THREE-LEVEL NPC INVERTER USED IN UPS

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The NPC Topology

The requirements in reliability and capacity are increasing in various industrial applications. Such as the medium voltage uninterruptible power system (UPS) which is widely used for high speed elevators, high-power electric drives and distributed generation systems as an interface between the utility grid and distributed power sources. Meanwhile, the limitations of traditional three-phase two-level inverters are disclosed. With the fast development of power converter technologies, multilevel converters are good choice for medium voltage industrial applications. Normally, the multilevel inverters are classified into three kinds, namely the neutral point clamping (NPC) multilevel inverter, the flying capacitor multilevel inverter and the cascaded H bridge multilevel inverter. Among them, the NPC three-level (NPC-3L) inverter has attractive features of simple configuration and control scheme, and these features make it attractive in both academia and industry [1].

Figure 1 shows the topology of the NPC three-level inverter with LC filter at the output side. Each leg has four IGBTs connected in series. The NPC-3L inverter uses two split capacitors in series for DC link, and produces zero voltage level. Thus, the voltage drop on the IGBT will be Udc/2 which is one-half that of the conventional two-level inverter, where Udc is the total voltage of DC link. This feature makes is more suitable for the application with higher DC bus voltage. What is more, the NPC inverter has some other favorable features including lower common-mode voltage and lower output current ripple for the same switching frequency compared with the conventional two-level inverter. As a result, a smaller output filter is required compared to an equivalent rated two-level inverter
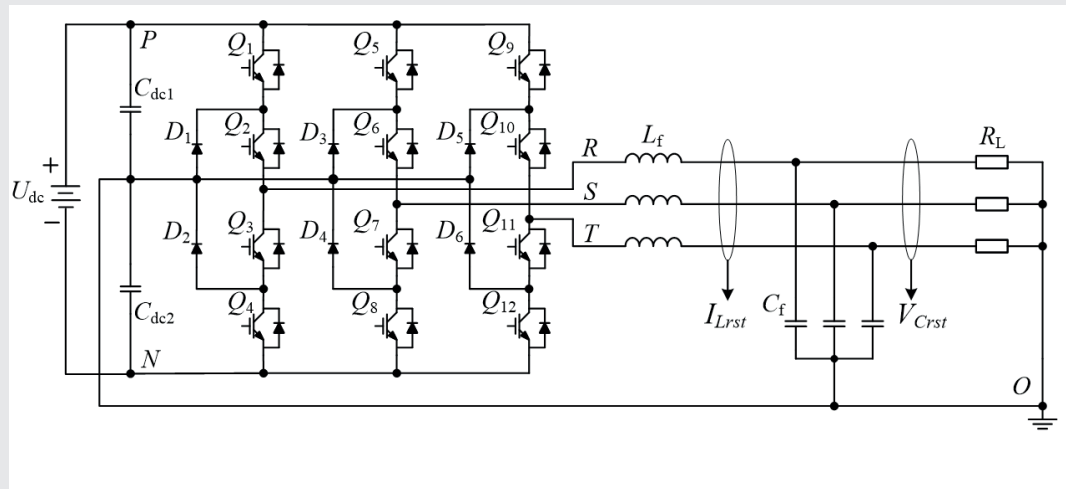

