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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 About Indirect AC-AC Converter

Présenté par : GHERSI Tarak

Encadré (e) par : M. BEN ACHOUR Ali

Soutenu publiquement, le :02/09/2020

Devant le Jury composé de :

M. HAMACHE Amar	Président (e)
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M. BOUTOUCHE Hicham	Co-encadreur
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Binôme N° : 20/Master / 2020

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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.

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Dedications

I dedicate this work:

Firstly, to my teacher Ali BEN ACHOUR, to thank him for standing by our side till the last minute.

To my parents, my light in those nights where I thought that there is no hope left, my road to the right. My candle that kept shining when the darkness left my heart whining.

To my six brother and sister and all my family that has been with me in the good and the bad

Special dedication to my other two brothers MEKHILEF Aymen Abd Elmonim and Kaced Abd Elrahman my friends and brothers and a lifelong company.

And finally, to my other sister that without whom I wound not be here. My sister that was an aid and a life savior for me throw 5 years. My sister that never turned me down.

To you MECHAB Nessrine.

GHERSI Tarak

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V_{DC} : DC bus voltage

i : phase curant.

R : resistance .

Φ : phase flux.

L1, 2,3 : phases inductences

Ω : machine's speed

P : poles number.

T_C : torque,

T_{em} : electromagnetic torque.

J : machines inertie .

I_{dc} : DC bus current.

THD% : distorsion factor.

PWM : Pulse Width Modulation.

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 مقدمة صغيرة عن تقنيات التحكم المطبقة عليها .تم تقديم هياكل مختلفة مع تحديد نقاط في الاختلاف بينها من حيث مرحلة المقوم وتخزين وصلة التيار الميتمر ومرحلة العاكس.
الكلمات المفتاحية VSD :، تقنيات التحكم ، المعدل ، تخزين وصلة DC ، العاكس.

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 small introduction to the control techniques applied on them was presented as well. Various topologies were presented while making points in the difference between them in term of rectifier stage, DC link storage and inverter stage.

Key words: VSD, control techniques, rectifier, DC link storage, inverter.

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 *VSD*) pour alimenter ~~d'~~une machine asynchrone. Une petite introduction aux techniques de contrôle appliquées sur eux a également été présentée. Différentes topologies ont été présentées tout en faisant la différence entre elles en termes d'étage redresseur, de stockage de liaison DC et d'étage onduleur.
Mots clés: VSD, techniques de contrôle, redresseur, stockage de liaison DC, onduleur.

General Introduction:

Electric motors have long been and will continue to be the general workhorse of industry providing an 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 change the speed of the motor through (either mechanical or electrical). Until the advent of the AC variable frequency drive in the late 1950's.[1]

Technology has made great strides in improving the AC variable frequency drive to present day standards. Variable speed drives (VSDs) together with motors have emerged throughout industry as the popular approach to improve process control, product quality, reduce energy consumption[1].

These variable speed drives come with different technologies, shapes, power range…etc. As well as the topology. Since the principle of the VSDs is an AC-AC converter, that gave the possibility to provide a great variety of VSDs especially indirect AC-AC converters that contains a DC bus which makes them suitable for braking applications.

AC-AC converters has many categories such as : Matrix converters (MC),Hybrid matrix converters, Cycloconverters and ndirect AC-AC (or AC/DC-AC) converters[2]

In what follows a state of the art regarding the indirect AC-AC converters is presented, where the VSI (Voltage Source Inverter) and CSI (Voltage Source Inverter)[3],[4] are compared with each other, then the Z source and multilevel are presented as well.

In the end a small presentation of the most known control techniques is presented.

CHAPTER I: STATE OF THE ART ON INDIRECT AC-AC CONVERTERS

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

In this section we will talk about the proposed topologies of the VSDs. The following figure (figure I.1) represents a global schematic of the basic families of AC-AC converters (both frequency and amplitude):

