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Cascaded H-Bridge Nine-Level Inverter for Solar PV Systems

Hari Prasad R[1], Dr. S.G. Srivani[2]

[1]*PG Student, Power Electronics, Department of EEE, RVCE, Bengaluru, Karnataka, India*
[2]*Associate Professor and Dean, Department of EEE, RVCE, Bengaluru, Karnataka, India*

Abstract – *Conventional inverters have more THD, higher switching losses and lower efficiency. Therefore, to overcome such problems multilevel inverters have evolved and are widely used in power applications and renewable energy systems. These inverters reduce the high switching losses and THD and maintain the efficiency using sinusoidal PWM method and thereby a smooth sinusoidal waveform at the load is recorded. In this proposed work, a cascaded H-bridge 9-level inverter is implemented along with the boost converters, solar PV array systems and filter circuits where as the 15-bus radial power grid system is connected at the load of the inverters through 11 kV step-down transformer. GA-Based MPPT controller is connected with solar PV panels to track the maximum power points of the load signal for boost converter. The filter circuits eliminate the THD and produce pure sinusoidal waveform. The proposed system records the values of THDs during simulation and they're found to be 2.40 %, 0.38 % and 1.95 % for phase A, phase B and phase C respectively.*

***Key Words*: Solar PV Arrays, Boost Converters, MPPT Algorithm, Multilevel Inverters, Filter Circuits , 15-Bus Radial System, MATLAB/Simulink, FFT Analysis**

1. INTRODUCTION

The non-renewable energy sources such as fossil fuels and nuclear energy cause dangers, environmental pollutions and hazards due to green house effect. [1] This is one of the prime reasons why renewable energy sources like solar energy and wind energy have huge demands since they are freely available and is clean and non-exhaustible. Moreover, they are more popular and demanding due to advancements in power electronic techniques. Photovoltaic (PV) sources are used today in many applications as they have the advantages of effective maintenance and pollution free [2]. It is also witnessed that among these renewable energy sources solar PV energy is found to be the most promising energy [3].

1.1 Multilevel Inverter

Conventional inverter has been used since the past decades in the field of industrial applications and power systems of lower power usage. Problems appeared when it comes to high power and medium voltages usage [4]. Conventional inverters are found that it no longer fulfils the requirement of voltage usage due to the incapable of reducing harmonic contents. It has high switching losses, lower efficiency and the lifespan of the systems due to long term constraining. This lead to the growth of Multilevel Inverter (MLI), the creation of multiple DC levels that combined into sinusoidal wave which reduces harmonic distortion. MLI topologies are introduced to be functioning under high frequency with lesser switching losses and higher efficiency [5]. Therefore, a 9-level cascaded multilevel inverter is designed and simulated to produces a lower THD content. Multilevel inverters are utilized generally in the regular applications due to the high voltage capacity and it delivers the multilevel with low composition with least concern in the exchanging gadgets [6].

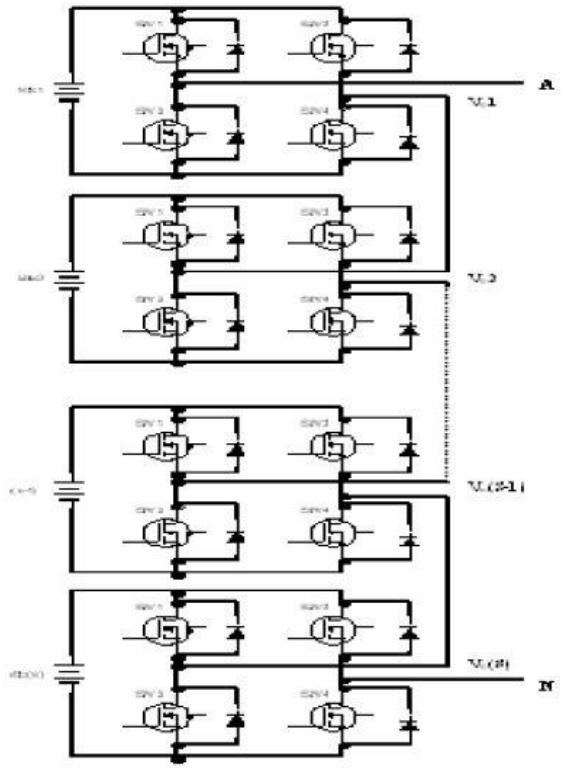

Fig 1 – Cascaded H-Bridge 9-Level Inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Fig 1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the fours switches S_1, S_2, S_3 and S_4 [7].

