ACTIVATION OF PITCH CONTROL FOR FREQUENCY REGULATION BY WIND TURBINE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By

ABDELQADER TAHA AKEEL

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical and Electronic Engineering

NICOSIA, 2019

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Abdelqader Taha Akeel

Signature:

Date:

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ABSTRACT

Stability operation of power system is indicated by frequency. Nowadays, penetration of wind power is increasing in the power system which resulting to reduce the inertia of power system also the difficulties in frequency control. Moreover, the fluctuation of wind power causes the imbalance of the power system that may leads to frequency deviation from the rated value. This thesis is proposed activation pitch control that allows wind generator to regulation the frequency deviation problem.

The approach of this thesis is adopting control strategy by using fuzzy and comparator logic control to activate pitch control of wind turbine. Extraction real power using wind turbine is increases and decreases with frequency fluctuation, pitch control in wind turbine adjusting the speed and real power whenever to enable a new activation signal.

Output power adjustments help and maintain frequency regulation as well as reduce the frequency fluctuations. Proposed activation signal adopted fuzzy and comparator logic control for the limited movements of the blades wind turbine.

The proposed fuzzy control and comparator control which are adopted in control strategy for issued activation signal is participating to smooth power generation from wind turbine. Hence a result, the frequency regulation of the power system can be achieved. Pitch angle controller will be consideration and simulated by using the MATLAB program for simulation analysis, and simulation results compared with and without activation signal.

Keywords: pitch control; activation signal; FLC; CLC; frequency deviation; wind turbine; grid; blade movement

ÖZET

Frekans kontrolü bir güç sisteminin stabil çalışması için gereklidir. Bugünlerde rüzgar gücünün güç sistemlerine girişinin artması güç sisteminin ataletinin düşmesine ve frekans kontrolünde zorluklara yol açabilir. Ayrıca, rüzgar gücündeki dalgalanma güç sisteminde fazladan güç dengesizliğine ve frekansın nominal değerden sapmasına neden olabilir. Bu tez, rüzgar jeneratörünün frekans kontrolünü sağlayacak bir aktivasyon sinyali sunmaktadır.

Bu tezin yaklaşımı bulanık ve karşılaştırıcı mantık kontrolü kullanarak rüzgar türbininin perde kontrolünü aktif edecek bir kontrol stratejisi kullanmaktır. Rüzgar türbininden elde edilen aktif güç frekans dalgalanması sırasında yükselir ve düşer, rüzgar türbini perde kontrolü rotor hızını ve aktif gücü ayarlayarak yeni bir aktivasyon sinyali elde etmeyi sağlar. Çıkış gücü ayarlamaları frekans düzenlemeleri ve dalgalanmalarını korumaya yardımcı olur. Sunulan aktivasyon sinyali rüzgar türbini kanatlarının kısıtlı hareketleri için bulanık ve karşılaştırıcı mantık kontrolü kullanmaktadır.

Verilen aktivasyon sinyali için kontrol stratejisinde kullanılacak olan bulanık kontrol rüzgar türbininden elde edilen güç üretimini düzleştirmeye yarar. Böylece sonuç olarak şebekenin frekans dalgalanması düşürülebilir. PI perde açısı kontrolörünün simülasyonu simülasyon analizi için MATLAB programı kullanılarak yapılmıştır ve simülasyon sonuçları aktivasyon sinyali dahil edilerek ve edilmeyerek karşılaştırılmıştır.

Anahtar kelimeler: perde kontrolü; aktivasyon sinyali; FLC; CLC; frekans sapması; rüzgar turbine; şebeke; kanat hareketi

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LIST OF ABBREVIATIONS

AC:	Alternative Current
AGC:	Automatic Generation Control.
APC:	Active Power Control.
CLC:	Comparator Logic Control.
CVDPC:	Combined Vector and Direct Power Control
DC:	Direct Current
DFIG:	Doubly Fed Induction Generator.
DMPC:	Distributed Model Predictive Control
ENTSO-E:	European Network of Transmission System Operators for Electricity
FLC:	Fuzzy Logic Control.
FSWT:	Fixed Speed Wind Turbine.
GSC:	Grid Side Converter.
GWEC:	Global Wind Energy Capacity.
I/P:	Input.
K.E:	kinetic energy
LFC:	Load Frequency Control.
MSC:	Machine Side Converter
O/P:	Output
PFC	Primary Frequency Control.
PLL:	Phase Lock Loop.
PMC:	Model Predictive Control.
PMSG:	Permanent Magnet Synchronous Generator.
PQ:	Power Quality.

PSS:	Power System Stabilizer
ROCOF:	Rate of Chang of Frequency
RSC:	Rotor Side Converter.
SCIG:	Squirrel Cage Induction Generator.
SG:	Synchronous Generator.
SMES:	Super Conducting Magnetic Energy Storage**.**
STATCOM:	Static Synchronous Compensator
T_m:	Mechanical Torque.
UPQC:	Unified Power Quality Conditioner.
VSC:	Voltage Source Converter.
VSVPWG:	Variable Speed Variable Pitch Wind Generator.
VSWT:	Variable Speed Wind Turbines.
WTG:	Wind Turbine Generation.
WF:	Wind Farm.

CHAPTER 1

INTRODUCTION

1.1 Introduction

New sources of power are focused in several researches. The grid has been developing significantly in worldwide due to the issue of gas emission (Ngamroo et al, 2013). Using the wind as a source of the energy has spread in the recently years. Wind turbines can provide torque with existing of the wind resource. Unlike most other generators.(Farag et al, 2017).

Most of wind turbine generators can be reduction the real power to zero that can be fulfill by the wind using variable speed and pitch control strategy. In addition, when the wind speed is higher than the rated value, the pitch control strategy keeps the turbine speed at the rated value. Penetration of (WGs) may gradually cause to low the inertia of the power system, consequently it will reduce the frequency regulation capabilities. (Miller et al, 2012) (Villena et al, 2012). The power of (VSWGs) can be effective and rapidly controlled by using the power electronics converters. Such as, STATCOM/SMES which may be placed at the output power generated by the wind to mitigate fluctuation frequency and the output power (Sheikh et al, 2009). Using of the power electronics is increased, particularly on the (GS), concerning on the control of the pitch angle of the blades could be capable emulate the traditional power plant. Since the wind speed interrupted and the output generated power proportion to cube the wind speed, the generated power produced by the wind turbine generator will be fluctuated (Ngamroo et al, 2013). Therefore, decreasing the fluctuation frequency is necessary from the power system stability point of view (Kundur et al, 2004) (Abdulraheem et al, 2016) (Kundur et al, 1994). Controlling of the power generated from the wind turbine enhances the load frequency successfully (Qudaih et al, 2011). Adjusting blade of WTG by means of varying pitch angle to smooth output wind power (Senjyu et al, 2006). There are several ways for mitigate fluctuation frequency and output power generation of wind turbine such as energy storage system (Ferdous et al, 2016) , (Muyeen et al, 2012) due to this way is very costly, there is another considered way which called SMES. There are many other devices designed to solve the fluctuation problem of the wind power generation (Kinjo et al, 2006). STATCOM/SMES is another control strategy, which is placed at output generation of the wind energy to mitigate fluctuations of output power and frequency as well (Sheikh et al, 2009). Installation the energy device is costly, therefore most researches concentrated on the pitch controller design to decrease the fluctuation frequency and the output power. Two types of control adopted to provide the contributions for the proposed of the new activation signal:

a) Comparator Logic Control (CLC).

b) Fuzzy Logic Controller (FLC).

The fuzzy logic is utilized for linear and nonlinear control system (Jauch, 2006). Moreover, the mathematical model of fuzzy logic is not important like the using of knowledge for the operation of wind turbine system. Through activation pitch control, the wind turbine insures to improve the frequency of the grid. The simulation results show that the controlled pitch angle using a new activation signal, which can be reduce the frequency oscillation in the grid effectively.

1.2 Thesis Objectives

The aim of this thesis is developing the performance of the WT in terms of regulation the frequency of grid. The second aim of this work is to eliminate the oscillation blade of the WT. Both issues can be achieved by means of pitch controller. When the frequency fluctuated at the permissible range, the pitch controller does not activate. For instance, if the nominal frequency is 50Hz, then the load is varied. Consequently, the frequency fluctuation will increase or /and decrease from the nominal value of the frequency. If this fluctuation within permissible range in this case, we will not need to activate pitch controller of WT. Consequently, the blade movements will be limited. On the other hand, if some faults occur, trajectory deviation frequency tends to reach to the bounder limits. Comparator Logic Control and Fuzzy Logic Control are using to enable the activation signal for the pitch controller of WT.

1.3 Problem Statement

Power system has to keep in stable frequency within operation limits. Deviation frequency is a significant problem which leads to unstable of the grid (Toulabi et al, 2017). Frequency stability is a significant issue in order to balance between the generators and loads. Maintaining a consistent electrical frequency is important because multiple frequencies cannot operate alongside each other without damaging equipment. All power grids are designed around a standard frequency usually 60 or 50 Hz. This standard frequency is the frequency that all devices on the grid are synchronized to and designed to operate. If frequency significantly deviates from the common frequency, equipment can be damaged. Generators can sustain damage to turbines due to speeding up too fast or sub-synchronous. Transformers can heat up and damage themselves if the current through them becomes too high which can happen during contingency events due to frequency issues. Even consumer devices are only designed to handle a certain frequency and can experience damage due to high or low frequency. In short, frequency in power system should be maintained constant to maintain stability of grid. Deviation the frequency for example to 51 Hz tend to increase the speed of the generator, which in turn increases of field current I_f then increases armature voltage E_A and terminal voltage. If that occur particular in duration time we get two type of problem.

First, the winding of the generator will be heated over rated temperature of the winding and insulation as well, that causes short circuit winding of the generator.

Second, when the voltage drowns from generator increases that mean the demand load will be damage because any load operates on a constant voltage such a constant frequency (Chapman, 2005).The goal of this work is to maintain the frequency within the rated operating range (ideally at nominal constant value). When the frequency exceed over the limits, protection units disconnects the power plant. When the frequency further decreases, it may leads to the total collapse of the whole system. The deviation of the frequency is appearing more clearly at the interconnected system or in the multi regions connected as one grid. The frequency will not be stable in case of unstable load as well. At that time, we can say mismatch occurred between the load and the source. However, there is a problem in the wind turbine performance, particularly in the blades movement, a change in the wind speed is proportion with change in pitch angle, it will produce the fluctuate in the blades movement. From mechanical point of view, fluctuate movement blades of the WT leads to a short lifetime. Moreover, the maintenance continuously, the pitch controller actually acts to mitigate the oscillation of the blades. Consequently, it mitigates the fluctuation frequency and fixed generated power as well. Aforementioned problems can be overcome by using the activation pitch control from the proposed control strategy (comparator and fuzzy controls) to enable the servo motor in order to adjust movements of blades.

1.4 Methods of Frequency Regulation

Maintaining the frequency in the whole system is to be very close to 50 Hz is very important. Every single generator in a big power grid must be spinning at the same frequency otherwise the system may become unstable. If the system frequency deviates a little from 50Hz, the generators will automatically compensate that deviation by using the governor generator control to return back the frequency to 50 Hz. The power frequency characteristic of diesel generators is shown in the Figure 1.1.

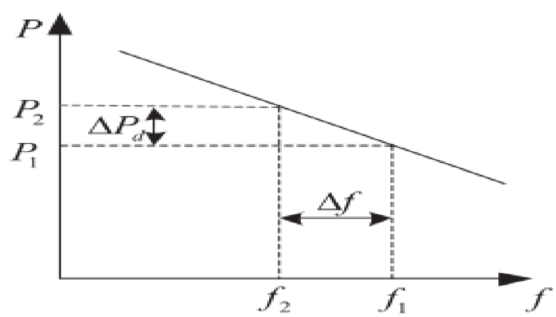

Figure 1.1: Power-Frequency characteristic (Chang-Chien et,al 2011)

According to figure 1.1, when frequency disturbance occurs, the active power will be released according to frequency deviation. Similar to the WT's, the increased active output power of a DFIG is proportional to the deviation of frequency when frequency disturbance occurs. This is given by

$$\Delta P_d = K_d \Delta f$$

where K_d is the droop control gain of DFIG (Vidyanandan et al, 2012) (Zhao et al, 2016). If the deviation is large, the grid will become unstable. In this part, we will focus on the frequency regulation methods by using the wind turbine.

In (Mauricio et al, 2009), enhancing performance of (VSWG) for the frequency regulation mechanisms. By changing the inertial control, the fast response of the kinetic energy is stored by the rotational masses, And it will released partly and transiently, in order to provide and support the frequency.

In (Wu et al, 2015), a wind power forms economical and environmentally-friendly. But, discontinuity of the wind power brings a new challenge in case of frequency stability problem. Limitation of the range frequency regulation is the reasons to limit the wind energy control. The output power from energy storing system (ESS) is regulated faster. Hence, it is suitable ESS to solve the frequency oscillation problem of the power system. Also, it helps to extend the limitation range of the frequency regulation control of the power system.

In (Li et al, 2013), the control planning of the WTs are designed for extraction maximum wind power, but it is not valid for the frequency regulation of the grid. The control planning provided in most of studies. For instance, the pitch control. Using of the (ESS) to reserve the energy during the off peak hour and inject during the peak hours to the network.

1.5 Thesis Organization

The thesis has organized into five chapters.

Chapter One: An Introduction of the thesis. This chapter contains (The introduction of the thesis. Thesis objective. Problem Statement. Thesis organization.

Chapter Two: Focus on Literature Review, including (An Introduction, other people's work with the frequency regulation, the pitch controller, and the wind turbine).

Chapter Three: Explain the methodology, grid structure, and proposed control strategy (comparator logic, fuzzy logic).

Chapter four: Implementation Result, which discussed compared simulation result with the proposed activation signal and without it.

Chapter five: Draws a conclusion for this work and proposes future work

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Wind farms have benefited from advances in technology over the last century. Now, we could be able to modify the output power to limit the power, frequency deviation and control voltage, speed, real and reactive power interchange the grid with the wind turbine. There are a lot of researches are going around the world, which are concerning on this field. Understand the power systems, machines, and implementation of the electronic power converters are very important. Unlike the traditional stations, which uses for the synchronous generators, The (WT) can be run in a constant or a variable speed. In the fixed speed, the stator of the machine is coupled to the network directly. However, in the variable speed, the generator is controlled and coupled to the network during the power electronic converter.

2.2 Literature Review

In this thesis, the literature review is classify into three major domains:
the performance of the (WT), the pitch angle controller, and frequency fluctuation.
In (Amrane et al, 2018), proposed a (CVDPC) for the (RSC) of (DFIGs). The direct current is adopted control by using a suitable voltage vectors. The advantages of the (VC) and the (DPC) in comparison with VC include fast dynamic response.
In (Bhavani et al, 2015), analyze power quality (PQ) problem due to stress voltage and current distortion, which resulting the interconnection wind turbine in the power system. Also, this work proposes a control strategy by utilize (FLC), to developed the UPQC performance, to eliminate the disadvantages by using constant gains in the PI controller. Hence, through the comparison between the implement of the fuzzy controller and PI controller, the proposed (FC) UPQC offered fast response and efficient to reduce the voltage droop and current distortion.

Thus, when the grid connects with the wind power system, it becomes good quality and reliable of power.

In (Jahan et al, 2017), proposed control (VSWTs) by using a permanent magnet synchronous generator regarding to offshore (WF), which is coupled to onshore grid via (VSC) to mitigate the frequency oscillation of the onshore grid..

In (Sharma et al, 2018), utilized a boost converter for wind turbine connected to grid. Due to variation blowing of wind, the voltage and frequency generated are varying. Therefore, it is important to use the power electronic equipment between the (WT) and the grid. The proposed power electronic converter consist of three phase uncontrolled diode rectifier, three phase inverter and DC-DC boost converter.

