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Jamil, Irfan
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Jamil, Rehan
School of Physics & Electronic Information, Yunnan Normal University

Nakamura, Kazuo
Research Institute for Applied Mechanics, Kyushu University

Tokunaga, Kazutoshi
Research Institute for Applied Mechanics, Kyushu University

他

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Matrix Converter in Power Electronics as a Power Supply for Plasma Control: A Short Review and a Foresight

Irfan JAMIL*1, Rehan JAMIL*2, Kazuo NAKAMURA*3, Kazutoshi TOKUNAGA*3, Makoto HASEGAWA*3, Kuniaki ARAKI*3, Hideki ZUSHI*3, Kazuaki HANADA*3, Akihide FUJISAWA*3, Hiroshi IDEI*3, Yoshihiko NAGASHIMA*3, Shoji KAWASAKI*3, Hisatoshi NAKASHIMA*3 and Aki HIGASHIJIMA*3

E-mail of corresponding author: *i.jamil@triam.kyushu-u.ac.jp*

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Abstract

In recent years, with the state advancement of R&D strategies in matrix converter and the increasing demand of high efficient power supply in power electronics, matrix converter has raised wide attention among the research scientists. In order to cope with these demands, various converters with different rate of power are being developed and related research is realized to accomplish the new matrix converters. Thus, matrix converter as a power supply for plasma control is an important case in this paper. Survey of matrix converter topologies with low cost, small volume and high efficiency are discussed as a power supply for the plasma control. And a short review and a foresight of milestones, significant research and development of a matrix converter from 1950 till present are appended in this paper. In addition, the major contributions which review includes primary, secondary and significant historical research milestones in matrix converters with thematical and chronological order respectively are demonstrated.

Key words : *Matrix Converter, Plasma Control, Milestones, Topologies, Review R & D*

1. Introduction

The matrix converter directly converts AC to AC rather than AC to DC to AC as in conventional voltage source PWM AC Drives. In power electronics, matrix converters have significant research & development issues which have undergone for the investigation more than three decades[1)]. The experts of power electronics have explored attention in state-of-art research in the area of matrix converter, and their intelligence and general knowingness were impressive. Therefore, several numbers of publications have been published throughout the year means the hereby matrix converter went off " evergreen interest " in power electronics[2)]. The first research review-work of matrix converter technology was introduced by author Wheeler et al in 2002. In this publication, the authors premised remarks on single-stage matrix converter and entire attention centered on the method of modulation, control and resolving the problem of communication method so that readers might understand[3)]. After later on 2003, the publication of V.I. Popov et al composed the overview research in matrix converter technology, which first focused on control algorithms and schemes of MCs in former Soviet and Russia from 1991 to 2003[4)]. Afterward, as a consequence, a large number of research articles in the area of technology of matrix converters have been taken into consideration. The matrix converter is a fast response and precise power supply for the plasma control in fusion reactor in terms of technological issues and performance[5)6)]. The matrix converter can make major contribution to the plasma control as a power supply. Therefore, in order to improve the control characteristics, stabilities and functional elements in matrix converter such as topologies are discussed from 1950 till present appended in this paper.

The aim and scope of this work are to look at the issue of the review and foresight, R&D milestones for matrix converters topologies in the investigatin of power supply in power electronics for the plasma control. The

*1 Interdisciplinary Graduate School of Engineering Sciences, Kyushu University
*2 School of Physics & Electronic Information, Yunnan Normal University
*3 Research Institute for Applied Mechanics, Kyushu University

historical flow chart of topologies of matrix converter has been demonstrated as shown in Fig. 1.

