High Performance and Archetype Boost ANPC Inverters

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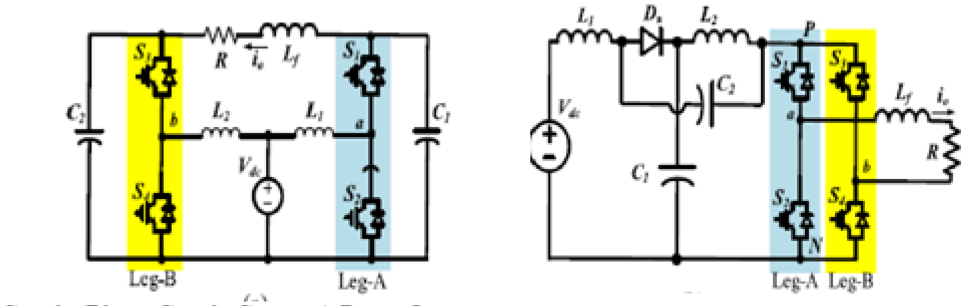
Abstract: In this paper deals with different types of energy conversion scheme for proposed in order to reduce the input current ripples, to reduce the output voltage ripples and to reduce the size of passive components with high efficiency for high power applications. The proposed converter is compared with other topologies, such as single-phase single-stage switched-boost inverter, Two-Stage boosting multilevel inverters (MLIs), Conventional 3L-ANPC topology, five-level ANPC topology with twofold voltage gain enhancement in order to examine its performance. To reduce the dc-link voltage, a recent topology that enhanced the voltage gain from half to unity has been presented. A less complicated logic-form-equations-based gating pulse generation scheme is designed for enabling the proposed MLI to maintain its capacitor voltage. an alternative ANPC topology is established by using two T-type inverters. Two floating capacitors with self-voltage balancing capability are integrated to achieve a voltage-boosting gain of 1.5. In addition, the proposed topology is capable of generating seven voltage levels. Further, a comparative study with state-of-the-art topologies is carried out to demonstrate the superior performance of the proposed topology. Finally, the feasibility of the proposed topology is validated through experimental tests and the corresponding results are elucidated.

Index Terms - **Boost ANPC, multilevel inverter, power quality, single stage, step-up, 3L, 5L, and 7L voltage-boosting.**

I. INTRODUCTION

Converter behind the increasing concern toward generating green power from renewable sources such as photovoltaic's and wind farms are the depleting fossil fuels and increased environmental concern. Furthermore, it is imperative to employ power electronic converters in order to efficiently harness such green power. Among the many varieties of converters, multilevel inverters (MLIs) are widespread due to their attractive features of reduced *dv/dt*, improved waveform quality, and reduced power losses A few of the classic topologies that are majorly used are cascaded H-bridge (CHB), neutral point clamped, and flying capacitor converters. However, as the number of voltage level increases, these topologies suffers from several drawbacks, such as dc-link capacitor voltage imbalance, complex control strategy, the requirement of more components. Three-level active-neutral-point-clamped (ANPC) (3LANPC) inverter depicted is widely used in the industry for dc–ac power conversion. Tremendous research efforts have been devoted to developing ANPC inverters with a higher number of levels. Improved ANPC topologies that are established by hybrid configuration with other topologies, such as H-bridge and flying capacitor inverters, have also been explored. An 11-level hybrid topology that consists of a 5L-ANPC and a low voltage Sub module that controls an additional isolated dc-source was presented.

The ANPC topologies are (a) Conventional 3L-ANPC topology (b) Recent five-level ANPC topology (c) Conventional 7L- ANPC topology with twofold voltage gain enhancement. Suffer from a common Drawback such that they are subjected to a high dc-link voltage requirement. The peak of ac output generated by an ANPC inverter with sinusoidal pulse width modulation (SPWM). The implications of the restricted gain become particularly apparent in grid-connected renewable energy applications. With the required minimum dc link voltage *V*dc twice the ac grid peak voltage, a boost dc–dc converter is essential to generate the demanded dc-link voltage. However, this two-stage power conversion structure reduces the efficiency of the system. Recently, an innovative ANPC topology has made a single stage dc–ac power conversion system possible to eliminate the need of a front-end boost dc–dc converter. It enhances the voltage gain from half to unity, thus reducing the dc-link voltage by half.