To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_1. By turning on S_1, S_2, S_3, and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage

waveform is the sum of the MLI outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of single dc sources .In the 9-level cascaded multilevel inverter with single DC sources are obtained [8]. The DC sources feeding the multilevel inverter are considered to be varying in time. The waveform is shown in Fig 2.

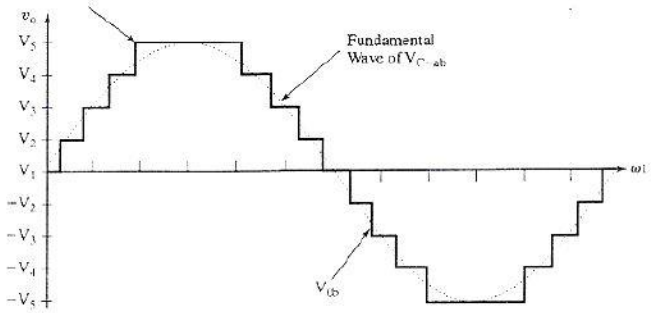

Fig 2 – Waveform of Cascaded Inverter

1.2 GA-Based Maximum Power Point Tracking (MPPT)

MPPT or **Maximum Power Point Tracking** is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called "maximum power point" (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature [9].

GA based MPPT: Genetic Algorithm (GA) is an optimization stochastic algorithm based on natural genetic selection. The advantages are:

- It uses its codes instead of parameters.
- It does not work with a point but with population of points.
- It just needs function values and does not have to calculate any other value (for instance differential).

MPPT techniques try to track the optimum point corresponding to the maximum PV power, this point is defined by an optimum current I_{mp} (current at maximum power). By using GAs, one can find this current and keep PV panels working around the maximum power. Fig 3 depicts the GAs-based MPPT PV system [10][11]. The main idea is to perform genetic transformations (selection, crossover, mutation and intersection) on a population of individuals in order to finally obtain an optimal individual corresponding to the maximum of a function (fitness function). The following flowchart (Fig 6) shows the steps of algorithm.

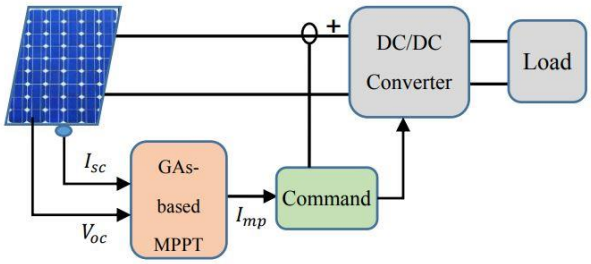

Fig 3 – GA Based MPPT System

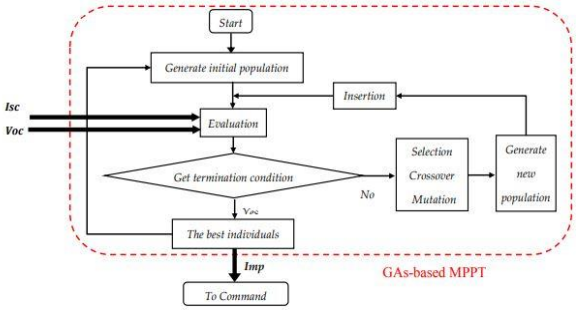

Fig 4 – Flowchart of GA based MPPT

2. PROPOSED TOPOLOGY OF THE SYSTEM

The proposed topology of the system is shown by block diagram (Fig 5) that indicates how the components are arranged and functioned through applied methods.

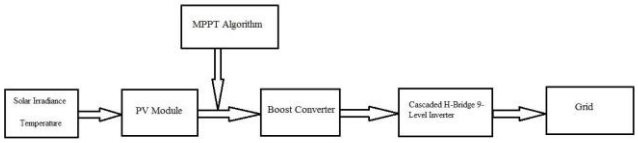

Fig 5 – Block Diagram of the Proposed Topology of the System

- Here, the PV Module receives solar energy whose solar irradiance is 1000 W/m^2 and its temperature is 25^0 C and converts it into electrical energy consisting of voltage and current signals.
- These signals are tracked with the help of Genetic Algorithm based MPPT controller system and are maintained constant to achieve maximum power.
- These constant voltage and current signals are fed to the Boost Converter that increases the voltage at the output.
- This maximum output voltage signals are converted to ac voltage signals using cascaded H-bridge 9-level inverter by Sinusoidal PWM method whose reference signals are compared with career signals.
- Further, the ac voltage signals are formed in sinusoidal fashion and then filtered using ac filter circuits in order to eliminate the unwanted signals and hence reducing the THD.

