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AUTOMATIC GENERATION CONTROL OF MULTI-AREA POWER SYSTEM WITH WIND POWER GENERATION

Rajeshwar Pratap, Monahil Chugh

ABSTRACT

Main challenge for interconnected multi area power system is first to meet demand-supply power ratio with a regulated power supply while maintaining constant frequency and tie-line power as per scheduled. Deviations in frequency and tie-line power are caused by fluctuating load demand. These deviations can lead to multi-area power system upto blackout, so these oscillations required to be controlled. AGC is power grid requirement, where several control areas are connected to each other to fulfil the requirement of varying load demand from different control areas generation units. In multi-area power system, the power is not only generated from thermal or hydro plants but also from more small scale power generation sources like wind, solar photovoltaic, battery banks etc. The main goal of power generation system is to provide economical, reliable and quality power supply.In recent years, wind power generation systems have attracted a lot of attention as a renewable source of energy. The Wind Power Generation is capable of producing unlimited power due to the abundance of wind energy. Wind power is an alternative to fossil fuels and it doesn't do greenhouse gas emissions. Cost of electricity generation from wind energy has come down due to improved technology of wind turbine and power electronics. Major challenge of the wind power generation is uncertainty in wind speed. Wind power is dependent on the cube of wind speed and wind speed varies over time. So, change in wind speed results fluctuations in generated power. This results more deviation in frequency with increasing penetration of the wind power like in large-scale wind farms. This change in frequency can effectively mitigated by AGC. Therefore, in order to meet objective, AGC mechanism is required to be proposed with integration of wind power generators in multi-area power system. In addition, impact of integration of wind power generator is also required to be examined. And in case of sudden power demand or change in wind speed, how effectively frequency deviation regulated by AGC.

Keywords: *Multi-Area Power System, Automatic generation control, Wind power generation, PID controller, AGC (automatic generation control).*

1. INTRODUCTION

The economic dependency reduction on fossil fuel-based energy has been among the main priority aims of governments and regulators around the world. During current years fossil fuel resources are not in huge amount and have a noticeable adverse impact on the environment by increasing the level of CO_2 in the atmosphere and contributing to global warming. Among renewable sources of energy, wind is one of the most promising technologies. It has already been in use for a significant period of time and, compared to other forms of alternative energy resources, has the potential to reduce the conventional generation. The ratio of wind-based generation in total energy production mix has been raising continuously in many parts of the world .it has been reported [1] that renewable energy provide 10% of the world's energy supply by 2020, and it will increase to 50% by 2050. Canada has outlined a future strategy for wind energy that would reach a capacity of 55,000 MW by 2025, fulfilling 20% of the country's energy needs [2]. The European Union plans to produce 22% of its electricity from renewable resources by the year 2010 [3].

Despite of the fact wind-based generation is well known and has been used for few years, but focus of the industry has been on turbine protection aspects because of low penetration levels of wind turbines. However, with the increasing amounts of wind energy into the network, new challenges with regards to the functioning of the current power grid are surfacing, especially in area of grid stability, balance, security, planning, cross-border transmission, and market design. A wind source is uncertain so, efficient integration of large amounts of variable sources of wind turbines into the existing electrical networks can significantly impact the design, operation, and control of the network.

The work in this thesis is an attempt to study and examine the role of variable speed based wind turbines, in particular the Doubly Fed Induction Generators (DFIG), in frequency regulation and control with different levels of wind penetration into the system. In particular the issue of optimal tuning of the DFIG control system in single-area and two-area frequency control problems has been presented as a means to help improve the performance of the system.

2. STUDY ABOUT WIND ENERGY

2.1 Wind Energy Globally

There is an increasing commitment from global leaders and policy makers to reduce Greenhouse Gas (GHG) emissions. Efforts are being made to increase the contribution of renewable sources of energy in the energy supply mix. Several countries have already formulated policy frame works and they are ensure that renewable resources play a major role in coming energy scenarios.

