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# Simulation of Grid Connected DFIG System Using Artificial Neural Networks

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***Abstract*** **– The electrical energy consumption is rising and there is a sudden increase in the demand of power generation. Due to this reason large number of renewable energy units are now being integrated to power system for meeting and the rising demand of power generation. Slip ring induction machine in the variable speed wind turbine popularly known as double fed induction generator is mostly used in wind power generation. DFIM is made available for power flow through both stator and rotor. Stator is directly connected to the grid and rotor is connected to the power electronic converter via slip rings and then to grid. The flexibility of DFIG is to operate at above and below synchronous speed. The objective of our project is to generate electrical energy from doubly fed induction generator driven by wind turbine and to control the active and reactive powers by injecting the proper rotor voltage to the DFIG from PI controller so as to maintain the constant terminal voltage. Actually it is difficult and complex to implement practically. So we want to implement this by using Matlab/Simulink. Basically it comprises of two models open model (is=0) and connected model. The induction machine is modeled in vectorized form in the synchronous frame associated with the stator voltage space vector.**

***Keywords:*** **DFIG, Stationary Reference frame, Dynamic Model, Artificial Neural Networks.**

## I. Introduction

Energy is main criteria for human development in any country. Any country that can produce energy in large scale can become a developed country in a short time. Mainly energy sources can be divided into two categories. Renewable energy sources and Non-renewable energy sources. Alternatively energy sources are the energy sources different from those in wide spread use at the moments (which are referred to as conventional). Alternative energy sources include solar, wind, wave, and tidal, hydroelectric and geothermal energy. Although they each have their own drawbacks, none of these energy sources produces significant air pollution, unlike conventional sources. Fossil fuels are (Carbon or Hydrocarbon) the fuels derived from what was living material, and found underground or beneath the sea. The most common forms are coal, oil and natural gas. They take millions of years to form. Their energy is only oxygen in air to form carbon dioxide or carbon monoxide and water. Other elements within the fuels are also released into the air after combining with oxygen causing further pollution with $SO_2$ and nitrogen oxide gasses. In the case of coal, ash particles are also a problem.

Non-renewable energy sources that exist in a limited amount on earth. Thus all available material could eventually be completely used up. Coal, Oil and gas are considered as non-renewable energy sources because the rate of their formation is so slow on human time scales that they are using them without being replaced. Generally wind energy is available in abundance. For conversion of this wind energy into electrical energy and induction generator is coupled with a wind mill offers an ideal solution. Wind energy is available in abundance in our environment. When compared with the conventional sources of energy, wind energy is clean, efficient, and sustainable form of energy. When the cost of supplying electricity to remote locations is expensive, wind energy provides a cost effective alternative. So to convert this wind energy into electrical energy, an induction generator will offer an ideal solution.

## II. Doubly Fed Induction Generator

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator.

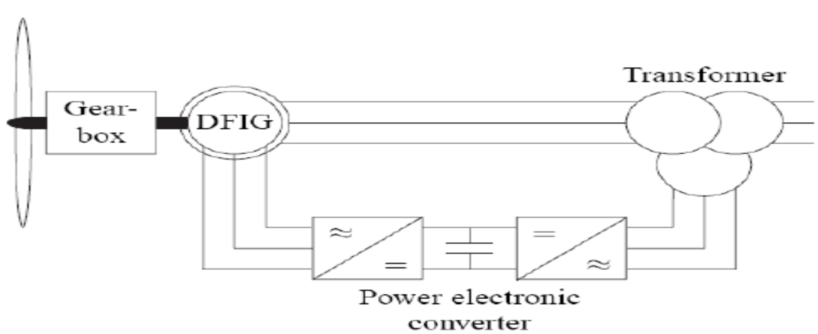


Fig 1.Variable-speed wind turbine with a doubly-fed induction generator (DFIG)

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2.1. Operating Principle of DFIG:

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltageThe slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges.