Fig.1. Topology of the NPC three-level inverter

Output Voltage and Switching States

The NPC inverter can generate three voltage levels on the output: the DC bus positive voltage, zero voltage and DC bus negative voltage. The two level inverter can only connect the output to either the positive bus or the negative bus. Take one phase operation for an example, when IGBTs Q1 and Q2 are turned on, the output is connected to VPO=Udc/2, when Q2 and Q3 are in on state, the output is connected to VO=0; and when Q3 and Q4 are turned on, the output is connected to VNO=-Udc/2. Table I shows the switching states for phase R. The clamp diodes D1 and D2 provide the connection for the output phases to the neutral point to get 0 voltage. From the switching states, it can be seen that IGBTs Q2 and Q3 are in on state for most of the cycles, resulting in greater conduction loss than Q1 and Q4 but far less switching loss. In addition, the free wheel diodes for Q2 and Q3 are for most cases, soft switched as the IGBT parallel to the diode is on, thus holding the recovery voltage across the diode to that of the IGBT Vce [2].
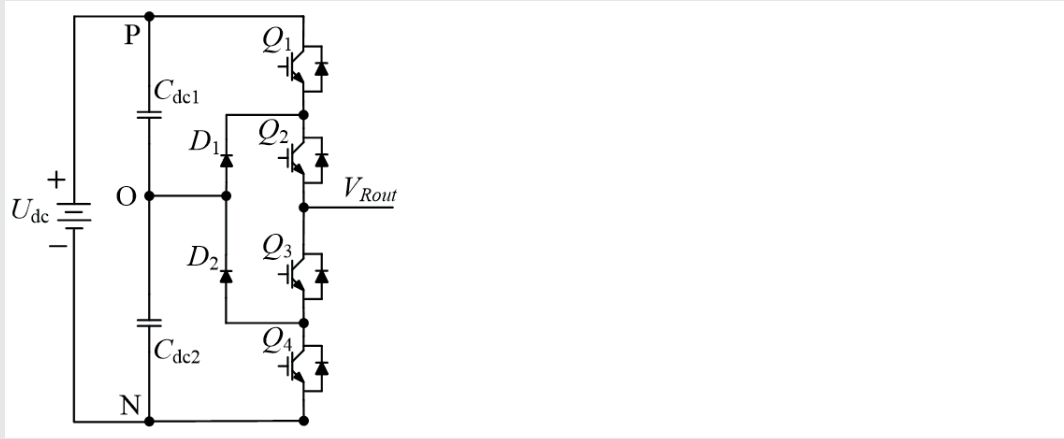
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Fig.2. Topology of phase R

GBT	$V_{Rout}=V_{PO}=U_{dc}/2$	$V_{Rout}=V_O=0$	$V_{Rout}=V_{NO}=-U_{dc}/2$
Q1	On	Off	Off
Q2	On	On	Off
Q3	Off	On	On
Q4	Off	Off	On

Table 1 Switching states of one phase

Power Loss

For an NPC three-level inverter, the phase to ground and phase to phase output voltage are shown in Figure 3 and Figure 4 respectively. It can be seen that the phase to ground voltage contains three-level, and the phase to phase voltage has five levels. Careful observation shows that the effective switching frequency of the phase-to-phase voltage in Figure 4 is twice that of the phase voltage shown in Figure 3. A two level inverter is required to use two times the switching frequency of an NPC inverter in order to achieve the same ripple in the output current. This simple fact coupled with the intermediate voltage steps of the NPC inverter offers two advantages over the two level inverter. First, there are much less switching losses in the NPC inverter and second, the output filter components will be smaller in both value and size than the filter components in a two-level inverter [2]. More details of power loss analysis are provided in the below.
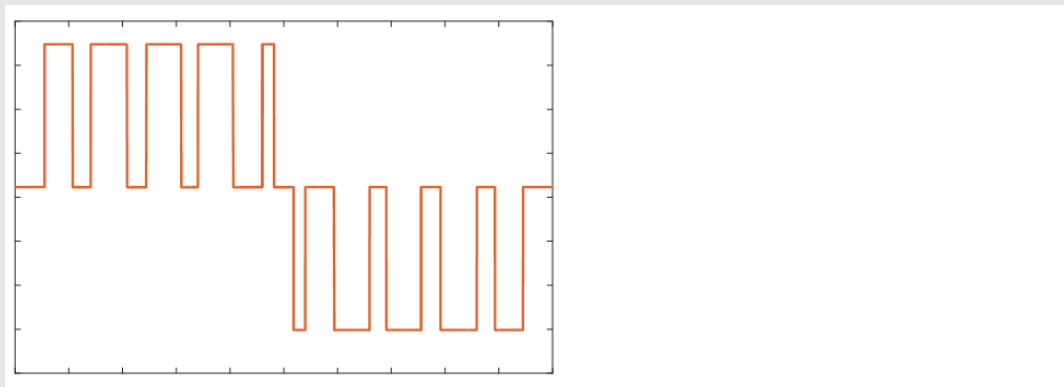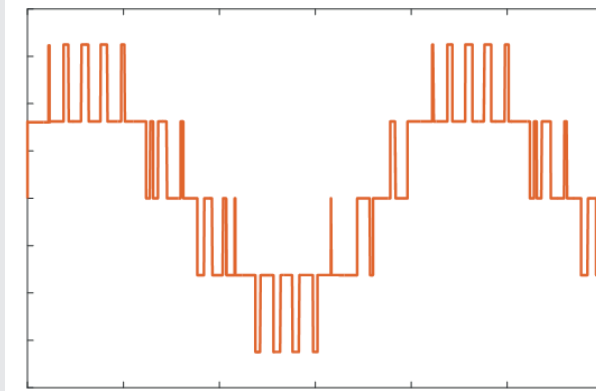

