IJCTA, 10(02), 2017, pp. 293-303

Grid Integration of Renewable Energy Sources with Power Quality Improvement Features using Multilevel Inverters

R. Karthick* and S. Manoharan**

Abstract : Hybrid power systems consisting of several alternative energy sources that includes solar cells, wind turbine, fuel cells and storage batteries. Wind and solar energy can play an important role in ensuring an emission free and clean energy generation for remote and isolated areas. In this paper, a grid connected wind and PV hybrid power generating system was developed with improved power quality features. A cascaded multilevel inverter and its control strategy that enables both islanded and grid tied operation of three phase inverter for this hybrid power system was developed. Furthermore, the load voltage in the islanding mode is distorted under non-linear load which is mitigated by the proposed control strategy. The entire system is build and the results are verified using MATLAB/SIMULINK software.

Keywords: Wind generator, Photovoltaic, multilevel inverter, hybrid power system, power quality.

1. INTRODUCTION

As generation and distribution companies in the market have been seeing an increasing interest in the renewable energy sources and also seeing demands from customers for higher quality and cleaner electricity, we are need to switch over for renewable energy generation methods.

In order to reduce the green house gas emission from electrical power generation and for growing demand of electricity, particular advantages in wind and PV energy technologies have increase their use in hybrid power generating systems, because of emission free and no cost of energy. Hybrid power wind and PV systems are one of the most efficient solution to supply power directly to a utility grid or to an isolated load[1]. In Ref [1] the authors have discussed the feasibility to model a micro grid consisting of SOFC and PV system. The authors have constructed the block set for power sources and power electronics in MATLAB Simulink.

For efficient utilization of the available sources, advanced power electronics systems are a good solution. In recent days the multilevel converters are considered to be the most promising technology for grid interaction of renewable energy because of their salient features like low harmonic distortion, low switching losses and to handle high voltage capacity and power [2] – [3]. The topologies of multilevel inverter have several other advantages such as lower Total Harmonic Distortion (THD), lower Electro Magnetic Interference (EMI) and higher output voltage.

The major problem associated with wind and solar energy sources is that they are unpredictable and interim in nature. Ref [4]-[5] addresses the various trends in wind energy systems. The authors in Ref [6] – [7] have discussed the grid connection of solar PV module. In the above sources, if a battery system is

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accompanied, the above said problems can be overcome. A separate controller will control the charging and discharging of the battery. The presence of non linear load in the grid will degrade the quality of voltage and current waveforms thus causing power quality issues. There are various filters which can mitigate the power quality issues but they are very complicated and costly affair.

This paper aims at the grid interconnection of hybrid renewable energy sources with power quality improvement features, using cascaded multilevel inverter with battery banks. The principle advantage of using multilevel inverters is the low harmonic distortion obtained due to the multiple voltage levels at the output and reduced stresses on the switching devices.

The rest of the paper is organized as follows: Section II discusses the wind and solar system. Section III discusses the structure of the proposed Hybrid system. Section IV presents an overview of Boost converters for hybrid system. Sections V discuss cascaded multilevel Inverter. In section VI the proposed closed loop control strategy of inverter is discussed. Finally, the corresponding simulation results and conclusions are discussed in Section VII and VIII**.**

2. WIND AND SOLAR HYBRID SYSTEM

2.1. Wind Power Generating System

A hybrid energy system consists of two or more renewable energy sources to enhance increased system efficiency as well as greater balance in energy supply. Wind turbine is a device that converts kinetic energy from the wind into mechanical energy and that mechanical energy is again converts into electrical power .The power from the wind is depends upon aerodynamically designed blades and rotor construction[8]-[9]. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time . that is expressed in equation

$$P_{air} = \frac{1}{2}(\text{air mass per unit volume})^2 \quad (2.1)$$

$$= \frac{1}{2}(\rho A V_\infty)(V_\infty)^2 \quad (2.2)$$

$$= \frac{1}{2}\rho A V_\infty^3 \quad (2.3)$$

P_{air} – Power contained in wind(in watts)
A – Swept area in (square meter)
V_∞ – Wind velocity without rotor interference

Although Equation (2.1) gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient, C_p

$$C_p = \frac{P_{\text{wind turbine}}}{P_{air}} \quad (2.4)$$

$$P_{\text{wind turbine}} = C_p * P_{air}$$

$$S = \frac{1}{2}\rho A V_\infty \quad 2.5)$$

A maximum value of C_p is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum C_p values in the range 25-45%.

2.2. PV Power Generating System

The building block of PV arrays is the solar cell, which is basically a *p-n* junction that directly converts light energy into electricity. PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. Due to the low voltage generated in a PV cell (0.5V), several PV cells are connected in series and in parallel to form a PV module for desired output. The power that one module can produce is not sufficient to meet the requirements of home or business. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads, lights etc. The modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current. Wind power generating system was connected to the grid and the PV system was used for supporting the DC bus of the hybrid power generating system [10]-[16]. The PV mathematical model used to simplify our PV array is represented by the equation:

$$\mathrm{I} = n_p \mathrm{I}_{ph} - n_p \mathrm{I}_{rs} \left[\exp^{\frac{q}{\mathrm{KTA}} \times \frac{\mathrm{V}}{ns}} \right]$$

I_{ph} – cell photo current
T – cell temperature(*k*)
N_p – cells in series
N_s – cells in parallel
A – *p-n* junction ideality factor

