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Replaced Capacitor Based 6-Boosting Factor, 13-level Inverter Topology with Variable Load Condition and Low Cost Function

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***Abstract*— Multilevel inverters (MLIs) have been widely accepted as a potential solution for high-efficiency electric power-electronic conversion systems by both research and industry community. The inherent features of MLIs like reduced dv/dt, high-quality output waveform, lower switching frequency, etc., are the key reasons for the usage of MLIs in a variety of fields including motor drives, renewable energy sources integration, locomotives, to name a few. The basic MLIs are cascaded H-bridge (CHB), neutral point clamped, and flying capacitor inverters. For a higher number of voltage levels, despite many variants of these basic MLIs are available i.e., symmetric CHB (SCHB), asymmetric CHB (ACHB), hybrid NPC with CHB, etc., overall the structure requires a huge number of components and increases the control complexity. This thesis describes two improved 13-level inverters based on switched-capacitor. Compared with their original structure which has been published recently, one less high-voltage capacitor is required in the proposed inverters and the blocking voltage of their inverting half-bridge is reduced by half. In addition, the new inverters inherit various advantages of the original structure, such as a high boost factor of 6, self-balanced capacitor voltages and reduced voltage ripples. Circuit description, operation principle, hybrid PWM modulation and capacitor voltage ripples are analyzed. And the feasibility of the proposed inverters is finally verified by experimental results.**

Keywords*— *Pulse Width Modulation (PWM), Matlab, ACHB, Multi Level Inverter (MLI), Cascaded H Bridge (CHB) and Power Quality

I. Introduction

The continuous increase in power demand leads to the attraction of alternative green energy sources. Photo Voltaic (PV) power generation is one of the most promising renewable green energy technologies used as an alternative source of power. The integration of PV to the load requires the support of power electronic converter for performance enhancement. The complications in power electronics converters are rapidly evolving, as their applications are extensively used with the stand-alone/grid-based systems[1].The electric power system in a sustainable future will augment the centralized and large grid dependent system of today with distributed smart grid based energy generation system. To achieve this world is increasingly adopting renewable energy sources e.g. solar, wind, tidal and fuel cells [2].

The power electronics is essential for harnessing energy from solar, wind and other green energy sources. As the power developed by photovoltaic (PV) system is DC, to convert it into AC power converters are required. Similarly, to convert wind energy a high efficient generator is required. Also power converters helps to improve waveform in terms of reduce harmonics and good power factor [3].

The advancement of innovation throughout the years, particularly the advance of power electronics applications, has achieved numerous specialized comforts and prudent benefits; however it has at the same time made new difficulties for power system operation concern [6]. Driven by testing ecological requirements, advancement of the energy market and privatization of the power supply industry, power systems are increasingly working at their maximal execution limits - and every now and again past them - to expand resource use. To dodge genuine utilitarian issues from happening under these conditions, the system's safe and dependable activity should be kept up with respect to different parts of power system task. One of the principle themes of unique concern is the part of power quality which manages, among others, voltage characteristics, current characteristics and in particular control and forecast of harmonics. Dugan et al. distributed a reading material in 1995 featuring this angle [8].

A. Power Quality: Power quality for the most part manages the interaction among the clients and the utility or it can be likewise said that it gives an interaction between the power system and the separate load. A definitive objective of power system is the supply of electric energy to its clients. Over the most recent 50 years or somewhere in the vicinity, as a result of the broad development of enterprises power request has massively expanded which has prompted establishment of numerous power generation and distribution grid. The interest for expansive measure of power for modern and local utilize expanded the weight on the generation. Electrical utilities working today are functioning as a subsystem of a vast utility network that are entwined with a specific end goal to shape an unpredictable grid. Every one of these factors have put the power system under the necessity of a power quality [9] [10].

II. LITERATURE REVIEW

Y. Ye et al. [1], a 13-level inverter dependent on exchanged capaci-pinnacle strategy is proposed in this article. It comprises of ten semiconductors, four diodes, and four capacitors with self-adjusted voltages. The ten semiconductors structure two H-extensions and one half-span bringing about straightforward construction and simple plan of entryway drivers. With a cross breed of level-moved and stage moved pulse width regulation calculation, voltage waves of capacitors and low consonant parts of result voltage are stifled at the same time. Contrasted and the current arrangements, the proposed 13-level inverter has an easier construction and the lower cost per level. Trial results show that the proposed inverter enjoys the benefits of high helping factor, self-adjusted capacitor voltages, low sounds, and high productivity, and the most extreme effectiveness is up to 97.2%.