Fig.3.Phase to ground output voltage

Fig.4. Phase to phase output voltage

Losses in two-level and three-level inverters have been reported extensively in the many academia literatures. The switching voltage of the IGBT-diode modules in a three-level inverter is half of that in a two-level inverter generating a voltage waveform with the same amplitude. The voltage rating of the IGBT-diode modules used in a three-level inverter therefore needs to be half that of an equivalent two-level inverter. So for an equivalent power rated converter, the two-level inverter will use high-voltage high-current IGBT-diode modules, while the three-level inverters use the low-voltage high-current module. This difference in voltage rating has a very significant impact on switching and conduction loss parameters of the modules. The power losses of the there-level inverter will be much lower than the traditional two-level inverter, which will increase the power efficiency while decreasing the cost of the system. The research of literature [2] indicates that the switching losses of the two-level inverters are significantly higher than that of the three-level inverters. Even though the switching frequencies of the two-level inverters are lower, three-level inverters exhibit a major advantage over switching losses. The decreased number of output voltage levels and the lower switching frequencies also have a negative impact on the output harmonic performance of the two-level inverters [2].

Modulation method, control diagram and simulation results

Generally, PWM generation methods can be classified into carrier based modulation method and space vector modulation method. Since the carrier base modulation method has some advantages such as less calculation, easier implementation, simpler principle, so it has been widely used in multilevel inverters. Double-carrier based pulse width modulation method is widely used for NPC three-level inverter to acquire lower harmonics in the output voltage. Figure 5 shows the principle of the double-carrier modulation method, in which, carrier1 and carrier2 will be compared with the modulation waveforms IRM, ISM, ITM for three phases. Figure 4 shows more details of PWM signal generation of Q1 and Q2 for phase R.

$$I_{RM} = I_m \sin(\omega t)$$
$$I_{SM} = I_m \sin(\omega t - 2\pi/3)$$
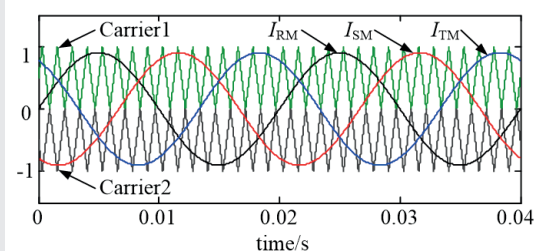$$I_{TM} = I_m \sin(\omega t + 2\pi/3)$$

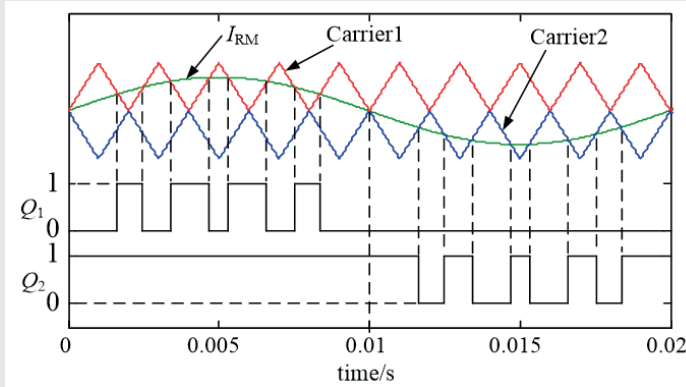*Fig.5.Principle of double-carrier modulation*

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Fig.6. PWM generation for phase R

Figure 7 shows the control diagram of an NPC three-level inverter. In a three-phase UPS system, the output is typically organized to be working with single phase, two phases or three phases to make it suitable for different kind of load, at the same time to have a more flexibility system. So the control scheme is under abc stationary coordinates frame. PR controllers for voltage and current control loop are used. Table II shows the simulation parameters for an UPS of 40kVA rated power.
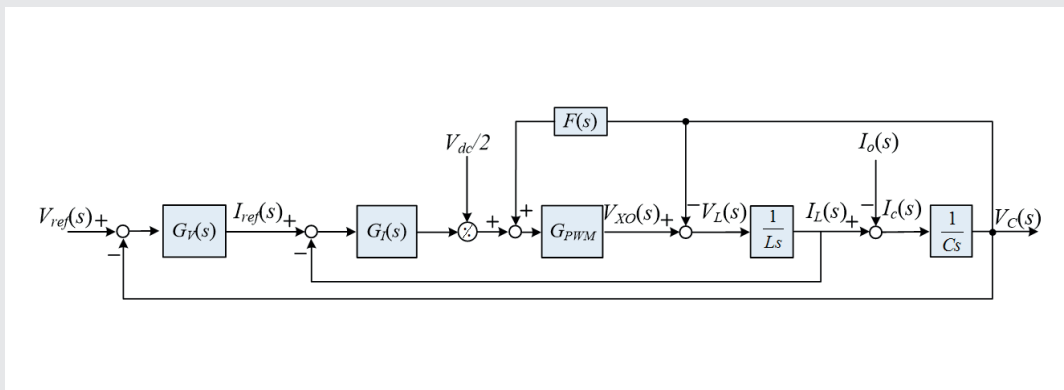