2. Development of Topologies in Matrix Converter

The development of topologies in matrix converter first evolution started by an American company of Hazeltine Research Inc in 1923 invented a power converter likewise matrix based on electro-mechanical switches[7]. Later contribution by H. Rissik[8)9)] new type class of " cyclo-converter " is manufactured early in second half age of 1930s. The first cyclo-converter is designed in Germany for locomotive purpose to control the frequency of railroad engines[10]. In 1931, Mercury Arc-Cyclo-Converter was demonstrated, which was built by Brown Boveri for Swiss Railways[11]. In 1934, the United States was using different approach of Thyratron Cyclo-Converter to control the large synchronous motors, installed in Logan Power Station[12)−14)]. Based on cyclo-converter, two classifications are introduced, and categorized into Natural Commutated Cyclo-Converter (NCCC) and Forced Commutated Cyclo-Converter (FCCC). In recent history late in 1950-1960, the NCCC is further classified into two basic topologies FCCC with Transistors and FCCC with Thyristors. The significant R&D as shown in Fig. 2 is documented by Black et al. development cooperation for Forced Commutated Cyclo-Converter with Transistors FCCC-Ts in 1959[2)15)]. While in 1960, Jesses & Gyugyi et al. Westinghouse Electric Corp., worked as secondary R&D in FCCC with Transistors (BJTs) for the aircraft power supply system as shown in Fig. 2[2)15)]. From 1964-1970, the researcher made effort in secondary and significant research to develop a new theory of evolution in practical systems with cyclo-converter-squirrel cage induction motor combination. Therefore cyclo-converters were preferred in large magnitude for AC motor drive applications running at low speeds[2]. After struggle in 1970-1980 there were a lot of works published to enhance the capability of conversion technology in reactive power generation and control thyristors circuits most chiefly documented by L. Gyugyi and B.R. Pelly. Their work is mainly published in the book as called "Static Power Frequency Changers" and " Existence Function Properties and Extence Matrix " based on one-stage static frequency changers, prophetic projections frequency changers with forced commutation, generalized transformer and bidirectional switches or four quadrant switches. The key R&D era was begun also in 1976 by Jones and base publication introducing the knowledge concept of phase FCCC with BJTs as shown in Fig. 1. As a new era began early in 1980s when M. Venturini and A. Alesina published novel concept of input and output frequency converter capable of sinusoidal waveforms, four quadrants capable power transfer, input power factor by continuously controllable and reactive power generation properties were proposed. Later, in 1985, Y. Yamamoto et al. and P.D. Ziogas et al. publications were succeeded in improving self-commutated inverters and FCCC structures respectively. According to P.D. Ziogas et al. through improved frequency changer structures, the harmonic distortion of the input current and output voltage was improved[16)−22)].

The CMC (HBMC) was approved a basic topology for further numerous generating topologies such as IMC, FEMC, SSMC, FBMC, CCMC, HCMC and ZMC etc. According to IMC topology of matrix converter was first proposed into indirect three-level output-stage-spare MC (SMC) with additional bridge-leg across the link which reduces the output current of harmonics. The SMC topology extended into USMC, UMC and ILMC Parallel to HIMC and FBIMC topologies in the behavior of extension of output voltage range. After in 1990, HBMC topology is investigated for actual concept of UPS (application) converter system based on cyclo-converter technique by Kawabata et al. while into next level topology of Isolated Matrix Converter (IMC) is proposed for isolated AC-AC power converters to improve the input and output variable frequency and constant frequency respectively. According to IMMC topology the concept of study is raised to control the output voltage range with modular interconnection of multiple matrix converters by multi pulse transformer then new class of matrix converter achieved title as MMTMC in 2009. The SSMC topology as a secondary R&D topology was accomplished early 1990s when first soft-switching is studied for matrix converter by Cho et al and later ARCPMC topology was examined in 1996 as a secondary R&D topology[2)1)].

3. Matrix Converter for Plasma Control

A matrix converter is a direct power conversion device that uses an array of controlled bidirectional switches as the main power elements for creating a variable-output current system[17]. Therefore, a precise power supply with a rapid response is needed to control the vertical position of the plasma. From the review work of matrix converter for plasma control, it is a kind of direct power conversion technology with fast, precisely controlled power supply that functions, features an array of controlled bidirectional semiconductor switches achieving design considerations such as a variable output current system.

