Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2020, 7(11):102-109**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Controlling of a Grid Connected Wind Turbine using Polynomial PID Controller

Helmy M. El Zoghby[1], Abdel-Azim Salem[2]

[1]Department of Electrical Power and Machines Engineering, Faculty of Engineering, Helwan University
helmy_028123288@yahoo.com
[2]Department of Electrical Engineering, Faculty of Engineering, October 6 University
am.salem90@yahoo.com

Abstract The aim of this paper is to control a fixed speed wind turbine driving a three-phase synchronous generator that directly connected to the utility grid at normal and abnormal conditions. The controller used in this work is a polynomial PID controller (PPID) that controls the turbine blade pitch angle during normal and abnormal conditions. The main task of this work is to find out optimum settings for the controller at any operating condition using root locus technique.

Different operating conditions are tested as: constant wind speed with stand alone load and with grid connected, step up and step down wind speed variation, open loop stability study at three phase short circuit at the generator terminals.

Finally a closed loop stability was studied at different cases as ; at low mechanical power and low fault time , at high power and different fault times, and finally at severe fault of long fault time and high pre fault power.

The performance of the simulated model is evaluated in a wide range of operating conditions. From the simulated results, it is concluded that, with using the proposed control technique, the system become more stable and can through the transient faults.

Keywords Wind farm, synchronous generator, Polynomial PID controller, Stability study

1. Introduction

There has been a continuous enhancement of power generation from renewable energy sources in recent years. The reasons for renewable energy sources getting more and more popular are that they are clean sources of energy, able to replenished quickly, sustainable, and eco-friendly. The only drawback is that they are intermittent in nature.

Before the installation of a wind power farm many analysis and studies are required in order to verify the possibility of integrating a wind power plant in the electrical network. Simulink models in different software like MATLAB and their simulation can bring the insurance of a secure operation and stability of the power system. With the increased penetration of wind power in certain power systems, the control of the wind power to support the power systems control has become an important issue in development and research of wind power.

Conventional power plants comprise synchronous generators, which are driven by steam, gas or running water turbines. Their characteristics and their controllability, of both the generator and the prime movers, are well understood and facilitated to their full potential. With such conventional power plants the voltage and the frequency of large interconnected AC power systems, can be controlled and held stable, in steady state, as well as in transient operating conditions. A control task of prime importance is the re-establishing of stable grid conditions after a transient fault, i.e. recovering the grid voltage and damping power system oscillations caused by the fault. Power plants with synchronous generators and conventional prime movers are very suitable for this task.

As wind power penetration in power systems increases, and hence more and more conventional power plants are replaced, the respective power system operators are concerned about the stability and reliability of their power systems. Therefore, more and more power system operators revise their grid connection requirements, and issue grid connection requirements specifically made for wind turbines and wind farms. Until recently, wind turbines were treated by and large as embedded generators, which were not to contribute to power system control. Hence wind turbines were required not to actively attempt to control voltage or frequency. In addition, wind turbines were required to disconnect from the grid when abnormal operating conditions occurred. If, however, wind power substitutes conventional power plants, it also has to take over the power system control and stabilization tasks, which the substituted conventional power plants were carrying out.

The PID controller is by far the most dominating form of feedback in use today. Due to its functional simplicity and performance robustness, the proportional-integral-derivative Controller has been widely used in load frequency control, blade pitch control, and others. Designing and tuning of PID controllers have been a large research area ever since Ziegler and Nichols presented their methods in 1942 [1].

2. Wind Farm Model

As shown in figure 2.1 the wind farm model represents the wind turbine , and three types of generators (three phase synchronous generator, three phase squirrel-cage induction generator and doubly-fed induction generator), all generators are connected in parallel at the point of common coupling (pcc), and connected to the utility grid, all generators are 500 kw in power rating. The model is created in MATLAB software that enables the dynamic and static simulations of electromagnetic and electromechanical systems.

A detailed description of the system dynamics, parameters and analysis can be found in [5]. Since the wind speed is varied, pitch control is used to control the turbine mechanical power and disconnect the turbine at high wind speeds to protect it from damage.

