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# Comparative Analysis of Virtual Inertia Techniques In Wind Energy

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***Abstract*— Due to increased demand of clean and green energy, the demand of the renewable energy is increasing day by day. So, the scientists and researchers are trying to design more efficient systems with minimal losses. Looking forward to increasing the efficiency and minimize losses, scientists and researchers are trying to design controllers for the systems. If the system experience disturbances in the system frequency there will be extra power loss in the system as well as it can damage the appliances used. Frequency response of the system is consequently important to be controlled for which a synthetic inertia controller is designed. In this research synthetic inertia control as well as pitch control for wind turbines are designed. The results are validated using the stability analysis of the system with different controllers.**

***Keywords—Wind Power, Virtual Inertia, Pitch Control, Frequency Response.***

## I. INTRODUCTION

There is a significant relationship between electrical power system and reshaping contemporary society. Presently, industrial process plays a crucial part to develop the economic stature of any country. However, industrial progress requires adequate electricity supply to ensure reliability and efficiency. Modern cultures are more environment oriented. Hence, environmental pollution poses a severe threat to the future of this planet. Consequently, green energy comes in as an alternate source which is spreading throughout the world every day. For their job, industry and other industries require reliable supplies of electricity. Most nations are therefore interested in penetrating the RE in their energy industries in order to achieve financial and environmental advantages. With fossil fuel depleting and their adverse effects on the atmosphere due to emissions, it had drawn the attention of the whole community towards the use of renewable properties of power.[1] It had been understood that the constant dependent on fossil fuels will have disastrous outcomes due to the drastic impacts of global warming on excessive carbon dioxide emissions. Continuous use of non-renewable energy can cause a concerning rise in the earth's average temperature in the years to come. By the end of 2011, the worldwide share of renewable energy in the power industry stood at 20.3 percent. As the ancient and most applicable type of bulk energy production, hydroelectric generation has a ratio of 15.3 percent, while other renewable generations contributed only 5 percent. As compared to the non-renewable sources of fossil fuel, renewable energy generation has cost drawbacks for power production. Electricity generation in Pakistan relies primarily on standard generation sources. Around 94,653 GWh of electricity was produced in the nation during 2010–11.[2] Thermal power (62.5%), hydel (33.6%) and nuclear power (3.9%) are the primary contributors in the energy mix. Renewable energy is nearly negligible in the complete energy mix. The prevalent perception of renewable energy generation is the cost disadvantage, but rising fossil fuel prices in Pakistan and the abundance of renewable energy resources can help achieve grid parity. However, the governments of developing nations such as Pakistan need to take many measures to boost environmentally friendly renewable energy production. Governments should ensure a correct economic support scheme, like tax rebates, tariff feed and the mechanism for providing adequate resources. Government can provide assistance in various ways to generate renewable energy.[3]

## II. LITERATURE REVIEW

The design of the energy grid in the normal to long haul (to 2050) relies vigorously upon various possible situations for the accompanying things: arrangement of environmentally friendly power (chiefly as far as innovation, execution, and topographical area); extension of the European power network to neighboring force frameworks (for example North African, Russia, and the Middle East). The reach of appropriated fuel sources requires more intelligent force framework to be grown, predominantly at lower voltage levels. Such factors will layout the basic underlying and operational necessities of things to come European energy matrix by distinguishing particular examples for cross-European and intercontinental energy streams. This paper depicts the advancing challenges confronting the European transmission framework as it helps meet the destinations of EU's energy and environmental change strategy. We are zeroing in on the European super high-voltage plot, which is now considered an "clever" framework yet is foreseen to create towards models that offer more prominent exchange capacities (a so-called "super grid"). [4] In delineating the pressures and complementarities inside the savvy lattice and super-grid ideas, we address the difficulties of making the power dissemination frameworks more astute just to the extent of transmission-distribution interfaces. In this light, the paper presents the European Union's essential approach objectives and dreams for power, significant figures and patterns identified with European energy and power frameworks in a global setting, and mechanical decisions and challenges posed to skillet European transmission grid.[5] In view of its long-term evolution, the article ends with the summary of various potential solutions and requirements for the EU transmission grid. [6] Also, the EC issued the Energy Roadmap 2050, outlining the possible scenarios leading up to 2050 and following a path towards a low-carbon economy, assuming a target 80% reduction in emissions of greenhouse gases. The following key elements are shared by all scenarios:

- Renewables' share of electricity will increase, reaching in excess of 40% of gross final power consumption in the year 2050, compared to the 20% anticipated in 2020.
- Energy savings will be critical compared to the peaks of 2005–2006, with 32–41 percent reduction in energy demand by 2050.
- Electricity's share of final uses will rise from 22% in 2009 to 37% in 2050.
- Capital investments will rise in assets for infrastructure and the bills on fossil fuel will decline.
- Decentralized energy generation, i.e. energy generation linked distribution systems for medium and low voltage will increase, representing up to 35% of complete generation capability by 2050.[7]

When renewable sources like wind and solar generate an increasing share of energy, the production of electricity can

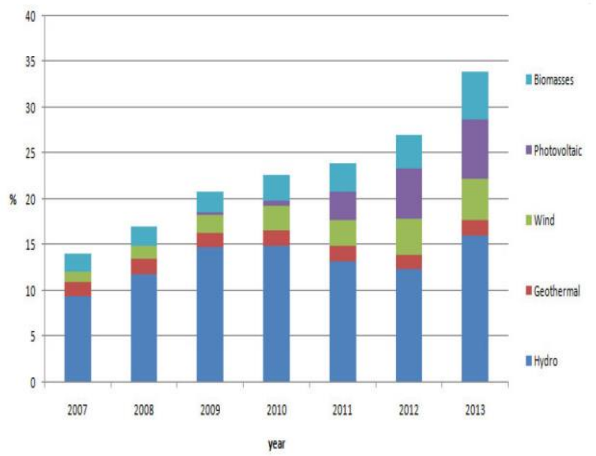


Figure 1: comparison of renewable energy resources

fluctuate significantly. Services that can assist balance energy systems beyond what standard assets can provide will be needed in the future. A promising new technique that can supply the needed stabilizing facilities is virtual power plants (VPPs). The objective of the second demonstration project of the Twenties was to demonstrate what VPP technology can actually do. The project for the demonstration involved the development of a Power Hub VPP. Power Hub works as an IT system capable of managing small power generators like small hydropower plants, industrial-grade combined heat and power plants (CHP), and emergency generation units such as wastewater pumps, greenhouse lighting and cooling units that are used mainly for cold storage facilities. Power Hub's goal is to ensure all units can be optimally used for the benefit of the owners of both the electrical system and the unit. [8]

## III. METHODOLOGY

As we have discussed earlier that the study must analyse the efficiency and performance of virtual inertia methods in wind turbines based on various conditions of a power system. The wind turbine-based virtual/synthetic inertia provision will enable further expansion of powerplants and subsequent systems based on the wind power with higher share of wind power generation as well as in high share of conventional power plants. Increasing renewable power plants also helps in reducing greenhouse gas emissions. [9]

To achieve desired results first of all we are supposed to know the problems with our basic system as we did this in this research work first of all the stability analysis of the wind turbines is done. The to overcome these problems some methods are suggested as we had fuzzy controller, PID controller but to get our best desired results first of all we used pitch controller to overcome the problem of pitch angle in the next step change in frequency was a second problem so we were supposed to design synthetic Inertia controller for our system as we did it we got Ideal like results in with a best and ideal step response.[10]

As we added Synthetic Inertia Controller with Pitch angle Controller we got all the oscillations in system step response to minimum (zero) and an excellent system step response.

### *1) Wind Turbine*

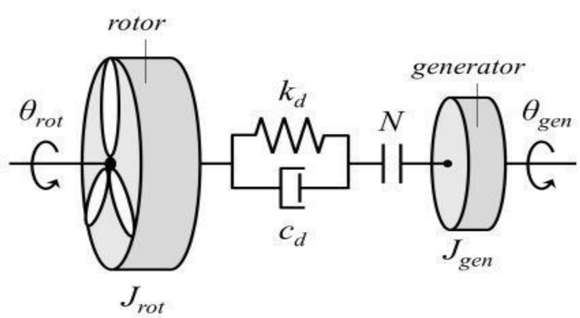


Figure 2: Wind Turbine Model

From the flow diagram of the system in Figure 1 first of all we are supposed to find out the transfer function of 1MW wind turbines the parameters of which are given in Table 3.1 below. Using the equations the transfer function of the system is determined. [5]

Now the system step response is determined using Mat lab Simulink to analyze the stability of the system. Then a Pitch angle controller is designed using PID algorithms as in Figure 3.6. After the determination of the step response of the wind turbine with Pitch angle controller Synthetic Inertia controller is designed to control the frequency of the system output and increase the stability of the system as given in the Figure 3.8.

