الجمهورية الديمقراطية الشعبية الجزائرية

République Algérienne Démocratique et Populaire

وزارة التعليم العالي والبحث العلمي

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

المدرسة العليا في العلوم التطبيقية بالجزائر

Ecole Supérieure des Sciences Appliquées Alger

المدرسة الوطنية المتعددة التقنيات

Ecole Nationale Polytechnique

Département de second cycle

Mémoire de Fin d'Etudes

En vue de l'obtention du diplôme de MASTER

Filière : **Electrotechnique**

Spécialité : **Traction électrique**

Thème :

STATE OF THE ART ON DIRECT AC-AC CONVERTERS

Présenté par : ZEROUALI Nabil

Encadré (e) par : BEN ACHOUR Ali
Co-encadré(e) par : BOUTOUCEHE Hicham

Soutenu publiquement, le :02/09/2020

Devant le Jury composé de :

M	HAMACHE Amar	Président (e)
M	BENACHOUR Ali	Encadreur
M	BOUTOUCHE Hicham	Co-encadreur
M	DEBOUCHA Abdelhakim	Examinateur

Binôme N° : 21/Master / 2020

Acknowledgment

First of all, all thanks are to allah the most powerful and most merciful. I thank allah for giving me the strength and the will to do this project and finish it.

A huge thanks to our beloved teacher M.BEN ACHOUR Ali, one of the most beloved teachers to our hearts, I can't thank him enough for being patient with me, for staying in my side no matter what and even when things got hard.

I thank as well all the teachers in ESSA-ALGER for all the valuable lessons and pieces of advice throughout those whole three years.

I thank our families, our aid and everything for us for helping and encouraging us all the way long and for believing in us.

And last but not least a special thanks to everyone that helped us in this project.

Dedications

I dedicate this work:

Firstly, to my teacher Ali BEN ACHOUR, to thank him for standing by our side and bear with us till the end.

To my parents, my support for all those years of hardship where I though there will be no end to them, my light in the darkest nights, my hope for a success that wouldn't be without them and there cheering visible or hidden to me.

To my three brothers that has been with me in the good and the bad.

My special dedication to the two persons that took care of me when I was far away from home, Mr.Saker Lamine & his wife Saliha .

To my family friends, Balamane Tamime-Dar and Radia Fenni for their help and support.

To my friends that I made in my promotion at ESSAA, a friend that we passed both Good and Bad moments, Special dedications to ALI MOUHERI Mawloud, GHERSI Tarak , BAHIDJ Ryad, MEKHILEF Aymen Abdelmounaim, KACED Abderrahmane and LABADI Saida.

TABLE DES MATIERES

FIGURES LIST

TABLES LIST

ABBREVIATIONS LIST

V_{DC} : DC bus voltage

THD% : distorsion factor.

IGBT: Insulated Gate Bipolar Transistor

الملخص:

الغرض الرئيسي من هذا العمل هو دراسة الهياكل المختلفة الموجودة في محولات التيار المتردد ثلاثية الطور المطبقة خصيصًا لتطبيقات تغيير السرعة (محركات السرعة المتغيرة) لتزويد آلة غير متزامنة .كما تم تقديم مفصل حول المحولات المباشرة من حيث الهياكل المباشرة ، الغير المباشرة و غيرها . كما تمت مقارنة بين هذه الهياكل من حيث الخصائص ، المميزات و العيوب .

الكلمات المفتاحية : محولات التيار ، محولات التيار المباشرة ، محولات التيار الغير مباشرة

Abstract:

The main purpose of this work is to study the different topologies existing in the three-phase AC-AC converters applied specifically for speed variation applications (variable speed drives in short VSD) to supply an asynchronous machine. A detailed presentation about the direct AC-AC converters also known as Matrix converters was displayed by its different structures in both direct MC , Indirect MC and others . A comparison between those structures was made to show their advantages and disadvantage .

Key words: AC-AC converters , Direct Matrix converters , Indirect Matrix Converters .

Résume:

L'objectif principal de ce travail est d'étudier les différentes topologies existant dans les convertisseurs triphasés AC-AC appliqués spécifiquement pour les applications de variation de vitesse (variateurs de vitesse en bref VSD) pour alimenter d'une machine asynchrone. Une petite présentation sur les convertisseur directe aussi connu sous les convertisseurs matriciels a été exposé avec les différentes structures qu'on y trouve . Une comparaison a été faite pour montrer non seulement les avantages mais aussi les inconvénients de chaque structure.

Mots clés: convertisseur AC-AC , Convertisseur Matriciel Direct , Convertisseur Matriciel Indirect .

General Introduction:

Electric motors have long been and will continue to be the major workhouse in industry due to their efficient and reliable transfer of power for industrial and commercial applications. In relation to the benefits of transferring electrical energy to mechanical energy the squirrel-cage induction motor is rugged and reliable requiring minimum maintenance at a very reasonable cost[1].