3. BLOCK DIAGRAM OF HYBRID SYSTEM STRUCTURE

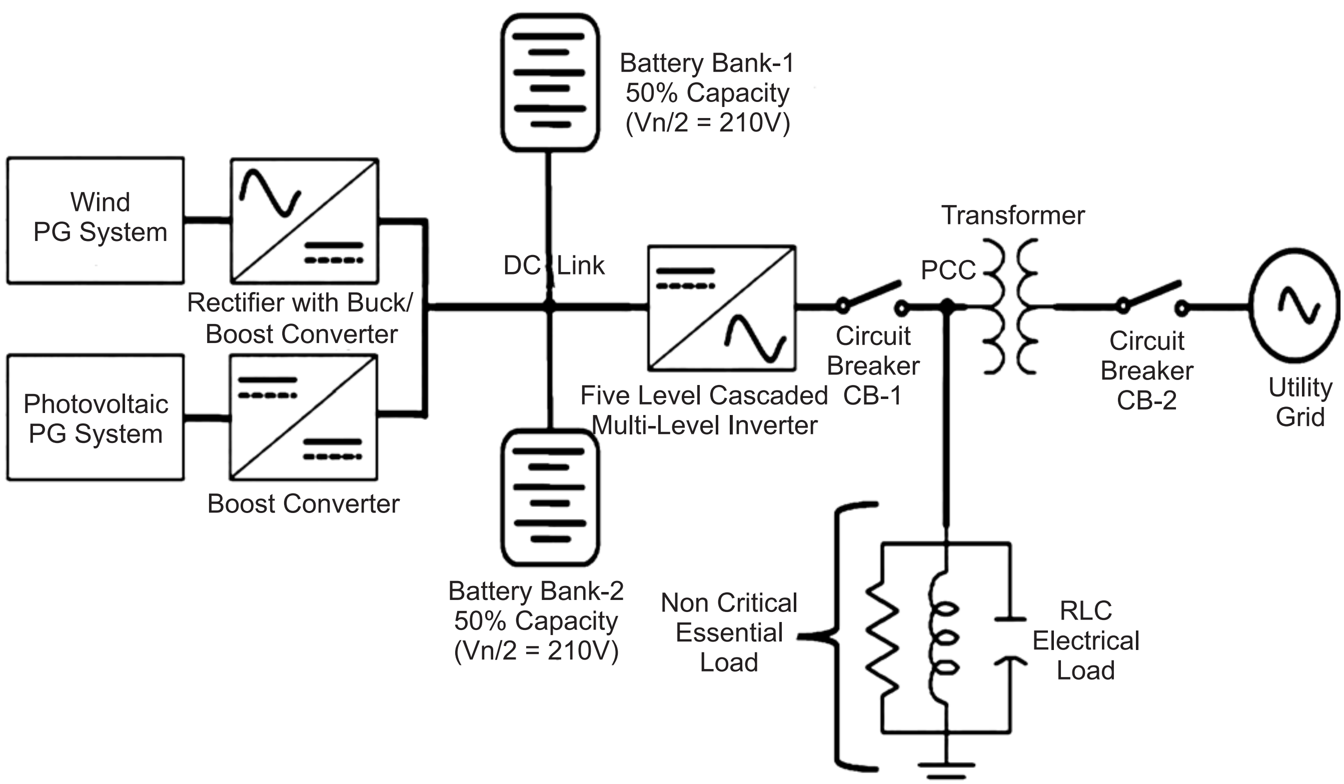


Figure 1: General Structure of the Proposed Model

Hybrid system consists of several alternative energy sources. such as solar cells, wind turbines, micro-turbines , fuel cells and storage batteries that are connected in addition to the main power grid. That is connected to the distribution network through power electronics. There are several reasons why micro-grids are so interesting. First, because they involve alternative energy sources, and most alternative sources offer far higher efficiency and less environmental issues than standard power generation. The hybrid system consisting of wind and photovoltaic system is shown in figure.1.Wind and solar systems are connected to the grid through cascaded multilevel inverter. The inverter is designed in the way to integrate the hybrid systems to the grid and also to eliminate the harmonics and to improve the power quality problems, which increases system efficiency. The system supplies the load and when there is excess power it is given to the grid. Manual switch is used to connect the sources with grid. Converters were designed in order to get the constant dc bus voltage. Battery banks are provided for backup storage power.

4. DC/DC CONVERTER MODEL

DC-DC converters are used to convert an uncontrolled dc voltage to a controlled dc output voltage. The regulation is normally achieved by PWM pulse at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency. Due to the variable characteristics of the wind the output voltage from PMSG is varying corresponding to wind speed so uncontrolled rectifier with boost converter is used in order to get constant DC voltage [7]. Output voltage of solar module and rectifier is not desired for inverter input, so that the converters were designed to obtain expected voltages from different source.

5. CASCADED MULTILEVEL INVERTER

Both the wind and solar after the conversion is connected to the battery banks through the common DC bus. Wind and solar systems are connected to the grid through cascaded five level multilevel inverter. The inverter is designed in the way to integrate the hybrid systems to the grid and also to eliminate the harmonics and to enhance the power quality problems. The proposed closed loop control of the inverter helps to enhance the power quality to system.

6. PROPOSED CLOSED LOOP CONTROL

The role of cascaded multilevel inverter in this paper is to integrate the source to grid as well as to eliminate harmonics and improve power quality problems. Battery banks were provided for energy storage purpose.