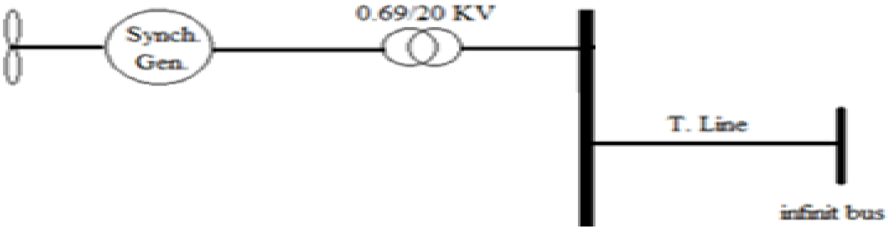

Figure 2.1: The wind turbine system schematic diagram

3. Dynamic Response at Constant Wind Speed

In this case the dynamic response of the wind farm will be simulated at a constant wind speed, this ideal case will aid in studying the response of the wind turbine and the different generators without any disturbance or abnormality.

Figure 3.1 shows the wind speed, which is taken constant at 13 m/s, this value is selected from the wind turbine characteristics to cover the generators rated power [5]. Figures 3.2 shows the active and reactive power in pu of the synchronous generator, squirrel-cage induction generator, and doubly-fed induction generator respectively. Figure 3.3 shows the grid frequency and root mean square voltage at the point of common coupling, the frequency and voltage values are satisfying the grid code requirement [7] no noticeable oscillations in the grid voltage and frequency, where the wind farm is directly connected to infinite bus of constant voltage and frequency.

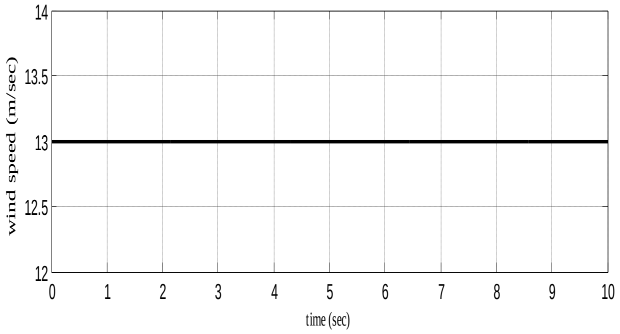

Figure 3.1: Wind speed (m/s)

