Enhanced Power Transition for Variable Pitch Wind Turbine using Artificial Neural Network

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Abstract - The unconventional sources of power generation got great attention for last few decades, due to its clean properties while generating, no pollution at all. So the researcher are also finding several ways to make this energy more efficient and reliable to deliver continuously to end users. As we all know the wind energy system converting wind energy into electrical energy and due to fluctuating nature the power generated is also changes very rapidly, which causes to damage devices at the load side. So there is a need to regulate these fluctuations. So in this work we are working towards controlling of harmonics to improve quality of power to be delivered to the load side. This work has incorporated artificial neural network(ANN) to control the harmonics and provide better power quality to the load.

Keywords - ANN, Wind Energy, Power Quality, Fluctuations, Harmonics.

I. INTRODUCTION

Today, wind turbine systems are one of the fastest growing technologies. In order to be competitive, optimizing control systems are used in large-scale wind turbines. These systems enable the wind turbine to work efficiently and produce the maximum power output in varying wind conditions while keeping torque variations low so as to avoid fatiguing structural components. Wind turbines are facing turbulent winds with varying speed. In high wind speeds, in order to prevent conditions such as overrunning, a control mechanism should limit the speed of rotation of the blades. In large wind turbines, blades with variable pitch angle are used. Active control of blade pitch angle can limit the rotor speed by changing the angle of attack in the blades to reduce aerodynamic lift and also, in limiting cases, to cause stall effects. In addition, pitch control can enable the system to track the optimal tip-speed-ratio to have the maximum power output in different wind conditions. In smaller wind turbines, passive control of the rotor speed is used to limit the speed of wind turbine using stall effect in a certain wind speeds.

In recent decades, fixed speed generators were common in wind turbines because of low cost and capability of direct connection to the grid with specific frequency. As a consequence of using fixed speed generators, wind turbines had to work at a certain speed. Therefore, they could not adapt to variable wind speeds to track optimal rotor speed or the so-called optimal tip-speed- ratio. To be more adaptable to variable wind speeds and to be more efficient, variable speed wind turbines with variable speed generators, which can be connected to the grid via electronic convertors, are the modern choice of alternative technologies. These convertors enable the generator to work in variable speed with a frequency which is isolated from the grid frequency.

The disadvantage of passive stall control of wind turbine is that it causes more stress in blades and reduces their lifespan. In addition, it wastes the useful wind power because of the drop in aerodynamic torque caused by the stall effect in the blades

Although, fixed speed wind turbines with stall controlled blades prevailed in large wind turbines for many years, recently, with a fast growth in the wind turbine industry, variable speed wind turbines with variable pitch blades are successful options because of their efficiency to capture more wind power and capability to achieve higher power qualities. Moreover, as the size of wind turbines increases, concerns about mechanical stresses in the blades and the structure and also failure of wind turbine components like the drive-train increases. Therefore, variable speed wind turbines with an active control of the rotor speed and blade pitch angle can alleviate the loads and stresses on the different parts of the wind turbines.

As shown in Fig. 1.2, the wind turbine control system consists of several subsystems. The aerodynamic block shows the conversion of wind force to mechanical torque in blades. The mechanical subsystem consists of two blocks. Drive-train block describes the conversion of the mechanical torque in the rotor to the rotational speed in the generator. The structure block describes the movement of tower, basement and mechanical parts in the nacelle because of thrust force of wind. The electrical subsystem shows the conversion of mechanical power of rotating shaft to electricity in the generator and connection to the grid. Actuator subsystem describes the dynamics of servomotors used for pitch control and the dynamics in yawing. Energy capture, power quality, and mechanical loads are the three main control objectives in wind turbine.

