A Survey on Neutral-Point-Clamped Inverters

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***Abstract*—Neutral-point-clamped (NPC) inverters are the most widely used topology of multilevel inverters in high-power applications (several megawatts). This paper presents in a very simple way the basic operation and the most used modulation and control techniques developed to date. Special attention is paid to the loss distribution in semiconductors, and an active NPC inverter is presented to overcome this problem. This paper discusses the main fields of application and presents some technological problems such as capacitor balance and losses.**

***Index Terms*—Neutral-point-clamped (NPC) inverters.**

I. Introduction

MOST industrial processes need to increase efficiency and reduce production costs. This is achieved by increasing the size of installations and increasing the power of all electrical machines and equipment. This increase in power is reached in two ways: 1) by developing high-voltage semiconductors with voltage blocking capabilities of 3300, 4500, and 6500 V and 2) by developing a multilevel inverter. Now, it is possible to directly connect the power converter to the medium-voltage (MV) network.

At low voltage, there is a single topology that dominates the market: the voltage-source two-level inverter. However, at medium and high voltages, the situation is completely different. A wide variety of topologies share the market and the applications of industrial MV drives [1, Fig. 1]. In effect, for high-power applications, it is possible to use direct converters (cycloconverters) or indirect converters (with current or voltage dc link).

The continuous development of high-voltage insulated-gate bipolar transistors (IGBTs) and integrated-gate commutated thyristors (IGCTs) and the application of these power semiconductors in several multilevel voltage-source converter (VSC) topologies have led to a drastic increase of the nominal voltage and power ratings of self-commutated converters in recent years. Pulsewidth modulation (PWM) VSCs have replaced thyristor-based converters in a wide range of applications. This is largely due to substantial system advantages, such as increased availability due to ride through capability and/or a redundant converter design, drastically improved dynamic performance, extended operating range, reduced line harmonics, and an adjustable power factor at the point of common coupling.

Highly popular are the voltage-source multilevel inverters, which can be divided into three categories, according to their topology: neutral point clamped (NPC), flying capacitor (FLC), and cascade H-bridge [1], [2].

Among the high-power converters shown in Fig. 1, the NPC inverter introduced 25 years ago is the most widely used in all types of industrial applications [3], [4], in the range of 2.3 to 4.16 kV, with some applications up to 6 kV.

This paper presents a survey of the most relevant developments of this topology: concerning the modulation strategies and control methods, as well as the efficiency and use of power semiconductors. New topologies like the active NPC (ANPC) inverter are also discussed. Special attention is paid to the use of these inverters in nonregenerative and regenerative applications. Finally, the future of development in operation, control, and applications is highlighted.

II. Diode-Clamped Three-Level Inverter

A. Basic Operation of the Three-Level NPC Inverter

Fig. 2 shows the power circuit of the three-level diode-clamped inverter. The clamping diode dc is used to connect the neutral point N to the midpoint of the transistor. This neutral N, generating an additional voltage level, yields the name "three-level inverter."

Fig. 3 shows the switching state that generates a positive voltage, at a load terminal. In this case, transitions S_{a1} and S_{a2} are switched ON, giving the value $V_{aN} = V_{\mathrm{dc}}/2$, where $\overline{S_{yx}}$ is the inverted signal of S_{yx} ($x = 1, 2$ and $y = a, b, c$), in order to avoid forbidden states, like short circuits. Table I shows the conduction state to be generated.

B. Modulation and Control Strategies for Three-Level NPC Inverters

As shown in Fig. 4, today, there are three main methods established to control the behavior of the fundamental voltage generated by the three-level inverter to the load. These methods are as follows: 1) carrier-based PWM; 2) space vector modulation (SVM); and 3) selective harmonic elimination (SHE).

Manuscript received March 19, 2009; revised May 14, 2009; accepted July 14, 2009. Date of publication September 22, 2009; date of current version June 11, 2010.

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Digital Object Identifier 10.1109/TIE.2009.2032430