Performance Enhancement of DFIG Based Wind Farms Integrated in Power System using AVR & PSS

Shivendra Saurabh[1], Varun Kumar[2], Yogesh Kumar Chauhan[3]

[1]M.Tech Student, EED, KNIT, Sultanpur, U.P., India,
[2,3]Professor, EED, KNIT, Sultanpur, U.P., India

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Abstract: *With the large increase of doubly fed induction generator (DFIGs) in power system, it seems necessary to ensure an adequate operating condition for this type of wind technology. Among the important requirements of DFIGs in fault conditions, low voltage ride-through (LVRT) is a very important issue. This paper is about improving the parameter performance of DFIG-based wind farms integrated with large-scale power systems, under voltage dips. This purpose is achieved by creating a coordination between the automatic voltage regulator (AVR) and the power system stabilizer (PSS) of the corresponding generators. In this study, the most important communication tool is fuzzy logic. The need to integrate a fuzzy controller designed (an agitated coordinator) to eliminate the harmful interaction between AVR and PSS under network interference conditions. A smart consultant converts the gain of AVR and PSS to require it to deliver the best performance in the event of fault. The proposed link supports the transmission of the point of common coupling (PCC) under voltage dips and reduces the need for the reactive power of the DFIGs. The functionality of the connector for performance is shown in the IEEE 10-machine 39-bus power system, with different levels of input from DFIG-based wind farms.*

Keywords: **DFIG-based wind farms, AVR, PSS, Fuzzy coordinator, Performance enhancement**

I. INTRODUCTION

The broad development of the use of renewable energy sources such as solar, sea, biomass, geothermal and wind has been avoided. Wind power is the major contributor to the generation of electricity among the various sources of renewable energy; This is due to its potential benefits, such as the free availability of wind power, its high power holding capacity, other land uses around wind farms and, most importantly, economically to build a wind farm [1]. In Europe and the United States, 2007 targets for wind farms will reach 20% of electricity consumption by 2030 [2]. The application of this amount of wind energy to electrical systems needs further clarification and attention. [3] provides some interesting data on the key combinations of wind power plants, impacts on electricity systems and emancipated systems.

With the introduction of new origination such as doubly fed induction generators (DFIGs) with various integrated production capabilities, optimizing power generation is facing new challenges. If the contribution to the DFIG network is small, it greatly affects the stability of the power system. In contrast, with the high penetration of DFIG wind farms into the grid, the dynamic performance of the grid can be significantly affected by the characteristics of the DFIG. The transient stability of the DFIG power system has been extensively studied in several cases [4]. Increased integration of wind farms with energy consumption can have both positive and negative effects on the stability and long-term sustainability of small-scale signals [5]. A safety guarantee without limiting the DFIG stability is coupled to an electric field with low voltage ride-through (LVRT) operating in a weak internal connection. The relationship between DFIG reactive control management and rotor angles of synchronous generators in a large power system was discussed in [6]. Reducing the use of DFIG power can reduce the injection of compressive power by cooperative induction generator and help reduce many variations in the rotor line.

Because the speed of the DFIG-based wind turbine engine is changed to extract maximum energy from the wind, the LVRT improvement attracts the most attention. In a wind turbine system, faults, even far from the location of the wind farm, can cause voltage dips at wind turbines. The winding current of the DFIG stator increases rapidly after a voltage drop at the point of common coupling (PCC). Current in the rotor circuit of the DFIG occur by the magnetic coupling between the stator and rotor of the induction generator. As a result, an excessive current can be observed in the electronic converter, which can destroy the converter. In view of this claim, most studies in the published professional literature are limited to improving the performance of PCC voltage for DFIG. To achieve this goal, there are two control strategies: from a network point of view, available control tools such as AVR, PSS and dynamic voltage regulators can be used. On the other hand, from the DFIG point of view, different control plans can be applied to the electronic current converter to improve the PCC voltage.

With a series damping resistance in the stator circuit, the rotor current tip is lowered in the fault state in [7]. To improve the LVRT, [8] proposes a robust decentralized control scheme for output feedback of DFIG inverters on the rotor and grid side. However, the performance of the control is limited to the working point after the system fault is installed in the area where the controller is designed. Ref. [9] requires configuration of DFIGs based on control functions to improve the voltage stability margin of the electrical system at both distribution and transmission levels. In [10], an extended LVRT scheme is proposed to support the response to a DFIG voltage drop. A passive compensator in series with the stator windings and an active compensator by regulating the rotor voltage is discussed in Ref. [11] Improve LVRT capacity of DFIG. A controller with various alternatives developed for a DFIG-based wind turbine to make a positive contribution from DFIG to network operation is presented in [12]. The controller ensures correct voltage control and voltage recovery in situations of damage.

Effective voltage support and reactive power restitution through FACTS (Flexible AC Transmission System) is one way to improve the increase of wind turbines in the field of voltage circulation. The effects of different types of FACTS units on the stability of the electric field relative to wind turbines are described in [13].

This study uses the control of synchronous generator in multi-machine systems to improve the performance of DFIG-based wind farms. Over the years, an automatic voltage regulator (AVR) and a power supply stabilizer (PSS) have been installed in electric power generators [14]. Voltage control, power control, transient and small signal stability enhancement are the main functions of these two controllers of the systems. It is conspicuous that the output of AVR and PSS has a voltage gender. Therefore, its effect on the DFIG based wind farms and PCC conditions of DFIG is of high quality. PSS and AVR are both designed for system performance modeling [15]. As a result, controllers may have coordinated under the fault circumstances. In the present work fuzzy logic is used to simulate the coordination between AVR and PSS. The normalized deviations of the rotor angle and terminal voltage of the alternator are selected as the input of the fuzzy logic unit. At the same time and with the fuzzy rules, the fuzzy coordinator generates the necessary gain for AVR and PSS. The important point of this fuzzy controller is that it does not need to install the remote control on all existing power generators in the area.

