Mathematical Modelling and Assessment of Multilevel Inverters for Grid Connected Solar PV Applications

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Abstract:- This paper defines a circuit-based simulation model for a PV cell which allows to estimate the electrical behavior of the cell with respect to changes on environmental parameter of temperature and irradiance. In this paper, an accurate PV module electrical model is presented which is based on the Shockley diode equation. The general model was developed on Matlab scrip file, and irradiance and temperature were taken as variable parameters. The I-V characteristics were accepted as output. The modern topology of multilevel converters were investigated in this paper, which were proved suitable for use in high power photovoltaic applications and along with it, put the focus on achieving lower total harmonic distortion and better efficiency. Several advantages were offered by multilevel converters compared to conventional types of converters. High quality output is provided by multilevel converters while using the low switching frequency. The switching losses, size of semiconductor switches and harmonic filters were affected by it. Various topologies of multilevel converter for high power photovoltaic applications were investigated in this research and their THD, efficiency, number of required semiconductors and other important characteristics were compared. All topologies were simulated using MATLAB/Simulink in the same operating conditions. Eventually, the more suitable multilevel topology was selected with respect to the simulation results.

Keywords:- Photovoltaic; Multilevel converter; qualitative study; high power application

I. INTRODUCTION

In recent years, the tendency to generate electricity from renewable energy sources is increasing. At the same time, the power rating of photovoltaic power plants, wind turbines, and other renewable equipment increased rapidly. In this context, multilevel converters are a timely and interesting challenge in the field of power electronics due to the high demand for medium power converters and high-power converters. New multilevel topologies that can provide lower THD and higher efficiency, especially at high power levels, are areas of interest for today's researchers; new ideas and research have been provided and researched by researchers.

Many PV modules that form strings and sub-arrays that are connected in series and in parallel and that are coupled to power the inverter are made up of conventional PV plants. The inverter is then connected to a medium voltage (MV) electrical grid using a low frequency (LF) transformer. Since price analysis has shown that inverter costs per watt can be reduced by increasing the rated power of the inverter, it is the industry trend to design and use higher inverter ratings. Therefore, inverter with rated power markets up to several megawatts are currently being offered on the market. The designer also recommends using a high nominal voltage for both the DC and AC side of the inverter. This reduces power loss and wiring costs.

The choice of these designs is important for reducing the generator connection box, reducing the cross section cable, reducing wiring at the DC end, and maintaining the balance of system cost [9, 5]. Therefore, the multilevel structure attracts the topology of mid-voltage grid integration of mega-watt scale PV inverter.

Many different multilevel topologies for PV applications are proposed by researchers. Cascade H bridge, neutral point clamp converter (NPC), capacitor clamp, Z source, quasi Z source, and Y connected hybrid cascade are important topologies that are proposed for use in PV modules.

It is possible to investigate these topologies from different perspectives during the study. In this study, concerns are raised about finding optimal structures for PV modules, so the study consists of two stages. We deal with quantitative and qualitative research respectively. The output specifications of converters analyzed using Matlab / Simulink are investigated in quantitative surveys.

The key parameters to be evaluated in the study are THD, line voltage and current, loss and efficiency. An important characteristic in implementing the converter is verified by qualitative research. However, modularity, converter reliability, functionality, scalability, qualitative research.

II. MULTILEVEL TOPOLOGY REVIEW

In this section, a brief review of the most common topologies is given. The topologies considered in this paper are shown in Fig.1-6.

A. Diode-Clamped Topology (NPC)

According to the record, the cascaded converter was the first multi-level inverter designed in 1975. This inverter was later converted to a diode-clamped multilevel inverter.

This topology is shown in Figure 1. The output of the inverter (each of the three phases) is connected to a common DC bus voltage divided into three levels by two DC bus capacitors.

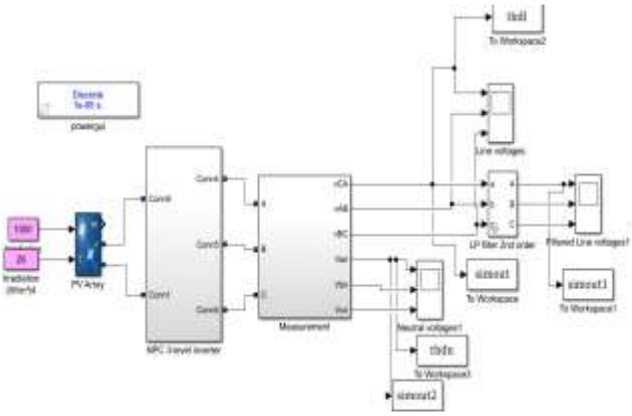

Fig.1: Three level NPC, PV source model in Matlab/Simulink.

