Cascaded multilevel Inverters: A Survey of Topologies, Controls, and Applications

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Abstract - Cascaded multilevel inverters synthesize a medium-voltage output based on a series connection of power cells which use standard low-voltage component configurations. This characteristic allows one to achieve high-quality output voltages and input currents and also outstanding availability due to their intrinsic component redundancy. Due to these features, the cascaded multilevel inverter has been recognized as an important alternative in the medium-voltage inverter market. This paper presents a survey of different topologies, control strategies and modulation techniques used by these inverters. Regenerative and advanced topologies are also discussed. Applications where the mentioned features play a key role are shown.

Key words—Cascaded inverters, regenerative topologies, advanced topologies, modulation and control, multilevel converters, reactive power compensation, traction and renewable interfacing.

1. INTRODUCTION

MULTILEVEL voltage-source inverters provide a cost-effective solution in the medium-voltage energy management market. These converters have been widely applied to chemical, oil, and liquefied natural gas (LNG) plants, water plants, marine propulsion, power generation, energy transmission, and power-quality devices. Nowadays, there exist three commercial topologies of multi-level voltage-source inverters: neutral point clamped (NPC) [6],cascaded H-bridge (CHB) [2], and flying capacitors (FCs) [6].Among these inverter topologies, cascaded multilevel inverter reaches the higher output voltage and power levels (13.8 kV,30 MVA) and the higher reliability due to its modular topology. Cascaded multilevel inverters are based on a series connection of several single-phase inverters. This structure is capable of reaching medium output voltage levels using only standard low-voltage mature technology components. Typically, it is necessary to connect three to ten inverters in series to reach the required output voltage. These converters also feature a high modularity degree be-cause each inverter can be seen as a module with similar circuit topology, control structure, and modulation [6]. Therefore, in the case of a fault in one of these modules, it is possible to replace it quickly and easily. Moreover, with an appropriated control strategy, it is possible to bypass the faulty module without stopping the load, bringing an almost continuous overall availability.

This paper presents a bibliographical review of cascaded multi cell inverters, its working principle, circuit topologies, control techniques, and industrial applications. This paper is organized as follows. Section 2 shows the working principle and basic and advanced topologies. Power circuit topologies addressed in section 3,Regenerative topologies and its control are addressed Section 4. In Section 5, several newly introduced topologies for cascaded inverters are shown. A complete review of control and modulation used in these inverters is presented in Section 6. A group of applications is reviewed in Section 7. Finally, conclusions are presented in Sections 8.

2. BASICS OF H BRIDGE INVERTERS

Fig.1 shows Full-bridge or "H-bridge" Voltage Source Inverter. The smallest number of voltage levels for a multilevel inverter using cascaded-inverter with SDCSs is three. To achieve a three-level waveform, a single full-bridge inverter is employed. Basically, a full-bridge inverter is known as an H-bridge cell, which is illustrated in Fig. 1. The inverter circuit consists of four main switches and four freewheeling diodes. According to four-switch combination, three output voltage levels, +V, -V, and 0 can be synthesized for the voltage across A and B. During inverter operation shown in Fig. 1, switch of S_1 and S_4 are closed at the same
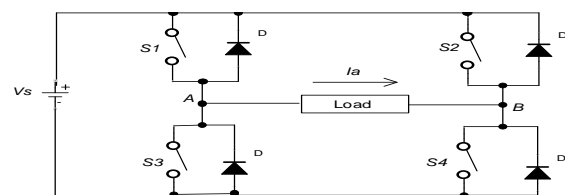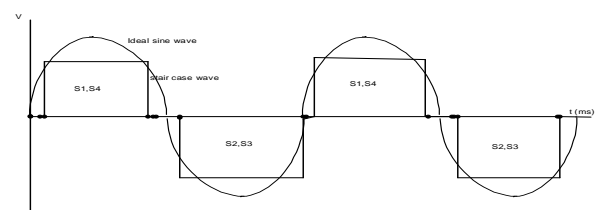

Fig.1 Diagram for basic H-Bridge structure

Fig.2 Stair case wave form of an H-bridge inverter.

TABLE I

Switching table for H-Bridge

Switch				Voltage
S1	S2	S3	S4	
1	0	1	0	0
1	0	0	1	+V
0	1	1	0	-V
0	1	0	1	0

time to provide V$_{AB}$ a positive value and a current path for Io. Switch S$_2$ and S$_4$ are turned on to provide V$_{AB}$ a negative value with a path for Io. Depending on the load current angle, the current may flow through the main switch or the freewheeling diodes. When all switches are turned off, the current will flow through the freewheeling diodes. In case of zero level, there are two possible switching patterns to synthesize zero level, for example, 1) S$_1$and S$_2$on, S$_3$and S$_4$off, and 2) S$_1$ and S$_2$off and S$_3$and S$_4$on.

To synthesize a multilevel waveform, the ac output of each of the different level H-bridge cells is connected in series. The synthesized voltage waveform is, therefore, the sum of the inverter outputs. The number of output phase voltage levels in a cascaded-inverter is defined by

$$M=2s+1………$$

where 's' is the number of dc sources. For example, a nine level output phase voltage waveform can be obtained with four-separated dc sources and four H-bridge cells. The phase voltage is the sum of each H-bridge outputs and is given as

$$V_{AN} = V_{dc1} + V_{dc2} + V_{dc3} ……..+V_{dc(s-1)} + V_{dcS}$$

because zero voltage is common for all inverter outputs, the total level of output voltage waveform becomes 2s+1. An example phase voltage waveform for a nine-level cascaded inverter and all H-bridge cell output wave forms are shown in Fig. 2. In this case, all dc voltage are assumed to be equal,

i.e., $V_{dc1} = V_{dc2} = V_{dc3} ……..= V_{dc(s-1)} = V_{dcS} = V_{dc}.$

For a three-phase system, the output of three identical structure of single-phase cascaded inverter can be connected in either wye or delta configuration (Fig 3 and Fig 4). Fig.5.shows the classification of cascaded multi level inverter topologies.

According to three-phase theory, line voltage can be expressed in term of two-phase voltages. For example, the potential between phase A and B is so-called V$_{AB}$ which can be written as follows:

$$V_{AB} = V_{AN} - V_{BN}$$

Where $V_{AB}$is line voltage, $V_{AN}$is voltage of phase A with respect to point N and V_{BN} is voltage of phase B with respect to point N .Theoretically, the maximum number of line voltage levels is 2m-1, where m is the number of phase voltage levels. The number of line voltage level depends on the modulation index and the given harmonics to be eliminated. The seven-level cascaded inverter, for example, can synthesize up to thirteen-level line voltage.