Over the years many different ways were applied to control the motors speed but were less recommended specially for electrical motors that are supplied by an AC source . Until the advent of the AC variable frequency drive in the late 1950's [1].

Technology has made great strides in improving those AC variable frequency drive to the present day standards . This improvement was , still and will always see many transformations and even the creation of new structures that will make the last ones look obsolete [1].

Variable speed drives (VSDs) were the fruit of this improvements since their Princip are the AC-AC converters making it possible to provide a great variety of them. VSDs together with motors have emerged throughout industry as the popular approach to improve process control , product quality and reduce energy consumption (that can be said the most crucial point) [1].

In what follows a state of the art regarding the future of AC-AC converters also known as Direct AC-AC converters or Matrix converters is presented , where the Direct and Indirect topologies are compared with each other .

CHAPTER I: STATE OF THE ART ON DIRECT AC-AC CONVERTERS (MATRIX CONVERTERS)

I.1 STATE OF THE ART ON AC-AC TOPOLOGIES:

AC-AC power converter is able to generate controllable sinusoidal AC output both in magnitude and frequency from an AC supply[2].

As shown in **Figure 1-1** AC-AC converters can mainly be classified to deferent families according to the type of AC-AC conversion. The classification of AC-AC frequency converters in the technical literature is varied , due to it's continue development[3],[4]. So basically the most based for it's classification depends on it containing a main DC energy storage element (indirect topology) or not (direct topology) .

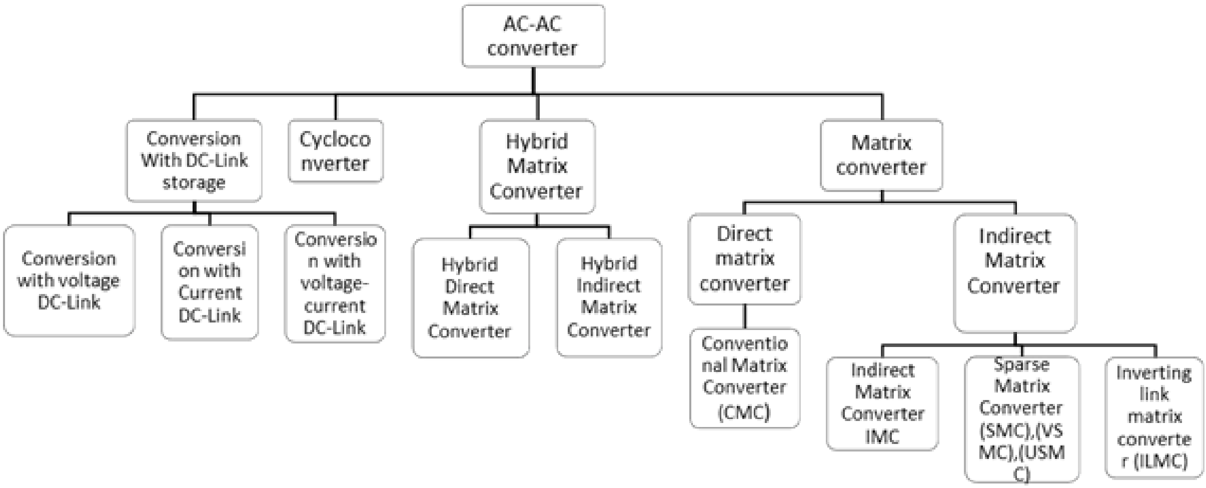


Figure I-1 global schematic of the basic families of AC-AC converters

I.1.1 **Indirect Topologies:**

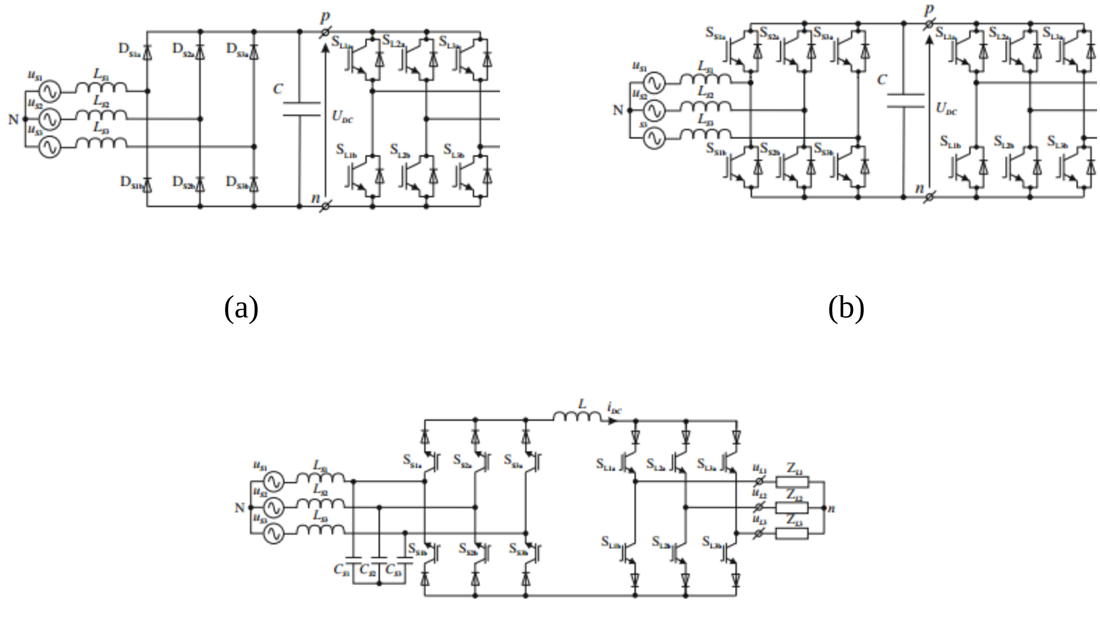
This family is basically the family of converters with DC-link . It's the most popular and widely used in industry and households voltage source inverter (VSI) and current source (CSI) inverter[5] .