- These filtered signals are distributed towards the 15-bus power grid system through 11kV Step-Down Transformer.
- This system is designed and simulated using MATLAB/Simulink software tool before proceeding to its hardware implementation.

The simulated values and readings are recorded.

2.1 Specifications

The values at the output of the filter circuit are recorded and hence the system is analysed using FFT analysis tool to check the reduction of THD corresponding to the voltage waveforms.

The specifications and suitable assumptions for Solar PV Array and MPPT algorithm are shown in Table. 1

Table-1: Specifications of PV Array Input and MPPT Algorithm

Specifications of PV Array Input and MPPT Algorithm			
PV Array Input		MPPT Algorithm	
Solar Irradiance	1000 W/m^2	PWM Switching Frequency	5000 Hz
Temperature	25 ^{o} C	Time Window Used by MPPT Control	200 µs
		Initial Value of Duty Cycle	0.5

There are 12 solar PV arrays used in this system where each array has 2 solar PV panels connected in series. Each panel has 55 parallel strings with 5 series-connected modules per string. The maximum power delivered by each panel is 305 W. Therefore the maximum power delivered by each array is formulated as the product of number of parallel strings, series conducted modules per string and maximum power of panel. i.e

$$55 \times 5 \times 305 = 83875 \text{ W}$$

(84 kW approx)

Therefore, the total power delivered by the entire solar PV systems having 12 arrays in total is

$$55 \times 5 \times 305 \times 2 \times 12 = 2013000 \text{ W}$$

(2.013 MW approx)

The specifications for the module and model parameters are shown in table 2 and table 3 respectively.

Table – 2: Specifications for MPPT Module

Module	Sunpower SPR-305E-WHT-D
Maximum Power	305.226 W
Open Circuit Voltage V_{oc}	64.2 V
Voltage at Maximum Power Point V_{mp}	54.7 V
Temperature Co-efficient of V_{oc}	-0.27269
Cells per module N_{cell}	96
Short Circuit Current I_{sc}	5.96 A
Current at Maximum Power Point I_{mp}	5.58 A
Temperature Co-Efficient of I_{sc}	0.061745

Table – 3 = Model parameters

Light generated current I_L	6.0092 A
Diode Saturation Current I_D	6.3014e^{-12} A
Diode Ideality Factor	0.94504
Shunt Resistance R_{sh}	269.5934 Ω
Series Resistance R_{se}	0.37152 Ω

For multilevel inverters, there must be (n-1) x 2 IGBTS to be used. Therefore, for n = 9, there are 16 IGBTs used.

For boost converter specifications: C =100 µF, R = 0.005 Ω, L = 5mH, C_{op} = 12000 µF

For filter circuit specifications: L_1 = 100 µH, L_2 = 100 µH, C_f = 8350 µF

For grid system specifications: Phase-to-phase voltage = 11 kV, Phase angle = 19.3277^0, Frequency = 50 kHz

3. SIMULATION MODEL

The simulation model of the proposed system is shown in Fig 5. Here, it consists of Cascaded H-Bridge 9-Level Inverters, Boost Converters, Solar PV Array, MPPT Controller, Filter Circuits and 15-bus Radial Power Grid System. Both the converters and inverters use IGBT switches as they are capable of reducing the switching losses.

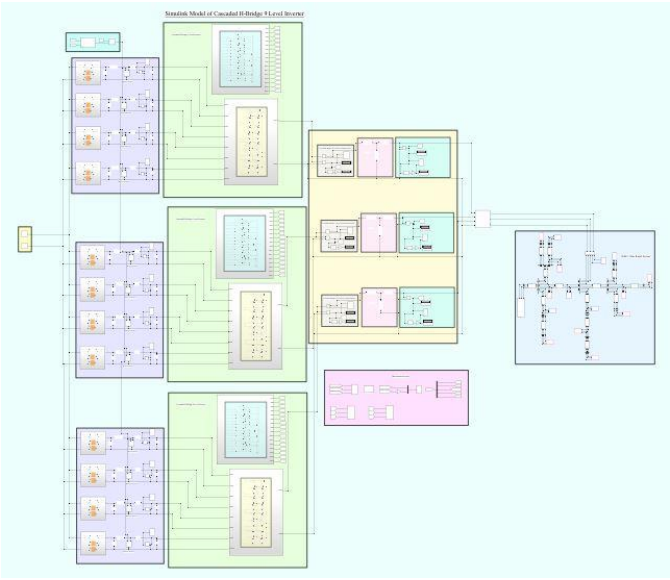

Fig 5 – Simulation Model of the Proposed System

During simulation, due to high voltage levels as per the number of switches, the output of the inverter is measured in terms of THD by filter circuits as shown in Fig 6 and also by FFT analysis.

