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# DESIGN AND SIMULATION ANALYSIS OF SEVEN LEVEL CASCADED GRID CONNECTED INVERTER FOR PV SYSTEM

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## ABSTRACT

This paper presents the simulation analysis of seven level cascaded grid connected inverter and also compared with five level inverter for %THD for voltage and current by using level shifted PWM techniques. The proposed system are modeled and simulated through computer software tool using MATLAB /SIMULINK. This paper also presents the design and development of the seven level cascaded grid connected inverter.The LC filter is also use in the output side to further reduce the THD values.Seven level inverter is utilise as a power converter to inject power generated from pv source to the grid.Multilevel inverters have been mainly used in medium- or high-power system applications, such as static reactive power compensation and adjustable-speed drives. In these applications, due to the limitations of the currently available power semiconductor technology.The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lowerVoltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected Percentage of THD for R, RL, RLC load taken and simulation results analyse and studied and comparison made between five level and seven level .

**KEYWORDS:**- Total hormonic distortion(THD), Multilevel inverter, PV array

## ACKNOWLEDGMENT

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## INTRODUCTION

The increasing number of renewable energy sources and distributed generators require new startgies for the operation and management of the electricity grid in order to maintain and improve the power supply reliability and quality.The multilevel inverter have been mainly use in medium or high power system appliation.Multilevel inverter concept is usually a unique alternative because it is having low switching frequency and also provides voltage and current sharing between power semiconductors.Acompilation of the most common topologies of multilevel converters is presented in[1],and it shows which ones are best suitable to implement inverters for stand-alone applications in the range of a few kilowatts.As an example, a prototype of 3 kVA was implementedin [1] ,andpeak efficiency of 96.0% is shown in[1]

In [2] by using feedback controller a digital proportional –integral current control algorithm is implemented in DSP TMS320F2812 to control overall operation of the invertercontrol.In this Photovoltaic system is recognised to be in the forefront in renewable electric power generation , it can generate dc without environmental impact and contamination when track by solar radiation.one of the problem in the PV generation system is the amount of electric power generated by solar arrays always changing with weather condition, so MPPT method implemented for the optimum results.

In [3] in phase disposition level shifted multi-carrier modulation is used as a control strategy, and cascaded H-bridge inverter require less no. of components as compared to diode clamped inverter and developed seven level inverter is integrated with PV array and by compared with conventional inverter

Renewable Energy Sources (RES) are rapidly gaining popularity for sustainable power generation, they being less polluting and readily available resources. Moreover, Solar-Photo Voltaic (PV) based power generation has much more importance, it being more reliable and requires less maintenance (as it has no rotating mechanisms). The trend of megawatt range PV plants will demand higher power ratings for the central grid tied converter, and traditional two level VSI topologies will not be able to fulfill power rating, power quality and efficiency requirements. The RES (PV source) is connected to the DC side of the multi level Voltage Source Inverter (VSI) for interfacing with the grid. The multi-level VSI is utilized as a power converter to inject the power generated from the RES (PV source) to the grid [3].

As the world is concerned with the fossil fuel exhaustion and environmental problem caused by conventional power generation, particularly solar have become very popular and demanding. PV sources are used in many applications because they have advantage of being maintenance and pollution free. It is used to convert the dc power from solar module to ac power to feed into load or grid. Multi-level inverter is used for PV application [4].

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Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to amultilevel converter system for a high power application. The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lowerVoltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected[5].
Multilevel inverters have been mainly used in medium- or high-power system applications, such as static reactive power compensation and adjustable-speed drives. In these applications, due to the limitations of the currently available power semiconductor technology, a multilevel concept is usually a unique alternative because it is based on low-frequency switching and provides voltage and/or current sharing between the power semiconductors [6].
This paper presents the simulation analysis of seven level cascaded grid connected inverter and also compared with five level inverter for %THD for voltage and current by using level shifted PWM techniques. The proposed system are modeled and simulated through computer software tool using MATLAB /SIMULINK. This paper also presents the design and development of the seven & five level cascaded grid connected inverter.The LC filter is also use in the output side to further reduce the THD values. Seven level inverter is utilise as a power converter to inject power generated from pv source to the grid. PV array cell is designed in matlab, and solar is taken as input to the seven level inverter and performance is evaluted.
% of THD for R, RL, RLC load taken and simulation results analyse and studied and comparison made between five level and seven level .

