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Improving Harmonics In An Advanced Three Phase Multilevel Inverter Connected To The Grid With A Hybrid Co-Generation Scheme

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***Abstract* – Renewable energy is the energy which comes from natural resources such as PV, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible, unlike dwindling conventional fossil fuels. In typical PV power generation systems, several photovoltaic panels are connected in series and parallel to form an array and feed energy to a single centralized three phase inverter or to a few parallel 'string' inverters. In this paper, a simple three-phase grid-connected hybrid generation scheme fed inverter topology consisting of a boost section, a low-voltage three-phase inverter with an inductive filter and a step-up transformer interfacing the grid is considered. This paper presents a three-phase 11, 13 and 15 level cascaded multilevel DC-AC grid-tied inverter operating under symmetrical & asymmetrical methodologies for many micro grid applications. A novel fundamental switching frequency scheme is proposed in this paper to be used with the energy source that can account for voltage profile fluctuations among the panels during the day, for this problem interfaced fuel cell across the PV system for attain affordable features. Simulation results are shown for voltage and current during grid connected mode to validate the methodology for grid connection of hybrid renewable resources.**

***Keywords* – Three Phase Grid Tied Inverter, Photo-voltaic System, Fuel Cell Stack, Hybrid Generation Scheme, Total Harmonic Distortion**

I. INTRODUCTION

Novel versatile photovoltaic PV systems still demand on at least one fuel cell with improved characteristics of robustness and efficiency, which can be achieved using hybrid topologies. In this paper, the boost-inverter topology is used as a building block for a single-phase grid-connected fuel cell (FC) with PV connected systems which offering low cost and compactness. Here proposed a reduced switch count converter topology is first proposed by integrating a forward energy-delivering circuit with a voltage-doubler to achieve high step-up ratio and high efficiency. It is seen that, for higher power applications, more modules can be paralleled to increase the power rating and the dynamic performance of the high step-up converter is proposed for a frontend PV/FC system interfaced to grid. Grid-connected three-phase co-generation systems are nowadays recognized for their contribution to clean power generation. A primary goal of these systems is to increase the energy injected to the grid by keeping track of the maximum power point (MPP) of the panel, by reducing the switching frequency, and by providing high reliability. In addition, the cost of the power converter is also becoming a decisive factor, as the price of the PV panels is being decreased as proposed in [1]. This has given rise to a big diversity of innovative converter configurations for interfacing the PV/FC modules with the grid. Currently, the state-of-the-art technology is the two-level multi string converter. The rapid evolution of semiconductor devices manufacturing technologies and the designer's orientation has enabled the development of new structures of inverters with a great performance compared to conventional structures. So, these new technologies of semiconductor are more suited to high power applications and they enable the design of multilevel inverters. The basic concept of a multilevel converter is to use a series of power semiconductor switches that properly connected to several lower dc voltage sources to synthesize a near sinusoidal staircase voltage waveform. The small output voltage step results in high quality output voltage, reduction of voltage stresses on power switching devices, lower switching losses and higher efficiency. Numerous multilevel converter topologies and wide variety of control methods have been developed in the recent literature as described. Three different basic multilevel converter topologies are the neutral point clamped (NPC) or diode clamped, the flying capacitor (FC) or capacitor clamped and the cascaded H-bridge (CHB) in [2].

The main drawbacks of NPC topology are their unequal voltage sharing among series connected capacitors that result in dc-link capacitor unbalancing and requiring a great number of clamping diodes for higher level. The FC multilevel converter uses flying capacitor as clamping devices. These topologies have several attractive properties in comparison with the NPC converter, including the advantage of the transformer less operation and redundant phase leg states that allow the switching stresses to be equally distributed between semiconductor switches [3], [4]. But, these converters require an excessive number of storage capacitors for higher voltage steps. The CHB topologies are proper option for high level applications from point of view of modularity and simplicity of control. The main advantage of multilevel inverters is that the output voltage can be generated with a low harmonics. Thus it is admitted that the harmonics decrease proportionately to the inverter level. For these reasons, the multilevel inverters are preferred for high power applications [5]. However, there is no shortage of disadvantages. Their control is much more complex and the techniques are still not widely used in industry [6]. More new applications have been for power system converters for VAR compensation and stability enhancement, active filtering, high-voltage motor drive, high-voltage dc transmission [7], and most newly for medium voltage induction motor variable speed drives [8].

Many multilevel converter applications focus on industrial medium-voltage motor drives [9], utility interface for renewable energy systems, flexible AC transmission system (FACTS) and traction drive systems. Multilevel inverters are commonly modulated, by using multicarrier pulse width modulation techniques, such as phase-shifted multicarrier modulation, and level-shifted multicarrier modulation. Amongst these, the level-shifted multicarrier modulation technique produces the best harmonic performance [10]. This work studies a multilevel inverter with un-equal DC sources, using the fundamental switching technique. By applying this concept, harmonics can be eliminated, and in the output voltage, the total harmonic distortion (THD) can be improved. A procedure to achieve the appropriate fundamental switching technique is presented in this paper.