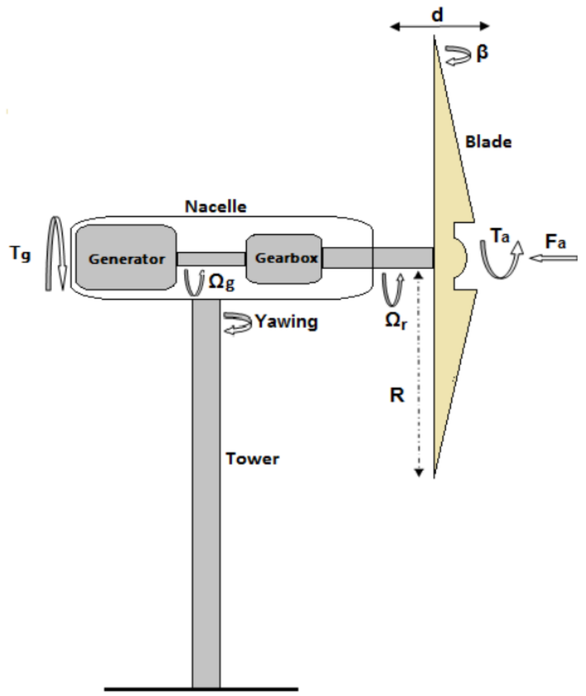

Figure 1.1 Wind turbine with horizontal Axis.

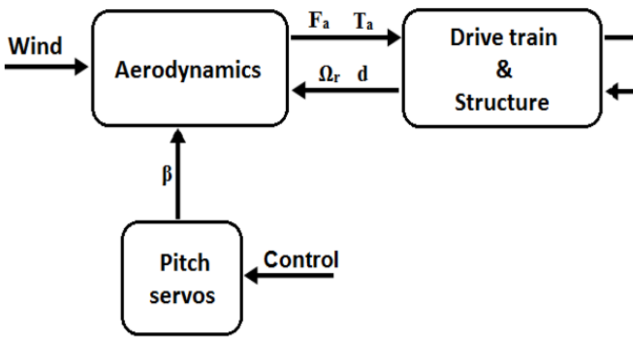

Figure 1.2 Sub System-level block diagram of a variable speed variable – pitch (VS-VP) Wind Turbine.

II. PROPOSED METHODOLOGY

The electrical model for the system is developed using dynamic phasors or complex space vectors in the anachronously rotating – reference frame. An illustration of the axes conventions The default convention assumed here aligns the -axis with the positive real axis and the -axis with the negative imaginary axis, and the complex vector. In certain instances it is convenient to locate the real and imaginary axes aligned with a particular complex vector, for instance , in which case the axes are designated and respectively, and the real and (negative) imaginary components with respect to the reference are designated and , a respectively.

The following simplifying assumptions are made in the development of the model.

1) The iron losses, mechanical and power converter losses are negligible.

2) The magnetic circuit of the machine can be represented bya linear model.

3) The entire mechanical system can be modeled using a lumped inertia parameter referred to the electrical angle and speed of the induction generator.

4) The power converters can be modeled using state-space averaged representation to represent their low frequency dynamics.

5) The wind farm collection network to PCC is electrically stiff. The conventional DFIG T circuit is transformed into an equivalent circuit

The system equivalent circuit model under these assumptions The complete set of nonlinear state equations are

$$\frac{d\underline{\lambda}_s}{dt} = -\underline{\lambda}_s\left(\frac{R_s}{L_s} + j\omega_e\right) + \underline{i}_R R_s + \underline{v}_f + \underline{v}_i$$

$$\frac{d\underline{i}_R}{dt} = \frac{1}{L_L}\Big[-\underline{i}_R\left(R_R + R_s + j\omega_{sl}L_L\right)\ldots + \underline{\lambda}_s\left(\frac{R_s}{L_s} + j\omega_r\right) + \underline{v}_R - \left(\underline{v}_f + \underline{v}_i\right)\Big]$$

$$\frac{d\underline{i}_{re}}{dt} = u(\underline{v}_f - \underline{v}_{re})\left(\frac{\underline{v}_{re} - \underline{v}_f}{L_{re}} - j\omega_e \underline{i}_{re}\right)$$