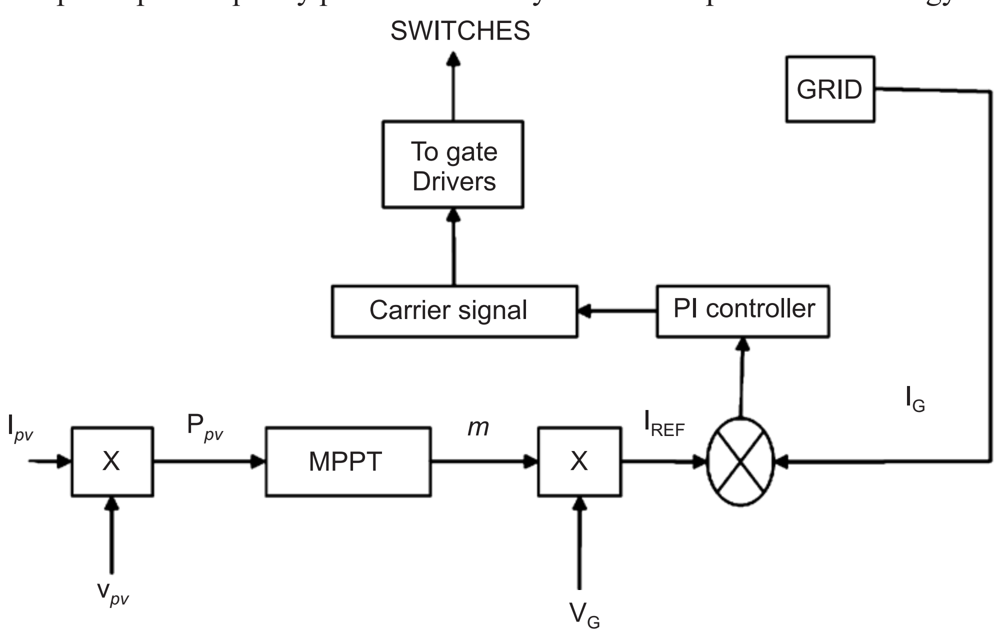


Figure 2: Block diagram of Control Strategy of cascaded multilevel Inverter

In this symmetric multilevel inverter 24 switches are used. Basically the inverter operation is to convert the variable DC into an AC. The input dc source is given by using batteries or hybrid power system to the cascaded inverter circuit. By using pulse width modulation technique the triggering pulse given to the switches which are controlled using the control strategy. The overall control diagram shows in fig 2.

7. SIMULATION RESULTS

7.1. Results Of Hybrid Wind And Solar System

The overall system of the proposed system is implemented in MATLAB which is shown below and each section is represented separately for better understanding. The system under consideration employs PMSG based wind turbine, solar system and an inverter with unified control strategy [17]. Moreover, the inverter in the DG is fed by a three-phase diode rectifier, and the dc-bus voltage is 400 V.

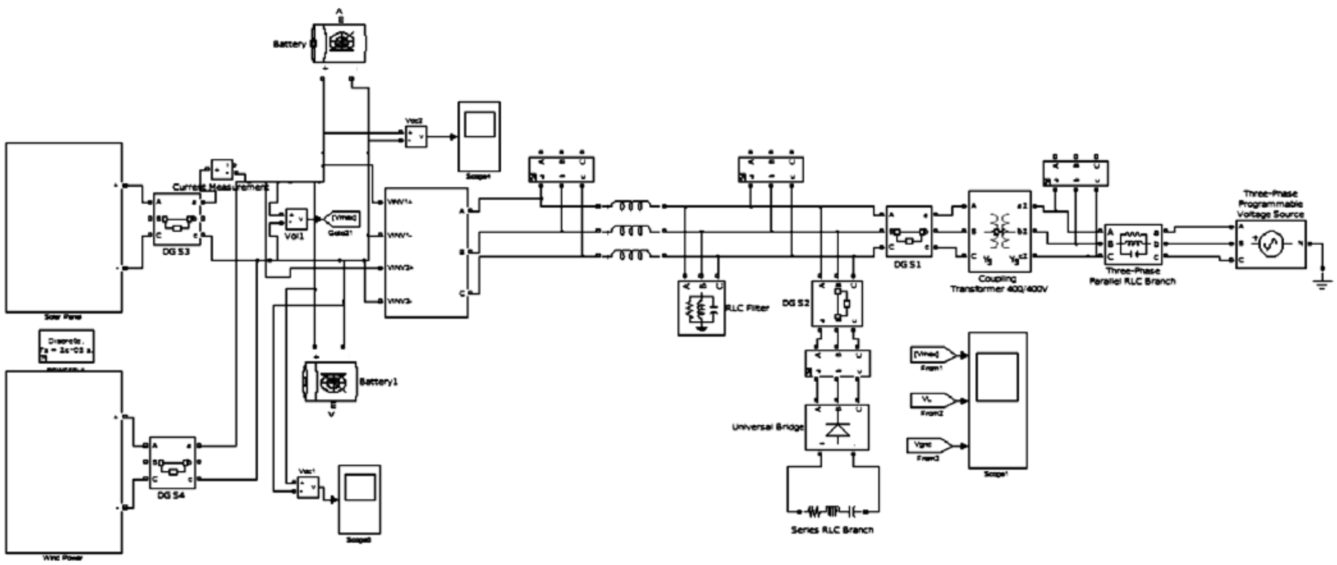
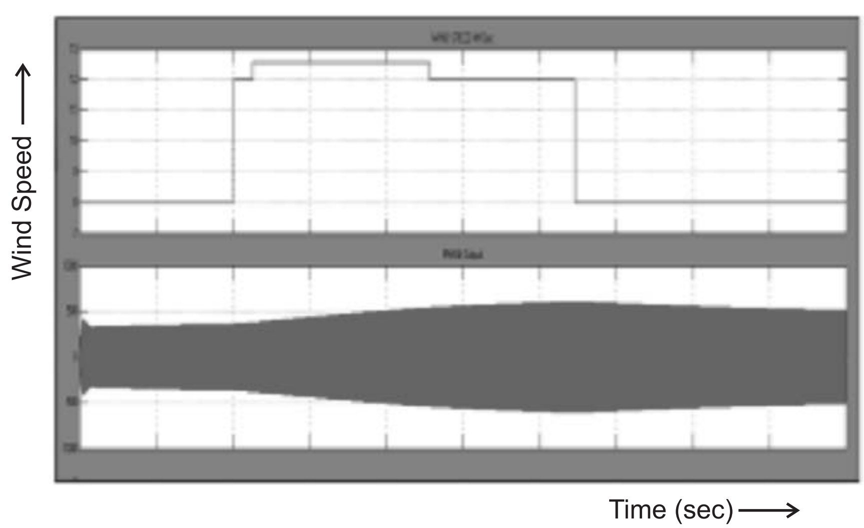


Figure 3: Grid Integration of renewable energy sources with cascaded multilevel inverter model

The systems under consideration employs grid inter connected hybrid wind and solar power generating system with dual purpose inverter. The wind turbine converts the power of the wind to mechanical power in the rotor shaft. This is then converted to electricity using a permanent magnet synchronous generator (PMSG). The output voltage is rectified using a three-phase diode bridge rectifier. The dc-to-dc converter is used to increase the rectified dc voltage. Same way solar energy is converted into electrical energy with the help of solar cells, the produced solar energy is not sufficient to support the DC bus so that dc –to- dc converter used to enhance the voltage. The role of dual purpose inverter in this project is to integrate the source to grid as well as to eliminate harmonics and improve power quality problems.