II. Concept of Multilevel Inverter Topology

The inverters in such application areas as stated above should be able to handle high voltage and large power. Therefore, two-level high-voltage and large-power inverters have been designed with series connection of switching power devices such as gate-turn-off thyristors (GTOs), integrated gate commutated transistors (IGCTs), and integrated gate bipolar transistors (IGBTs), because the series connection allows reaching much higher voltages. However**,** the series connection of switching power devices has big problems as specified in [11]**,** namely, non-equal distribution of applied device voltage across series-connected devices that may make the applied voltage of individual devices much higher than blocking voltage of the devices during transient and steady-state switching operation of devices. As alternatives to effectively solve the above-mentioned problems, several circuit topologies of multilevel inverter and converter have been researched and utilized. The cascade H-bridge inverter is a cascade of H-bridges, or H-bridges in a series configuration. A single H-bridge inverter is shown in fig.2.1 and three phase cascaded H-bridge inverter for five-level inverter is shown in Fig. 2.2, Fig.2.1 and Fig2.2 shows the basic power circuit of single H-bridge inverter and the cascade of H-bridge inverter for seven-level inverter respectively. An N level Cascaded H bridge inverter consists of series connected (N-1)/2 number of cells in each phase. Each cell consists of single phase H bridge inverter with separate dc source. There are four active devices in each cell and can produce three levels 0, Vdc/2 and –Vdc/2. Higher voltage levels can be obtained by connecting these cell in cascade and the phase voltage van is the sum of voltages of individual cells, van = v1 + v2 + v3 + Vn.

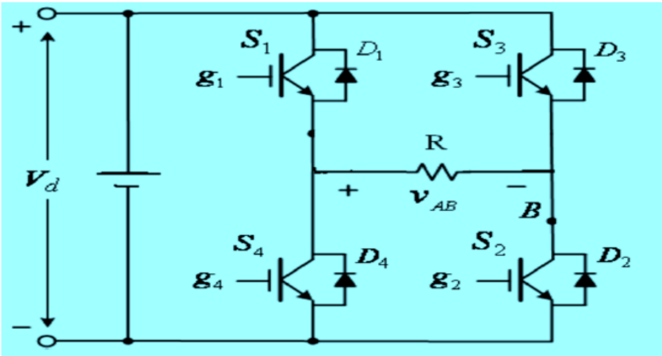

FIGURE 2.1: The Single-Phase H-Bridge Inverter

Figure 2.1 shows a single-phase three-level inverter. It has single arm. Each arm has four switches. Every switch is connected in antiparallel with a diode. In this topology there are two pairs of switches and two diodes are consists in a single bridge inverter. In an H-bridge inverter, there are three different feasible switching states which apply the stair case voltage on output voltage relating to DC link capacitor voltage rate [13]. At any time a set of two switches is on for a three-level inverter, and in a five-level inverter, a set of four switches is on at any given time and so on. Switching states of three level inverter are summarized in table-1.

Table 2.1: Switching states in one leg of the three-level H-bridge inverter

Output Voltage Levels	Switching States			
	S1	S2	S3	S4
+Vdc	1	1	0	0
-Vdc	0	0	1	
0	1/0	0/1	0/1	1/0

Fig.2. shows a five-level CHB type converter in which the dc bus consists of two dc sources in each bridge, such as. Vdca, Vdcb, Vdcc, For dc-bus voltage Vdc, the voltage across all sources is same with series combination will get high respective voltage and each device voltage stress will be limited. Five level output voltage as shows in fig.3.