Many different structures of this family exist and the difference as seen in Figure1-2 is shown in the rectifier bridge where the difference is made.

Figure 1-2 (a) Represent the most standard topology of them which is a voltage source inverter (VSI) with a front-end diode rectifier and a DC link capacitor[6].

Figure 1-2 (b) represent another topology where the bidirectional flow of energy is insured by coupling the DC-link capacitor a fully controlled rectifier bridge based on IGBTs with the VSI inverter and is called Back to Back VSI (B2B-VSI)[7].

Figure 1-3 (c) represent another DC-link fully controlled rectifier bridge but this time with a DC-link inductor making it a current source inverter (B2B-CSI) [8].



(a) (b)

(c)

Figure I-2 main topologies for indirect AC-AC converters with DC-link : (a)VSI using a diode rectifier bridge , (b) BBC-VSI and (c) BBC-CSI

In [9] , Peng et all proposed a new topology as seen in Figure 1-3 by putting a Z source DC-link between the front-end diode rectifier and the controlled inverter.

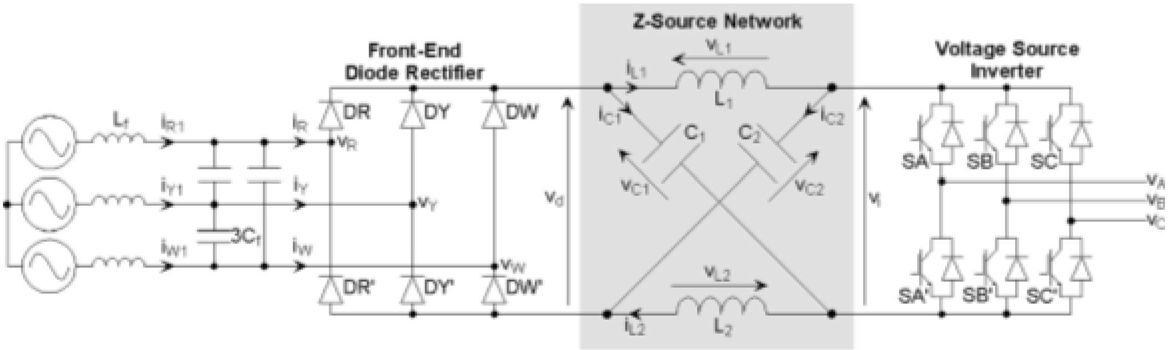


Figure I-3 AC-DC-AC Converter with Z source

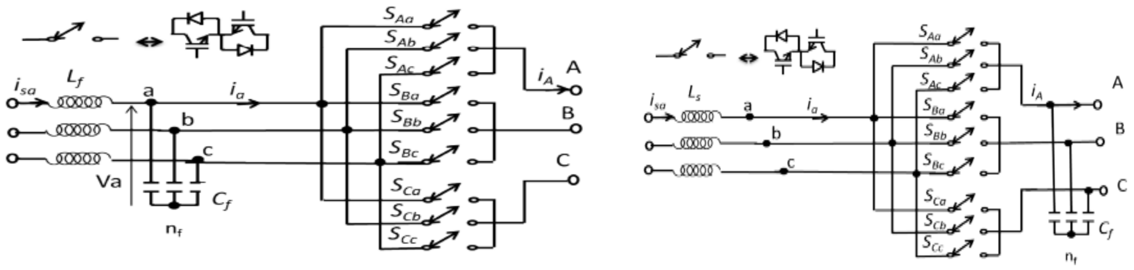
I.2 MATRIX CONVERTERS:

I.2.1 DIRECT MATRIX CONVERTERS:

Also known as Matrix Converter (MC) . MC was proposed in 1976 by Guygyi-Pelly [10],[11] . It uses a matrix (n x m) of bidirectional power switches , this both bidirectionality in both current and voltage allows the MC to generate m output voltages with a variable frequency (theoretically unlimited) from n phases of voltages[12] .