High cost and different limitations for high voltage level applications arise as a result of multiple clamping diodes. In addition, special control is necessary to balance capacitor voltage. As a result, most of the practical applications of diode-clamped multi-level inverters are 5 levels.

B. Capacitor Clamped Topology

The flying capacitor inverter or capacitor clamp multi-level inverter shown in FIG. 2 is another type of multi-level inverter. It has a topology similar to the NPCMLI topology.

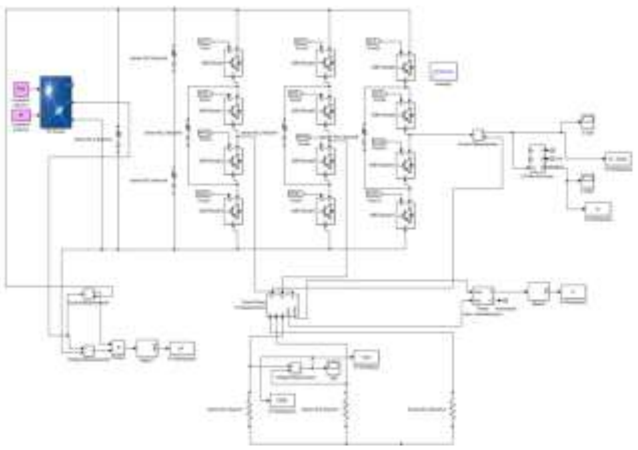

Fig.2: Three level capacitor clamped, PV source model in Matlab/simulink

However; it uses capacitors instead of using clamping diodes to keep the voltages to the favored values.

C. Cascade H-Bridge Topology

Cascaded Multi-Cell Inverter (CMCI) differs from NPCMLI and CCMLI in several respects. This has been proposed in various studies, especially how to construct multilevel voltage waveforms.

Step waveforms are created by a cascaded H-bridge topology using a cascaded full-bridge inverter with separate DC sources as shown in Figure 3.

DC sources with different voltage values can be used depending on the cascade topology and high resolution multi-level waveforms can be reached even when the number of parts is quite small.

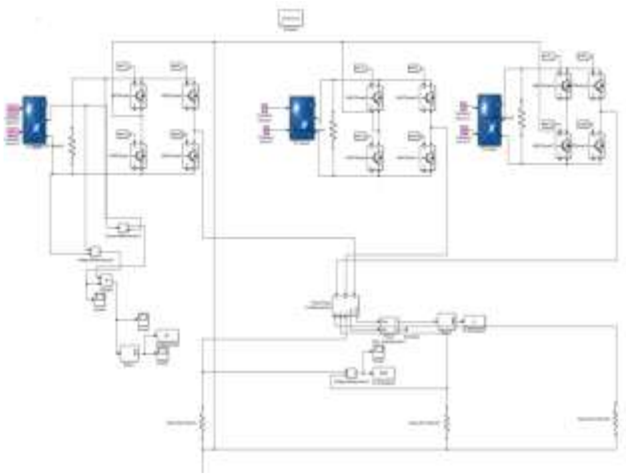

Fig.3: Three level cascaded PV source model in Matlab/simulink

D. Z-source Topology

For the first time, an impedance source or a Z source inverter was proposed. The common inverter voltage boost function is provided by Z - source inverters and is distinguished from other types of inverters via these inverters. Conventional inverters are always buck converters. Conventional inverters generate lower output voltage than DC input voltage. In addition, low power switch and high-power switch cannot conduct together. In such a case, the DC power supply is short-circuited. Therefore, a dead zone is intentionally provided between switch-on and switch-off of complementary power switches of the same leg. As a result, this dead zone causes some deformation of the output current. The Z-source inverter overcomes these limitations.