## III. Mathematical Representation of DFIG

An induction motor can be looked on as a transformer with a rotating secondary, where the coupling coefficients between the stator and rotor phases change continuously with the change of rotor position. The machine model can be described by differential equations with time varying mutual inductances, but such a model tends to be very complex, such as vector control, based on the dynamic d-q model of the machine. Therefore to understand vector control principle, a good understanding of d-q model is mandatory.

The transformation equation from a-b-c to this d-q-o reference frame is given by

$f_{qdo}$=$K_s$*fabcs

$$where,\quad (\mathbf{f}_{qd0s})^T = \begin{bmatrix} f_{qs} & f_{ds} & f_{0s} \end{bmatrix},$$

$$(\mathbf{f}_{abcs})^T = \begin{bmatrix} f_{as} & f_{bs} & f_{cs} \end{bmatrix},$$

$$\mathbf{K}_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix},$$

Where the variable f can be the phase voltages, current, or flux linkages of the machine. The transformation angle $\theta_r$ between the q- axis of the reference frame rotating at a speed of w and the a-axis of the stationary stator winding may be expressed as

$$\theta = \int_0^t \omega(t)dt + \theta(0).$$

3.1. qdo Torque Equations:

The sum of the instantaneous input power to all six windings of the stator and rotor is given by:

Pin=Vas Ias + Vbs Ibs+ Vcs Ics + Var Iar+ Vbr Ibr+ Vbr Ibr

$T_{em}=(3/2)\,(p/2)[(\psi_{qr}\, i_{dr}-\psi_{dr}\, i_{qr})]$

$=(3/2)\,(p/2)[(\psi_{ds}\, i_{qs}-\psi_{qs}\, i_{ds})]$

$=(3/2)\,(p/2)L_m[(i_{dr}\, i_{qs}-i_{qr}\, i_{ds})]$

One can rearrange the torque equations by inserting the inserting the speed voltage terms given below:

$E_{qs}=\omega\psi_{ds}$ $\qquad E_{ds}=-\omega\psi_{qs}$

$E_{qr}=(\omega-\omega_r)\psi_{dr}$ $\qquad E_{dr}=-(\omega-\omega_r)\psi_{qr}$.

## IV. SIMULINK IMPLEMENTATION OF DFIG

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. With this interface, you can draw the models just as you would with pencil and paper (or as most textbooks depict them). This is a far cry from previous simulation packages that require you to formulate differential equations and difference equations in a language or program. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. You can also customize and create your own blocks. For information on creating your own blocks, see the separate Writing S-Functions guide.

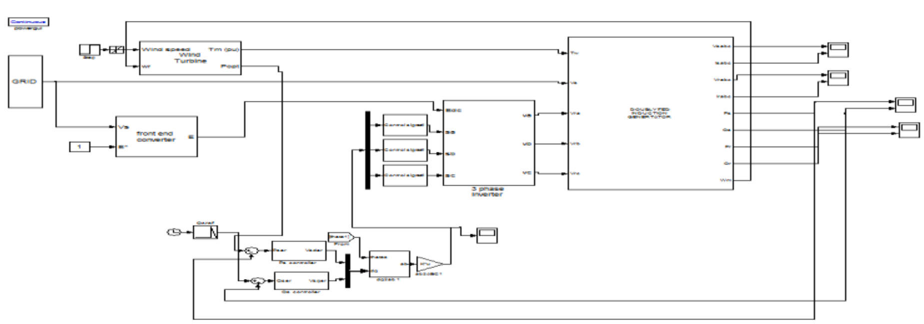

Fig.2: DFIG with PI CONTROLLER

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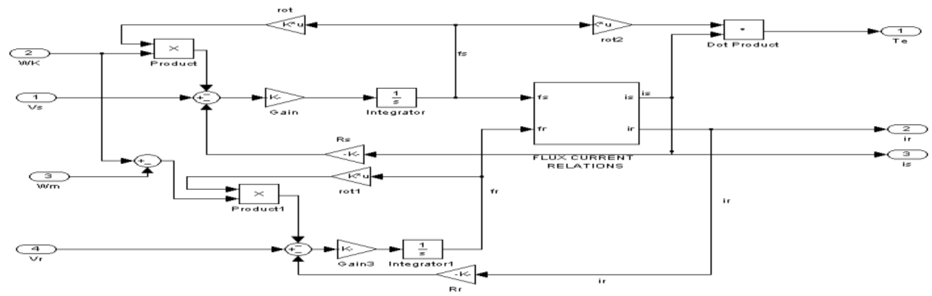


Fig.3: Dynamic Model of Induction Machine in Arbitrary Reference Frame

The rotor-side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. This characteristic is illustrated by the ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds.