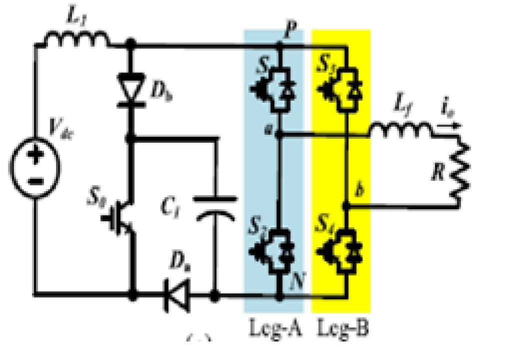
Single-Phase Single-Stage a) Boost Inverter *b) Z-Source Inverter*

Single-Stage Power Conversion

To overcome both the limitation of the output voltage and the shoot-through (or open-circuit) problem, the Z-source inverter (ZSI) was proposed in for single-stage power conversion. Quasi-Z-source inverters (QZSIs) are proposed to reduce the voltage stress on the capacitor and improve the input current profile. Where a QZS network with two inductors and two capacitors is connected two legs of H-bridge inverter and shoot through state is used to boost voltage without any damages in the power circuit.

In one switching period, the number of the shoot-through states is two. Therefore, the operating frequency of the inductors is twice the switching frequency. Because the source voltage is directly connected to the inductor, the input current of the QZSI is continuous. The used Z-network with two inductors and two capacitors in the classic ZS/QZSIs increases the size, weight, and cost of the power inverter. To reduce the size, weight, and cost of the power inverters, a switched-boost inverter (SBI) is proposed. The SBI with a lower number of passive components also has the same features as the ZSI, where the shoot-through state is used to boost voltage with the single-stage power conversion.

A new single-phase single-stage SBI with four switches is proposed. The proposed inverter benefits from shoot through Immunity over the boost inverters and it has one less switch and one more capacitor compared to QSBI.



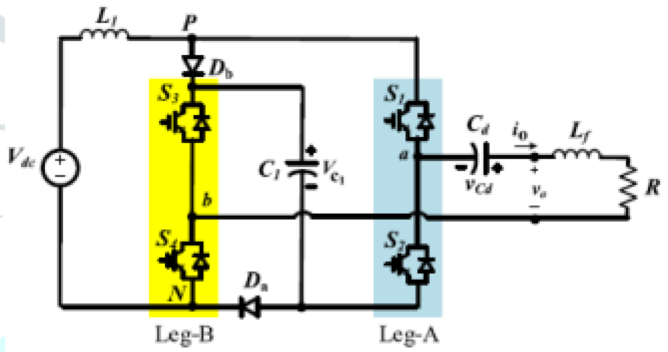
Single-Phase single-stage switched boost inverter

In comparison to the QZSI, the proposed inverter uses one more diode and one less inductor. The proposed inverter has all inherent advantages of the QZSI and QSBI as single-stage power conversion, continuous input current, buck/boost voltage, and shoot-through immunity.

Single-Phase Single-Stage SBI with Four Switches:

The switch *S*0 in the QSBI is replaced by the second H-bridge leg with two switches *S*3 and *S*4. As a result, the proposed inverter is reduced one active switch compared to the QSBI. A switched-boost network is a combination of one inductor (L_1), one capacitor (C_1), two diodes (D_a,D_b), and four switches. A capacitor C_d filter is used to remove the dc offset component at the output.