Usually, in plasma control to stabilize the plasma

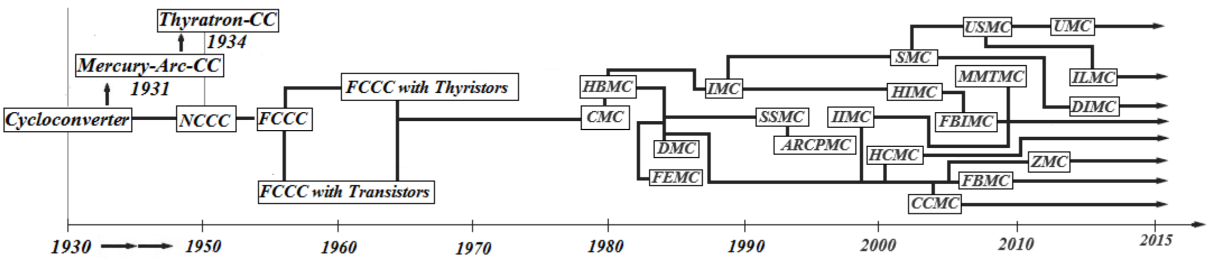

Fig. 1 Historical flow chart of topologies for matrix converter from 1950-2013.

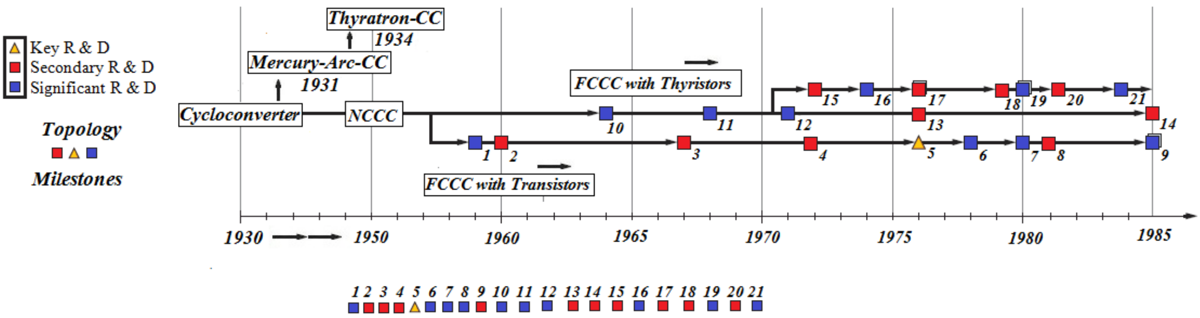

Fig. 2 Primary R&D of matrix converter topologies with FCCC (Forced Commutated Cyclo-Converter) and NCCC (Naturally Commutated Cyclo-Converter) from 1950-1985.

vertical position and achieve a unity input power factor, matrix converter as a power supply is highly recommended proposing as an experiment. According to following facts worthy of attention, matrix converter has desirable characteristics such as arbitrary amplitude and frequency switched into load voltage generation; not require for a DC-link circuit; for any load, fix operation with unity power factor; and regeneration feedback capability[5)6)]. As central needs for energy deliverances have increased in recent years, matrix converter is being practiced in a wide range of technological applications as a power supply in plasma control and capable with high efficiency, smaller in size and in economic cost, keeps continuing further advancement in expanding the conversion technologies.

4. Matrix Converter in Commercial Industry

In global industry, the commercial matrix converters have been manufactured and supplyied by different industrial-automation drive companies for many years[8)]. But “Yasukawa” first Japanese company “the leader in inverter drive technology”which manufactured product name ”Varispeed AC Matrix Converter”. It is next level direct inverter drive product incorporates innovative technology as the globe ’ s first MC to directly converter input to output AC voltage[9)]. The operation of Varispeed AC Matrix Converter works as a direct inverter drive which connects line voltage to the motor using bi-directional IGBTs without function of an intermediate circuit[18)]. In this way, the resultant of maximum output voltage has gained about 95% of the input voltage. From this performance typical application for the Matrix converter gives two primary advantages of Varispeed AC Matrix Converters: power regeneration supply function and less harmonic distortion[9)18)]. According to Yasukawa, after product drive technology of CMC topology in 2002, new development is leading to MMTMC technology in 2009 and so on[1)]. The new era of matrix converter in commercial industry brings a number of manufacture product items. Almost twenty popular companies have published 3,636 publications, including their product patent, review reports and as well as research articles from 1988 to 2012[2)]. The below Fig. 4 shows review report of commercially manufacture of MCs milestone in industry from 1985 to 2012.