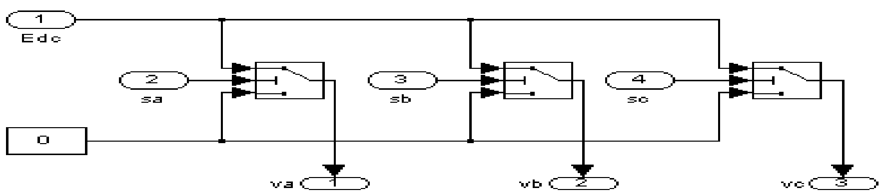


Fig.4: Simulink Diagram for Rotor Side Converter

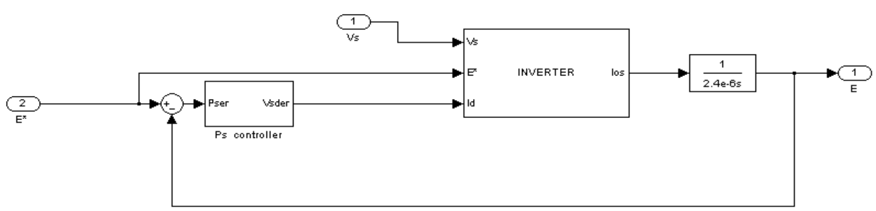


Fig.5: Simulink Diagram for Stator Side Converter

Artificial Neural Networks

Numerous advances have been made in developing intelligent systems, some inspired by biological neural networks. Researchers from many scientific disciplines are designing artificial neural networks to solve a variety of problems in pattern recognition, prediction, optimization, associative memory, and control. Conventional approaches have been proposed for solving these problems. Although successful applications can be found in certain well-constrained environments, none is flexible enough to perform well outside its domain. ANNs provide exciting alternatives, and many applications could benefit from using them. This article is for those readers with little or no knowledge of ANNs to help them understand the other articles in this issue of Computer.

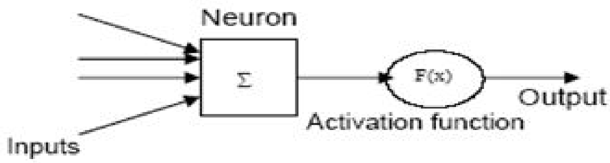


Fig. 6 Simple Artificial Neuron

The long course of evolution has given the human brain many desirable characteristics not present Invon Neumann or modern parallel computers. These include massive parallelism, distributed representation and computation, learning ability, Generalization ability.

The above figure shows three phase open circuit voltages $e_a$, $e_b$, $e_c$ which are displaced by 120 electrical degrees apart. Hence from this we can say that power is generated from doubly fed induction generator.