## BLOCK DIAGRAM:

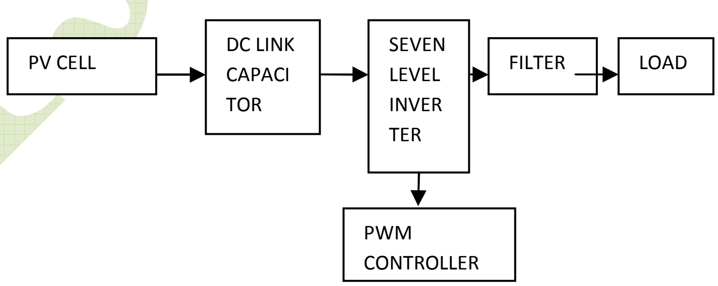


**Figure.1: Block Diagram of proposed Multi Level Inverter**

Fig(1) shows block diagram of proposed model before implementation of PV cell as input source seven level & five level inverter is design with using separate dc source with dc link capacitor and after implementation of PV cell model in matlab PV cell taken as input of the seven level and five level inverter

Need of the inverter**: -** One of the drawback in the solar energy sources is the need of the energy storage for the system to be utilized for the significant percentage of the day, one way to overcome this disadvantage by utilizing the inverter and its controller circuits for PV based DG units during the day and nights times for improving the reactive power compensation and harmonic elimination on its neighboring DG units and the grid by proper exchange of reactive power between the sources.

**H-Bridge Inverter:**

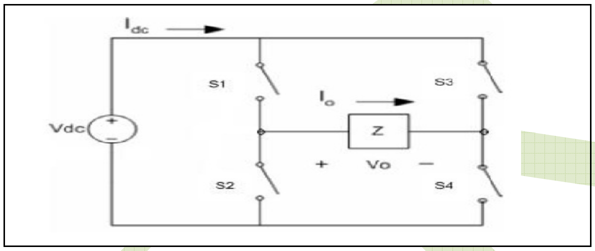


**Figure 2: H- bridge inverter**

The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output waveform. Therefore, using the multilevel inverter as an alternative to traditional PWM inverters is investigated. In this topology the number of phase voltage levels at the converter terminals is 2N+1, where N is the number of cells or dc link voltages. In this topology, each cell has separate dc link capacitor and the voltage across the capacitor might differ among the cells. So, each power circuit needs just one dc voltage source. The number of dc link capacitors is proportional to the number of phase voltage levels .Each H-bridge cell may have positive, negative or zero voltage. Final output voltage is the sum of all H-bridge cell voltages and is symmetric with respect to neutral point, so the number of voltage levels is odd.

**Five level Inverter:-**

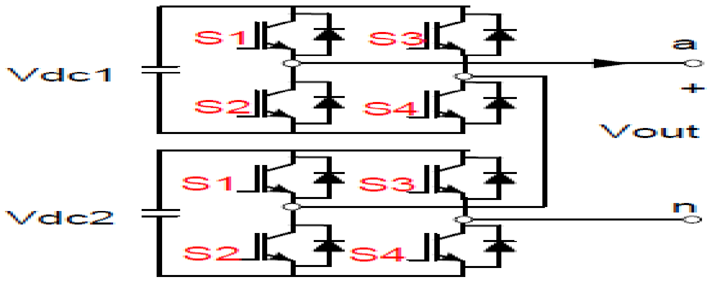


**Figure 3: Single phase diagram of 5-level CHB inverter**

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In five level inverter two H-bridges are used and each H –bridge required four switch with separate dc source and it is simulated through matlab Simulinkby using simpower system platform..