$$\frac{dv_{dc}}{dt} = \frac{-3}{2v_{dc}C_{dc}}\left[\underline{v}_i \cdot \left(\frac{\underline{\lambda}_s}{L_s} - \underline{i}_R\right) - \underline{v}_{re}\cdot\underline{i}_{re} + \underline{v}_R \cdot \underline{i}_R\right]$$

$$\frac{d\omega_r}{dt} = \frac{p}{2J_m}\left[\frac{3p\ \underline{\lambda}_s \times \underline{i}_R|}{4} + T_m - \frac{2\omega_r}{pG_m}\right]$$

where $u(\cdot)$ is the unit step function.

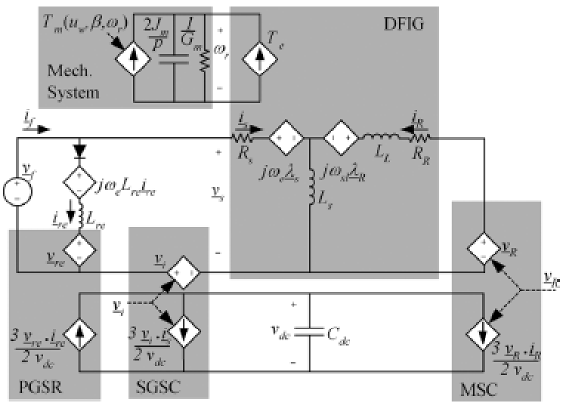

Figure 2.1 Proposed Control mechanism.

The complex vector dynamic state equations are used form the evaluation of steady state properties and the development of control laws. The dynamic states of the system include the stator flux, , rotor current , rectifier current , dc link voltage, , and rotor speed, . Controllable inputs to the system include the complex voltage vectors for the MSC and SGSC, and respectively.

Since the PGSR is a passive network, its conduction state is determined by the state of the diode which conducts when the voltage is greater than. The mechanical power generated at the wind turbine shaft is proportional to the coefficient of performance and the cube of the wind speed. The mechanical torque production due to wind energy capture can be throttled via the blade pitch actuators.

A. DFIG Control

When the DFIG is connected to a network, connection must be done in three steps which are presented below the first step is the regulation of the statoric voltages with the network voltages as reference the second step is the stator connection to this network. As the voltages of the two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the third step, which constitutes the topic of this work, is the power regulation between the stator and the network.

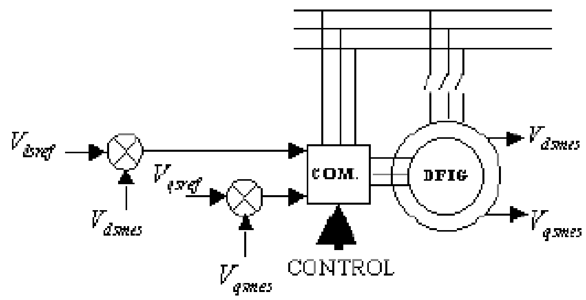

Figure 2.2 DFIG Control Step 1.

First step :

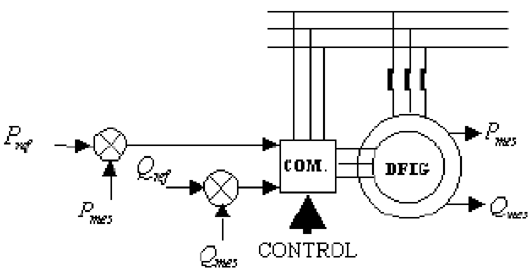

Figure 2.3 DFIG control Step 3.

