Fault Tolerant Reconfiguration System for Asymmetric Multilevel Converters Using Bi-Directional Power Switches

Pablo Barriuso, Juan Dixon, *Senior Member, IEEE*, Patricio Flores, and Luis Morán, *Fellow, IEEE*

Abstract— **Asymmetric multilevel converters can optimize the number of levels by using H bridges scaled in power of three. The shortcoming of this topology is that the H bridges are not interchangeable and then, under certain faulty conditions, the converter cannot operate. A reconfiguration system based on bi-directional electronic valves has been designed for 3-phase cascaded H-bridge inverters. Once a fault is detected in any of the IGBTs of any H-bridge, the control is capable to reconfigure the hardware keeping the higher power bridges in operation. In this way, the faulty phase can continue working at the same voltage level by adjusting its gating signals. Some simulations and experiments with a 27-level inverter, to show the operation of the system under a faulty condition, are displayed.**

Index Terms— **Fault tolerance, power conversion, multilevel systems.**

I. INTRODUCTION

Today, multilevel converters have become to be very popular, because they are able to generate voltage waveforms with less distortion than conventional inverters based on two-level topologies [1-4]. One step ahead has been the new multi-stage converter technology [5, 6], which allows to generate much more levels of voltage with less power semiconductors. When the number of levels is high enough (over 20), multi-level inverters are able to produce current waveforms with negligible THD. Besides, they can work using both, amplitude modulation and pulse width modulation strategies. This way of operation allows almost perfect currents, and very good voltage waveforms, eliminating most of the undesirable harmonics. One of the multi-stage technologies that allow producing many levels of voltage with a low number of transistors is the one based on cascaded H-bridges [6-8]. Topologies using H-bridges use relatively few power devices, and each one of the bridges work at a very low switching frequency, which gives the possibility to work at high power levels with low speed semiconductors, and to generate low switching frequency losses.

The objective of this paper is to show the performance of a reconfiguration technique that allows a cascaded H-bridge inverter to keep working even with a faulty bridge. This is of much importance on a multi-stage converter used for critical loads, like active power generators from fuel cells in a hospital or where a failure may cost thousands of dollars of losses. The topology of the reconfiguration system is described and simulations and experimental results are exposed. There are some authors that have covered the fault tolerant control in some types of multilevel inverters, but very different from the one addressed in this paper [9-17], and some others more alike [18-19], but this work is a more hardware oriented proposal that provides a very good solution to the problem under study.

II. OPERATION CHARACTERISTICS

A. Basic Topology

The circuit of Fig.1 shows the basic topology of one converter used for the implementation of multi-stage high-level inverters. It is based on the simple, four switches device ("H" converter), used for single phase inverters. These converters are able to produce three levels of voltage at the *AC* side: *+Vdc, -Vdc*, and *zero*.

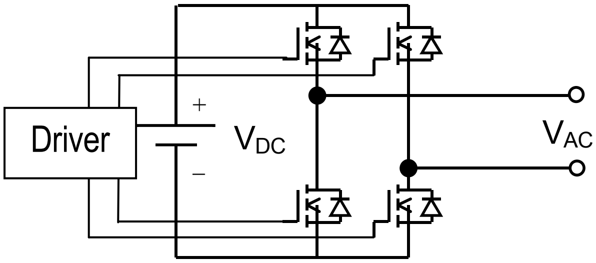

Fig. 1. Three-level module for building multi-stage converters.

Reference [20] has proposed a per phase power conversion scheme for synthesizing multilevel waveforms, connecting many converters like the one shown in figure 1 in series, but with all the dc voltages equal to "Vdc".