**Seven level inverter:**

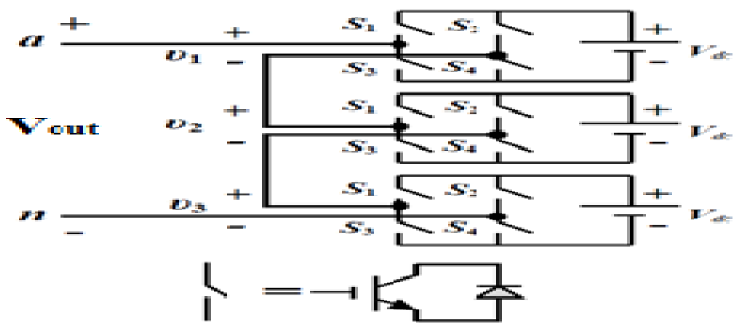


**Figure 4: Single phase diagram of 7-level CHB inverter**

**Control strategy:**

The following are the different control strategies for an inverter,

(i) Bipolar and Unipolar PWM

(ii)Carrier based PWM

(a) Phase shifted multi-carrier modulation

(b) Level shifted multi-carrier modulation

(iii)Stair case modulation

(iv)Selective harmonic elimination scheme

(v)Space vector modulation scheme

**Level shifted multi-carrier modulation:**

For an N level inverter, level shifted multicarrier modulation requires (N-1) carriers, all having the same frequency and amplitude. The (N-1) triangular carriers are vertically disposed such that the bands they occupy are contiguous. The frequency modulation index is given by mf=fcr /fm and the amplitude modulation index isdefined as ma =2Vm / Vcr (m-1); for 0<ma<=1 where Vm is the peak amplitude of the modulating wave and Vcr is the peak amplitude of each carrier wave. Shows three schemes for the level-shifted multicarrier modulation:

(a) In-Phase Disposition (IPD), where all carriers are in phase;

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(b) Alternative Phase Opposite Disposition (APOD), where all carriers are alternatively in opposite disposition; and

(c) Phase opposite Disposition (POD), where all carriers above the zero reference are in phase but in opposition with those below the zero reference. In this paper, IPD type level shifted multicarrier modulation control strategy is employed because it results in better THD performance than the POD and APOD. For a 7-level inverter, six carrier waves with each of 0.33V amplitude and frequency of 1000Hz and one reference wave with 1V amplitude and frequency of 50Hz, required for an amplitude modulation index of 1 and a frequency modulation index of 20.

Filter: -Filter is use to reduce the harmonics and ripples, LC capacitor is used to reduce the %THD and results are taken.

**Various types of load:**

Resistive load: **-** Resistive loads are loads which consume electrical energy in a sinusoidal manner. This means that the current flow is in time with and directly proportional to the voltage.

It is a load that contains no inductance or capacitance, just pure resistance. Therefore; when a resistive load is energized, the current rises instantly to its steady-state value without first rising to a higher value.

It includes loads such as incandescent lighting and electrical heaters.

Inductive Loads: **-** An Inductive Load is a load that pulls a large amount of current (an inrush current) when first energized. After a few cycles or seconds the current "settles down" to the full-load running current. Inductive loads can use excessive voltages to appear when switched. Examples of Inductive Loads are motors, transformers, and wound control gear.

Capacitive Loads: - A Capacitive Load is an AC electrical load in which the current wave reaches its peak before the voltage. Capacitive loads are loads that capacitance exceeds inductance. Example of a Capacitive Load is the flash of the camera.