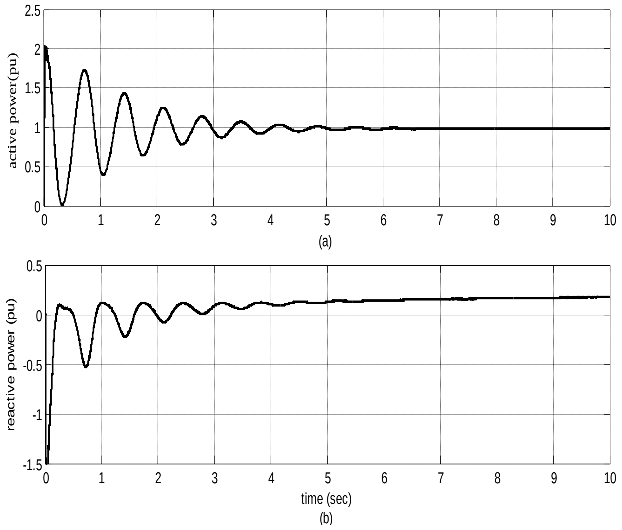

Figure 3.2: Active and reactive power of the synchronous generator

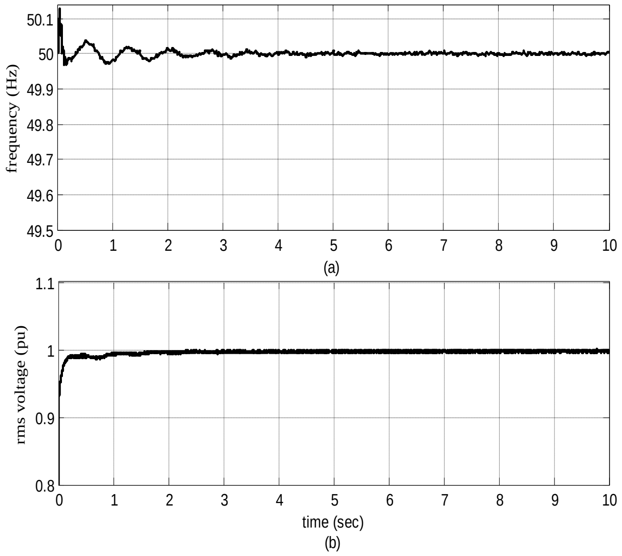

Figure 3.3: Grid frequency and rms_voltage PCC

4. Dynamic Response at Three lines short circuit

This case represents three lines short circuit fault, this fault is the most severe type of faults [5]. phase A, phase B, and phase C are shorted for 300 ms at 70 Km distance from PCC, before the fault was cleared. Figure 4.1 show the grid frequency and voltage at the point of common coupling pre and after the fault, during the fault period the frequency has a very high oscillations as and the remaining voltage become 5% of its rated value, and after fault clearance the frequency and voltage not come back to its rated values, the system become unstable and needs a control system to dampen the oscillations or disconnection of the wind turbine to avoid its failure or damage.

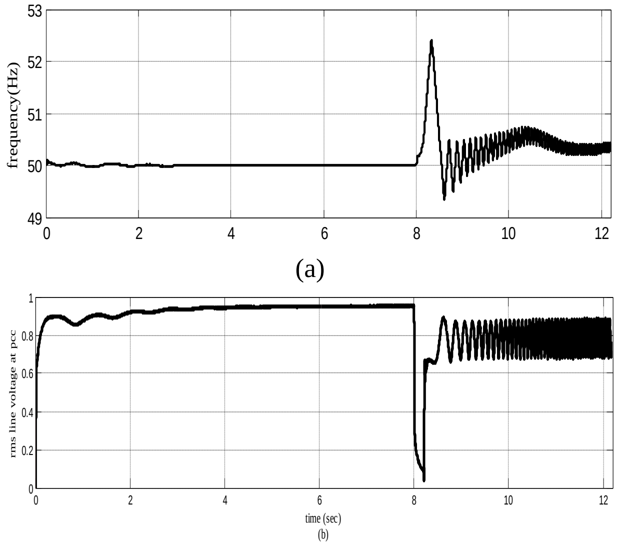

Figure 4.1: Frequency and Rms-voltage of the power system at pcc pre and after fault

During the fault the voltage at the generators terminals drops and hence also the active power drops to close to zero. Since the wind turbine controller does not attempt to reduce the mechanical power input, the turbine accelerates and the current increases, this can be seen from the generator speed and current curves of each generator as shown in the following figures. The speed increases rapidly linear in synchronous generator and become unstable operation. The generator accelerates for two reasons: One reason is that the rotor accumulates rotating energy during the fault, since there is still mechanical power input, although no power can be exported during the fault. The second reason is that the drive train acts like a torsion spring that gets untwisted during the fault. In practice the over speed protection system of the turbine would stop the turbine to prevent damages. The mechanical structure of the turbine would ultimately suffer severe damage from such extensive speed oscillations.

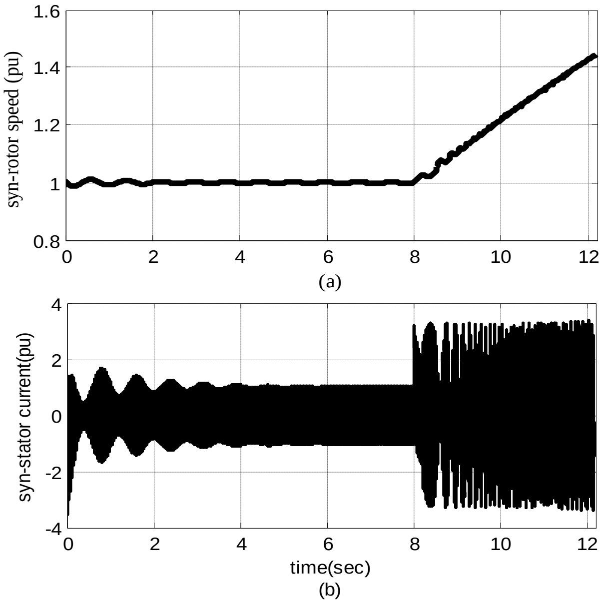

Figure 4.2: Synchronous generator rotor speed and line current pre and after fault clearing

5. Designing of a Controller for Power system stabilization at abnormal cases

Since the frequency oscillations are caused by an imbalance between generated power and consumed power.