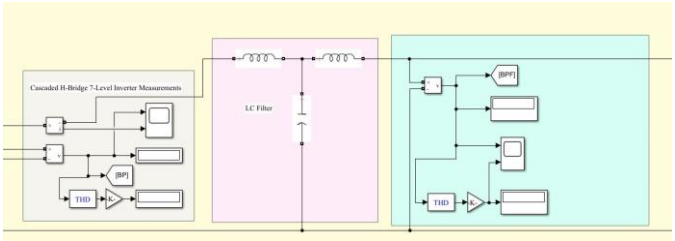

Fig – 6: Filter Circuit

4. RESULTS

As explained in Section 3, the THDs are recorded by filter circuits and they are analyzed using FFT analysis. From simulation results, it is found that the reduction of THDs from each inverter is successfully executed. The THDs of Phase A, Phase B and Phase C are found to be 12.92%, 15.03% and 15.43% respectively before filter; and 2.40%, 0.38% and 1.95% respectively after filter. Fig 7a,b,c,d (Phase A), Fig 8a,b,c,d (Phase B) and Fig 9a,b,c,d (Phase C) shows the waveforms and THDs in filter circuits by FFT analysis.

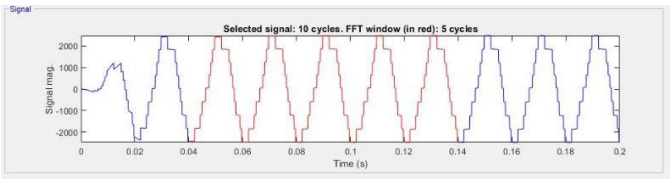

Fig 7a: FFT waveform for Phase A before filter circuit

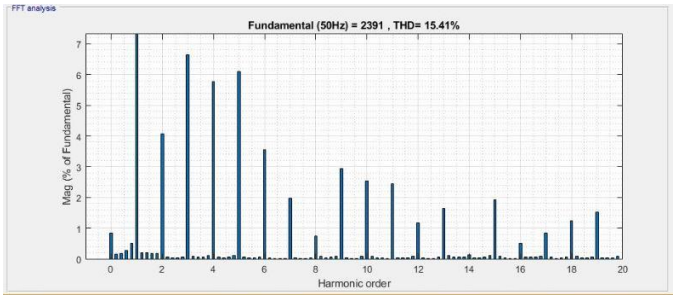

Fig 7b: FFT THD for Phase A before filter circuit

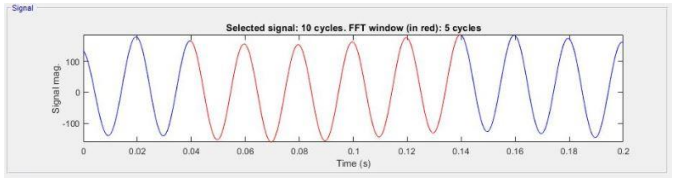

Fig 7c: FFT waveform for Phase A after filter circuit

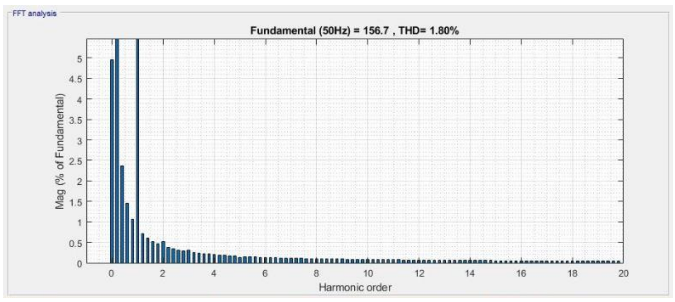

Fig 7d: FFT THD for Phase A after filter circuit

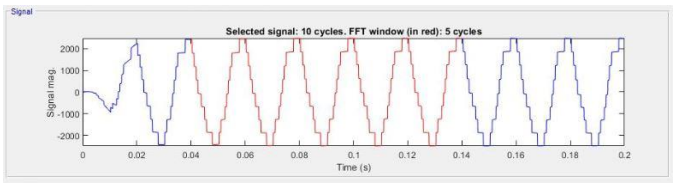

Fig 8a: FFT waveform for Phase B before filter circuit

