# Grid Connected Multi Level Inverter with Power Converters for Renewable Energy System

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***Abstract- A single-phase nine-level inverter for grid-connected photovoltaic systems, with pulse width-modulated (PWM) control scheme is proposed. Three reference signals that are identical to each other with an offset that is equivalent to the amplitude of the triangular carrier signal were used to generate the PWM signals. The inverter is capable of producing nine levels of output-voltage levels from the dc supply voltage. Multilevel inverters offer improved output waveforms and lower THD. A PWM switching scheme for the multilevel inverter is generally preferred. By controlling the modulation index, the desired number of levels of the inverter's output voltage can be achieved. The DC–DC converters based topology applied for high-voltage and high-power applications were introduced. The converter is configured such that the boost - half-bridge (BHB) cells and voltage doublers are connected in parallel and in series to increase the output voltage and the output power. In addition to reduced device voltage and current ratings by the connection, the converter has the advantages of high-step-up voltage gain with significantly reduced transformer turn ratio, low input current ripple due to interleaving effect, zero-voltage switching turn-ON of switches and zero-current switching turn-OFF of diodes. The converter has reduced volume of input and output filters resulting from the interleaved switching. Another advantage provided by the multiphase converter is output ripple cancellation, which results in increasing the effective output frequency.***

***Keywords — Inverter, DC-DC Converter, THD, Pulse Width Modulation, Boost Half Bridge.***

## I. INTRODUCTION

The main objective is to increase the output voltage by using BHB cell and voltage doublers for parallel or series connections. The proposed converter having the significant features such as, ZVS turn-ON of switches and ZCS turn-OFF of diodes, no additional clamping and start-up circuits required. Thus the input converter is suitable for high-voltage and high-power applications. The ever-increasing energy consumption, fossil fuels' soaring costs and exhaustible nature, and worsening global environment have created a booming interest in renewable energy generation systems, one of which is photovoltaic. Such a system generates electricity by converting the Sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW. A common topology of this inverter is full-bridge three-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence, also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation.

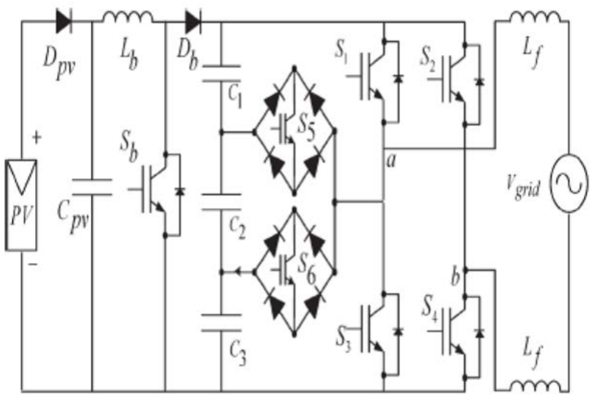



Figure.1 Grid-Connected Inverter for Photovoltaic Systems

Multilevel inverters are promising; they have nearly sinusoidal output-voltage waveforms, output current with better harmonic profile, less stressing of electronic components owing to decreased voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size, and lower EMI, all of which make them cheaper, lighter, and more compact. This paper recounts the development of a novel modified H-bridge single-phase multilevel inverter that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique. The topology was applied to a grid-connected photovoltaic system with considerations for a maximum-power-point tracker (MPPT) and a current-control algorithm.

In the meanwhile, the boost half bridge (BHB) converter has been presented. It demonstrates the following features: small input filter due to continuous input current, low EMI due to ZVS turn ON of all power switches, wide input voltage range application due to wide duty cycle range. The BHB converter with a voltage doubler rectifier at the secondary has no dc magnetizing current of the transformer, reduced voltage surge associated with diode reverse recovery, and no circulating current due to absence of output filter inductor.

## II. MULTILEVEL INVERTER TOPOLOGY

The proposed inverter comprises of a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by $C_1$, $C_2$, and $C_3$, as shown in Fig.1. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels. Photovoltaic (PV) arrays were connected to the inverter via dc–dc boost converter. The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used. The dc–dc boost converter was required because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid. A filtering inductance $L_f$ was used to filter the current injected into the grid. Proper switching of the inverter can produce seven output-voltage levels from the dc supply voltage.