Third step:

Types of double fed induction generator:

1. Brushless Doubly-Fed Induction Electric Generator:

Brushless doubly-fed induction electric generator (i.e., electric motors or electric generators) are constructed by adjacently placing two multiphase winding sets with unlike pole-pairs on the stator body. With unlike pole-pairs between the two winding sets, low frequency magnetic induction is assured over the speed range. One of the stator winding sets (power winding) is connected to the grid and the other winding set (control winding) is supplied from a frequency converter. The shaft speed is adjusted by varying the frequency of the control winding. As a doubly-fed electric machine, the rating of the frequency converter need only be fraction of the machine rating.

The brushless doubly-fed induction generator does not utilize core real-estate efficiently and the dual winding set stator assembly is physically larger than other electric machines of comparable power rating. In addition, a specially designed rotor assembly tries to focus most of the mutual magnetic field to follow an indirect path across the air-gap and through the rotor assembly for inductive coupling (i.e., brushless) between the two adjacent winding sets. As a result, the adjacent winding sets are excited independently and actively participate in the electro-mechanical energy conversion process, which is a criterion of doubly-fed electric machines.

The type of rotor assembly determines if the machine is a reluctance or induction doubly-fed electric machine. The constant torque speed range is always less than 1800 rpm @ 60 Hz because the effective pole count is the average of the unlike pole-pairs of the two active winding sets. Brushless doubly-fed electric machines incorporate a poor electromagnetic design that compromises physical size, cost, and electrical efficiency, to chiefly avoid a multiphase slip ring assembly. Although brushless doubly-fed electric machines have not seen commercial success since their conception in the early 1970s, the promise of a low cost, highly efficient electronic controller keeps the concept under perpetual study, research, and development.

2. Brushless Wound-Rotor Doubly-Fed Electric Generator

The brushless wound-rotor doubly-fed electric generator (i.e., electric motor or electric generator) incorporates the electromagnetic structure of the wound-rotor doubly-fed electric machine, but replaces the traditional multiphase slip ring assembly with a brushless means to independently power the rotor winding set (i.e., doubly-fed) with multiphase AC power. The torque of the wound-rotor doubly-fed electric machine is dependent on both slip and position, which is a classic condition for instability.

For stable operation, the frequency and phase of the multiphase AC power must be synchronized and fixed instantaneously to the speed and position of the shaft, which is not trivial at any speed and particularly difficult about synchronous speed where induction no longer exists. If these conditions are met, all the attractive attributes of the wound-rotor doubly-fed electric machine, such as high power density, low cost, ultra-high efficiency, and ultra-high torque potential, are realized without the traditional slip-ring assembly and instability problems. One company has patented and is selling a brushless, fully stable, synchronous wound-rotor doubly-fed electric machine with symmetric quality of motoring or generating. Another brushless wound-rotor construction invented by Lars Gertmar has been described in the patent application.

3. Wound-Rotor Doubly-Fed Electric Generator

- Construction

Two multiphase winding sets with similar pole-pairs are placed on the rotor and stator bodies, respectively. The wound-rotor doubly-fed electric machine is the only electric machine with two independent active winding sets, the rotor and stator winding sets, occupying the same core volume as other electric machines. Since the rotor winding set actively participates in the energy conversion process with the stator winding set, utilization of the magnetic core real estate is optimized.

The doubly fed generator operation at unity stator power factor requires higher flux in the air-gap of the machine than when the machine is used as wound rotor induction machine. It is quite common that wound rotor machines not designed to doubly fed operation saturate heavily if doubly fed operation at rated stator voltage is attempted. Thus a special design for doubly fed operation is necessary.

A multiphase slip ring assembly (i.e., sliding electrical contacts) is traditionally used to transfer power to the rotating (moving) winding set and to allow independent control of the rotor winding set. The slip ring assembly requires maintenance and compromises system reliability, cost and efficiency. Attempts to avoid the slip ring assembly are constantly being researched with limited success (see Brushless doubly-fed induction electric machines).