The NPC topology has become an established technology in power electronics inverters. The total number of levels using cascaded five-level NPC inverters is given by

$$L_{ph}^{NPC} = 4N_{NPC} + 1$$

whereN$_{NPC}$is the number of NPC inverters connected inseries. Fig.6 and Fig.7 shows the cascaded diode clamped and Flying capacitor inverters respectively.
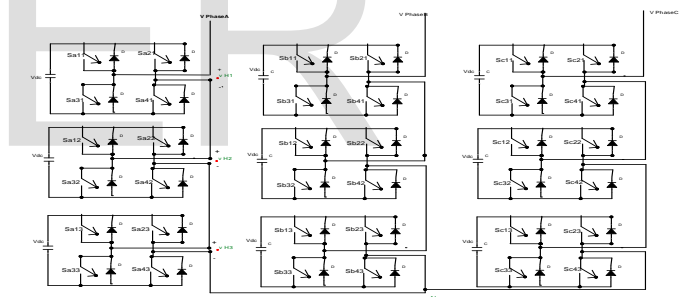

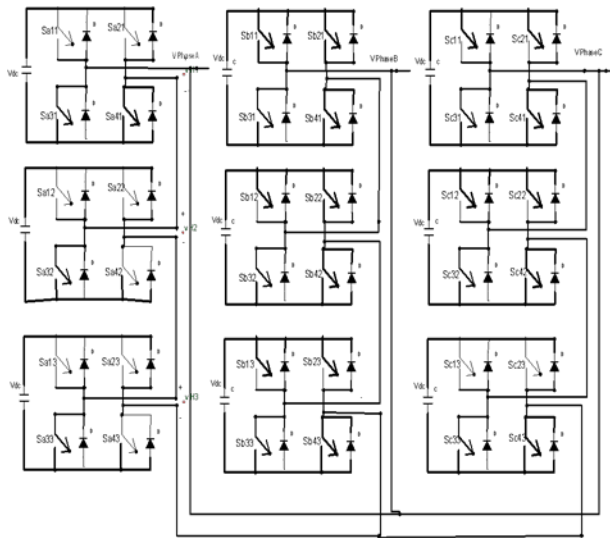Fig.3. level Wye configuration of Cascaded Multilevel Inverter.

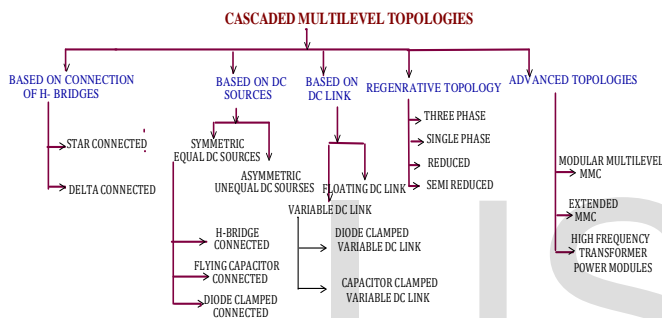Fig.4.Delta configuration of Cascaded Multilevel Inverter.

Fig.5.Classification of Cascaded multi level topologies.

3. POWER CIRCUIT TOPOLOGIES

3.1) Symmetric topologies:

In cascaded multi level structure each inverter requires an isolated dc voltage which is usually obtained by an arrangement of three-phase or single-phase rectifiers, as shown in Fig. 8, In some applications, these dc voltages can be obtained directly by isolated dc sources, for example, photovoltaic panels [3] or dc/dc isolated converters. In another applications, like STATic COMpensator (STATCOM), which does not require the injection of active power, the dc voltages can be floating, and the control strategy keeps the dc-link voltage adjusted to the reference .A further optimization in terms of input current harmonic scan be done when a multi pulse transformer is used to provide the isolated dc sources. By using a different phase angle for each group of

secondary's, i.e., secondary's that fed the inverters of each output phase, it is possible to eliminate characteristic harmonics produced by the diode-based rectifiers . These phase angles can be calculated using

$$\Delta\varphi = \frac{\pi}{3\,N_{inv}}$$

Where $\Delta\phi$ is the relative angle between group of secondaries. When single phase rectifiers are used the secondaries must be arranged in a more complex structure. By using the same principle, there is a possibility to connect in series two or more FC inverters in order to increase the number of output voltage levels. Two FC inverters are connected in series to obtain a 13 level output voltage.

Usually, cascaded multilevel inverters use the same dc-link voltage value for every cell. However, using different dc-link voltages, it is possible to increase the maximum number of output voltage levels. The topologies that have different dc-link voltages are called in the literature as asymmetric cascaded inverter.
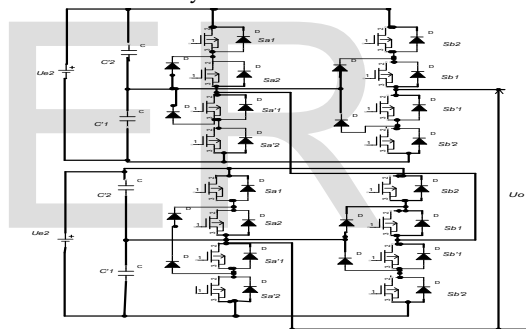

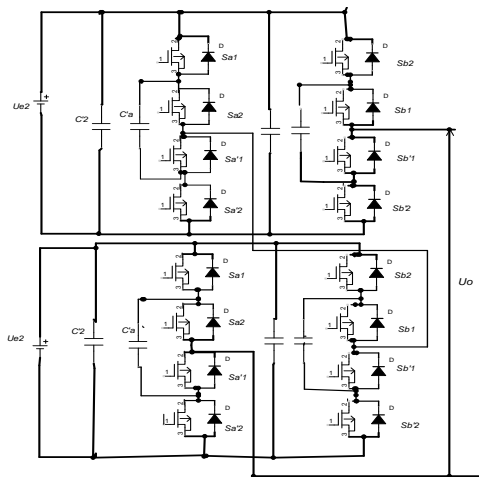Fig.6. Schematic of 9 level diode clamped cascaded Inverter.

Fig.7. Schematic for 9 level Flying capacitor type cascaded multi level inverter.

