INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

IJARIIT

ISSN: 2454-132X
Impact factor: 6.078
(Volume 6, Issue 4)
Available online at: https://www.ijariit.com

Grid-Connected PV system using Single and Three Phase Neutral Point Clamped ML

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ABSTRACT

In grid-connected photovoltaic systems, a key consideration in the design and operation of inverters is how to achieve high efficiency with power output for various modes of operation. The classical inverters are three level having reduced complexity and robust design, but efficiency is low and harmonics are high. Hence increased power losses. These power quality issues can be over-come by designing a multi-level inverter (MLI). MLIs have a higher number of output voltage levels as compared to the two/three levels in traditional inverters. The advantage of MLIs is its staircase-like output waveform, which resembles more closely to sinusoidal waveform than the traditional inverters; hence THD is very low. In the proposed work a neutral point clamped MLI is designed for grid integration of PV system. The performance analysis have been carried out for both single as well as three phase system to obtain low THD and high efficiency.

Keywords: *Multi Level Inverter (MLI), Neutral Point Clamped Inverter (NPCMLI), Flying Capacitor Inverter (FCMLI), Cascaded H Bridge Inverter (CHBMLI), Grid Tied Solar System (GTSS)*

1. INTRODUCTION

The daily and yearly patterns of solar power are highly variable, and demand requirements also vary extremely [1]. Hence, operating PV system in stand-alone mode is very challenging in terms of reliability aspects. Either energy storage capacity has to be maintained or a grid-connected PV power generation may be the only practical solution [2].

For grid integration, the use of simple two-level conventional inverter produces higher harmonic, which pollutes the utility system. With the arrival of new high-power semiconductor devices (HPED), wide range of power converter structures is designed to meet the needs of the converter systems [3], [4], [5]. In this context the modular multilevel inverters (MMI) topologies and circuits have presented application for Grid tied solar system (GTSS) [6], [7], [8]. The component numbers of MMI grow up linearly with the number of levels, individual modules are identical [9]. However, the MMI requires balanced multiple clamped diode, clamped capacitors or isolated dc sources [10], [11]. Accordingly, its application is not upfront, especially in GTSS. From the MMI side, challenges are nowadays focused on increasing the inverter efficiency [12], [13], [14], refining the Power Quality (PQ) and reducing THD, also losses decreasing in conduction and switching [15], [16]. However losses are proportional to the number of switching states [17], [18].

A good survey on MMI converter topologies is presented in literature [19], [20]. Three main group of MMI are classified as: (1) cascaded H-bridge (CHB), (2) diode clamped, and (3) flying capacitor/ capacitor clamped [4]. The most preferred MMI for GTSS is neutral point clamped (NPC), due to its modular structure, absence of energy storing elements, and the ability to isolate faults [5–8]. Practical multilevel inverters have typically five or more output voltage levels. Five-level MMIs are most widely used as they offer a reasonable trade-off between performance and economics. Therefore, in this paper, we have focused on five-level MMI.

In the proposed work a neutral point clamped MMI (NPC-MMI) is designed for grid integration of PV system. The performance analysis have been carried out for both single as well as three phase system to obtain low THD and high efficiency.

2. 5-LEVEL NPC-MMI

Topologies which are proposed / presented with an exclusive claim of obtaining more replica of sine wave in terms of stair case like waveform is called as multi-level inverters. MMC is one such converter topology designed specifically to meet grid integration requirement of renewable energy.

The NPC converter provides multiple voltages through connecting the phases to a series capacitors banks. The concept can be increased to number of levels by increasing the number of capacitors. Earlier this methods was only limited to three levels in which two capacitors connected across the dc bus resulting in one additional level that is the neutral point, so the terminology Neutral Point Clamped (NPC) MMI was introduced in the theories.

The cnceptual architecture for single phase system is presented in figure 1. Simulation model of 5-level NPC is presented infigure 2 with its output voltage waveform (figure 3), and simulation model of 3-phase 5-level NPC is presented in figure 4 with its output voltage waveform in figure 5.