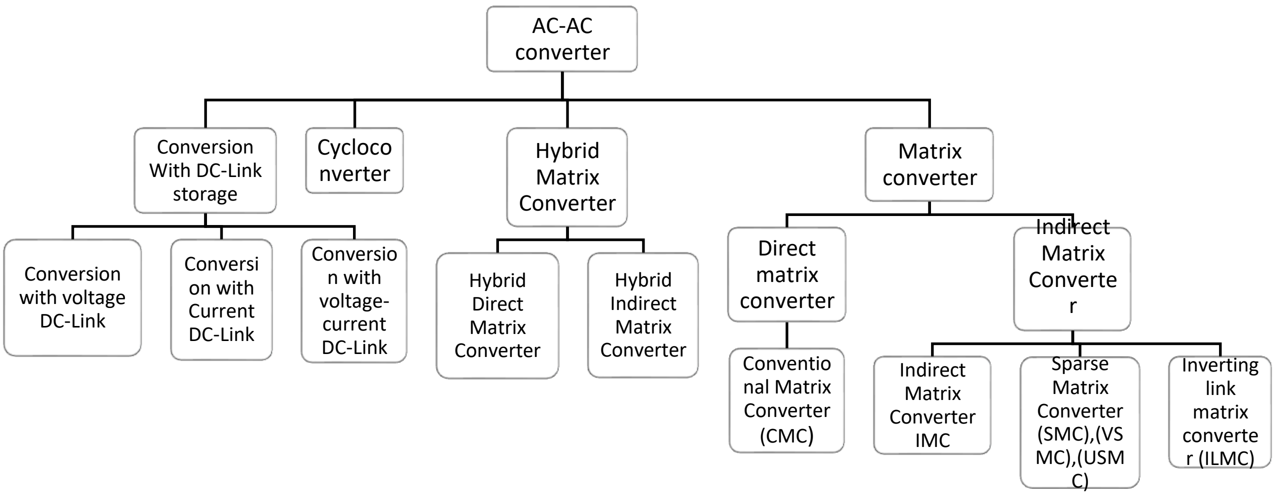
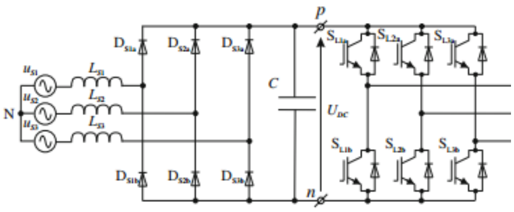


Figure I-1 global schematic of the basic families of AC-AC converters

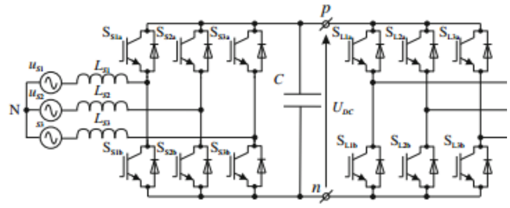
As shown in figure 1.1 AC-AC converters can mainly be classified to deferent families according to the type of AC-AC conversion. The classification of AC–AC frequency converters in the technical literature is varied, because its development is still in progress [5],[6] .So basically AC-AC converters are classified into indirect topologies that contains a main DC energy storage element, direct topologies (without a DC energy storage element) and hybrid structures with small local DC energy storage elements.

I.1.1 Indirect Topologies:

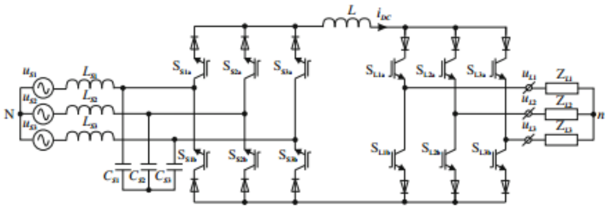
This family is basically the family of converters with DC-link .It includes the most popular and widely used in industry and households voltage source inverter (VSI) and current source (CSI) inverter.[3]



(a)



(b)



(c)

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

Figure I.2 (a) Represents the most standard topology of an AC-AC converter which is a voltage source inverter (VSI) with a front-end diode rectifier and a DC link capacitor [4]. It is also called a two-level indirect converter voltage source inverter. It consists of two converter stages and an energy storage element, the first stage (rectifier) converts the supply's AC voltage to DC and then the inverter stage reconverts it back into output AC voltage with variable amplitude and frequency. One of the major disadvantages of this topology is the high distortion of the input current due to the high amount of low-order harmonics such as the 5^{th} and 7^{th} [7].

Figure I.2 (b) represent another topology where the bidirectional flow of energy is ensured by coupling the DC-link fully controlled rectifier bridge based on IGBTs with the VSI inverter. It's called Back to Back VSI (B2B-VSI),[8]. The dc-link quantity is then impressed by an energy storage element that is common to both stages which makes it possible to command them separately [6],[3].The main disadvantage of this topology lays in the medium power converters where the required input filter inductors are bulkier and heavier than the DC link capacitor [3].

Another topology other than the B2B-VSI is presented in Figure I.2 (c) using a Current Source Inverter (B2B –CSI) presented in [9]. It generates an input current waveform similar to the B2B-VSI while using a DC link inductor which is generally larger than DC link capacitor in the VSI. The B2B –CSI also requires an input filter usually smaller than the one used in the VSI (a low pass LC filter)[3].