3.2) Multi winding Transformer topology:

The multi winding transformer topology can be considered as a variation of the multiple source topology. A three –cell
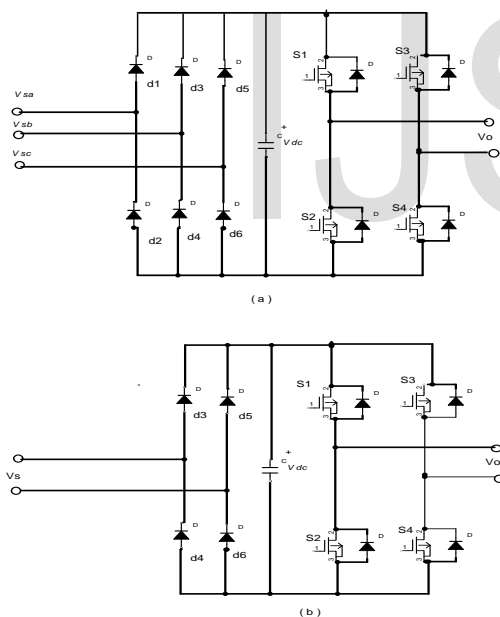

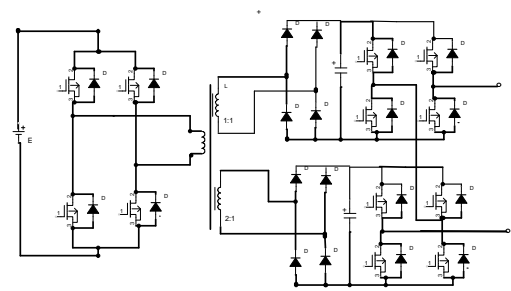Fig.8 Diode-based rectifier power cell topologies. (a) Three-phase.(b) Single-phase.

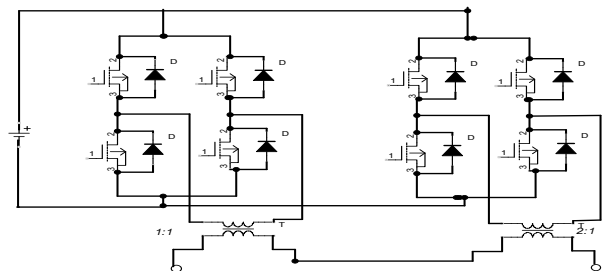Fig.9 Multi winding transformer based cascaded multilevel inverter

Fig.10 Multiple transformer based cascaded multilevel inverter

multi winding Inverter is shown in Fig 9.The multi winding topology requires a single dc input which is achived using amulti winding line frequency transformer.It provides input-output isolation and because it employs only one transformer,high efficency can be achived .Themajor disadvantage is the relatively high number of switches presented in the output stage.

3.3) Multiple transformer topologies:

Fig.9 shows a multiple-transformer topology composed of two cells. It is similar to the cascaded H-bridge topology, but the outputs of the isolation transformers are cascaded instead of directly cascading the H-bridge outputs. As a result , only one dc source is required. Currently , there are commercial inverters (for SARES applications) in the market that are based on this topology .In practice, these inverters have been proved to be robust and reliable. One disadvantage of this topology is the fact that it requires several low –frequency transformers.

3.4) Asymmetric Topologies:

A symmetric cascaded multilevel inverter has identical cells with equal DC voltages. For an asymmetric cascaded

inverter, individual cells DC voltages differ. The advantage of an asymmetric cascaded inverter is an increased voltage levels number for a given modules count. If the DC voltages of individual cells are arranged according to a geometric progression with a common ratio of 2, then the output voltage levels count grows with a modules number approximately as a power of 2. For converter cell DC voltages arranged as a geometric progression with a common ratio of 3, the levels count grows as a power of 3 of cells number Cascaded multilevel inverter output voltage quality may be significantly compromised by the DC voltages deviations from their nominal values, especially, for large DC voltage "low resolution" modules of asymmetric inverters.

For asymmetric cascaded multilevel inverter, DC voltage sources of different cells are non-equal. Asymmetric inverter provides an increased number of voltage levels for the same cells number than its symmetric counterpart. If the DC voltages of individual cells (Fig.11) are selected according to a geometric progression with a common ratio of 2 , then the available voltage levels count is

$$L = 2^{N+1} - 1 \qquad (i)$$

Where N is a cells count.

For the DC voltages arranged according to a geometric progression with a common ration of 3, the levels count

$$L = 3^N \qquad (ii)$$

According to (i)-(ii), for N=2 the levels count of symmetric, asymmetric power 2 and power 3 inverters is 5, 7, and 9 respectively, for N=3 - 7, 15, and 27. A large number of levels of asymmetric multilevel cascaded inverter comes at the expense of modularity (individual modules significantly vary in voltage and power ratings) and increased output voltage sensitivity to DC bus voltages
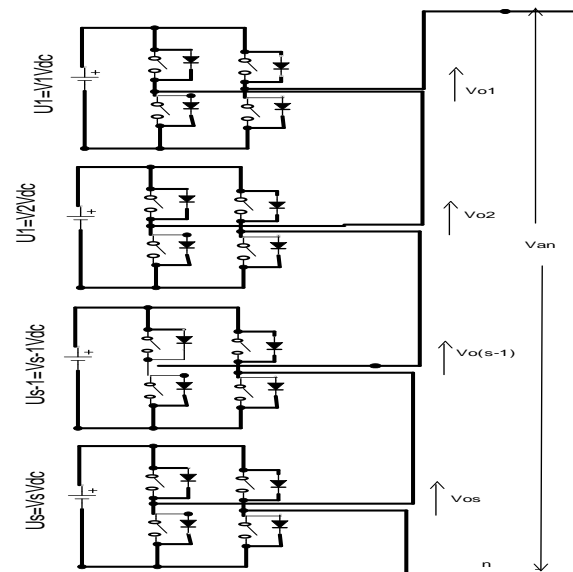

Fig.11.Single Phase Cascaded multi.level inverter with un equal Dc sources

deviation from their nominal values (especially, for low resolution high power modules). Charge balance control in asymmetric inverters is not possible.
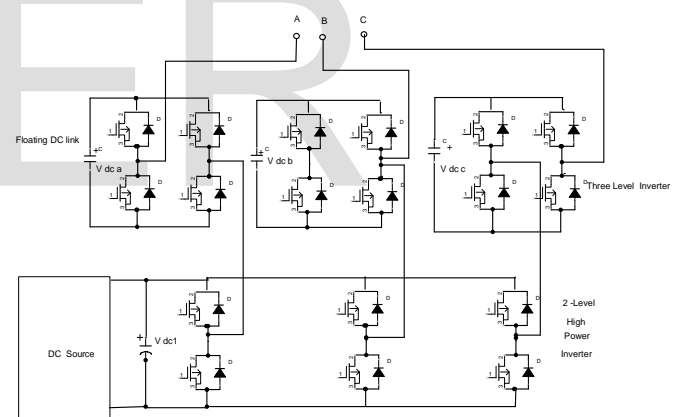

Fig. 12. Cascaded circuit topologies with floating dc link.

