Voltage And Frequency Controller for An Induction Generator Based Stand Alone Wind Energy Conversion System

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Abstract: This paper presents a voltage and frequency controller (VFCs) for induction generator for standalone wind energy conversion systems. In wind turbine-driven isolated asynchronous generator, magnitude and frequency of the generated voltage vary because of varying consumer loads and wide fluctuation in wind speed. The performance of the controller is analyzed under different electrical (varying consumer loads) and mechanical dynamic conditions (varying wind speed) using MATLAB software.

Keywords – Wind power conversion system, Voltage source converter, PWM signal generator, Voltage and frequency controllers.

1. INTRODUCTION

There has been a huge increase in energy demand during the last few decades which has accelerated the depletion of the world fossil fuels supplies. Environmental concerns and international policies are supporting new interests and development for small scale off grid power generation. Remotely located villages, island, military equipment, ship etc are some of the areas that are mainly isolated from the power system grid and require a stand-alone generating system. However, because of continuous depletion of fossil fuels and concern about global warming, the importance of locally available natural renewable energy source has increased such as wind, hydro etc[1]-[3]. The wind energy is one of the prominent sources of the energy used commonly these are environmentally friendlier power source. Wind energy into a useful from of energy, such as using wind turbine to make electricity. Wind power, produces no greenhouse gas emission during operation, and uses little land. In operation, the overall cost per unit of energy produced is similar to the cost for new coal and natural gas installations. Constant speed prime movers such as solar, biomass the speed of the asynchronous generator is constant.

In the case of wind both the input power and consumer load varies. The wind energy is one if the prominent sources of the energy and it are explored tremendously in grid connected applications using wound rotor asynchronous generators. The main challenges in a squirrel-cage asynchronous generator-based isolated wind energy conversion system are related to its voltage and frequency control. To minimize the number of control loops, a single loop control was proposed in [12].The basic principal of its operation is that at high wind speeds the generated power is also high and accordingly for frequency regulation the total generate power should be consumed otherwise difference of mechanical and electrical power is stored in the revolving components of the generator and by which the speed of the generator and in turn it increases the output frequency. To maintain constant output power at load terminals, many researchers have suggested control strategies and application of different power conditioning systems [9 – 11] for SEIG terminal voltage and frequency control. Therefore this additional generated power is used to charge the battery to avoid the frequency variation.

Therefore, need of a voltage frequency controller for such an isolated system is mandatory for satisfactory operation of wind energy conversion system. The Isolated Asynchronous Generator (IAG) operates at practically constant speed. In variable speed operation, IAG needs an interface to convert the variable voltage and the variable frequency output of the generator to the fixed frequency fixed voltage at the load terminals. To maintain constant output power at the load terminals. In the recent literature [7-8], the Battery Energy Storage System (BESS) with a Voltage Source Converter (VSC) is employed for isolated system. Methods have been proposed to regulate both the SEIG terminal voltage and frequency using two loop controls [15 – 17]. In [5-6] an investigation has been carried out using modulation index to control the terminal voltage and load angle to control the system frequency. Voltage source converter (VSC) along with battery storage system is used, while the output voltage is maintained constant with fixed excitation. An efficient voltage and frequency controller for a standalone wind energy conversion system based on self-excited squirrel cage asynchronous generator where the control of magnitude and frequency of the generated voltage[4] have greater challenge because of unavailability of grid. The off-grid wind system stores electrical produced by wind generator in a bank of batteries. Bonert and Hoops [13] have proposed a terminal impedance controller for an isolated asynchronous generator. A shunt-connected thyristor converter followed by a PWM controlled buck chopper with resistive load is used to absorb the surplus active power for frequency control.

The VFC control scheme is realised using synchronous reference frame theory. Joshi et al. [14] have reported a genetic algorithm-based technique for estimating and steady-state analysis of IAG for obtaining constant voltage and constant frequency. This paper deals with an efficient voltage and frequency controller for a stand-alone wind energy conversion system based on self-excited squirrel cage asynchronous generator where the control of magnitude and frequency of the generated voltage have greater challenge because of unavailability of the grid.

The proposed voltage and frequency controller is having additional capability of harmonic elimination and load balancing. The performance of the controller is demonstrated under different electrical (varying consumer load) and mechanical (wind speed variation) dynamic conditions using standard MATLAB software.

2. VOLTAGE AND FREQUENCY CONTROLLER BY WIND TURBINE WITH OFF GRID:

3.

2.1 Block Diagram of the Proposed Isolated Wind Energy System

Off –grid wind turbine system, namely off grid wind –electric standalone system are not connected to an electric distribution system or grid, so they should use batteries to store power from wind turbine.

Though the force and power of the wind are difficult to quantify, various scales and descriptions have been used to characterize its intensity. Wind power has the advantages that it is normally available 24 hours per day, unlike solar power which is only available during daylight hours. Unfortunately the availability of the wind energy is less predictable then solar energy.

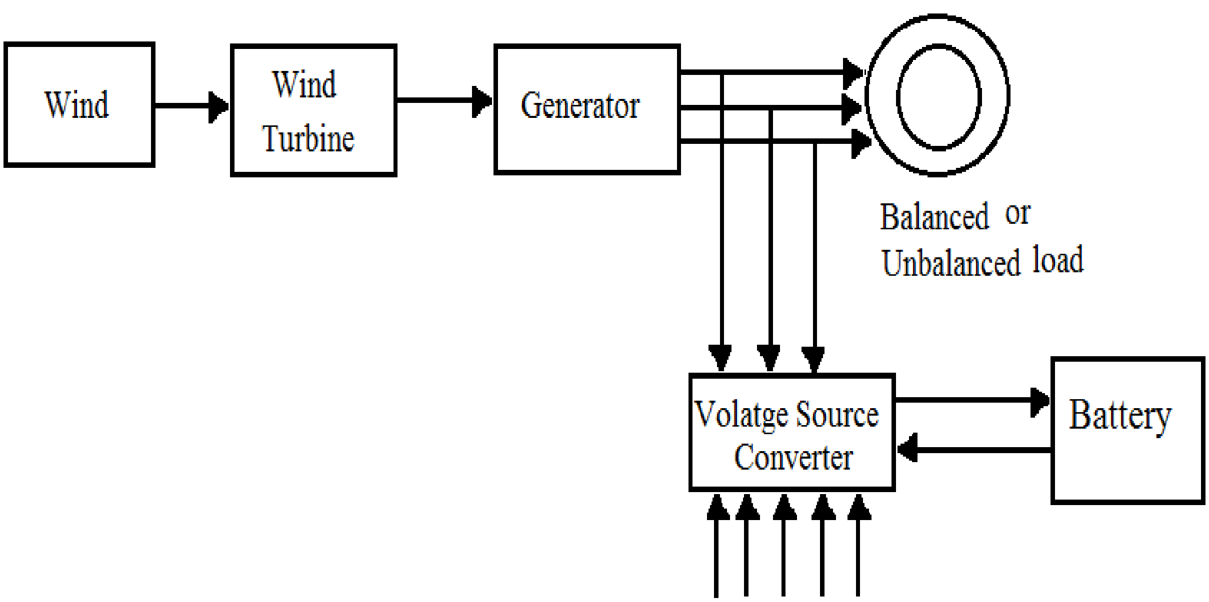

Figure.1 Isolated wind energy system

Figure.1 shows that the wind turbine is connected directly to the generator and load, the voltage source converter is connected across the generator and load it act as a rectification and inversion mode. Battery which is connected is used to store energy whenever the energy is not required, from voltage source converter the gate signal is given to IGBT.