- Electronic Control

The electronic controller, a frequency converter, conditions bi-directional (i.e., four quadrant), speed synchronized, and multiphase electrical power to at least one of the winding sets (generally, the rotor winding set). Using four quadrant control, which must be continuously stable throughout the speed range, a wound-rotor doubly-fed electric machine with two poles (i.e., one pole-pair) has a constant torque speed range of 7200 rpm when operating at 60 Hz. However, in high power applications two or three pole-pair machines with respectively lower maximum speeds are common.

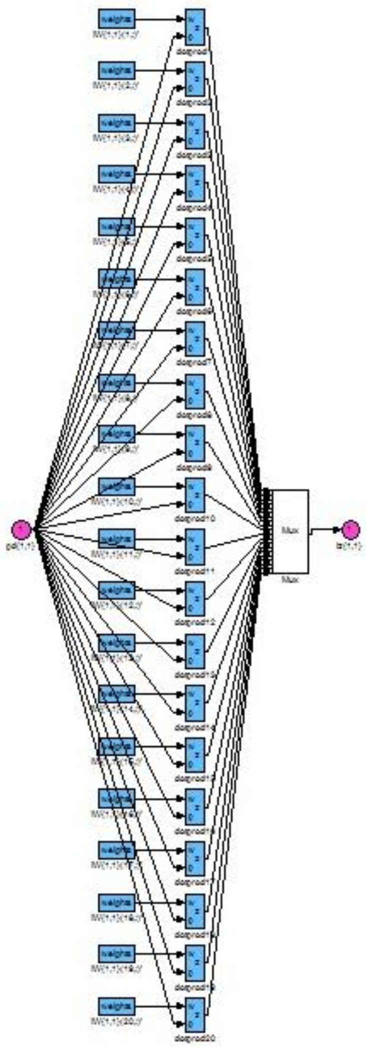

Figure 2.4 . Artificial Neural Network Neuron Layers

The electronic controller is smaller, less expensive, more efficient, and more compact than electronic controllers of singly-fed electric machine because in the simplest configuration, only the power of the rotating (or moving) active winding set is controlled, which is less than half the total power output of the electric machine. Due to the lack of damper windings used in synchronous machines, the doubly fed electric machines are susceptible to instability without stabilizing control. Like any synchronous machine, losing synchronism will result in alternating torque pulsation and other related consequences.

Doubly-fed electric machines require electronic control for practical operation and should be considered an electric machine system or more appropriately, an adjustable-speed drive.

- Efficiency

Neglecting the slip ring assembly, the theoretical electrical loss of the wound-rotor doubly-fed machine in super synchronous operation is comparable to the most efficient electric machine systems available (i.e., the synchronous electric machine with permanent magnet assembly) with similar operating metrics because the total current is split between the rotor and stator winding sets while the electrical loss of the winding set is proportional to the square product of the current flowing through the winding set. Further considering the electronic controller conditions less than 50% of the power of the machine, the wound-rotor doubly-fed electric motor or generator (without brushes and with stable control at any speed) theoretically shows nearly half the electrical loss (i.e., winding set loss) of other electric motor or generator systems of similar rating.

- Power Density

Neglecting the slip ring assembly and considering similar air-gap flux density, the physical size of the magnetic core of the wound-rotor doubly-fed electric machine is smaller than other electric machines because the two active winding sets are individually placed on the rotor and stator bodies, respectively, with virtually no real-estate penalty. In all other electric machines, the rotor assembly is passive real estate that does not actively contribute to power production. The potential of higher speed for a given frequency of excitation, alone, is an indication of higher power density potential. The constant-torque speed range is up to 7200 rpm @ 60 Hz with 2 poles compared to 3600 rpm @ 60 Hz with 2 poles for other electric machines. In theory, the core volume is nearly half the physical size (i.e., winding set loss) of other electric motor or generator systems of similar rating.