One of the best suited topologies to use floatingcells is the asymmetric converter, where the high-voltage inverter can positively deliver the entire output powerand the low-voltage inverters are used with floating dc links. Alternative configurations use a combination of two-level or three-level NPC three-phase inverter with cascadedsingle-phase inverters as shown in Fig. 12. It

offers an optimumtradeoff between output quality, reliability and efficiency.

3.5) Varible DC link topologies:

Recently, the use of a multilevel dc-link voltage has been studied in order to increase the number of total output voltage

levels using only a few single-phase inverters. The topology is based on a variable dc-link voltage which could have zero to several voltage levels; then, a single-phase full-bridge (SPFB) inverter could apply this voltage or its negative. These topologies could deliver a high output current with low switching frequency in the SPBF. The variable dc-link voltage can be produced by cascaded NPC or FC configurations or even buck dc–dc converters. Fig. 13 shows two of these configurations.
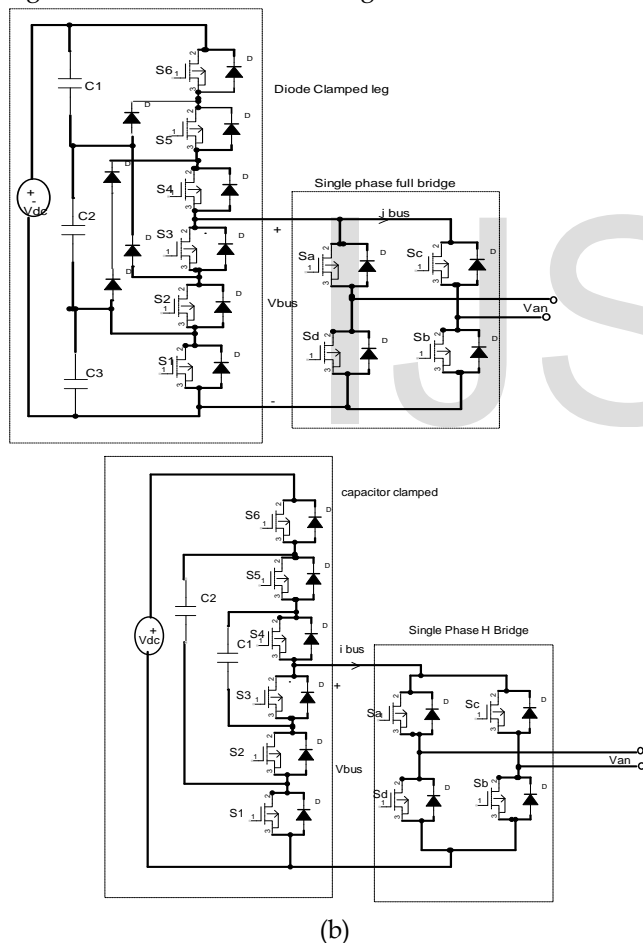

(b)

Fig. 13 Variable DC link (a) Diode clamped type MLI,(b)Flying Capacitor type MLI

4. REGENERATIVE TOPOLOGIES

The standard topology with a diode-based rectifier is extensively used with pumps and fans applications where the regenerative issues are minimal and can be managed by resistive damping. However, several applications like downhill conveyors, elevators, and energy plants require operations with a bidirectional power flow. In those applications, classical cascaded multilevel inverters cannot provide the required regenerative operation. In order to increase the applicability of cascaded multilevel inverters, regenerative topologies have been proposed recently.

To achieve the regenerative operation, the diode-based rectifier must be changed by an active front-end rectifier, as shown in Fig. 14(a). Although these rectifiers require an additional controller, they have several attractive features, namely, regenerative operation, independent control of the active and reactive powers, precise control of the dc voltage, and smaller harmonic content than that of the diode-based rectifiers in the input current. Moreover, the active front-end rectifiers do not produce low-order harmonics in the input current, and therefore, they do not require the secondary phase angle, simplifying the transformer design.

The regenerative drive could use a three-phase or single-phase active rectifier as it is shown in Fig. 14(a) and (b), respectively. It is possible to merge the rectifier and inverter stage to produce the topologies shown in Fig. 14(c) and (d) which have a reduced number of switches and less related electronics. Specifically, the topology shown in Fig. 14(d) uses only four switches per power cell. The main drawback of the reduced topologies is the increase complexity of the control system .By using a regenerative rectifier in each cell, the complete drive acts as a regenerative multilevel converter managing bidirectional power flow. By using a proper controller, it is possible to decouple and control the active and reactive in-put powers. Compensation techniques allow the reduction of dc-link voltage ripple , improving the output voltage wave-form. Moreover, pulse width modulation (PWM) using phase-shifted carriers reduces significantly the low-order input current harmonics.

4.1)Active Front End for regenerative inverters:

An AFE for a 2-level inverter is a common part of frequency converters. There are many applications in the current market with an AFE in it. The control of the AFE consists of 3 main blocks as seen in figure 15.
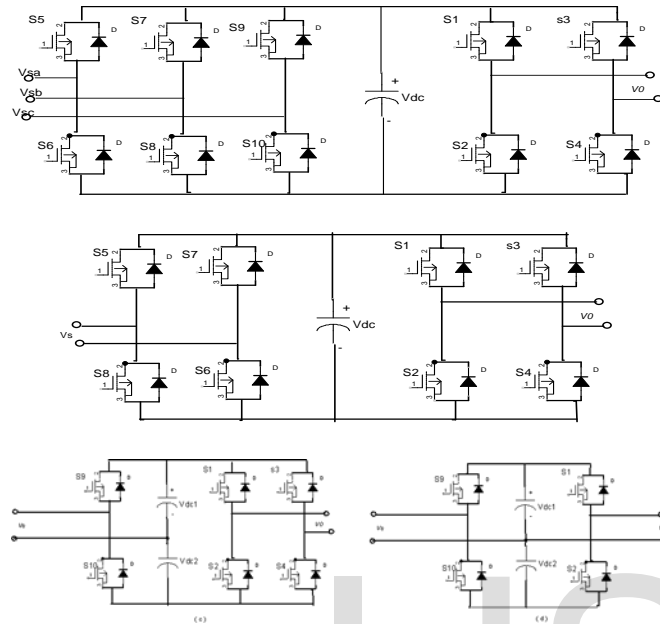

Fig.14 Regenerative Topologies (a) Three –phase (b) Single –phase (c) reduced (d) semi –reduced.