In (Cerqueira et al, 2017), study a comparison of the different control ways for the (PFC) of the wind power farms. These controllers comprise the inertia and the pitch angle. Inertia control is rapidly effects to fluctuation of the frequency, and the change rate of frequency. Both of controllers try to face the (MPPT). Also, they investigate the impact of canceling the MPPT whenever the inertia is activated.

In (Muttaqi et al, 2017), proposed the direct voltage to (DFIG) based on (WT). Due to the events and emergencies, which occur in the power system, DFIG faced low voltage rid through, that may resulting to disconnect from the grid. In order to reconnect DFIG to the grid again, DFIG has to synchronize with the grid to avoid transient impacts get smoothing connection to the grid. The proposed technique checked out by simulation utilized different ways such as, the voltage transient, steady state voltage and frequency.

In (Hui-qun et al, 2014), comparing the wind speed simulation, which is depend on Kamal's spectrum with the PID controller using by the fuzzy self-adaptive control. Utilize PID control to hold the critical wind power at bellow rated wind speed.

In (Pahasa et al, 2014), applied (MPC) to blades of the (WT) via the pitch control. The optimization method is adopted in model predictive control to obtain future control signal. The MPC actuate the blades by pitch angle control to produce soft power generated the wind turbine.

In (Ferdous et al, 2016), utilized pitch control to decrease the fluctuation frequency and output power generated from the wind turbine. This control strategy performed due to randomly variation wind speed which results the fluctuation generated the power and frequency as well. As a result, this decreases the energy.

In (Farag et al, 2017), studied the performance of self-excitation induction generator (SEIG) based on (VSWT). Also, the pitch angle control is available for the speed of generator over the nominal value. The base idea of this paper is to study the dynamic for SEIG under the different wind speeds. Also, it focus on the impact of the wind speed on the produced power, the pitch angle and speed angle of the rotor.

In (Chamorroet al, 2013), analyzed the performed of the inertia problems in case of available (WT), The power electronic introduces the ability to recover the frequency stability after a large disturbance, penetration of (WT) in the transmission and distribution can be affected on the inertia response.

In (Sahoo et al, 2016), Utilized the PID and fuzzy controller methods for the pitch control, pitch angle control system is using for regulated the output power and the wind speed when increases above the rated speed. The simulation result shows that the fuzzy logic control can be achieved better control performance than the covenantal pitch control.

In (Verma et al, 2012), studied the dynamic performance of the (DFIG) based on (WT) for frequency regulation. Modify inertia also proposed which helps DFIG to support the grid during the transient through providing an active power in short term. The frequency deviation occurs during providing the inertia controller. Reference the output power helps DFIG to release the stored active power in the (WT).

In (Sonkar et al, 2018), they coordinated the control technique for malty area (two-area) content thermal unit and wind farm. LFC merges in the wind turbine control and compared with the inertia controller. It is a combination of the inertial and the droop controller.

In (Raoofsheibani et al, 2014), investigated the ability of (DFIG) to provide the primary control reserve, where the (ENTSO-E) grid code requirement for frequency regulation. (RSC) control is improved to be flexible for any change of real power when contingency events occur to the frequency and their rotor inertia participate frequency stability by offering derivative frequency.

In (Lopes et al, 2006), proposed a parallel coupled (VSI) for regulation. The voltage and frequency in (S-ESCIM) based on the wind energy. A huge battery is placed in the dc side of the VSI, for inject or absorb the real power. The features of the (WT), (S-EG), and function of the VSI for the voltage and frequency regulation for a given (WS) range.

In (De Almeida et al, 2006), proposed a control that allows (DFIWG) to share in frequency regulation system. In this work, the (WGs) run based on a deloaded curve, which provided injection or absorbing real power during the changes of the frequency system. The control strategy uses the pitch control to modify the rotor speed and the real power according to the deloaded optimum power extraction curve.

In (Arani et al, 2015), proposed simple modification for control the (DFIG) to implement the torque and the power droop, They used small signal modeling, with presence effects of pitch angle control, variation of wind speed and issue isolated mode of wind turbine solved.

In (Wilches-Bernal et al, 2016), Utilized the small-signal analysis to research frequency response in the grid and prove how Type-3 (DFIG) (WT) can effected on this response on the grid. Frequency response is specified by a frequency-regulation. By run the (WT) in a deloaded mode.

In (Zhao et al, 2016). They proposed a variable inertia and (PFC) for (DFIG) with conventional generator to share in the wind turbine and diesel and photovoltaic microgrid frequency regulator. Frequency response characteristic in case of different wind speed is analyzed. In order to enhance the frequency of micro grid. Portion of the wind power is preserved during over speed and pitch angle control.

In (Liu et al, 2017), proposed distributed (MPC) for the power system. It consists (WT) ,(DMPC) provide prediction data and information to the control central for the (LFC) of the grid in order to coordinate control. (LFC) is coordinated by modify the wind speed, pitch angle and load input based on (DMPC) data. The (LFC) is important for the power system, and formed more crucial when the power system includes the wind power generators.

In (Zhang et al, 2018), they studied the differences between de-loading speed control and (WS), Also, how they gets the critical de-loading curve of the wind turbine. This de-loading curve and pitch control de-loading are division. This way is supported the frequency regulation. In the last century, the wind energy has been fast progressed, frequency control of the power system is forms as significant challenge.

In (Chowdhury et al, 2008), they developed a plan for the frequency regulation of the WT, like the droop response of the traditional generator. Modifying the O/P real power can be accomplished by means of the converter and the pitch angle control. Furthermore, the inertia response of the WT.

In (Moutis et al, 2009), proposed sharing of the (VS) with the (VPWG) (VSVPWG) for (PFC) using pitch-control. The approach operation is coupled the conventional generator with the (WTG).

In (Yuan et al, 2010), proposed the coordinate between the speed generator of wind turbine and its pitch angle, to extract the active energy generated, according to consumption of demand. Adjusting the speed and pitch angle actually for controlling the speed and output the wind power as well. That case study unreliable power system, where the equilibrium between the generated power of the wind and the load is not available.

In (Bevrani et al, 2012), They proposed fuzzy logic control in term of LFC of the interconnected power system to decrease frequency deviation at tie-line where the power change for the two or more places using wind power. due to entering wind power in interconnected power system. Load Frequency Control (LFC) should be able to handle complex problem, like widely the distribution and demand and sources of the grid should be able to keep at generation -load balance, wind power leads to disturb in the network which causes frequency deviation.

In (Buckspan et al, 2012), This paper concentrated on improving and application for stationary and varying droop curves, for the frequency indication the output power signals is utilized on set point power tracking control system. Wind energy formed considerable energy in the world, this penetration of wind energy addressing to provide (APC) services. This utility is common with traditional generator. Decoupling wind farm from the grid via power electronic devices which able to cumulative APC command by means of control the generator torque blade pitch signal command. For this reason APC provides more flexible control than traditional generator.

In (Aziz et al, 2015). They studied to develop fuzzy LFC under stochastic related on the power and frequency regulation in industry demand. Fluctuation power in industry leads to disturb the frequency of the power system. LFC must be able to mitigate fluctuation of the frequency when the presence of stochastic demand.

In (Chang-Chien et al, 2011). Their research on the issue of lack frequency control supporting by units, solving this problem via frequency response providing by the wind turbine. For achieving this goal, controllable output active power generated by wind turbine, therefore predict consumption of fossil fuel by units will be less.

In (Vidyanandan et al, 2012), mentioned some problems in frequency deviation due to penetration wind energy in the power system significantly. When multi mix resource utilized in the grid that is lead to reduce effects on the conventional generators, the conventional synchronous generators form the main resource of grid because it is easy to control the grid frequency. Two important parameters possess the traditional generator make the power system in balance state, the parameters are inertia and speed droop. Moreover, this feature does not exist in WTG. The electrical connection between the generators may be lost due to the power electronic interfacing. Therefore, widespread of wind turbine in the grid leads to reduce the inertia and increasing in droop system. That results to increase the frequency deviation.

CHAPTER 3

METHODOLOGY

3.1 Overview

The frequency deviation must remain within specific limits to avoid blackouts or damaged equipment. To ensure this, a number of control strategies need to be incorporated into electrical power system (Abdulraheem et al,2016) (Frunt et al,2009). The power systems have to operate in a stable manner (Schlabbach et al, 2014) and be capable to withstand a wide variety of contingences events (Kundur et al, 19994). Figure 3.1 and Figure 3.2 illustrate the main frequency operation limits of both European transmission system and Malaysian transmission system. The information in the two figures is referred from ENTSO-e (2015) and Malaysian Transmission System Reliability Standards (2006). And it is clearly show that the interval between 49.8-50.2 Hz the primary control activate.

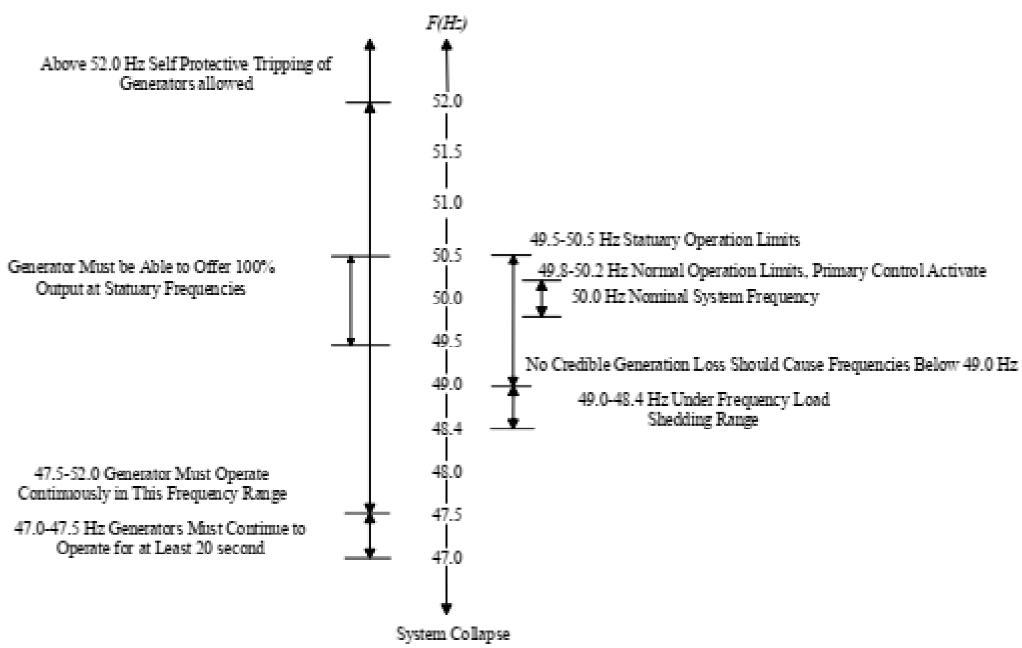

Figure 3.1: European transmission system main frequency thresholds and operating limits (Wang et al, 2016)

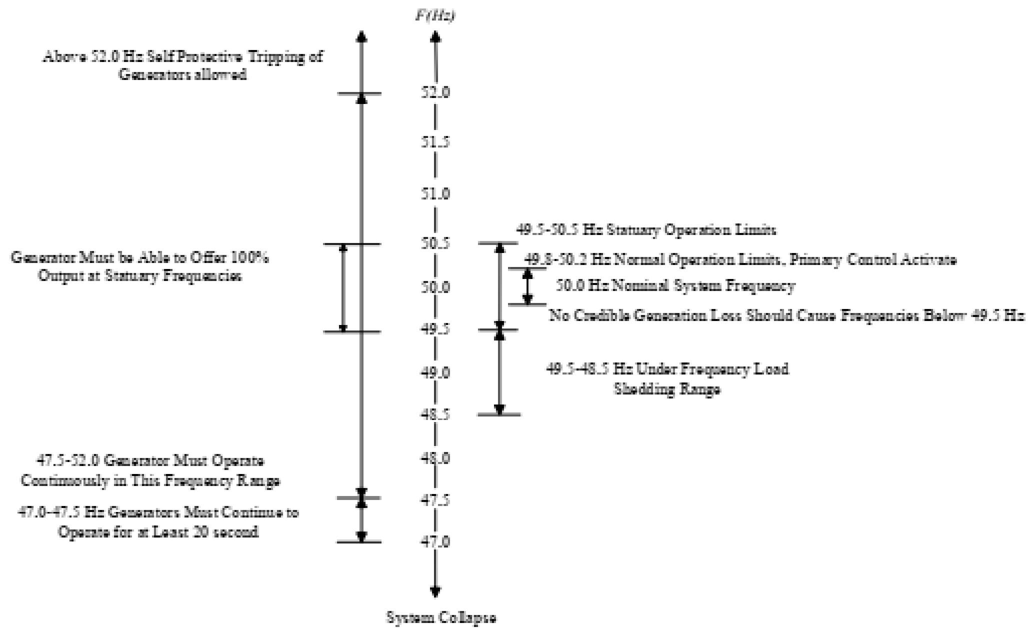

Figure 3.2: Malaysian transmission system main frequency thresholds and operating limits (Tenaga et al, 2015)

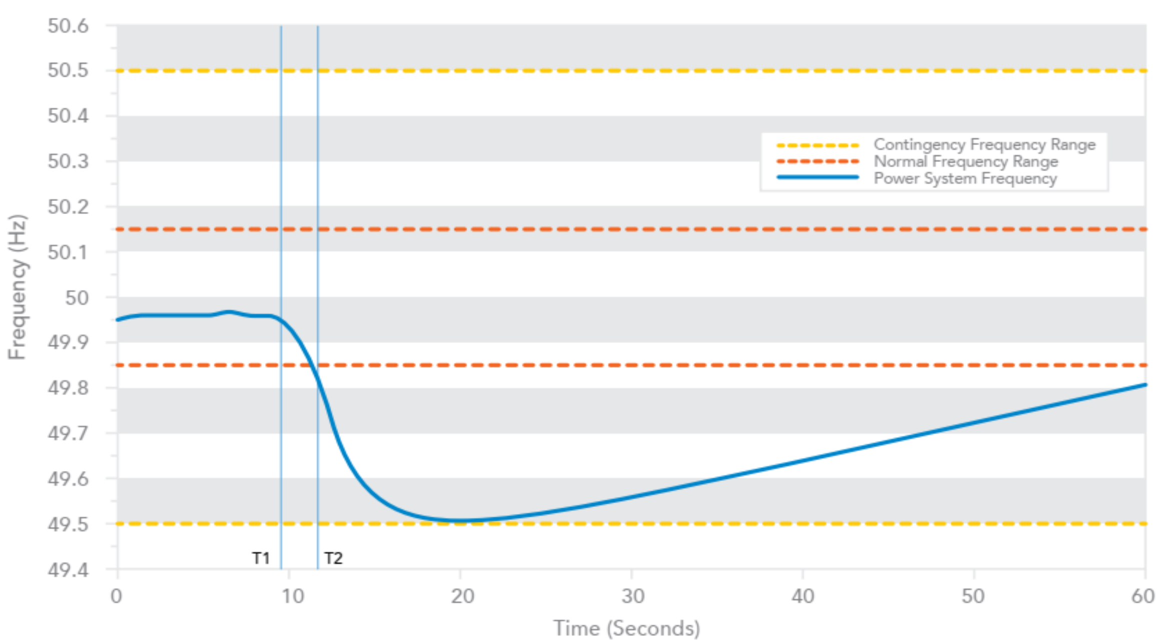

Figure 3.3: An example of the frequency deviation due to contingency event (Rieszet al, 2015)

Figure 3.3 shows the control of frequency during normal operation (at the left of the figure), and following a contingency event. In this figure, a contingency event at the time shown as T1 results in a sharp drop in power system frequency which passes outside the normal frequency operating range at T2. After T2 to arrest the fall and begin restoring frequency to the normal range. If frequency moves outside the contingency band, emergency protection equipment may disconnect generation (for a high-frequency event) or electricity load (for a low-frequency event).