N. Sandeep et al. [2], a new helping staggered inverter with exchanged capacitors is introduced in this brief. By utilizing 13 switches, two diodes, and three capacitors, a 13-level voltage waveform is integrated. The capacitor voltages are self-adjusted as they are associated in corresponding with the info voltage hotspot for quite some time in each key cycle. A straightforward rationale entryway based heartbeat width regulation plan guaranteeing power balance among the capacitors is introduced. Trial results got from a research center model are introduced for approving the activity and capacity of the proposed inverter to help the contribution by an element of six. At long last, a point by point examination with existing geographies demonstrates the expense viability, an easier design requiring lesser space and impression space of the proposed geography.

M. J. Sathik et al. [3], in this concise, another cross-associated minimized exchanged capacitor (C 3 SC) cell is presented for staggered inverter applications. The proposed CCS cell utilizes four switches and two diodes for interconnecting the information dc source and drifting capacitors (FCs). A nine-level inverter is determined with the proposed C 2 SC cell requiring just ten switches and two FCs. The proposed C 3 SC cell-based MLI is self-adjusting and has a voltage gain of two. Every one of the switches of the proposed geography have a most extreme hindering voltage inside the info dc voltage (v in) esteem. The working guideline is nitty gritty, and a straightforward rationale door based entryway beat age conspire is introduced. Itemized recreations and exploratory outcomes acquired from a 850 W model with a few experiments are introduced to approve the activity of the proposed geography. At last, a definite similar appraisal is performed with other ongoing SCMLIs to exhibit the benefits and predominance of the proposed geography.

J. Zeng et al. [4], this article proposed a solitary source staggered inverter (MLI) in light of the clever K-type unit (KTU). The 13-level geography with two KTUs and 1.5 voltage gain is first presented, and its activity modes at various result levels are portrayed in this article. The two capacitors in series association with each KTU can get self-voltage funds owed to their symmetric activity in a cycle, lessening the intricacy of control contrasted and customary MLIs. The investigations of self-equilibrium and capacitance estimation are given exhaustively. A short time later, the single-source summed up structure outfitted with more KTUs is introduced for expanding yield levels. The result levels are essentially expanded with extra KTUs, and the voltage gain ascends also. Additionally, through the relative review against other MLI geographies proposed lately, the benefits of the proposed KTU geography are shown in the perspectives for diminished parts, self-balance, voltage stress, and generally cost. At long last, the 13-level recreation and 1-kVA exploratory model with principal recurrence balance (FFM) are executed to check the achievability and transient execution of the proposed geography.

Y. Ye et al. [5], a 13-level inverter dependent on exchanged capaci-pinnacle strategy is proposed in this article. It comprises of ten semiconductors, four diodes, and four capacitors with self-adjusted voltages. The ten semiconductors structure two H-extensions and one half-span bringing about basic construction and simple plan of door drivers. With a half and half of level-moved and stage moved pulsewidth balance calculation, voltage waves of capacitors and low symphonious parts of result voltage are stifled at the same time. Contrasted and the current arrangements, the proposed 13-level inverter has a more straightforward construction and the lower cost per level. Test results exhibit that the proposed inverter enjoys the benefits of high supporting element, self-adjusted capacitor voltages, low music, and high effectiveness, and the greatest productivity is up to 97.2%.

III. PROBOLEM FORMULATION

Most of the power supplies practice two-stage converter for boost operation. But, they have serious problems like size, losses and cost that reduce the efficiency of the converter and the whole system. With the intention of reducing the component count, size and cost, single-stage resonant converter has been developed. However, it has high voltage stress in switches by the Discontinuous Conduction Mode (DCM) boost operation and Electromagnetic Induction (EMI) problem. To improve the power quality, harmonics can be harvested at device, building and distribution levels and then injected back to the system to repair distorted wave shapes. Harmonics are created by nonlinear loads and switching devices that are usually 40% of utility load. A normal two-level inverter gets its limitation when handling high voltage and power thus, producing a higher-order harmonics. This limitation is becoming the main drawback, when using the two-level inverter. A multilevel inverter reduces the limitation of the two-level inverter. Tremendous 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. At the case of low DC voltage we have to required step up buck transformer for connecting with load or connected with grid. So, it will increase the bulkiness of the system. So this works suitable for transformer less structure because of high boosting factor.

