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High-Efficiency Three-Level Stacked-Neutral-Point-Clamped Grid-Tied Inverter

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Abstract – *This paper proposes a novel three-Level neutral-point-clamped (NPC) inverter with two independent dc sources coupled for the grid-tied photovoltaic (PV) application, which can effectively solve the unbalanced operational conditions generally, appeared between two coupled independent PV sources induced by the unequal irradiation and temperature distribution. Compared to the traditional two-stage PV inverter, the proposed NPC inverter could reduce the PV array voltage requirement and dc-link capacitors' voltage rating, meanwhile show the advantage in operational efficiency. In recent years, high photovoltaic array voltage up to1000 V and transformerless grid-tied inverter have been increasingly researched and applied to elevate the inverter and the dc power collection efficiency. With the same reasons, a three-level neutral point clamped (3L-NPC) inverter featuring low power device voltage stress and low leakage current becomes increasingly attractive. In this paper, the operation and the features of a novel grid-tied 3L-NPC are presented. The proposed topology is a derivative of the three level stacked neutral point clamped (3L-SNPC) structure. However, compared with the conventional 3L-SNPC and its pulse width modulation (PWM) strategy, the new topology with novel PWM strategy features completely inactive intrinsic body diodes. Furthermore, only two outer power devices are working with switching frequency, while the other four Insulated Gate Bipolar Transistors (IGBTs) are actually with the grid frequency.*

Key Words: PWM strategy, three-level neutral point clamped (3L-NPC) inverter, grid tied, IGBT, MOSFET, body diode.

1.INTRODUCTION

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photovoltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free. Solar-electric-energy demand has grown consistently by 20%–25% per annum over the past 20 years, which is mainly due to the decreasing costs and prices. This decline has been driven by the following factors: 1) an increasing efficiency of solar cells; 2) manufacturing technology improvements; and 3) economies of scale. PV inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of electromagnetic interference (EMI) generated by switching operation of the inverter .In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three-level pulse width-modulated (PWM) inverters.

1.1 Need of grid-tie Inverter in Renewable Energy System

A grid-tied inverter is a power inverter that converts direct current (DC) into alternating current (AC) and it has an ability to synchronize and could be interfaced with the utility grid. They found applications in converting direct current obtained from solar panels into AC before being tied to the utility grid. The residential and commercial loads are grid-tied in many countries which sell their surplus energy to the utility grid. There are several ways of taking compensation of the electricity which is delivered to the grid. By net metering, the consumer that has the renewable energy power source receives compensation from the utility for its net outflow of power. For example, if during a given month a power system feeds 500 kilowatt-hours of electricity into the grid and uses only 100 kilowatt-hours from the grid, it would get a compensation for 400 kilowatt-hours of electricity. Feed-in tariff is another policy, by which the person is paid for delivering electricity to the grid for every kilowatt hour by a special tariff which is based on a contract with distribution company.

Inverters changes DC power into AC power so it can be fed to the utility grid. But before feeding it to the grid the frequency of the grid tie inverter (GTI) must synchronize with that of the grid (e.g. 50 or 60 Hz) using a local oscillator and also its voltage is limited from having magnitude higher than that of grid voltage. A high-quality modern GTI having fixed power factor of unity, which means its output voltage and current are entirely lined up, and its phase angle is within one degree of the AC power grid. The inverter has an on-board computer for sensing the current AC grid waveform and the output voltage should correspond to that of the grid voltage. However, to keep the voltage within its allowed limit in the local grid supplying reactive power to the grid might be necessary. Otherwise, the grid segment

with significant power from renewable sources, voltage levels may rise in excess at times of high production, i.e. at noon.

Grid-tie inverters are designed in a manner that it could be disconnected quickly from the grid if the utility grid fails. An NEC requirement ensures that in the event of a blackout, the GTI shall be shut down to prevent the energy transfers and harming any line man or worker responsible for maintenance work.