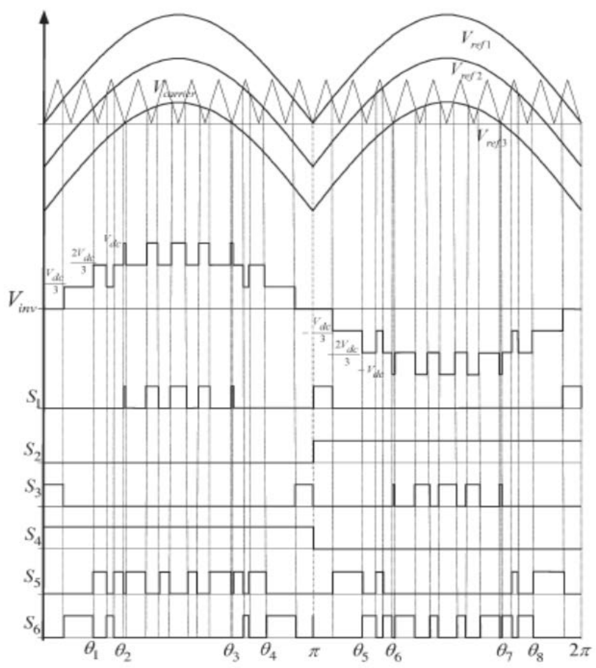



Figure. 2 Switching Pattern for the Inverter.

Three reference signals have to be compared with the triangular carrier signal to produce switching signals for the switches. A novel PWM modulation technique was introduced to generate the PWM switching signals. Three reference signals (Vref1, Vref2, and Vref3) were compared with a carrier signal (Vcarrier). The reference signals had the same frequency and amplitude and were in phase with an offset value that was equivalent to the amplitude of the carrier signal. The reference signals were each compared with the carrier signal. If Vref1 had exceeded the peak amplitude of Vcarrier, Vref2 was compared with Vcarrier until it had exceeded the peak amplitude of Vcarrier.

Then, onward, Vref3 would take charge and would be compared with Vcarrier until it reached zero. Once Vref3 had reached zero, Vref2 would be compared until it reached zero. Then, onward, Vref1 would be compared with Vcarrier. Fig. 2 shows the resulting switching pattern. Switches $S_1$, $S_3$, $S_5$, and $S_6$ would be switching at the rate of the carrier signal frequency, whereas $S_2$ and $S_4$ would operate at a frequency that was equivalent to the fundamental frequency.

## III. PROPOSED POWER CONVERTER

The figure shows the BHB cell that is used as a building block of the proposed multi-phase converter. Fig. 4 shows the generalized circuit of the multi-phase DC-DC converter for high voltage and high power applications.

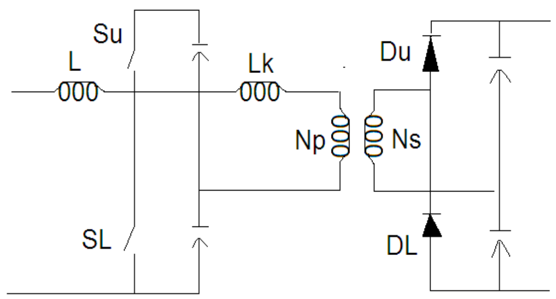



Figure.3 BHB cell for proposed converter

The generalized converter has “N” groups of converters, where each group of switch legs is connected in parallel at the low voltage high current side while each group of voltage doublers is connected in series at the high voltage low current side. That is, “N” is the number of voltage doublers connected in series to form the output voltage. Each of N groups also has “P” parallel connected legs, where “P” is the number of switch or diode legs connected in parallel to increase the output power.

For example, the “N” group having “P” parallel-connected legs includes input inductors $L_{N1}$ to $L_{NP}$, upper switches $S_{U,N1}$ to $S_{U,NP}$ (lower switches $S_{L,N1}$ to $S_{L,NP}$), transformers $T_{N1}$ to $T_{NP}$, and upper diodes $D_{U,N1}$ to $D_{U,NP}$ (lower diodes

$D_{L,N1}$ to $D_{L,NP}$) which are connected to the same output capacitors $C_{OU,N}$ ($C_{OL,N}$).

In summary, "N" should be increased to get higher output voltage, and "P" should be increased to get higher output power. In both cases the interleaving technique can be applied to reduce the size of input filter inductors and input and output capacitors. Therefore, "*N*" and "*P*" could properly be chosen according to given output voltage and power level. This could give flexibility in device selection resulting in optimized design even under harsh design specifications.