3.2 Schematic Diagram of the Proposed Isolated Wind Energy System

The complete off grid stand-alone system with asynchronous generator, wind turbine, excitation capacitor, balanced/unbalanced, linear/non-linear/dynamic consumer loads and proposed controller is shown in Figure.2.

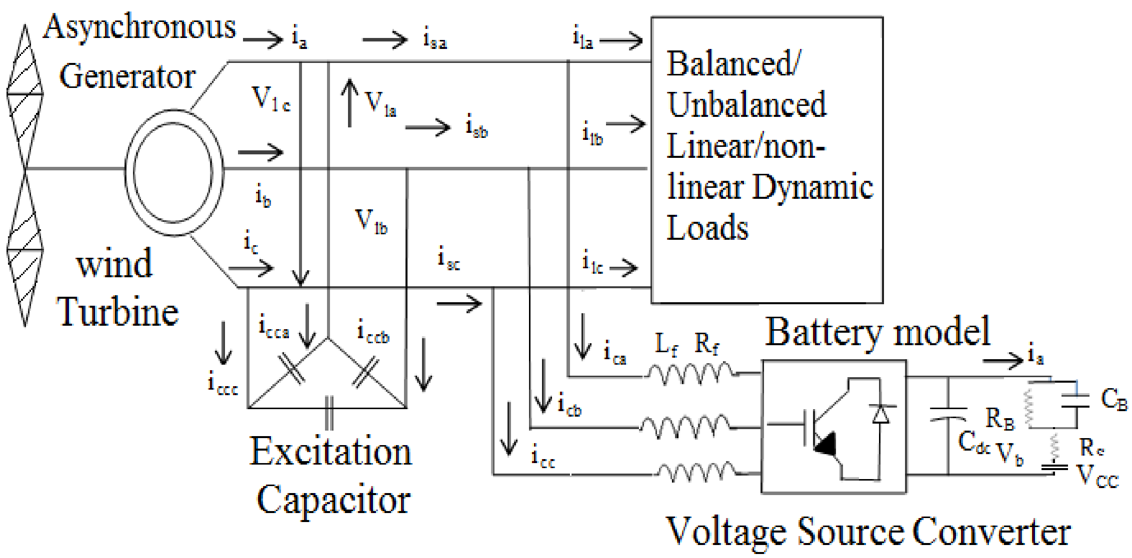

Figure.2 Block diagram of the proposed isolated wind energy system

The proposed controller includes

1. Voltage source converter
2. Battery
3. Inter-facing inductor
4. Excitation capacitor.

4. PULSE WIDTH MODULATION SIGNAL GENERATION

Pulse-width modulation is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off period, the higher the power supplied to the load. The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power.

Reference source current (i_{sa}^{r} i_{sb}^{r} i_{sc}^{r}) are compared with sensed source currents(i_{sa}, i_{sb} and i_{sc}). The current error are computed as

$$i_{saerr} = i_{sa}^{r} - i_{sa}$$
$$i_{sberr} = i_{sb}^{r} - i_{sb}$$
$$i_{scerr} = i_{sc}^{r} - i_{sc}$$

These current errors are amplified with a gain (K) and the amplified signals are compared with fixed frequency (10 kHz) triangular carrier wave of +1 amplitude to generated gating signals for IGBTs of VSC of the controller.

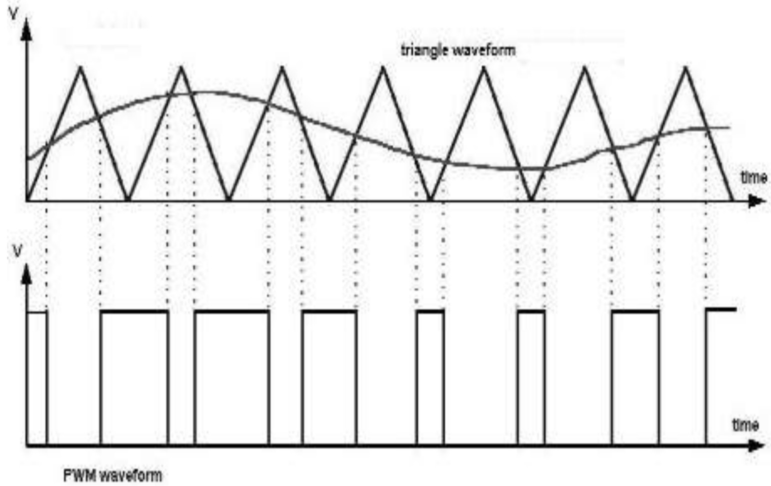

Figure.3 Pulse Width Modulation signal generation

The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. PWM is generated by comparing current errors with the fixed frequency triangular wave. The current errors are computed by comparing reference source current with the sensed source current. In PWM control, the inverter switches are turned ON and OFF several times during a half cycle and output voltage is controlled by varying the pulse width. The gating pulses are shown in Figure 3. Pulse Width Modulation (PWM) control strategy development tries to reduce the total harmonic distortion (THD) of the output voltage.

5. PI CONTROL ALGORITHM

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. PI control is developed using the control system toolbox. The gate signals are generated using PWM strategy. Hence whenever the load is nonlinear the distortion in the output is more. PI controller settings K_p and K_i are designed in this work using Ziegler – Nichols tuning technique. The designed values of K_p and K_i are 0.1 and 0.01 sec respectively. The response becomes more oscillatory and needs longer to settle, the error disappears. PI controller having the no offset. The PI controller fuses the properties of the

P and I controllers. It shows a maximum overshoot and settling time similar to the P controller but no steady-state error.