IV. METHODOLOGY

Electrical energy and potable water are the essential needs for the life of the human in the present world scenario. The conventional energy resources are degrading day by day which leads to the turning in the use of renewable energy resources. Industrialization in the present world pollutes the nature of the environment, mainly the potable water available below and above the ground level. Over one billion people in the globe, lack access to drinking water. About 80% of all diseases in the developing world happens because people consume unsafe water and without an adequate sanitation. The most effective renewable energy source is the solar energy. Solar power can be harvested in many ways, one of which is by using photovoltaic (PV) panels. These panels operate based on the PV effect. Power is generated when sunlight falls on PV panels. The power output is reduced when irradiation is lacking. Solar energy is the combination of both light and heat from the sun in which light is used by PV cells for power production. PV cell is a tool which directly generates electricity by the incident photons. Also, photovoltaic conversion plays a major role in industrialized countries.

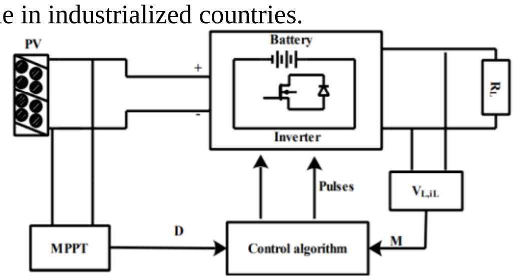

Fig. 1: Block diagram of stand-alone solar PV system

The 13-level inverter of involves a triple-mode SC unit, a double-mode SC unit and two inverting half-bridges, as shown in Fig. 2(a). It has several advantages like a high boost factor of 6 and reduced capacitor voltage ripples etc. However, two high-voltage capacitors C3 and C4 withstanding 3 times of the dc input voltage are employed in the inverter. Moreover, one inverting half-bridge Q1-Q2 connected in parallel with the series-connection of C3 and C4 withstand 6 times the dc input voltage. The high-voltage capacitors and transistors make it difficult to improve the inverter in the respects of size and cost.

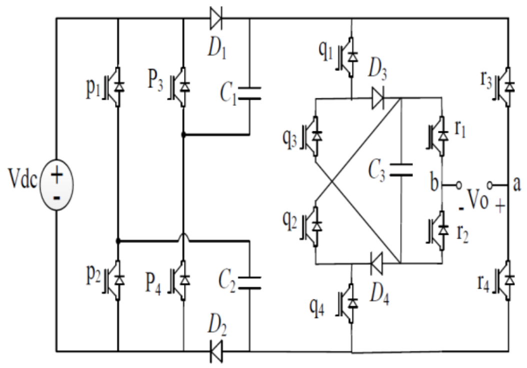

Fig. 2: 13 level Inverter Topology

In this work, two simplified SC units are developed to replace the double-mode SC unit used in [10]. As a result, two new 13-level inverters are developed, which employ single high-voltage capacitor and no high-voltage inverting half-bridge. Additionally, the merits of high boost factor and self-balanced capacitor voltages highlighted in [10] are also inherited in the new inverters. These features make the new inverters very suitable for low-voltage sources such as PV and fuel cells. Of course, the main disadvantage is the use of more active switches than [10].

Designing Inverter

In this work proposed a T-type inverter which is suitable to connect PV and transmit a power to the grid. Proposed inverter generates a 13-level at the output of the inverter as Vdc/6, Vdc/4, Vdc/2, 0, -Vdc/2, -Vdc/4, -Vdc/6. Proposed topology is represented in figure 4.2. By connected three modules in the cascaded form we can create 13-level as a levelled output of the inverter. This cascaded T-type system provides a levelled voltage as 6Vdc, 5Vdc, 4Vdc, 3Vdc, 2Vdc, 1Vdc, 0, -6Vdc, -5Vdc, -4Vdc, -3Vdc, -2Vdc, -1Vdc.