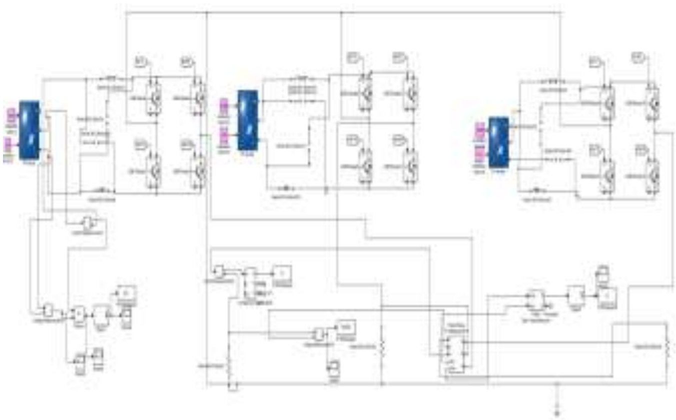

Fig.4: Three level Z-source PV connected inverter in Matlab/simulink

E. Quasi Impedance Source or QZSI Topology

The QZSI topology proposed in [13, 17] is the previous version of the original Z-source inverter. Therefore, all the advantages of ZSI are included. The Z-source inverter or impedance source inverter has a high voltage weak point across the capacitor, discontinuous input (DC) current during boost mode, and higher stress on the power switch. QZSI overcomes these limitations.

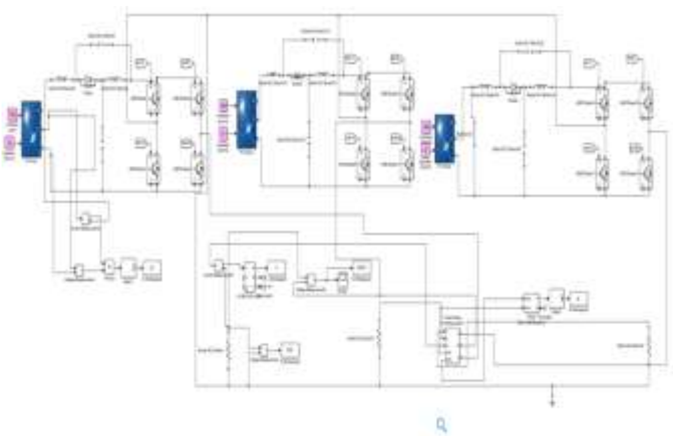

Fig.5: Three-level Quasi Z source PV connected model in Matlab/simulink

The main advantage of QZSI is to reduce the voltage across capacitor C2, draw continuous current from the DC supply, reduce the number of elements, and thus apply low voltage stress to the power switch to ensure high reliability.

F. Y-Connected Hybrid Cascaded Topology

This type of topology is obtained to reduce the number of distinct DC sources by replacing the conventional two-level legs in the CMI's H-bridge module with capacitor-clamped multilevel legs or diode clamps.

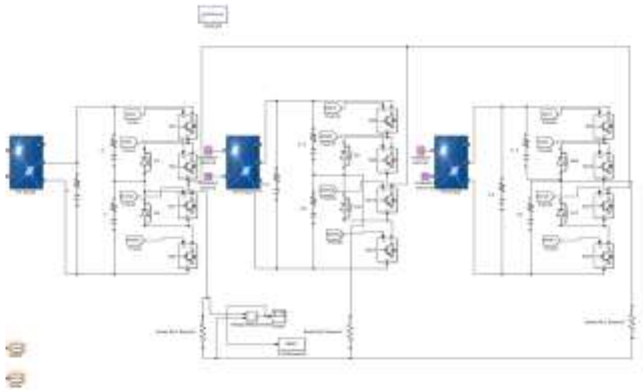

Fig.6: Three level Hybrid Cascade PV source inverter in Matlab/simulink

As the output of each module of this topology, 3 levels of voltage can be given. Cascaded NPC-based H bridge modules exist in each phase. By taking a hybrid topology, you can reduce the number of switching devices in the conversion system.

III. RESULTS DISCUSSION

A. Quantitative study

In this section, we will investigate the most common topology of multilevel converters connected to a PV array with six case studies. The most suitable inverter configuration is obtained by comparing the output waveform and its characteristics with other outputs. All scenarios are used to collect output using the same PV array source and are loaded in the same situation. On the other hand, all switches are modeled as IGBTs. The PV array module is known as Canada's Solar Road CS5C90M. It has 40 parallel strings and 10 string connection modules. Three-phase resistive load with temperature ≈ 25 ° C, irradiation rate 1000, R = 10.

a) Three-Level NPC PV Source Inverter

Figure 1 shows a 3 level NPC PV source inverter model taken from Matlab. Inverter is connected to predefined PV array and load. The voltage waveform of this simulation is shown in FIG. 7.