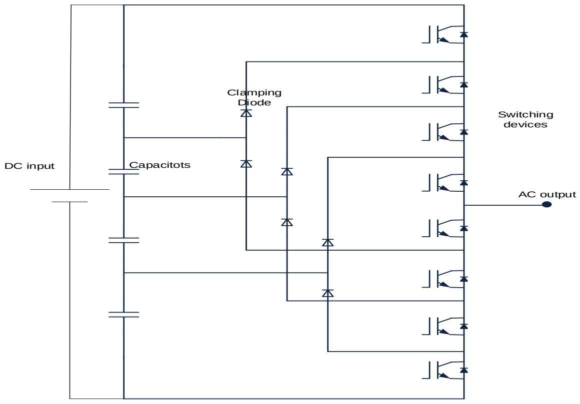

Fig. 1: Conceptual architecture of 5-level 1-phase NPC inverter

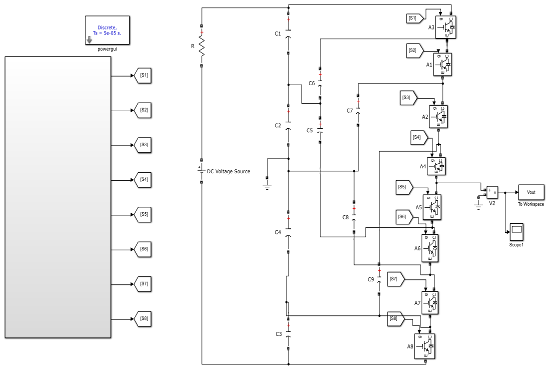

Fig. 2: Simulation model of 5-level 1-phase NPC

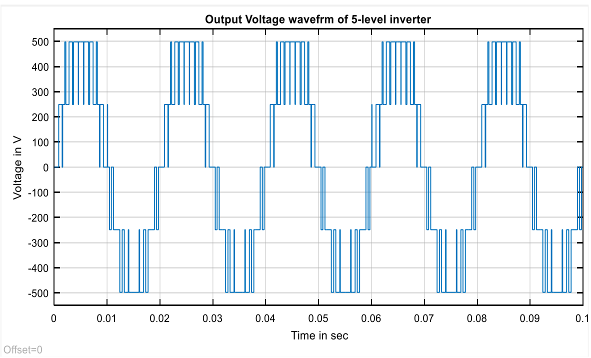

Fig. 3: Output voltage waveform for 5-level 1-phase NPC

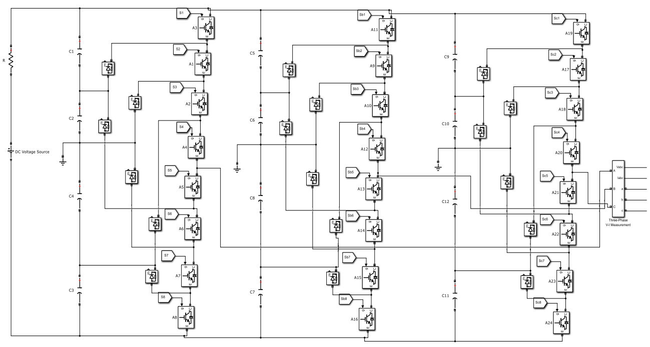

Fig. 4: Simulation model for 5-level 3-phase NPC

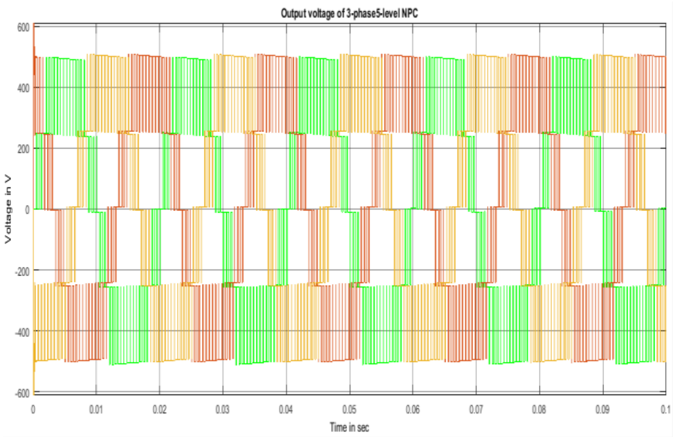

Fig. 5: Output voltage waveform of 5-level 3-phase NPC

3. PROPOSED WORK

MMIs have a higher number of output voltage levels as compared to the two/three levels in traditional inverters. To carry out comprehensive literature survey on various power quality issues associated with grid-connected operation of PV system has been carried out.