The simulation of this work has shown in Figure 3.4. In this proposed, the power system is connected by the wind Turbine. The frequency is constant as 50Hz, which is considered as nominal value which may deviation and fluctuated. In this work, the frequency deviation is simulated by connecting the proposed grid to the wind power system. The Activation Signal is provided for the frequency regulation and eliminates the blades oscillation, the adopted control strategy in this work is provides a signal to effective mitigation of the frequency deviation. The pitch controller of the wind turbine will be utilizing for both issues. Hence, the goal of this work is concentrate in the control strategy, which comes before the pitch controller. In another word, pitch controller receives command from the control strategy to solve those problems.

3.2 Modeling and Control Strategy of WT

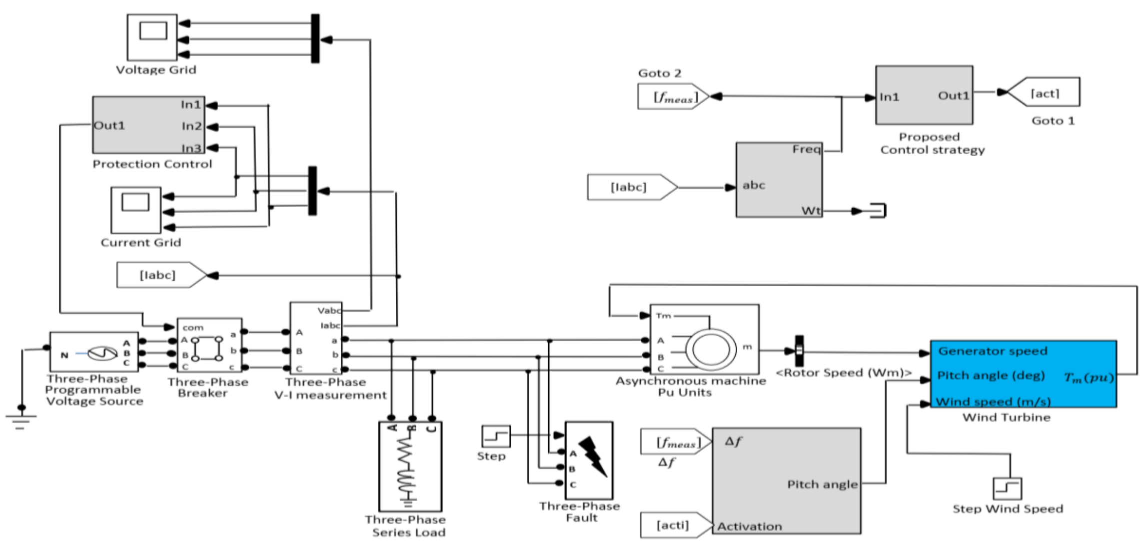

Figure 3.4: Main circuit of the methodology

The scheme of the WT is shown in Figure 3.4. In this work, simplified model of the WT is interested to mitigate the frequency fluctuation and limiting oscillation blades of the wind turbine.

The configuration of the WT system includes three parts:

- Main equipment's of the grid.
- Controllers.
- Wind Turbine Generator.

3.2.1 Main Equipment's of Grid

In order to construct the real power system, we have to utilize all equipment, which are related with the network as shown in Figure. 3.4, the equipment is:

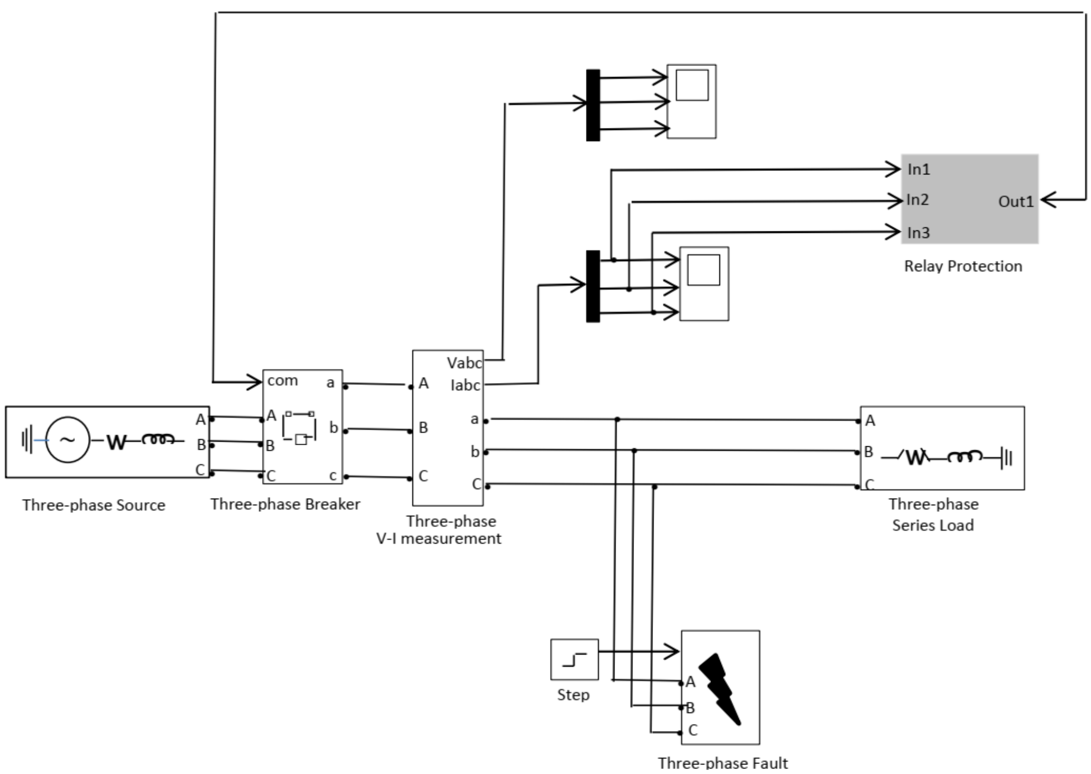

Figure 3.5: Simulated Power System without WT

3.2.1.1 Voltage Source

That is supply power to the grid in order to feeding energy to the load.

3.2.1.2 Fault Generating System

Protection topology as shown in Figure 3.5 consists of:

1- **Fault generator:** This part generates phase-to phase, phase- to ground or two and/or three phase-to ground short circuit, this fault in order to emulate fault current, which is might over the rated current of the grid. In order to simulate a real power system, we have to impose events to the system. Therefore we add the fault as a contingency to the system. After selected type of the fault, we have to enable the fault which is represented by the Step operation in Matlab Simulink.This step represents the time of the fault occurs, we will be able to specify when the fault happen.

2- **Relay controller of the protection system**

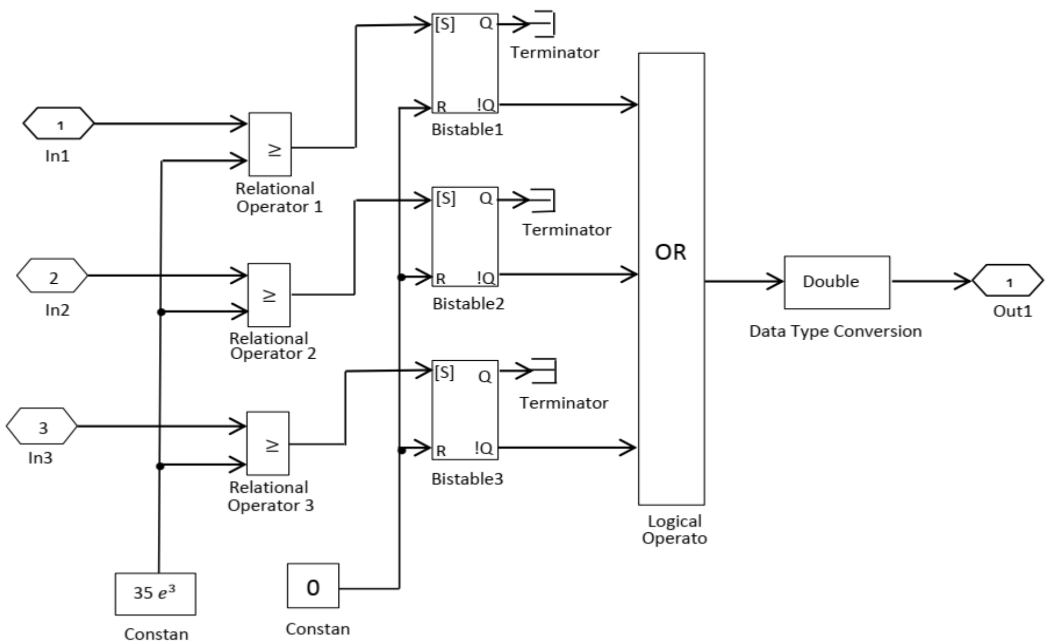

Figure 3.6: Relay controller of the protection system (https://youtu.be/NX0fFj4VSKA Usman Hari Nov 16, 2014)

The current of the power system is measured from the three- phase network. This measured current sensing by protection relay as shown in Figure 3.6, and compared with the set point reference current of the system, at any phase. If the measured current equal or greater than the set point value $35e^3 A$, the signal issued to SR Flip-Flop operator which sent the signal to OR Gate. This signal is still in holding case until the Reset to enable the RS operator. Constant "0" represents the reset of this operator. Then, the OR Gate sends the signal to the output of the relay protection, which activates the circuit breaker to isolate the system.

3.2.1.3 Monitoring Measurements

Analyzing the performance of the operation system, by using the monitoring measurement to show the parameters such as:

Grid current (A), grid voltage(V), active power generated (W), grid frequency Hz, step of the wind speed(m/s), speed of wind turbine w_r, pitch angle $\Delta\beta$, and mechanical torque T_m.

3.2.2 Controllers

Methodology of this thesis proposed control strategy for activation pitch control of wind turbine to regulation frequency deviation of power system, the contribution of this work is focus in activation pitch control of the wind turbine. Therefore we adapted the control strategy to activate pitch control as see in the Figure 3.7.

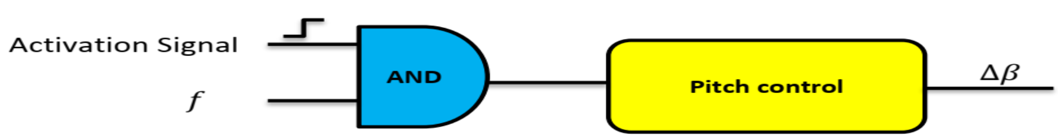

Figure 3.7: Proposed activation pitch control

In this work, two controllers each controller adopted has explained in details as in the following.

3.2.2.1 Comparator Logic

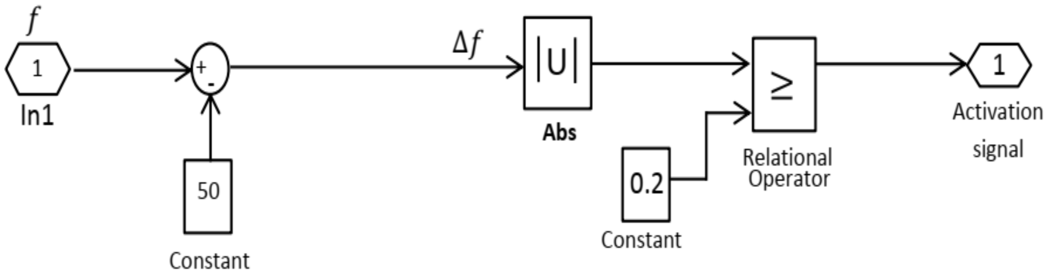

Figure 3.8: Proposed Comparator Logic Control

As the Figure 3.8, we see actual frequency f apply to comparator with the set point reference 50Hz, then the absolute value, that the output error of the comparator applied to the logic comparator($\geq$) with the setting value, which we assumed 0.2Hz. In this case, any deviation value equal or greater than 0.2, activation signal will be enabled.

3.2.2.2 Fuzzy Logic

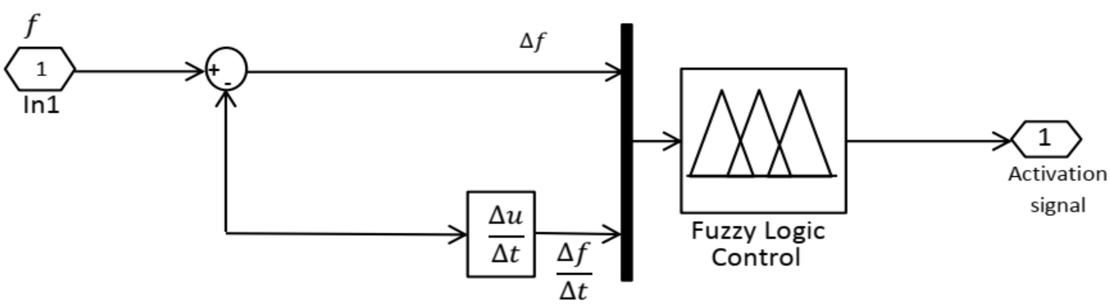

Figure 3.9: Proposed Fuzzy Logic Control

To improve the performance of regulation frequency, by using the Fuzzy Logic Controller (FLC) as shown in Figure 3.9, which suggested to deletes the disadvantages of using fixed comparator logic control. Such simulation results, we will compare the performance the controller, the approach fuzzy controlled provides an effective accurate and fast regulation for the frequency deviation than the comparator logic as well as the conventional PI controller.

To illustrate the steps procedure of the fuzzy logic control as followed (Musyafa et al, 2010) , (Putrus et al, 2009):

(i) fuzzification: find the I/Ps and O/Ps member functions.

(ii) Putting the bases.

(iii) defuzzification: obtained the output signal via fuzzy result of the rules (Musyafa et al, 2010). The Figure 3.6 illustrated the main configuration of the fuzzy logic.

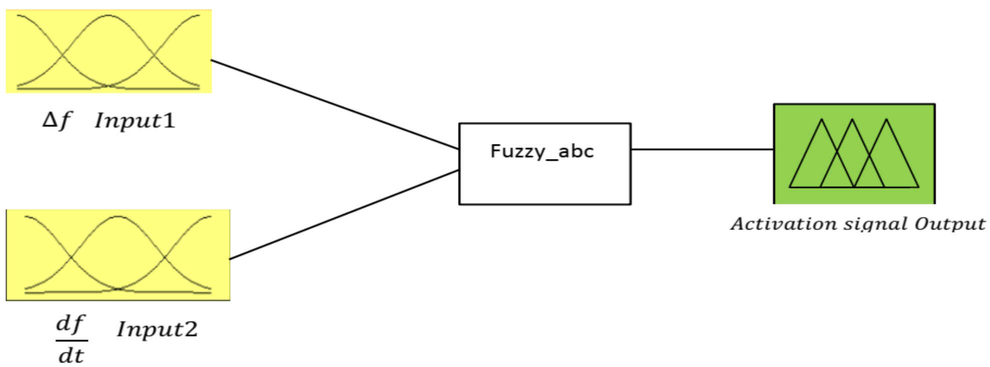

Figure 3.10: Scheme of Fuzzy logic control

As we see in Figure 3.10.The actual frequency (Δf) and its derivative have been sitting as input. The frequency Hz range was supposed to be [49.6, 50.2] Hz and its derivative is equal to [-15, 15] Hz. The rated frequency of the grid is equal to 50Hz. In this branch, we have activated two signals of the I/P and one signal of the O/P. As it has shown in Figure. 3.11 and Figure 3.12 five members for every I/Ps.