Being subject for around thirty years of research and development , the MC has a possibility to replace the conventional indirect converters (AC-DC-AC) , specially for embedded systems [10],[11]. Due to the absence of the DC-link (capacitors or inductors) make it less bulky then then indirect topologies , therefore it can be encapsulated in a semiconductor module[10],[11].

Figure 1-4.a shows the first MC topology proposed by Venturini and Alesena in 1980 , they described it as a matrix of bidirectional switches and named it “Matrix converter” [13].This structure alternate a voltage source with a current source . There is another MC structure that alternate a current source with a voltage source (figure 1-4.b) . It’s objective is to control the frequency and amplitude of the output current making it possible to obtain voltage ratios superior to 1[14] .



a) Direct MC **b) Direct MC of current**

Figure I-4 Direct MC Topologies

I.2.2 **INDIRECT MATRIX CONVERTERS:**

IMC in figure 1-5.a is constituted of two stages , the first being the rectifier stage that is a matrix converter [3x2] made by 6 bidirectional switch making it possible to operate in four quadrants as the Direct MC . The second stage being an inverter .

In every instant , two transistors and two diodes conduct in the rectifier in the rectifier stage . This topology give the same advantages as the direct MC convertors with less inconvenient. In fact , commutation as well as the protection circuit (clamp circuit) are way easy than in direct MC . Furthermore n being constituted of 18 IGBT and 18 diodes as the direct MC[5],[4]. Adding to it from a realization point of view , this topology (figure 1-5.a) is more easy due to the inverter stage . Another advantage is being able to use it in case of multi-machine by adding inverters in parallel[5].

This Topology (figure 1-5.a) generate less loss by conduction compared to the next topologies , on the other hand it necessities more transistors [12] .

A major step was accomplished in 2001 by the development of other types of IMC following the invention sparse IMC by Kolar and al[15] (figure 1-5.b) .

This convertor being an IMC but with less semiconductors that we can command at the rectifier stage .

This Topology being engender by pooling a first interrupter that we can command from the cell a and a second from cell a' for the same arm . With this structure a unit power factor in the input is accomplished with a sinusoidal current and voltage in the output very similar to the Conventional IMC [2] .

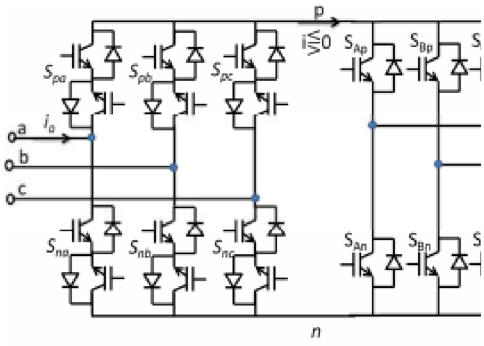
However, depending on the direction of power transit, three transistors and three diodes (power transmitted to the load) or two transistors and two diodes (power fed back into the input network) are conductive. The conduction losses of this topology will therefore be greater than those generated by the rectifier of the IMC [16].

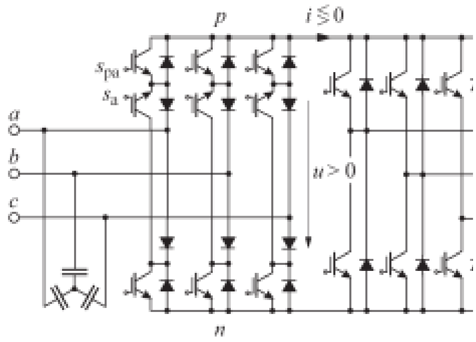
Another topology , named Matrix convertor " Very-Sparse" has been proposed and experimentally verified by Kolar [15],[17] (figure 1-5.c) , this structure is composed of six single transistor four segment switch . This topology permits to limit the number of commendable components in the rectifier stage to six , reducing it to half compared to IMC . The conduction losses for this topology is higher than the last one cause in functioning more the rectifier needs two IGBTs and four diodes to be active in the same time.

If the DC bus operation is in a single quadrant (that means the current flow is in one direction), the number of IGBTs can be reduced to 12 with 12 diodes as well (unidirectional very sparse MC) (figure 1-5.d) . Or to 9 IGBTs and 18 diodes for the "Ultra Sparse IMC" (figure 2-1.e). The last two don't permit regeneration or brake [2],[12],[18] .

Another topology called "Inverter stage IMC" (figure1-5.f) is composed of a rectifier with unidirectional interrupters in current , in cascade with a second inverter stage . This rectifier permits energy recovering thanks to it inverter stage . This topology engenders more commutations loss and more complexity to command it [12],[19].