Hence, grid frequency oscillations (as well as inter-area oscillations) can be counteracted with a controlled active power injection into the grid cannot supply enough reactive power to let the voltage recover quickly and hence suppress the oscillations.

Figure 5.1 shows the block diagram of the closed loop control circuit of the wind farm and the controller, a PID controller has been developed that enables the wind turbine to ride-through with the transient faults. The control circuit, from which it can be seen that the turbine power is controlled in a closed loop. If the frequency of the power system F_{meas} deviates from the set point, F_{ref}, the frequency error F_{err} causes a power signal P_{diff} with a gain depends on the power system GCR, in this work this gain is 500 Kw/Hz to get P_{diff} equal P_{ref} when an error of frequency around 1Hz , which acts as set point on the inner closed power control loop, contributing to the power error signal P_{err}. Since the wind turbine type considered here is a direct connected wind turbine, the only mean of controlling its output power is the pitch system that controls the aerodynamic power, which drives the generator.

The three phase short circuit of the transmission system is chosen such that this kind of fault leads to instability as shown:

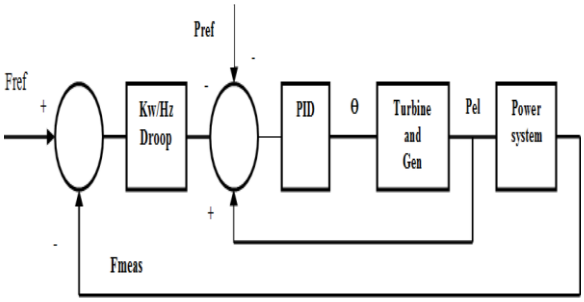

Figure 5.1: Closed loop control of wind system

The basic principle of the transient fault controller is to reduce the aerodynamic power of the rotor as soon as a grid fault is detected. The general sequence of the transient fault control strategy is as follows:

1. Detection of fault
2. Controlling pitch angle to get zero power during fault period, and check that the power reaches the required value
3. Check whether grid voltage has recovered and generators speed is in normal range
4. Re adjust the pitch angle to the value pre fault to resume normal operation.

If at least one of the conditions for a grid fault is given (step drop in power, under voltage or over speed) the controller steps the pitch angle set point to the value of no power. When the transient fault controller steps the pitch angle set point to this value, the pitch system ramps the pitch angle with its maximum pitch rate to the new set point. Once this pitch angle is reached, the fault has to be cleared by the grid protection system, and the grid has to have recovered from the fault, i.e. the voltage and the frequency returned to its normal.

For a wind turbine with synchronous generator the relations of the PID gains and the wind speed are illustrated by the following equations

$$K_p = -0.01v^2 + 0.26v - 0.88 \qquad (1)$$

$$K_i = -0.031v^2 + 0.82v - 2.8 \qquad (2)$$

$$K_d = -0.0022v^2 + 0.057v - 0.274 \qquad (3)$$

Where v is the wind speed in m/sec.

Figure 5.2 shows the relations of the PID controller gains with the wind speed in the different operating regions.