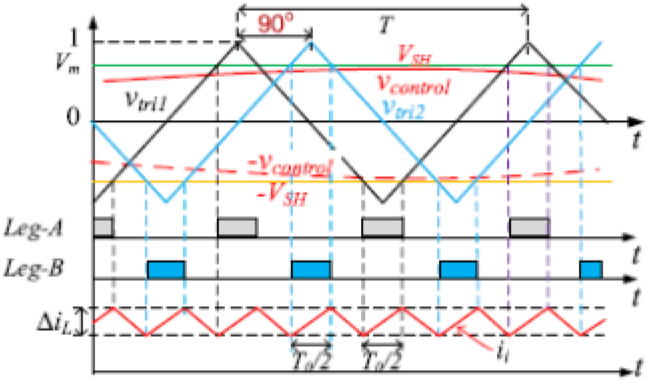
The output of the inverter is connected to a passive load (RL_f).When D_a is fully forward-based, a combination of $L_1 - C_1 - D_b - S_1 - S_2$ plays a role as a boost converter. When *Db* is fully forward based, a combination of $L1 - C1 - Da - S3 - S4$ plays a role as another boost converter. As a result, two boost converters are integrated to one in the proposed inverter. Compared to the single-phase boost inverter, where two separated boost converters are used, the proposed inverter uses one less inductor and one less capacitor, but two more diodes.



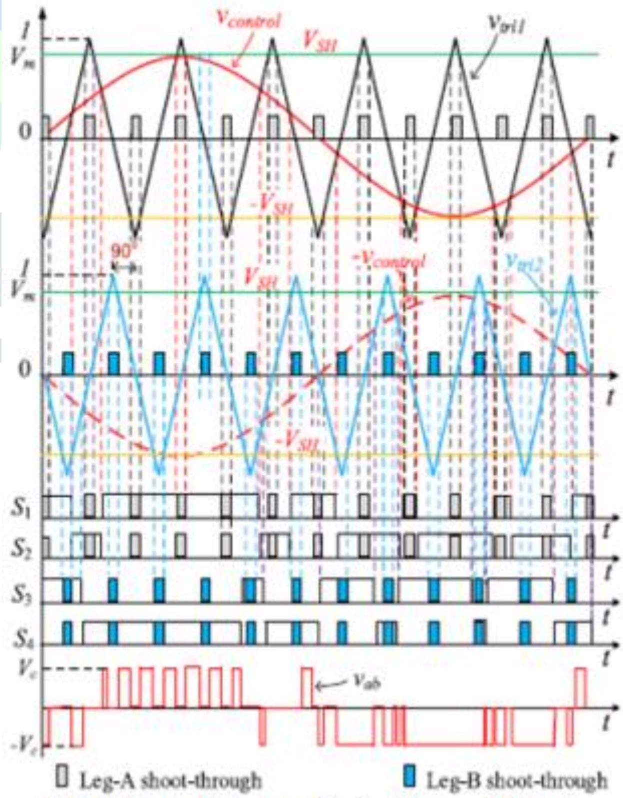
Single-Phase Single-Stage SBI with Four Switches

PWM Control Strategy:

This proposed single phase single stage SBI a control waveform and control, is compared to a high frequency (HF) triangle waveform, Vtri1, to generate control signals for the *S*1 and *S*2 switches in leg-A. Two constant voltages, +*V*SH and −*V*SH, are compared to *V*tri1 to generate the shoot-through control signal. The shoot-through control signal is then inserted into the control signals of switches *S*1 to *S*2 through OR logic gates to generate the shoot-through states in leg-A. Likewise, another HF triangle waveform, vtri2 that is shifted in 90° from vtri1 is compared to – v control to generate control signals for the S3 and S4 switches in leg-B. Two constant voltages, VSH and −VSH, are



PWM control strategy for the proposed single-phase SBI.



PWM Control Strategy for the Proposed Inverter

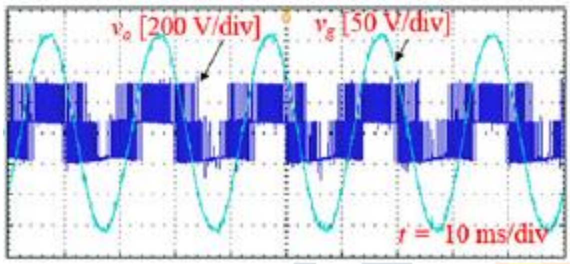
compared to triangle waveform Vtri2 to generate the shoot-through control signal. The shoot through control signals is then inserted into the control signals of switches S3 to S4 through other OR logic gates to generate the shoot-through states in leg-B.