2.2 Wind Power in Canada and Ontario

Wind energy development in Canada was mainly focused in Ontario, Quebec and Alberta. From early 1990s and since the beginning of the 21st Century all Canadian provinces have pursued wind power development to supplement their provincial energy grids. The first commercial wind farm is built by Alberta in Canada in 1993. British Columbia was the last province to add wind power to its grid with the completion of the Bear Mountain Wind Park in November 2009 [4]. With population growth of the country results in growth of energy demand .Canada has seen wind power as a way to diversify its energy supply, and to help moving away from its traditional reliance on fossil fuel based thermal plants and hydroelectricity. In provinces like Nova Scotia, where only 12% of the electricity comes from renewable resources [5], wind energy development projects can provide a measure of electricity security that some jurisdictions are lacking. In the case of British Columbia, it is envisaged that wind energy will help close the electricity deficit gap that the province is facing in the next decade, and reduce its reliance on importing power from other jurisdictions that may not use renewable energy sources. An additional 2004 MW of wind power is scheduled to come on-line in Quebec between 2011 and 2015 [6]. In 2008, Wind Energy Association of Canada (CanWEA),A non-profit trade organization, outlined for wind energy that envisages a capacity of 55,000 MW by 2025, fulfilling 20% of the country's energy needs. The plan, Wind Vision 2025 [1], could create over 50,000 jobs and represent around CDN$165 million yearly revenue. CanWEA‟s target would make the country a major player in the wind power sector and would create around CDN$79 billion of investment opportunities. It would also eliminate an estimated 17 megatons of GHG missions annually [1].

2.3 Wind Power in Us

At the end of 2009, the installed capacity of wind power in the US was just over 35GW [10] [11], making it the world leader ahead of Germany. Wind power accounts for about 2% of the electricity generated in the US [12].

New wind power capacity of 9,900MW was brought online in 2009, up from 8,800 in 2008. In 2009, the added new capacity was enough to power the equivalent of 2.4 million homes or generate as much electricity as three large nuclear power plants [13]. These new installations place the US, on a trajectory to generate 20% of the nation's electricity from wind energy by 2030 [11]. Growth of MW capacity in 2008 channeled some $17 billion into the economy, positioning wind power as one of the leading sources of new power generation in the country, along with natural gas. New wind projects completed in 2008 accounted about 42% of the whole new power-producing capacity merged in the US in the year [14] In the end of 2008, almost 85,000 people were employed in the US wind industry[15], and GE Energy was the biggest national wind turbine manufacturer [15]. Wind projects improved local tax bases, and revitalized the economy of rural communities by providing a constant income stream to farmers by wind turbines on their own land [16] Wind power in the US provides sufficient electricity to power the equivalent of about 9 million houses, preventing the emissions of 57 million tons of C per year and reducing expected C emissions from the electricity sector by 2.5% [17]. Texas is one of the most installed wind power capacity of any US state with 9,410 MW of capacity, followed by Iowa with 3,053 MW [11]. The Roscoe Wind Farm (780 MW) in Texas is the world's largest wind farm [18].

2.4 Wind Power in the European Union

In 2008, according to Wind Energy Association (EWEA) of Europe, there were 5,000 wind turbines with capacity of 64.93 GW in the European Union, generating 142 TWh of electricity which took an investment of 11 billion euro [19]. In 2008, 4.2% of its electricity is produced by European union from the wind [19][20]. As of 2009, the leading countries are Germany (25 GW) and Spain (16.7 GW). The European Environment Agency (EEA) report [21] states that potential of wind energy is enough to power Europe many times over. The report priviliged Europe‟s wind power potential will be three times greater than it‟s expected electricity demand in 2020, rising the factor of seven by 2030 [22]. In 2008, 8.48 GW (8.1 onshore and 0.37 GW offshore) of wind energy capacity was installed in the European Union compared to 27 GW in the world [19][22]. The market of European wind power capacity grew noticeably in 2006, according to statistics from the European wind energy association. A total of 7,588 MW of wind power capacity, some 9 billion Euros, was installed in the EU in 2006, with raise of 23% compared to 2005. Presently more than 25,000 wind farms are operating in Europe, and capacity is expected to double by 2015.

3. LOAD FREQUENCY CONTROL

Despite the increasing popularity of wind turbines injection grid frequency regulation and AGC's mission is mainly composed of conventional generators. FM and AGC's goal is to keep within the limits of the frequency range by primary and secondary control provisions of the governor.

Traditionally, wind energy conversion system (WECS) is not involved in supporting the system frequency. Therefore, the wind turbine does not increase or decrease the frequency of its time of production falls or rises, respectively, which means that the inertia of the system, they do not. With the growth of wind power capacity high rate, its contribution to total electricity generation portfolio is growing, but the inertia of the system frequency control is to reduce participation levels appropriate to restore the power system frequency imbalance or deficiency under grid disturbance.