6. SIMULATION RESULTS

Wind power produce connected to a grid system for defined load system. With change in load condition the power flow of the system (active & reactive power demands) changes with the variation of load. Since the wind farm and grid are defined for supplying the power for a load range. If extra load is added the power demand is not met as a result the synchronous machine/ the grid slow as a result frequency is reduced and hence more of the active power takes place. Therefore ensuing in high power losses. We developed three mat lab/Simulink models; the first model is simulated to get the results of linear unbalanced load. Second model is simulated to show wind power generation with fault occurred in the individual phases. This provides the voltage compensation at the load side, current compensation at the source side. Third model is simulated to show wind generation with fault occurred in the individual phases with the nonlinear loads.

The following Figure.4 shows the MATLAB based simulation model of the proposed system to get results of get results of linear unbalanced load.

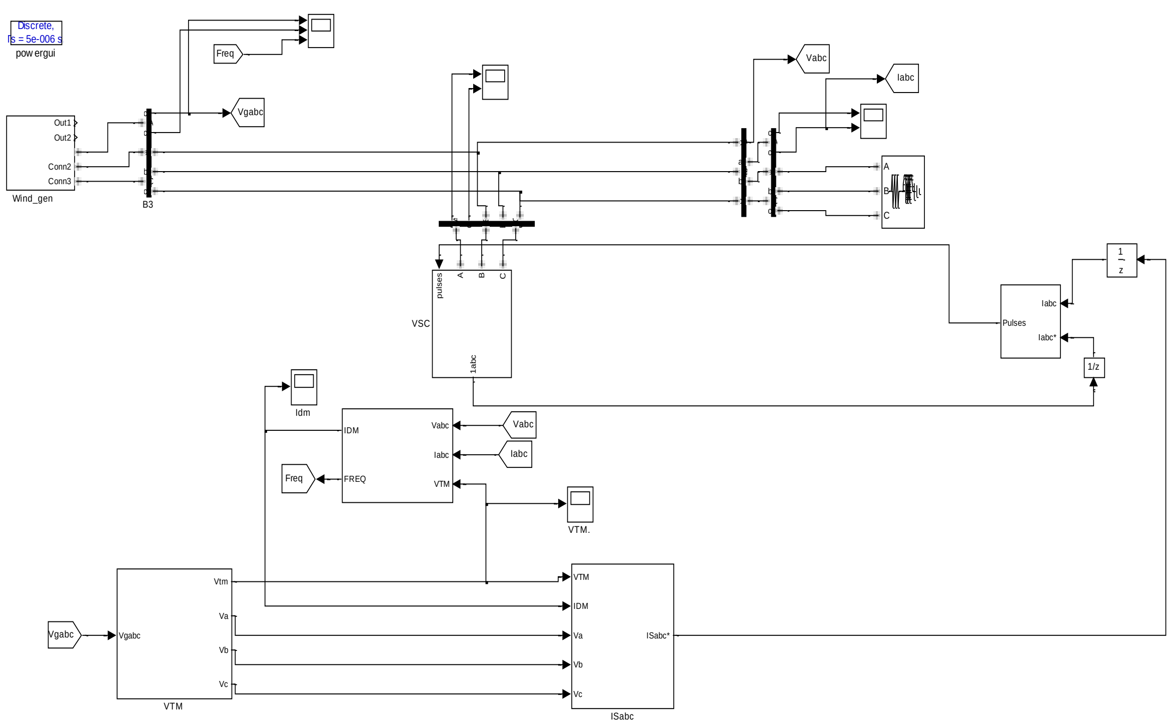

Figure.4 Simulink model of proposed system with linear load

The following Figure.5 shows the MATLAB based simulation model of the proposed system to get results of wind generation with fault occurred in the individual phases. This provides the voltage compensation at the load side, current compensation at the source side.

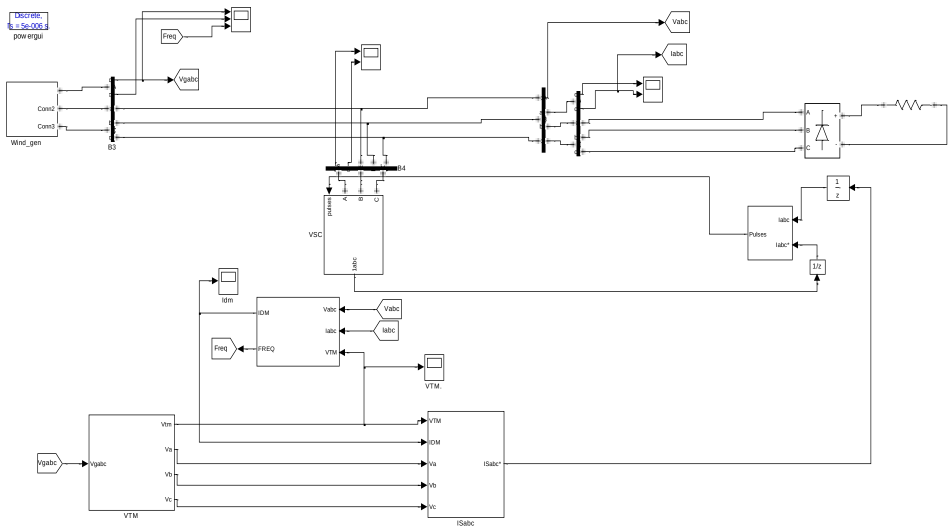

Figure.5 Simulink model of proposed with fault occurred in the individual phases

The Figure.6 shows the MATLAB based simulation model of the proposed system to get wind generation with fault occurred in the individual phase with the nonlinear loads the outputs.

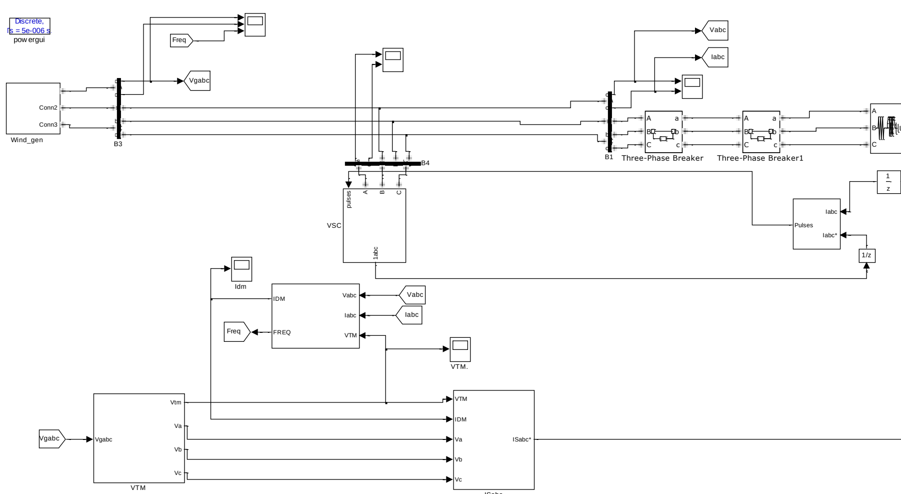

Figure.6 Simulink model of proposed system with nonlinear load

The performance of the proposed controller is demonstrated under different electrical and mechanical dynamic conditions. Figure 7, Figure 8 and Figure 9 shows the MATLAB based simulation for the proposed isolated electrical power generation system. The different simulation results shown here are

1. The performance of proposed system with linear load.
2. The performance of proposed system with fault.
3. The performance of proposed system with non-linear load.