In the topology presented in Figure I.2 (a), beside the harmonics and the distortion problem there is another problem in the non-reversibility of the rectifier current due to the functionality of diodes which may cause a problem to handle an eventual energy flow reversal, such as during an electromagnetic braking, thus the possibility of the DC bus voltage reaching destructive levels. So the use of dissipation load (resistor) is required (can only be dissipated) which makes it effective only in low energy dissipation applications.[10] The solution was to use the B2B-VSI with IGBTs bridge rectifier Figure I.2.b .With this solution the breaking energy can be fed back to the power grid [8].

I.1.2 **Z source topologies:**

Peng et al.[11] proposed a new topology by putting a Z source DC link between the front-end diode rectifier and the controlled inverter, as descripted in [12] the Z-source inverter allows the system output voltage to be stepped down or up as desired by inserting an X-shaped LC impedance. This impedance contains two inductors and two capacitors figure I.3.

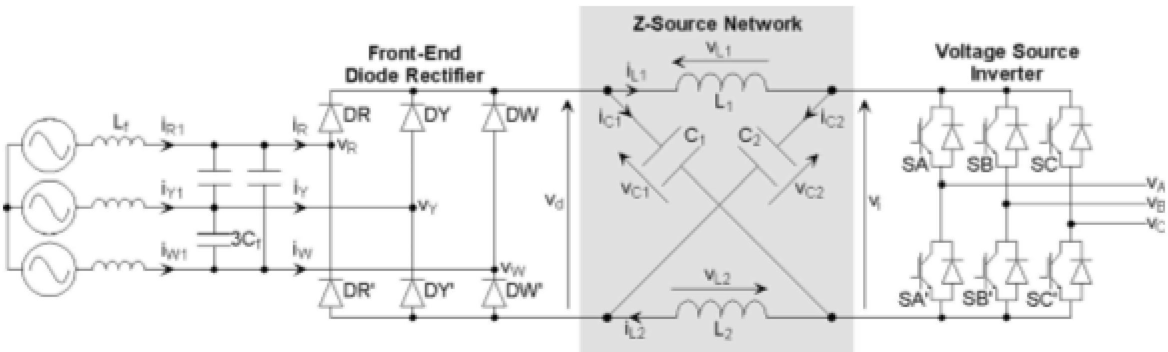


Figure I-3 AC-DC-AC Converter with Z source

Another topology of the Z source is presented in figure I-4

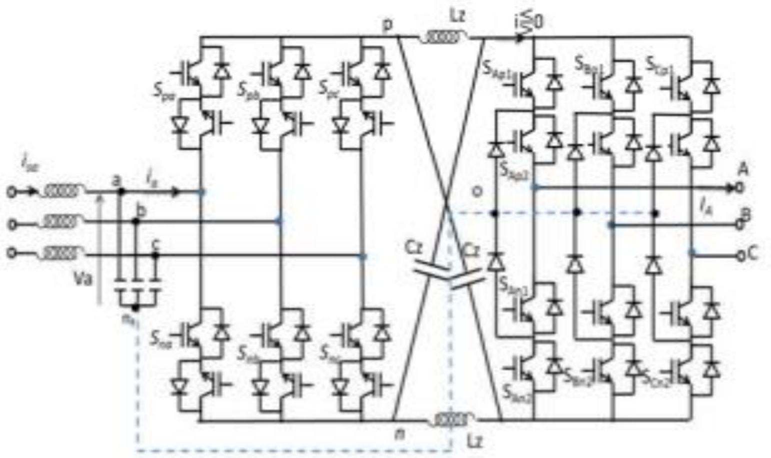
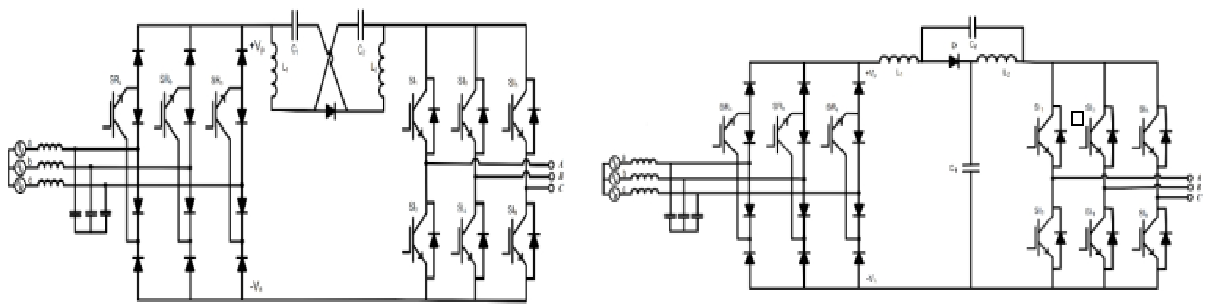