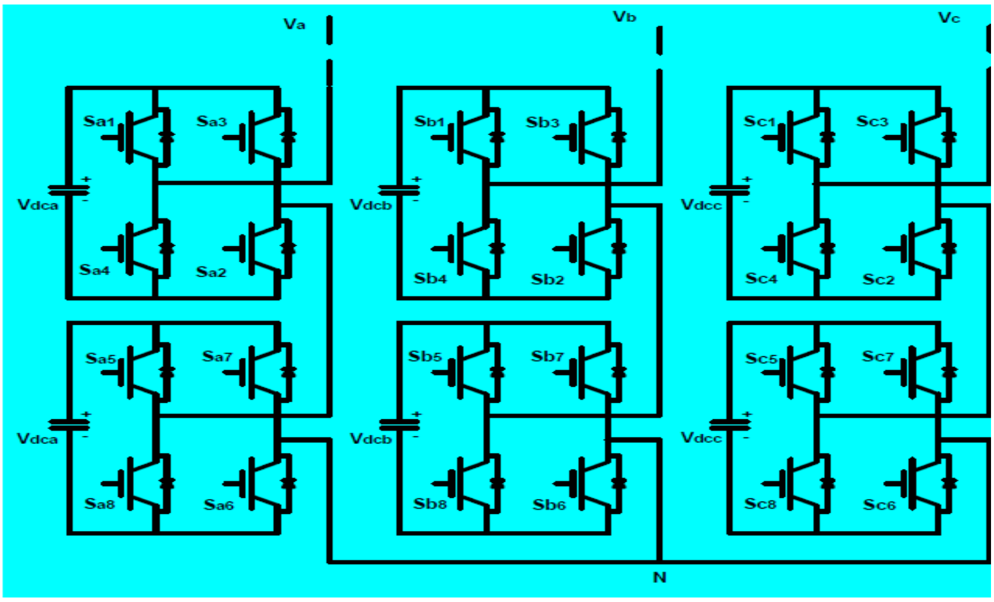

Figure 2.2: Five level CHB type Multi-Level Inverter

Table 2.2: Switching states in one CHB of the five-level cascaded H-bridge inverter

Output Voltage	Switching States							
	Sa1	Sa2	Sa3	Sa4	Sa5	Sa6	Sa7	Sa8
Va=0	0	1	0	1	0	1	0	1
Va=Vdc	1	2	0	0	0	1	0	1
Va=2Vdc	1	1	0	0	1	1	0	0
Va=-Vdc	0	0	1	1	0	1	0	1
Va=2Vdc	0	0	1	1	0	0	1	1

The inverter output voltages are written as follow:

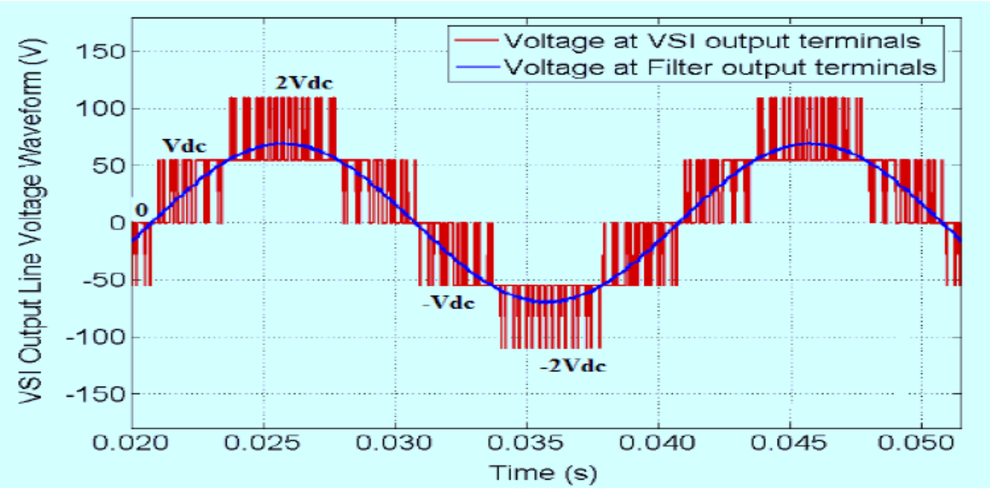

Figure 2.3: Five Level Output Voltage

III. Proposed Co-Generation Based Grid Connected Scheme

Hybrid renewable energy systems have the remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply A hybrid energy system is a photovoltaic array coupled with a wind turbine. This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output. Hybrid energy systems oftentimes yield greater economic and environmental returns than wind, solar, geothermal or regeneration stand-alone systems by themselves.