The work is organized as follows: Wind turbine, DFIG model, power system and controller's models are depicted in the "System model and description" section. The need for coordination and fuzzy coordinator are described in the "Proposed fuzzy coordinator" section. The "Fuzzy Coordinator" section explains the fuzzy approach and structure of the coordinators. The simulation results for 39 bus power systems with DFIG based wind farms are shown in the "Simulation results" section, and the final conclusions are presented in the "fuzzy coordinator" section.

II. SYSTEM MODEL AND DESCRIPTION

(a) Wind turbine:

The wind turbine is a device that converts the kinetic energy of the wind into electrical energy. The main components of the wind turbine are the rotor (generates aerodynamic torque), a nacelle (conversion of torque to electrical energy), a tower and foundation (ensure that the wind turbine is maintained) [1]. The amount of electricity generated by a wind turbine depends on the wind speed. the availability of wind turbines and how wind turbines are planned.

Apparently, power generated by wind turbine is obsessed by,

$$P_m = \frac{1}{2}.A_r\rho.V_w^3.C_p(\lambda,\beta) \qquad ....1$$

Where, ρ = density of air=1.2 Kg/m^3; V_w= wind velocity, m/sec; C_p= Power Coefficient

λ= Tip speed ratio of the turbine and β= Pitch angle of the blade (in degrees)

$$C_p(\psi_k,\beta) = c_1\left(\frac{c_2}{\psi_k} - c_3\beta - c_4\beta^{c_5} - c_6\right)\exp(-\frac{c_7}{\psi_k}) \qquad ....2$$

$$\frac{1}{\psi_k} = \frac{1}{\lambda+c_8\beta} - \frac{c_9}{\beta^3+1} \qquad ....3$$

$$\lambda = \frac{R_{bld}.w_{bld}}{V_w} \qquad ....4$$

where is the w_{bld} blade angular speed (rad/s), $R_{bld.}$ is the blade radius (m), λ is the tip speed ratio, β is blade pitch angle (degrees), and are c_1-c_9 the constant coefficients for power coefficient Cp.

The influence of the wind on the system is strongly influenced by the design of the blades, a good analysis of the blades should be done in the form of paper [17]. Wind turbines used in wind farms can be of a fixed or variable speed type.

These wind generators can be classified as follows-

1) Fixed speed wind turbine with induction generator
2) Variable speed wind turbine with a cage bar induction generator or synchronous generator.
3) Variable speed wind turbine with multiple pole synchronous generator or multiple pole PMSG
4) Variable speed wind turbine with DFIG

Among the four wind turbines, DFIG has gained popularity due to its many advantages, such as high efficiency, flexible control, rapid control of real and reactive power and the ability to separate active power and control of wind turbine rotor excitation current.

(b) DFIG model:

Fig. 1 shows the DFIG configuration analogous to a variable speed wind turbine with a wound rotor induction generator along with a partial-scale converter. DFIG is the most prominent type of wind turbine among the techniques used for wind power generation. DFIG has a wind turbine with a pitch angle regulator, a wound rotor induction generator and frequency converter. The stator of the DFIG is directly connected to the grid, while the generator rotor is coupled through back-to-back variable frequency converters. The power electronic converter, which is used in the heart of DFIG, plays a crucial role in controlling the rotor current to obtain maximum wind power in all circumstances. On the other hand, these electronic converters have a production of about 25-30% of the production capacity for DFIG. This concept is therefore more attractive from an economic point of view. The detailed model and parameter data for DFIG simulation in this document are included in [18].

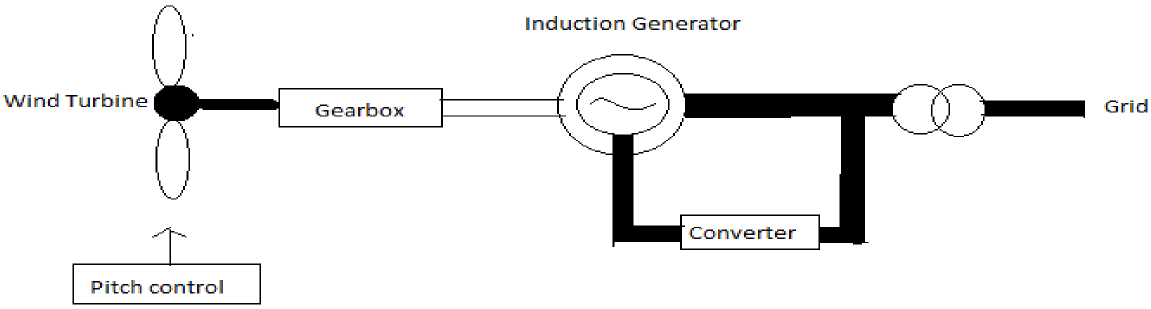


Fig.1 DFIG Model

(c) Test case power system

A system is known as a test system called the IEEE 39 bus power system. This network is known as the 10 machine New England Power System. This system consists of 39 buses, 10 generators, 19 loads, 34 transmission lines and 12 transformers. The experimental control system for bus system 39 is often used as a standard system to demonstrate the effectiveness of new control methods in a large power system over the years. The single line diagram of this system is shown in Fig. 2. The information and numerical parameters of the system used for reproduction are included in [19]. Generator 1 represents the aggregation of the significant number of generators. All the following parameters are taken from the book "Analysis of the energy function of the stability of the electrical system" [20]. She has adapted this book to T. Athay et al. The feed system with 39 buses and 10 machines consisted of three operating areas. Each region has significant generators. In zone 1, generators 1, 2 and 3; In zone 2, they are equipped with generators 8, 9 and 10; Zone 3 consists of generators 4, 5, 6 and 7. The total installed power for the three areas system is 840 MW. The phase in which this research is conducted is the IEEE 39 bus system, which generates an incredibly small model of the New England power grid. In now days 39 bus system is a standard test system for testing new techniques by various researchers.