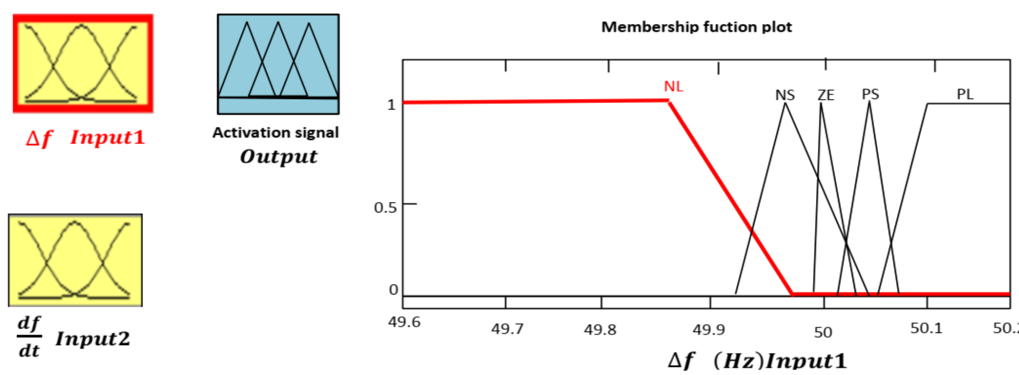

Figure 3.11: Δf (Hz) member functions

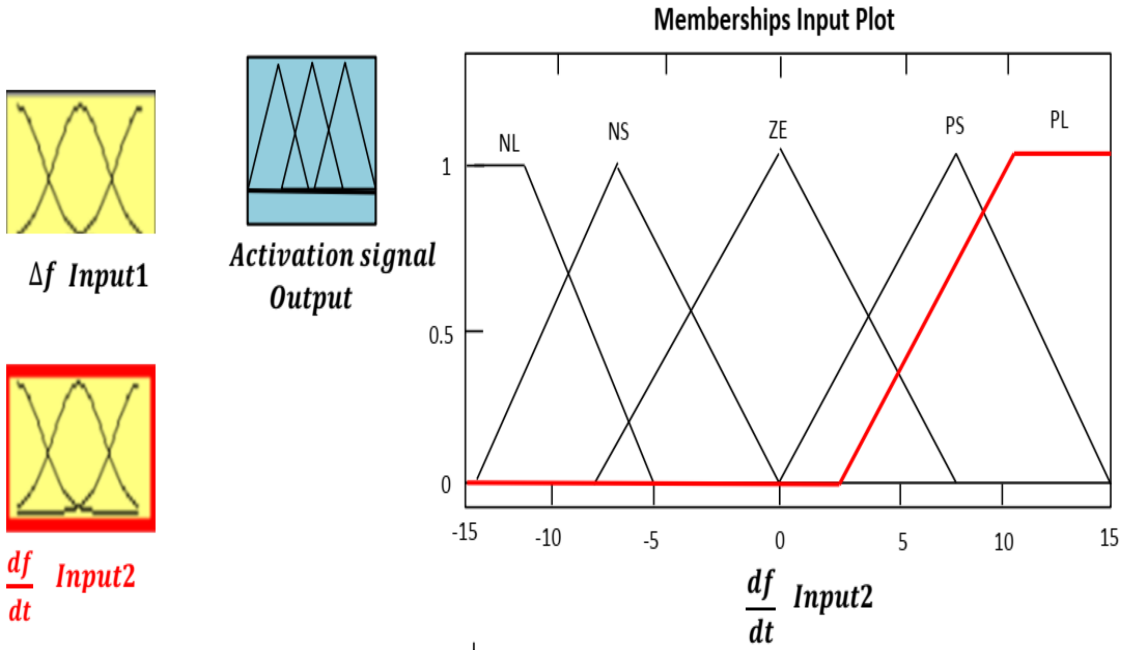

Figure 3.12: df/dt(Hz) member functions

The input membership functions are described in the Table 3.1

Table 3.1: Input member function subdivision.

Member function	**Descriptions**	**HZ range**	$\frac{df}{dt}$ **range**
NL	Negative Large	0 – 49.95	-15 -5
NS	Negative Small	49.9 – 50.03	-15 – 0
ZE	Zero range	49.98 – 50.02	-7.5 – 7.5
PS	Positive Small	50.01 – 50.1	0 – 15
PL	Positive Large	50.07 – 50.2	3.5 – 15

The pitch saturation range between -30/30 deg/sec. Seven membership functions described the output result as shown in Figure 3.13, and reported in the Table 3.2.

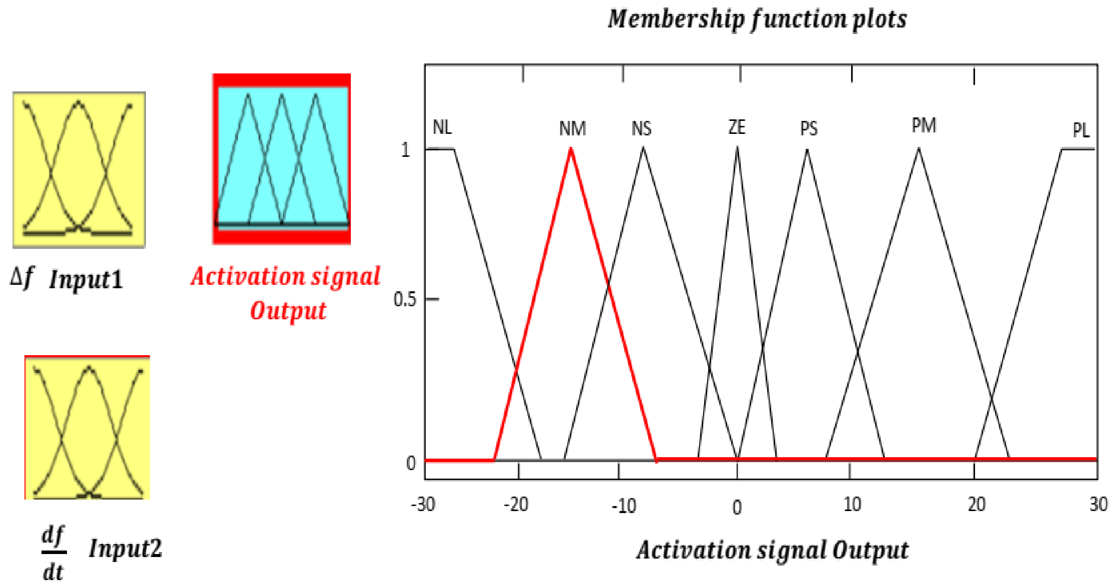

Figure 3.13: Output activation signal membership function

Table 3.2: O/P member function

Member Function	Pitch angle (β)
Negative Large (NL)	-30 -18
Negative Medium (NM)	-23 -8
Negative Small (NS)	-14.8 0
Zero range (ZE)	-4 4
Positive Small (PS)	0 12
Positive Medium (PM)	8 22
Positive Large (PL)	20 30

From the I/P and the O/P member function, 25 rule have been obtained.

Table 3.3: Fuzzy rules.

Δf	df/dt				
	Negative Large	Negative Small	Zero range	Positive Small	Positive Large
Negative Large	Negative Large	Negative Medium	Negative Small	Zero Range	Zero Range
Negative Small	Negative Large	Negative Large	Negative Small	Positive Small	Positive Medium
Zero Range	Negative Large	Negative Small	Zero Range	Positive Medium	Positive Large
Positive Small	Zero Range	Zero Range	Positive Small	Positive Medium	Positive Large
Positive Large	Zero Range	Zero Range	Positive Large	Positive Large	Positive Large

Table 3.3 indicate to rules of fuzzy logic, as we see included the two inputs in each range to get the output, the forms of the output fuzzy can we obtained as the following surface. The output fuzzy surface is represented in the Figure 3.14.

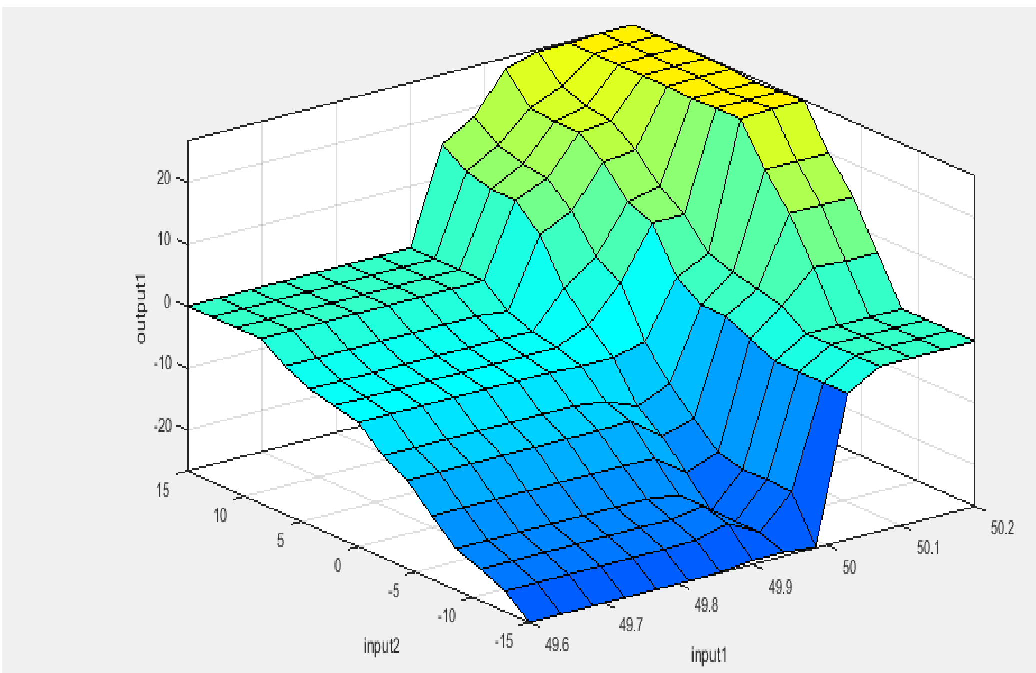

Figure 3.14: Output fuzzy surface

The rules representation with both I/Ps & O/p as shown in the Figure 3.15.

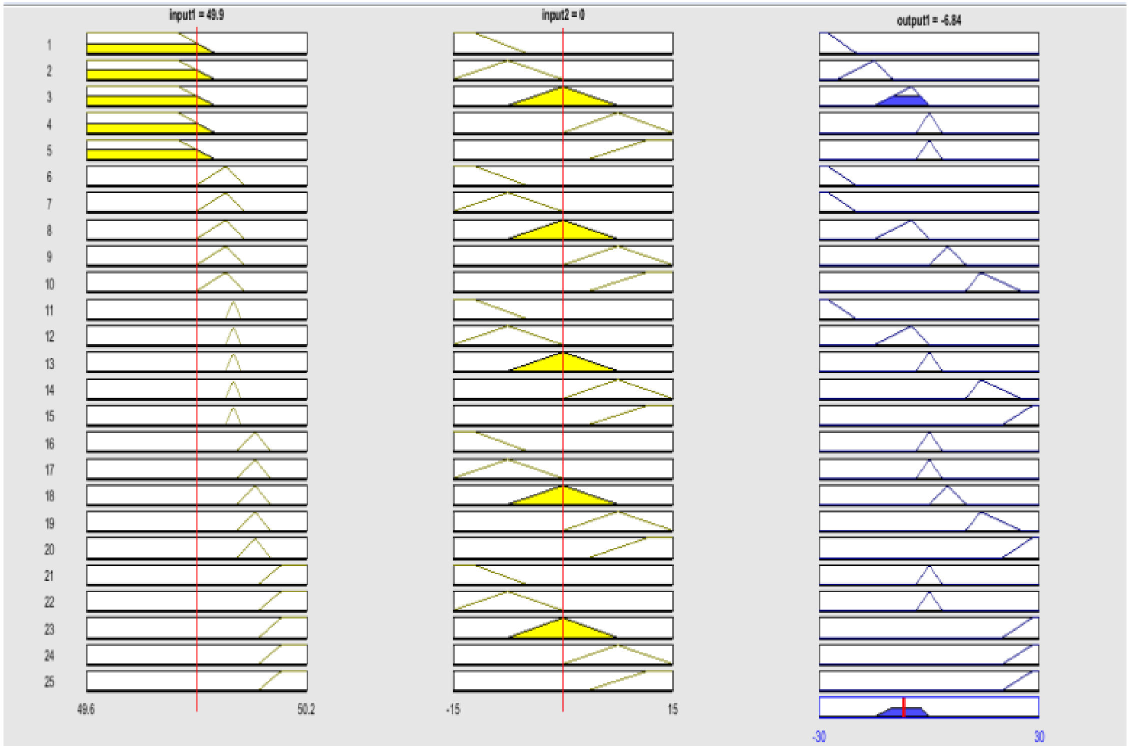

Figure 3.15: Rules in I/Ps and O/P

3.2.2.3 Pitch Control

The Pitch control is producing a signal ($\Delta\beta$) based on the PI controller. As shown in Figure 3.16. represent the previous work acting by researchers, the input of the PID controller getting from actual frequency, therefore any instantaneous deviation in the frequency the pitch control will be activate directly, thereby the blades of the wind turbine continuously movement, and this behavior is not effectively for performance of wind turbine.

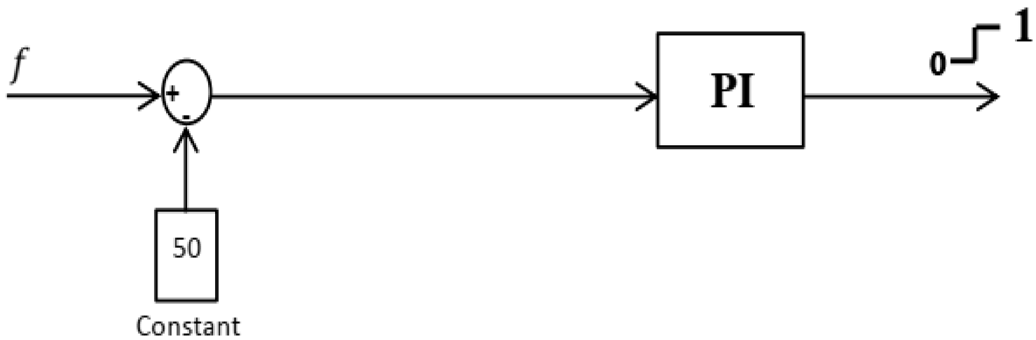

Figure 3.16: Ordinary pitch control

The input of proposed pitch control is selected (using the selector switch) either the activation signal providing by proposed control strategy (the comparator logic or fuzzy logic), or the actual frequency deviation(f). For simulation, the selector switch adds to see the performance of the blade movement by using the activation pitch control or without the activation pitch control, and check the difference of both results. Scheme of the pitch control illustrated as in the Figure 3.17.