5. 1 PROPOSED SYSTEM WITH LINEAR LOAD

First model is simulated for to get the results of proposed system with linear load. The results are shown below, the source current, voltage and frequency waveforms are shown in figure.6.

The wind speed is continuously varying. The generator terminal voltage and frequency remains at rated value. It is observed that due to the insufficient power generation at low wind speed an additional power is supplied by the battery to regulate the frequency.

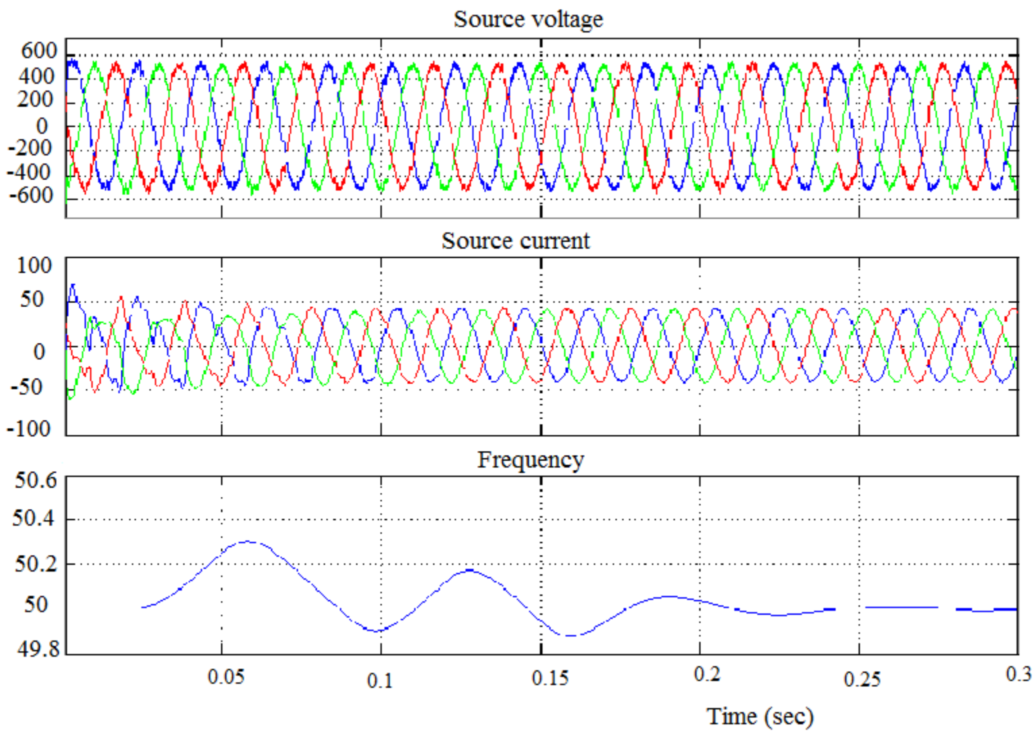

Figure.7 the source current, voltage and frequency waveforms

The load current and voltage waveforms for linear load is shown in figure 8 below

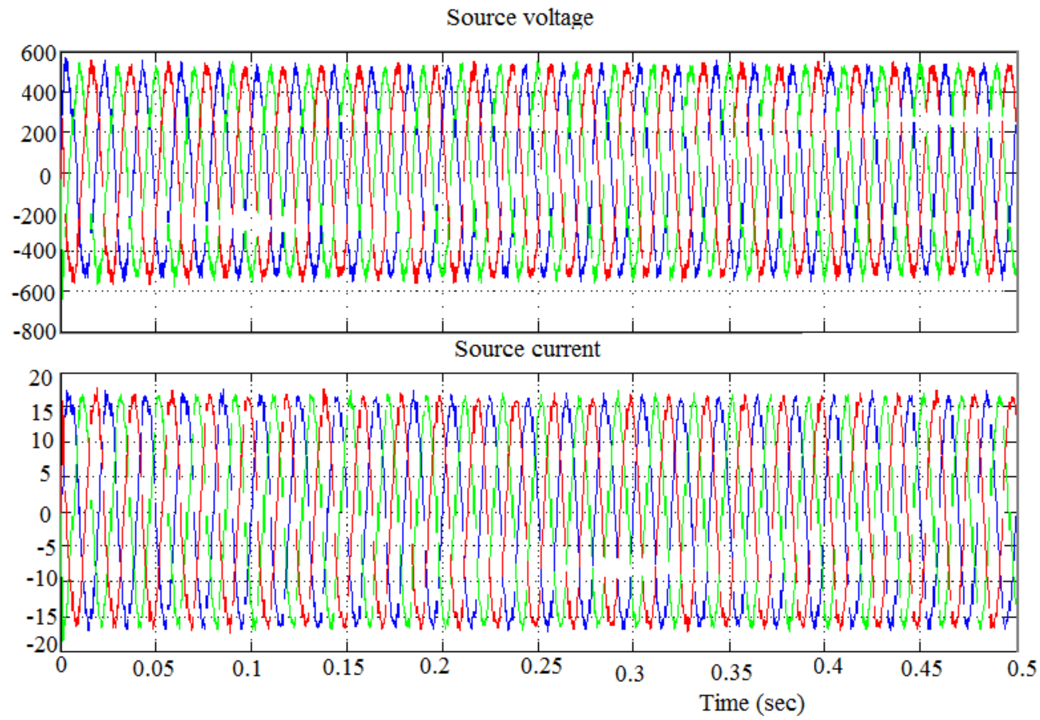

Figure.8 output load

The voltage source inverter current and voltage waveforms for linear load is shown in figure.9 below