(a) AVR (Automatic Voltage Regulator) & PSS (Power System Stabilizer)

The 39-bus power system in this study are equipped with AVR and PSS. AVRs are added to the generation units to maintain a voltage terminal at a fixed value per unit. In other words, the AVR is used to control the voltage of the generator to which it is connected. AVRs ensure stable operation of the electrical system, even in the event of severe disturbance [14]. As shown in fig. 3, this paper uses a first order static model for AVR. Previously, AVR synchronous generators were used only in power systems. When frequency and voltage fluctuations occur, the generators are equipped with a PSS as another control unit to improve the small signal stability. The PSS control function is to generate the appropriate torque in the rotor of the generator to compensate for the phase lag between the exciter inputs and the machine's electric revolution [21]. Fig. 4 shows a conventional pattern with two lead-lag transfer functions for the PSS modelling used in this paper. AVR and PSS both have capability to support the power system network is in stable mode. These controllers provide the appropriate action to the interconnected system with power grid that means any changes occur in the electrical system that have also change in the interconnected system.

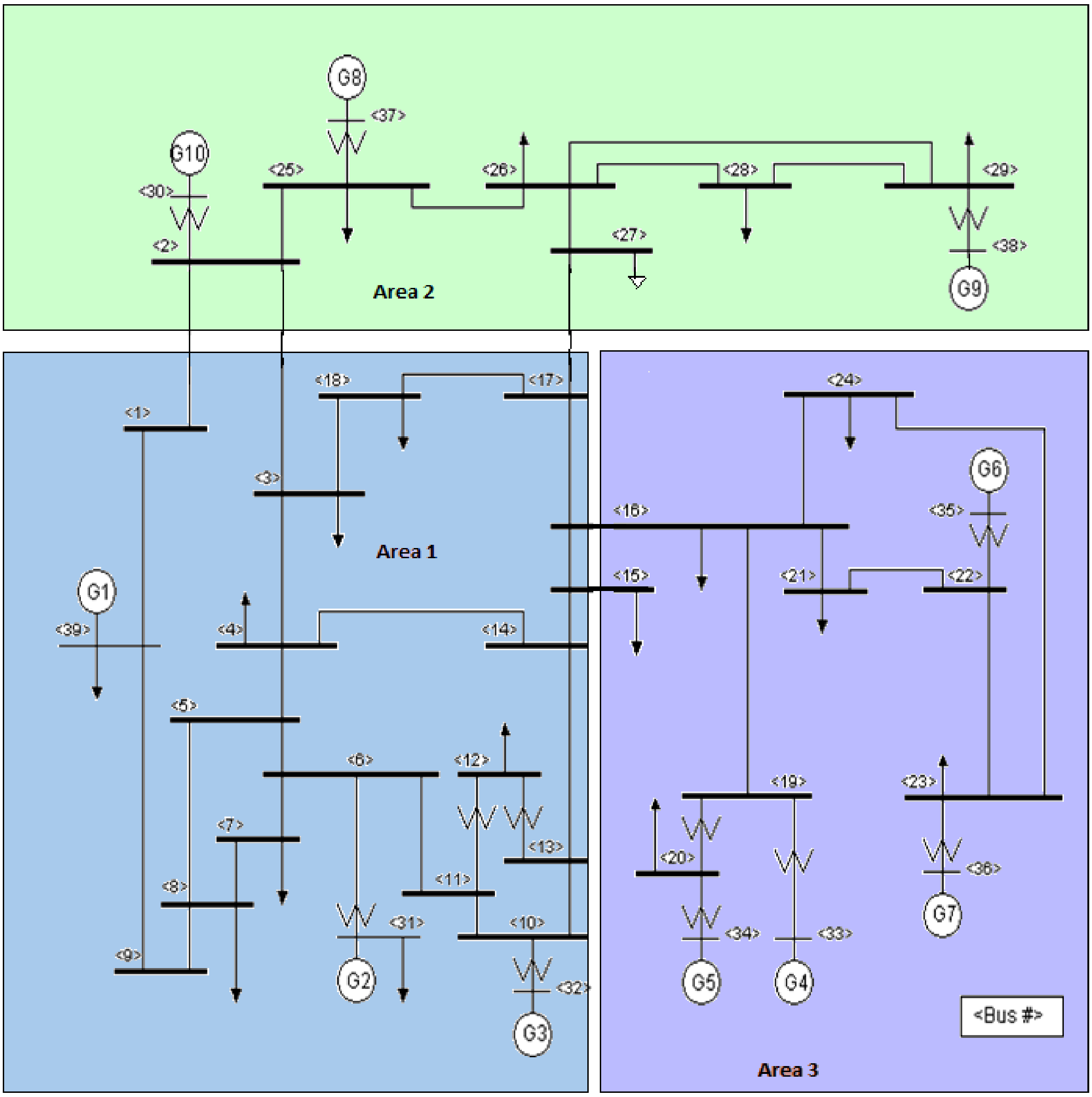


fig. 2 IEEE 39-Bus New England Power System

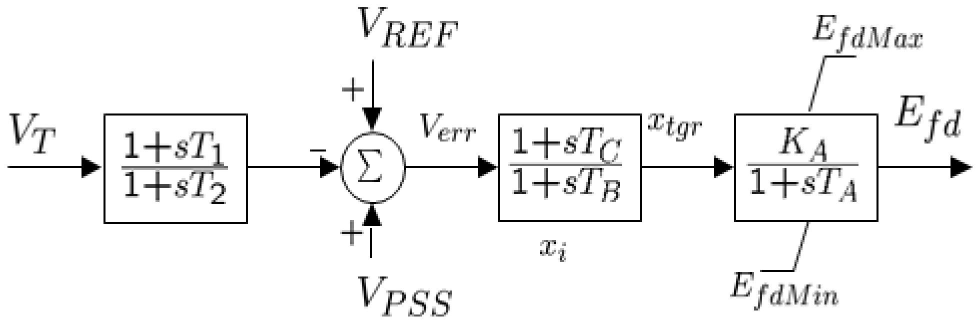


fig.3. Automatic Voltage Regulator (AVR) Structure

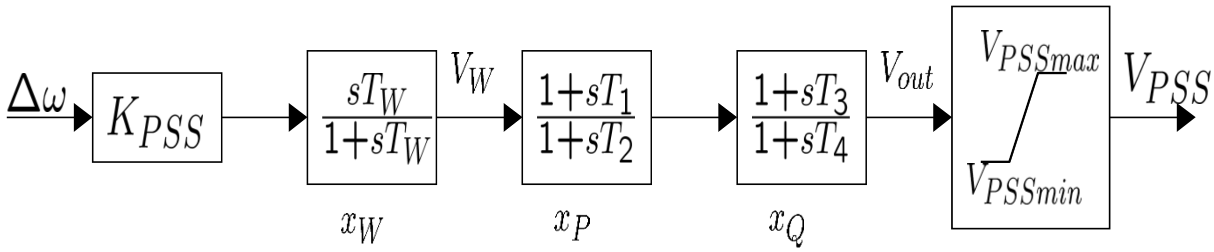


fig.4. Power System Stabilizer (PSS) Structure

III. Proposed Fuzzy Coordinator

(a) Need for coordination

Lack of synchronization / damping torque or both leads to system instability. Before AVRs were widely used in the power system, instability was mainly due to a lack of synchronization moments. This type of instability is manifested in an aperiodic operation of the synchronous machine's rotor angle. The AVRs installed in the generating units compensate for the missing synchronization moment in the power supply. Other types of instability have meant that there is no damping moment in the form of retained or increased vibrations of rotor angles [22]. About these conditions, AVRs affect the performance of the energy system by improving transient stability. In addition, as indicated in [23], the transient stability for fast response and AVR with high gain also adversely affects the stability of the small signal. Further control is PSS. It is used to generate additional damping torque to eliminate low frequency vibrations. Properly adjusted PSS can affect the operation of the AVR [23].

AVR and PSS produce torques with rotor angle variations or speed deviations. But both AVR and PSS use the field voltage to create foci that are not in phase. In other words, a control signal is applied to the generator to satisfy two conflict control measures. As shown in fig.5, the AVR and PSS controls simultaneously improve vibration damping and voltage stability in one direction. However, one-way improvement can cause deterioration in the other direction. For this reason, a compromise between AVR and PSS control measures seems necessary.

The problem of coordination is investigated in the literature. To achieve this goal [24], the AVR-PSS system can be protected from fatal faults through a robust transformation of the control method. In [25], the structure of the conventional system has been modified to coordinate the operating system. The bode frequency response with a step algorithm is discussed in [26] to compensate for AVR and PSS. The control strategy proposed in the ongoing work on the coordination of AVR and PSS is based on the ideas described in [27, 28]. Both controllers have provided the support to whole grid that can be system in stability. It is essential to change in generator unit section that also change in the whole interconnected system. Faults are affected to each area of the system. AVR & PSS can exhibit their property at time of activation in the grid.