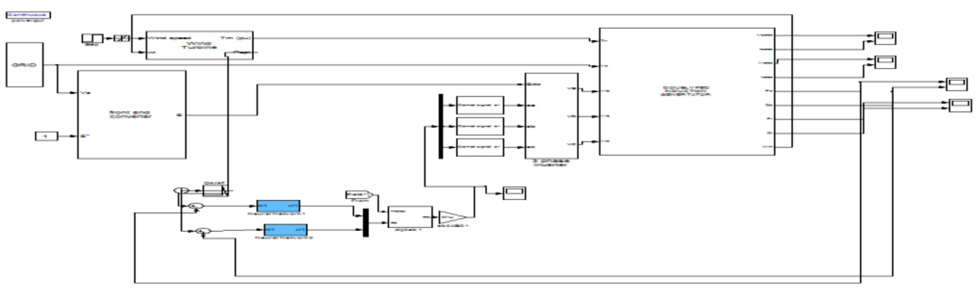

Fig.7 DFIG with ANN

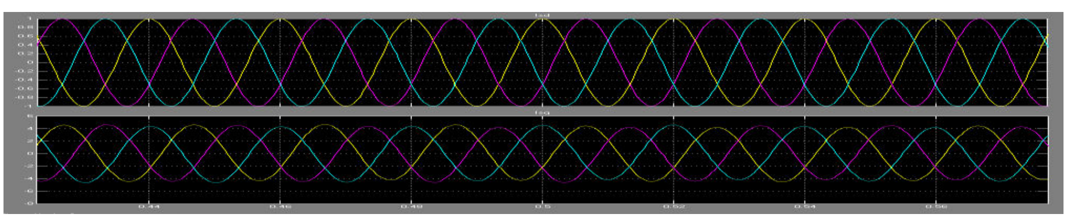

Fig.8.Stator Open Circuit Voltage

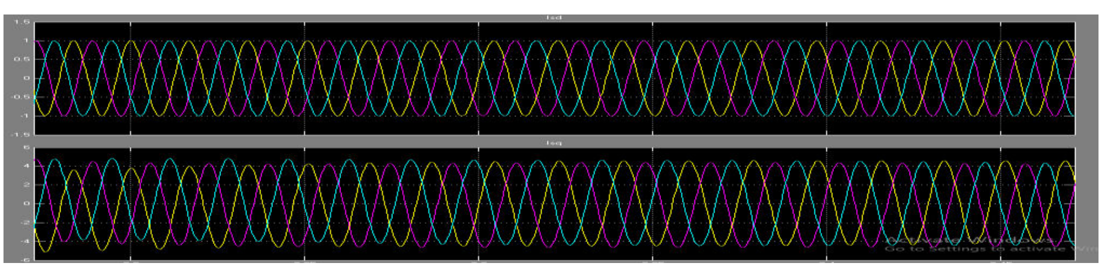

Fig.9.Three Phase Rotor Output Voltage

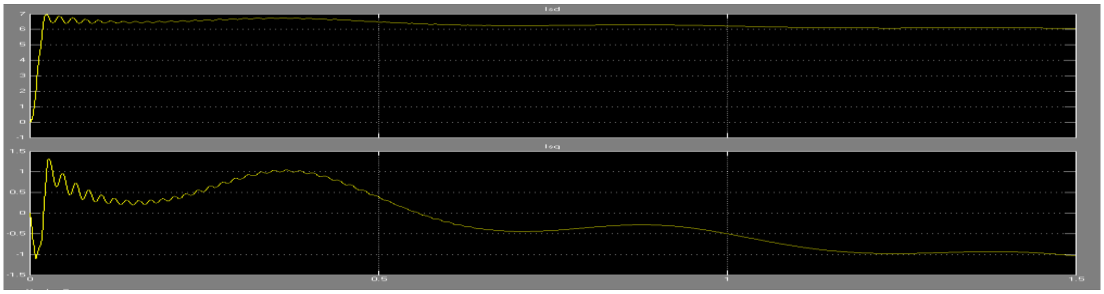


Fig.10. Stator Activeand Reactive Power

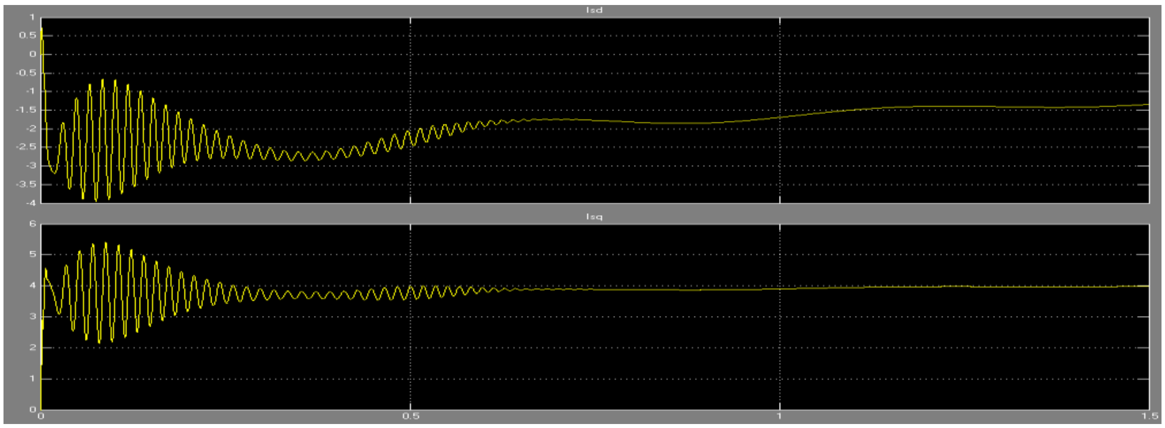


Fig.11. Rotor Active and Reactive Power

The above figures represent simulation results for one reactive power and one active power set values. These figures shows that even though there is a change in Reactive power set value the Active power is not changed i.e., independent control of Active and Reactive power takes place. So we can conclude that Vector Implementation is applied.