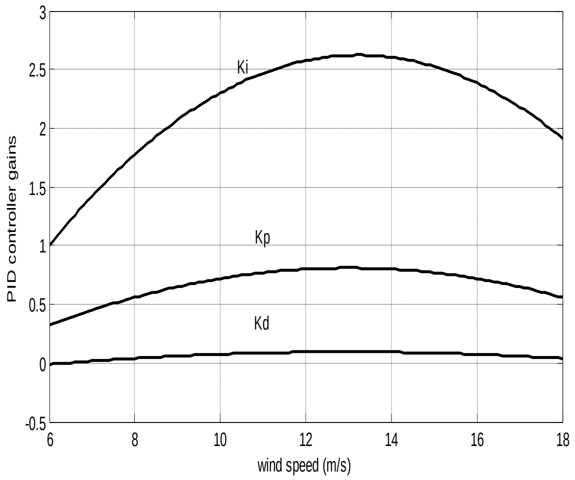

Figure 5.2: The PID controller gains for the synchronous generator loop at different operating regions

Figure 5.3 shows the simulation model of the PID controller built in MATLAB/SIMULINK software. Each wind turbine has a different PID controller where the parameters of the controller are varied according to the type of the generator used, and the value of the wind speed.

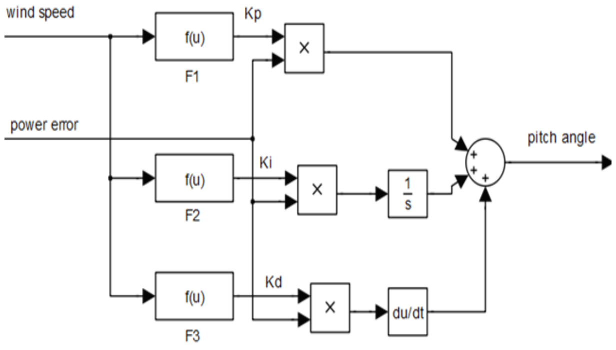

Figure 5.3: The PID controller simulation model

6. Dynamic Response of the Overall Wind Farm with a Transient Fault Controller

By detecting the fault case or the abnormal operation, the controller will control the pitch angle to control or to disconnect the wind turbine during the fault period and reconnect it after the fault clearance depend on the severity of fault.

The following figures show the effect of adding the controller on the wind power system stability at three phase short circuit.

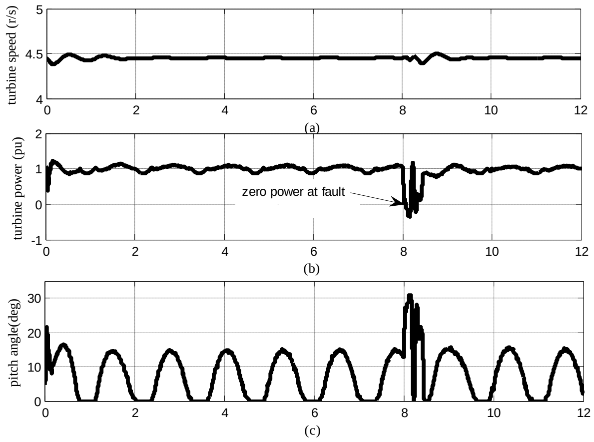

Figure 6.1: (a) turbine speed (b) turbine power (c) pitch angle pre and after three-phase short circuit with transient fault controller

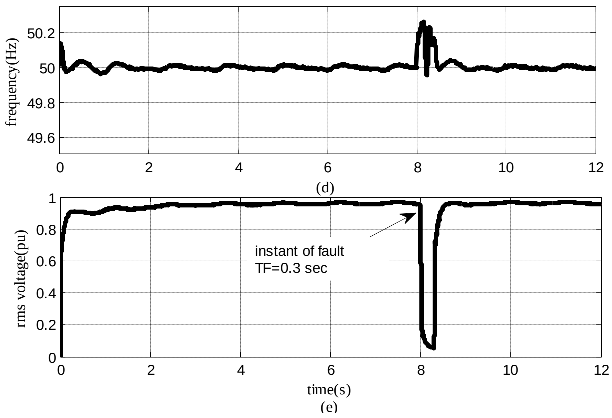

Figure 6.2: Frequency and Rms voltage of the grid and at the pcc after adding the transient fault controller