(b) Fuzzy Coordinator

A fuzzy logical approach is an artificial method of decision-making that can compensate for the inability of classical management theory to capture the complexity and non-linearity of physical systems with their uncertainties and inaccuracies. Therefore, this unclear logic can be considered as a powerful tool for solving the system stability problems [29]. To design a controller based on a fuzzy approach to dynamic systems, the following steps should generally be considered [30]:

Step (1) Information on the characteristics of the dynamic behavior of the system. Define state and I / O control variables and their variations.
Step (2) Identify the fuzzy sets and functions for fuzzy membership. Create a degree of fuzzy membership function for each input / output variable and fulfill the indefinite fuzzification.
Step (3) Determine the appropriate inference engine. Build a rule base using the rules the system runs on. Determine how the action is performed by adding force to the rules.
Step (4) Determine the defuzzification method. Incorporate the rules and defuzzify the outcome.

The AVR and PSS controllers are basically designed for the system's rated operating point and must switch between these controls due to faults. In this study, the diffuse unit acts as a coordinator between the AVR and PSS controllers. The fuzzy system has four main parts: fuzzification, the fuzzy rules, the inference system and the defuzzification. The fuzzy controller system proposed in this paper has two inputs and two outputs. Main interest lies in the input signals from the fuzzy unit. The voltage terminal deviation and the rotor phase difference can be selected as input signals. However, it should be remembered that after severe interference, the terminal voltage and generator rotor phase can vary considerably. The normalization method is used to limit these deviations. A normalization technique is connected to restrain these deviations. $\Delta\delta_i'$ and $\Delta V_i'$ are the normalization rotor phase deviations and terminal voltage deviations. Normalization process present in the fig. 6. The $\Delta\delta_i'$ and $\Delta V_i'$ can change in range of [-1, 1] for all generators. Fig. 7 shows a fuzzy logic system that is broadly utilized in fuzzy logic controllers and signal handling applications. A fuzzy logic systems represents crisp input to crisp outputs. It contains four noteworthy parts; fuzzifier, fuzzy rules, inference engine and defuzzifier.

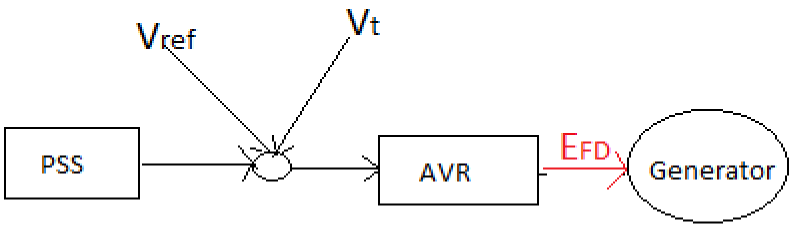


Fig.5 Mode of operation

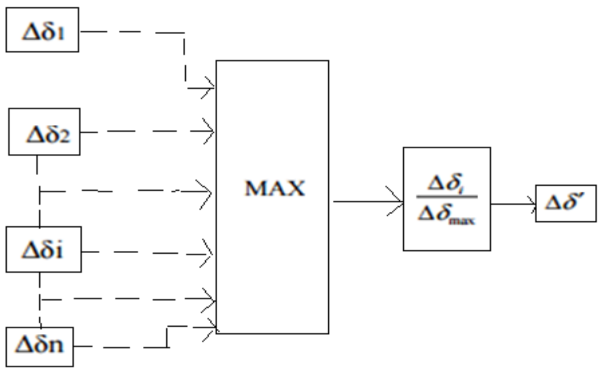


Fig.6. Normalization method

The elementary functions of the input and output signals are arranged according to the trapezoidal method. In this paper, membership functions corresponding to the input and output variables are distributed as big negative (NL), small negative (NS), zero (ZR), small positive (PS) and big positive (PL). The current study defined five membership functions for the input and output signals. The membership functions for the input and output variables are identical and are shown in fig. 8. The Mamdani inference system is also used for the proposed fuzzy. In this research the output of the fuzzy coordinator is generate the gains K_P & K_A for the controllers AVR & PSS respectively. The fuzzy rules implemented are listed in Table I. An outstanding feature of this fuzzy coordinator is its simplicity. Ref. [31] used a fuzzy coordinator to establish coordination between AVR and PSS to improve the stability of a multi-machine power system. In this paper, the condition of coordination of the fuzzy coordinator is designed to reduce the voltage at the terminal to DFIG-based wind turbines in a large power system.