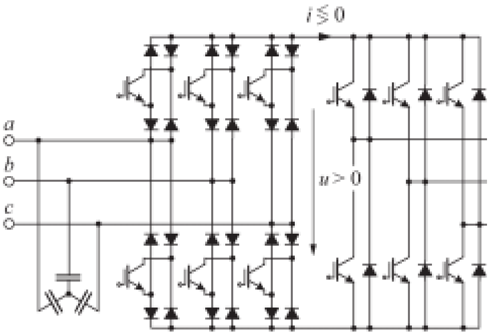
A.Benachour [16] made a comparison between these topologies in term of number of IGBTs and diodes needed, number of conductive components at a time number of isolated drives supplies needed and the bidirectionality of each topology (Table 1)

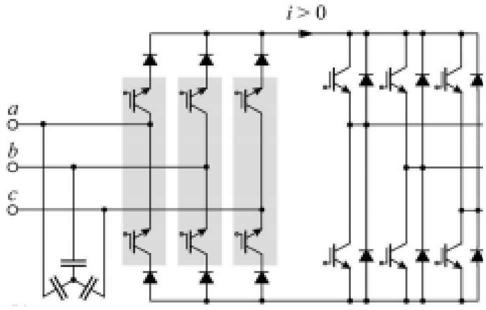




a-Indirect MC

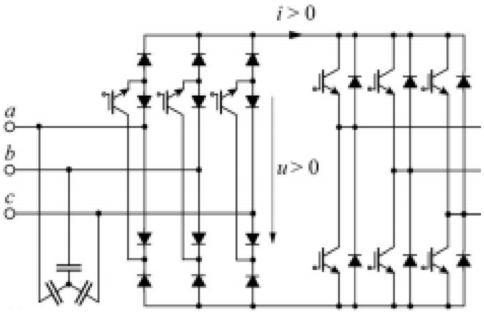
b-Sparse IMC

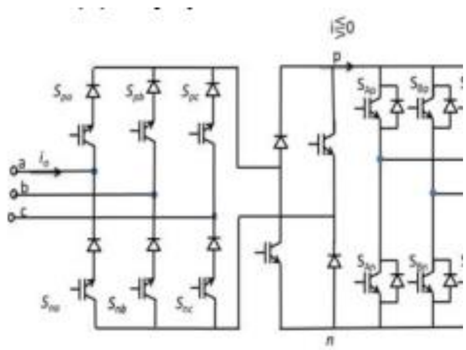




c-Bidirectional Very Sparse IMC

d-Unidirectional Very Sparse IMC





e-Ultra Sparse IMC

f-Inverter Stage IMC

Figure I-5 IMC different topologies

Table 1 Comparison between MC topologies

topology	Number of conductive components	Bidirectional power flow	IGBTs	Diodes	Number of isolated gate driver supplies
MC	6	Yes	18	18	9
IMC	7	Yes	18	18	8
SIMC	9	Yes	15	18	7
VSIMC	9	Yes	12	30	10
USIMC	9	No	9	18	7
MC with inverter stage	9	Yes	14	14	11

A structure named Isolated IMC was introduced in 1990 by Kawabata for a compact UPS [10] . In 2003 Cha and Enjete [10],[20] proposed a new topology for I-IMC for a direct AC-AC isolated conversion , characterized by a variable input frequency and a constant output frequency . They called it High Frequency Matrix Convertor (figure 1-6) . This topology contains two stages as an IMC , the first stage being a four quadrants rectifier that converts the variable frequency three phase AC input to high frequency monophasic HFAC . The second stage as the first convert the monophasic HFAC to a constant frequency Three phase AC . A HF transformer is added between the two stages to assure an isolation between them and voltage ratio adjustment . This structure also give an unitary Power Factor and a low THD .

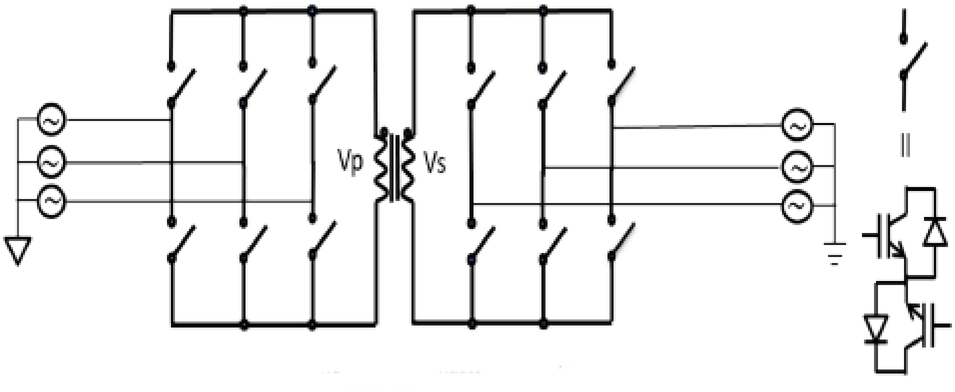


Figure I-6 High Frequency IMC

A multi-level structure called H-bridge MC was proposed , analyzed and experimented by Erikson in [14],[21] (figure 1-7) . This structure being similar to Direct MC but in place of using bidirectional interrupters we use CCH-b (Clamped capacitor H-bridge) . It permits to synthesize the input voltage and also the output voltage . This permits to exceed the ratio limit (Vo>Vin). This structure is complicated to command due to the capacitors [14],[22].