III. SIMULATION RESULTS

The fundamental part of an ANN is the neuron, which acts on the input signal (xy) and sends it altered forward. The neurons are interconnected via synapses which holds the weights (w_{jk}), deciding the strength of the connection to the next step, being the summing junction where the weighted input signals of the neuron are added. The activation function (O) limits the output of the neuron to the set finite range, normally [0,1] or [-1,1], and returns an output (y_k). Figure 3.1 demonstrate simulation waveform of various parameters of a ANN based control system for wind turbine. Figure 3.1 illustrated the waveform of control pinch angle of proposed system. Figure 3.2 illustrated the waveform of Controlled Output Voltage (Single Phase). And figure 3.3 shows the Reactive Power of a proposed system and last figure 3.4 demonstrated the waveform of speed of wind.

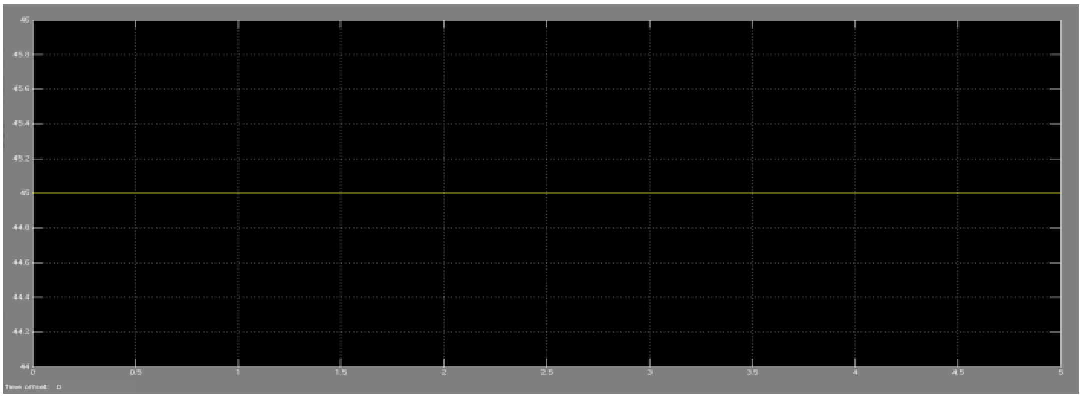

Figure 3.1 Controlled Pitch Angle

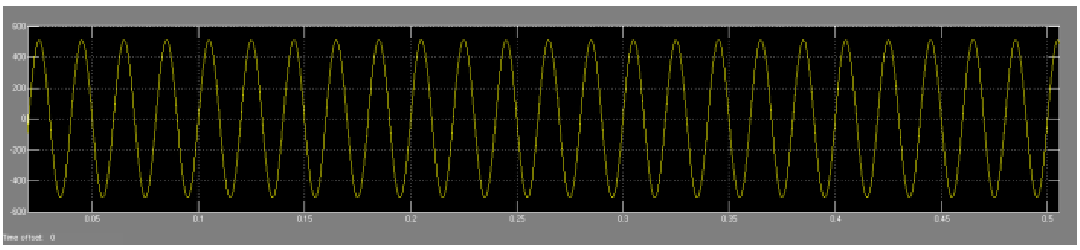

Figure 3.2 Controlled Output Voltage (Single Phase).

