Developments in Matrix Converter - A Review

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ABSTRACT
A matrix converter is a converter with a single stage conversion comprising a group of nine switches connecting the three phase source to the load. Matrix Converter can transform inputs with constant amplitude, frequency, variable amplitude and variable frequency into three-phase outputs because it can generate any output frequency because of multiple inputs. The Matrix Converter has four intrinsic features, a powerful input power factor, no intermediate DC link for energy storage, high regenerative capacity, and improved power density, lightweight and robust features. It is a result of several innovations over the decades due to which has made matrix converter very versatile. This paper presents developments that have taken place in nine way matrix converter topologies and modulation, protection and diversified applications.

Keywords: Development of Matrix Converter, Electrical Drives, protection of matrix converter

I INTRODUCTION

In the academic community, for over three decades, the research on matrix converter and its extended topologies has been performed. Large numbers of research papers have been published on Matrix a converter which has made it a 'Power Electronics Evergreen'. The researchers continue to develop various AC-AC/AC-DC-AC converter topologies.

The author [1] presented the effective voltage aspect of AC-AC pulsed direct converters. There was an implicit threshold irrespective of control strategy. An innovative converter control algorithm was presented for maximum output with some interesting features. The prospect of enhancing the matrix conversion control technique using feedback approaches and the converter's feedback-based modulation approach was discussed.

The authors [2-3], discussed development and growth with comprehensive history of matrix converter. Thus far, the best mechanism developed for modulation has been the control techniques. New approaches are developed and used to solve the current switching problem that includes nine switch arrays in one module in both the directions. The author finally addressed the issues related to high-voltage safety, filter use and fault driving power of the MC. Author presented a well-known, intermediate DC-converter system for use in AC-AC converters. Eventually the vector modulation governs direct matrix converter. The proposed converter clearly demonstrates the power converter information, resulting in versatility of PWM control technology. A new topology [6]-[7] was developed in which the converter transforms input AC to output power by direct transfer, avoiding the use of input filters or intermediate DC connector condensers with the exception of certain minor Snubber parts. On the converter's proposed topology input line, the current waveform is similar to the diode corrector, with an intermediate DC inducer. Induction motors are normally operated using PWM-based source voltage inverters. The matrix converter is the best option among various switching combinations [9-10]. The advantage of such converters is that they operate in both directions and deliver sinusoidal output. The main drawback was the unreliable bidirectional transition [11]. By connecting two switches to diodes, two-way load switches can be used.

In this paper, the key features of matrix converter are mentioned in section II whereas section III presents a brief account of the developments taken place in matrix converters. Section IV describes the protection and operational safety aspects. Section V presents the applications of matrix converters.

A 3-phase to 3-phase converter topology is shown in Fig No. 1.

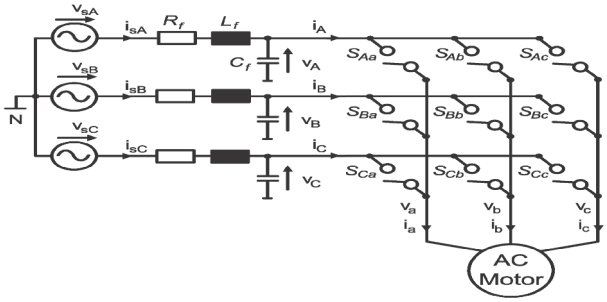

Fig.1 A 3-phase to 3-phase Matrix Converter Topology [3]

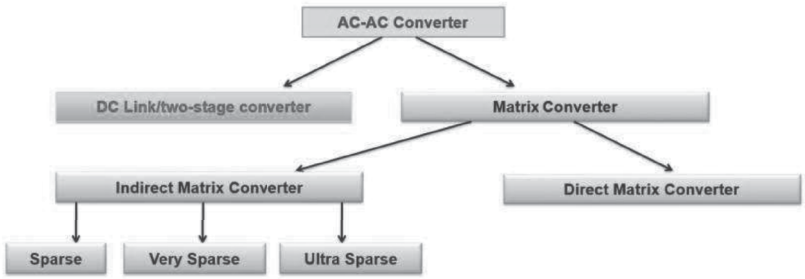

Fig. 2 Classification of AC-AC converters used in electrical drives [6]

II KEY FEATURES OF MATRIX CONVERTER

(a) AC/AC direct electrical power conversion.
(b) There are 2^9 (512) possible combinations.
(c) Each output phase can be connected to any input phase.
(d) Compact
(e) Safer (being used in hostile environments, aircraft, submarine.)
(f) Bidirectional power flow, 4 quadrant converter.
(g) No restriction on input and output frequency within limits imposed by switching frequency.
(h) Sinusoidal input and output current /voltage waveforms.
(i) 9 bidirectional switches. (18 IGBT + 18 diodes).
(j) The matrix converter topology provides universal power conversion options such as AC-DC, DC-AC, DC-DC or AC-AC besides 1-3 phase conversions and vice versa. .
(k) Matrix converter can convert three phase to single phase or single phase to three phase power at desired frequency.