5. Historical Tendency of Power Density for Power Converters

The continual development trend of power electronic converters has been boosted up over the last few decades[19)]. Since 1970, the power density of an isolated DC-DC power converters is calculated from the limit of 28 kW/dm^3 at 300 kHz while for a three-phase unity power factor PWM rectifier, the limit of 44 kW/dm^3 at 820 kHz is estimated. General speaking, the limit of 35 kW/dm^3 for single-phase AC-DC conversion becomes from the DC link capacitor.

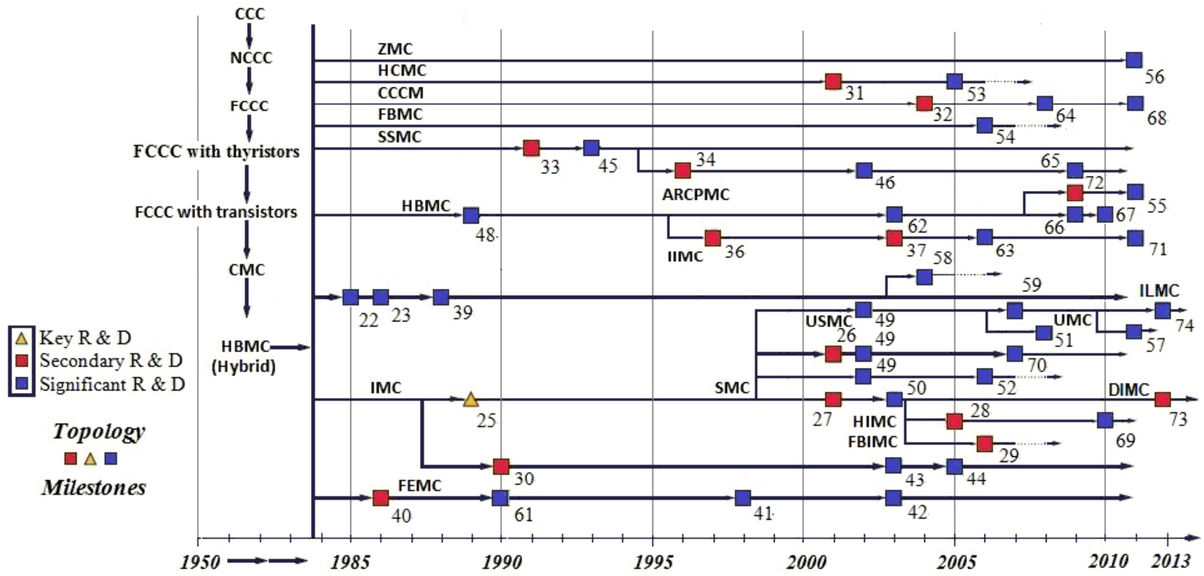

Fig. 3 Milestones R&D of matrix converter topologies from 1985-2013 CMC (Conventional Matrix Converter), HBMC (Half-Bridge Matrix Converter), IMC (Isolated Matrix Converter), SSMC (Soft-Switched Matrix Converter), FBMC (Full-Bridge Matrix Converter), HCMC (Hybrid Clamped Matrix Converter), FEMC (Fundamental Frequency Front-End Matrix Converter), DMC (Direct Matrix Converter), IMC (Indirect Matrix Converter), DIMC (Dual-Input Matrix Converter).