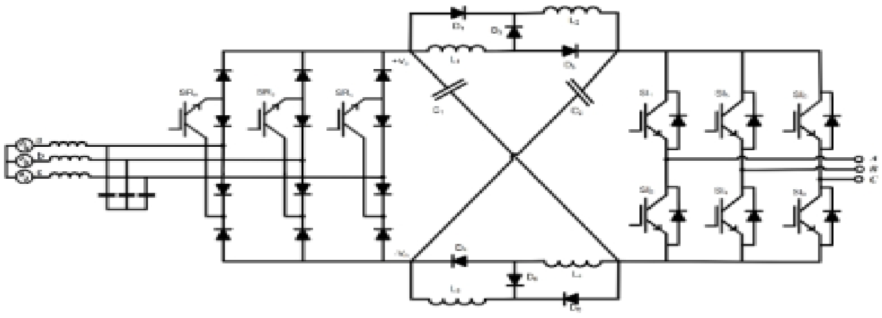
Figure I-4 I3LMC topology with Z-source

A ZSIMC topology with a three-level NPC inverter stage has been studied in [13] (Figure I-4) where carrier-based modulation was simulated. A comparison between two indirect z-source topologies have been proposed in [14].

[15] presents many other topologies of Z-source some of them are presented in the following figure (figure I-5)



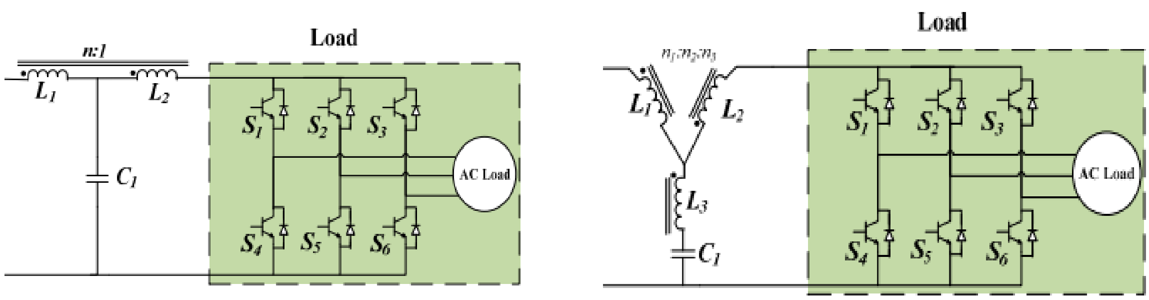
(a) (b)



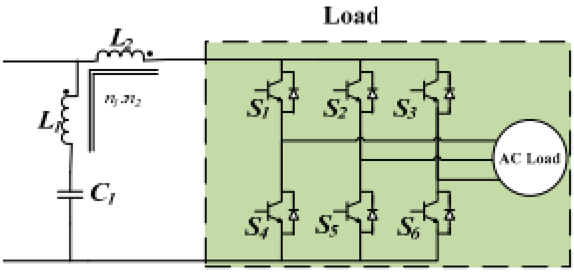
(c)

Figure I-5 (a) Series Z-source converter; (b) Quasi-Z-source and (c) Switched-inductor Z-source converter topologies.

As shown in Figure I-5. Series Z-source, quasi Z-source or switched inductor Z-source network is inserted in either rail of the indirect matrix converter. These converters constitute an improvement over the cascaded Z source by reducing the voltage across the Z source network's capacitor, limiting the inrush current at startup for series Z-source and widening the boost ratio for quasi Z-source and very high boost ratio for switched inductor Z-source matrix converter. The FFT analysis of these converters input/output currents can be carried out [16],[17] , indicating a slight superiority of the switched inductor Z-source converter over the quasi Z-source converter and the series Z- source converter over the cascaded Z-source converter with respect to the quality of input currents.



(a) (b)



(c)

Figure I-6 (a) Trans-Z-source inverter topology, (b) Y-source inverter topology, (c) Γ-source inverter topology.

Trans-Z-source(figure I-6 a) (two voltage-fed and two current-fed) inverters were proposed to have higher voltage gains and to keep voltage stress low with Z-source network reduced to one transformer (or one coupled inductor) and one capacitor [18].In addition to maintaining the main purpose of the Z-source, the Trans-Z-source holds some unique advantages by increasing voltage gains and reducing voltage stress. They are also able to operate at very low input voltage [19].

The Trans-Z-source network has the operation and working principle similar to Z-source network and also eliminates the shoot-through barriers[19].

Based on the Trans-Z-source a new topology was proposed in [20] which is the Y-source inverter (figure I-6 b), its performance is similar to the Trans-Z-source inverter. This new topology permits users to choose the boost voltage comparatively to a classical impedance network design with boost converter. It reduces the total harmonic distortion (THD) of the inverter and realizes a higher voltage gain with small shoot-through duty cycle[19].