The first one in order is the voltage control. It consists of a DC-voltage comparison and a PI-controller as seen in figure 5. The PI-controller was designed using the symmetric optimum method described in Pöllänen's dissertation. In the symmetric optimum method, a design parameter

$$tr = \frac{ln9}{\alpha}$$

α is calculated from the desired rise time. Time constant of the voltage controller can be calculated with the design parameter α and the desired phase margin φ, which is set to $\frac{\pi}{4}$
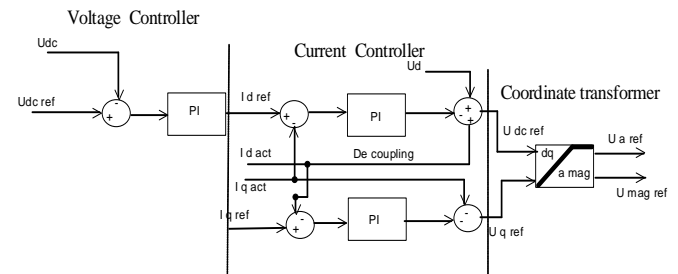

Fig.15.Block diagram for Active Front End Controller.

$$T_{i,dc} = \sqrt{\frac{1+\sin\varphi}{\cos\varphi}}\ T_{\alpha}.$$

The gain Kp,dc for the PI-controller can thus be calculated.

5. ADVANCED TOPOLOGIES

There are a number of alternative topologies based on the basic principle of cascaded single-phase inverter proposed in the literature. Two of them are discussed in this section. The first approach presented is the use of a high-frequency transformer-based module used to build cascaded multilevel converters without the need of isolated dc links. The power module, shown in Fig. 16, uses a single-phase rectifier, a high-frequency transformer, and a single-phase inverter. These modules are intended to be connected in series to handle medium voltage levels (6.6 kV) in distributed generation based on renewable energy and fuel cells. The main features of this topology are the inherent galvanic isolation, bidirectional power flow, reduction of the transformer size and weight, and high efficiency.
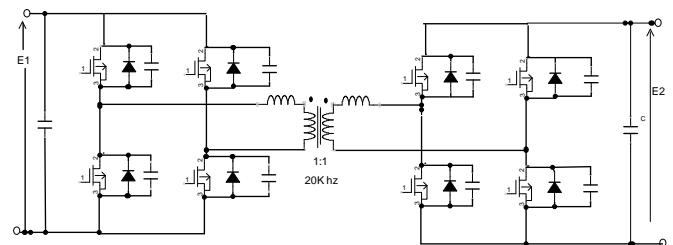

Fig. 16. High-frequency transformer-based power module to be used in cascaded inverters.

The second topology is the modular multilevel converter(MMC) shown in , where several dc/dc modules with floating dc link are connected in series to obtain a

single-phase or three-phase output voltage. Fig. 17 shows the complete topology of a single-phase inverter and the basic module used. If the input voltage is directly an ac voltage, then the basic module must be a single-phase inverter. The MMC provides high scalability, it has low filter requirements and, in addition, it does not require an input transformer. To control the input/output currents and the floating dc voltages, a scheme composed by linear PI controllers and switching logic has been proposed. There are several suppliers of CHB inverters in the market of medium-voltage drives. Three of those suppliers and the technical characteristics of the CHB inverters they offer are shown in Table II.

6. Modulation and control

This section presents a review of the most commonly used modulation techniques and control strategies in cascaded multi-level inverters.
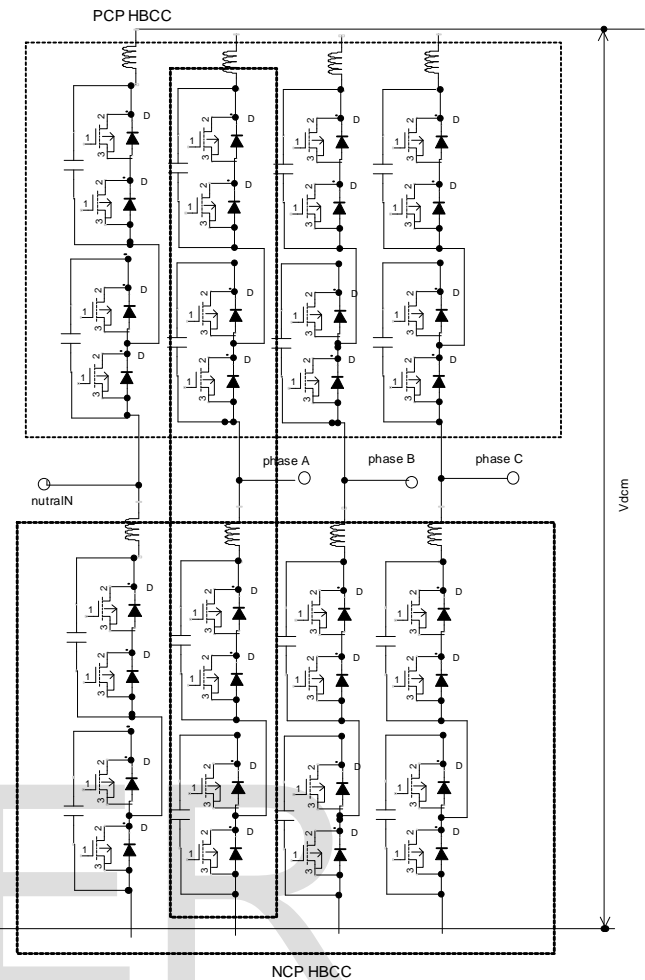

Fig.17 MMC based on cascaded modules

Several modulation techniques have been proposed for cascaded multilevel inverters. A high number of power electronic devices and switching redundancies bring a higher level of complexity compared with a two-level inverter counterpart. However, this complexity could be used to add additional capabilities to the modulation technique, namely, reducing the switching frequency, minimizing the common-mode voltage, or balancing the Modulation techniques for cascaded multilevel inverters. According to their switching frequency, they can be classified as follows 1) fundamental switching frequency, where each inverter has only one commutation per cycle, for example, multilevel selective harmonic elimination (SHE), space vector control,and nearest voltage level, and 2) high switching frequency, where each inverter has

several commutations per cycle, for example, multilevel PWM and space vector modulation (SVM).