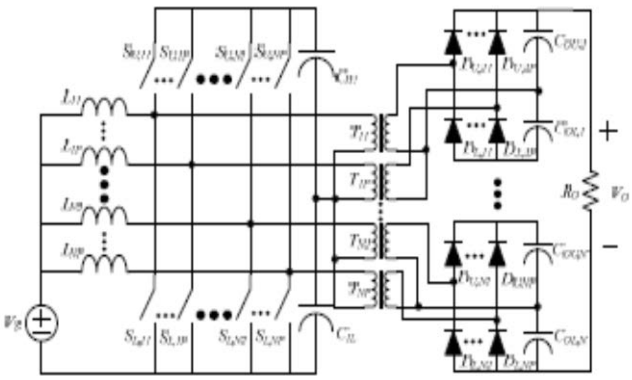


Figure.4 Proposed DC-DC converter.

The proposed converter has the following features:

a. Reduced turn ratio of the transformer and voltage rating of the diodes and capacitors, and therefore especially suitable to high voltage applications.

b. Natural ZVS turn-on of main switches using energy stored in transformer leakage inductor, and ZCS turn-off of rectifier diodes which results in greatly reduced voltage surge associated with the diode reverse recovery.

c. No primary clamping and start-up circuits required due to the proposed interleaved asymmetrical PWM switching.

d. High component availability and easy thermal distribution due to the use of multiple small components instead of single large component, and no dc magnetizing current of the transformer. Flexibility in device selection by proper choice of topology resulting in optimized design under harsh design specification.

## IV. CONTROL SYSTEM

The control system comprises a MPPT algorithm, a dc-bus voltage controller, reference-current generation, and a current controller. The two main tasks of the control system are maximization of the energy transferred from the PV arrays to the grid, and generation of a sinusoidal current with minimum harmonic distortion, also under the presence of grid voltage harmonics.

The proposed inverter utilizes the perturb-and-observe (P&O) algorithm for its wide usage in MPPT owing to its simple structure and requirement of only a few measured parameters. It periodically perturbs (i.e., increment or decrement) the array terminal voltage and compares the PV output power with that of the previous perturbation cycle. If the power was increasing, the perturbation would continue in the same direction in the next cycle; otherwise, the direction would be reversed. The P&O algorithm was implemented in the dc–dc boost converter. The output of the MPPT is the duty-cycle function. As the dc-link voltage $V_{dc}$ was controlled in the dc–ac PWM inverter, the change of the duty cycle changes the voltage at the output of the PV panels. A PID controller was implemented to keep the output voltage of the dc–dc boost converter ($V_{dc}$) constant by comparing $V_{dc}$ and $V_{dc}$ ref and feeding the error into the PID controller, which subsequently tries to reduce the error. In this way, the $V_{dc}$ can be maintained at a constant value and at more than$\sqrt{2}$ of $V_{grid}$ to inject power into the grid.

To deliver energy to the grid, the frequency and phase of the PV inverter must equal those of the grid; therefore, a grid synchronization method is needed. The sine lookup table that generates reference current must be brought into phase with the grid voltage ($V_{grid}$). For this, the grid period and phase must be detected.

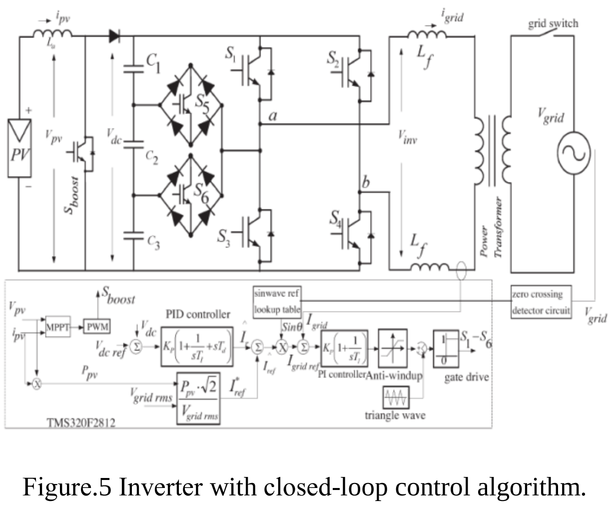



Figure.5 Inverter with closed-loop control algorithm.

The proposed inverter provides an analog zero-crossing detection circuit on one of its input ports where the grid voltage is to be connected. A PI algorithm was used as the feedback current controller for the application. The current injected into the grid, also known as grid current $I_{grid}$, was sensed and fed back to a comparator that compared it with the reference current Igridref . Igridref is the result of the MPPT algorithm.