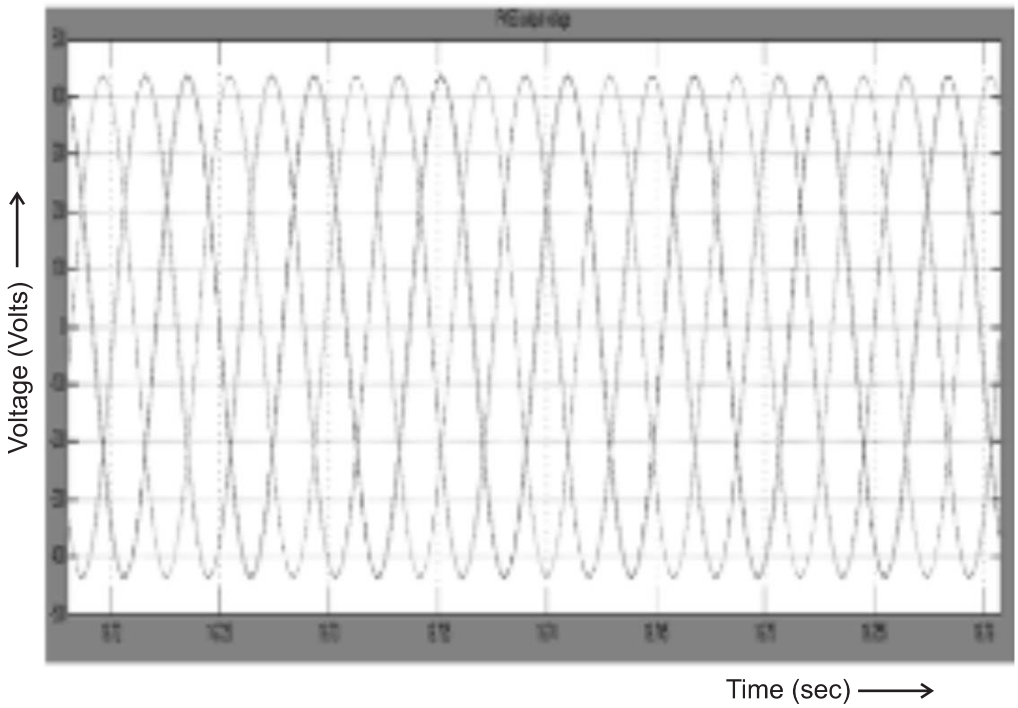


Figure 4: Varying Wind Speed and corresponding PMSG Output

Due to the variable characteristics of the wind the output voltage from PMSG is varying corresponding to wind speed so uncontrolled rectifier with boost converter is used in order get constant DC voltage.

The PV module has been designed taken into consideration its depends upon the irradiance, temperature, number of PV cells connected in series and parallel. The detailed block of PV module is shown in Fig.5.Solar output voltage is not sufficient to support DC bus so boost converter is used in order to get desired output**.** The output voltage of boost converter is shown in the fig.7. The output waveform shows that 180V of PV panel is boosted into 400V and fed into the common DC bus.