O level

Vo = 0

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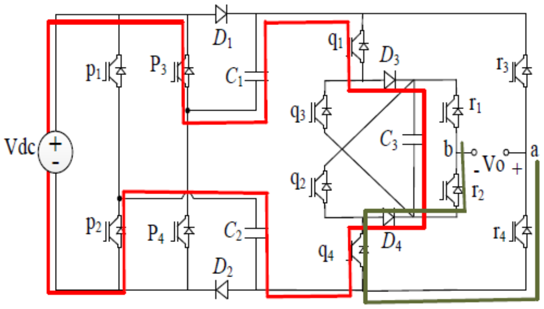

Fig. 3: 0.5V_{DC}level

Vo = +Vdc

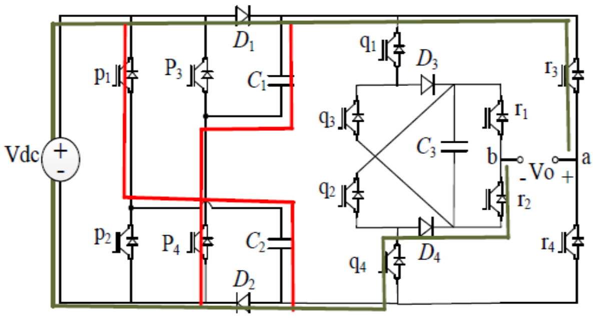

Fig. 4: +V_{DC} Level

Vo = +2Vdc

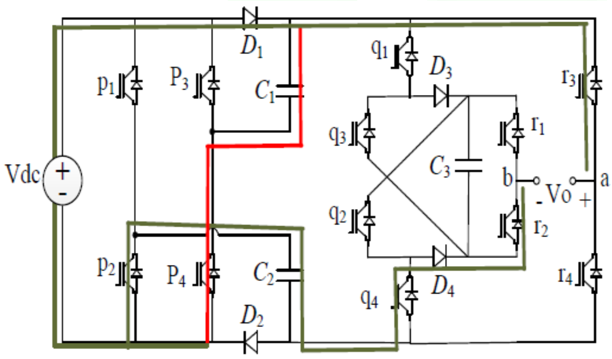

Fig. 5: +2V_{DC} Level

Vo = +3Vdc

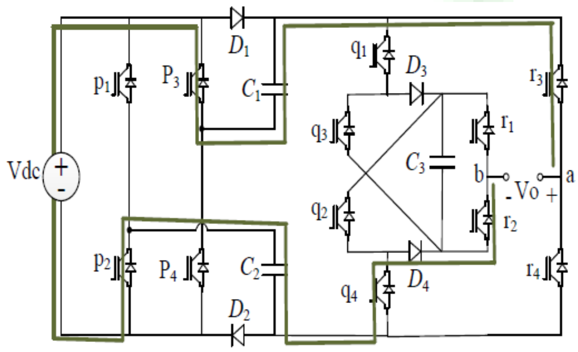

Figure 4.5: +3V_{dc} Level

Fig. 6: +3V_{DC} Level

Vo = +4Vdc

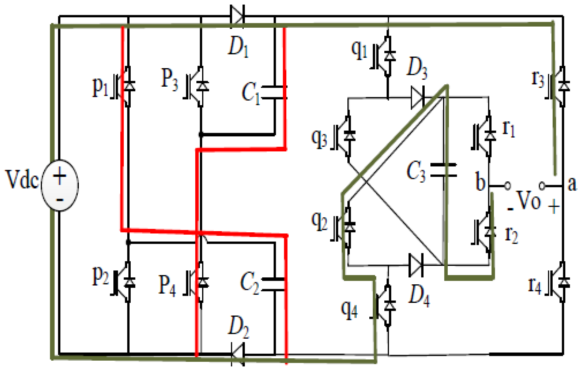

Fig. 6: +4V_{DC} Level

Vo = +5Vdc

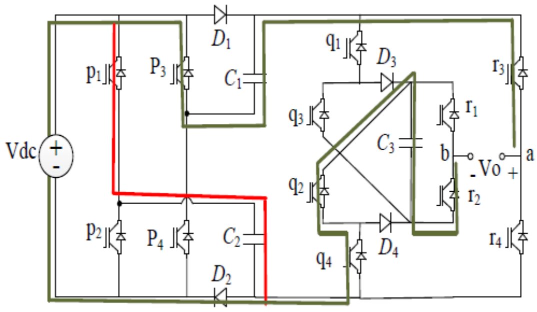

Fig. 7: +5V_{DC} Level

Vo = +6Vdc

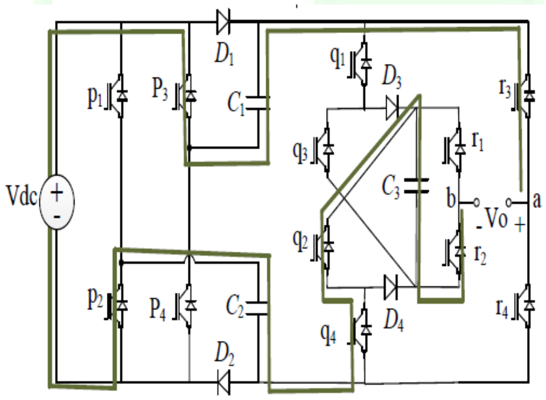

Fig. 8: +6V_{DC} Level

Table 4.1: Switching states of the 13-level inverter

Vo	p1	p2	p3	p4	q1	q2	q3	q4	q4	r1	r2	r3	r4
+6Vdc	0	1	1	0	0	1	0	1	0	0	1	1	0
+5Vdc	1	0	1	0	0	1	0	1	0	0	1	1	0
+4Vdc	1	0	0	1	0	1	0	1	0	0	1	1	0
+3Vdc	0	1	1	0	0	0	0	0	1	0	1	1	0
+2Vdc	0	1	0	1	0	0	0	0	1	0	1	1	0
+1Vdc	1	0	0	1	0	0	0	0	1	0	1	1	0
0	0	1	1	0	1	0	0	1	0	0	1	0	1
-1Vdc	0	1	1	0	1	0	0	1	0	1	0	0	1
-2Vdc	1	0	0	1	0	0	0	0	1	1	0	0	1

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Designing Of Stage One Dc-Dc Boost Converter DC-DC boost converter used for constant output voltage for grid connected photovoltaic application system. The boost converter is designed to step up a fluctuating solar panel voltage to a higher constant DC voltage. It uses voltage feedback to keep the