To design a Grid connected solar system for radial distribution system, which is capable of injecting active power into the grid with its inherent advantages to mitigate the following Power Quality Issues:

- To suppress load current harmonic;
- To compensate load unbalances;
- To compensate utility voltage unbalances;
- To suppress utility voltage harmonic;
- To regulate the output voltage;

The advantage of MLIs is its staircase-like output waveform, which resembles more closely to sinusoidal waveform than the traditional inverters; hence THD is very low. In the proposed work a neutral point clamped MMI is designed for grid integration of PV system. The performance analysis have been carried out for both single as well as three phase system to obtain low THD and high efficiency

4. SIMULATION RESULTS

A PV system is designed, 40 parallel strings and 8 Series-connected modules. The rated capacity of the PV panel is 100 KW. To obtain the constant DC output from Solar system a DC-DC boost converter is designed with switching frequency 7 Khz. The output voltage of the boost converter is approx. 1000 V. A matlab simulink model of the solar panel with 100KW (Figure 6) rating has been developed whose DC output is regulated using DC-DC boost converter.

The integration of PV system with the grid a DC/AC inverter is simulated. The design of a DC/AC converter is carried out through 5 level inverter is designed whose pulse width modulation technique is designed using level shifted carrier modulation technique. One side of the converter is connected to the synchronized AC output of the PV system and other side to the grid. A low pass filter is connected at the output of the NPC-MLI to filter out the harmonic and to obtain the sinusoidal waveforms. The system is synchronized with the grid using PI controller and Phase Lock Loop. While employing NPC the DC battery of MMI is replaced by solar, and the DC output of PV pane is regulated using Dc-Dc boost converter whose conceptual architecture is given in figure 7

The inverter is designed for both single and three phase system using 5-level Neutral Point Clamped Multilevel Inverter (NPC-MLI), which is synchronized using PLL and PI controller. The system has been analyzed for two scenarios;

a) For constant solar irradiations for 1000w/m^{2}.
b) For Variable solar irradiations for 1000w/m^{2} to 600 w/m^{2}.