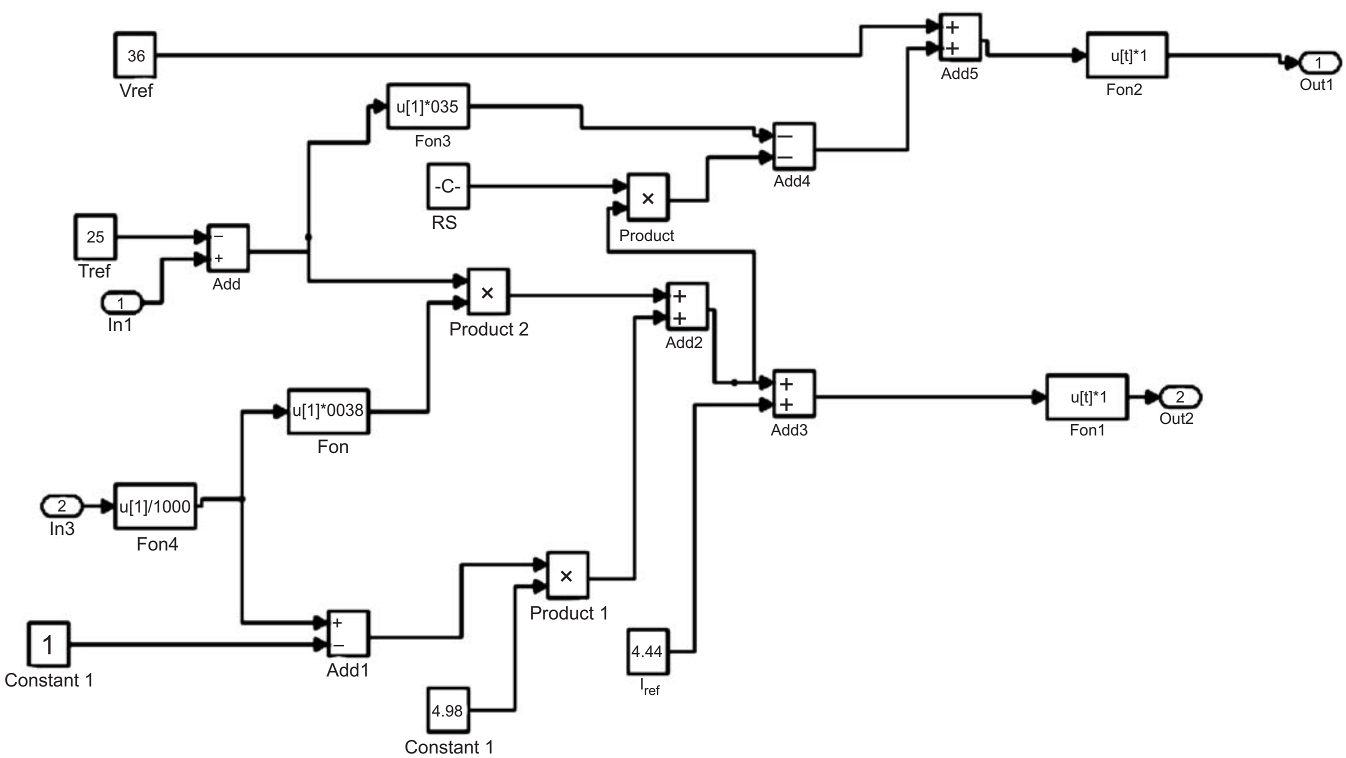


Figure 5: Simulink diagram of solar model

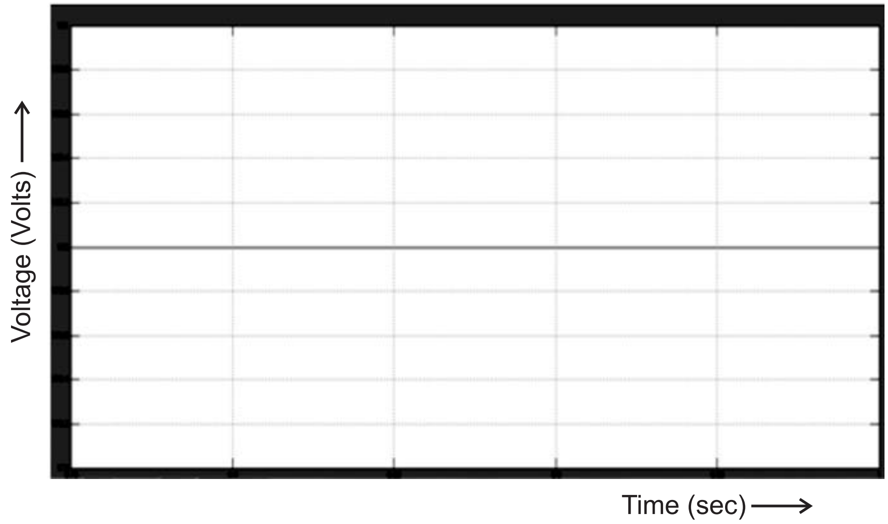


Figure 6: Output Voltage of Single PV module

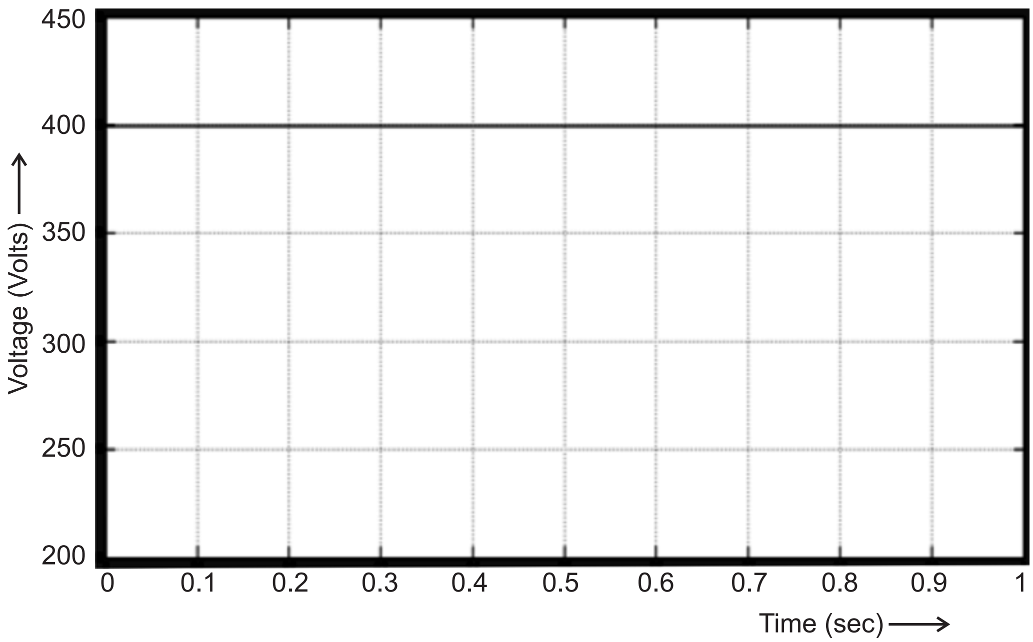


Figure 7: Output Voltage of Boost Converter (PV)

7.2. Results of Multilevel Inverter Model

The cascaded multilevel inverter regulates dc- voltage from battery bank and injects the generated power into the grid as well as to the non- linear load [18]. In addition to this, the inverter is also eliminating harmonics generated by non-linear loads. The proposed strategy helps to achieve improved power quality at PCC. The corresponding Cascaded multilevel inverter model is shown in fig .8.

The Fig.9. shows that the load voltage wave form is distorted without controller and harmonic component is presented.

The Fig.10. shows the waveforms when DG feeds nonlinear load in the islanded mode with control circuit. It can be seen that the distortion of the load voltage is improved by proposed control strategy.

7.3. THD Analysis for Non Linear Load

The Fig.13. shows THD of the load voltage is minimized from 15.63% to 1.49%. The proposed cascaded multilevel control strategy helps to achieve IEEE standard requirements with improved power quality at PCC. The corresponding results were obtained.