With the diverse properties and the specific future of the Y-source network, many researchers and engineers continue to examine and modify the topology for the wide range of power-conversion applications[19].

In figure I-6 (c) another derivation of the Tran-Z-source in presented it is called Γ-Z-source inverter [21], Two Γ-shaped inductors are coupled in Trans-Z-source inverter to form the Γ-Z-source inverter, permitting it to increase the gain and modulation ratio, simultaneously [21]. The drawback of this topology constitutes the presence of the leakage inductance that can affect the voltage and current stress on semiconductors [19].

In [22] other topologies that are included in the Z-source family are presented as well and a comparative study between them is presented and is resumed in the following table:

Table I-1 Summary of the impedance source network topologies' advantages and disadvantages.

topology	Advantages	Disadvantages
Z-source	- Overcomes the disadvantages of voltage source and current source inverters. - Offers novel power conversion concept. - Both switches from the same leg can trigger at the same time do not cause any failure. - Inductor of current fed ZSI sustains high current. - Benefits to motor drives and renewable-energy generation applications	- Discontinuous input current. - Not suitable for very low input DC voltages - Cannot suppress the inrush current. - High-voltage capacitors, which are required, increase the cost and volume of the system.
Quasi Z-source	- Reduces passive component ratings. - Provides lower current stress on inductors compared to ZSI. - Benefits to motor drives and renewable-energy generation applications.	- Not suitable for very low input DC voltage.
Trans- Z-source	- Increases voltage gain more than the case of Z-source and quasi-Z-source network. - Reduces component stress. - Able to operate on very low input voltage. - Suitable for renewable-energy generation.	High gain is obtained with high winding turns ratio. - Discontinuous input current. - Transformers and coupled inductors increase volume and cost.
Y-source		- Discontinuous input

	- Higher voltage boost and higher modulation index can be obtained at the same time. - Reduced THD of the inverter. - Suitable for power-conversion applications	current. - Electromagnetic interference noise affects its reliability.
Γ-Z-source	High gain can be achieved by lowering turn ratio. - Better spectral performance. - Convenient for renewable energy generation	- Have high winding-turns ratio. - Electromagnetic interference noise affects its reliability.

I.1.3 **Multi-level inverter topologies:**

Another type of topologies which is used for industrial medium-voltage drives is presented in [23]. In these topologies the element that differs is the inverter. It is switched from two levels inverter into multi-level inverter

The multi-level inverter has many structure or topologies, most of them depends on the DC link energy storage element. The next figure represents the topologies existing in the multi-level inverter according the review published in 2017[24]