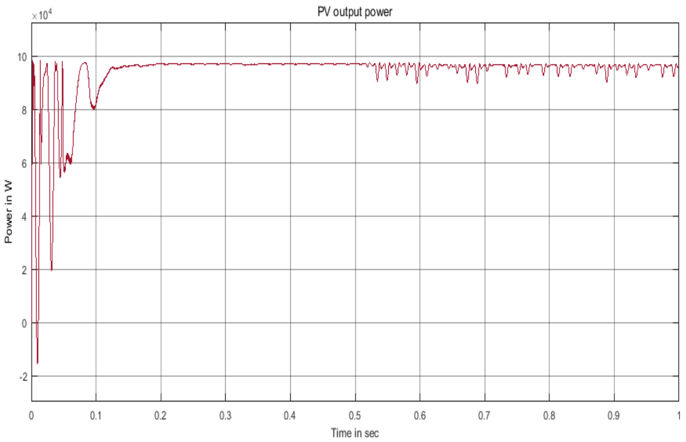

Fig. 6: Power Output of PV

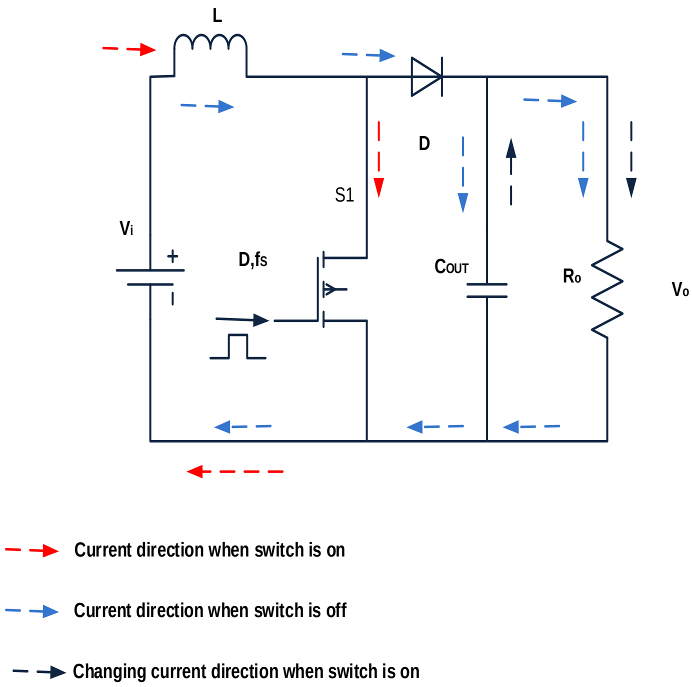

Fig. 7: Schematic of boost converter

4.1 Simulation results for single-phase system

The complete simulation model for GTSS single-phase 5-level system is presented in figure 8. The PV module has voltage of 600V, which is boosted to 1000V using boost converter. The output of PV-boost converter is connected across the single-phase 5-level module of NPC. NPC produces a stepped waveform, which is converted into sinusoidal using a single-phase RL filter element whose parameters are presented in table 1. The performance analysis of the 1-phase system is carried out under constant and variable irradiance. The DC bus voltages under constant and variable irradiance are given in figure 11 and 12. The output voltage and current waveform of Simulation model for GTSS single phase 5-level-NPC system is presented in figure 9 under the constant irradiance of 1000w/m^{2}. Figure 10 presents the output voltage and current waveform of Simulation model for GTSS single phase 5-level-NPC system under the condition of variable irradiance. At t=0.6 sec irradiance is varied from 1000 to 600 w/m2.