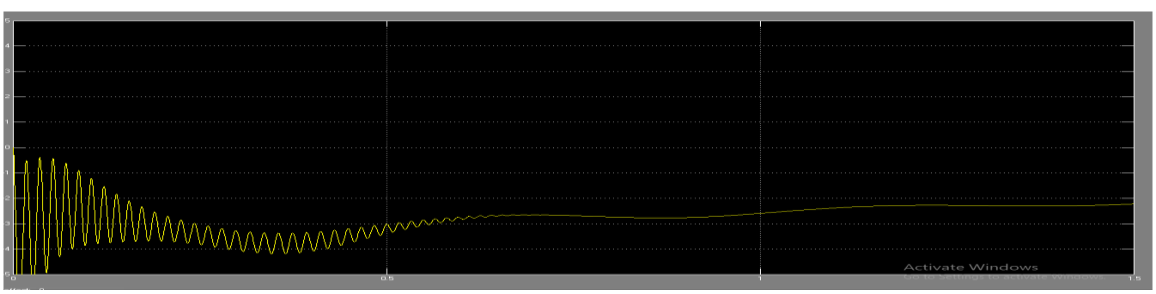

Fig.12.Speed (Sub-Synchronous)

Above figure shows the speed of the generator in sub-synchronous mode. From the figure we can say that when we applying negative torque to turbine suddenly, the speed of the rotor rises rapidly and again come to steady state.

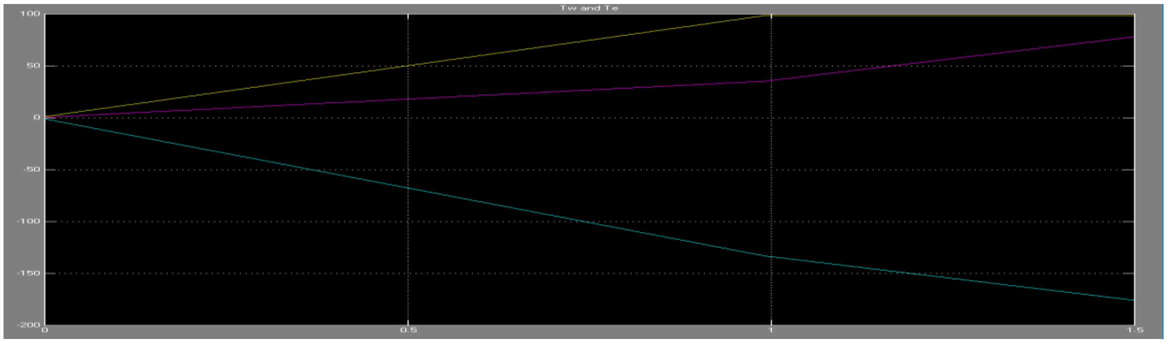


Fig.13.Torque of the Generator

Above figure shows the torque of the generator. From the figure we can say that when we applying negative torque to turbine suddenly, the torque of the rotor decreases rapidly and again come to steady state.