**Matlab simulation of above block diagram :**

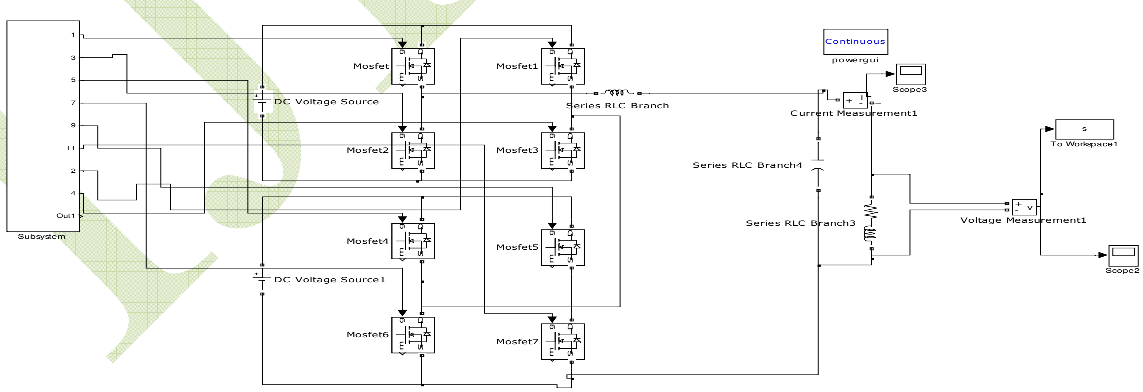



**Figure.5: Five level simulation model:-**

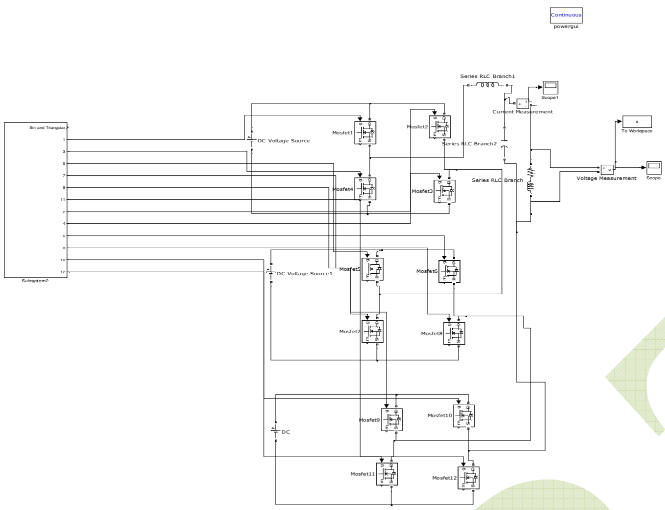


**Figure. 7: Seven level inverter simulation model**

**PV model:**

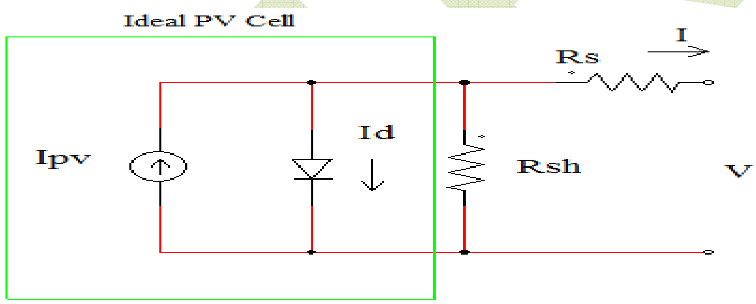



**Figure 8 : Equivalent circuit of Solar PV cell**

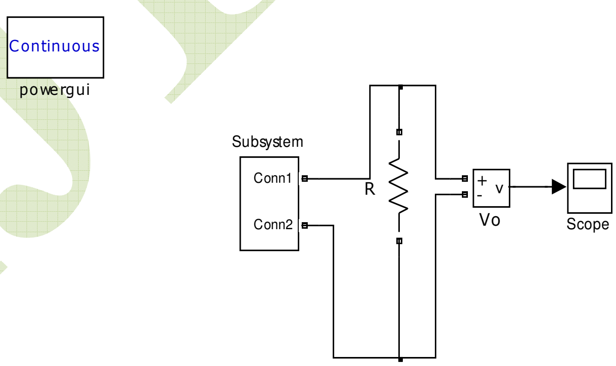



**Fig (8) Solar cell model**

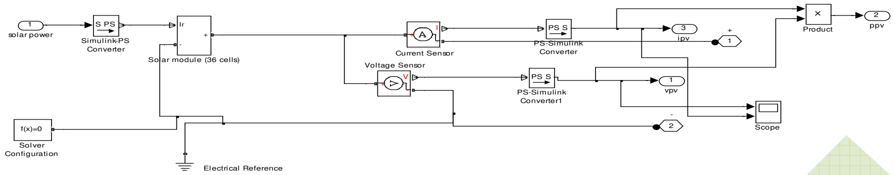



**Figure. 9: Simulation model of solar cell**

PV array reverse saturation current Irs:

$$I\,rs = \frac{Iscr}{[\exp\,(qVoc/\,NskAT\,) - 1]}\text{......................}1$$

PV array saturation current Io:

Io = Irs[T/ Tr ]3 exp[q Ego /Bk{1/Tr -1/T}]…2

The current output of the PV array is:

Ipv = Np*Iph-Np*Io[exp{q (VPV+IPV*Rs)/ NsAkT}-1]……….3

Where

Vpv is output voltage of a PV array (V)

Ipv is output current of a PV array (A)

Tr is the reference temperature=298 K

T is the cell temperature in oC

Io is the PV array saturation current (A)