Manufacturer	ABB	Siemens	TMEIC GE
Product Model	ACS500	Perfect Harmony	TM drive - MVG
Topology	5-L NPC	3-L	3-L
Power	1.7-24MVA	0.3-30 MVA	0.18-10 MVA
Voltage	2.3 -13.8 kv	4.16-6.9 KV	3-11kV
Semiconductor	IGCT	LV/MV IGBT	GCT

Level-shifted PWM is widely used in NPC inverters and canal so be used in cascaded inverters. This modulation technique produces an uneven distribution of power among cells, such as that in Fig. 18(a), which produces a high harmonic content in the input current. this drawback is avoided using a rotating carrier, which balances the power of each cell. The level-shifted modulation is used inside each NPC inverter and synchronized with the other cells to produce the multilevel output voltage.

Phase-shifted PWM is the most commonly used modulation technique for cascaded multilevel inverters because it offers an evenly power distribution among cells and it is very easy to implement independently of the number of inverters, This modulation shifts the phase of each carrier in a proper angle to reduce the harmonic content of the output voltage,as shown in Fig. 18(b) . Moreover, it is possible to work in the over modulation region when a common-mode term is added to the reference.

SVPWM aims to generate a voltage vector that is close to the reference circle through the various switching modes of inverter. To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary dq reference frame that consists of the horizontal (d) and vertical (q) axes as depicted in Fig.18

The relation between these two reference frames is below
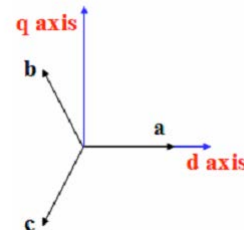
$$F_{dqo} = k_s f_{abc}$$

Where

Fig. 18 The relationship of abc reference frame and stationary dq reference frame.

$$[C_c] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

$$f_{abc} = [f_a \quad f_b \quad f_c]^T$$

$$f_{dqo} = [f_d \quad f_q \quad f_o]^T$$

and f denotes either a voltage or a current variable this transformation is equivalent to an orthogonal projection of [a, b, c]^{t}on to the two-dimensional perpendicular to the vector [1, 1,1]^t (the equivalent d-q plane) in a three-dimensional coordinate system. As a result, six non-zero vectors and two zero vectors are possible. Six nonzero vectors (V1- V6) shape the axes of a hexagonal as depicted in Fig. 6 and feed electric power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V0and V7) are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by V0, V1, V2, V3, V4, V5, V6, and V7. The same transformation can be applied to the desired output voltage to get the desired reference voltage vector V$_{ref}$in the d-q plane. The objective of space vector PWM technique is to approximate the reference voltage vector V$_{ref}$using the eight switching patterns. One simple method of approximation is to

generate the average output of the inverter in a small period, T to be the same as that of Vref in the same period.

The control of a cascaded inverter depends mainly on its circuit topology. When a diode-based rectifier is used to generate the dc-link voltages, only the output current must be controlled. If any of the dc-link voltages is floating, a control for   that voltage balance is required. In regenerative topologies, an additional controller for the input current and dc-link voltage is required. In this section, a review of
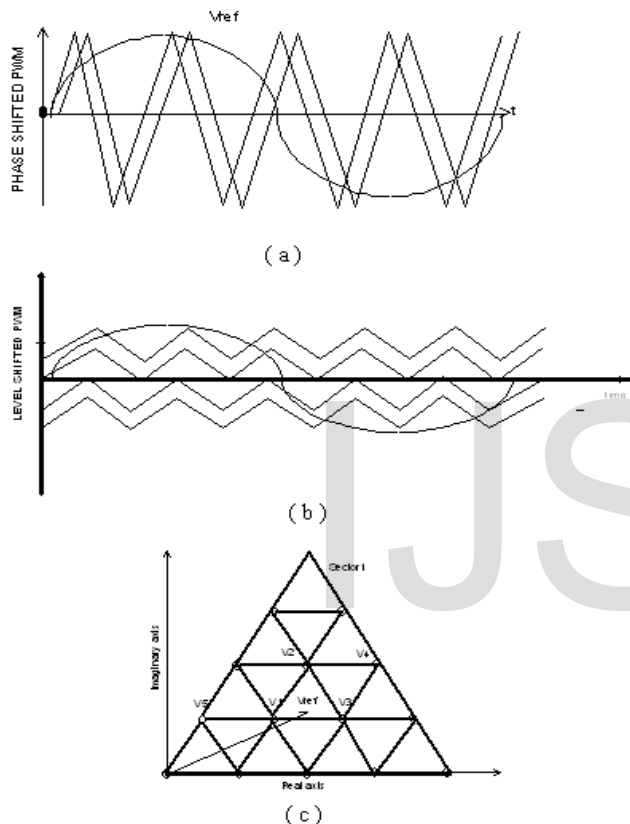

(a)

(b)

(c)

Fig.19 (a) Phase shifted waveform (b) Level shifted pwm wafeform (c) Space vector PWM

different control strategies   applied to cascaded multilevel inverters is shown.

In a dc-link voltage compensator is proposed. The dc-link voltages are feedback to the controller modifying the reference in order to compensate its deviations. This control strategy is well suited to cascaded inverters due to the high dc-voltage ripple produced by the single-phase inverter opertion.   Rotating   dq-transform-based

controllers have a simplified analysis and design because they can be a linear PI work on dc variables. However, this control scheme requires

a robust synchronization method to implement the rotating transform.

To control the ac current with a high bandwidth and without requiring a synchronous transformation, it is possible to use a resonant control .This controller has the restriction of constant frequency operation; therefore, it could be applied to control the input current in a regenerative topology. Control strategies based on passivity could be used to control both input and output currents. This approach offers linear and nonlinear controllers which can mathematically prove stability .

Recently, predictive control has been applied to cascaded inverters .Predictive control considers the inverter as a system with a finite number of switching states and, using a suitable model, finds a state that optimizes a given objective function. In the previously cited references, this cost function contains terms related to the output current error and the switching frequency minimization. The main drawback of predictive control when applied to multilevel converters is the high number of possible switching states that must be evaluated.
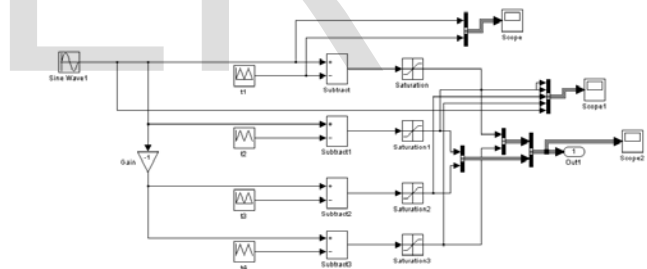

Fig.20 Matlab Simulink block Diagram for 5-level converter.