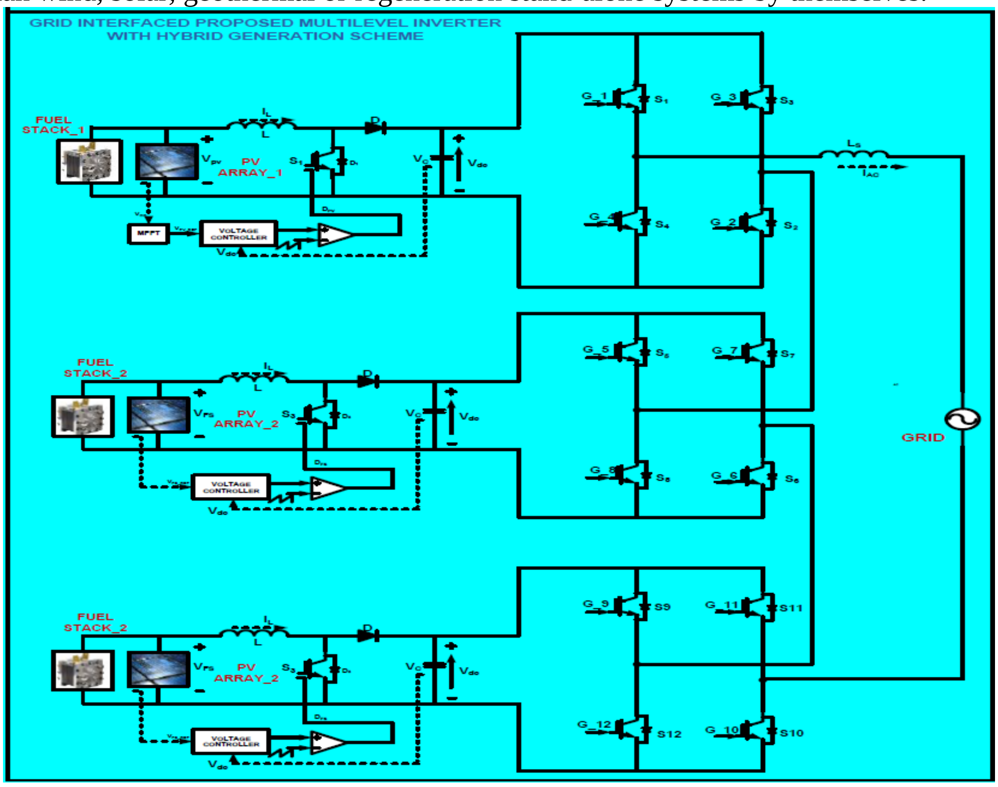

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Figure 3.1: Proposed Hybrid generation Scheme Based Reduced Switch Type 15-level Inverter Fed Grid Connected Scheme

The photovoltaic (PV) and fuel cell power generation systems are renewable energy sources that expected to play a promising role in fulfilling the future electricity requirements. The PV systems principally classified into stand-alone, grid connected or hybrid systems. The grid-connected PV/FC systems generally shape the grid current to follow a predetermined sinusoidal reference using a HCC, which has the advantages of inherent peak current limiting and fast dynamic performance [15]. The model of grid connected photovoltaic system to control active and reactive power injected in the grid is presented. The structural design of this new power converter allows an 11 level shaped output voltage wave at the output of multilevel inverter with hybrid source as shown in Fig 3.1, with the help of co-generation system, system achieves more stability factor, with low error values and minimize the voltage fluctuations coming from grid, maintain high reliability.

3.1Photovoltaic Array Modelling:

Numerous PV cells are connected in series and parallel circuits on a panel for obtaining high power, which is a PV module. A PV array is defined as group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction that directly converts solar radiation into dc current using photovoltaic effect. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode, shown in Fig. 3.2.

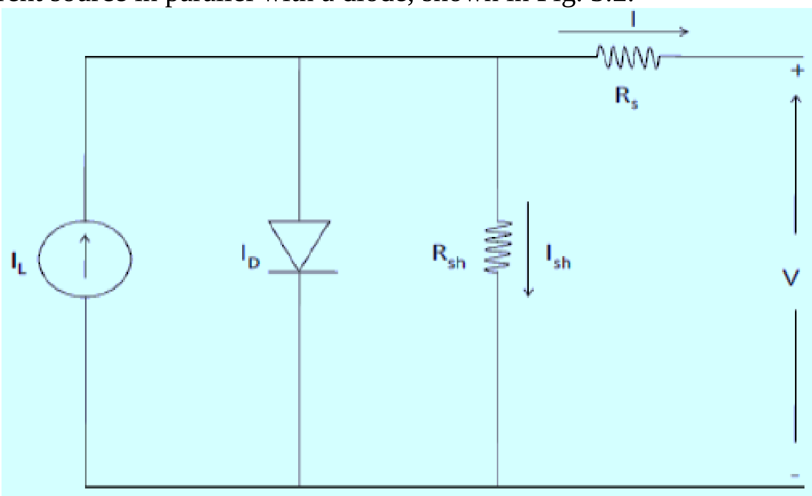


Figure 3.2: Circuit Diagram of a Solar Cell

The series resistance RS represents the internal losses due to the current flow. Shunt resistance Rsh, in parallel with diode, this corresponds to the leakage current to the ground. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behavior of the PV cell. The grid integration of RES applications based on photovoltaic systems is becoming today the most important application of PV systems, gaining interest over traditional stand-alone systems. This trend is being increased because of the many benefits of using RES in distributed (aka dispersed, embedded or decentralized) generation (DG) power systems.