Surface view of rules for K_p & K_a shown below in fig. 9 (a) & (b) respectively.

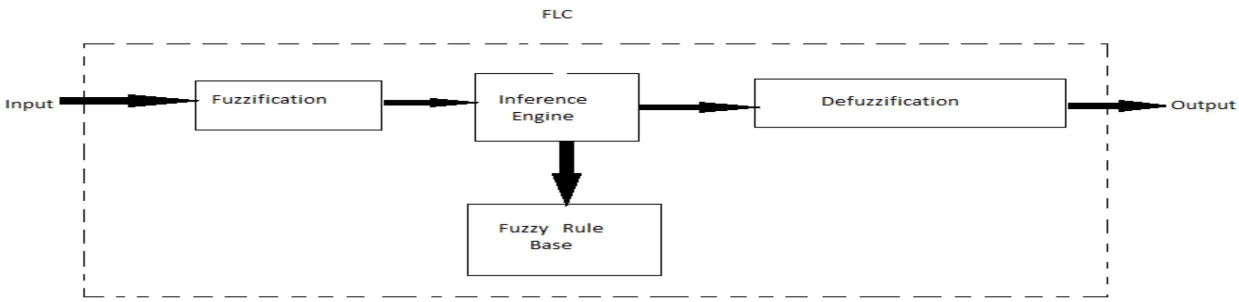


Fig. 7 Schematic of fuzzy logic system

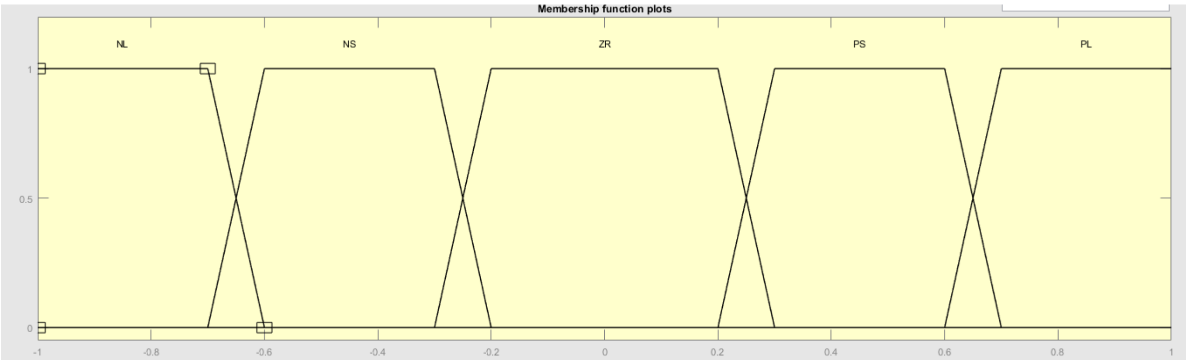


Fig . 8 Membership function for input and output variables

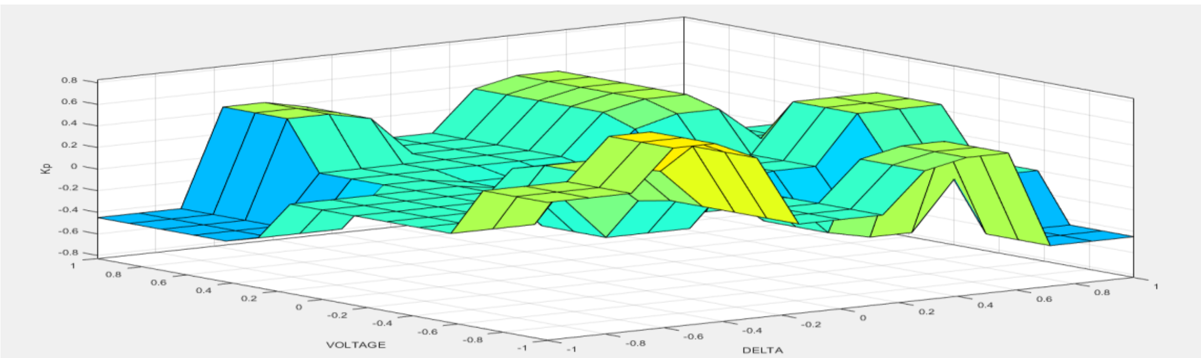


fig. 9 (a) Surface view of rule base for K_P

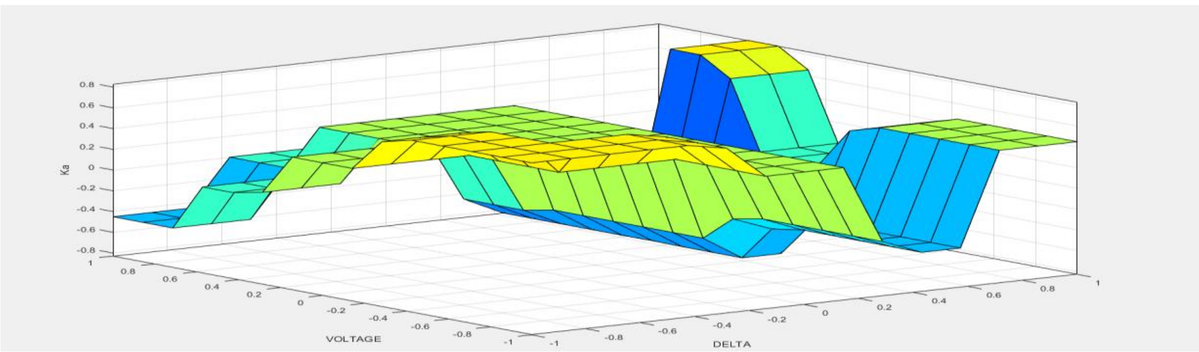


Fig. 9 (b) Surface view of rule base for K_A

Table 1: Fuzzy Rule for (a) PSS gain (b) AVR gain

K_P		ΔV′				
		NL	NS	ZR	PS	PL
(a)						
Δδ′	NL	PS	ZR	ZR	NS	NS
	NS	PL	PS	ZR	ZR	PS
	ZR	ZR	ZR	NS	ZR	ZR
	PS	PS	NS	ZR	PS	PS
	PL	NS	ZR	PS	ZR	NL

K_A		ΔV′				
		NL	NS	ZR	PS	PL
(b)						
Δδ′	NL	PL	PL	PS	ZR	NS
	NS	PL	PS	PS	PS	ZR
	ZR	PS	PS	PS	PS	ZR
	PS	NS	NS	NL	NL	NL
	PL	PS	PS	ZR	PL	NL

IV. Simulation Results

Simulink model of this bus system with wind farm shown in fig.10.

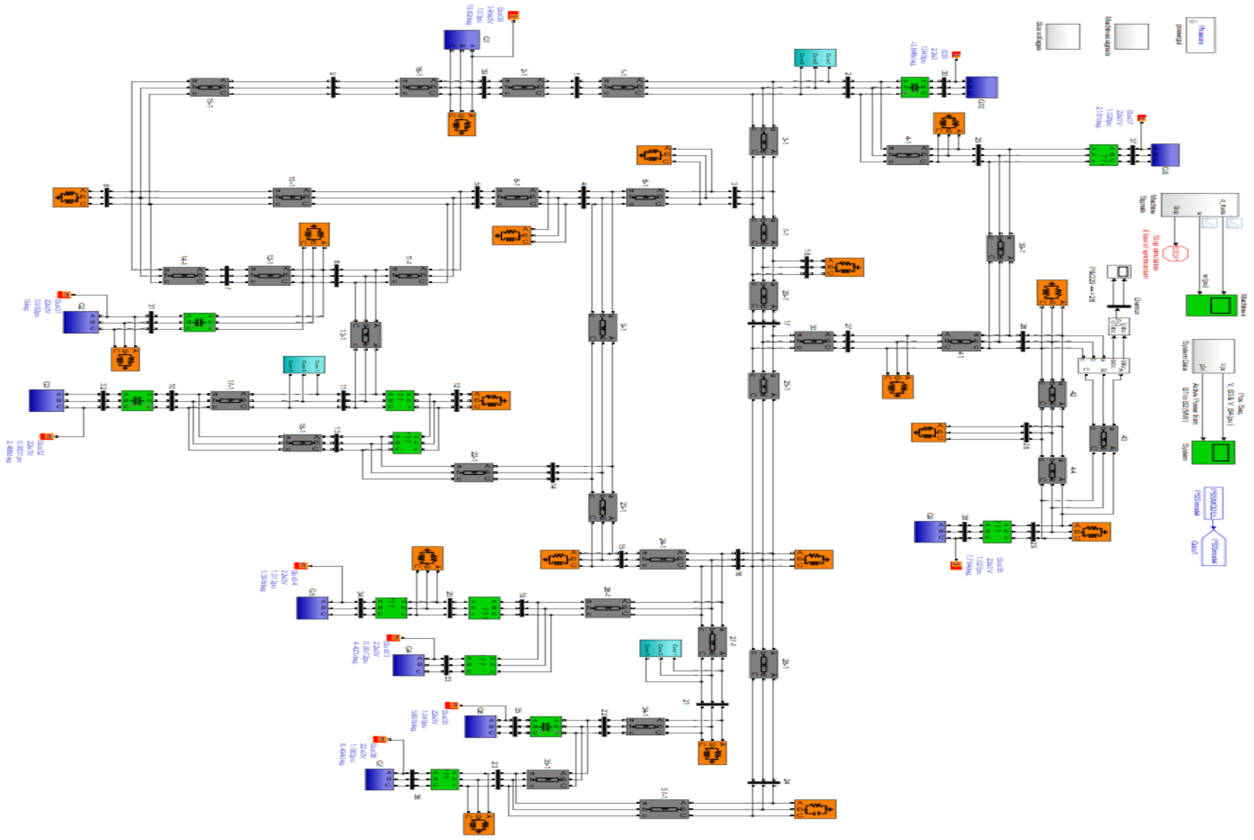


Fig.10 Simulink model of IEEE 39 bus power system with wind farms.

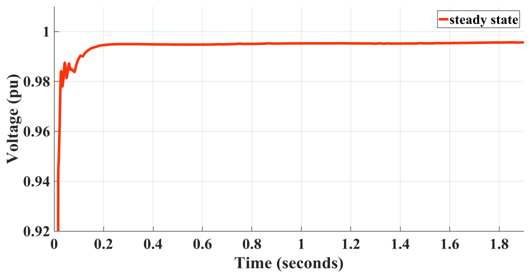
Test system includes 39 buses, 10 generators, 19 loads, 34 transmission lines and 12 transformers. Total generation includes 840 MW of conventional power. This power system organized in three areas, that have consisting a DFIG based wind farm of 60 MW in each area of the system. The test system is available in MATLAB/Simulink library and is widely used for grid connected application because it strikes a balance between detail and simplicity. The test system shown below consists of a DFIG connected to the grid. 19 constant load having total capacity of 6097.1 -MW and 1408.9 MVAR. In this case we represent the normal operating conditions of the three wind farms and their PCC voltages. This system operating on the base of 100 MVA and 60 Hz. For making the 60 MW find farm we use 40 wind turbines of 1.5 MW rating. Wind farms are integrated in the grid by transmission line and the transformer. All the waveforms presented in this paper for every parameter with respect to time. DFIG is consisting the partial scale converter and which is corresponds with the wound rotor induction generator. For simulating work of this dissertation, we are using the phasor simulation method. Reason behind the phasor simulation method is the generally used for the electromechanical oscillation of power framework consisting of large generators. For this purpose, the DFIG based wind farms are also operate in the phasor type DFIG. Phasor simulation method is much faster to execute. Three areas of the system have consisting different -2 generators like as G1, G2 and G3 in area one, G8, G9 & G10 in area two and G4, G5, G6 & G7 in area three presents in the below figure. Wind farms integrated in this large-scale power system in each area like as wind farm 1 integrated at the bus no. 11 in area one of the system, wind farm 2 connected at bus no. 2 in area two of the system and wind farm 3 is connected at the bus no. 21 in area three.