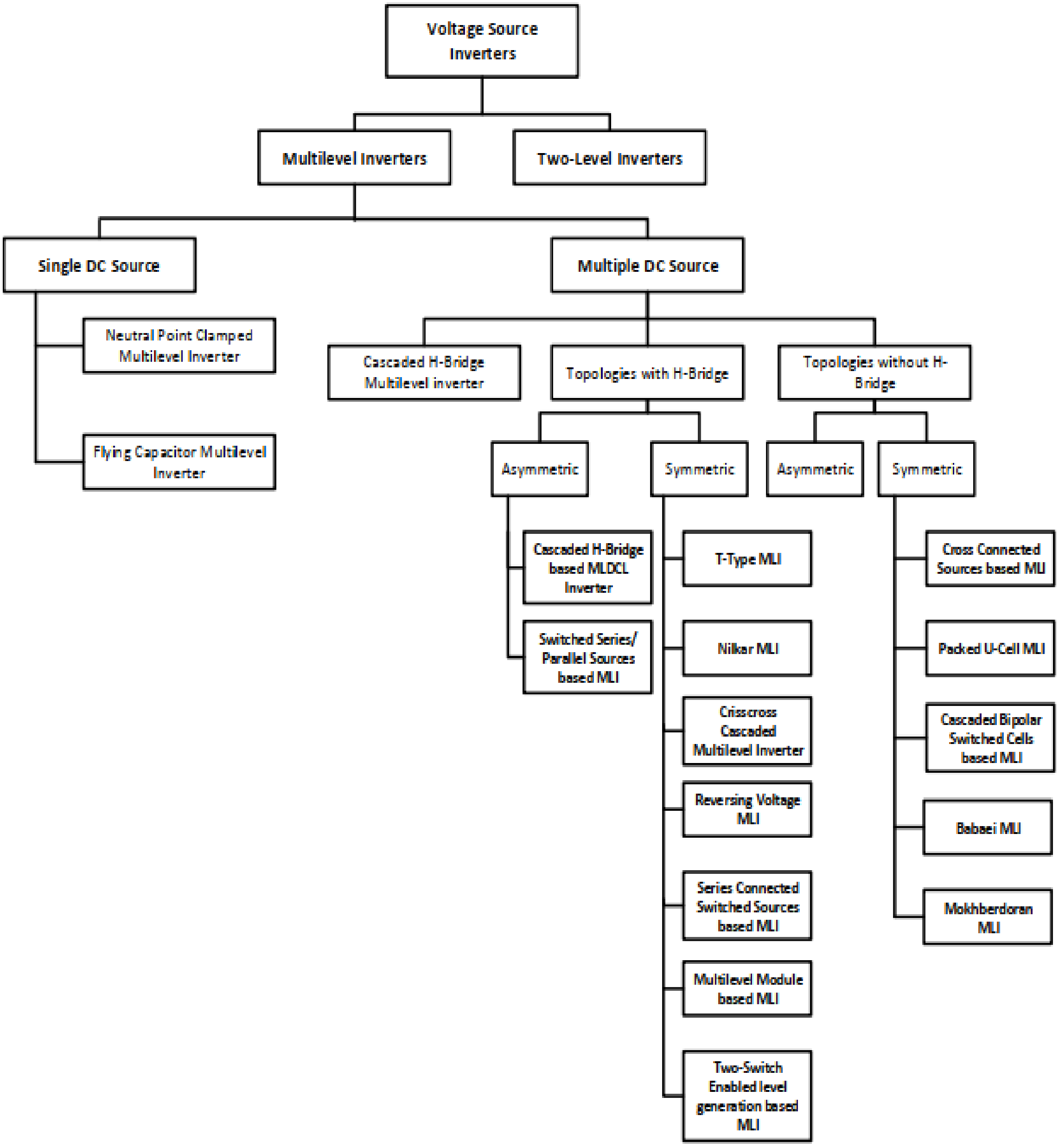
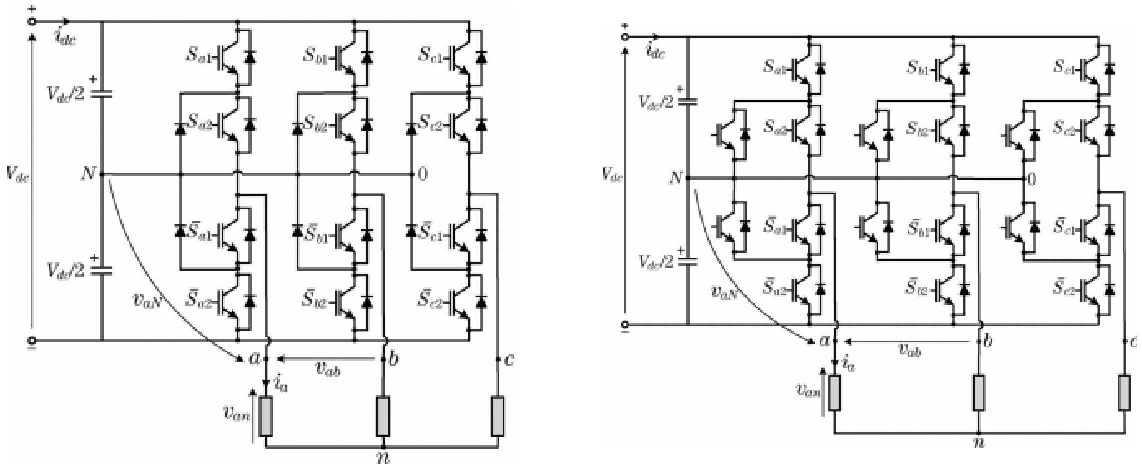


Figure I-7 Main topologies of the multi-level inverter

figure I-8 represents some of the given topologies that were chosen for the study:



(a) (b)

Figure I-8 (a) Circuit configuration of 3L NPC-VSC, (b) Circuit configuration of 3L ANPC-VSC

Figure I-8 presents 3 level voltage source inverters where the first one is called Neutral-Point Clamped Voltage Source Converter (NPC-VSC) while the second one is called Active Neutral-Point Clamped Voltage Source Converter (ANPC-VSC).