3.2. About Fuel Cell:

The fuel cells are electrochemical devices that convert chemical energy directly into electrical energy by the reaction of hydrogen from fuel and oxygen from the air without regard to climate conditions, unlike hydro or wind turbines and photovoltaic array. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied. Thus, the fuel cells are among the most attractive DGs resources for power delivery. However, batteries need to be placed in parallel or in series with the fuel cells as a temporary energy storage element to support during startup or sudden load changes because fuel cells cannot immediately respond to such abrupt load changes. Generally, fuel cells produce dc voltage outputs, and it keeps on varying with the load. So they are always connected to electric power networks through power conditioning units such as DC/DC and DC/AC to maintain the voltage constant or to stabilize the voltage.

IV. MATLAB/SIMULINK Modelling & Results

Here simulation is carried out in several cases, in that here simulation is carried out in several configurations, in that

- Proposed Asymmetrical & Symmetrical 11-Level Inverter operating under high Switching Frequency Interfaced to Grid Connected System with Hybrid Generation Scheme.
- Proposed Asymmetrical 13-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System with Hybrid Generation Scheme.
- Proposed Asymmetrical 15-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System with Hybrid Generation Scheme.

Case 1: Proposed 11-Level Inverter operating under high Switching Frequency Interfaced to Grid Connected System

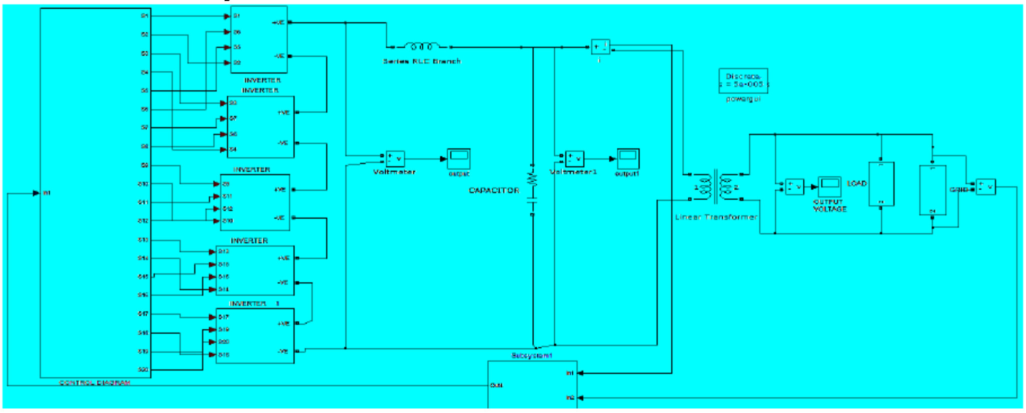
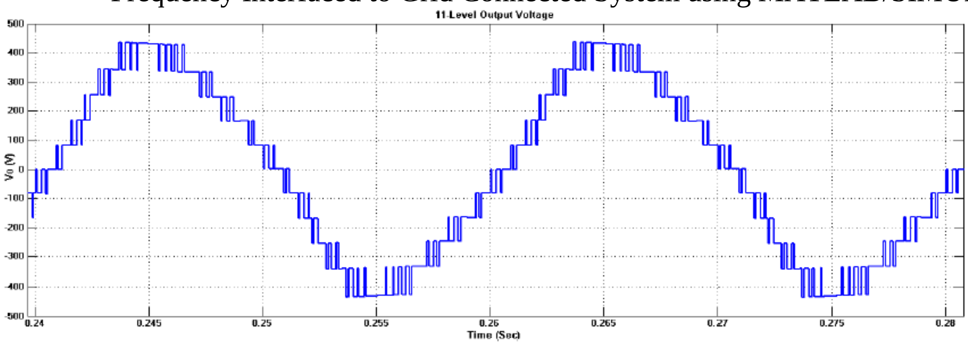
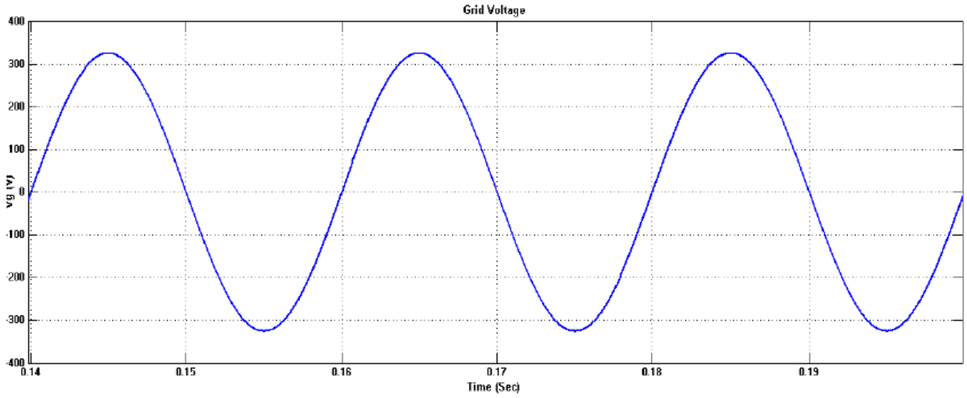