Thus, the contribution of wind power in a network and further penetration of the required AGC from adjusting the frequency of the wind turbine in order to prevent a reduction in the total inertia of the system network.

3.1 Dynamic Model of Primary Frequency Regulation with DFIG-Based Wind Turbines

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Dynamic performance of the power system, including the traditional model of a prime mover, a small perturbation model shown in Figure 3.4 by the non-reheat and double-fed wind turbine generator sets to represent [3]. This model simulates the primary frequency interference, including traditional system parameters, such as load damping factor (D) regulating sagging (R) inertial H, governor of the time constant of thorium and TT systems equivalent units (governor and turbine).

The system behavior depends on the choice of network parameters and DFIG-based wind turbine speed controllers are K_{wp} and K_{wi}

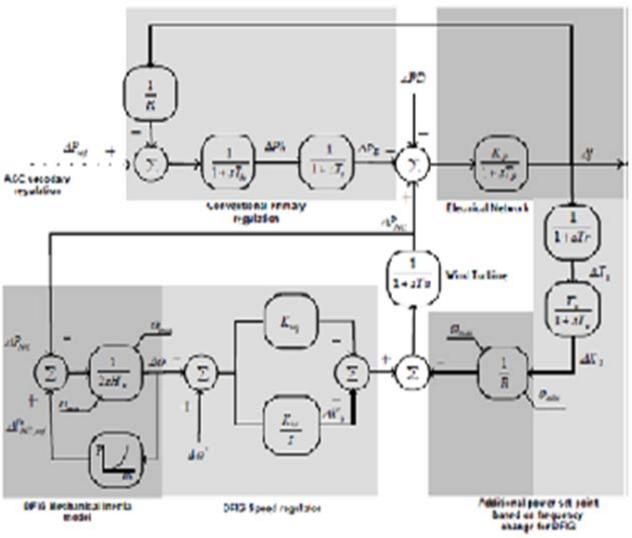

Figure 1 Primary frequency regulation block diagram with DFIG based WT

In Figure 1, ΔP_h is the incremental hydraulic governor valve position change, $\Delta\omega$ is incremental speed of the wind turbine, Δf is the incremental frequency change, ΔX_1 is frequency increment after being measured by transducer, ΔX_2 frequency change after the washout filter and ΔX_3 is the incremental change in DFIG integral speed control. The incremental model is obtained by linearizing the system around a nominal operating point. The dynamic model in state-space form can be obtained from the transfer-function model given below:

$$\frac{d\underline{X}}{dt} = A\underline{X} + \Gamma \underline{p}$$

3.2 Optimal adjustment of DFIG-Based Wind Turbine Controller Parameters

The purpose of this section is to determine the speed of the wind turbine DFIG based optimal control parameter settings to improve the control response of the system to participate in the frequency disturbance. Squared error (ISE) of the integral [40] techniques are used to obtain the optimum value of KWP and KWI. In the state space model (3.20), 0.02 units of the disturbance step is considered, which is still in the kinetic constant of the process. To check the influence of the wind increase, the total energy Hybrid systems, penetration index (αW) is defined as

$$\alpha w \frac{\textit{Total wind generation}}{\textit{Total generation from all source}} \times 100$$

Four cases of DFIG penetration are considered:

- $\alpha W = 5\%$
- $\alpha W = 10\%$
- $\alpha W = 20\%$
- $\alpha W = 50\%$

The initial value of the state variables, in this study, the incremental change from their nominal values will be zero because the system is stable. To t∞, a state close to the new steady state, so that at any time t, the state vector X (t) represents the deviation from the state of its steady state value of the variable. Therefore, the dynamic performance of the system, for a given set of control parameters, the performance can be measured using a secondary Index represents the square of the deviation of state variables, as follows

$$J = \int_0^\infty \left[X_1^2(t) + X_2^2(t) + X_3^2(t) + \ldots\ldots + X_n^2(t)\right]dt$$

In this work, the frequency deviation squared error is considered for tuning controller parameters, performance metrics described below.

$$J = \int_0^\infty \left[\Delta f^2(t)\right]dt$$

For the purpose of the performance index J is calculated by adding a very small time interval to calculate the discrete values, in quite a long time until a steady state is to achieve, as given below.

$$J = \sum_{k=1}^{K}\left[\Delta f^2(t_0 + k\Delta t)\right]$$

WP DFIG and controller parameters of the rotational speed of an optimum value by searching Kwi is initially determined minimum value J, KWI is fixed at a certain value and KWP vary over a wide range. It was observed that the J with Kwp increased, reaching a minimum, Jmin, then increase. KWP and Kwi can produce a minimum value JMin (J * minimum), is the best controller parameters. Figure 3.6 shows several values Ĵ with the Labor Party's conspiracy Kwi.