7. APPLICATIONS

In this section, successful applications of CHB inverters are presented. Each one of these applications has particular requirements where cascaded inverters are well suited. Main Futures of cascaded multilevel inverters area) pure sinusoidal voltage possible with minimal LC filter requirements. b)Extremely low voltage ripples and low EMI c) high speed response unlike the traditional PWM

inverter with large LC filters that delay response and causes resonance. d) High efficiency, major applications of cascaded compact size, and light weight. There are three multi level inverters1. Utility

based applications 2. Traction based applications 3.Industrial application

7.1)Utility based applications

7.1.1.Reactive power control and compensation:

The system configuration for reactive power control and compensation shown in fig .1This is the one of the best suited applications for cascaded multilevel inverters is the power quality devices, like STATCOMs and universal power quality conditioners. These devices are connected directly to medium-voltage networks, as shown in Fig. 1,and do not require the injection of active power in a nominal operating point. The topologies used for this applications are symmetrical topologies , asymmetric topology, cascaded diode clamped topology, cascaded FC topology , for In some applications, these dc voltages can be obtained directly by isolated dc sources, for example, photovoltaic panels [9] or dc/dc isolated converters like Three-phase and single phase Diode-based rectifier power cell topologies.. Regenerative strategies are useful for UPFC applications. The Voltage regulation and Phase shifting and Hormonic reduction is other application of cascaded multilevel inverters.

7.1.2) Renewable energy sources:

Another important application is Utility Interfacing of Renewable energy sources. As can be seen in the structure of cascade inverters, each H – Bridge needs a separate or isolated dc source. This requirement makes the cascade inverter a perfect fit for utility interface of renewable energy sources such as photo volotics or fuel cells where isolated dc sources naturally exits. Since cascaded inverter eliminates custom designed transformers, a tremendous cost reduction can be effected. The topologies used for these applications are conventional symmetrical topologies and asymmetric topologies.The diagram for arrangement is shown in Fig.2
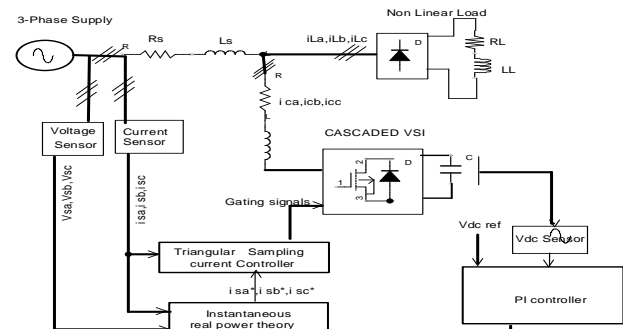

Fig21.Block Diagram for Reactive power control and compensation by using cascaded multilevel inverter.

7.2) Transportation and Traction applications

Cascaded multilevel inverters can be applicable for hybrid electric vehicles, more electric ships and airplanes where efficiency, weight of power electronic devices are more considerable.

Traction systems require a rectification stage of a high-voltage low-frequency ac power and a fully controllable
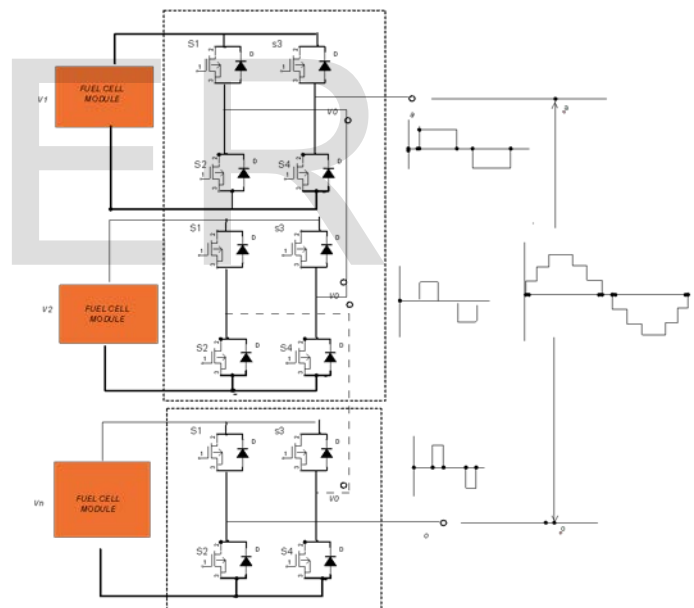

Fig.22.Cascaded multilevel Inverter Configuration for Renewable Energy Interfaces.

inversion stage to feed the traction motors. MMCs have been proposed to be used as an interface between the catenary voltage and low-voltage motor drives. Classical cascaded multilevel inverters have also been proposed as a

part of a power-quality compensator to reduce harmonics, reactive power, negative sequence, and the volatility of the load. Applications of cascaded inverters on electric vehicles have been found in[14], where a back-to-back multilevel cascaded topology is proposed, and in [3], where a cascaded inverter with floating dc link is used as an inductor less boost inverter.Fig shows the 10 KW proto type;.

7.3) Industrial Applications:

7.3.1)Pumps and Fans

Pumps and fans are intensively used in almost all industry sectors. High-voltage high-power pumps and fans are used in

water plants, oil and gas plants, cooling systems, geothermal and nuclear power plants, underground mining, furnaces and boilers, and so on.