In the last step the all the three step responses will be compared for the stability of the system.

*2) Parameters OF Wind Turbine*

Table 1 Parameters of Wind Turbine

| | |
|---|---|
| Rated generator power, Pe | 1000 KW |
| Rated generator Speed, Wg | 1500 rpm |
| Rated turning speed of rotor, Wt | 20 rpm |
| Wind turbine blade radius, R | 35 m |
| Reference pitch angle, $B_d$ | 0 to 90 deg |
| Rate of change of pitch angle | 0.6 deg / sec |
| Control accuracy of pitch angle | 0.3 deg |
| Damping coefficient, B | 2 N.m/rad/sec |
| Drive-Train Inertia , $J_t$ | 0.75 $N.m^2$ |

Table 2 Mechanical Model Parameters of Drive Train

| Parameter | Description |
|---|---|
| $J_t$ | Wind turbine inertia [$kg.m^2$] |
| Jg | Generator inertia [$kg.m^2$] |
| Ks | Stiffness coefficient [M.m/rad] |
| B | Damper Coefficient [N.m/rad/sec] |
| Tt | Wind turbine torque [N.m] |
| Tg | Generator electro-mechanical torque[N.m] |
| Wr | Wind turbine shaft speed [rad/s] |
| Wg | Generator shaft speed [rad/s] |
| θt | Wind turbine shaft angle [rad] |
| θg | Generator shaft angle [rad] |
| 1:n gear | Gear ratio |

*3) Equation of Wind Turbines*

These Specifications in Table 1, are of 1 Megawatt Wind Power Turbine which are further used to derive the transfer function of the wind Model. The symbols in Table 2 are defined as well.

The Change in pitch angle is given by the equation;

$$\frac{d\beta}{dt} = \frac{(\beta d - \beta)}{T_\beta} \text{-----------------------------------}(1)$$

$$T_\beta \frac{d\beta}{dt} + \beta = \beta d \text{-----------------------------}(2)$$

On both sides apply Laplace transform

$$T_\beta . \beta s + \beta = \beta d \quad \text{------------------------}(3)$$

$$\frac{\beta}{\beta d} = \frac{1}{(T_\beta s+1)} \quad \text{----------------------------}(4)$$

$$\frac{\beta}{\beta d} = \frac{1}{(0.5s+1)} \text{-----------------------------------}(5)$$

The Dynamics of the drive train are represented by the equations below

$$J_t.\frac{d}{dt}(Wt) = T_t - (Ks\delta\phi + B\,\delta w) \text{------------}(6)$$

$$\frac{d}{dt}(\delta\phi) = \delta w \text{ -------------------------------------}(7)$$

Using Newton's Second Law of Motion

$$J_t.\frac{d}{dt}(W) = T - BW \text{------------------------------}(8)$$

On both sides applying Laplace transform

$$J.Ws = T - BW \text{-----------------------------------}(9)$$

$$J.Ws + BW = T \text{-----------------------------------}(10)$$

$$W(Js + B) = T \text{------------------------------------}(11)$$

$$\frac{W}{T} = \frac{1}{(Js+B)} \quad \text{---------------------------------}(12)$$

Now by putting the values from the table 1 we will get

$$\frac{W}{T} = \frac{0.5}{(0.37s+1)} \text{--------------------------------------}(13)$$

From equation [5] and equation [13]