4. INTEGRATED WIND WITH LOAD FREQUENCY CONTROL

In an interconnected power system frequency control multi-zone problems are more significant and complex than those associated with the isolated network. In the isolated network (single zone) Assuming frequency control network across the region leading to a single unity. Of course this is not one of the many control regions can be identified in case of large interconnected systems. These control regions traditionally associated with vertical integration competent defined geographical area associated with their secondary frequency control.

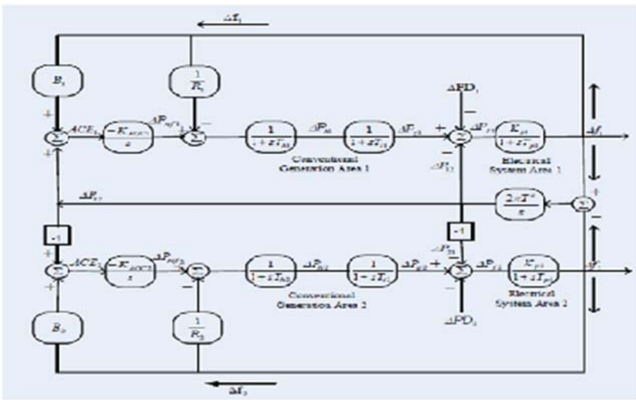

Figure 2: Linear model of frequency control two Area System

Dynamic performance of the two regional interconnected systems with a small perturbation transfer function model (Figure 4.1) for analysis. The model includes both primary and secondary frequency control after a disturbance. The system performance depends largely on the integral control gain (KAGC1 and KAGC2) and a frequency deviation factor (B1 and B2), in addition to the system parameters and operating conditions.

4.1 Dynamic Model of Primary Frequency Regulation with DFIG-Based Wind Turbine

Dual-zone inverter control system transfer function of the small perturbation model in block diagram form, including a simple model of the traditional prime mover, with a non-reheat steam turbine and double-fed wind turbine in each area shown in Figure 3

DFIG-based frequency regulation and automatic generation control (AGC), serving multi-zone control system involvement is a complex issue. DFIG contrary to fixed speed WT can participate and improve the high frequency performance and reduce ACE supports traditional generation frequency regulation services in each region.

This chapter describes two aspects of the power system, equipped with a transfer function based on small perturbations DFIG model for each region. As in the previous chapters, integral square error optimal adjustment based controllers were doubly-fed. However, the optimal adjustment process becomes due to the presence of multiple parameters simultaneously be tuned much more complex. Therefore, heuristic iterative optimization adjustment programs proposed to help determine the optimal parameters of success.

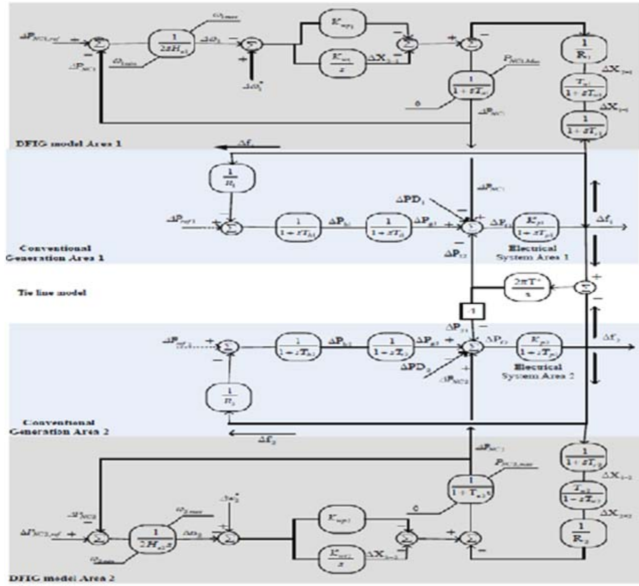

Figure 3: Linear dynamic model of primary frequency control of two area system with DFIG