output voltage constant. To do so, a microcontroller is used as the heart of the control system which it tracks and provides pulse-width-modulation signal to control power electronic device in boost converter. The boost converter will be able to direct couple with grid-tied inverter for grid connected photovoltaic system.

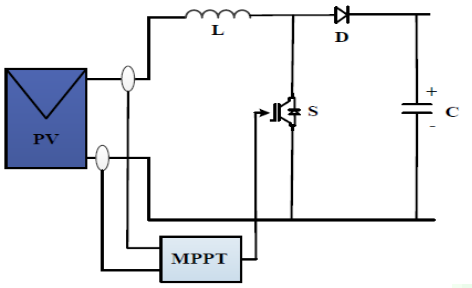

Fig. 9: DC-DC boost converter

V. SIMMULATION RESULTS AND COMPARISION

The proposed inverters are capable of generating 13 levels of the output voltage and each level is equal to the dc input voltage 100V. The operation is very stable for step-change in either pure resistive load (R = 500 Ohm) or inductive load (R = 50 Ohm, L = 50 mH). The capacitors' voltages are also very stable and are balanced automatically. Their current decrease along with the load increases. For resistive load change current decreases instantaneously with 0.6 A and for inductive load current decreases to 5 A. At different load condition with sudden changes across the load MLI gives stable output voltage and current. Also only current has been change voltage at every condition fixed to 100V step size and 600V boosting factor. Peak inverse voltage (PIV) limits to 300V so total standing voltage (TSV) get also reduce.

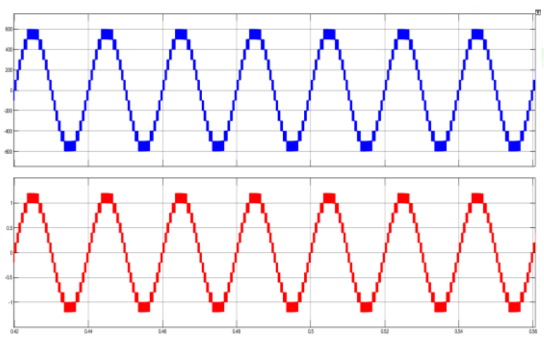
Fig. 10 : Level voltage and current with R-load R=500Ω