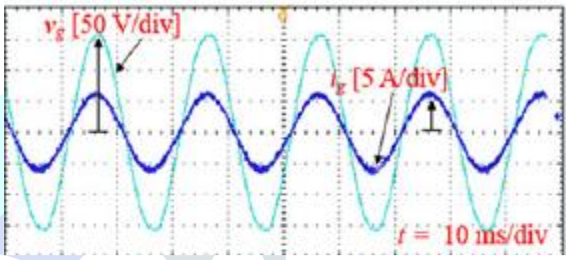
Comparison between the proposed inverter and the conventional single-stage boost inverters:

	Inverter in [4]	Inverter in [8]	Inverter in [9]	qZSI	qSBI	Proposed Inverter
Switch	4	4	4	4	5	4
Diode	4	5	6	5	6	6
Capacitor	2	1	1	2	1	2
Inductor	2	1	1	2	1	1
Shoot-through immunity	No	No	No	Yes	Yes	Yes
Input current	*Cont. high ripple*	*Discont.*	*Cont.*	*Cont.*	*Cont.*	*Cont. high ripple*
Capacitor voltages	*Very high ripple*	–	–	*Very low ripple*	*Very low ripple*	*Low ripple*

As a result, the number of shoot through states in one switching period of the proposed inverter is four. With the modulation strategy in Fig. 5, the output voltage of the inverter has three levels (+VC, 0 and −VC). Compared to the conventional PWM strategies, the modified PWM strategy does not have any main advantages.

Single-Stage Boost Inverters Results:

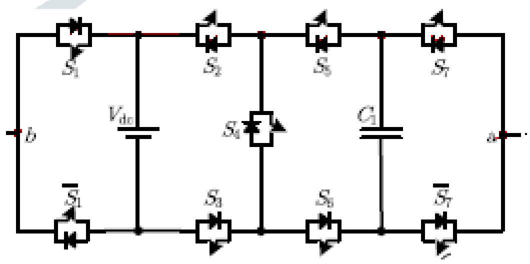




Output voltage of the inverter, *Vo* and grid Voltage, *Vg* under using PLL controller.
Voltage and current of the grid.

Single-Phase Five-Level (5L) Boosting Inverter:

It consists of nine power switches, The arrangement of switches *S*2, *S*3, *S*4, *S*5 , and *S*6 interconnecting the dc source and SC is referred to as an intermediate switching cell (ISC). The remaining four switches (*S*1, S1, S7, and *S*7) operate only once in every half-cycle of the fundamental voltage and thus are termed as line frequency switches (LFSs). It is evident that only one dc supply is employed for the 5L voltage generation. A photovoltaic cell/array, EV battery, or fuel cell can act as such dc supply. Besides, the proposed circuit arrangement exhibits a uniform blocking voltage across all the switches and has a voltage boosting factor (VBF) of two.

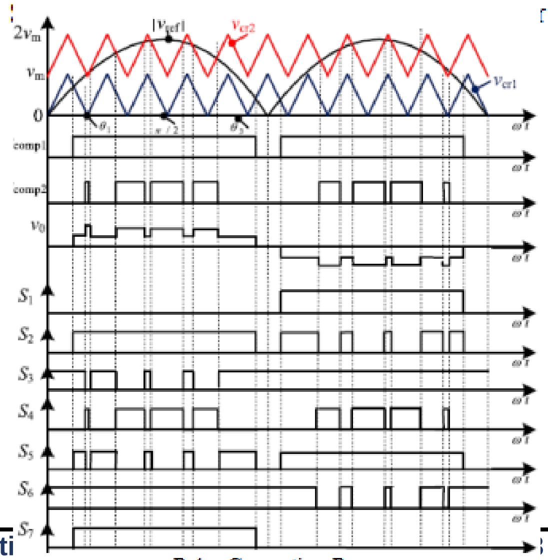


Unlike many other structures where in an H-bridge is used for the polarity generation, the proposed architecture has an inherent voltage reversal capability. The voltage across the SC is balanced around a voltage of magnitude *V*dc without any need for sensors. The 5L basic unit, the number of voltage levels (*N*L) can be increased and resulting configuration has a higher *N*L and VBF. Such an arrangement is highly suitable for the interconnection of multiple renewable sources.