In this paper we discussed simulation results in two cases one is describe for the normal operating condition when the wind farm integrated in the power system and second case is the description of the comparatively waveform of wind farms with and without fuzzy coordinator. Without fuzzy coordinator is also equivalent to system with subjected to fault. Fault details are described in the case 2. Conventional AVR & PSS are active in the case 1 and for without fuzzy coordinators waveforms. Coordinated AVR & PSS described in case 2 for waveform of wind farms with fuzzy coordinator. For each operation are gives affection to system with area wise.

(a) Case 1: DFIG based wind farms integrated in 39 bus power system results at normal operating conditions

(i) Wind Farm 1:

DFIG terminal voltage in p.u. [fig.11(a)], current through DFIG terminals in p.u.[fig.11(b)], Active power of WF in MW [fig.11(c)], reactive power of WF in MVAr [fig.11(d)], Voltage across dc link capacitor of DFIG in Volt [fig.11(e)], wind turbine speed in p.u [fig.11(f)] . and pitch angle in degree [fig.11(g)] waveforms are shown in Fig.11 under the normal conditions. This wind farm integrated into the system at bus no.11 in area 1 voltage across the bus no.11 or point of common coupling voltage wave form shown. in the fig.11(h). Wind speed is constant all the time that is 14 m/s.



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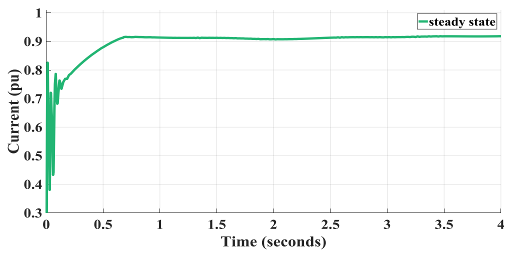

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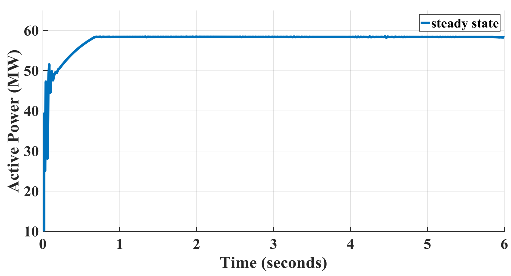

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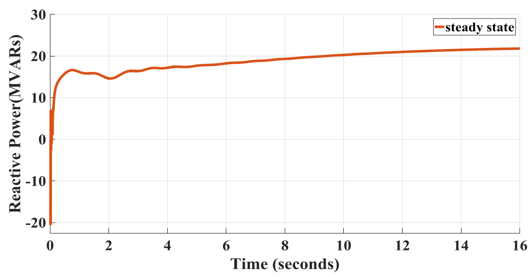

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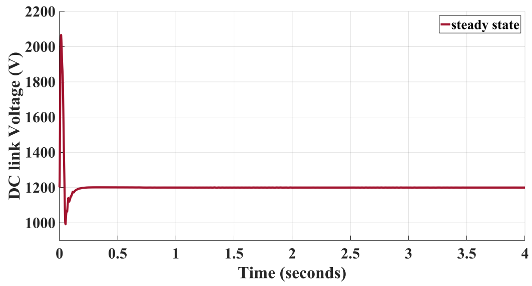

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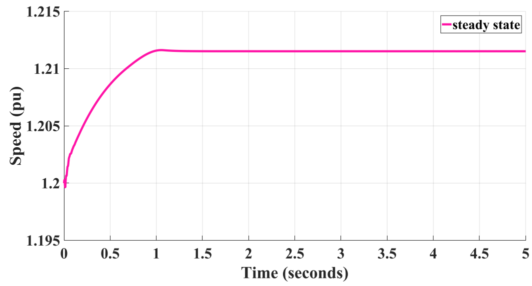

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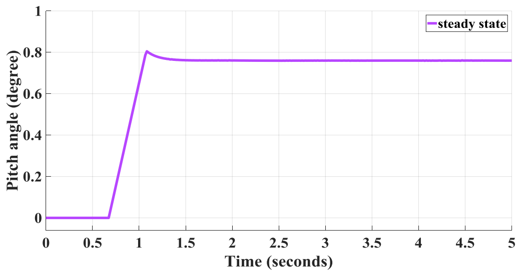

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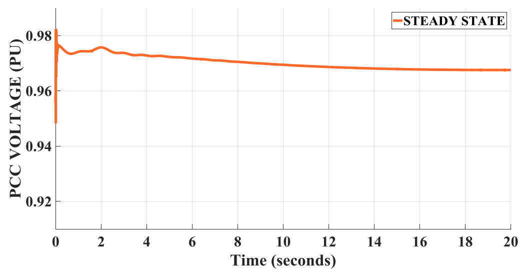


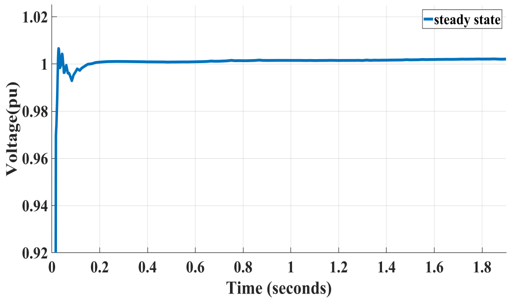
(h)

Fig. 11 Wind Farm1 waveforms under normal conditions

- From the above wave form, it is obtained that the generated power is not exactly equal to 60 MW, for which it is designed. The generated active power is equal to 58.4 MW; the rest of the active power is dissipated into losses of the DFIG.
- Reactive power of wind farm 1 is 21.6 MVARs at steady state or normal conditions.
- Voltage across the terminals of DFIG is 0.995pu. Current through the terminal of DFIG at steady state is 0.918 pu. Pitch angle is 0.76 degree and wind turbine speed are 1.2115 pu at normal conditions. The grid side converter of DFIG maintain the DC link voltage to almost constant i.e. 1200V under normal operating condition.
- Point of common coupling voltage of wind farm 1 is 0.968pu.

