with reasonable prices, that take advantage of the renewable resources in a sustainable and non-polluting way. There are several power converter topologies for micro-grid applications.

Potential of isolated AC/AC direct converter topologies has been discussed. Identification of problem in a single cell i.e. in a single phase to single phase topology. Modification of the topology comes at the cost of an increased number of switching devices while keeping modularity intact as well as bi-directional power flow. This new AC/AC isolated topology will have a wider range of applications e.g. grid applications, AC drives etc.

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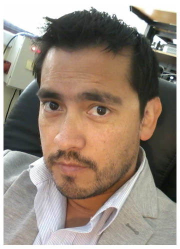

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