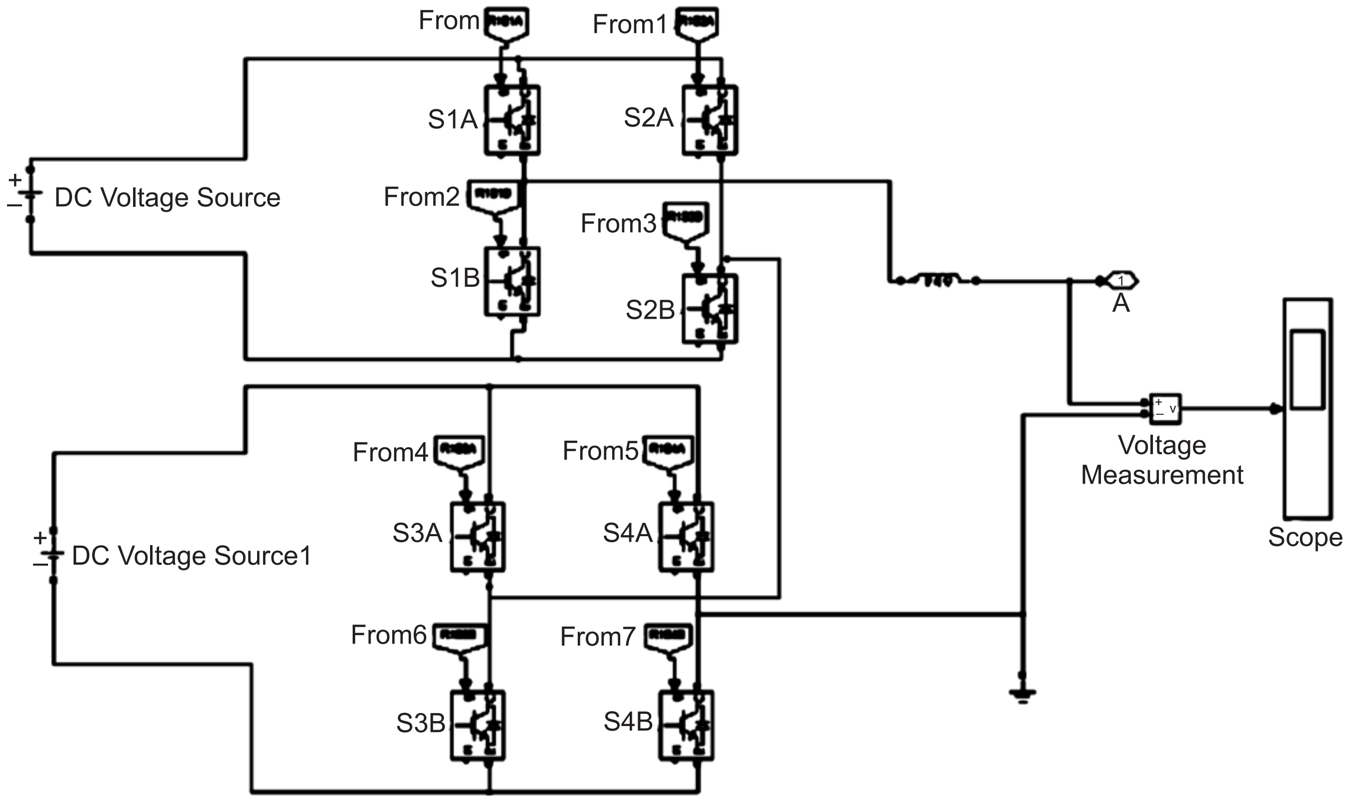


Figure 8: Cascaded fivel level Inverter Model

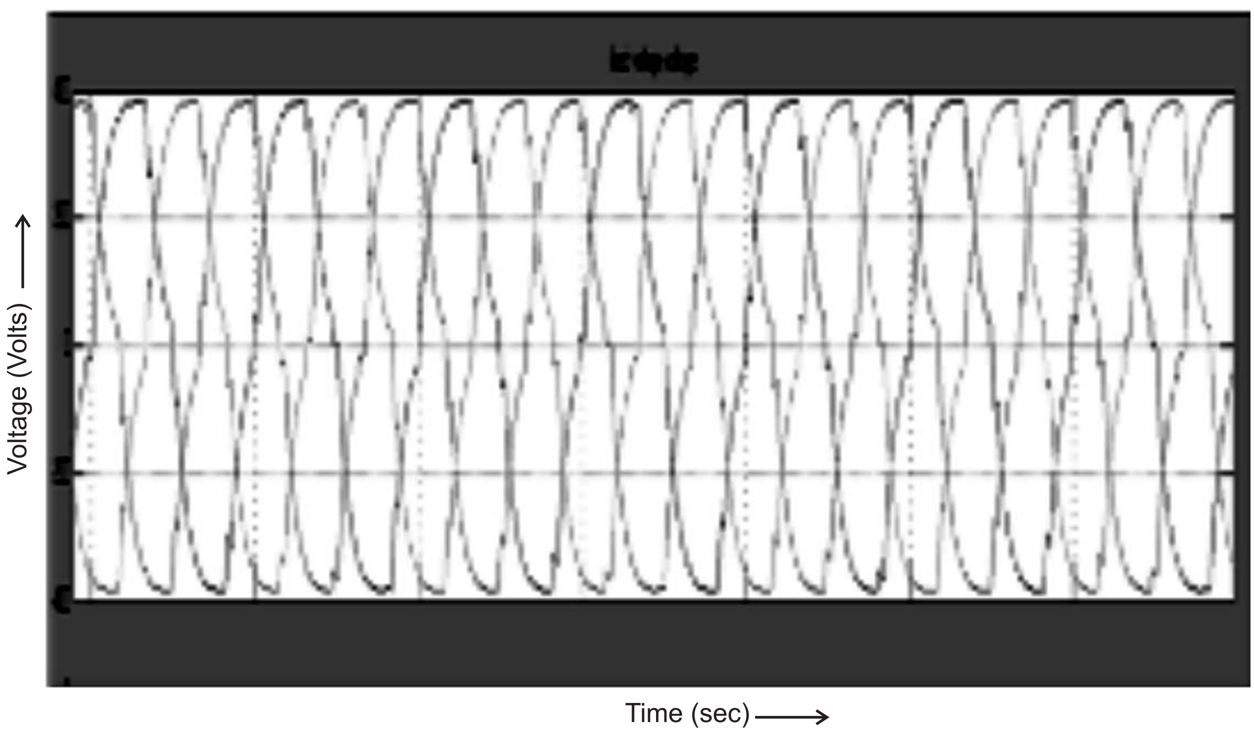


Figure 9: Distortion Waveform of Inverter without controller

8. CONCLUSION

In this paper, a grid connected solar and wind hybrid power system was developed using MATLAB/ SIMULINK software. The hybrid power system is connected to the load and also to the grid through a manual switch. Cascaded five level inverter was designed, with a PWM control, to improve the power quality problem and also to integrate hybrid power system to grid. Results are simulated and discussed. The THD of the load voltage is minimized to 1.49%, to achieve IEEE standard.