III DEVELOPMENTS IN MATRIX CONVERTER

The Hazeltine Research Cooperation in 1923 filed a patent for a matrix like electric power converter based on electromechanical smirches.

In 1959 a patent from Specialties Development Corporation was filed for half bridge matrix converter (HBSC) topology using BJTs.

In 1960, Westinghouse Electric Corporation filed a patent for forced commutated current converter (FCCC) for aircraft generator systems.

In 1967, Westinghouse filed another patent for controlling the variable frequency converting switching units of FCCC's in order to control the output voltage.

In 1976, Jones and Bose were first to publish experimental results of three phases to single phase FCCC's using BJTs.

In 1980, the power circuit of the conventional matrix converter as a matrix of bidirectional switches and introduced the "matrix converter"

The use of space vectors and control of MCs was proposed by Braun and Hasse in 1983.

In 1985 number of research projects has been conducted for the application of MC, staring with the investigation of AC motor drives.

In 1988 it was experimentally confirmed that a MC with nine four-quadrant switches can be effectively used for vector control of an induction machine.

In 1989, Holtz and Boclkens, published the research article on indirect matrix converter (IMC) topology.

In 2001 first experimental results of IMCs were published.

A novel topology of IMC for isolated direct AC-AC power conversion for a variable frequency input and a constant frequency output. was proposed in 2003 by Cha and Enjeti.

A modified version of IMC for UPS applications was investigated in 2005.

In 2006, Mohapatra and Mohan suggested full bridge IMC topology for supplying an open winding AC machine with a limited common mode voltage.
In 2009, Yamamoto described another means of extending the output voltage range by a modular interconnection of multiple identical MCs by a common multi-pulse transformer.

In 2011, Ge and Peng proposed the most recent topologies, Z-source MCs (ZSMCs).

In 2012, Sergio Sausa and Sonio Pinto, proposed a control system for an IMC with a Z-source while at same time guaranteeing unity power factor.

In 2015, V.V. Subramayana and Martin Jara, proposed a new ZCS single phase matrix converter for the traction applications. This soft switching MC is enhanced with auxiliary resonant circuit in order to achieve a zero current switching for main bidirectional switches of the matrix converter.

In 2018, Boran Fan and Kui Wang, proposed modular multilevel matrix converter for high voltage high power applications. This research offers its significant advantage in adjustable motor speed drives.

In 2020, Yuzhau Li and Yun Wei Li proposed a general synthesizing approach of multilevel MC (MLMC) topologies and analyzed with the considerations of the voltage source, current source and matrix type MLMC.

IV PROTECTION AND OPERATIONAL SAFETY

The absence of DC-link affects the safety and failures of the matrix converter e.g. over-voltage. In 1997 protection circuit was introduced which consisted of six additional diodes. In 1998 a new protection circuit was invented by Schuster, without reactive clamp elements using var istors only. Barun, in 2000 proposed a new protection circuit based on varistors and suppressor diodes. This circuit replaced the standard diode clamp circuit. Schonberger in 2007 proposed an active clamp circuit for PMSM drive. The latest technology for protection of matrix converter is Field programmable gate arrays (FPGA) circuits. FPGA are semiconductor devices that are on a matrix of configurable logic blocks connected by programmable interconnect.

V APPLICATION OF MATRIX CONVERTERS

The matrix converter is considered for bidirectional variable frequency AC drives for low and medium voltage applications. Application areas are as follows:

(a) Field control.
(b) SCIG conversion of wind energy,
(c) Dual generators.
(d) Deep sea robots.
(e) Contact less energy transmission
(f) AC utility power units.

In 2005, Yaskawa, the Japanese drive manufacture, presented the world's first commercial MC. Table No. 2 gives an overview of the research on matrix converters reported by various industries.

Table 1
An overview of reported research on MC in industries [23]

Company	MC topology	Year
Westinghouse	CMC	1988
Mitsubishi Electric	I-IMC	1990
ABB & Daimler	CMC	1997
ABB	CMC	2002
Alstom	CMC	2003
Bosch	S-A-X	2004
Fuji Electric	I-IMC	2005
Hitachi Electric	CMC	2006
Meidensha	CMC	2007
Yaskawa	ARCP MC	2009
Schneider-Toshiba	CMC –IMC	2010
Hyundai heavy industry	CMC	2011
Siemens Electric	Multilevel MC	2013
Samsung	Z-source MC	2014
Arvi system and Control	IMC	2016
Emerson Network Power	CMC	2017
Toyo Electric	CMC-IMC	2019
Reillo PCI	I-IMC	2020

VI CONCLUSION

A review of developments in matrix converters has been presented. The paper concludes that topology, modulation methods, protection circuit algorithms have been extensively developed which has made provided it versatility in any combination of AC/DC and 1/3 phase conversions at required voltages and frequencies. It has widened the applications of matrix converters in industries, power sector, transportation section etc. The innovations in matrix converters continue.

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