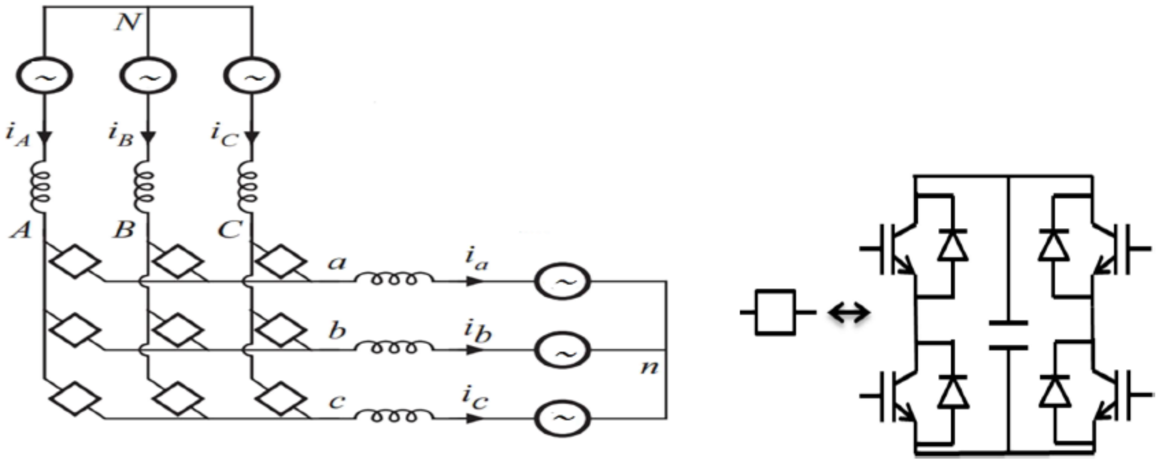


Figure I-7 H-bridge MC

Another Multi Level structure named Multi-levels MC with floating capacitors was proposed [23]. The structure is shown in figure 1-8. This converter is obtained by replacing each interrupter in the direct MC by two series or more of connected interrupters and floating capacitors . It permits to improve the output voltage however its command is complex due to the floating capacitors voltage interference that have to be controlled [23].