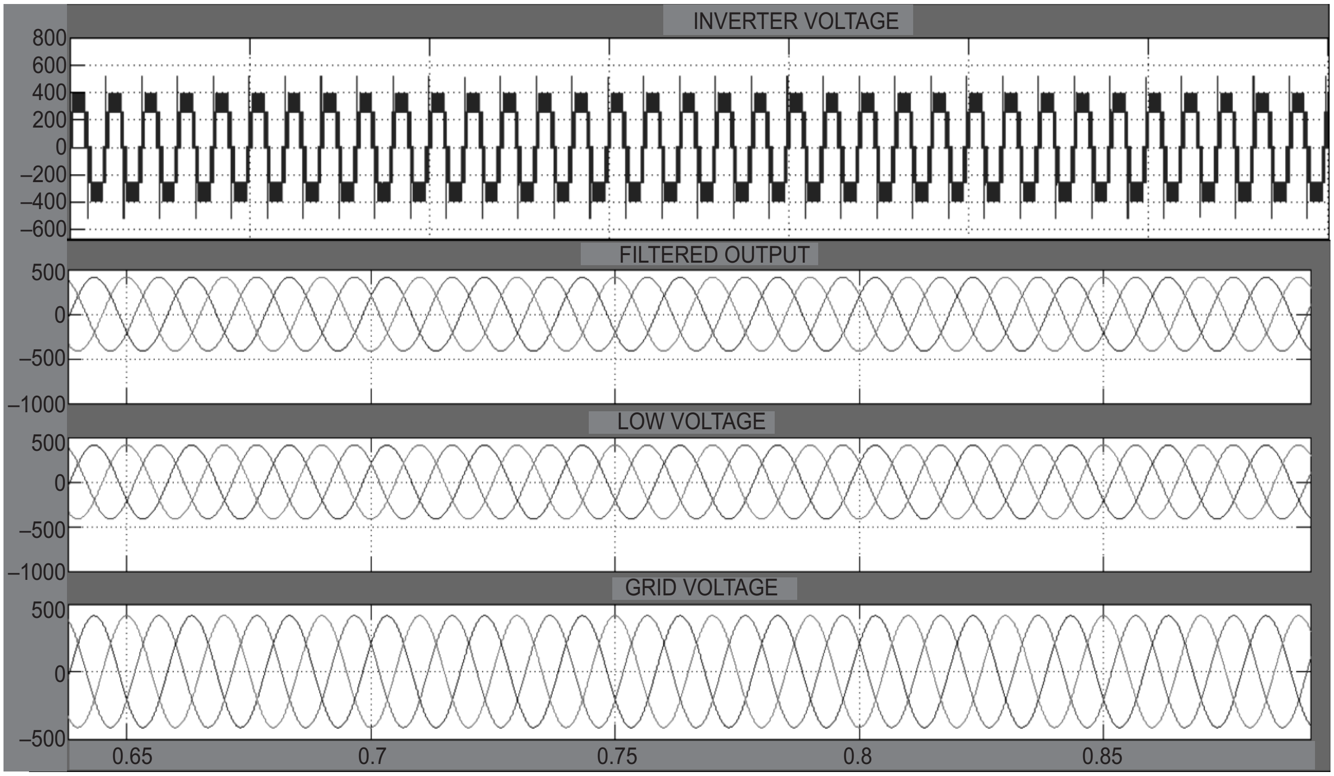


Figure 10: Waveform of Improved Inverter voltages with controller

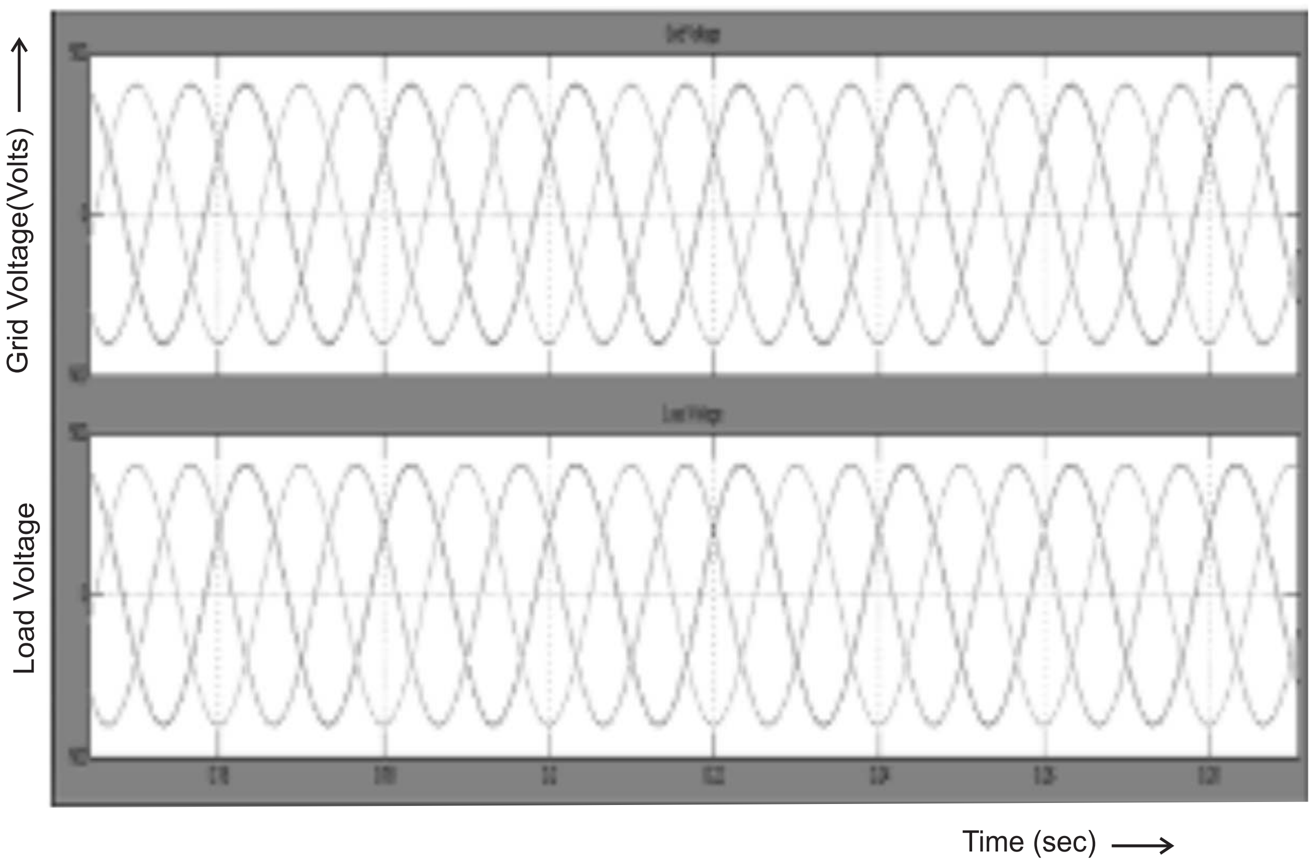


Figure 11: Output Voltage Waveform of Grid and inverter