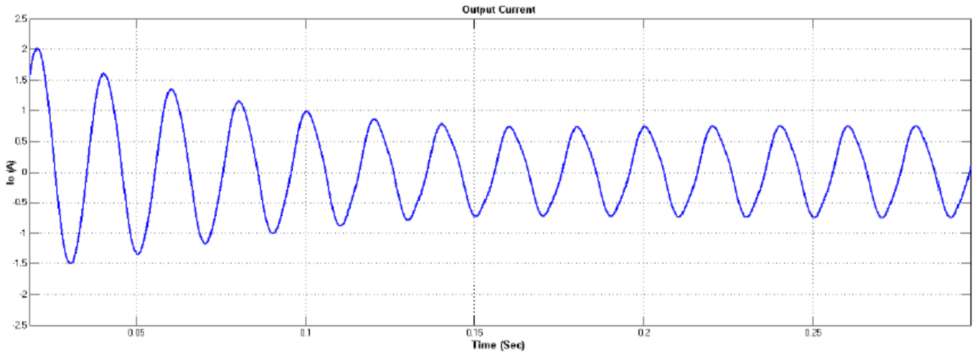
Figure 4.1: Matlab/Simulink Model of proposed 11-Level Inverter operating under high Switching Frequency Interfaced to Grid Connected System using MATLAB/SIMULINK Tool



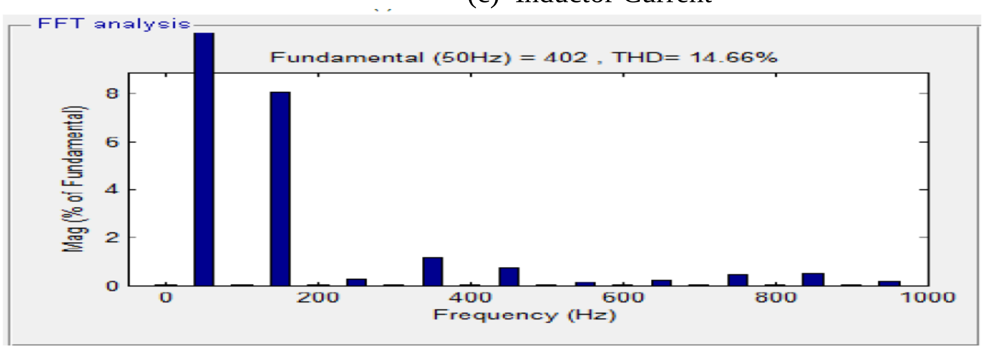
(a) Output Voltage



(b) Grid Voltage



(c) Inductor Current



(d) THD Analysis of Output Voltage

Figure 4.2: (a) 11-Level Output Voltage, (b) Grid Voltage, (c) Inductor Current before Grid, (d) THD Analysis of 11-Level Output Voltage of proposed 11-Level Inverter operating under high Switching Frequency Interfaced to Grid Connected System, attain THD value is 14.66%.

Case 2: Proposed 11-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System Fed Hybrid Generation Scheme.

