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Review Study on Topologies of Multilevel Inverters

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Abstract:
This paper reviews state of the art of multilevel inverter topologies. Power electronics devices are which converts DC power to AC power at required output voltage and frequency level is known as inverters. Multilevel inverter has three different major topologies have been applied in industrial applications: Cascaded H-bridges converter, Diode clamped, and Flying capacitor multilevel inverter. A multilevel inverter can be preferred for multipurpose applications, such as an active power filter, a static VAR compensator and a machine drive for sinusoidal and trapezoidal current applications. Some of the drawbacks to the multilevel inverters are the requirement of isolated power supplies for individual stages, the fact that they are a lot complex to design, they are more costly, and they are more difficult to control in software.

Key words*: Multi-Level Inverter, topologies, Active power filter, Static VAR compensator, isolated power supplies*

1. Introduction

At present, numerous industrial applications have begun to require higher power apparatus ("1"). Power-electronic inverters are becoming popular for various industrial drives applications ("2"). A multilevel inverter is a power electronic system that synthesizes a desired output voltage from several levels of dc voltages as inputs. Recently, multilevel power conversion technology has been developing the area of power electronics very rapidly with good potential for further developments. As a result, the most attractive applications of this technology are in the medium to high voltage ranges ("3"). A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for a high power application.

The advantages of multilevel converters is their smaller output voltage step, which results in high voltage capability , lower harmonic components, lower switching losses, better electromagnetic compatibility, and high power quality("1"), ("4"). Also it can operate at both fundamental switching frequency and high switching frequency PWM. It must be noted that lower switching frequency usually means lower switching loss and higher efficiency ("5").

The results of this study search show that multilevel inverter circuits have been around for more than 25 years. Today, multilevel inverters are extensively used in medium voltage levels with high-power applications ("6").

The field of applications includes use in laminators, pumps, conveyors, compressors, fans, blowers, and mills. Subsequently, several multilevel converter topologies have been developed ("3"), ("7"). Three major topologies have been proposed for multilevel inverters: cascaded multi cell with separate dc sources, diode-clamped (neutral-clamped) and capacitor-clamped (flying capacitors) ("15"). Each of these topologies has a different mechanism for providing the voltage level. The first topology introduced was the series H-bridge design but several configurations have been obtained for this topology as well ("7"). Since this topology consists of series power conversion cells, the voltage and power levels may be scaled easily. The H-bridge topology was followed by the diode-clamped converter that utilized a bank of series capacitors ("8"). The flying-capacitor topology followed diode-clamped after few years. Instead of series connected capacitors, this topology uses floating capacitors to clamp the voltage levels ("9"). H-bridge inverters have isolation transformers to isolate the voltage source but they do not need either clamping diode or flying capacitor inverters.

One clear disadvantage of multilevel power conversion is the great number of power semiconductor switches needed. Another disadvantage of multilevel power converters is that the small voltage steps are typically produced by isolated voltage sources or a bank of series capacitors. Isolated voltage sources may not always be readily available and series capacitors require voltage balance ("16").

Although low-voltage-rated switches can be utilized in a multilevel converter, each switch requires a related gate driver and protection circuits. This may lead the overall system to be more expensive and complex ("7").So, in practical implementation, decrease the number of switches and gate driver circuits is very important ("8").
As previously mentioned, three different major multilevel converter topologies have been applied in industrial applications: cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. Before continuing discussion in this paper, it should be noted that the term *multilevel converter* is utilized to refer to a power electronic circuit that could operate in an inverter or rectifier mode. The multilevel inverter structures are the focus of in this paper; however, the illustrated topologies can be implemented for rectifying operation as well.

2. Inverter Topologies

2.1. Cascades H-bridge Multilevel Inverter

A cascade multilevel inverter is a power electronic device built to synthesize a desired AC voltage from several levels of DC voltages. Such inverters have been the subject of research in the last several years ("1")("2")("3")("4")("5"), where the DC levels were considered to be identical in that all of them were either batteries, solar cells, etc. In ("6"), a multilevel converter was presented in which the two separate DC sources were the secondaries of two transformers coupled to the utility AC power. In contrast, in this paper, only one source is used without the use of transformers. The interest here is interfacing a single DC power source with a cascade multilevel inverter where the other DC sources are capacitors. Currently, each phase of a cascade multilevel inverter requires n DC sources for 2n+1 level in applications that involve real power transfer. In this paper, a scheme is proposed that allows the use of a single DC power source (e.g., battery or fuel cell stack) with the remaining n−1 DC sources being capacitors. It is shown that one can simultaneously maintain the DC voltage level of the capacitors and choose a fundamental frequency switching pattern to produce a nearly sinusoidal output.
To operate a cascade multilevel inverter using a single DC source, it is proposed to use capacitors as the DC sources for all but the first source. Consider a simple cascade multilevel inverter with two H-bridges as shown in Figure 1.