A=B is an ideality factor =1.6

K is the Boltzmann constant =1.3805e-23J/K

q is electron charge=1.6e-19C

Iscr is the PV array short circuit current at 25°C and 1000W/sq.m =2.55A

Ki is the short circuit current temperature coefficient at Iscr =0.0017A/°C

S is the PV array illumination (W/sq.m) =1000W/sq.m

Ego is the band gap for silicon =1.1eV

Voc is the output voltage of the PV array

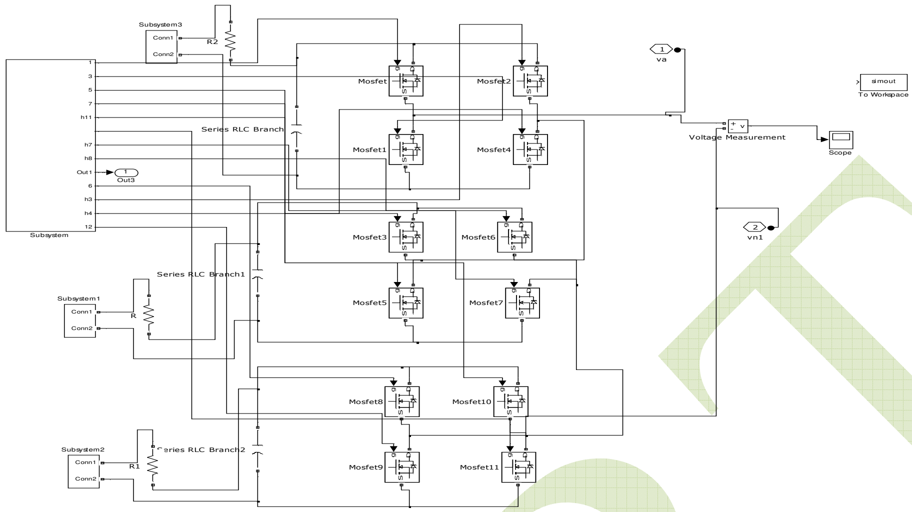


**Figure 10: Single phase seven level inverter with solar as input.**

## SIMULATION & RESULTS:

The seven level inverter operation and its results at various load condition like R, RL, RLC are studied and discussed below. The simulink output voltage and current are taken for the seven level inverter and its graph is taken and its waveform is given below.

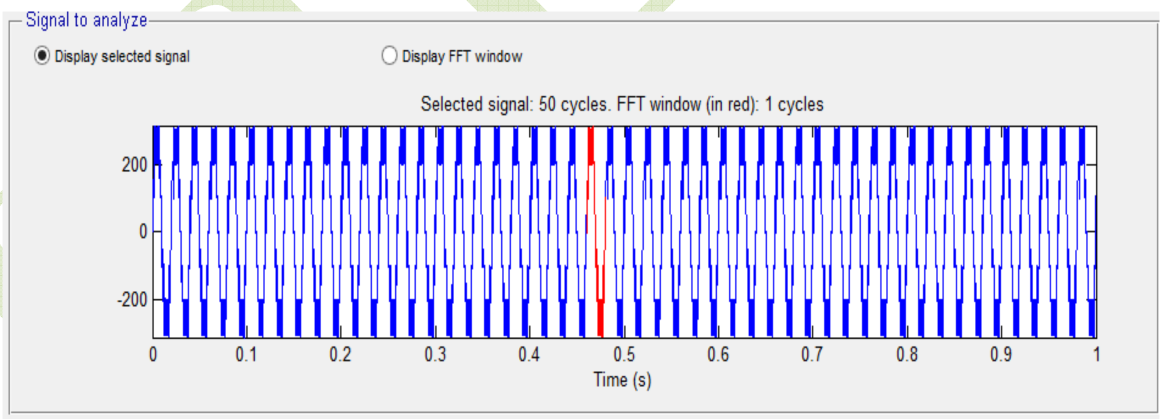
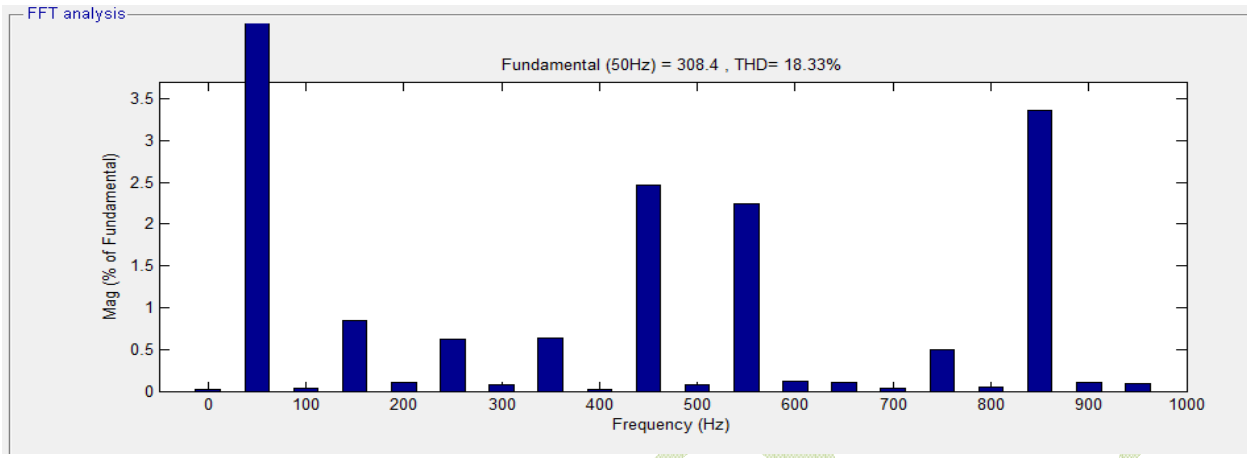