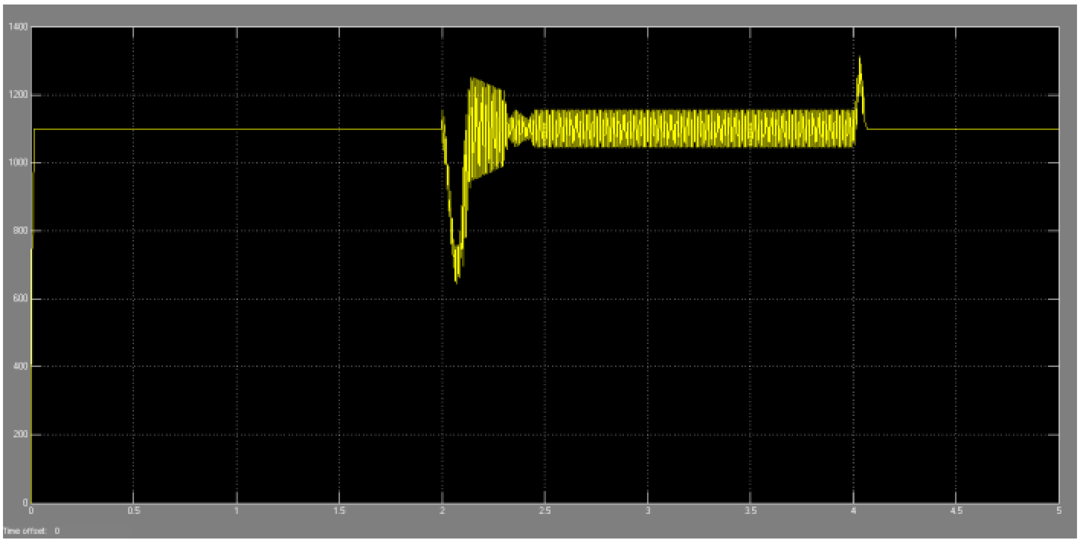

Figure 3.3 Reactive Power.

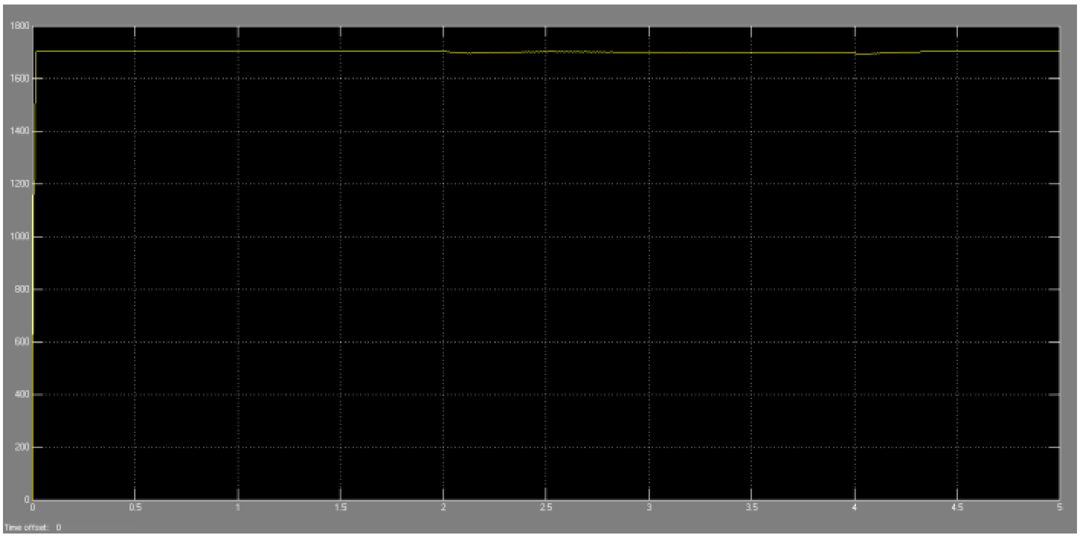

Figure 3.4 Wind Speed.

IV. CONCLUSION AND FUTURE SCOPE

This work demonstrates the benefits of utilization of soft computing technique to control the fluctuations generated by the variable speed of wind generation system due to variation in the wind speed. The proposed methodology control signals based on the fluctuations from wind generator and intelligently, reduces the harmonics present in the system, which was affecting the load due to lower power quality. The proposed system has been taken into consideration with continuous variable speed scenario of wind to get the real life results. Simulation results show the output voltage is sinusoidal which improves the quality of power delivered to the load. Reactive power is also shown that the stability of the system with proposed approach. For further enhancements in the system various conventional and unconventional controllers can be utilized as per the system requirements to maintain the stability of power delivered while fluctuating wind speed.

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