The error from the comparison process of $I_{grid}$ and Igridref was fed into the PI controller. The output of the PI controller, also known as Vref , goes through an anti windup process before being compared with the triangular wave to produce the switching signals for $S_1$–$S_6$. Eventually, Vref becomes Vref1; Vref2 and Vref3 can be derived from Vref1 by shifting the offset value, which was equivalent to the amplitude of the triangular wave.

## V. SIMULATION RESULTS

### A. Inverter Simulation Model

MATLAB/SIMULINK simulated the proposed configuration before it was physically implemented in a prototype. The PWM switching patterns were generated by comparing three reference signals (Vref1, Vref2, and Vref3) against a triangular carrier signal (see Fig. 6). Subsequently, the comparing process produced PWM switching signals for switches $S_1$–$S_6$.

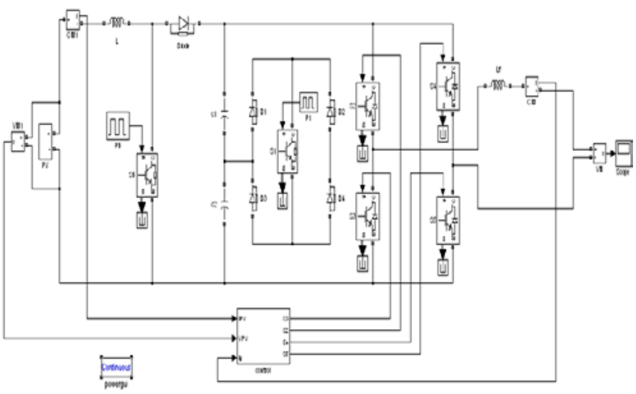


Figure.6 Simulation of seven-level inverter.

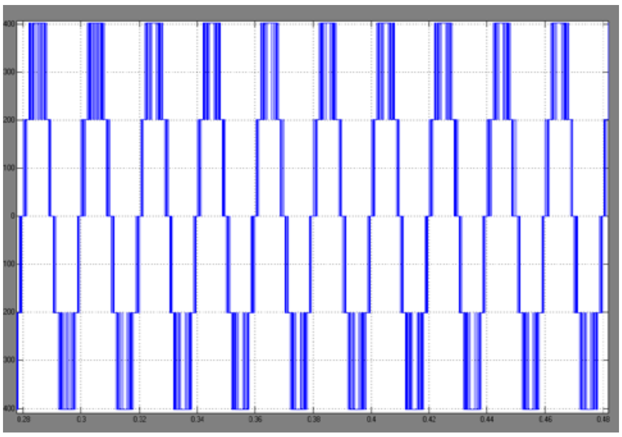


Figure.7 Simulation output for seven-level inverter

One leg of the inverter operated at a high switching rate that was equivalent to the frequency of the carrier signal, while the other leg operated at the rate of the fundamental frequency (i.e., 50 Hz). Switches S5 and S6 also operated at the rate of the carrier signal.

Therefore, operation is recommended to be between Ma = 0.66 and Ma = 1.0. $V_{inv}$ comprises seven voltage levels, namely, $V_{dc}$, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}$, $-2V_{dc}/3$, and $-V_{dc}/3$. The current flowing into the grid was filtered to resemble a pure sine wave in phase with the grid voltage. As $I_{grid}$ is almost a pure sine wave at unity power factor, the total harmonic distortion (THD) can be reduced compared with the THD.

The nine level inverter with motor load is designed to verify the switching operation and other parameter which are connected together. Figure shows the simulation of the nine level inverter with a motor load.

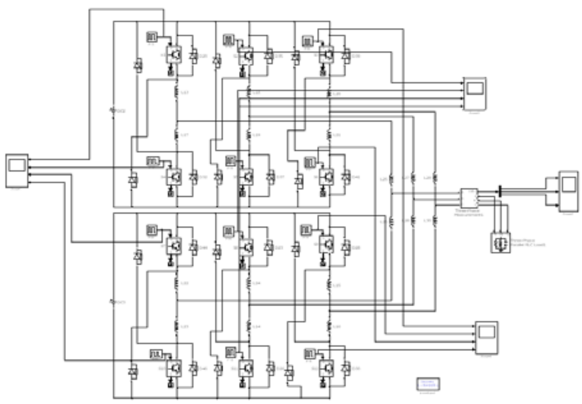
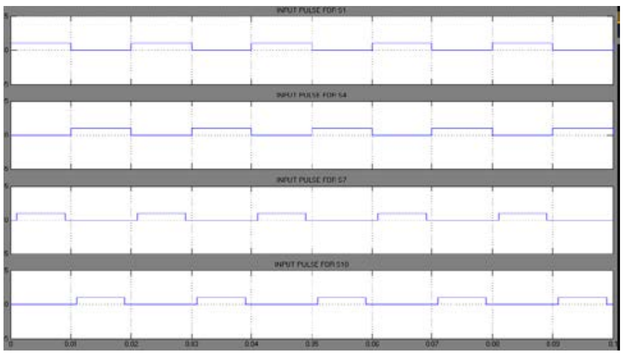


Figure.8 Simulation of nine-level inverter.