The SiC matrix converters are calculated at 60 W/cm^3 estimated in 2020 and for a sparse matrix converter is calculated 26 kW/dm^3 at 21 kHz[19,20]. Some reports for SiC converters say that the loss of SiC converter will decrease to 30 %-70 % of SiC converter case. Also, the operating temperature at junction will be increase to 250 degree, which is 175 degree for SiC junction. It means the temperature difference between air and junction can be almost twice with use of SiC. With two reason, the area for cooling surface will be decreased around 1/4, then the power density can be increased 8 times higher than the SiC converter, if the other components can work under such high temperature. And if the same operation-temperature is selected, the cooling surface will be around 50 % then the volume will be around 40 % of SiC converter. The article of Japanese author, H. Ohashi: Recent Power Density, 2002 shows distinguished trend line of power density for R&D and commercial industry. In Fig. 5, the Refs. 2) and 3) show a power density of 50 kW/dm^3, which is emphasized and another Japanese author, Takahashi: SiC Power Converters and their Applications in Near Future, leads the time frame of power density of inverters utilizing SiC power semiconductors more than 20 years including pattern of three-phase AC-AC, three-phase AC-DC, isolated DC-DC and One-phase AC-DC etc.[21,22]. The analysis report of European Center of Power Electronics (ECPE) confirmed the power density for industrial AC drive PWM inverters of 1 to 2 kW/dm^3 for the year 2000. From the Fig. 5, as Refs. 1) and 4) indicate, the power density of embedded power converters [AC-DC Power Module] increases from 30 W/dm^3 in 1976 to 120 W/dm^3 in 1986 and went off a 244 W/dm^3 in 1996[19,22]. The Ref. 19) shows, M. Hartmann, S. D. Round, H. Ertl, and J. Kolar: Digital current controller for a 1 MHz, 10 kW three-phase VIENNA Rectifier, shows improvement of the power density to around 1 kW/dm^3 in 2008 for PFC rectifier and a DC/DC converter including in AC-DC Power Module such as telecom DC/DC converter is investigated 5 kW 400V/48V[21,22].

The Ref. 5), A. Mertens: Innovation und Trends in der Leistungs Elektronik (in German), shows power density increasable doubling from 1994 to 2004. Similarly, Ref. 6), US Freedom CAR & Fuel Partnership: Electrical & Electronics Technical Team Roadmap, shows automobiles converters boosted up with approximately by 2020 year with the value of 5 kW/dm^3 in year 2013 to 10 kW/dm^3 of power density is required[19]. Cooling method and power loss are the major term of the size of converter and power density. Higher switching frequency makes higher switching loss and it will make power density lower. Switching method is one important factor because it is related to switching loss. In the conventional Si converter, the switching loss is more than 50 % of total loss, so ZVZC switching technology is very effective. For SiC device, switching loss become so small but forward drop is higher than SiC device, and