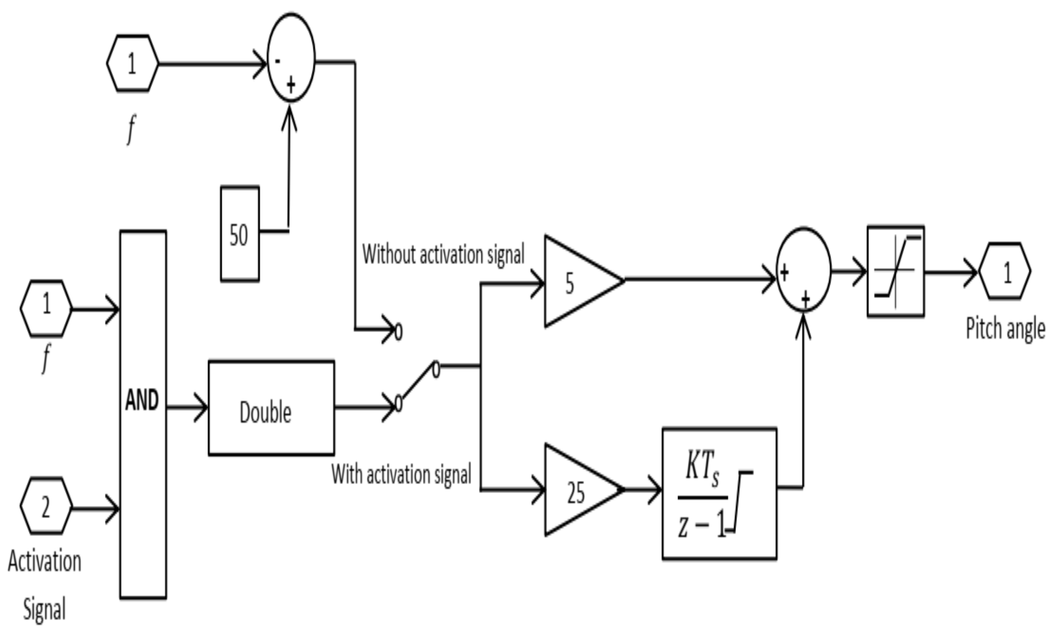

Figure 3.17: Scheme of proposed Pitch control

3.3 Model of WTG

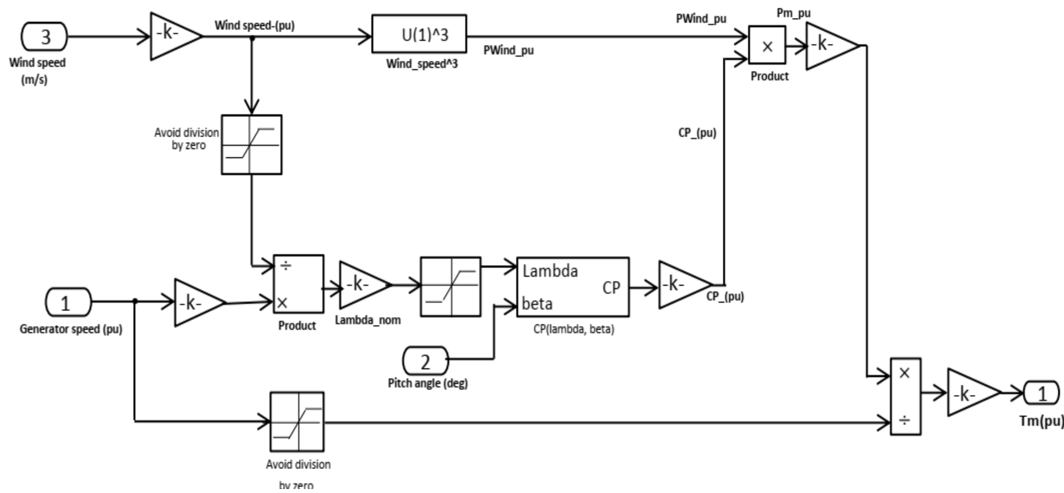

Figure 3.18: Model of WT (Farag et al, 2017)

The output signal of the wind turbine control provides from the generator speed. According to the other inputs such as the rated power or MPP, wind speed, and frequency control, as shown in Figure 3.18. The output of WT controller is a mechanical torque T_m utilized to increases or decreases the active power. Another input is the wind speed, where blades faced the variation of the wind. According to that flow of the wind and the blade movements, the wind turbine generator provides command the torque of the WTG. All previous discussions can be illustrated in Figure 3.18 and Figure 3.19.

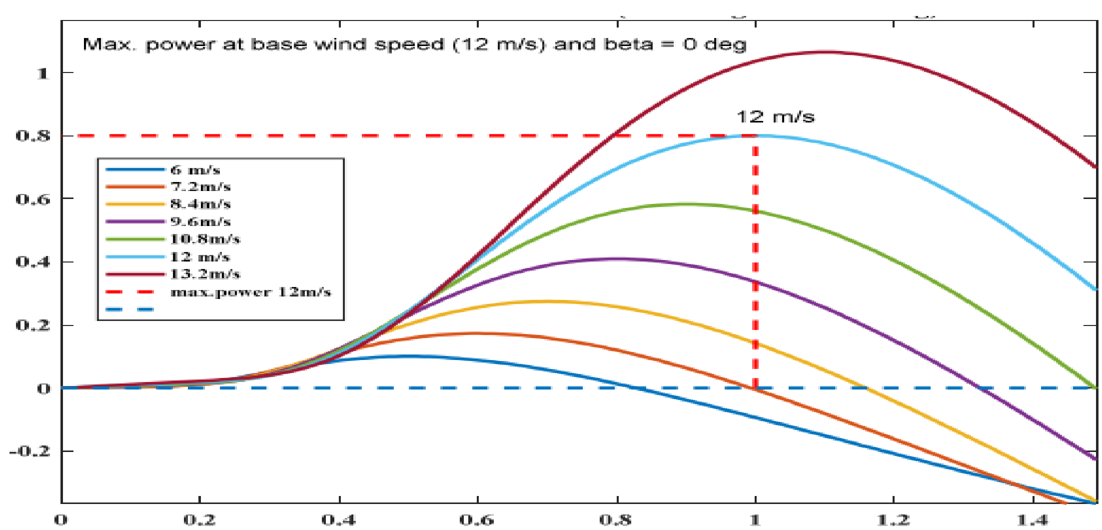

Figure 3.19: Wind Turbine Power Characteristic (Sharma et.al, 2017)

From the Figure 3.19, we noticed that, when the (WS) is 12 (m/s) and the turbine generator speed 1.2 (pu), we will get the MPP generated almost 0.75(pu). Therefore the wind turbine controller decided to use the output signal of the controller T_m (pu), to inject or reserve the power (by blades movement). All these conditions are provided in the WT controller as the input signals that mentioned above. Scheme of the WT controller can be shown in the Figure 3.18.

The model of power generated from WT derived as follows.

$$\mathrm{P_{wt}} = \frac{\rho}{2}\,\mathrm{A_{wt}}\ C_p\ (\lambda, \theta)\ V_w^3 \qquad (3.1)$$

where C_p could be witted as follows:

$$C_p = (0.44 - 0.0167\ \theta)\ \sin\left[\frac{\pi(\lambda - 3)}{15 - 0.3\theta}\right] - 0.00184\ (\lambda - 3)\ \theta \qquad (3.2)$$

where P_{wt} the output power of the (WT), it's proportional with the (WS) , V_w (m/s), density air, ρ (kg/ m3), C_p the power coefficient, which relevant on the pitch angle, the tip-speed ratio**,** which denoted by $\lambda = \frac{w_{m\,R}}{V_w}$, R the radius of blades (m), w_m the speed of (WT) (rad/s).

The output power $\mathrm{P_{wt}}$ extracted from wind turbine can be used to regulate the deviation frequency, and the $\mathrm{C_p}$ represent the power coefficient which is based on the angle of pitch control θ, so the active power of WT is proportion to pitch angle, for this reason the variation in the pitch angle is associated with the active power injected to the grid and thereby the deviation frequency can be regulated (Aziz et al, 2015) (Hou et al, 2016) (Zhang et al, 2018).

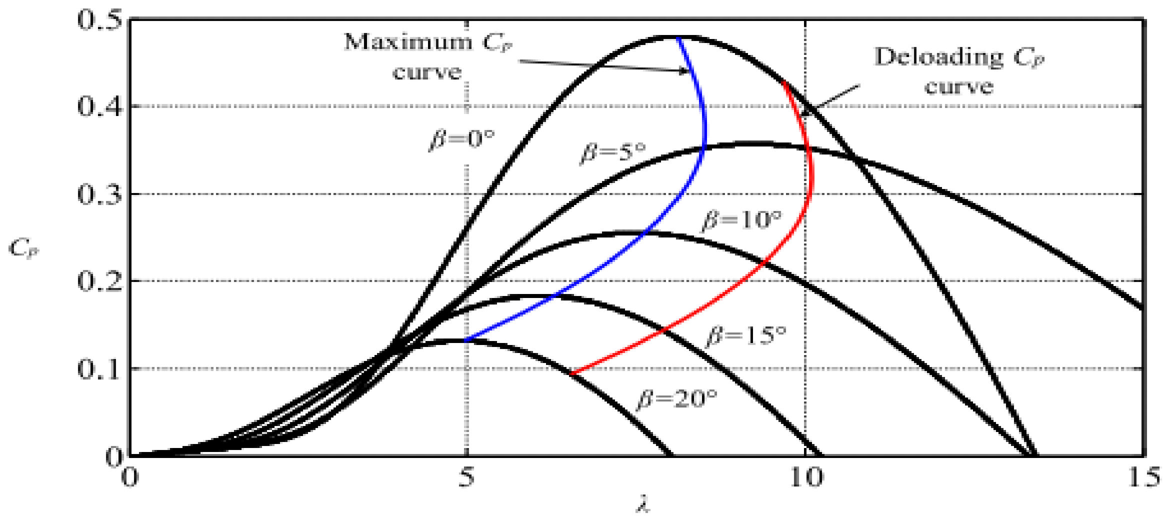

Figure 3.20: Typical C_p --- λ (Haixin et al, 2018)

Typical C_p ---- λ curves are illustrated in Figure 3.20. In case of different pitch angles, as shown. When MPPT verify that means maximum C_p is obtained. The normal operation of WT to get maximum power, the maximum C_p curve located. The deloaded operation of WT its take as shown, the deloaded C_p curve in the Figure 3.20. Hence, deloading C_p curve of WT is proportion with the frequency change. Deloading characteristic of the WT has limited range to control actually over speed control (Wang et al, 2018), (De Rijcke et al, 2015). The power–frequency control can be achieved by its control system (Wang et al, 2014), (Chen et al, 2003). Therefore to frequency stability, conventional droop control method is utilized (Hu et al, 2005) , (Bevrani et al, 2013).

For a givenC_p, (T_m) produced by the (WT) is given by:

$$T_m = \frac{\rho\ A\ C_p\ V_w^3}{2\ w_t} \tag{3.3}$$

As shown in Figure 3.21.The normal operation of MPPT. On the other hand, the maximum wind power is achieved. The electric magnetic torque $T_{e,i}$ with MPPT control is calculated by (3.4) (Abdelaziz et al, 2014).

$$T_e = K_{opt}\, \mathrm{w}_\mathrm{r}^2, \qquad w_0 < w_r < w_1$$

$$T_e = \frac{\mathbf{T_{e,nom}} - K_{opt}\, \boldsymbol{w_1^2}}{W_{r,nom} - W_1}(w_r - W_{r,nom}) + \boldsymbol{T_{e,nom}}\ \boldsymbol{,}\ w_1 < w_r < w_{r,nom}$$

$$T_e = \frac{P_{e,nom}}{w_r}, \qquad w_{r,nom} < w_r < w_{r,max} \qquad (3.4)$$

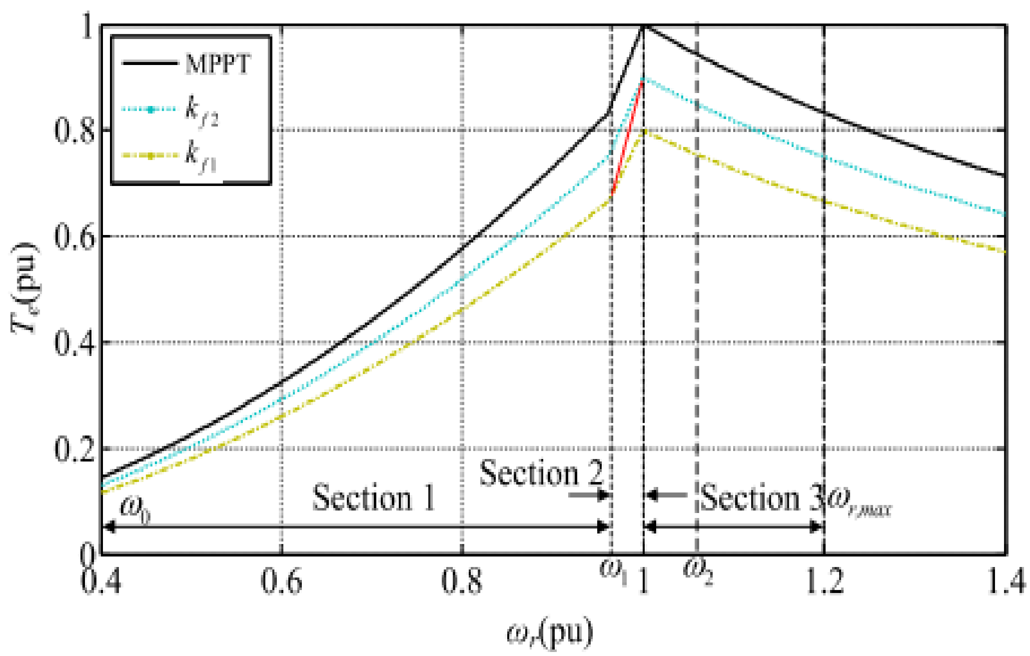

Figure 3.21: Torque of WTG with different speed (Wang et al, 2018)

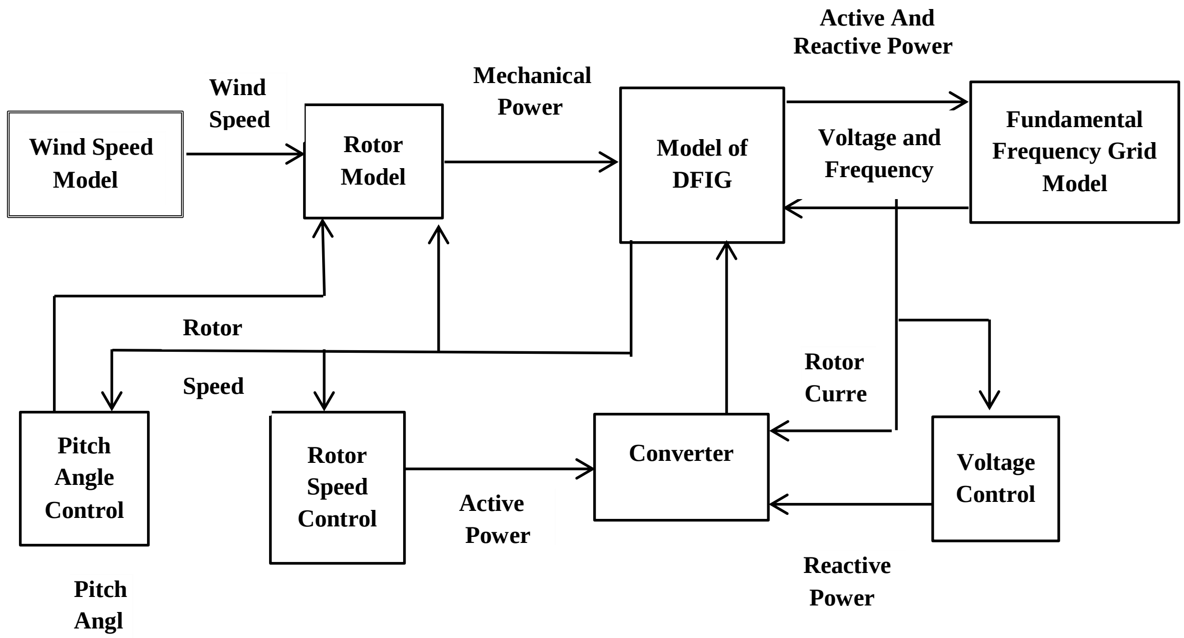

Figure 3.22: General Structure of a model of (IG) Variable speed wind turbine (Wang et al, 2015)

Figure 3.22 illustrated the structure of DFIG of wind turbine and the relevant signals with the models such as the pitch control, rotor speed control, frequency grid, converter, voltage control, and wind speed, active and reactive power.

CHAPTER 4
SIMULATION AND RESULT

4.1 Overview

When WT's utilized, the simulation is necessary to see the significant problem in the frequency of the grid. By using MATLAB simulation, we can observe that problem which might extend to lack the quality performance of WT's blades. We can see that by the output angle of pitch control which enables the servo motor to blade movement. A fluctuation blade of WT is directly proportion with the fluctuations frequency. Simulation results would be compared the performance of the blades movement with and without activation pitch control. On the other hand, we will compare the frequency regulation response by using the fuzzy control and the comparator logic.

4.2 Simulation Results

The proposed system as shown in the main circuit in Figure 3.4 is implemented based on the wind turbine by using MATLAB Simulink. The simulation result for the frequency response and movement blades in case of using proposed activation pitch control based on the fuzzy control or comparator logic. On the other case, the simulation without utilize the proposed activation pitch control.