Fig. 10 and 11 show the experimental waveforms of the two prototypes. It indicates that the proposed inverters are capable of generating 13 levels of the output voltage and each level is equal to the dc input voltage 60V. The operation is very stable for step-change in either pure resistive load or inductive load. The capacitors' voltages are also very stable and are balanced automatically. Their ripples increase along with the output power. When the load is 100Ω and 200Ω, the measured output voltage for the prototype of Fig. 5.2 are 226.5V and 230.6V, and the corresponding efficiencies are 95.9% and 96.7%, while that for the prototype of Fig. 11 are 221.8V and 226.6V, and the corresponding efficiencies are 95.5% and 96.4%.

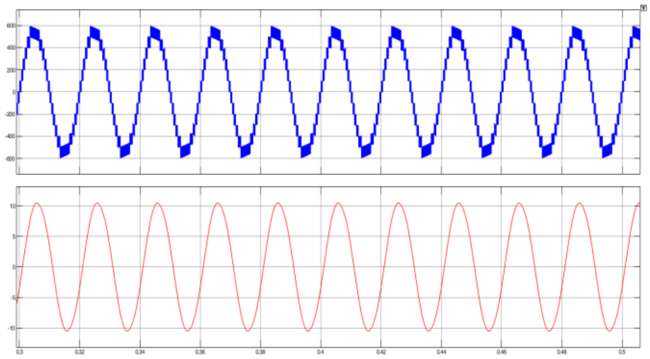
Fig. 11: Level voltage and current with Sudden change RL-load, R=50Ω, L= 50 mH

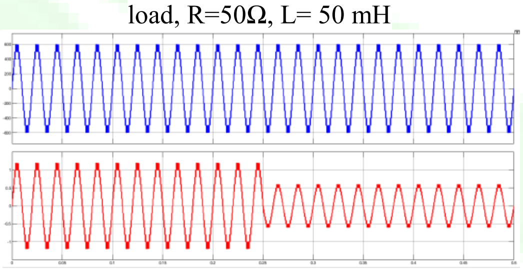
Fig.12 : Level voltage and current with Sudden change R-load, R=500Ω after 0.25 sec R=1000Ω

For reduction of this ripple and increase the dc voltage required a DC-DC boost converter. Output voltage of DC-DC boost converter is ripple free and high voltage as 400V so it can be easily connected to the single-phase grid by using inverter. This DC-DC boost converter also useful for MPPT (Maximum Power point tracking) which is performed by perturb and observe method. This converter worked as a first stage of our system and work on a 5KHz Switching frequency. Level voltage and current with Sudden change RL-load, R=50 ohm, L= 50 mH after 0.25 sec R=100 ohm, L= 100 mH is shown in figure 13.

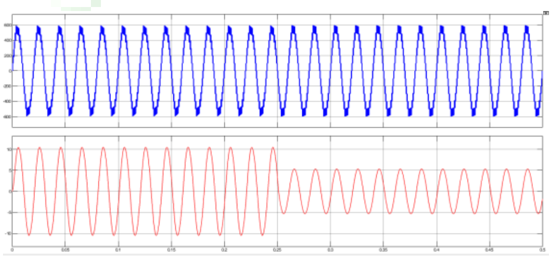
Fig. 13 : Level voltage and current with Sudden change RL-load, R=50 ohm, L= 50 mH after 0.25 sec R=100 ohm, L= 100 mH

Additionally, Fig. 14 shows input current iSource of the prototype of Fig. 14. Its main component is the charging current of capacitors. The waveform shows that the largest charging current spike occurs when the output level is ±3Vdc and 0. As the effect of parasitic resistance of the charging loops and stray inductance of the PBC board and connecting wires, the capacitors are charged partially and the charging current flowing through switches falls exponentially.