Pulse width Modulation Strategy:

The switching combination required for the generation of a 5L output voltage. As per table the entry “1” indicates that a particular switch is ON and “0” indicates the OFF condition. The table also indicates the effect of each of the voltage levels on the SC voltage. It is essential to produce appropriate gating signals in order to synthesize the output voltage with the desired steps. For this, two level shifted high frequency carriers (Vcr1 and Vcr2) and a single fully rectified signal of the sinusoidal reference (Vref = Vmsinωt) are employed. A zero crossing detector (Zc) defined as Zc = 1 for Vref > 0 is required for the construction of the SFs.

The floating nature of the dc source in the proposed 5L topology, a solid connection between the PV module and the grid is not possible and the same is equally applicable for motor drives. This may generate variable



Pulse Generation Process

common mode voltage and in turn leading to leakage current in the system, which needs to be tackle through a suitable modulation technique or special thought. The output voltage is composed of five levels with a peak value of 200 V, confirming the boosting ability. The inductive loading ability is validated corresponds to the dynamic change in load power factor (PF). A step change in load is applied at time *t*1. The 5L topology is able to maintain its SC voltage irrespective of PF and has the ability to operate satisfactorily during the dynamic conditions as well.

v_{ab}	S_1	S_2	S_3	S_4	S_5	S_6	S_7	C_1
$2V_{dc}$	0	1	0	1	0	1	1	Discharging
V_{dc}	0	1	1	0	1	1	1	Charging
0	0	0	1	0	0	1	0	No Effect
0	1	1	0	0	1	0	1	No Effect
$-V_{dc}$	1	1	1	0	1	1	0	Charging
$-2V_{dc}$	1	0	1	1	1	0	0	Discharging

Switching States for the 5L Inverter

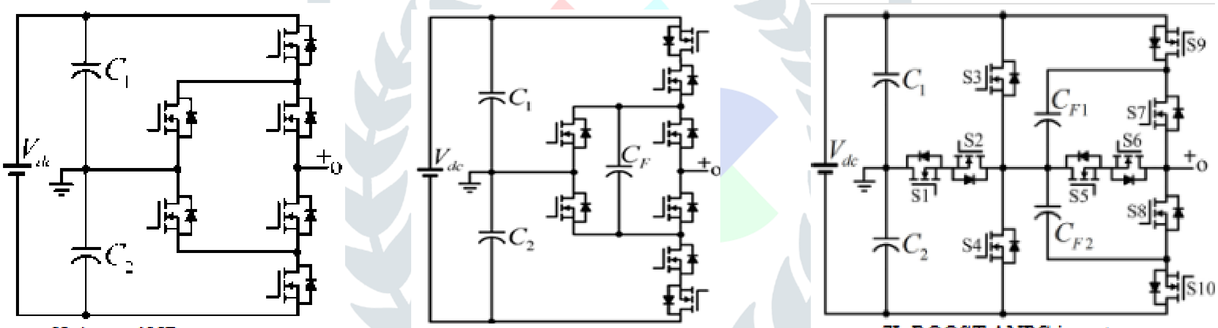
3L active-neutral-point-clamped (ANPC) inverter:

The three-level active-neutral-point-clamped (ANPC) inverter is widely used in the industry for dc–ac power conversion. The research efforts have been devoted to developing ANPC inverters with a higher number of levels, but at the expense of the voltage balancing problem. Additional voltage balancing circuits with especially designed control algorithms are normally necessary to resolve the balancing problem. To Improved ANPC topologies that are established by hybrid configuration with other topologies, such as H-bridge and flying capacitor inverters.