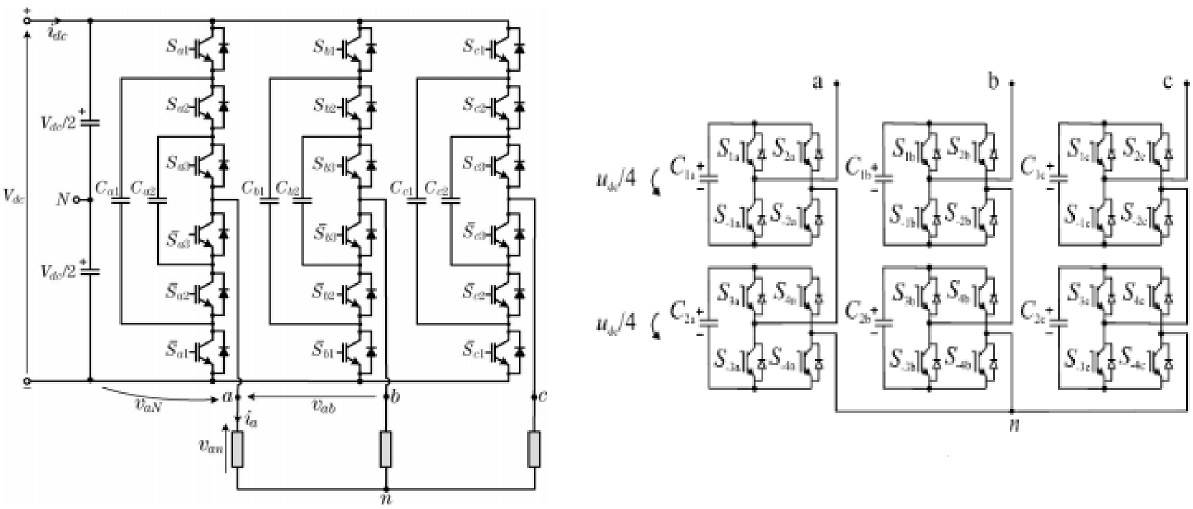
For the (NPC-VSC) - Figure I-8 (a) - it was presented in early 1980 in [25] and [26] , it is also known as diode-clamped converter. The possibility of the IGBTs to operate a commutation voltage of half of the DC link makes this topology a simple solution to extend voltage and power ranges of the existing 2L-VSC technology that are severely limited by the blocking voltages of power semiconductors with active turn-on and turn-off capabilities. According to [23] the converter was of particular interest for MV applications (2.3–4.16 kV) and was soon introduced to the market by leading manufacturers and gained more and more importance.

The 3L NPC-VSC features two additional diodes per phase leg as compared to a 2L VSC with a direct series connection of two devices per switch position. These so-called NPC diodes link the midpoint of the "indirect series connection" of the main switches to the neutral point of the converter. This allows the connection of the phase output to the converter neutral point *N* and enables the three-level characteristic of the topology. [23].

The NPC-VSC have unequal loss distribution and unsymmetrical semiconductor-junction temperature distribution due to the existing of the so-called NPC Diodes [27] that's why they were replaced by IGBTs creating the so-called ANPC-VSC presented in Figure I-8 (b) . so as to distribution enables a substantial increase of the converter output current and power at nominal operation and at zero speed.[23]

The concept of using either NPC or ANPC can be applied on higher levels as well so that we can have 4L- NPC/ANPC 5L- NPC/ANPC and so on in condition of keeping the DC capacitor balanced always.

Other topologies are presented in the following figure, 4-level inverter and 5-level inverter as well:



(a) (b)

Figure I-9 (a) Circuit configuration of 4L FC-VSC, (b) Five-level cascaded multi-level inverter.

In figure I-9 (a) another topology called the Flying Capacitor-VSC (FC-VSC).

The FC-VSC was proposed in [28] and [29] .Currently, the four-level FC-VSC (4L FC-VSC) is produced by one manufacturer of industrial MV drives. The nominal voltages of the FCs, $Cx1$ and $Cx2$, are $vcx1 = 2/3Vdc$ and $vcx2 = 1/3Vdc$, respectively. [23]

In figure I-9(b) another topology is presented were an H-Bridge cell is required. Thus, it is called CHB Multilevel inverter topology. The CHB multilevel inverter appeared first in 1988 [30]. It was matured during the 1990s and gained more attention after 1997[19]. It is composed of series connection of H-bridge power cells. For this reason, the CHB is also known as a multicell inverter. Each cell includes a single-phase 3L H-bridge inverter, a capacitive dc-link, a rectifier, and an independent or isolated voltage source provided a by transformer secondaries or batteries.

Figure (figure I-10) Represents the general configuration for the CHB topology with K-level inverter