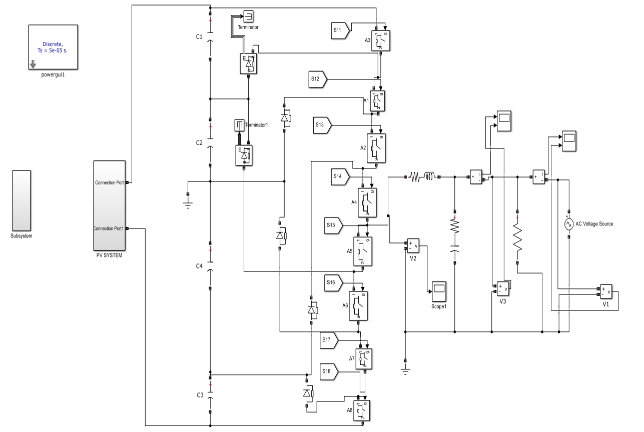

Fig. 8: Simulation model for GTSS single phase 5-level-NPC system

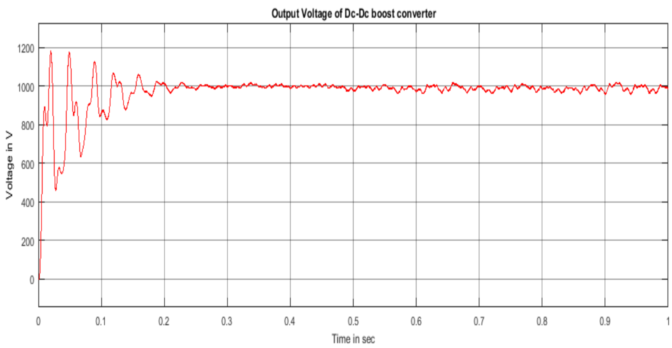

Fig. 9: Output of DC-DC boost converter for constant irradiance

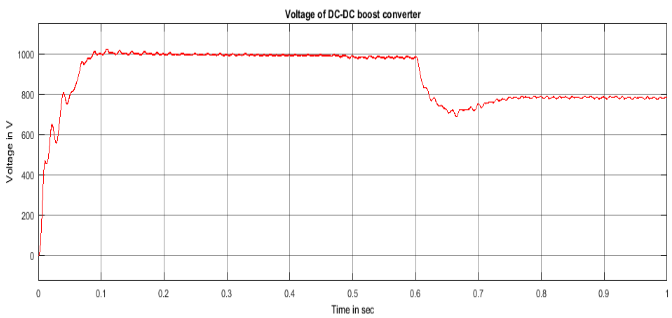

Fig. 10: Output of DC-DC boost converter for constant irradiance

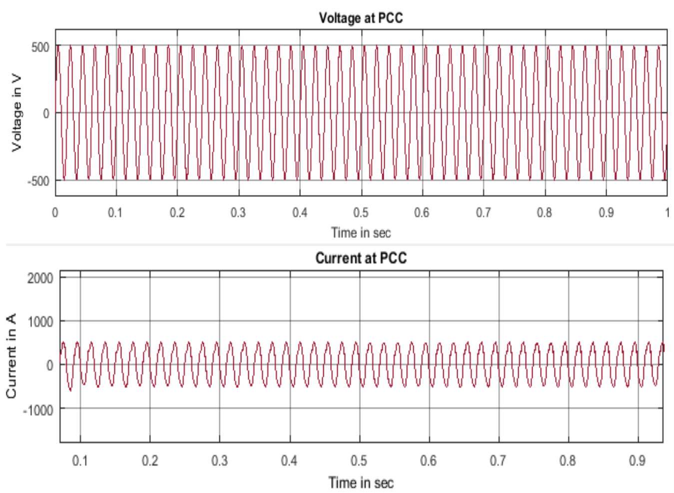

Fig. 11: Output Voltage and current waveform of Simulation model for GTSS single phase 5-level-NPC system under constant irradiance

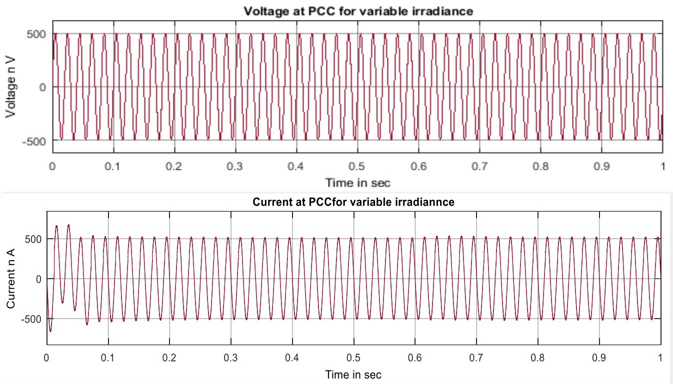

Fig. 12: Output Voltage and current waveform of Simulation model for GTSS single phase 5-level-NPC system under variable irradiance.

4.2 Simulation results for three phase system

The Simulation model for GTSS 5-level 3-phase NPC is presented in figure 13. The output voltage of PV module is connected to the DC-boost converter whose output is connected to the input of the three phase NPC. The subsystem of figure 13 comprises of three phase 5-level NPC as previously mentioned in figure 4. NPC yield stepped waveform, which is converted, into fine sine-wave using filter elements as mentioned in table 1. A linear three-phase RLC load is connected with 100 KW active power and 100 KVAr inductive and capacitive reactive power. The output voltage and current waveform of Simulation model for GTSS 3-phase 5-level-NPC system is presented in figure 14 under the constant irradiance of 1000w/m2. Figure 15 presents the output voltage and current waveform of Simulation model for GTSS 3-phase 5-level-NPC system under the condition of variable irradiance. At t=0.6 sec irradiance is varied from 1000 to 600 w/m2.

Table 1: Parameters selection

Parameters	Values
Effective nominal voltage of the utility (RMS) V_S	415 V
Nominal utility grid frequency f_S	50Hz
Dc-link capacitor	1200mF
For single phase system	
Inductance of filter	1.5mH
Capacitances of the parallel filters	200mF
Resistances of the converter filter	1 ohms
For three phase system	
Inductance of filter	10mH
Capacitances of the parallel filters	15μF
Resistances of the converter filter	0.1 ohms