Figurte.9 Input pulse waveform of switch (S1, S4, S7, S10)

The nine level output voltage waveform is shown in figure.12.

A nearly sinusoidal wave is obtained by increasing the level of inverter. A PWM is generated by comparing carrier and reference signal. By calculating the modulation index the desired level of output voltage can be obtained.

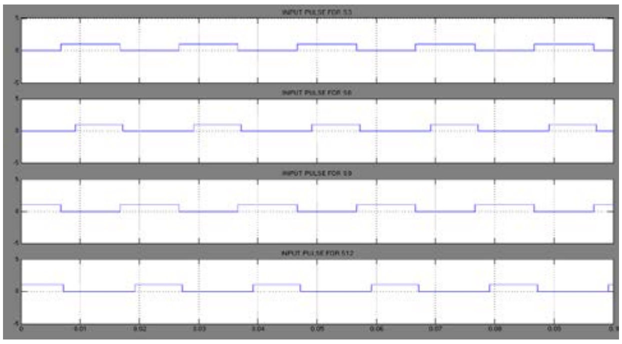


Figure.10 Input Pulse Waveforms of switches (S3, S6, S9, S12)

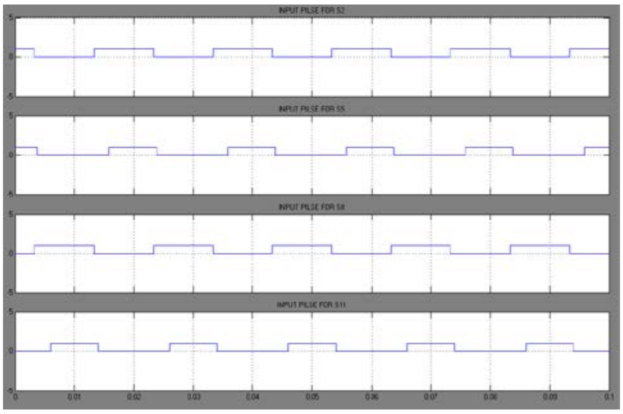


Figure .11 Input Pulse Waveforms of switches (S2, S5, S8, and S11)

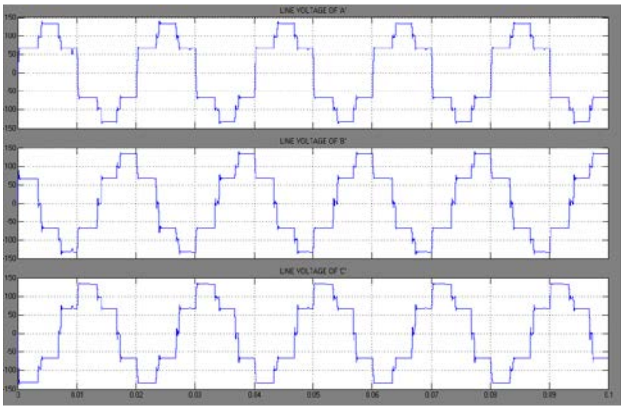


Figure.12 Output Voltage Waveform

For the case of $M_a$ being more than 1.0, the results are not shown because the PV system was designed to operate at the condition of $M_a$ being less than one. This was done by calculating the input current and voltage corresponding to the output voltage and current. Ma was then varied accordingly for the inverter to operate at minimum and maximum power conditions.

## VI. CONCLUSIONS

Multilevel inverters offer improved output waveforms and lower THD. It utilizes three reference signals and a triangular carrier signal to generate PWM switching signals. The behavior of the existing multilevel inverter was analyzed in detail. The less THD in the seven-level inverter compared with that in the five- and three-level inverters is an attractive solution for grid-connected PV inverters. A generalized multiple input dc–dc converter using the BHB cell and voltage double for parallel or series connection to increase the output voltage or the output power is illustrated. The proposed converter has the following features high-component availability and easy thermal distribution, and flexibility in device selection resulting in optimized design. Therefore, the proposed converter is suitable for high-voltage and high-power applications. A way of determining the optimum circuit configuration for given output voltage and power level has been presented.

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