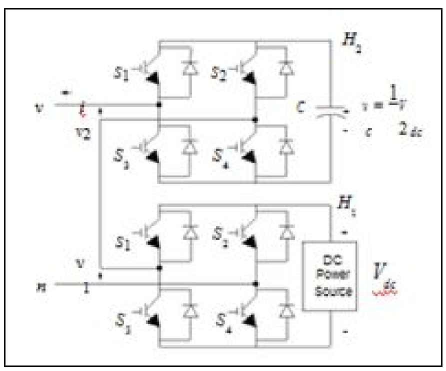

Figure 1: Single-phase structure of a multilevel cascaded H-bridges inverter

The ac outputs of each of the different full -bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels *m* in a cascade inverter is defined by $m = 2s+1$, where *s* is the number of separate dc sources. An example phase voltage waveform for an 11- level cascaded H -bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 2. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$.

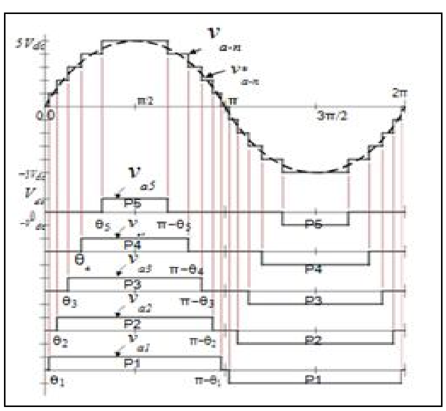

Figure 2: Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources

Multilevel cascaded inverters have been proposed for such applications as static VAR generation, an interface with renewable energy sources, and for battery-based applications. The inverter could be controlled to either regulate the power factor of the current drawn from the source or the bus voltage of the electrical system where the inverter was connected. Peng ("6") have also shown that a cascade inverter can be directly connected in series with the electrical system for static VAR compensation. Cascaded inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaic's or fuel cells.
The main advantages and disadvantages of multilevel cascaded H-bridge converters are as follows ("10")("13").

Advantages

- The number of possible output voltage levels is more than twice the number of dc sources ($m = 2s + 1$).
- The series of H-bridges makes for modularized layout and packaging. This will enable the manufacturing process to be done more quickly and cheaply.

Disadvantages

- Separate dc sources are required for each of the H-bridges. This will limit its application to products that already have multiple SDCSs readily available.

2.2. Diode-Clamped Multilevel Inverter

The neutral clamped converter proposed by Nabae, Takahashi, and Akagi in 1981 was essentially a three -level diode-clamped inverter ("9"). In the 1990s several researchers published articles that have reported experimental results for four-, five-, and six-level diode-clamped converters for such uses as static VAR compensation, variable speed motor drives, and high-voltage system interconnections ("8")("11"). A three-phase six- level diode-clamped inverter is shown in Figure 3. Each of the three phases of the inverter shares a common dc bus, which has been subdivided by five capacitors into six levels. The voltage across each capacitor is V_{dc}, and the voltage stress across each switching device is limited to V_{dc} through the clamping diodes. Table 1. lists the output voltage levels possible for one phase of the inverter with the negative dc rail voltage V_0 as a reference. State condition *1* means the switch is on, and *0* means the switch is off. Each phase has five complementary switch pairs such that turning on one of the switches of the pair require that the other complementary switch be turned off. The complementary switch pairs for phase leg *a* are (S_{a1}, $S_{a'1}$), (S_{a2}, $S_{a'2}$), (S_{a3}, $S_{a'3}$), (S_{a4}, $S_{a'4}$), and (S_{a5}, $S_{a'5}$). Table 1. also shows that in a diode-clamped inverter, the switches that are on for particular phase legs are always adjacent and in series. For a six-level inverter, a set of five switches is on at any given time.