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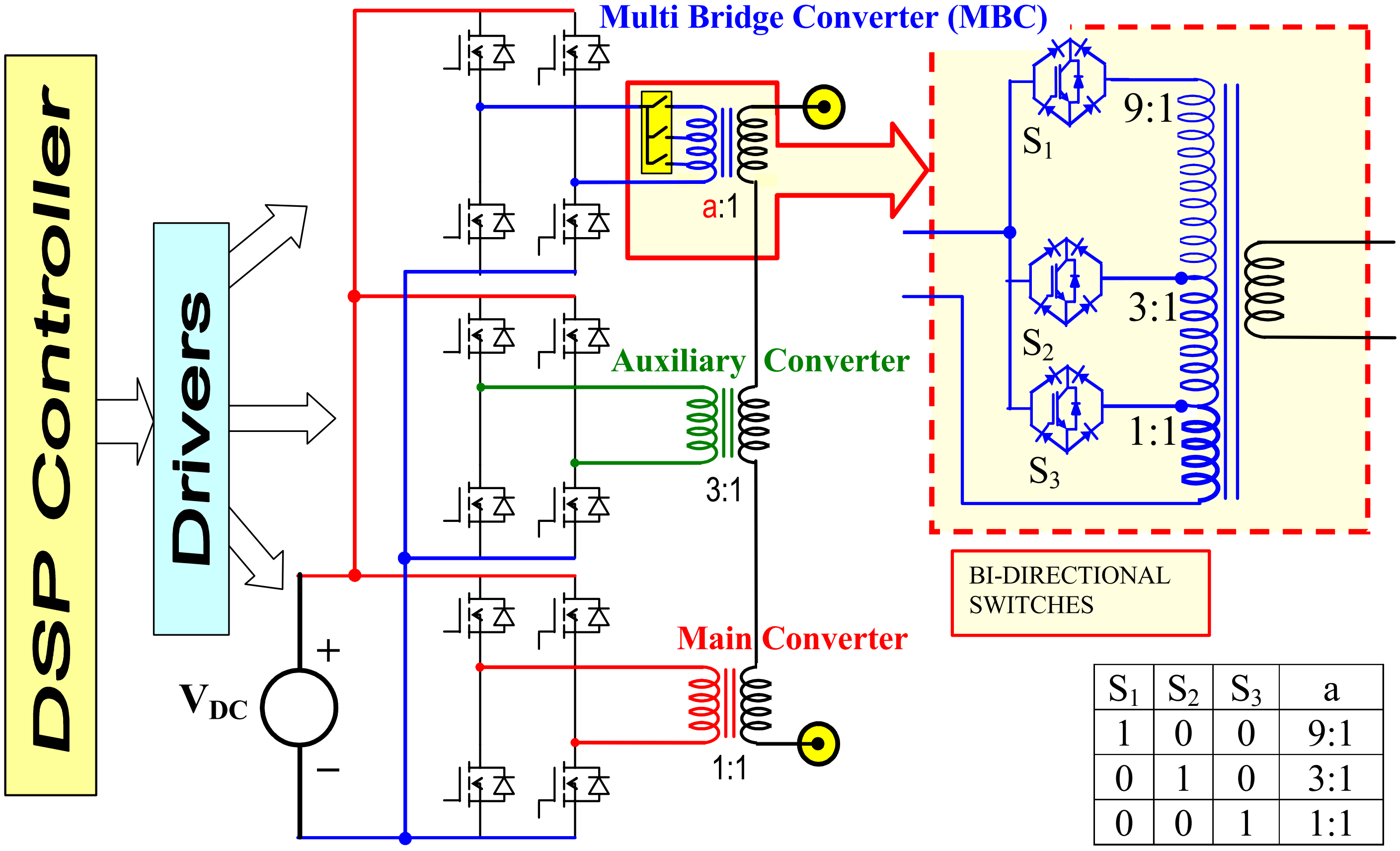
Pablo Barriuso is with CDEC-SIC, Santiago, Chile, e-mail: pbarriuso@cdec-sic.cl

Juan Dixon (corresponding author), email: jdixon@ing.puc.cl, and Patricio Flores, e-mail: paflorel@ing.puc, are with the Department of Electrical Engineering, Pontificia Universidad Catolica de Chile, Vicuña Mackenna 4860, Santiago, Chile, fax 56-2-552-2563.

Luis Morán is with the Department of Electrical Engineering, Universidad de Concepción, Concepción, Chile, e-mail: luis.moran@udec.cl



S_1	S_2	S_3	a
1	0	0	9:1
0	1	0	3:1
0	0	1	1:1

Fig. 2. Main components of the system (one phase).

Such a multilevel inverter with ‘n’ equal *DC* voltage levels can offer only *2n+1* distinct voltage levels at the phase output. The reference [21] goes one step ahead with dc voltages varying in binary fashion, which gives an exponential increase in the number of levels. For ‘n’ such cascaded inverters, with *DC* voltage levels varying in binary fashion, $2^{n+1}-1$ distinct voltage levels may be achieved.

In this paper, the outputs of the modules are connected through transformers whose voltage ratios are scaled in power of three, allowing 3^n levels of voltage. Then, with only three converters (n=3), 27 different levels of voltage are obtained: 13 levels of positive values, 13 levels of negative values, and zero. As a comparison, the first topology only achieves 7 levels with three converters, and the second topology just 15 levels. This strategy represents an optimization of the number of levels, and its drawback is that there are no redundant levels (same output voltage with different switching combinations), requiring bidirectional power flow at the auxiliary converters. However, in the particular applications mentioned above, redundant levels or bi-directional supplies are unnecessary because the topology uses output transformers that allow bi-directional power flow.

B. System Components

Fig. 2 displays the circuit of the three-stage converter used in this work: a three-stage, 27-level inverter. The figure only shows one of the three phases of the complete system. The dc voltage V_{DC} of Fig. 2 can be a fuel cell system (Static Genset), a battery pack (UPS) or a solar cell. In the experimental prototype, V_{DC} is a battery pack, which is charged from photovoltaic cells through a MPPT (Maximum Power Point Tracker) [22]. The most important part of this topology, related with the purposes of this work, is the multi-winding transformer with bi-directional switches, which allows reconfiguration from a three-stage (27 levels) converter to a two-stage (9 levels) converter, keeping the bridges working with the higher power bridges.

The module located at the bottom of Fig. 2 has the highest voltage ratio, and is called Main Converter. The second module is the Auxiliary Converter (Aux) and the third module is the Multi-Bridge Converter (MBC), which normally works at the lowest voltage ratio and delivers small steps of amplitude modulation, but can also accomplish (after reconfiguration) the functions of the Main or the Auxiliary Converters and is essential for the purpose of this work. As the Main and Auxiliary Converters are commonly known and widely discussed in literature, only the MBC will be described

The MBC shown in Figure 3 consist on a full power “H” Bridge, plus a special power transformer with three bi-directional switches (S_1, S_2 and S_3). Full power means the MBC must be able to replace anyone of the H bridges of Figure 2. The basic idea behind the Multi Bridge Converter (MBC) is to provide flexibility at the output power of the bridge. If a fault occurs in any of the H bridges, then the MBC will replace it. The faulty bridge is electronically isolated and