**Figure.11: Output voltage for RLC load seven level inverter (without filter).**

**Figure 12: Graph for RLC load seven level inverter**



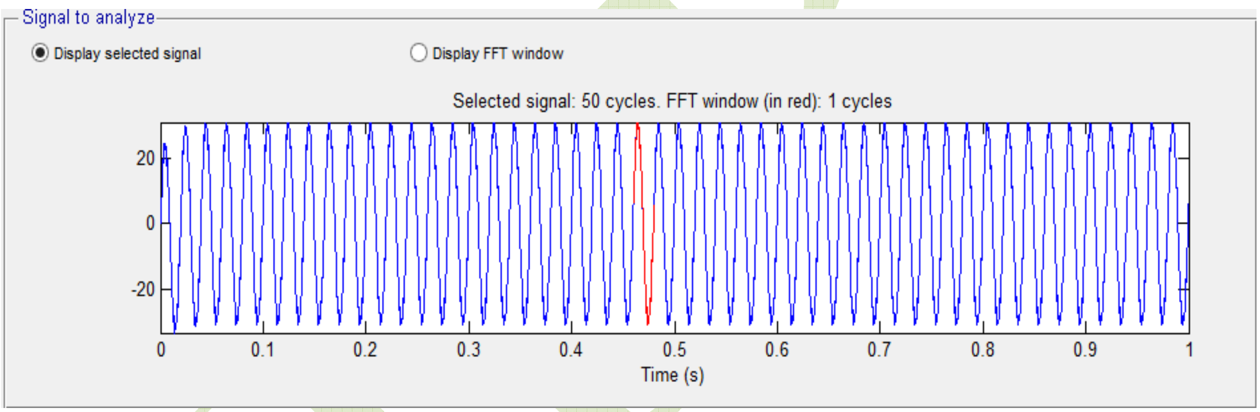




**Figure.13: Output current for RLC load seven level inverter(Without filter)**

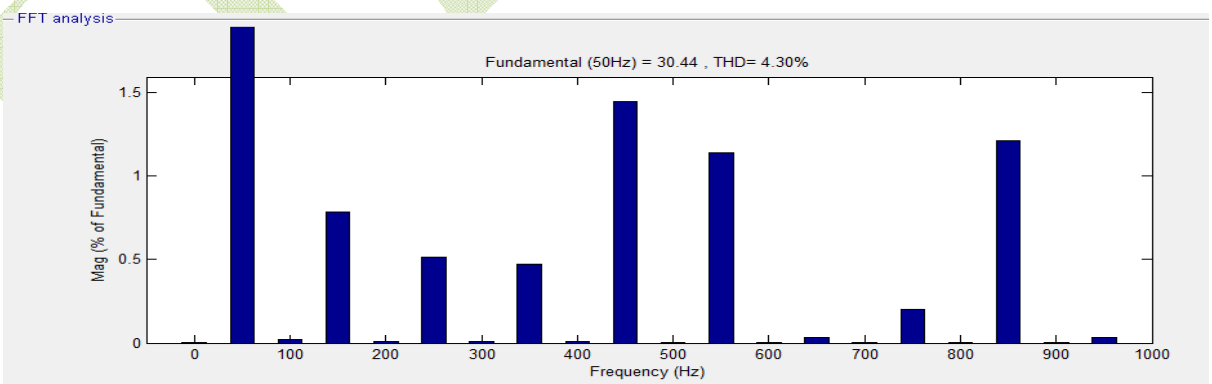



**Figure. 15: Graph for output current RLC load seven level inverter**

The total harmonic distortion of seven level inverter is taken for voltage and current harmonics and it's tabulated below.