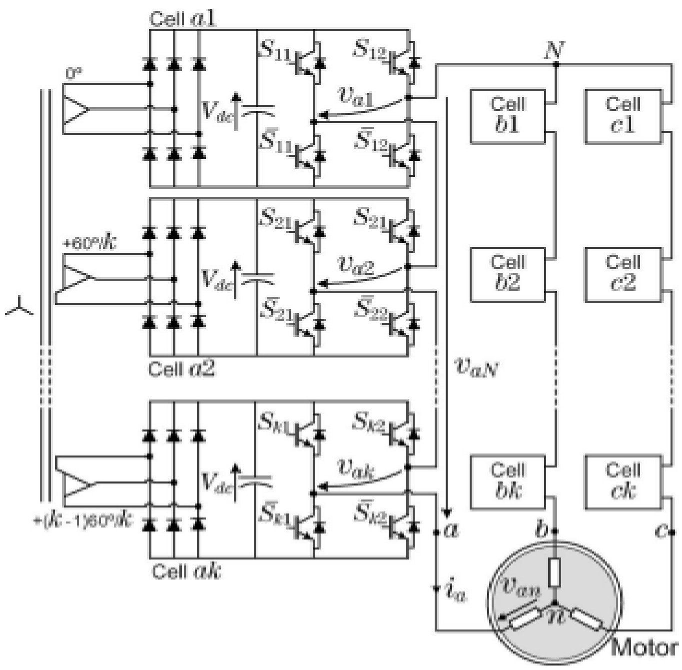


Figure I-10 CHB power circuit configuration

As it can be seen using this configuration a k-level inverter can be made.

The rectifier used in here is based on diodes, it can also be an IGBT rectifier in order to assure the regenerative stage.

I.2 Control Techniques:

All of the previous designs have at least one stage out of two which is controlled. The control techniques have developed through time and now there are many of them that can be classified in three sections:

I.2.1 Scalar based control:

This type of control is easy to implement and offers a steady state response. But it has a slow dynamic due to the non-controlled transients. The most popular scalar control is V/f control, in V/f control, the speed of induction motor is controlled by the adjustable magnitude of stator voltages and frequency, in such a way that the air gap flux is always maintained at the desired value at the steady-state.

The principle of the V/f control is to keep the V/f ration a constant in order to keep the core stator flux constant.

I.2.2 Vector based controls:

The slow dynamic that comes with the scalar control led to the invention of the victor control schemes, by Blaschke and Hasse in the 1960s and 1970s when they gave two approaches: Direct Flux Oriented Control[31] and Indirect Flux Oriented Control.

later on, many other vector control techniques appaired such as Direct Torque Control (DTC), (DTC-SVM), Stator Oriented Control… etc.

There are many vector-based control techniques from them we mention:

I.2.2.1 Field-Oriented Control (FOC):

The concept of Field-Oriented Control (FOC) which was introduced by Siemens company. Its implementation is based on transferring the vector from a rotating reference to a stationary one. This method has a good dynamic response[32].

FOC provides a decoupling between the magnetic component of the current (produces the flux) and the torque component (produces the torque)[32] Therefore, it provides independent control of torque and flux, which is similar to a separately exited dc motor[32].

I.2.2.2 Direct Torque Control (DTC):

The direct torque control (DTC) for induction machines was proposed in the middle of 1980s by Takahashi [33]and Depenbrock [34]. This method ensures a dynamic performance equivalent to that obtained by the DC machine.

The basic DTC scheme uses a switching table in order to determine the switching state selection and a proper estimation of the stator flux vector and the torque[33].

Following the diagram presented by Takahashi in his paper, the DCT requires two hysteresis controllers, the stator flux controller that imposes the period of active voltage vector and the torque controller to determine the zero voltage vectors so as to create a band of hysteresis and keep the motor’s torque within it[33].

I.2.3 Advanced Control:

This category contains the modern techniques such as neuron network, predictive control, fuzzy-logic and sliding mode. An example of these controls was taken which is the predictive control:

Predictive Control:

Predictive control predicts the change in the dependent variable in the modeled system. This control technique requires a complete design that includes the necessary mechanisms in order to obtain the best results [35]. The use of the process is determined by the necessity to calculate a predicted output at a future instant. The MPC (Model Predictive Control) uses various models in order to represent the relationship between the measurable inputs and the outputs. The non-measurable inputs can be represented as a disturbance model.

I.3 GENERAL CONCLUSION:

Changing the speed of motors was not that easy before the introduction of variable speed drives. These last were a great revolution that changed the industrial word forever after their introduction in the late 1950's. the main topology used in the VSDs is the AC-AC.

From their introduction till the present, AC-AC converters have been evolving rapidly and widely.

In this chapter a stat of art about the AC-AC converters topologies has been presented with a small comparison between them, these topologies are divided into several families. Z-source family was presented with its main topologies with a comparative study that takes into consideration their advantages, disadvantages and their applications.

Another family was presented which is the Multi-lever converters, where the inverter parts contains either NPC diodes or IGBTs in order to add another level. Thus, to have a better output with lower THD.

Then, a simplified model of the induction machine (taking the Simplifying assumptions into account) was also presented with Park's model and the simplified equivalent circuit of the IM as well.

Another stat of art about the control methods where V/f constant control, FOC , DTC and the Model Predictive Control methods were slightly presented.

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