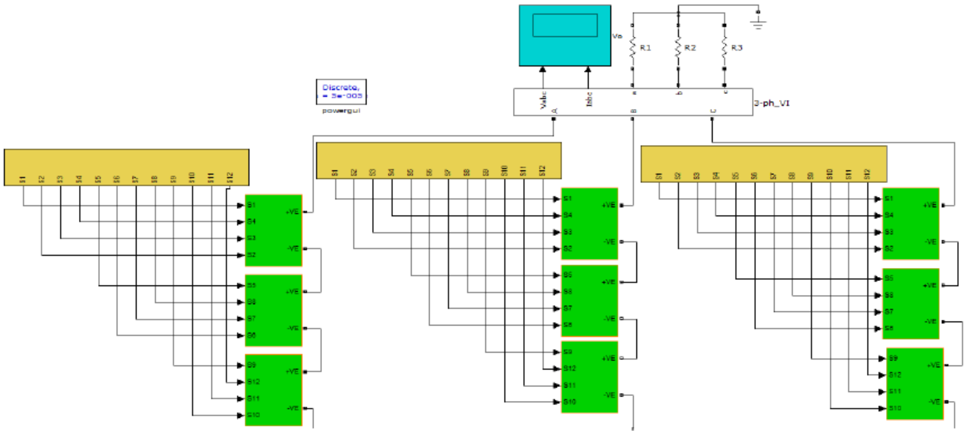
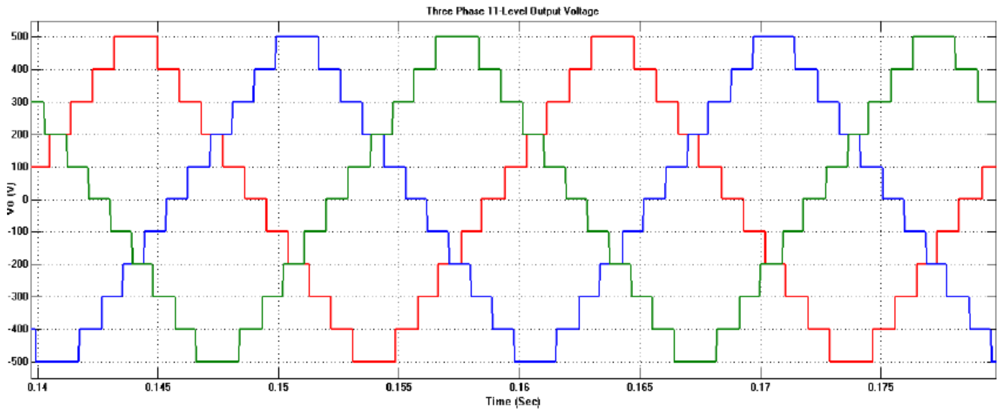
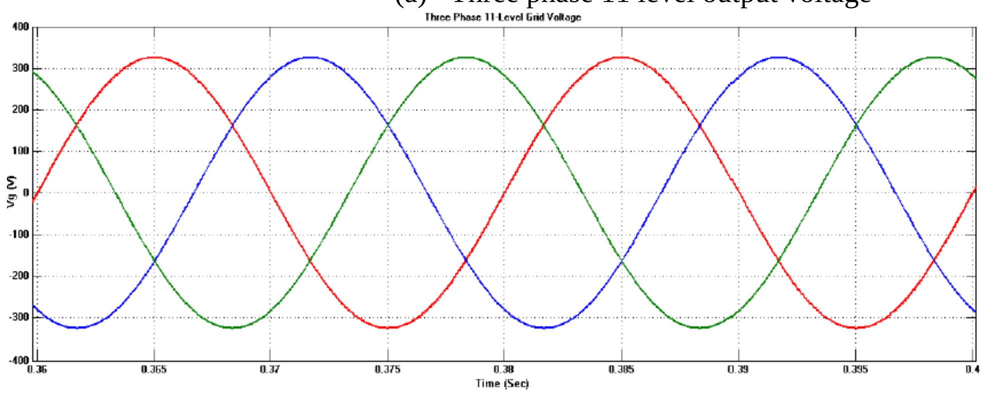


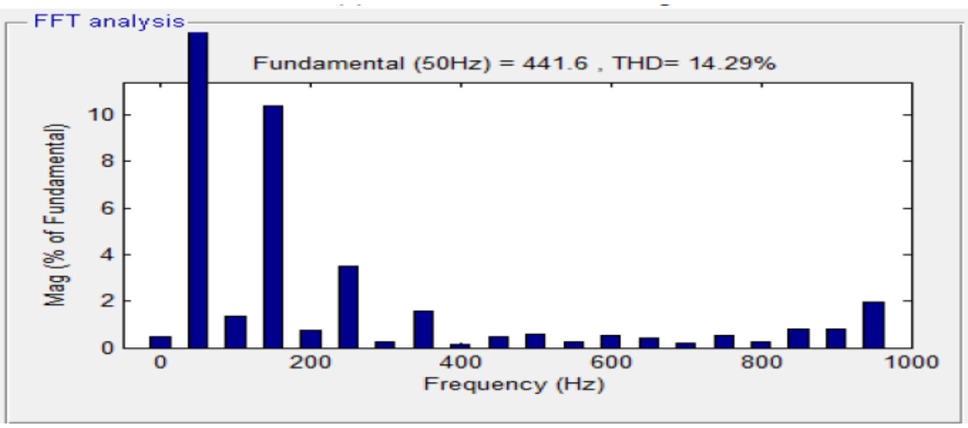
Figure 4.3: Matlab/Simulink Model of Proposed Three Phase 11-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System Fed Hybrid generation Scheme using MATLAB/SIMULINK Tool.