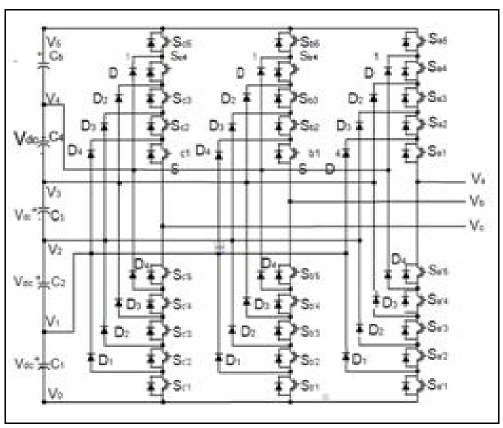

Figure 3: Three-phase six-level structure of a diode-clamped inverter

To solve the voltage balancing problem an additional balancing circuit can be added or more complex control methods can be implemented.

Voltage V_{a0}	Switch State									
	S_{a5}	S_{a4}	S_{a3}	S_{a2}	S_{a1}	$S_{a'5}$	$S_{a'4}$	$S_{a'3}$	$S_{a'2}$	$S_{a'1}$
$V_5 = 5Vdc$	1	1	1	1	1	0	0	0	0	0
$V_4 = 4Vdc$	0	1	1	1	1	1	0	0	0	0
$V_3 = 3Vdc$	0	0	1	1	1	1	1	0	0	0
$V_2 = 2Vdc$	0	0	0	1	1	1	1	1	0	0
$V_1 = Vdc$	0	0	0	0	1	1	1	1	1	0
$V_0 = 0$	0	0	0	0	0	1	1	1	1	1

Table 1: Diode-clamped six-level inverter voltage levels and corresponding switch states

Figure 4. Shows one of the three line-line voltage waveforms for a six-level inverter. The line voltage V_{ab} consists of a phase-leg *a* voltage and a phase-leg *b* voltage. The resulting line voltage is an 11- level staircase waveform. This means that an *m*-level diode-clamped inverter has an *m*-level output phase voltage and a (2*m*-1)-level output line voltage.

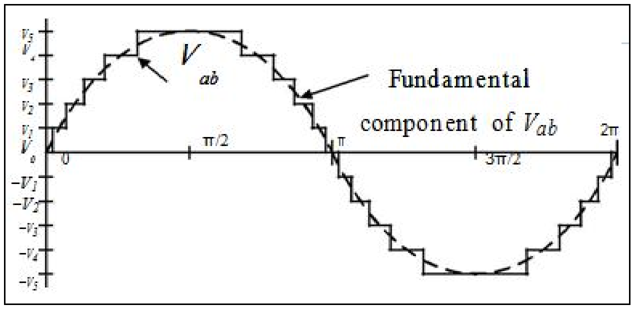

Figure 4: Line voltage waveform for a six-level diode clamped inverter

Although each active switching device is required to block only a voltage level of V_{dc}, the clamping diodes require different ratings for reverse voltage blocking. Using phase *a* of Figure 4. as an example, when all the lower switches $S_{a'1}$ through $S_{a'5}$ are turned on, D_4 must block four voltage levels, or $4V_{dc}$. Similarly, D_3 must block $3V_{dc}$, D_2 must block $2V_{dc}$, and D_1 must block V_{dc}. If the inverter is designed such that each blocking diode has the same voltage rating as the active switches, D_n will require *n* diodes in series; consequently, the number of diodes required for each phase would be (*m*-1) × (*m*-2). Thus, the number of blocking diodes is quadratically related to the number of levels in a diode-clamped converter (“3”).

One application of the multilevel diode-clamped inverter is an interface between a high-voltage dc transmission line and an ac transmission line (“3”). Another application would be as a variable speed drive for high -power medium-voltage (2.4 kV to 13.8 kV) motors as proposed in (“3”)(“6”)(“15”).

Static VAR compensation is an additional function for which several authors have proposed for the diode-clamped converter. The main advantages and disadvantages of multilevel diode-clamped converters are as follows (“1”)(“3”):

Advantages

- All of the phases share a common dc bus, which minimizes the capacitance requirements of the converter. For this reason, a back-to-back topology is not only possible but also practical for uses such as a high-voltage back-to-back inter-connection or an adjustable speed drive.
- The capacitors can be pre-charged as a group.
- Efficiency is high for fundamental frequency switching.