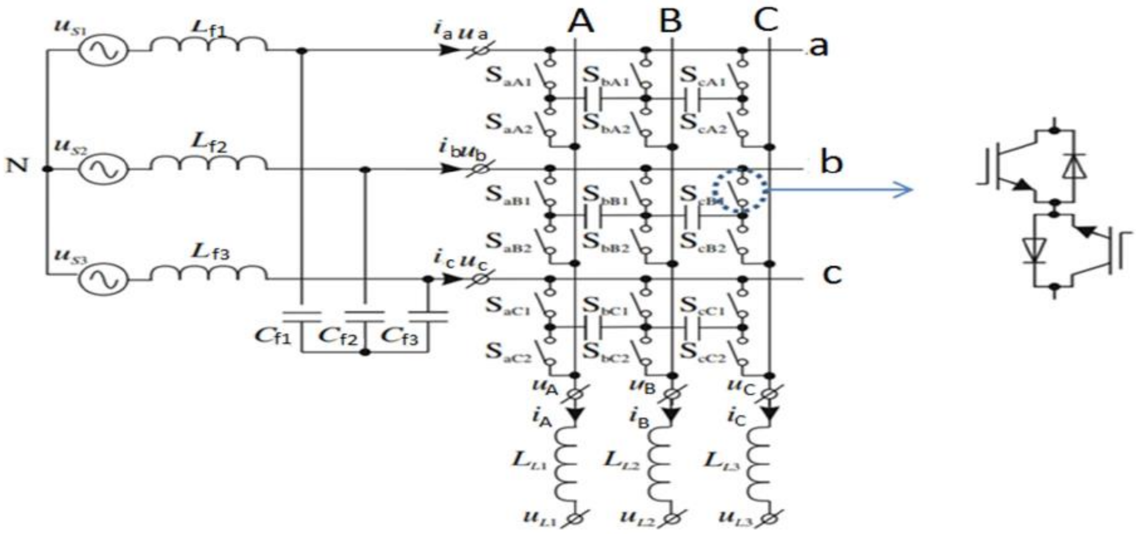


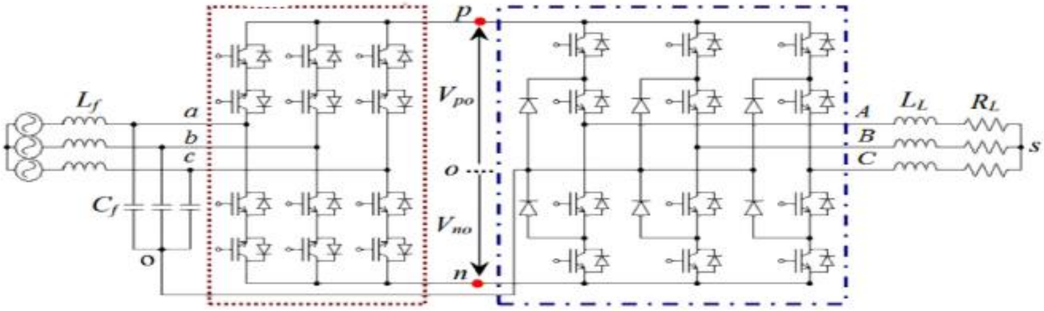
Figure I-8 Multi level MC with floating capacitors

Kolar and al. proposed another kind of structure called indirect three level matrix converter [24],[17],[18],[2]. Having similarities with the conventionnel IMC , only changing the two level inverter stage by a three level inverter stage[2],[25] (figure 1-9.a) . This structure permits to have multi-level voltages and better performances than a conventional IMC [2]. But with a complex command [2].

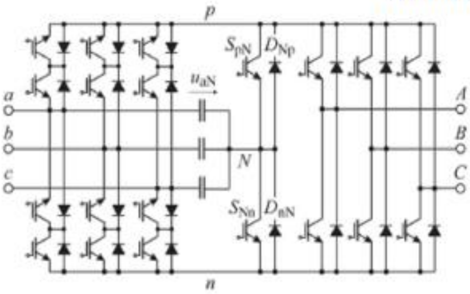
S. Ali Khajehoddin and al. proposed and studied a sparse multi level IMC with less semiconductors than the precedent structures . By using unidirectional interrupters in the rectifier stage and a three level diode-clapmed inverter in the inverter stage [26].

Another multi-level structure was proposed by M.Y.Lee and al.[2] (figure 1-9.b) with less interrupters than the conventional I3LMC . A SVM modulation was proposed [17],[27]. This structure being analyzed and experimented [17] and compared to the other multi level structures in [27] . Presenting good output performances specially for weak ratios compared to the conventional IMC . It has the advantage of having less interrupters than the I3LMC and produce multi-level voltages but in output signal quality, l'I3LMC give better results . One of its inconvenient being the input current distortions more important than the conventionnel structures [2],[27].

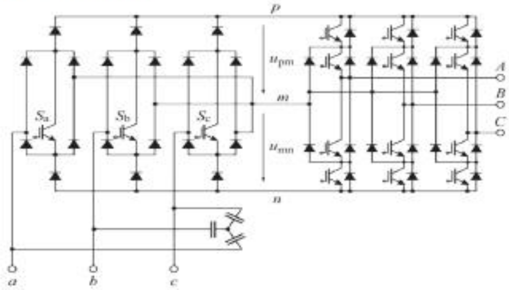
Another unidirectional multi-level structure at input and output based on the Vienna rectifier has been proposed in [28] (figure 1-9.c) . This structure is less presented in literature. It has the advantage of having less interrupters than I3LMC and the connection to the neutral point is not done in the input capacitor level.



(a) Three level IMC (I3LMC)



(b) Sparse three level IMC (I3SMC)



(c) Vienna three level IMC

Figure I-9 Three level IMC topologies

I.3 GENERAL CONCLUSION:

In this chapter a state of art about AC-AC converters has been presented and a small comparison between them displayed , these converters with their different topologies are divided into several families but two big families on the Top that are the direct AC-AC converters also known as Matrix converters and indirect AC-AC converters with DC-link bus .

Matrix Converters topologies has been detailed in this chapter where as seen ,those topologies have underground many improvement with time , mostly with advantages a but also disadvantages in some fields as the command …etc.

The most developed and improved Matrix converters are the indirect Matrix Converters (IMC) where we could find a consistent number of structures developed an experimented .

In the future those IMC will replace the actual indirect AC-AC converters in the industrial field due to their interest and proprieties .