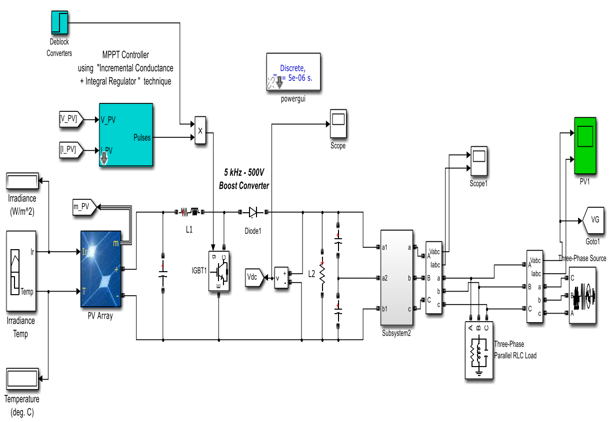

Fig. 13: Simulation Model of proposed topology for three phase system

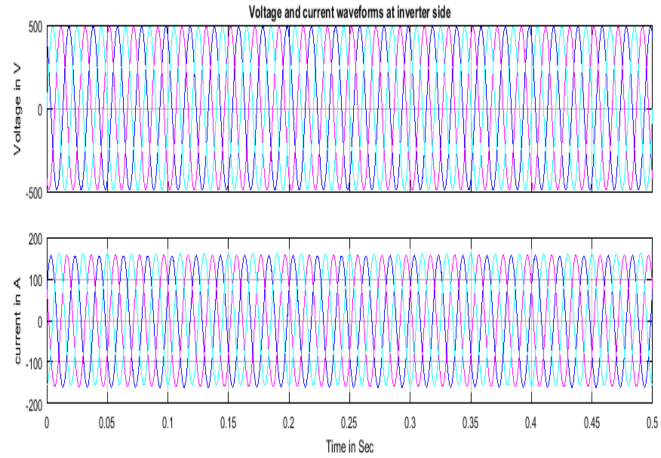

Fig. 14: Output Voltage and current waveform of Simulation model for GTSS 3-phase 5-level-NPC system under constant irradiance

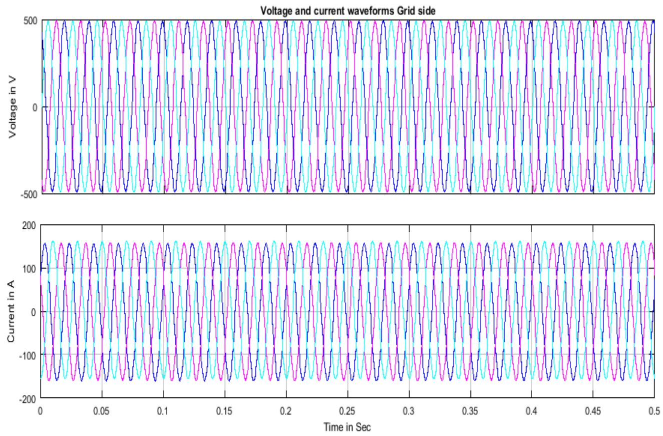

Fig. 15: Output Voltage and current waveform of Simulation model for GTSS 3-phase 5-level-NPC system under variable irradiance

5. RESULT DISCUSSION

This paper presents a 5-level NPC-MMI for grid integration of single and three phase GTSS. To account for intermittency of solar power proposed NPC-MMI converter is analysed under constant and variable irradiance and from the voltage and current waveforms at PCC obtained are constant and sinusoidal hence the proposed converter efficiently connect the PV to the grid. To account for switching losses and harmonics THD analysis of the system is presented in table 2, which shows that the harmonics for single as well as three phase system harmonic content are very low.

Table 2: Comparison of THD for unbalanced linear loading for single phase and three-phase system

THD analysis of	Single phase	Three phase
Efficiency	98%	98%
Load current	1.6	1.6
Inverter output voltage	10	10.8

6. CONCLUSION

The proposed 5-level NPC-MMI can be a good solution to feed solar power to the grid. A 5-level inverter was considered and controlled by using sinusoidal carrier wave PWM technique, requiring only 8 switches per phase. Simulation studies have been performed on three as well as single-phase system under the condition of constant and variable irradiance. The obtained simulation results have shown a 10% voltage THD and the load current harmonics are 1.6 % both minimum number of switches and less number of switching states with a simplified inverter control scheme The low-frequency switching reduces the inverter power losses leading to a better efficiency of the proposed topology.

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