Fig.7. The control diagram for the NPC inverter

Parameters	Value
Nominal output voltage	230V/RMS
Switching frequency	20kHz
DC bus voltage	800V
Rated power	40kVA
Filter capacitance	60uF
Filter inductance	200uH

Table 2 Simulation parameters

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A soft star-up is enabled in the simulation. From Figure 8 and Figure 9, it can be seen that pure sinewave output voltages and currents are obtained. Figure 10 shows the phase to ground output voltage at the inverter side, and figure 11 shows the phase to phase output voltage. Figure 12 shows the spectrum of the THD for the output voltage which is less than 1%. From the simulation results, it reveals that a good performance can be obtained with proper design of the controller and filter.
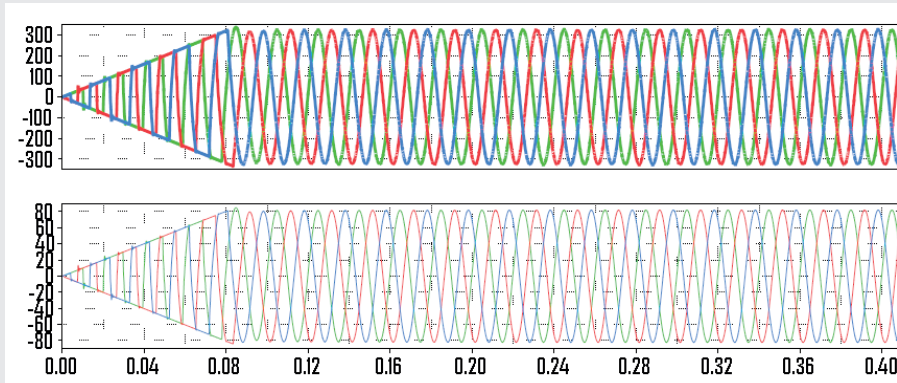

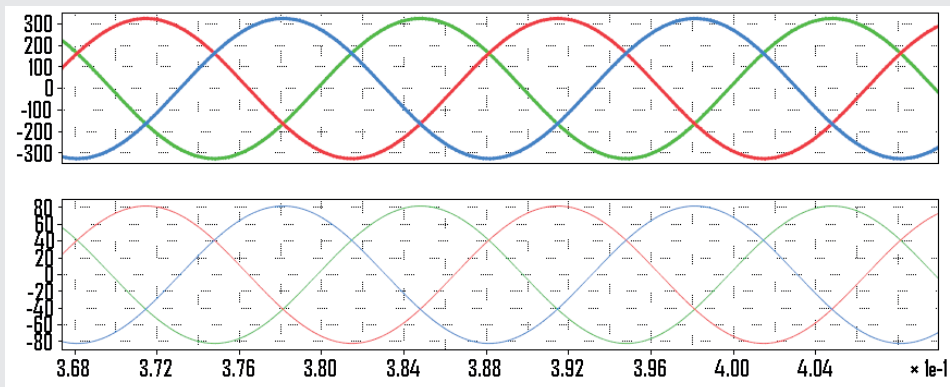Fig.8. Output voltage (up) and current (down)

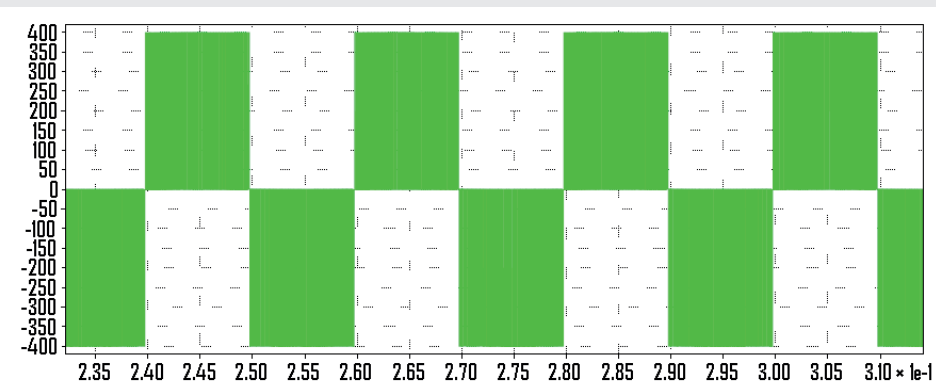Fig.9. The zoomed-in output voltage and current