BIBLIOGRAPHY

[1] D. E. Roethemeyer et D. Yankaskas, « Evolution of motor and variable frequency drive technology », 1995, p. 541-552.
[2] M. Y. Lee, « Three-level neutral-point-clamped matrix converter topology », 2009.
[3] S. Bhowmik et R. Spee, « A guide to the application-oriented selection of AC/AC converter topologies », *IEEE Transactions on Power Electronics*, vol. 8, nº 2, p. 156-163, 1993.
[4] J. W. Kolar, T. Friedli, J. Rodriguez, et P. W. Wheeler, « Review of three-phase PWM AC–AC converter topologies », *IEEE Transactions on Industrial Electronics*, vol. 58, nº 11, p. 4988-5006, 2011.
[5] P. Szczesniak, « Three-phase AC–AC power converters based on matrix converter topology », *Springer*, 2013.
[6] M. P. Kazmierkowski, R. Krishnan, et F. Blaabjerg, *Control in power electronics*. Elsevier, 2002.
[7] J. W. Wilson, « The forced-commutated inverter as a regenerative rectifier », *IEEE Transactions on Industry Applications*, nº 4, p. 335-340, 1978.
[8] D. G. Holmes et T. A. Lipo, *Pulse width modulation for power converters: principles and practice*, vol. 18. John Wiley & Sons, 2003.
[9] F. Z. Peng *et al.*, « Z-source inverter for motor drives », *IEEE transactions on power electronics*, vol. 20, nº 4, p. 857-863, 2005.
[10] T. Friedli et J. W. Kolar, « Milestones in matrix converter research », *IEEJ Journal of industry applications*, vol. 1, nº 1, p. 2-14, 2012.
[11] L. Empringham, J. W. Kolar, J. Rodriguez, P. W. Wheeler, et J. C. Clare, « Technological issues and industrial application of matrix converters: A review », *IEEE Transactions on Industrial Electronics*, vol. 60, nº 10, p. 4260-4271, 2012.
[12] F. Gruson, « Modulation naturelle généralisée des convertisseurs matriciels pour la variation de vitesse », 2010.
[13] A. Alesina et M. G. B. Venturini, « Analysis and design of optimum-amplitude nine-switch direct AC-AC converters », *IEEE Trans. Power Electron.*, vol. 4, nº 1, p. 101-112, janv. 1989, doi: 10.1109/63.21879.
[14] R. W. Erickson et O. A. Al-Naseem, « A new family of matrix converters », 2001, vol. 2, p. 1515-1520.
[15] J. W. Kolar, M. Baumann, F. Schafmeister, et H. Ertl, « Novel three-phase AC-DC-AC sparse matrix converter », 2002, vol. 2, p. 777-791.
[16] B. Ali, « Commande sans Capteur basée sur DTC d'une Machine Asynchrone alimentée par Convertisseur Matricie », 2017.
[17] M. Y. Lee, C. Klumpner, et P. Wheeler, « Experimental evaluation of the indirect three-level sparse matrix converter », 2008.
[18] J. W. Kolar, F. Schafmeister, S. D. Round, et H. Ertl, « Novel three-phase AC–AC sparse matrix converters », *IEEE transactions on power electronics*, vol. 22, nº 5, p. 1649-1661, 2007.
[19] T. Friedli, J. W. Kolar, J. Rodriguez, et P. W. Wheeler, « Comparative evaluation of three-phase AC–AC matrix converter and voltage DC-link back-to-back converter systems », *IEEE Transactions on industrial electronics*, vol. 59, nº 12, p. 4487-4510, 2011.
[20] H. J. Cha et P. N. Enjeti, « A three-phase AC/AC high-frequency link matrix converter for VSCF applications », 2003, vol. 4, p. 1971-1976.

[21] R. Erickson, S. Angkititrakul, et K. Almazeedi, « A new family of multilevel matrix converters for wind power applications », *National Renewable Energy Laboratory*, 2006.
[22] P. Wheeler, X. Lie, M. Y. Lee, L. Empringham, C. Klumpner, et J. Clare, « A review of multi-level matrix converter topologies », 2008, p. 286-290.
[23] Y. Shi, X. Yang, Q. He, et Z. Wang, « Research on a novel multilevel matrix converter », 2004, vol. 3, p. 2413-2419.
[24] P. C. Loh, F. Blaabjerg, F. Gao, A. Baby, et D. A. C. Tan, « Pulsewidth modulation of neutral-point-clamped indirect matrix converter », *IEEE Transactions on Industry Applications*, vol. 44, nº 6, p. 1805-1814, 2008.
[25] K. GHEDAMSI, « Contribution à la modélisation et la commande d'un convertisseur direct de fréquence: Application à la conduite de la machine asynchrone », 2008.
[26] S. A. Khajehoddin, A. Bakhshai, et P. Jain, « A sparse multilevel matrix converter based on diode-clamped topology », 2007, p. 224-228.
[27] L. Huber et D. Borojevic, « Space vector modulated three-phase to three-phase matrix converter with input power factor correction », *IEEE transactions on industry applications*, vol. 31, nº 6, p. 1234-1246, 1995.
[28] F. Schafmeister, « Sparse und indirekte matrix konverter », 2007.