The parameter of grid and WT give in Table 4.1.

Table 4.1: Parameter of the analyzed system

symbol	Quantity	Value	symbol	Quantity	Value
V_s	Ideal Grid Voltage L-L	400 V	P	pole pairs	2
f	Grid Frequency	50 Hz	H	Inertia constant	0.09526
P_e	Power of WTG	1.6e6 W	P_m	Mechanical power	1.6e6 W
R_s	Stator resistance	19.65 mΩ	ws	wind speed	12 m/s
L_s	Stator inductance	3.9 µH	R_r	Rotor resistance	19.09 mΩ
L_m	Mutual inductance	1.35 µH	L_r	Rotor inductance	3.9 µH

4.2.1 Case (1): Simulation without activation pitch control

In the following, the simulation figures ignored the initial transient in the starting of simulation, at 3 (Sec) WTG starting to run. Therefore we will highlighting on the response from 3 (Sec) to end of the simulation duration. The duration of the simulation time takes up to 10 (Sec).

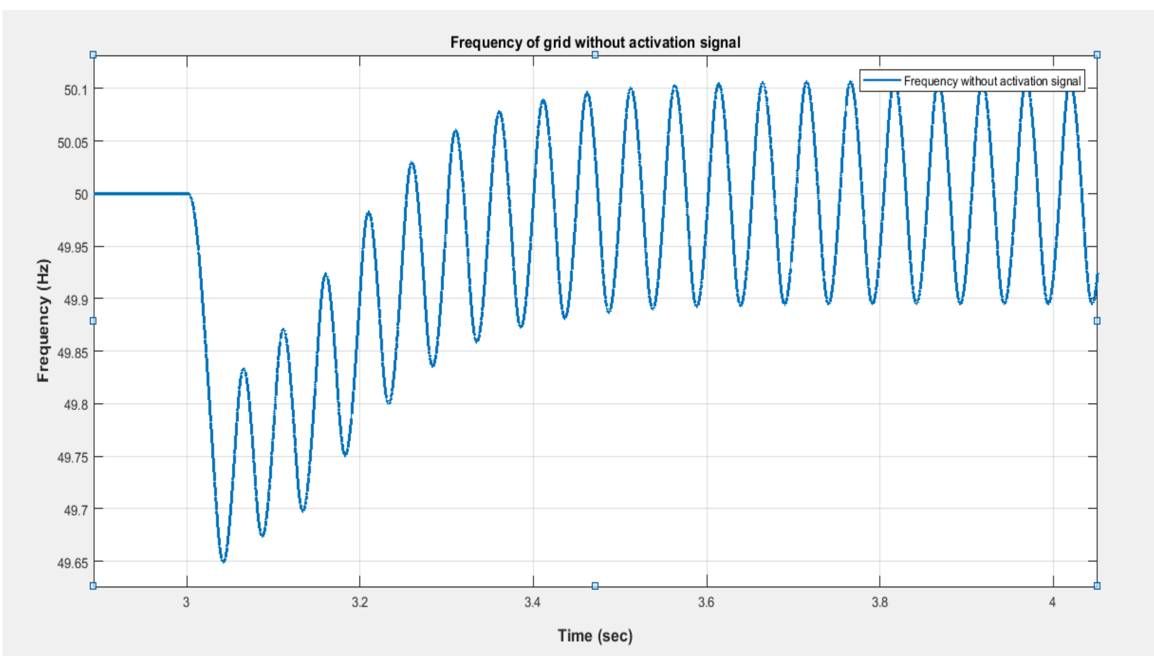

Figure 4.1: Frequency of grid without activation signal

As shown in the Figure 4.1, when the wind apply to the WT at 3 (Sec), because there is no frequency control. We noted that the fluctuation frequency result of blade fluctuation which faced the variety of the wind speed. In another word, the pitch control will be adjusts the blade, in order to generate requirement power by using the mechanical torque. But the oscillation blade is still exists due to absents the activation pitch control. Therefore, the absence activation pitch control causes the frequency fluctuation and oscillation blades.

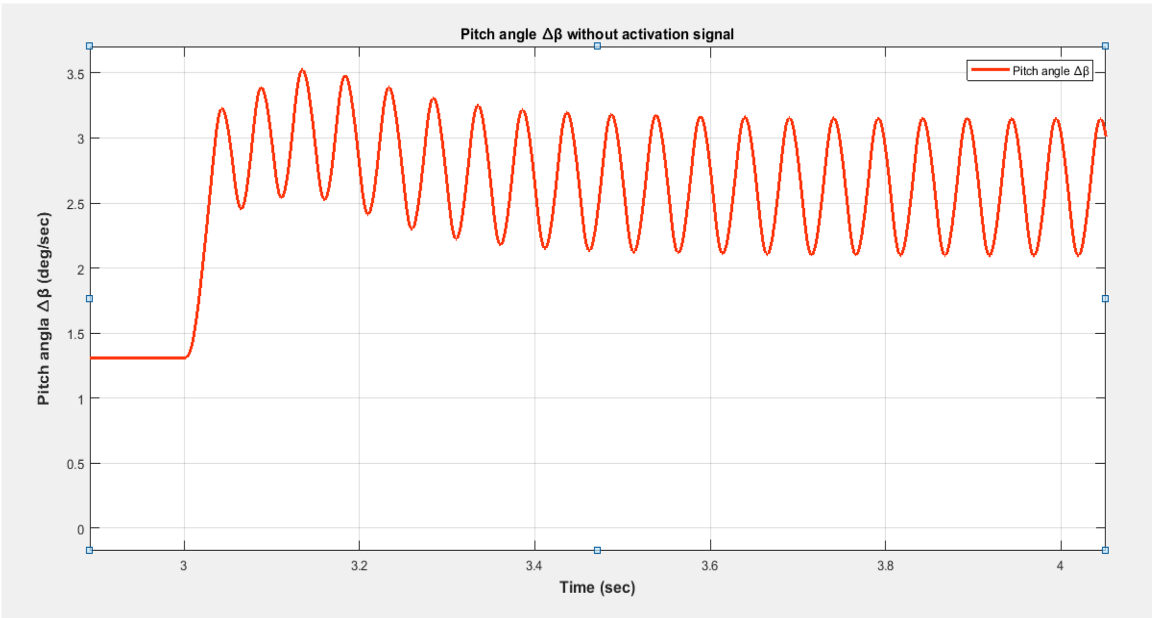

Figure 4.2: Pitch Angle (β) Without Activation Signal

As we mentioned above, we noticed that, there are two things. The pitch angle (β) analysis response in the Figure 4.2. Once, the pitch angle fluctuation due to absence proposed activation pitch control, which is obtained from the proposed control strategy. Because the blades oscillation, we will see the power generated fluctuation and thereby fluctuation frequency as well. Other things, Rising pitch signal at 3 (Sec) to give the command to T_m , to produce the rated power generated from the wind power as the curve characteristic wind turbine.

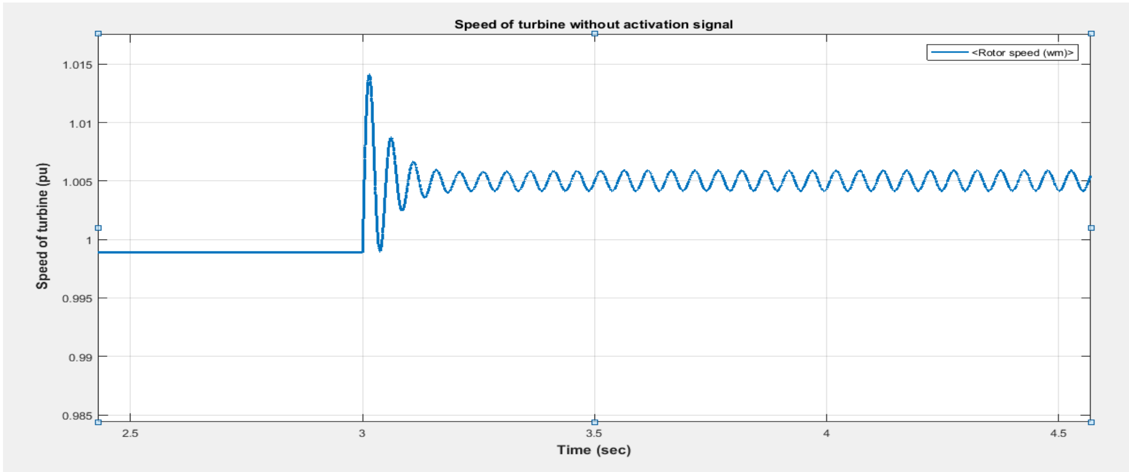

Figure 4.3: Speed of WT (pu) Without activation Signal

The speed of WT has responded as shown in the Figure 4.3, also the fluctuation after 3(sec). In the other side, the rotor of turbine faced the variation of the wind speed. Therefore, we see the responded speed disturbance is the first impact at 3(Sec) then the turbine activate to generate the requirement produced power. All those actions actually provide from O/P of T_m controller of WT.

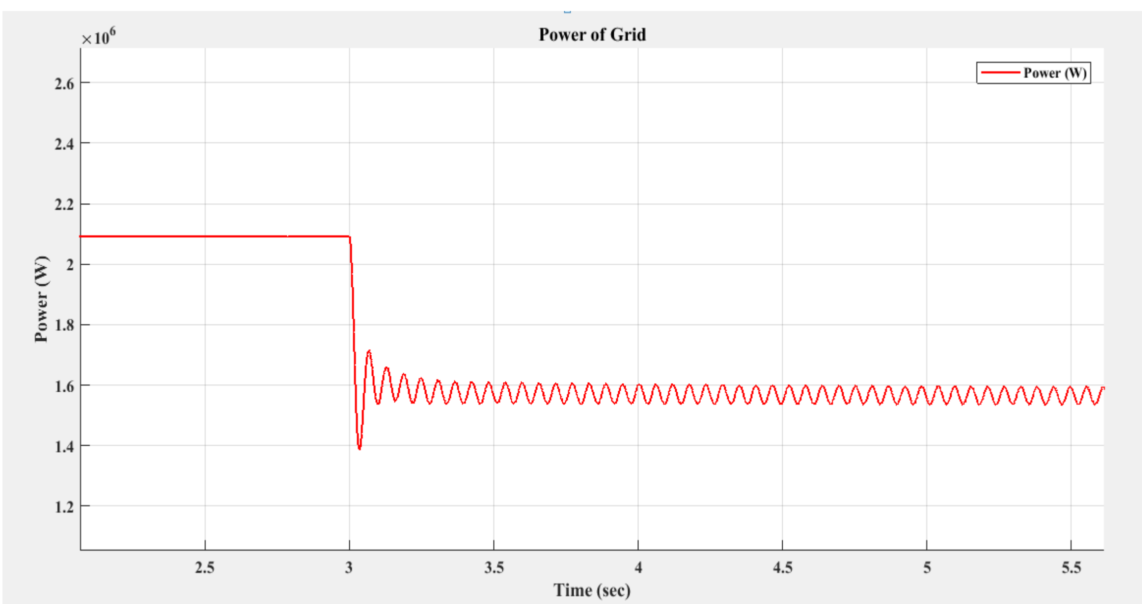

Figure 4.4: Power of Grid without Activation Signal

In the Figure 4.4, notice that, the power is fluctuation due to the blade oscillation, resulting by the pitch angle $\Delta\beta$. The response is within value of the rated power of WT.

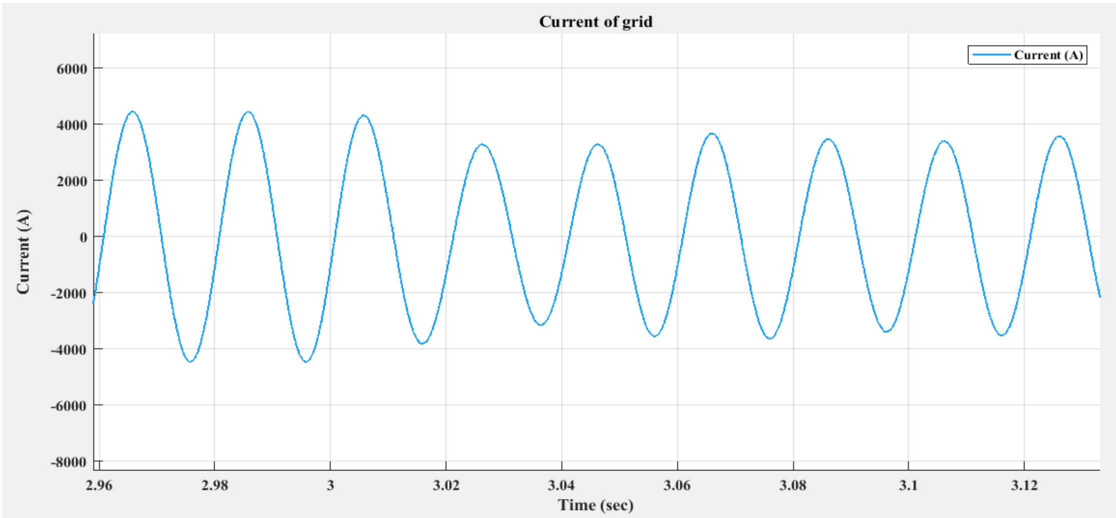

Figure 4.5: Current of Grid

From the Figure 4.5 the grid RMS current is

$$I_{rms} = \sqrt{\frac{area\ of\ the\ squared\ waveform\ over\ full\ cycle}{period\ of\ the\ squared\ waveform}} \tag{4.1}$$

which we can obtained from the following derivative

The current waveform $i = a \sin wt$

$i = a \sin \theta$

$a = 4450$

$i = 4450 \sin \theta$

The period for one cycle of waveform from $0 - 2\pi$ is 2π

$i^2 = (4450)^2 \; sin^2 \theta$

$i^2 = 19802500 \; sin^2 \theta$

since $2 \, sin^2 \theta = 1 - cos2\, \theta$

$$i^2 = 19802500 * \frac{2\,sin^2\,\theta}{2}$$

$$= 19802500\left(\frac{1}{2} - \frac{\cos 2\theta}{2}\right)$$

$\int_0^{2\pi} i^2 \; d\,\theta$ from (4.1)

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 \; d\,\theta}$$

$$= \sqrt{\frac{\int_0^{2\pi} i^2 \; d\theta}{2\pi}} \quad (4.2)$$

$\int_0^{2\pi} i^2 \; d\,\theta$

$$= 19802500\left[\frac{\theta}{2} - \frac{\sin 2\theta}{4}\right]$$

$$= 19802500\left[\frac{2\pi}{2} - \frac{\sin 2*2\pi}{4} - \frac{0}{2} + \frac{\sin 0}{4}\right]$$

$$= 19802500\,(\pi - 0 - 0 + 0)$$

$$= 19802500 * \pi$$ from (4.2)

$$I_{rms} = \sqrt{\frac{19802500*\pi}{2\pi}}$$

$$= \sqrt{\frac{19802500}{2}}$$

$$= \sqrt{9901250}$$

$$I_{rms} = 3146.6 \;\; A$$

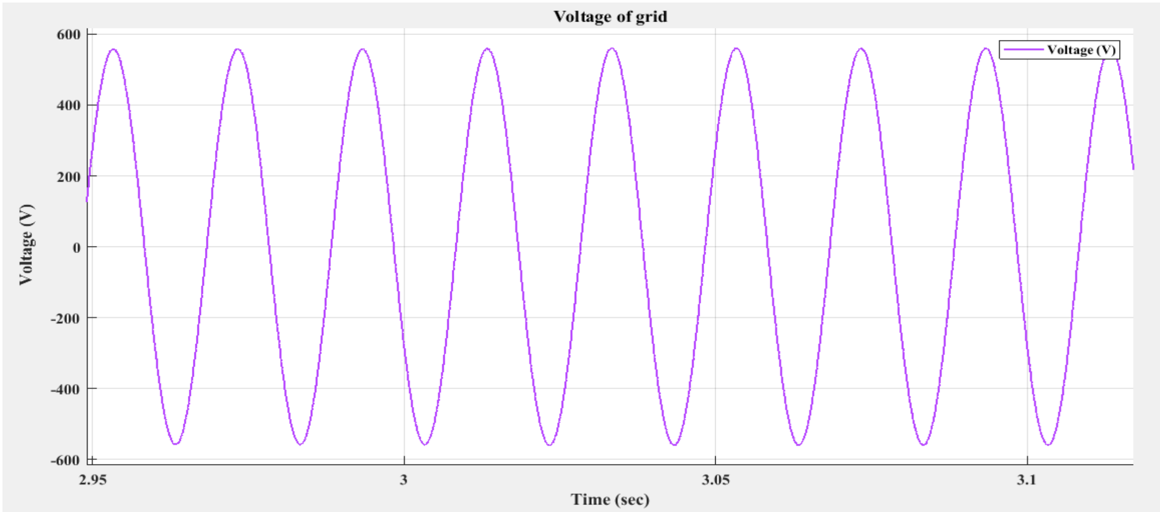

Figure 4.6: Voltage of Grid

As we shown in the Figure 4.6, response of the grid Voltage is sinusoidal waveform that is 400V RMS value, even at the moment 3 Sec the response is constant value and constant waveform because it is very important to keep the value of the voltage at constant potential. Otherwise the system will be at instable state and causes damage for the demand and the power system.