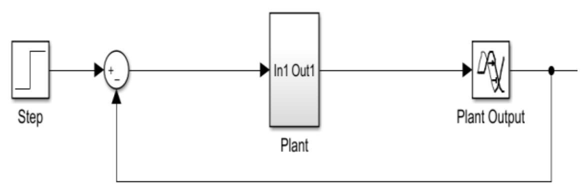


Figure 3: Block diagram of the Wind Turbine with an input step function

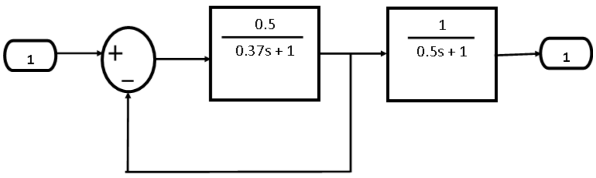


Figure 4: Block diagram of the Wind Turbine with an input step function

Then a Pitch Angle controller next to our Blades is installed and configured and checked the results of the system. The feedback is taken and fed to the Pitch Angle controller for the system. It is presented in the following Figure 5. The result was noted.

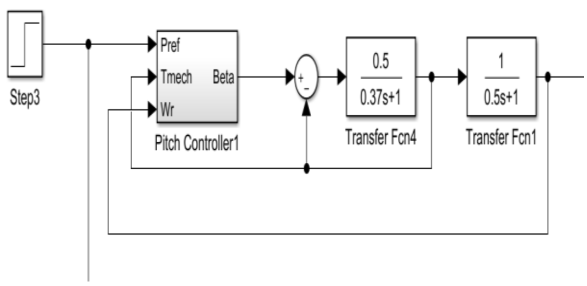


Figure 5: Block diagram of Wind Turbine and Pitch Angle controller with input step function

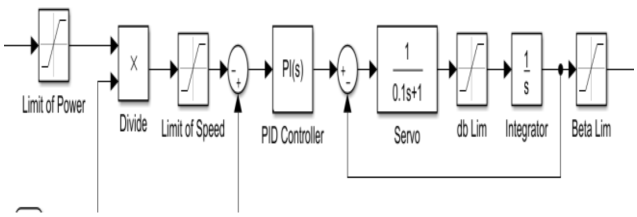


Figure 6: Pitch Angle Controller Using Mat lab Simulink

In this controller we clearly see that we have used a PI Controller (Proportional Integral Controller) to overcome the problem and the problem in the system is stability of the Pitch angle.

Then I installed and configure a Synthetic Inertia controller next to the Pitch Angle controller and checked the results. The following figure shows the scheme.

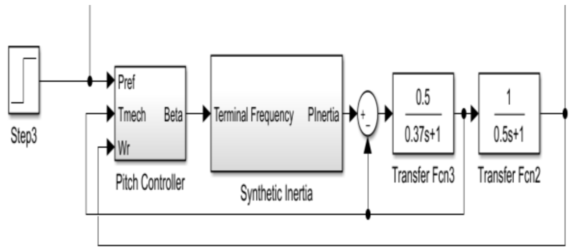


Figure 7: Block diagram of Wind Turbine and Pitch Angle controller and Synthetic Inertia controller with an input step function

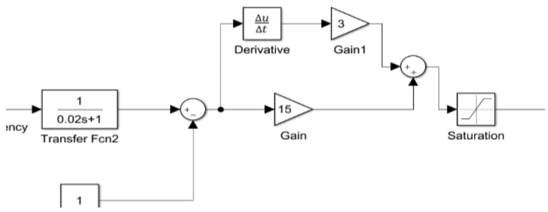


Figure 8: Synthetic Inertia Controller

The result of the step response of the system is recorded. By comparison of the results, we noticed that the Synthetic Inertia controller were refined the results of the Pitch Angle controller.

## IV. Results

From the Figure 9 we can see the stability analysis of the system without any controller. From this Figure the Rise time, settling time, Maximum overshoot and Steady state error is calculated which is given in the Table 3 below. Now as we had added a Pitch angle controller to over system, we got a more stable system. The step response of the system can be seen in Figure 10. The system is more stable and there is no steady state error in the system. The Stability analysis of the Wind Turbines with Pitch angle controller is given in the Table 3 below.