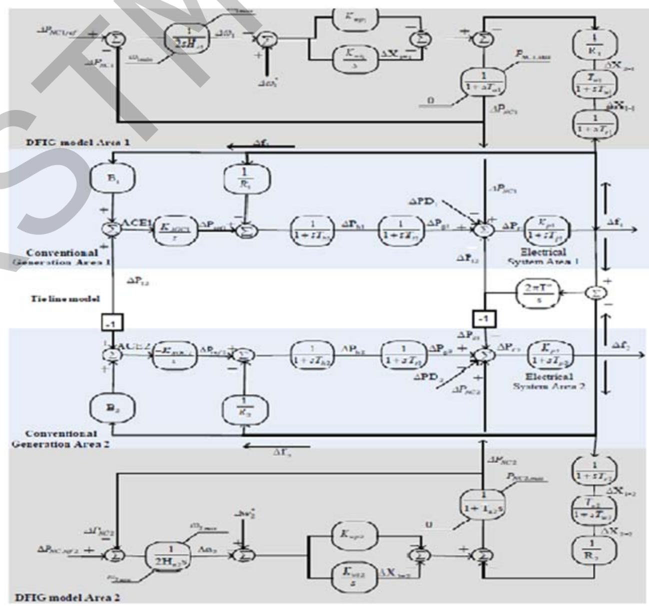

Figure 4: Linear dynamic model of secondary frequency control of two area system with DFIG

Detailed simulation study has been proposed to be adjusted to optimize performance and to compare its contribution DFIG controller for power system frequency adjustment and AGC two region. In addition, studies have raised the impact to a system of 5% of the comparison, 10%, 20% and 50% of wind power penetration.

5. RESULTS AND FINDINGS

The frequency response can be observed below the disturbance is improved by reducing the frequency at which peak shift is considered to participate in the DFIG mode. Also observed that, when viewed from 5 to 50% to increase the level of air permeability, while the lower peak permeability, but the frequency response by increasing the settling time of the frequency error and higher steady-state manner reduced. It can be concluded that in general, have a lower permeability, the settling time is increased, no DFIG under the case where the steady-state error of nearly two.

5.1 Examine Effect of Load Frequency Control

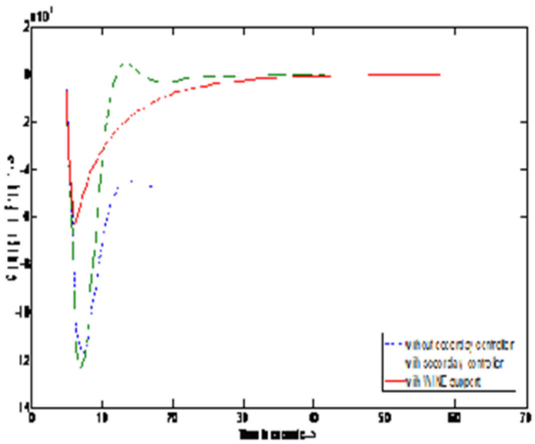

Figure 5: Comparison of frequency response on step load change without secondary controller, with secondary controller and without secondary controller and WIND support

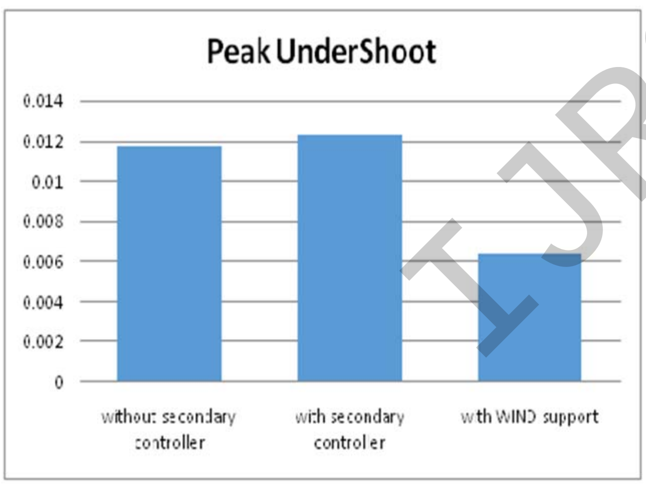

Figure 6: Comparison of peak undershoot for deviation in frequency response on step load change without secondary controller, with secondary controller and with secondary controller and WIND support