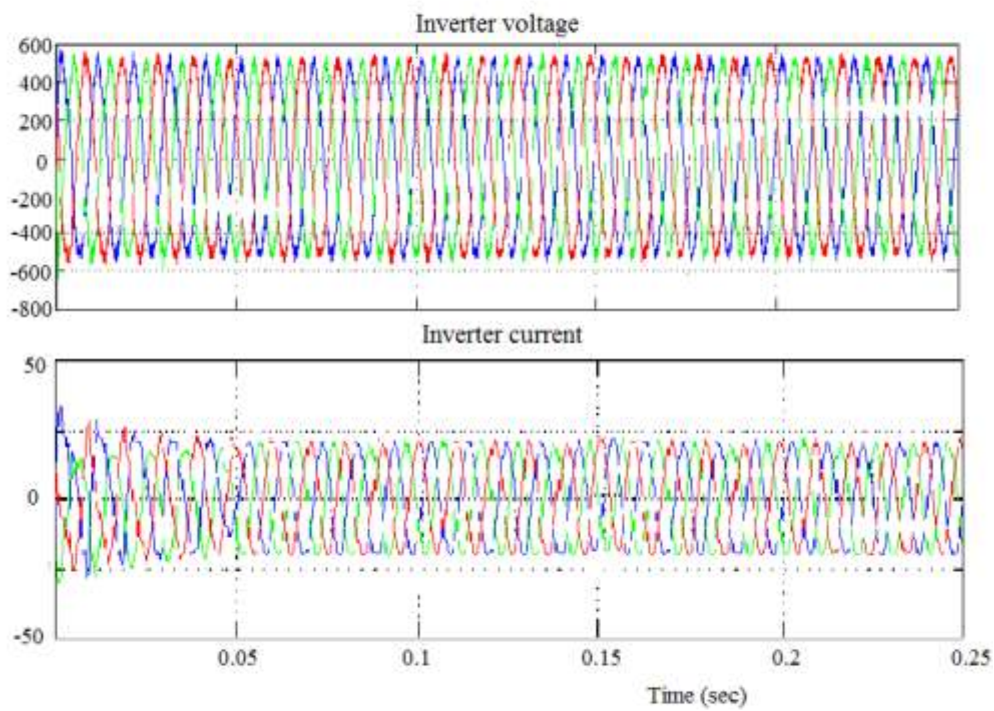

Figure.9 output waveform of voltage source inverter

6.2 WIND GENERATION WITH FAULT OCCURRED IN THE INDIVIDUAL PHASES

Second model is simulated to show wind generation with fault occurred in the individual phases. This provides the voltage compensation at the load side, current compensation at the source side. The source current and voltage when fault occurred in the individual phases are shown in figure.10. A three phase diode bridge rectifier with L-C filter based non-linear load is applied. By opening one phase at time t=0.1 sec, the load become unbalanced. But it is observed that the voltage and frequency of the system remains constant. At time T=0.2 sec another phase is opened, the load become unbalanced. But it is observed that the voltage and frequency of the system remains constant.

The voltage source inverter current and voltage waveforms for wind generation with fault occurred in the individual phases. Load is shown in figure.11.