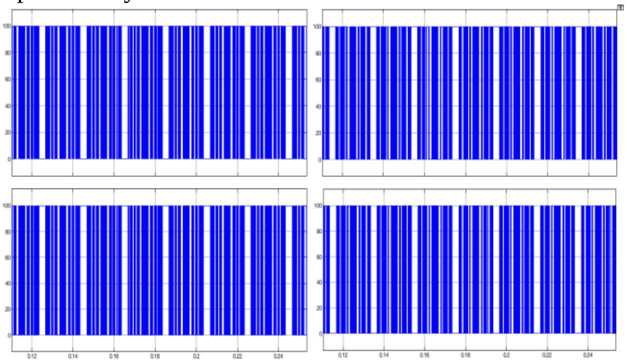

Fig. 14 Peak inverse voltage across switches p1, p2, p3, p4

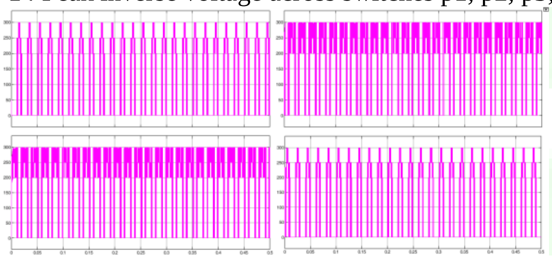

Fig.15: Peak inverse voltage across switches q1, q2, q3, q4

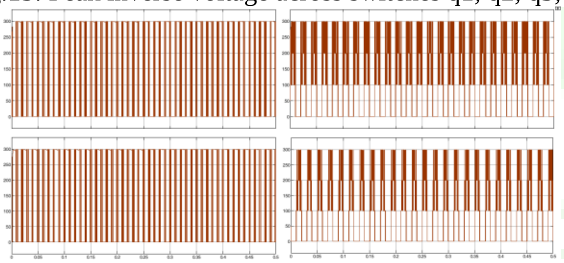

Fig.16: Grid voltage, grid current, inverter current

5.2 *Comparison With Other Sc Based Circuits*

- No of switches (Ns) = 12
- No of gate driver circuits (Gd) = 12
- Number of diodes (Nd) = 4
- Reduces the total standing voltage (TSV) = 28
- Reduces Peak inverse voltage (PIV) = 3
- Number of capacitor (Nc) = 3
- Number of level (NL) = 13
- Boosting factor (BF) = 6
- Costfunction(CF) = (Ns+Gd + Nd + Nc + TSV + PIV) / NL
- CF = 4.5

Table II: Comparison with other SC based circuits

Circuits	NS	Gd	ND	NC	TSV	CF	BF
[12]	19	19	0	5	39	6.7	6
[4]	10	10	10	5	59	7.6	6
[14]	29	29	5	5	34	8.2	6
[3]	14	14	0	4	40	5.8	1.5
[7]	10	10	4	4	36	5.5	6
[1]	13	13	2	3	33	5.3	6
This work	12	12	4	3	28	4.5	6

VI. CONCLUSION AND FUTURE WORK

Modelling of photovoltaic array based on a simplified single diode model is depicted. The performance of the developed mathematical model is tested using MATLAB/SIMULINK. The developed PV model and actual model is compared. The presented research work has been focused on the construction of variable amplitude sinusoidal voltage using the different topologies. The first effort has been related to the development of new MLI topology using diodes and switching devices under symmetric and asymmetric mode. The advantage of the topology articulates any desired voltage level with a reduced total number of devices and sources over basic and similar topology. The reduced stress of the sources achieved through pulse swapping among the cell switches, balances the load power and reduces the voltage stress of the devices. This thesis presents two improved SC-based 13-level inverters which have a boost factor of 6 and self-balanced capacitor voltages. Compared with the recent work, the primary advantage of these inverters is that one less high voltage capacitor is required. This directly causes the blocking voltage of their inverting half-bridge to be reduced by half. As a result, these inverters involve two types of transistors of which the blocking voltages are *Vdc* and 3*Vdc*, respectively. With a hybrid PWM strategy, capacitor voltage ripples are also optimized in this work. Experimental results indicate that the proposed inverters have good dynamic performance and high efficiency.

The current work deals with the change in irradiance and temperature of PV panel whereas this could also be extended by adding essential variables like partial shading parameter etc. The seven level boost ANPC inverter with PV panel is implemented with a single phase stand-alone load and it could also be implemented in online grid connected power system. In the future extension of the work, the number of switches used in the QZSI could be optimized. The various topologies could be analysed as well as the most efficient one could be identified.

- ➢ Different multicarrier PWM techniques can be investigated for dual T types boost ANPC inverter.
- ➢ A cost effective MPPT technique can be developed and analyses through simulation and hardware.

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