5.2 Examine Effect of Load Frequency Control with Wind Inertia Support

It can be concluded that the general performance of the higher wind energy penetration AGC, initially relatively low permeability, and ultimately there is no double-fed wind power compare when, due to the fact that the kinetic energy released by the DFIG, its mechanical speed is reduced

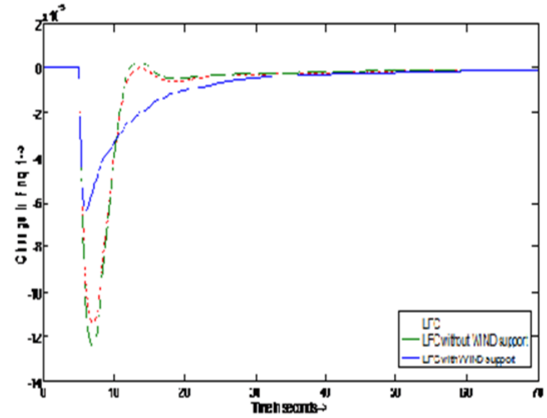

Figure 7: Frequency deviation in area

So as, to reduce the power output of the DFIG, the front stable situation. Thus, for larger DFIG penetration, which reduces the power output of the AGC and the additional burden conventional power generation, in order to balance the load of the control frequency.

5.3 Examine Effect of Load Frequency Control with Wind Inertia Support in Different Areas

Figure 8 shows the comparison of peak undershoot for lfc-Lfc integrated area 1 and lfc integrated wind area 2

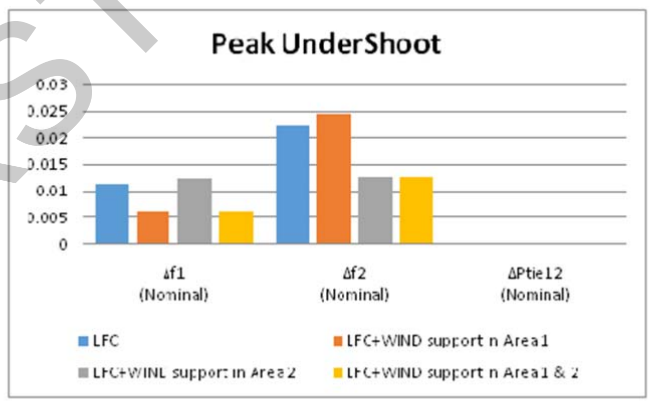

Figure 8: Comparison of peak undershoot for LFC, LFC integrated wind in area 1, LFC integrated wind in area 2 and LFC integrated wind in both areas system responses under step load change

6. CONCLUSION

This paper attempts to address some of integrated power systems and wind power total energy supply mix important issues related to conventional power sources. In this paper, with particular emphasis on regulation and inspection frequency doubly-fed wind turbine based on the automatic generation control (AGC) impact. From the main findings and conclusions of this study are as follows small perturbation transfer function model in state-space form first developed for the power system and two single-zone area with a combination of conventional power generation and wind power resources. Development of the primary regulatory state space model, and two types of models in automatic gain effect. Based on double-fed wind power generation is considered to be the model of

1. Standards-based ISE, a simple parameter optimization technology to optimize the adjustment doubly-fed controller parameters. In the case of two regional power systems, dual-fed in these two areas, the number of parameters can be optimized adjustments is large, and therefore the order of the ISE application guidelines presented.
2. Dynamic performance analysis is considered optimal adjustment of double-fed controller to check their contributions to the system frequency support services, the primary regulator and AGC.
3. Define and study the effect of variation o a penetration of wind power penetration index of 5%, 10%, 20% and 50% of the wind energy penetration and in 2020 and 2050, respectively, through the goal line for the Global world wind energy.

6.1 Scope for Future Work

A) State-space model development of the system, taking into account the variable speed generator can be further expanded to include the wind turbine pitch control effect. As a change in wind speed and the pitch control system in response to the disturbance as a whole, at one side of the settling time of the second frequency adjustment section 3 and the results presented in Figure 4 is substantially the same simulation and close, so further research can be carried out, based on studies using double-fed wind turbine and to load operation (operating less than the maximum power) to adjust the frequency DGFIG full participation transient, and pitch control to increase production.

B) By This work considers the traditional proportional - integral controller of doubly-fed machine. Other research studies have room controller structure, adaptive feed forward controller contribution dual frequency control can provide, because of the special design of intermittent wind power dynamics to improve the performance.

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