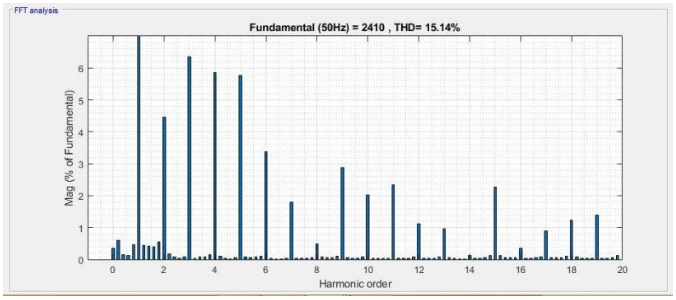

Fig 8b: FFT THD for Phase B before filter circuit

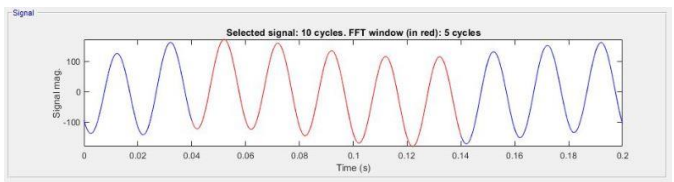

Fig 8c: FFT waveform for Phase B after filter circuit

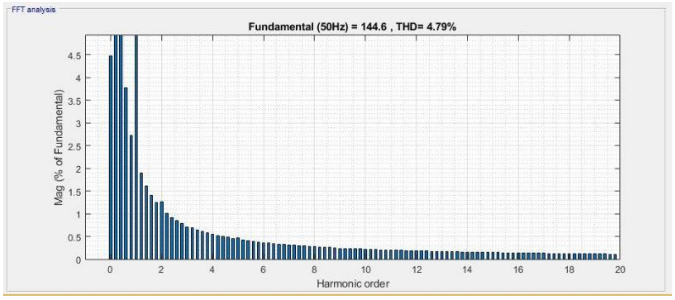

Fig 8d: FFT THD for Phase B after filter circuit

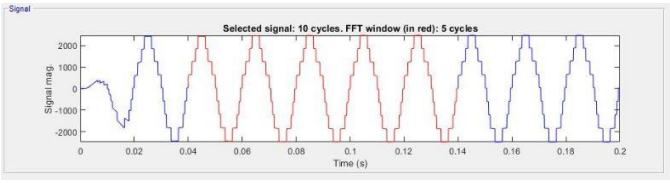

Fig 9a: FFT Waveform for Phase C before filter circuit

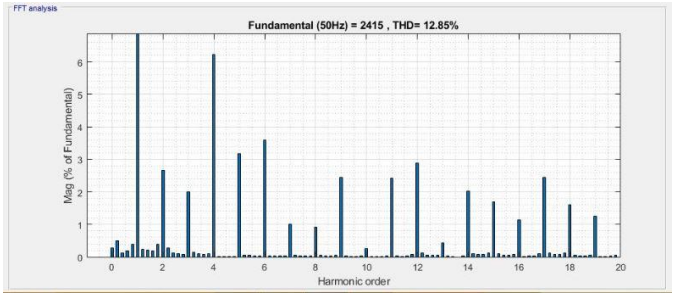

Fig 9b: FFT THD for Phase C before filter circuit

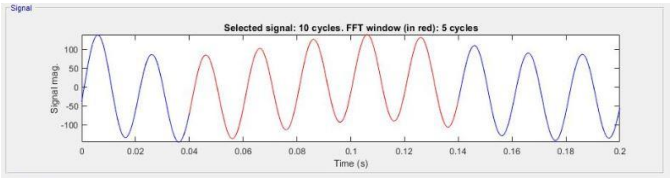

Fig 9c: FFT Waveform for Phase C after filter circuit

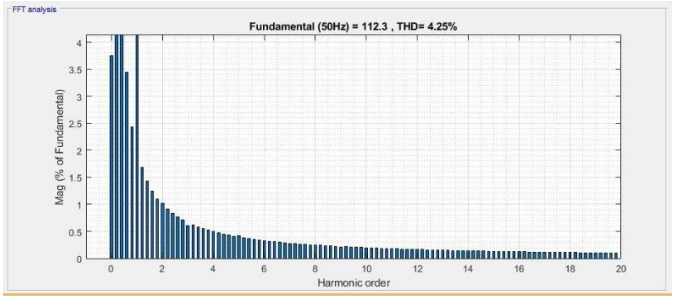

Fig 9d: FFT THD for Phase C after filter circuit

5. CONCLUSIONS

The cascaded H bridge 9 level inverter helped in increasing the voltage levels and thus producing the smooth sinusoidal output voltage. The produced voltage signals were then filtered by filter circuit to reduce the THDs. This is proven by simulation results and FFT Analysis and therefore the proposed inverter maintains efficiency.

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