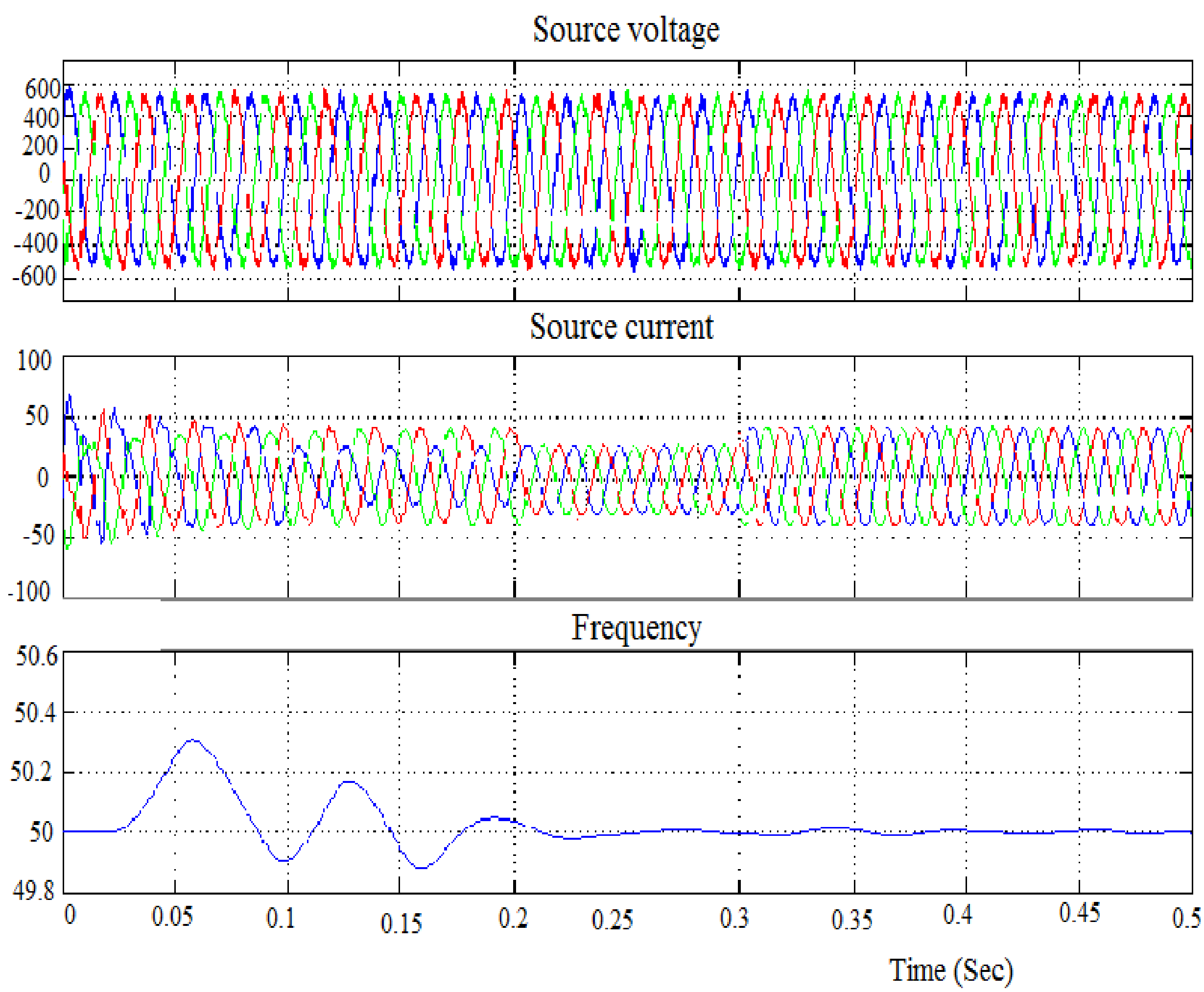

Figure.10 source input with fault in the individual phases

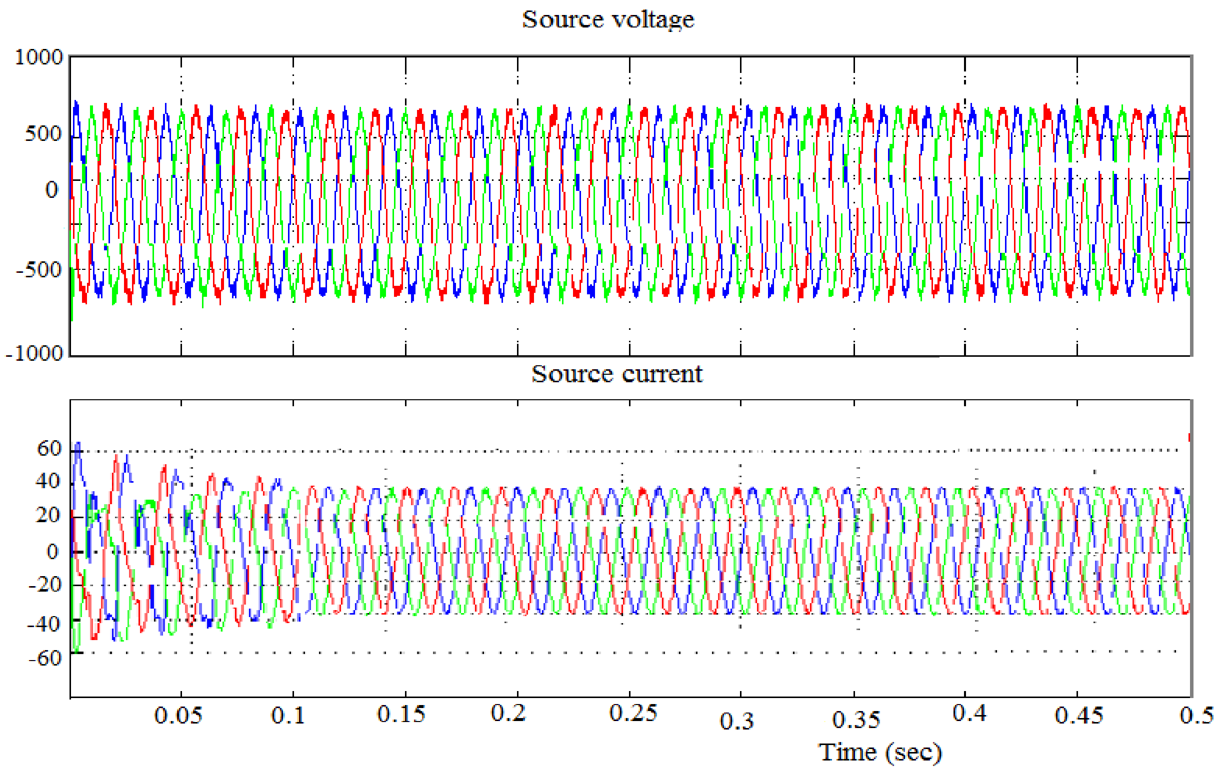

Figure.11 voltage source inverter current and voltage waveforms

The load current and voltage waveforms for wind generation with fault occurred in the individual phases is shown in Figure.12. This provides the voltage compensation at the load side, current compensation at the source side.

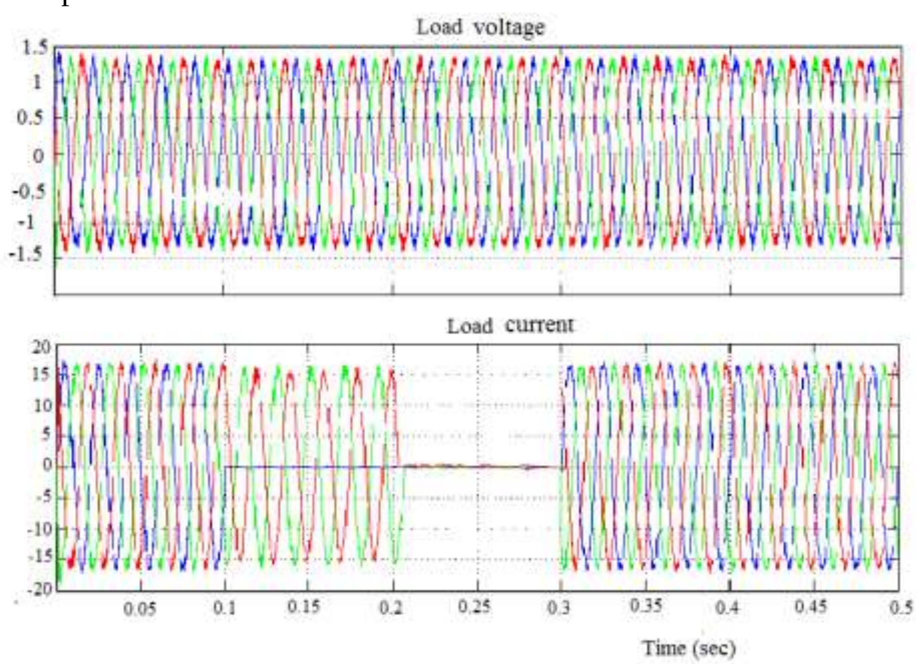

Figure.12 output load

6.3 PROPOSED SYSTEM WITH NON-LINEAR LOAD

Third model is simulated for to get the result of wind generation with the non-linear loads the outputs are shown below. Figure.13 shows the source voltage, current and frequency of wind generation with fault occurred in the individual phases with the non-linear loads.

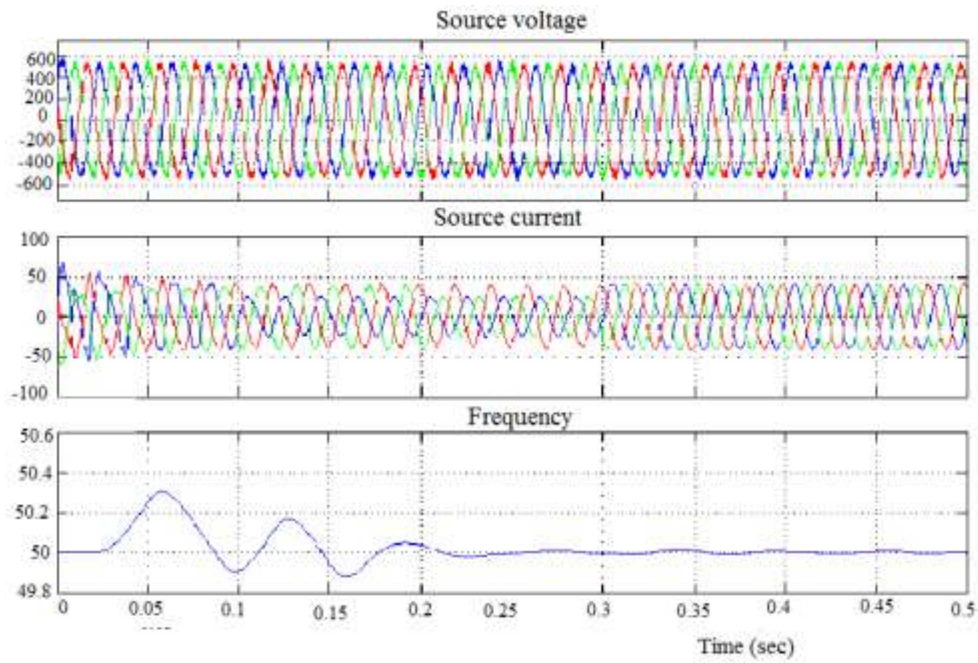

Figure.13 source voltage, current and frequency

Figure.14 shows the voltage source inverter output.