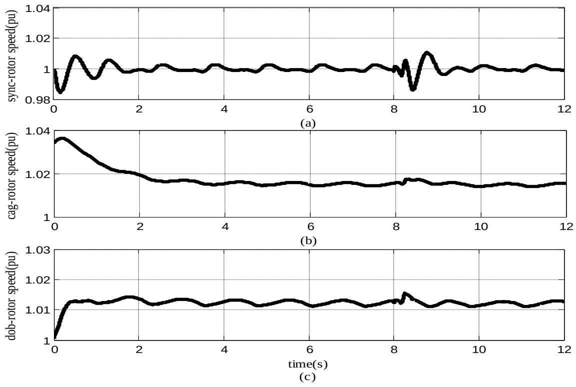

Figure 6.3: Rotor speed of synchronous, squirrel-cage, and doubly-fed generators pre and after fault clearance with controller

7. Conclusion

It is shown in this paper that a fixed speed active-stall wind turbine, which has only its pitch system to control its output power, is capable of contributing to the damping of power system oscillations due to the variation in wind speed, a PI controller used here to control the turbine mechanical output power as the wind speed varied. If the controller is not used the turbine power depends on the wind speed and the tip speed ratio at that speed.

It is shown in this paper that the doubly-fed induction generator is more robust and smooth characteristics than squirrel cage induction generator than synchronous generator respectively but needs a complicated control system.

At a variable wind speed the generators power is not the maximum available power in the wind, so a power electronic control system must be used to adjust the generators speed with the variation in wind speed to obtain optimal tip speed ratio and maximum power coefficient.

Since the rotor in a SG rotates synchronously with the stator field, the rotor speed is the same as the electrical frequency. Hence, rotor speed oscillations are grid frequency oscillations, which have to be dampened before the whole system becomes unstable. In a conventional power plant, SG equipped with power system stabilizers dampens these oscillations. If future wind farms substitute a considerable amount of conventional power plants, these wind farms have to be involved in the damping of grid frequency and inter-area oscillations.

References

[1]. Kling W.L., and Slootweg J.G., Wind Turbines as Power Plants. Proceedings of the IEEE/Cigré Workshop on Wind Power and the Impacts on Power Systems, p. 7 pp., (Oslo, Norway), 2002.

[2]. ELTRA. Specifications for Connecting Wind Farms to the Transmission Network-Second Edition. Http://Www.Eltra.Dk/Media/ShowMedium.Asp?12321_LCID1033, VOL: Doc No 74557, 2000.

[3]. Jauch C., Hansen A.D., Sørensen P., and Blaabjerg F., Simulation Model of an Active-Stall Fixed-

Speed Wind Turbine Controller. Wind Engineering, Vol 28, issue 2, pp. 177–198, 2004.

[4]. D. G. Infield, G. W. Slack, N. H. Lipman, and P. J. Musgrove, “Review of wind/diesel strategies,” Proc. Inst. Elec. Eng. A, vol. 130, no. 9, pp. 613–619, 1983.

[5]. H.M. Elzoghby “Dynamic response and control of a gid connected wind farm with different types of generators” Ph.D thesis, 2012.

[6]. O. Honorati, G. L. Bianco, F. Mezzetti, and L. Solero, “Power electronic interface for combined wind/PV isolated generating system,” in Proc. European Union Wind Energy Conf., Goteborg, Sweden, 1996, pp. 321–324.

[7]. S. A. Daniel, K. Pandiaraj, and N. Jenkins, “Control of an integrated wind-turbine generator and photovoltaic system for battery charging,” in Proc. 19th British Wind Energy Conf., Edinburgh, U.K., 1997, pp. 121–128

[8]. B. S. Borowy and Z. M. Salameh, “Dynamic response of a stand-alone wind energy conversion system with battery energy storage to a wind gust,” IEEE Trans. Energy Conversion, vol. 12, pp. 73–78, Mar. 1997.

[9]. S. Kim, C. Kim, J. Song, G. Yu, and Y. Jung, “Load sharing operation of a 14 kW photovoltaic/wind hybrid power system,” in Proc. 26th IEEE Photovoltaic Specialists Conf., 1997, pp. 1325–1328.

[10]. K. Kurosumi et al., “A hybrid system composed of a wind power and a photovoltaic system at NTT kume-jima radio relay station,” in Proc. 20th Int. Telecommun. Energy Conf., 1998, pp. 785–789.