Grid tie inverter enables a person to use an alternative power generation sources at home like solar or wind power without extensive rewiring and without batteries. If the non - conventional source generate power which is insufficient, then this deficit would be taken from the utility grid.

1.2.Neutral point clamped inverter

The neutral point clamped topology is also known as diode clamped topology. The main advantage of the NPC topology is that it requires only one DC source similar to two-level inverter, and gives better performance. With the increase in level ‗n', not only the number of clamping diodes increases but also the problem of ensuring the DC-link balance becomes more severe. Due to these reasons, the NPC topology is mainly used for 3- level inverter. Figure 1 shows its 3-level NPC topology.

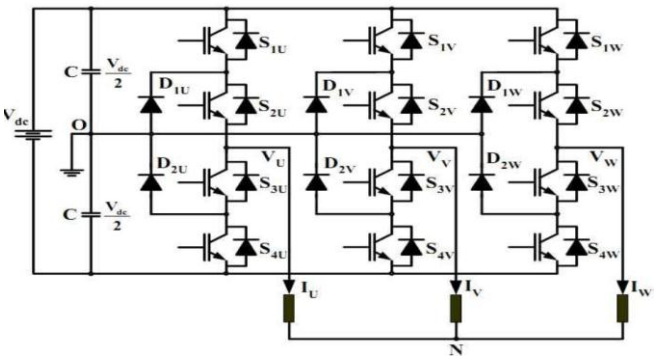

Fig. 1. Three -level Neutral Point Clamped topology

1.3.Different Types Of NPC Inverter Topologies

Photovoltaic (PV) power generation systems are playing an important role in the developing distributed electric power systems. In order to achieve low cost and compactness, as well as higher reliability and efficiency, high PV array voltage up to 1000 V and transformer less topology are proposed and increasingly researched. Among them, three-level neutral point clamped (3L-NPC) is becoming more and more attractive for low power device voltage stress and low leakage current as shown in Fig. 2. Floricau et al. proposed the three-level stacked neutral point clamped (3L-SNPC), as shown in Fig. 3. Floricau et al. proposed the three-level active stacked neutral point clamped (3L-ASNPC), as shown in Fig. 4. The topologies from 3L-NPC topologies, and various PWM strategies have been proposed for these topologies. The most popular PWM strategies like the PWM-1 depicted used in 3L-NPC, 3L-SNPC, or 3L-ASNPC topologies are believed to have better performance over traditional 3L-NPC because of the following.

1) Apparent switching frequency is increased.
2) The above advantage leads to a better total loss balancing.
3) The load current passes simultaneously through two parallel paths in some switching states..
4) At least two power devices are included in the load current path at any switching states.
5) At least one body diode is included in the current freewheeling path, particularly when the current is freewheeling through two body diodes to the positive dc bus or negative dc bus.
6) At least four IGBTs are working with switching frequency fsw, and therefore, the switching loss will be too high with enhanced fsw.

In this paper, a novel high-efficiency 3L-SNPC (named N-3L-SNPC) using hybrid CoolMosfet and IGBT power module is proposed and applied into grid-tied PV non isolated applications. Based on the grid-tied inverter's current source property, a new PWM strategy is also proposed. The proposed configurations and PWM strategy feature high efficiency, complete inactive body diode control, low switching power losses, high switching frequency, and reduced inverter output filter inductance.

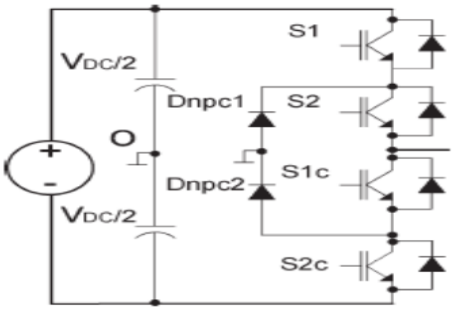

Fig. 2. 3L-NPC inverter topology.