5L active-neutral-point-clamped (ANPC) inverter

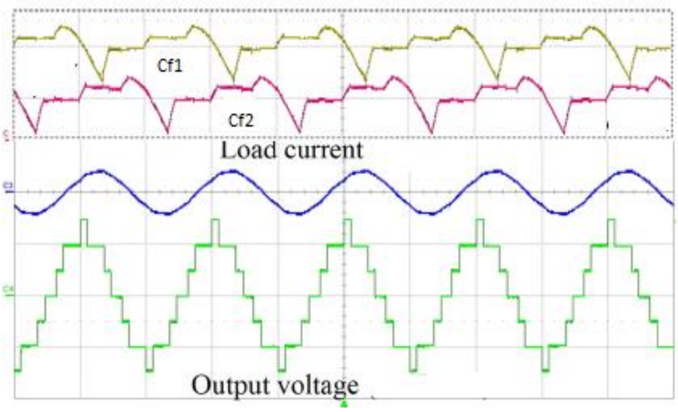
An 11-level hybrid topology that consists of a 5L-ANPC and a low voltage sub module that controls an additional isolated dc source was presented. Instead of increasing the number of voltage levels, some studies have attempted to establish different ANPC inverters with switch count reduction, thereby enhancing the efficiency.

Dual-T-Type Seven-Level Boost ANPC (DTT-7L-BANPC) Inverter:



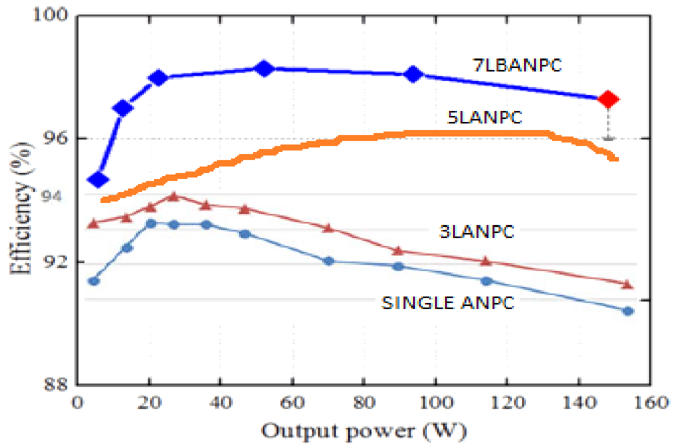
3L boost ANP converter 5L Boost ANPC inverter 7L BOOST ANPC inverter

Its circuit structure is comprises two T-type inverters and also using all the power switches are metal-oxide-semiconductor field effect transistors type. Two floating capacitors (*CF* 1 & *CF* 2) are integrated to achieve a voltage-boosting gain of 1.5v With the magnitude of each level is 0.5 *V*dc, the capable of generating seven levels from −1.5 *V*dc to 1.5 *V*dc.



Switching Angles with SHEPWM

The transient response of the DTT-7L-BANPC inverter for a no load to full load, the load current increases instantly when the load is turned ON, without influencing the performance of the output voltages and the average floating capacitor voltages. The proposed DTT-7L-BANPC inverter is highly efficient, with the peak efficiency recorded at 98.3%. The peak of ac output voltage is 1.5 times that of the input voltage, thereby validating the voltage-boosting capability of the proposed topology.



Efficiency of the 7L Boost ANPC Inverter

To further validate the efficiency of the proposed DTT-7LBANPC, the power switches used in the prototype were modeled in PSIM software. Efficiency was approximately 98.2%. Simulation was then conducted to consider higher output power generation in a grid connected application, where the ac grid peak voltage is 330 V. The input voltage was set to 220 V, which is 2/3 of the ac grid peak voltage.

CONCLUSION:

A new single-phase single-stage SBI with four switch inverter has a high reliability because it immunizes both shoot-through and open-circuit phenomenon. The ac output voltage of the proposed inverter is higher or lower than the dc input voltage. Because the dc capacitor filter is used to remove the dc component of the output voltage. The research should be carried out to eliminate the LF input current of the SBI inverter. In a 5L MLI with the features of voltage boosting, self-voltage balancing, reduced components, inductive-loading ability and uniform were blocking voltage across the switches. The DTT-7L-BANPC proposed topology is capable of generating seven voltage levels with a voltage-boosting gain of 1.5. Self voltage balancing of two floating capacitors was achieved during operation. Experimental results validated its operation and feasibility. It is an alternative for a single-stage multilevel boost dc–ac power conversion system.

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