(a) Three phase 11 level output voltage



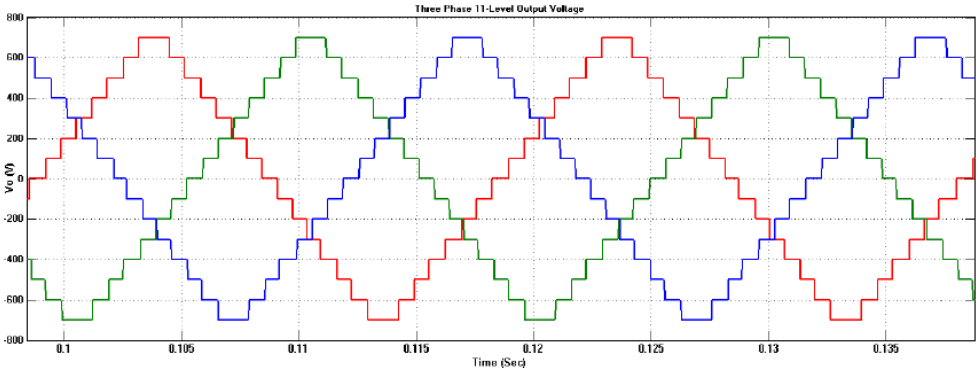
(b) Three phase grid Voltage



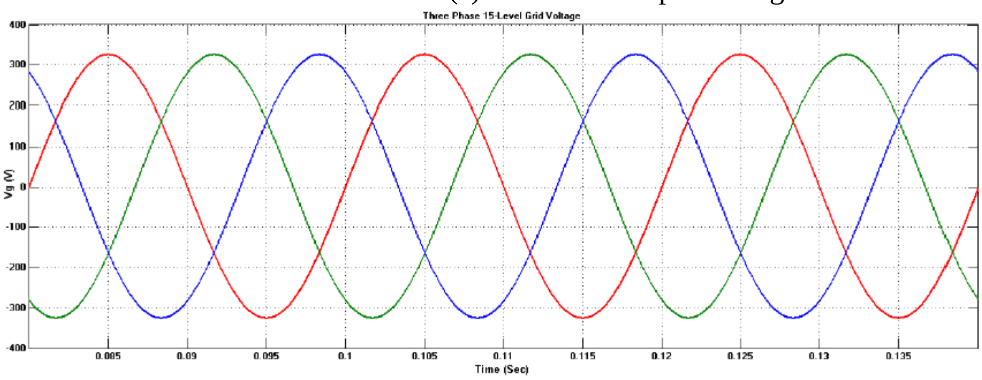
(c) THD Analysis of 11-Level Output Voltage

Figure 4.5: (a) Primary Voltage & Current, (b) Grid Voltage, (c) THD Analysis of output Voltage of proposed Three Phase 13-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System Fed Hybrid generation Scheme and attaining THD value is 11.60%.

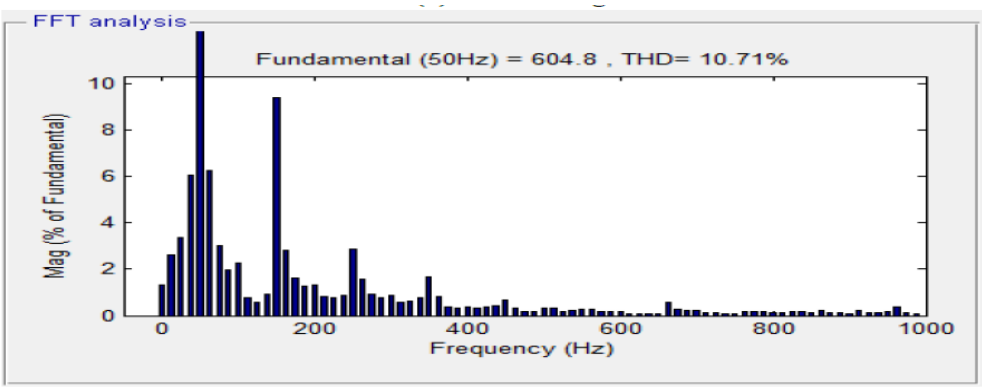
Case 04: Proposed 15-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System Fed Hybrid Generation Scheme.



(a) 15 Level Output Voltage



(b) Grid Voltage



(c) THD Analysis of 15 Level Output Voltage

Figure 4.6 :(a) Primary Voltage & Current, (b) Grid Voltage, (c) THD Analysis of output Voltage of proposed Three Phase 15-Level Inverter operating under Fundamental Switching Frequency Interfaced to Grid Connected System Fed Hybrid Generation Scheme and attaining THD value is 10.71%.

V. CONCLUSION

This paper presented a three phase 11, 13, 15-level cascade H-bridge inverter with grid connected hybrid generation system is act as input source, this type of systems are mostly preferred in distribution generation scheme. A fundamental switching technique approach was presented to deal with the uneven power transferring characteristics of the conventional modulation technique. This technique proved to be successful due to the irradiance profile and the use of extra source to smooth the voltage fluctuation with the help of fuel cell source.. Grid connection results were shown using the proposed symmetrical & asymmetrical inverter modules. The entire PV/FC system structure and its interaction with the grid through PLL and MPPT algorithms were shown by the simulation results. The FFT analysis of proposed inverter topologies are well within the IEEE standards

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