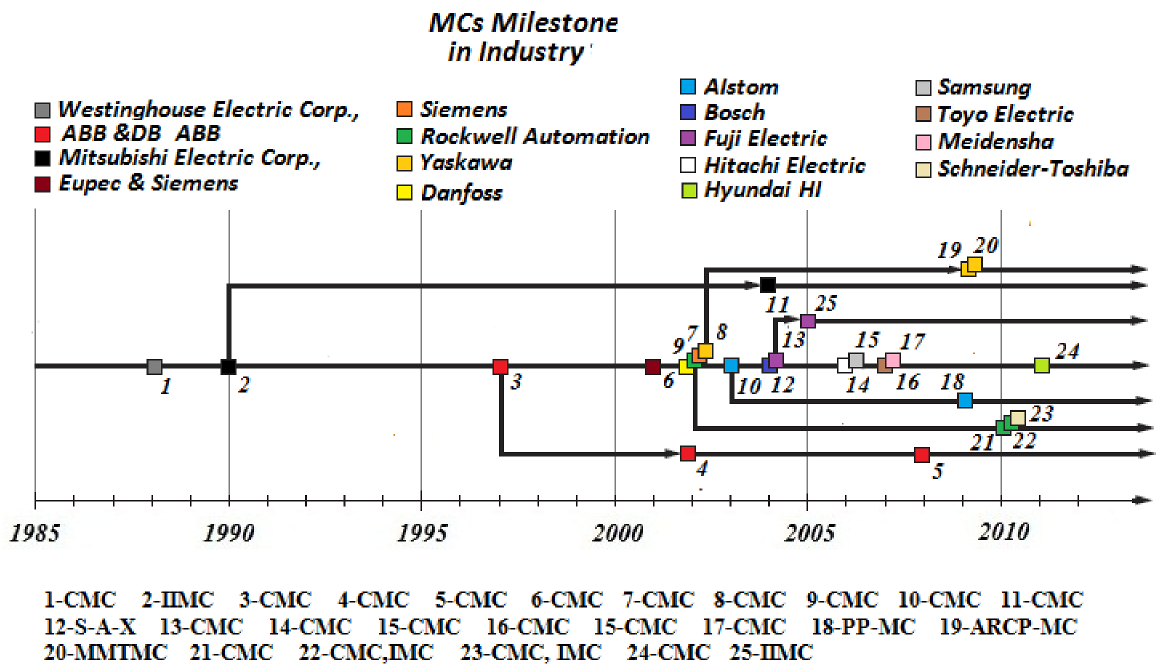

Fig. 4 Review report of commercially manufacture of MCs milestone in industry.

then the switching frequency is not effective for total loss. Topology is also important. For example, number of devices connected in series is related to forward drop loss. How many devices are used in the module and how long the devices are ON (and the current flowing in the devices) are related to total loss. The final bottle neck is the forward drop loss and it's cooling, because the switching loss can be reduced with switching technology or optimization of switching frequency. In addition, power density of air-cooled DC-DC has been achieved 30 kW/dm^3 without an EMI filter. In 2008-2009, the power densities of high frequency DC-DC converters reached 25 kW/dm^3 while three-phase AC/DC converters reached 10 kW/dm^3 [2)19)]. The Refs. 15) and 18) show power density barrier of forced air cooled converter systems and converter systems with H_2O-cooling are calculated on the R&D trend line[11)]. Therefore, high power density will increase the high efficiency in converter with high unity power factor. Unity power factor means the minimum operation current, and it leads the power loss minimum and leads highest power density. Generally power density limit is applicable at frequencies. For plasma control, the control frequency of 20 kHz can be enough. The specifications of power supplies for JT-60SA plasma controller could be a reference for control frequency and power.

6. Conclusion

This paper concludes reliable topologies are CMC, IMC and 3-phase AC-AC power converters, these topologies can be proposed for efficient circuit design. From the review, the matrix converter drives stable operation, could be used as direct AC-AC converter and can become an efficient candidate as a power supply for the plasma control due to controllable function of variable voltage and capability of frequency. The R&D topologies of MCs demonstrate knowledge of multiple operational functions such as control of variable output voltage and output current, generation of sinusoidal input current and input power factor correction in conversion technology of converter are incorporated into one semiconductor-phase with obstacle in operating features. And short description was also appended on the role of a matrix converter for plasma control and how are their applications, how improved in term of strategies through research & development by commercial industry. Hence Fig. 5 concludes that road map of power density of power converters demand goes doubling over the next 10 years.

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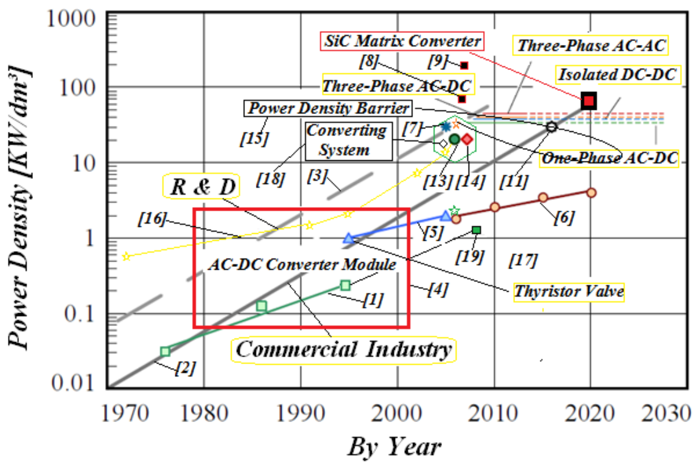

Fig. 5 Road map of historical tendency of power density for power converters.

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