Disadvantages

- Real power flow is difficult for a single inverter because the intermediate dc levels will tend to overcharge or discharge without precise monitoring and control.
- The number of clamping diodes required is quadratically related to the number of levels, which can be cumbersome for units with a high number of levels.

2.3. Flying Capacitor Multilevel Inverter

Meynard and Foch introduced a flying- capacitor-based inverter in 1992 (“3”). The structure of this inverter is similar to that of the diode -clamped inverter except that instead of using clamping diodes, the inverter uses capacitors in their place. The circuit topology of the flying capacitor multilevel inverter is shown in Figure 5. This topology has a ladder structure of dc side capacitors, where the voltage on each capacitor differs from that of the next capacitor. The voltage increment between two adjacent capacitor legs gives the size of the voltage steps in the output waveform.

One advantage of the flying -capacitor-based inverter is that it has redundancies for inner voltage levels; in other words, two or more valid switch combinations can synthesize an output voltage. Unlike the diode-clamped inverter, the flying-capacitor inverter does not require all of the switches that are on (conducting) be in a consecutive series. Moreover, the flying-capacitor inverter has *phase* redundancies, whereas the diode-clamped inverter has only *line -line* redundancies (“2”)(“13”). These redundancies allow a choice of charging/discharging specific capacitors and can be incorporated in the control system for balancing the voltages across the various levels.

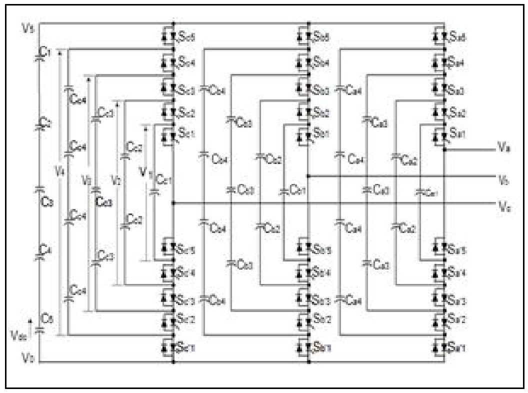

Figure 5: Three-phase six-level structure of a flying capacitor inverter

In addition to the (*m*-1) dc link capacitors, the *m*-level flying-capacitor multilevel inverter will require (*m* -1) × (*m*-2)/2 auxiliary capacitors per phase if the voltage rating of the capacitors is identical to that of the main switches. One application proposed in the literature for the multilevel flying capacitor is static VAR generation (“2”)(“3”). The main advantages and disadvantages of multilevel flying capacitor converters are as follows (“12”)(“3”).

Advantages

- Phase redundancies are available for balancing the voltage levels of the capacitors.
- Real and reactive power flow can be controlled.
- The large number of capacitors enables the inverter to ride through short duration outages and deep voltage sags.

Disadvantages

- Control is complicated to track the voltage levels for all of the capacitors. Also, recharging all of the capacitors to the same voltage level is complex.
- Switching utilization and efficiency are poor for real power transmission.
- The large numbers of capacitors are both more expensive and bulky than clamping diodes in multilevel diode-clamped converters. Packaging is also more difficult in inverters with a high number of levels.

3. Comparison of Multilevel Inverters

All three converters have the potential for application in high voltage applications. The diode clamped converter is most suitable for the back to back intertie system operating as a unified power flow controller, other two are also applicable for the same but they would require more switching per cycle .

All devices are assumed to have same voltage ratings but not necessarily same current ratings. The cascaded inverter uses full bridge in each level as compare to the half bridge versions in other two types. The cascaded inverter requires the least number of components and has the potential for utility interface applications because of its capabilities for applying modulation and soft switching techniques.

4. Conclusion

This paper has demonstrated the state of the art of multilevel power converter technology and also has presented several topologies for multilevel inverters (MLI), some of them well known with applications on the market. Every topology has been described in detail. Today, more and more commercial products are based on the multilevel inverter structure, and more and more worldwide research and development of multilevel inverter-related technologies is occurring. Authors intentions are to provide the brief idea about the major topologies of multilevel inverter in Section II.

Thus after this study we found that cascaded inverter is the better when we compare the reliability, modulation scheme and switching techniques with other topologies.

5. Proposed Work

The results will be obtained by using simulation. The goal of simulation is to simulate cascaded inverter topology. It helps us to understand how effectively the performance of inverter is improved.

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