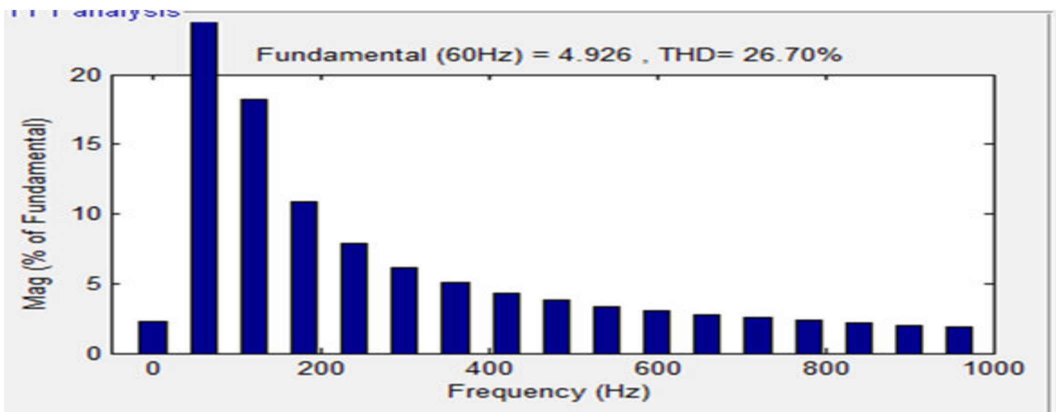


Fig:14-The Total Harmonic Distortion for PI Controller

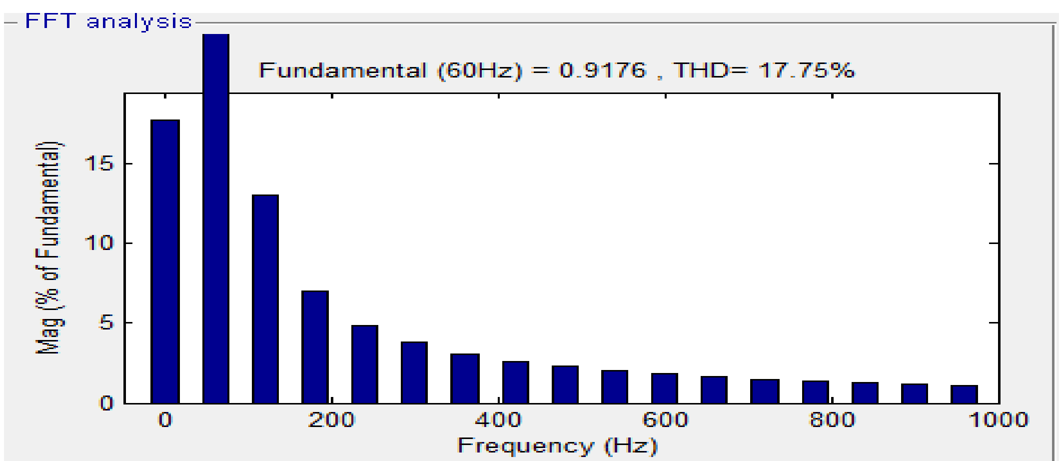


Fig:15-THD for Artificial Neural Networks

## V. Conclusion

In this project induction machine is modeled in vectorized form in the synchronous frame. The d-axis is aligned with the stator voltage space vector. Electrical energy is generated from doubly fed induction generator driven by wind turbine. Actually it is difficult and complex to implement practically. So we want to implement this by using MATLAB/SIMULINK. Basically it comprises of two models open model and connected model. In open model doubly fed induction generator is isolated means stator is not connected to grid then stator current is zero and electrical is generated from DFIG by injecting the rotor voltage by PI regulator.In connected model doubly fed induction generator is connected to grid by injecting the rotor voltage to the rotor terminal of DFIG by PI regulator.The injected rotor voltages (at slip frequency) are derived from PI controllers that regulate the active and reactive powers delivered by the generator. The speed is adjusted by the turbine pitch control to maximize the power generated at a given wind speed. It was shown that it is possible to develop a set of equations describing the behavior of the wind turbine. So, finally we simulated DFIG and the corresponding results have been displayed.

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