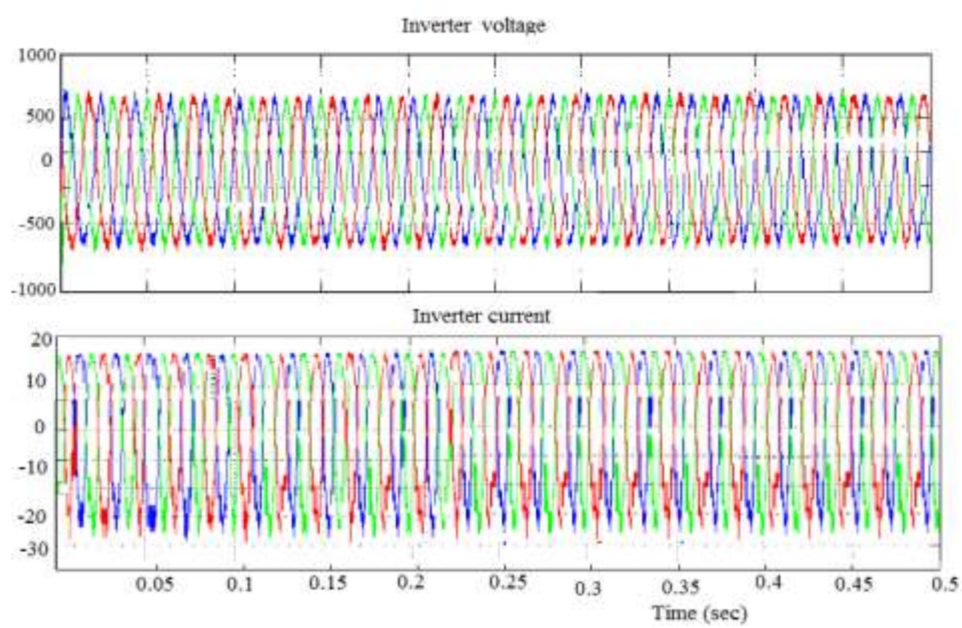

Figure.14 the voltage source inverter output

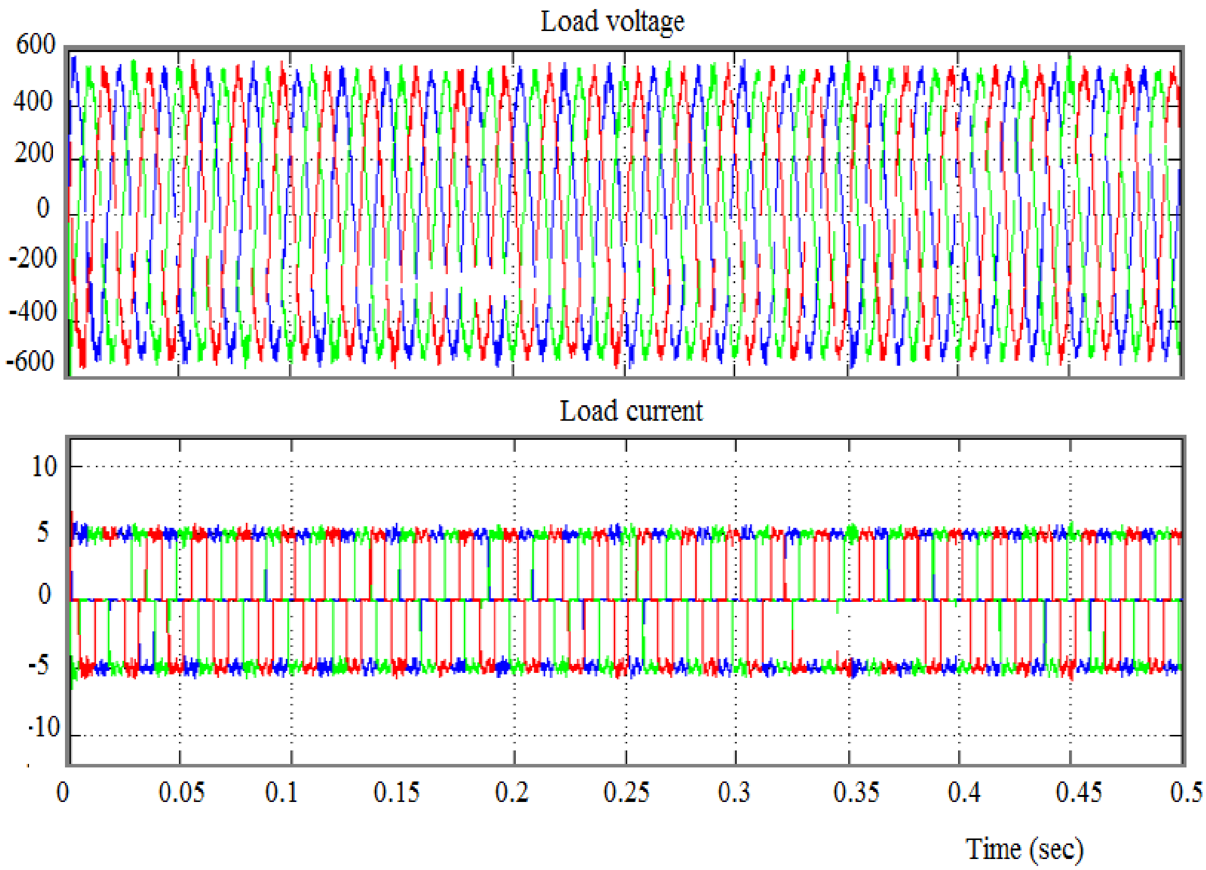

Figure.15 the load output voltage

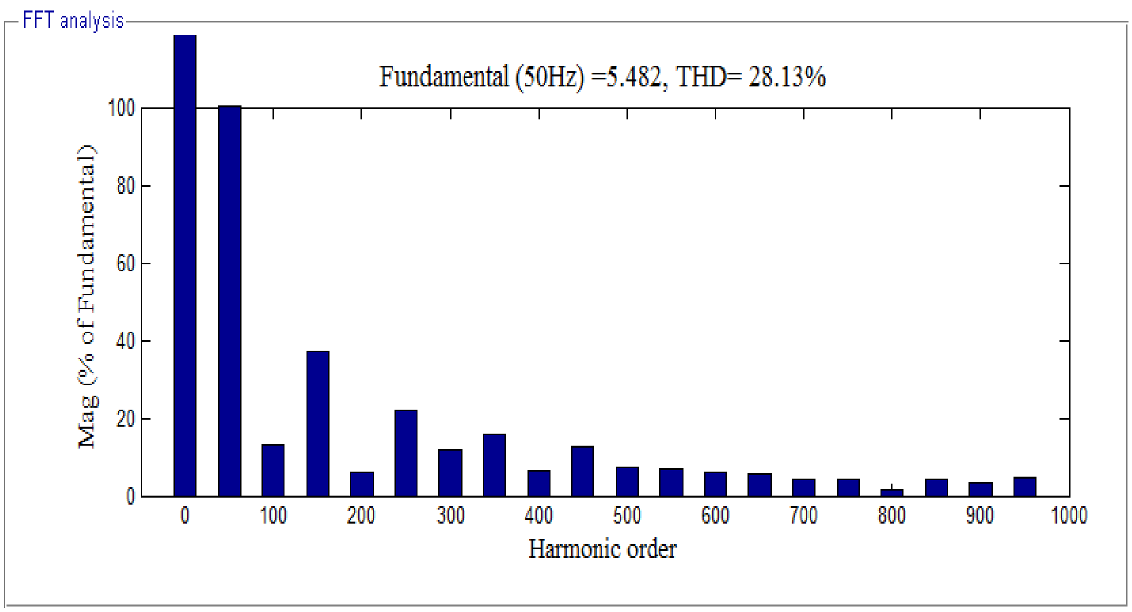

Figure.16. Load Current THD

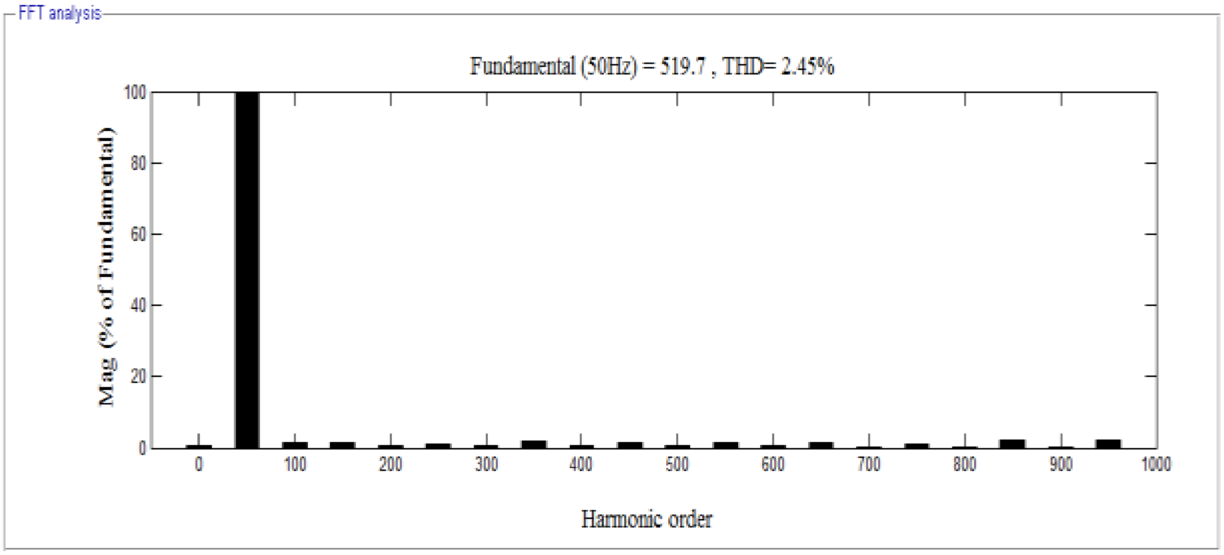

Figure.17. Source side voltage THD

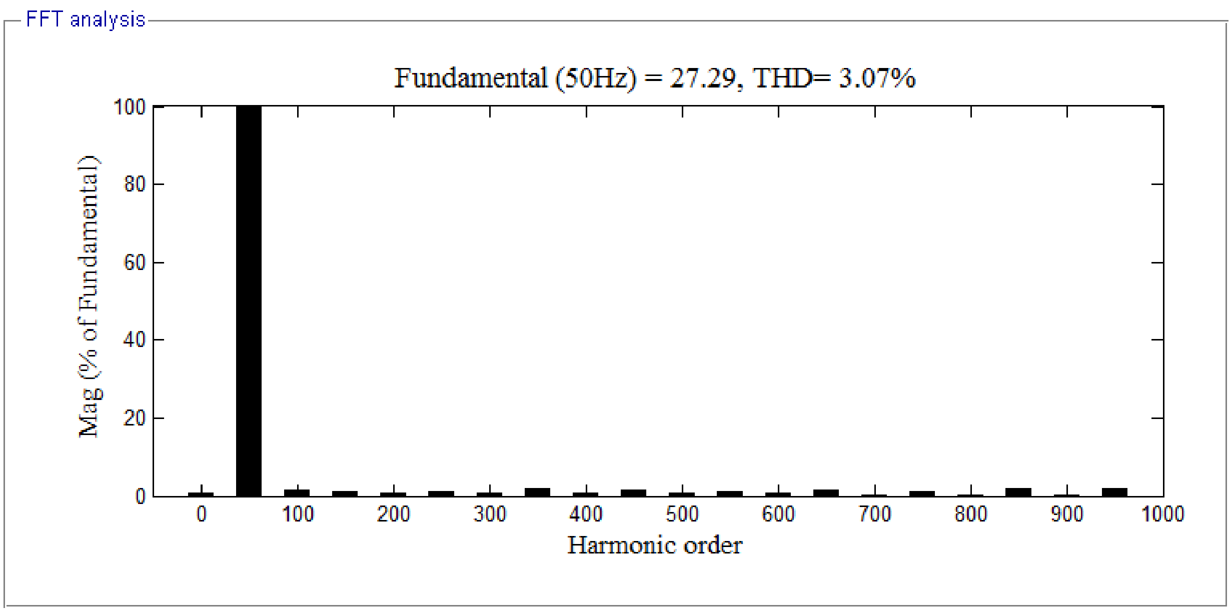

Figure.18. Source side current THD

7. CONCLUSION

The performance of the voltage and frequency controller has been analyzed under different electrical (varying consumer loads) and mechanical dynamic conditions (varying wind speed) using MATLAB software. From the simulation results, it is observed that the proposed controller regulates the magnitude and frequency of the generator voltage constant in isolated wind energy system.

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