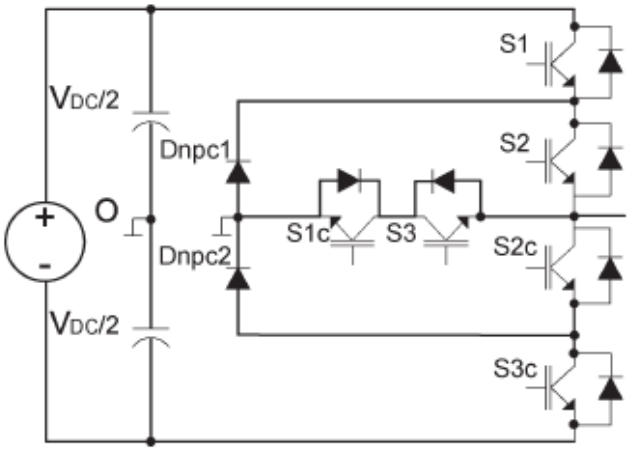

Fig. 3. 3L-SNPC inverter topology.

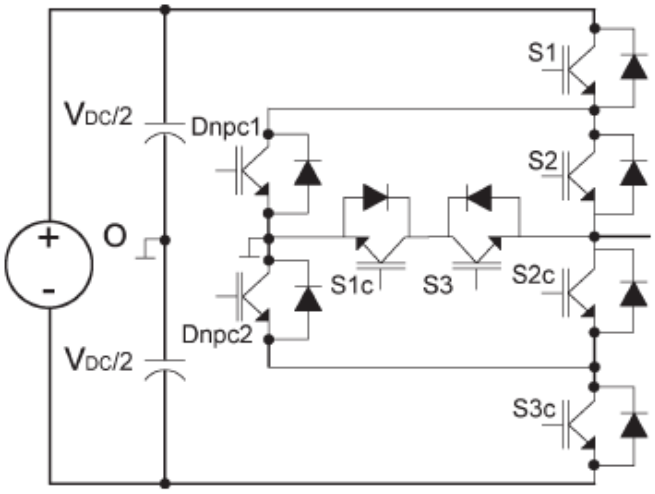

Fig. 4. 3L-ASNPC inverter topology.

1.4.Proposed Noval Topology And Its PWM Strategy

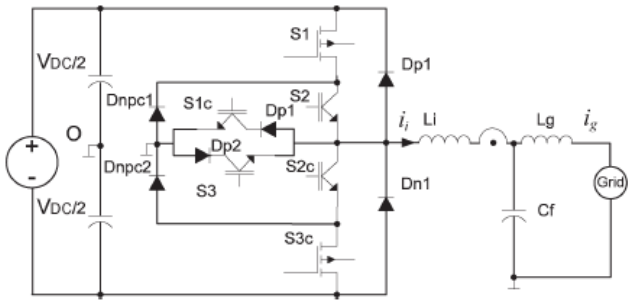

Fig. 5. Proposed N-3L-SNPC circuit diagram.

Fig. 5 shows the proposed N-3L-SNPC circuit diagram applied in PV application.

In the new topology, first, the IGBTs do not have internal body diode. However, there are four extra diodes compared with the traditional 3L-SNPC. The diodes Dp1 and Dn1 provide the freewheeling path to the dc bus instead of the body diodes of S1, S2, S2c, and S3c. Also, Dp2 and Dn2 replace the body diodes of S1c and S3 to the neutral. In this way, there is more design freedom to optimize the inverter efficiency. Furthermore, the outer IGBTs are replaced by the CoolMosfet to elevate the switching frequency. Hence, the inverter output filter size is reduced with the improved switching frequency

Finally, in grid-tied inverter, the special point is that the modulation function *m* is in phase with the output current *ii*. Therefore, during the positive half period of *m*, *ii* is also positive. Although S1c is switching complementarily with S1, it actually does not conduct during *m*'s positive half period. Therefore, the switching signal for S1c is redundant and could be disabled. However, for the reason described the S1c switching signal should be enabled around the zero-crossing point to conduct the high frequency ripple current which could have both a positive and a negative current polarity within one switching period. Based on the aforementioned analysis, this paper proposed a new PWM control strategy derived from the PWM-1 strategy in [15], as shown in Fig.6.