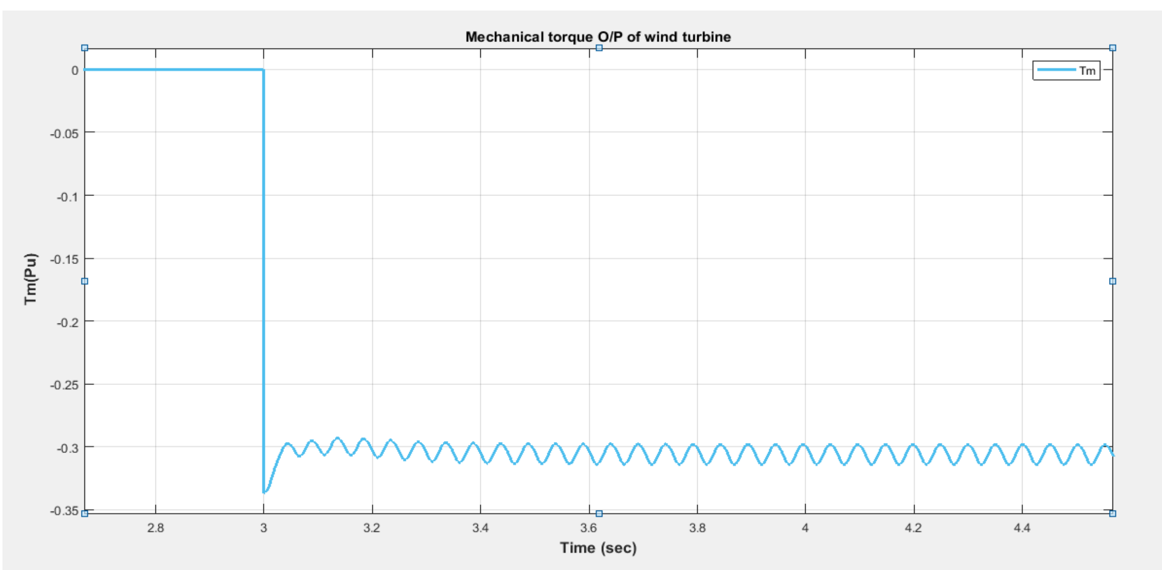

Figure 4.7: T_m Output of WT

Because the mechanical torque T_m output of WT responsible to increases or decreases production the power of WT, as in the Figure 4.7. The mechanical torque steps down to activate generator of the wind turbine to produce the requirement rated generating power.

4.2.2 Case (2): Simulation with Activation Pitch Control Using Proposed Control Strategy.

From activation pitch control, we will see the differences in the frequency performance as well as the pitch angle, speed and torque of the wind turbine.

By adapted two types of control strategy which are comparator control and fuzzy logic control to activate pitch control.

The frequency response shown in the Figure 4.8 is by utilizing comparator control strategy. As we see the frequency regulated because the pitch control activated. The pitch control is receiving the activation signal from output of comparator control.

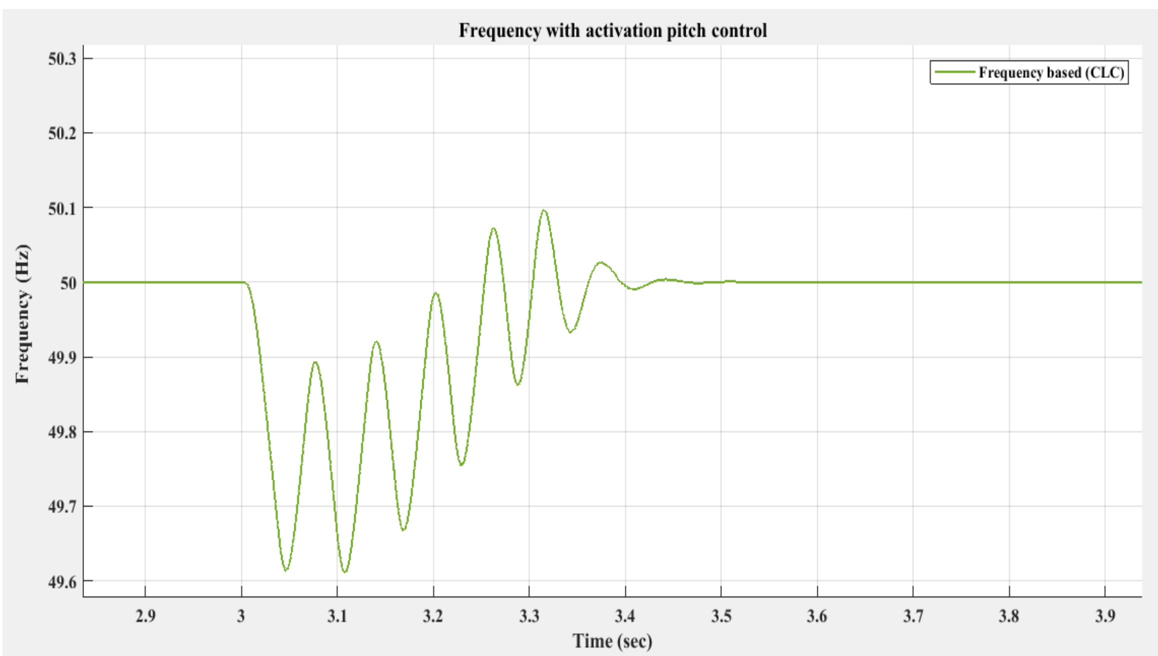

Figure 4.8: Frequency with activation pitch control based (CLC)

In the Figure 4.9, we will see the frequency response in case of fuzzy logic control strategy.

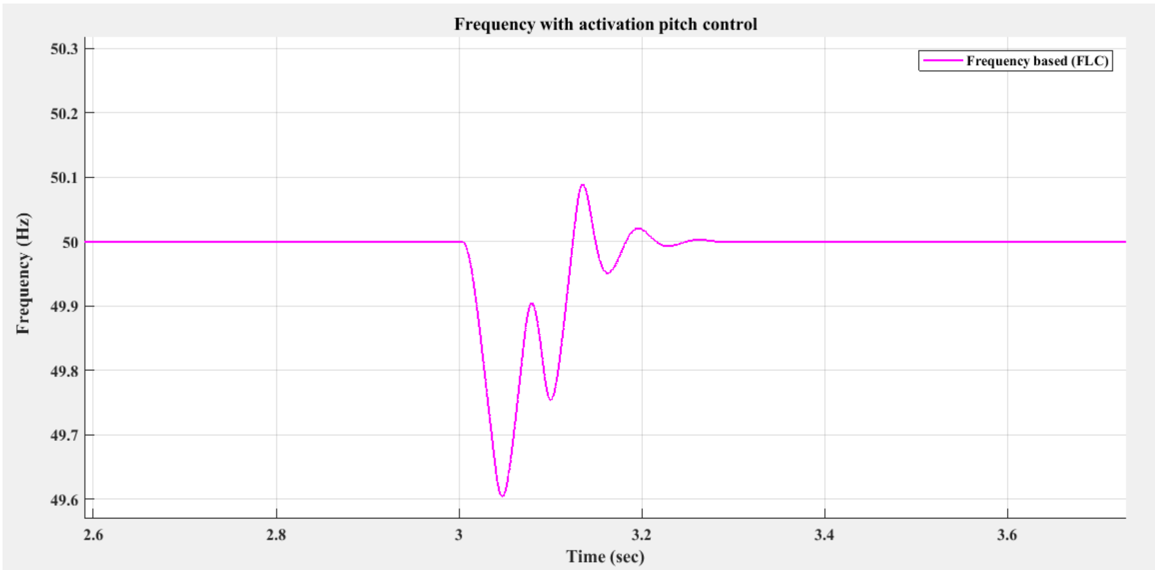

Figure 4.9: Frequency with activation pitch control based (FLC)

The response of the frequency in Figure 4.9 is regulated in less time compared with the other control strategy (CLC), this response is very accurate and efficient for the power quality requirement.

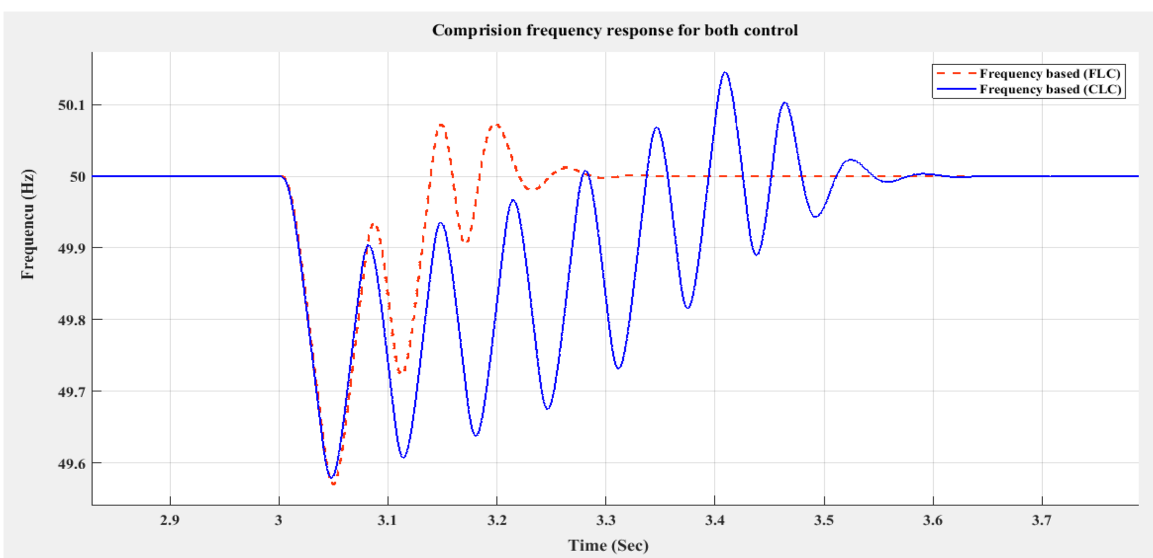

Figure 4.10: Comparison Frequency responses for both controls

The grid frequency as we see in the Figure 4.10, both responses is oscillation after 3 Sec for a short time ($<$ 1 Sec) then the frequency is regulating to reach at steady state without fluctuation, unlike the previous case. According to the fuzzy logic and comparator logic control the deviation frequency is not significant, the proposed controls is responsible if the deviation of frequency exceed over ($\pm 0.2HZ$), the output signal activated the pitch control. Therefore, this activation signal of the proposed controls enables the pitch control to contribute in regulation frequency. Then, the blade avoids from the oscillation movements. As shown in Figures 4.8 and 4.9. The response of the fuzzy logic control is better than the comparator logic control. In terms of regulation the frequency.

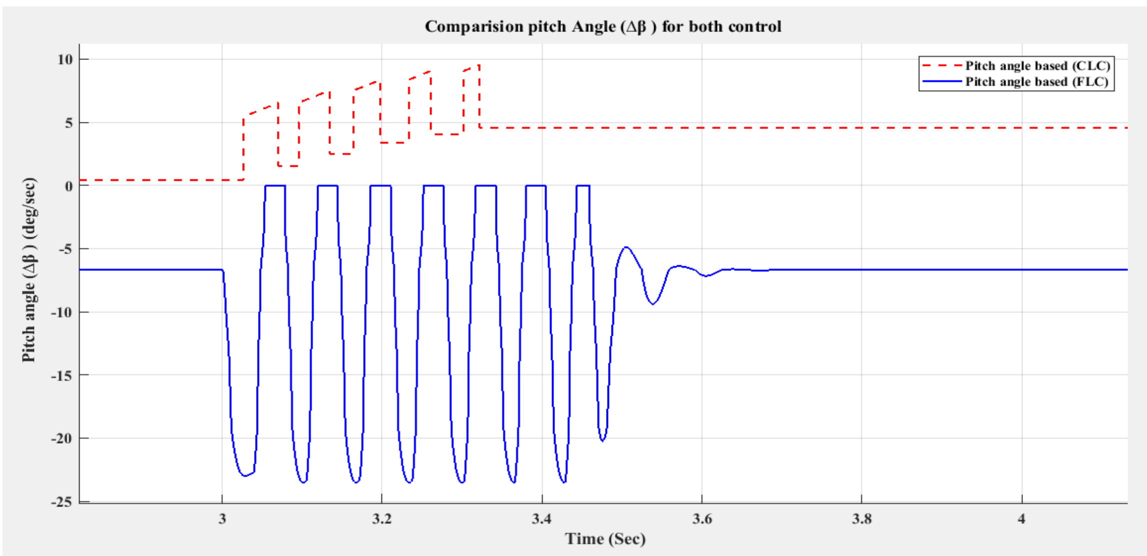

Figure 4.11: Pitch Angle ($\Delta\beta$) With Activation Signal

From the Figure 4.11, we notice that, due to the activation pitch control, we see the pitch angle is limited pulses. Thereby, the blades have limited the movement, so the frequency becomes fast to regulate. Unlike the previous case, when there is not an activation pitch control. Also for this reason, constant generated power from the wind turbine as well as the speed of turbine.

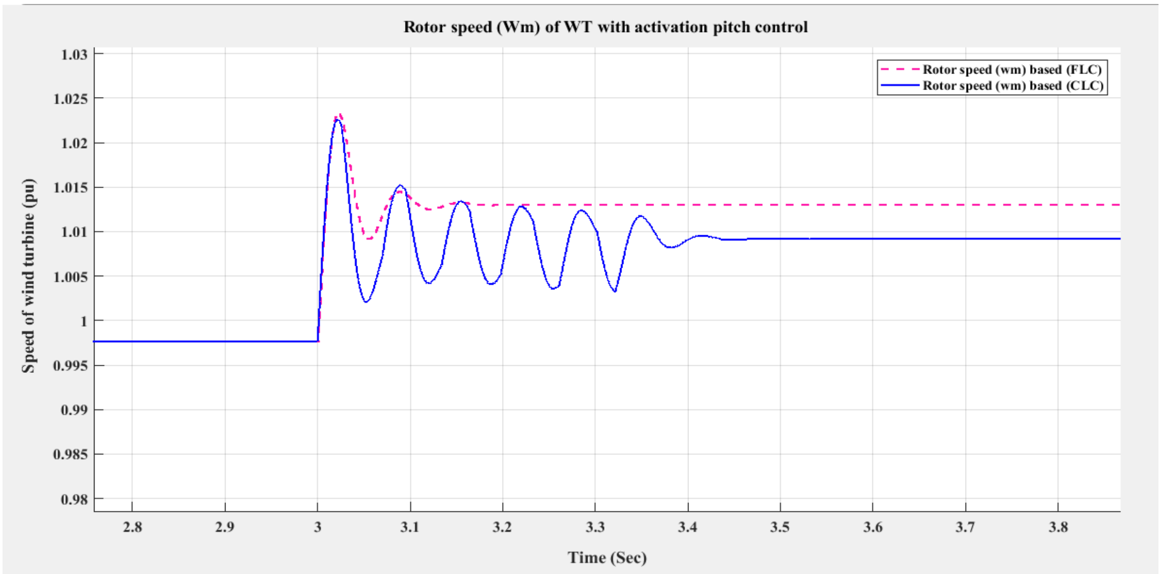

Figure 4.12: Speed of WT (pu) With activation Signal

As we see in the Figure 4.12, the speed of WT after transient with 3 (sec), we notice that, the oscillation is eliminated in the speed after (0.4 sec) in case (CLC) and to fast damping after (0.2 sec) in case of (FLC). For this reason, we will see the power keeps in constant value, unlike in the previous case. Also, because no fluctuation of the pitch angle, we will not see the fluctuation frequency. All this performance is satisfy for the proposed activation pitch control.