| Multilevel inverter | R load | RL load | RLC load |
|---|---|---|---|
| 5 level | 24.87% | 31.88% | 25.88% |
| 7 level | 17.59% | 18.34% | 18.33% |

**Table 1. Comparison table for 5 level and 7 level inverter (For voltage without filter)**

| Multilevel inverter | R load | RL load | RLC load |
|---|---|---|---|
| 5 level | 24.87% | 11.87% | 13.12% |
| 7 level | 17.59% | 4.28% | 4.30% |

**Table 2. Comparison table for 5 level and 7 level inverter (For Current without filter)**

The above table 1 & 2 deals with comparison of five levels and seven level inverter, while studying the table, we can justify that the seven level inverter will gives low harmonics compared to five level inverter. The THD simulink output waveform with for the seven level inverter is below.

The THD value of the seven level inverter for voltage is for RLC load is 18.33% and current THD value is 4.30 %, these output are taken without usage of filter, when we use the filter the harmonics in the output will be reduced, and results are tabulated below.

| Multilevel inverter | R load | RL load | RLC load |
|---|---|---|---|
| 5 level | 8.61% | 10.76% | 8.40% |
| 7 level | 1.47% | 1.48% | 2.24% |

**Table 3. Comparison table for 5 level and 7 level inverter (For voltage with filter)**

| Multilevel inverter | R load | RL load | RLC load |
|---|---|---|---|
| 5 level | 8.61% | 10.48% | 8.31% |
| 7 level | 1.47% | 1.27% | 2.11% |

**Table 4. Comparison table for 5 level and 7 level inverter (For current with filter)**

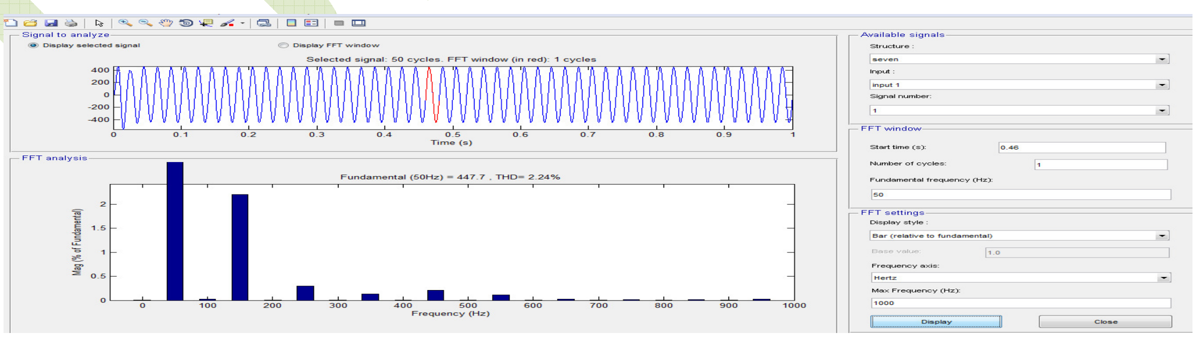



**Figure 15:Voltage THD value for RLC load for seven level inverter**

| | |
|---|---|
| Control strategy | Level shifted multi – carrier modulation |
| Fundamental frequency | 50 Hz |
| R | 10 Ohm |
| L | 5e-3 H |
| C | 1000e-6 F |

Table (5) multilevel inverter parameter

| | |
|---|---|
| Operating temperature of PV array | 25 deg.cel |
| Irradiation of PV array | 1000 w/sq.mm |
| Output voltage of PV array | 12 V |
| Output current of PV array | 4.8 A |
| Output power of PV array | 57.6 W |

**Table (6) PV array parameter**

## CONCLUSION

Cascaded H-bridge 5 level inverter is compared with 7 level inverter and concluded that seven level inverter will gives low harmonics compared to the five level inverter, Simulations has been done using MATLAB Simulink, with developed topology and found that the developed topology provides the better amount of THD and also there is increase in the fundamental voltage magnitude which implies good performance. PV array and boost converter is modelled and its performance is analysed. Also, the 7-level Cascaded H-bridge inverter is simulated with the PV array as its input and found to be good performance with same THD as that of Cascaded H-bridge inverter with dc link as its input. And also, the developed 7-level inverter is integrated with the PV array and found to be good performance.

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