Table I shows the switching states with the improved PWM strategy.

Compared with [15], O1+ and O2– are the added states, in which the drive signals of S1c and S3 are disabled. The P state commutates with O1+ during [$\theta 1$, $\theta 2$], and the N state commutates with O2– during [$\theta 3$, $\theta 4$], as shown in Fig. 5. Only around the zero-crossing region [$\theta 2$, $\theta 3$] are the drive signals of S1c and S3 enabled. The P state commutates with O2+ during [$\theta 2$, 0], and the N state commutates with O1– during [0, $\theta 3$], respectively. Therefore, in Fig. 5, S2 and S2c work completely with line frequency, and S1c and S3 only work with switching frequency in the short period [$\theta 2$, $\theta 3$] around the zero-crossing point conducting very low current. Δii is the inverter current ripple given by

$$\Delta i_i = \frac{|(u_{\mathrm{dcBus}} - u_g).m|}{L_i \cdot f_{\mathrm{sw}}}.$$

Δii, $u$dcBus, ug, Li, and $f$sw are the grid current ripple, dc link voltage, grid voltage, inverter side inductance, and switching frequency, respectively.

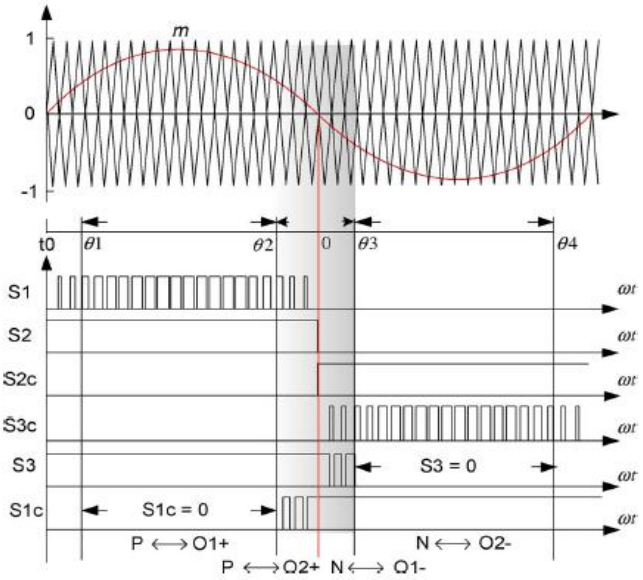

Fig. 6. Improved PWM strategy.

TABLE I- Switching Stages Of The New PWM Strategy

Switching states	Switch sequence					
	S1	S2	S2c	S3c	S1c	S3
P	1	1	0	0	0	1
O1+	0	1	0	0	0	1
O2+	0	1	0	0	1	1
O1-	0	0	1	0	1	1
O2-	0	0	1	0	1	0
N	0	0	1	1	1	0

2.CONCLUSIONS

This paper investigates the conventional 3L-SNPC working principle. The disadvantages are summarized considering the efficiency. To overcome the drawbacks, the authors proposed an N-3L-SNPC topology together with a new PWM strategy. In the new configurations, only two CoolMosfets are working with switching frequency. Therefore, the switching losses are soundly reduced. Furthermore, the load current paths are optimized, the conducting devices are reduced, and there are no body diodes active as in the conventional 3L-SNPC. Therefore, the conduction loss is also reduced.

Finally, in the new PWM strategy, no dead time is necessary except in the very narrow region around the zero-crossing point. Therefore, the voltage utilization and output quality together with its efficiency are improved.

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BIOGRAPHIES

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