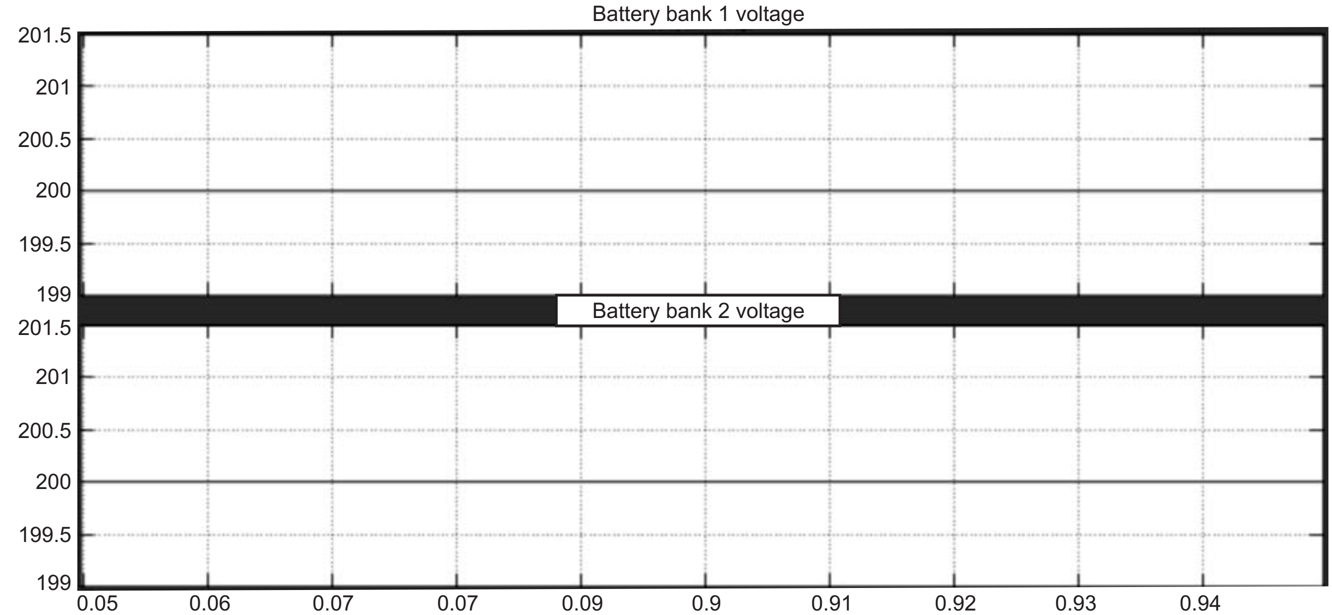


Figure 12: Battery bank voltage

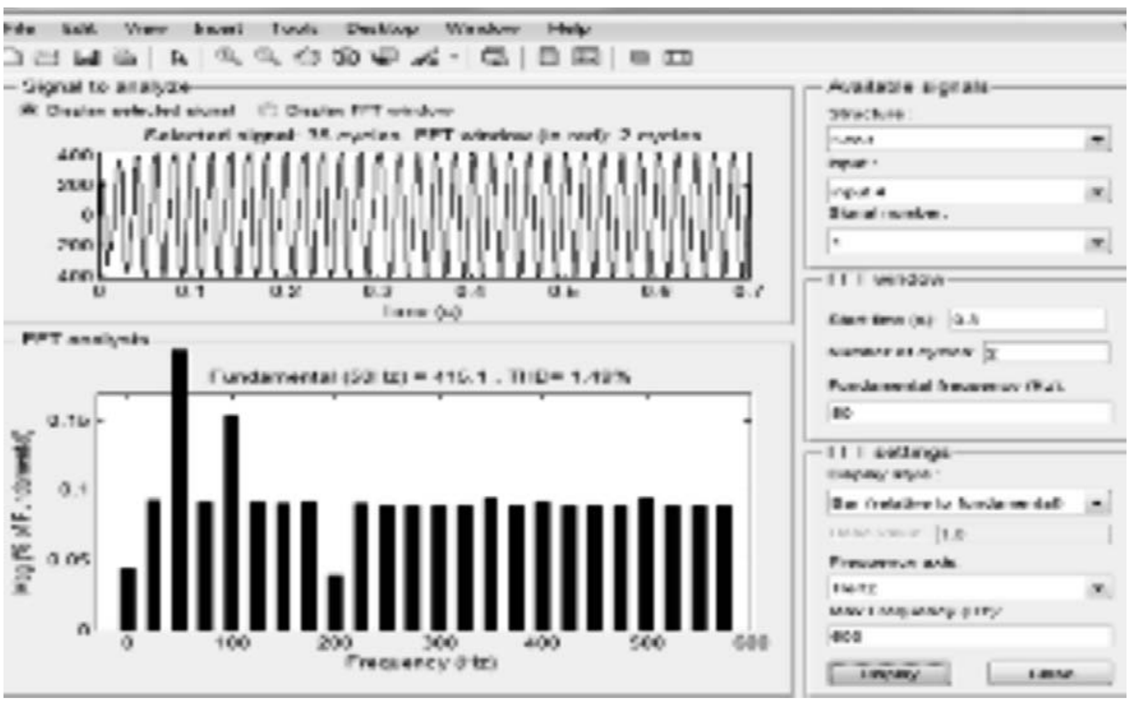


Figure 13: THD ANALYSIS

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