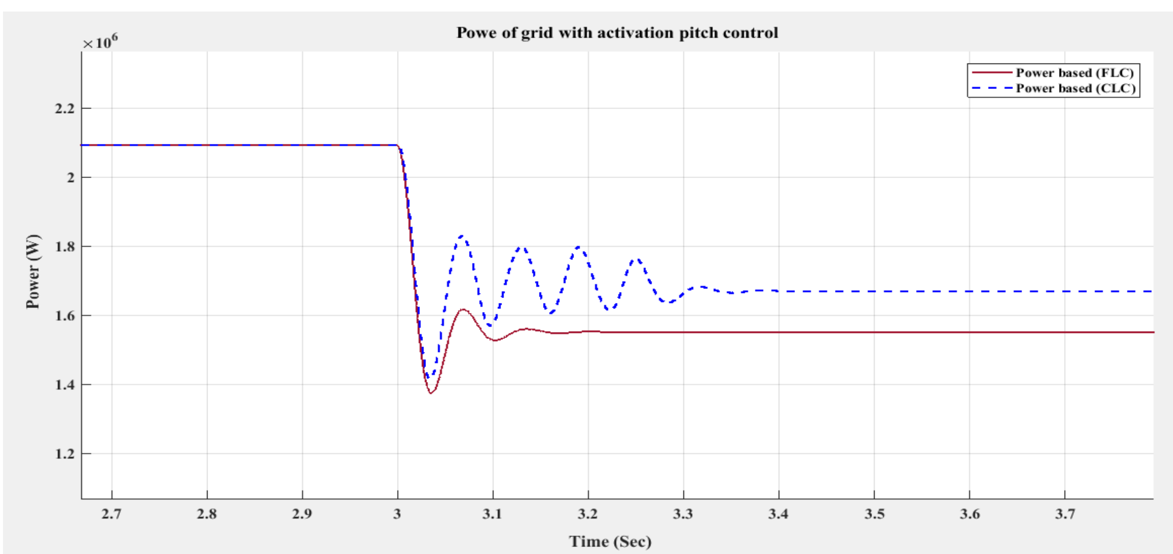

Figure 4.13: Power of Grid with Activation pitch control

In the Figure 4.13, because the steady state of the pitch angle, we notice that, the power is constant value. Also, the difference response between the (FLC and CLC) is not significant.

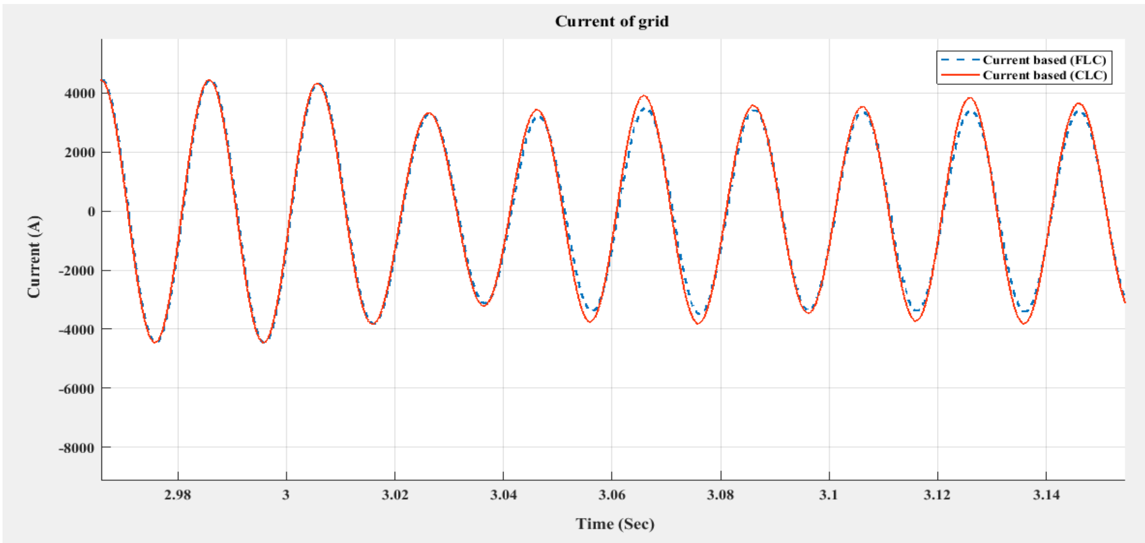

Figure 4.14: Current of Grid

As shown in the Figure 4.14, the current in both control strategy is sinusoidal and very close to identical waveforms form for both control strategy (CLC and FLC).

4.3 Comparison Results With and without Activation Pitch Control

As the Figure 4.15, when the WT utilized at 3(sec) in case of the activation pitch control, we see that, the frequency regulated due to activate the proposed controller. Also, the activation pitch control has limited the blades movement of wind turbines. Therefore, the goal of this work has achieved.

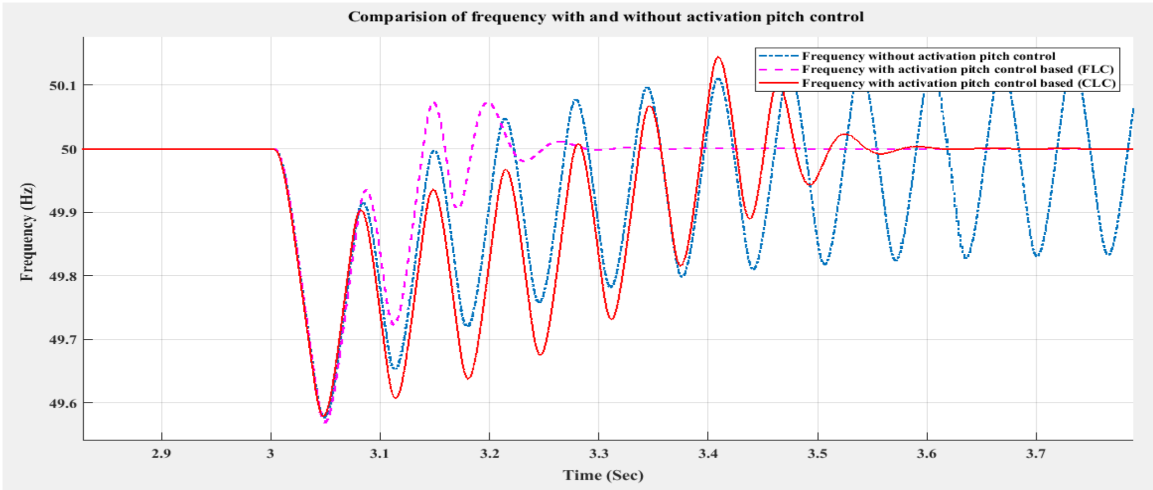

Figure 4.15: Comparison Frequency with & without activation signal

In another case, if it does not use activation pitch control, the frequency is still fluctuated. Because absence activation pitch control, which causes oscillation the blades of the wind turbine, the generated power will be oscillated.

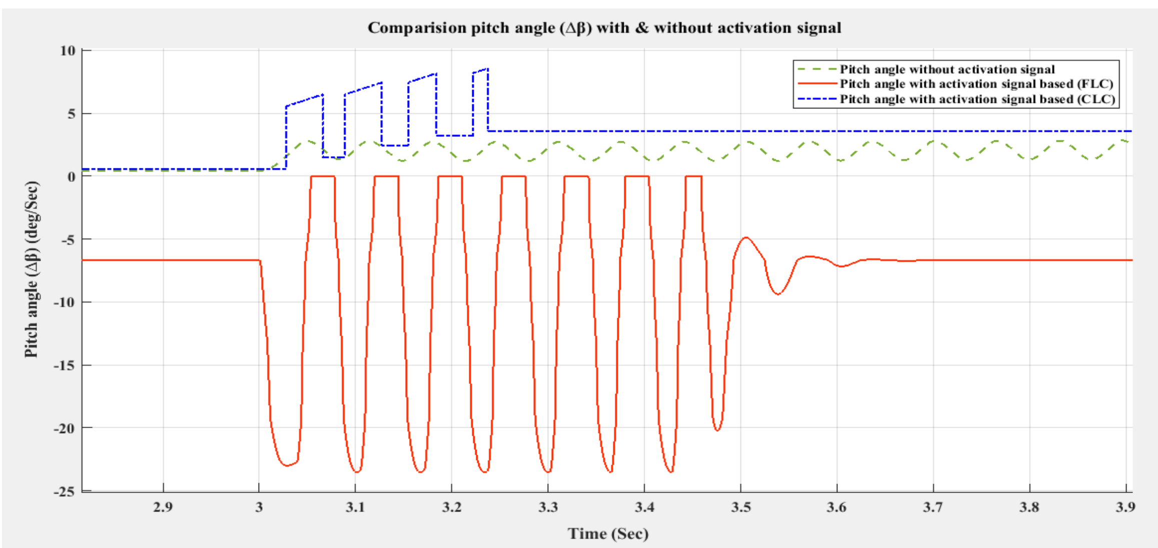

Figure 4.16: Comparison pitch angle ($\Delta\beta$) with & without activation signal

As we see in the Figure 4.16, the pitch angle with the activation pitch control is as pulses. Particularly in case of (CLC). When the wind turbine is running, the frequency reaches to the steady state rapidly as well as blade of the wind turbine reaches to the stationary state. This is the benefit of this work.

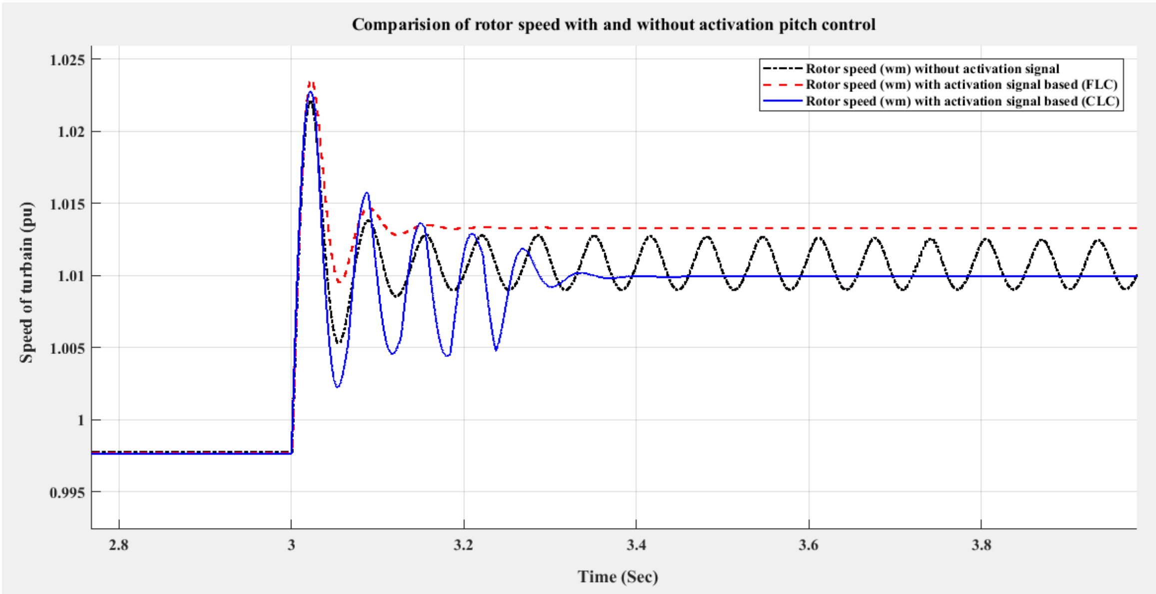

Figure 4.17: Comparison speed of WT with & without activation pitch control

As shown in the Figure 4.17, the rotor speed oscillated, which is causes the fluctuation in the generated power and frequency. When we adapted the proposed activation pitch control, there is not drawback in this study. Thereby, the steady state of the rotor speed has been achieving fast. Also, the performance of the generated power is in the constant state and regulated in the frequency.

4.4 Discussion

In this chapter, we have approved that the benefit of the enabled activation pitch control, as it has shown in the simulation result by using a control strategy (comparator logic & Fuzzy logic). The regulation frequency and damping movement blades of the wind turbine both are the goal of this work. As we see in the case of without issued activation signal, most of the simulation results from 3(Sec) it has shown that the oscillation in responses figures such as the frequency, the wind speed, the pitch angle, the mechanical torque and the generated power.

The problem of absence activation pitch control is a short life time blade of the wind turbine. From mechanical point of view, any movement parts need to continuously periodically maintenance. Also in the case of regulation frequency, if frequency of the grid is still fluctuating, the overall power system performance will not be reliable in the power quality.

On the other hand, the simulation results in the present activation pitch control which is resulting the CLC and Fuzzy control. When the wind turbine utilizes in the grid (exactly from 3Sec), all the responses are in a good behavior. As we have shown that, the steady state in responses has taken in the frequency, wind speed, pitch angle, mechanical torque and in generated power. Hence, the robust grid is desirable without any oscillation in frequency as well as in the power generated.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusion

A novel approach to the WT power generator was developed continuously. This work is using a new approach to regulate the frequency by using activation pitch control. This thesis is a complete model of the wind turbine power generator and its controllers such as, the pitch control. All of them are implemented to enhance the grid frequency.

This work has implemented and simulated, also the results have given and discussed. The approach of simulated has divided in to two strategies. The first strategy has taken results with activation pitch control, the second one has taken without activation pitch control. We compared together to see which case is the better.

The simulation result demonstrates that approach of the wind turbine power generator by using the activation pitch control. That had achieved efficient and steady state operation for the frequency, power generated, and speed rotor of the wind turbine. The simulation result has compared the (FLC) with (CLC). The simulation result of the FLC is completely and fast to regulate the frequency deviation than the CLC controller. Hence, the proposed Fuzzy control has proven successfully as an efficient performance to improve the regulation of the frequency deviation, which is occur in the power system connected with the wind turbine. The output signal of the proposed control strategy used as a command to activate the pitch controller to enable the blades to move in order to adjust the output power generated. In this work, the deviation of frequency concerns f as the input to PI controller of the pitch angle. So that, the output of the pitch controller proportional with the actual frequency. Therefore, the injected and/or absorbed active power generated by the (WTG), actually capable to regulate the frequency deviation.

5.2 Future Work

WTGs challenges are significant in the case of emulated the conventional generator, such as, the diesel generators, which utilize in the governor control, that created the inertia and damping. All of these features are efforts to the future works to implement the wind turbine generators. There are another challenges, how to charge the extra power generated from the wind turbine, in case the speeds are available in non-consumption durations. Also, avoid the outage wind turbine farm due to a fault or contingency occurs in the power system. So, in the future, the efforts work is to prevent the outage of WTF.

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