   The use of cascaded inverters to drive these devices could lead to an important efficiency improvement, because they typically run with variable speed at partial load. The use of variable speed drives, instead of dampers and throttling valves, to control the flow speed can reduce drastically the amount of power required. Fig. 13 shows an industrial fan application, where a 1-MW 13.8-kV induction motor is
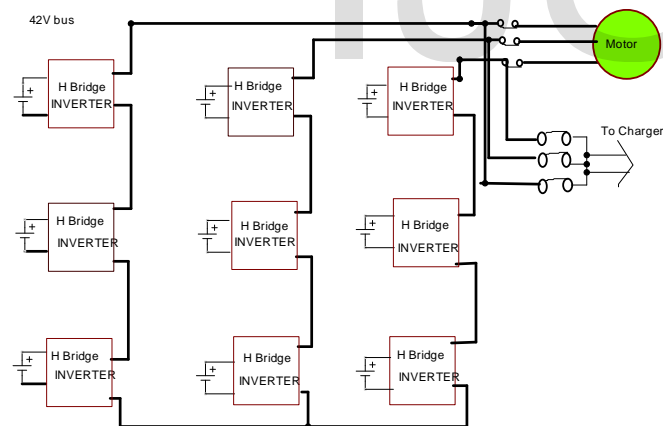

Fig.23 System Configuration of an EV motor drive by using cascaded multi level inverters.

driven by a converter connected directly to the distribution system. The distance from the drive and the motor is about 800 m. However, if a CHB inverter is used,

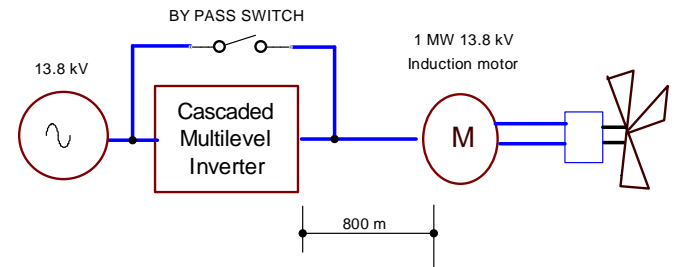the voltage variations are greatly reduced, and the filter is also smaller if any.

Fig. 24 Cascaded multi level application: Pumps and Fans.

7.3.2)LNG Plant

   The LNG plant presents a cyclic behavior during the year, motoring the turbine from the energy station in summer and reversing the power direction in winter when the energy consumption is higher. The use of a compressor directly connected to a gas turbine leads to an efficiency of 25%, due to the low efficiency of the turbine (approximately 30%). By using the scheme shown in Fig. 15, where the gas turbine has been replaced by a synchronous motor and a cascaded multi-level regenerative converter, the efficiency has been improved to 36%.Due to the high power involved in this system (45 MW) and the bidirectional power flow, it is necessary to use a high-power converter with regeneration capability. The cascaded multilevel inverter emerges as the appropriate choice, considering also its extremely high availability. Cascaded inverters can minimize the maintenance effect in the production cycle, increasing the mean time between failures and, at the same time, reducing the maintenance work duration.
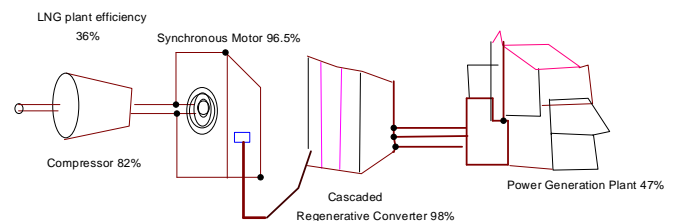
(a).
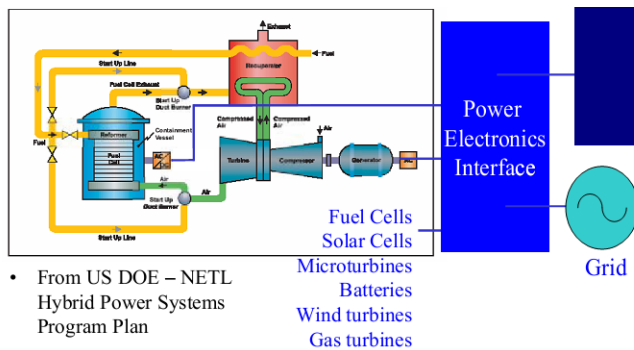
(b).

Fig. 25. Cascaded multilevel inverter application(a) LNG plant.(b)Hybrid PSP(Power Systems Program)Plan.

Although this inverter topology has been established in the market of medium-voltage drives, there are some aspects that require further development and research. The first issue that needs attention is the efficiency improvement. Several advances have been reported to reduce the switching losses using an optimal modulation technique; however, the conduction losses are far more critical due to the series connection of several semiconductors and high output currents. In order to reduce these losses, new advances in the semiconductor technology are expected. The use of floating cells could simplify the design of the input transformer or even eliminate it, which should reduce losses, cooling requirements, cost and volume. To reach higher voltage levels is a challenge for semiconductor technology, increasing the blocking voltage and other related technologies like gate drivers and sensors. Finally, the further increase on availability requires research on fault management, intelligent modularization, and the possibility of change modules and reconfigurations .The Table III shows the applications with suitable topologies.

TABLE III
TOPOLOGIES SUITABLE FOR APPLICATIONS

Applications	Sub application	Topologies used
Utility applications **Requirements:** *1.High Efficient* *2.Highpower* *3.Low THD* *4. low Cost*	1.Reactive power compensation(STATCOM) 2.Voltage regulation and phase shifting(SSSC,DVR) 3.Hormonic filtering(APF) 4. Power flow control.(UPFC)	a)symmetric or equal Dc voltage sources. b) asymmetric or unequal Dc Voltage sources. c) MMC based.
	Interfacing of Renewable energy sources	d)Diode clamped cascaded multi level topologies e)Flying capacitor cascaded multi level topologies. variable multilevel dc-link voltage (i) Diode clamped. (ii) Capacitor clampled
Transportation and Traction applications **Requirements:** *1.Effeciency* *2.low weight*	**EV motor drives** Ships airplanes	a) Diode-based rectifier power cell topologies. b)regenerative topologies (i) Three-phase. (ii) Single-phase. (iii) Semi reduced. (iv) Reduced
Industrial Applications **Requirements:** *1.High Effeciency* *2.low cost*	**Pumps,Fans** water plants, oil and gas plants, cooling systems, geothermal and nuclear power plants, underground mining, furnaces and boilers, and so on.	1.standard topology with a diode-based rectifier (i) single phase (ii) Three phase
	LNG Plant Hybrid power system program plan	Regenerative topologies (i) Three-phase. (ii) Single-phase. (iii) Semi reduced. (iv) Reduced

8 .CONCLUSION

The cascaded multilevel inverters have evolved from a theoretical concept to real applications due to several remarkablefeatures like a high degree of modularity, the possibility of connecting directly to medium voltage, high power quality, bothinput and output, high availability, and the control of power flow in the regenerative version.The deravative topologys of cascaded multi level inverters based on application is presented. This paper has reviewed the recent developments and applications of these inverters, including new proposed topologies,modulation techniques, and control strategies.

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