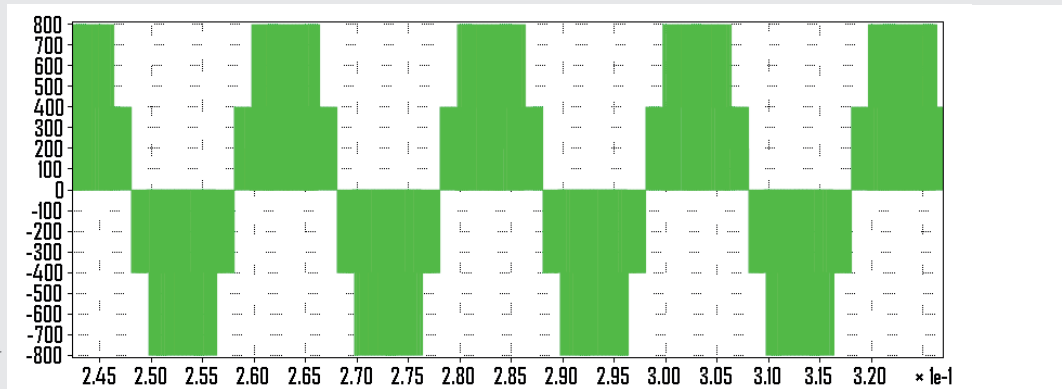Fig.10. Phase to ground output voltage at inverter side

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*Fig.11. Phase to phase output
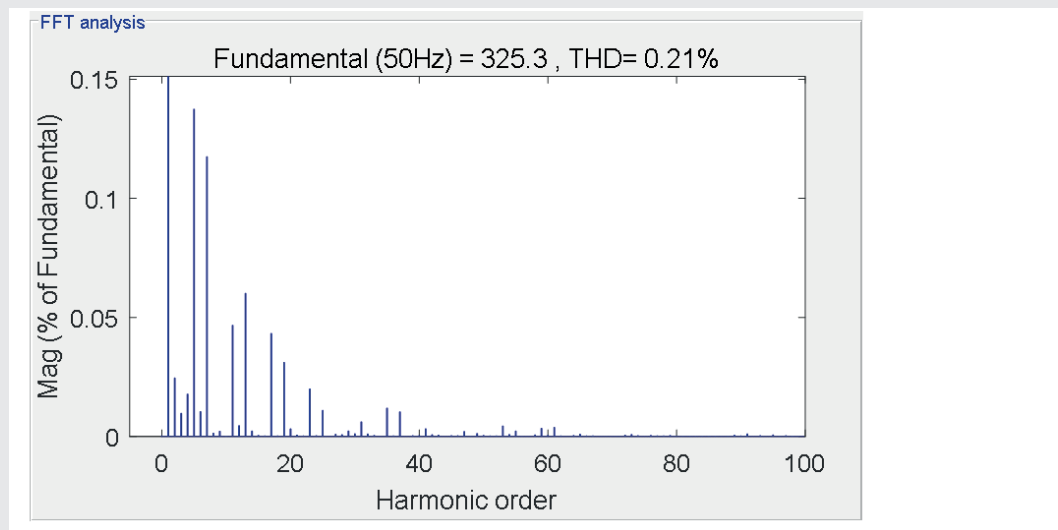voltage at inverter side*

*Fig.12. Spectrum of the THD
for output voltage*

Conclusion

NPC three-level inverter is more suitable for higher power UPS since the IGBTs are only subjected to half of the DC bus voltage, lower voltage rated IGBT modules can be used to reduce the cost which will also decrease the power losses of the system. And with three-level output voltage, a lower THD is obtained which leads to higher quality output voltage and current waveforms.

References

[1] Z. Wang, J. Chen, and M. Cheng, "Modeling and control of neutral-point-clamping (NPC) three-level inverters fed dual-three phase PMSM drives," in Proc. IEEE ECCE 2015, Sept. 20–24, pp. 1 - 8.
[2] POWEREX Semiconductor, "Introduction to Three-Level Inverter", 2009, Jun. 1.
[3] G. I. Orfanoudakis, S. M. Sharkh, M. A. Yuratich and M. A. Abusara, "Loss Comparison of Two and and Three-Level Inverter Topologies," in Proc. IET PEMD 2010, Apr. 19–21, pp. 1 - 6.

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