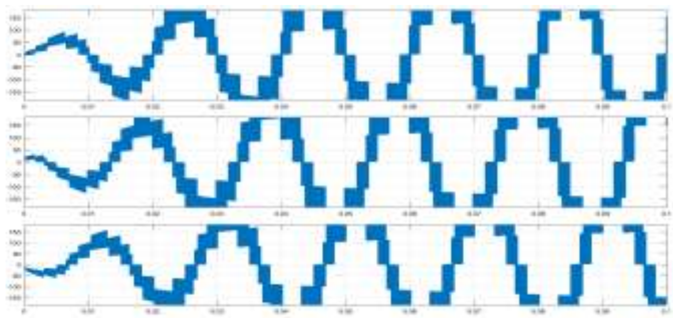

Fig.7: Three level NPC inverter voltage

The total harmonic distortion (THD) value of each waveform is calculated by Matlab / Simulink. Thus, in this case study, the value of the capacitor is 2200 µF.

b) Capacitor Clamped Three-Level PV Source Inverter

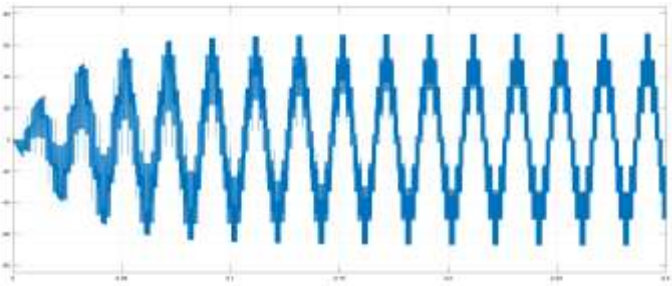

Fig.8: Three level Capacitor clamped voltage

A 3-level capacitor clamp PV source inverter model is shown in Fig. The value of the capacitor is 1000 µF. The voltage waveform of this simulation is shown in FIG. 8.

c) Three level Cascaded PV source inverter

Matlab's three-level cascade PV source inverter model shown in Figure 3 and its voltage waveform are shown in Figure 9.

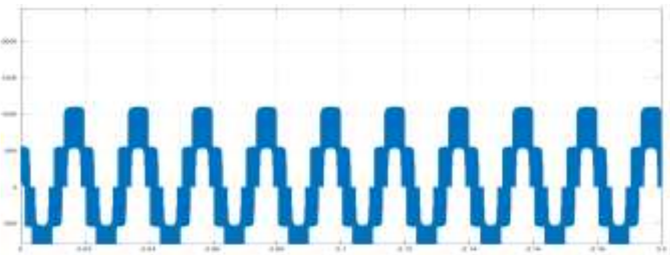

Fig.9: Three level Cascaded inverter voltage

d) Three-level Z-source PV Connected Inverter

A 3-level Z - source PV connected inverter is shown in FIG. 4, and its output waveform is shown in FIG. The inductance value is the same as 0.5 mH, but the capacitor value is 0.4 mF.

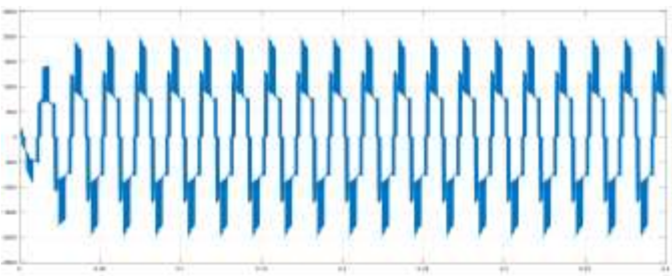

Fig.10: Three level Z-source inverter voltage

e) Three level Quasi-Z source PV Source inverter

The Quasi-Z source model is prepared as shown in Figure 5. The output waveform is shown in Fig. The value of the inductance is the same as the 3-level Z power PV connected inverter, but it is the same as 0.5 mH, but the value of the capacitor is also the same.