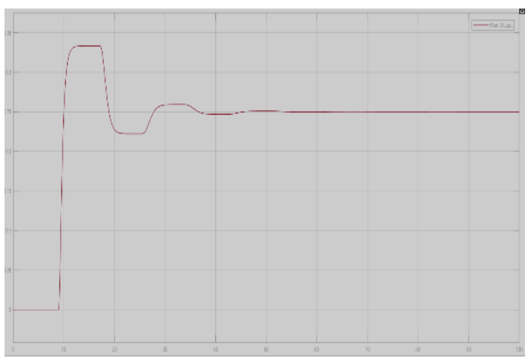

Figure 9 System Step Response without Controller

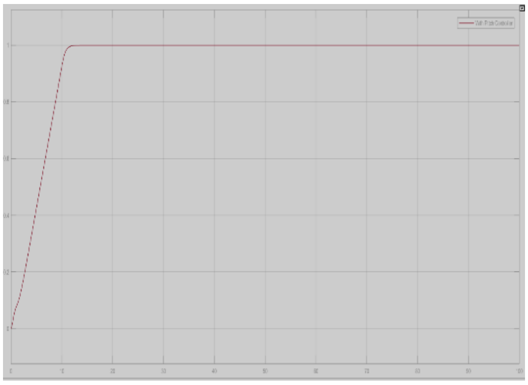

Figure 10 System Step Response with Pitch angle Controller

Figure 11 System Step Response with Pitch Angle Controller and Synthetic Inertia Controller

Now as the system has a rise time more than 7 Seconds so we had to minimize the rise time and for this we used a synthetic Inertia Controller. After adding Synthetic Inertia controller and Pitch angle Controller to the system the system stability is like ideal the rise time of the system is almost negligible less than one second. The rest of the parameter for stability analysis of the system can be found from the Table 3. All the three outputs of the system are compared below in the Figure 12.

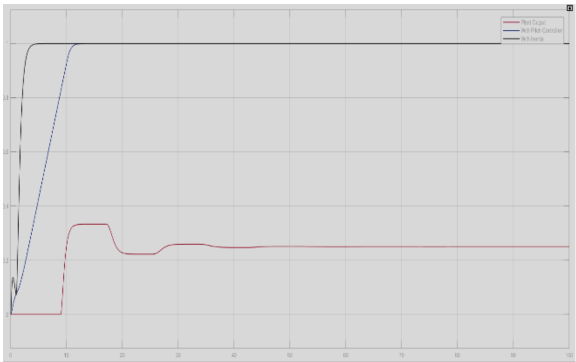

Figure 12 Stability Analysis of the overall system

Figure 12 shows the stability analysis of the system without any controller with Pitch Angle Controller and with Inertia Controller from which we can clearly identify that the system is more stable with Pitch angle controller and when Inertia Controller is used we got the desired Results of the system step Response. The Stability of the system is evaluated below in the table 3.

Table 3 Stability Analysis of the system

| Specs | Without any Controller | Pitch Angle Control ler | Synthetic Inertia Controller |
|---|---|---|---|
| Rise Time (s) | 0.73 | 7.3 | 0.8 |
| Steady State error | 0.3 | 0 | 0 |
| Peak Overshoot % | 11.8 | 3.34 | 1.02 |
| Settling Time (s) | 27 | 11 | 1.2 |
| Delay Time(s) | 8 | 2 | 1.1 |

## V. Conclusion

As we have discussed earlier that the purpose of the study is to analyse performance and efficiency of virtual inertia methods for wind turbines according to different power system conditions. Provision of virtual/synthetic inertia by wind turbine will allow further expansion of wind power plants in power systems with higher share of wind power generation as well as in high share of conventional power plants. Increasing renewable power plants also helps in reducing greenhouse gas emissions.

To achieve desired results first of all we are supposed to know the problems with our basic system as we did this in this research work first of all the stability analysis of the wind turbines is done. The to overcome these problems some methods are suggested as we had fuzzy controller, PID controller but to get our best desired results first of all we used pitch controller to overcome the problem of pitch angle in the next step change in frequency was a second problem so we were supposed to design synthetic Inertia controller for our system as we did it we got Ideal like results in with a best and ideal step response

As we added Synthetic Inertia Controller with Pitch angle Controller, we removed all the oscillations in system step response to minimum (zero) to achieve excellent system step response.

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