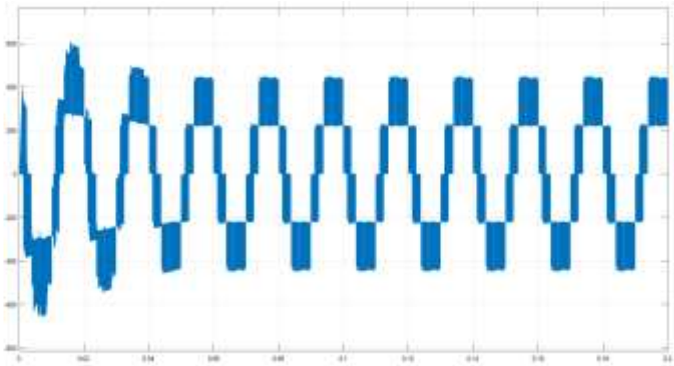

Fig.11: Voltage waveform of three level Quasi-Z inverter

f) Y-Connected Three-Level Hybrid Cascaded PV Source Inverter

A three-level hybrid cascade NPC PV source inverter model is shown in FIG. 6, and its voltage waveform is shown in FIG. The value of the capacitor is assumed to be 2200 uF. Typically, a hybrid topology is used to generate a high-level output voltage. This concept was introduced by presenting 17 levels CMI which is the most suitable for PV power generation application. The low THD rate of this topology is confirmed by the simulation result of this topology.

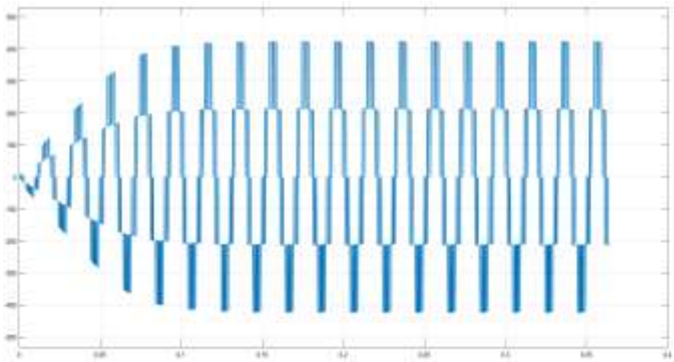

Fig.12: Voltage waveforms of three level hybrid model

B. Qualitative Study

This system is analyzed by dividing more research into three cases.

Case 1 - The grid system is connected to the thin film PV system using six different inverter topologies.

Case 2 - The grid system is connected to a polysilicon PV system using six types of inverter topology.

Case 3 - The grid system is connected to monosilicon PV system using six types of inverter topology.

Quantitative results of case studies are shown in Table 1. The NPC topology uses many clamp diodes in the NPC topology and is expensive due to different problems with high voltage level applications. Therefore, the diode-clamped multi-level inverter is divided into five stages according to practical use. [18].

The second inverter is a capacitor clamp topology with a topology very similar to the first inverter. Using a clamping capacitor instead of a clamping diode is a big difference and since the capacitor does not block the reverse voltage, the number of switching combinations increases.

Topology and NPC clamped with capacitors are single input inverters, but other types of topologies are more modular than NPCs and therefore more reliable.

Since quasi-Z-source inverters are capable of solving Z-source topology problems such as high stress on the power switch and high voltage across the capacitors, they are expressed as previous versions of the Z-source inverter, THD.

TABLE1. THD OF DIFFERENT TOPOLOGIES

R	Converter Topology	THD %		
		Thin Film	Poly Silicon	Mono Silicon
1.	NPC	35.88%	36.24%	36.06%
2.	Capacitor clamped	43.83%	40.75%	41.09%
3.	Cascaded	67.56%	47.21%	55.68%
4.	Hybrid	36.39%	42.79%	41.64%
5.	Z-source	48.92%	42.09%	42.16%
6.	Quasi Z source	41.52%	42.18%	40.54%

IV. CONCLUSION

Multilevel converters are more economical than traditional types according to the price analysis of converters for medium and high-power applications. In this study, various multilevel converter topologies were investigated and compared to compare optimal topologies proved suitable for use in PV applications. Quantitative and qualitative studies were conducted to investigate the topology. The key output parameters of the proposed multilevel topology were quantitatively evaluated in the same operating environment using Matlab / Simulink. Also, in order to investigate the advantages and disadvantages of each topology, qualitative analysis which cannot be considered in simulation is carried out. The results demonstrate that the neutral point clamp converter (NPC) shows superior performance compared to other types.

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