(ii) Wind Farm 2

DFIG terminal voltage in p.u. [fig.12(a)], current through DFIG terminals in p.u.[fig.12(b)], Active power of WF in MW [fig.12(c)], reactive power of WF in MVAr [fig.12(d)], Voltage across dc link capacitor of DFIG in Volt [fig.12(e)], wind turbine speed in p.u [fig.12(f)] . and pitch angle in degree [fig.12(g)] waveforms are shown in Fig.12 under the normal conditions. This wind farm integrated into the system at bus no.2 in area 2 voltage across the bus no.2 or point of common coupling voltage wave form shown. in the fig.12(h).



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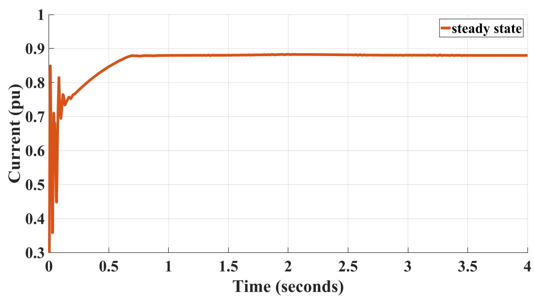

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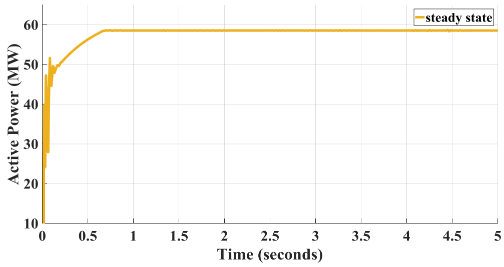
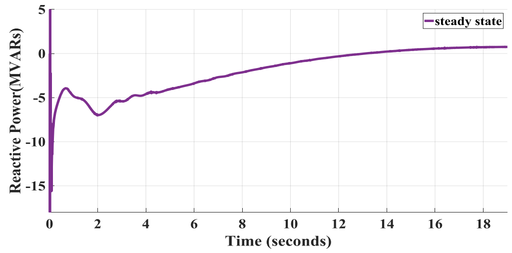
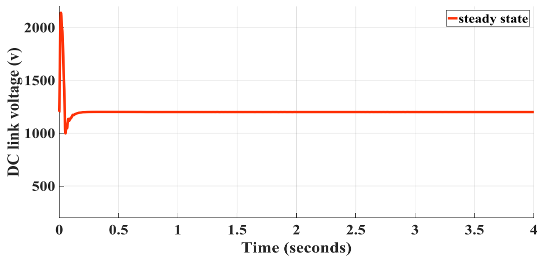


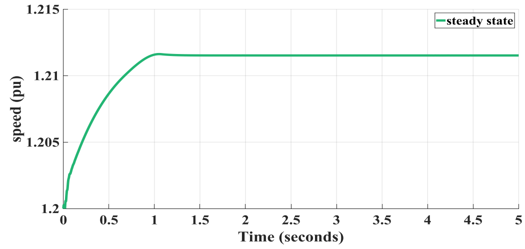
(c)



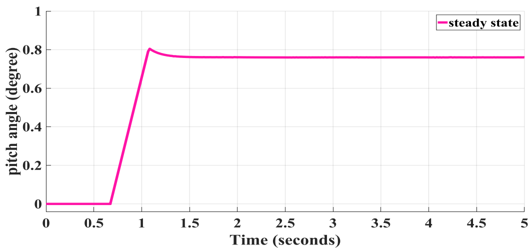
(d)



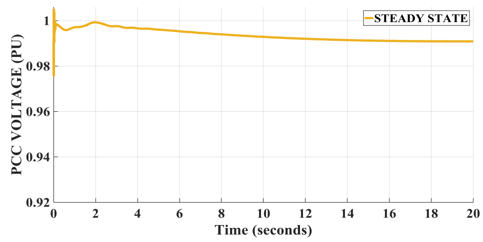
(e)



(f)



(g)



(h)

Fig. 12 Wind farm 2 under normal conditions

- We obtained from the above waveforms that the generated power is not exactly equal to 60 MW, for which it is designed. The generated active power is equal to 58.5 MW; the rest of the active power is dissipated into losses of the DFIG.
- The grid side converter of DFIG maintain the DC link voltage to almost constant i.e. 1200V under normal operating condition.
- Reactive power of wind farm 2 is 0.6 MVARs at steady state or normal conditions.
- Point of common coupling voltage of wind farm 2 is 0.991pu.
- Voltage across the terminals of DFIG is 0.995pu. Current through the DFIG is 0.884 pu.
- Pitch angle of the DFIG is also be normal in steady state that is 0.76 degree. Wind turbine speed is 1.211 pu.

(iii) Wind Farm 3

DFIG terminal voltage in p.u. [fig.13(a)], current through DFIG terminals in p.u.[fig.13(b)], Active power of WF in MW [fig.13(c)], reactive power of WF in MVAr [fig.13(d)], Voltage across dc link capacitor of DFIG in Volt [fig.13(e)], wind turbine speed in p.u [fig.13(f)] . and pitch angle in degree [fig.13(g)] waveforms are shown in Fig.13 under the normal conditions. This wind farm integrated into the system at bus no.21 in area 3 voltage across the bus no.21 or point of common coupling voltage wave form shown. in the fig.13(h).

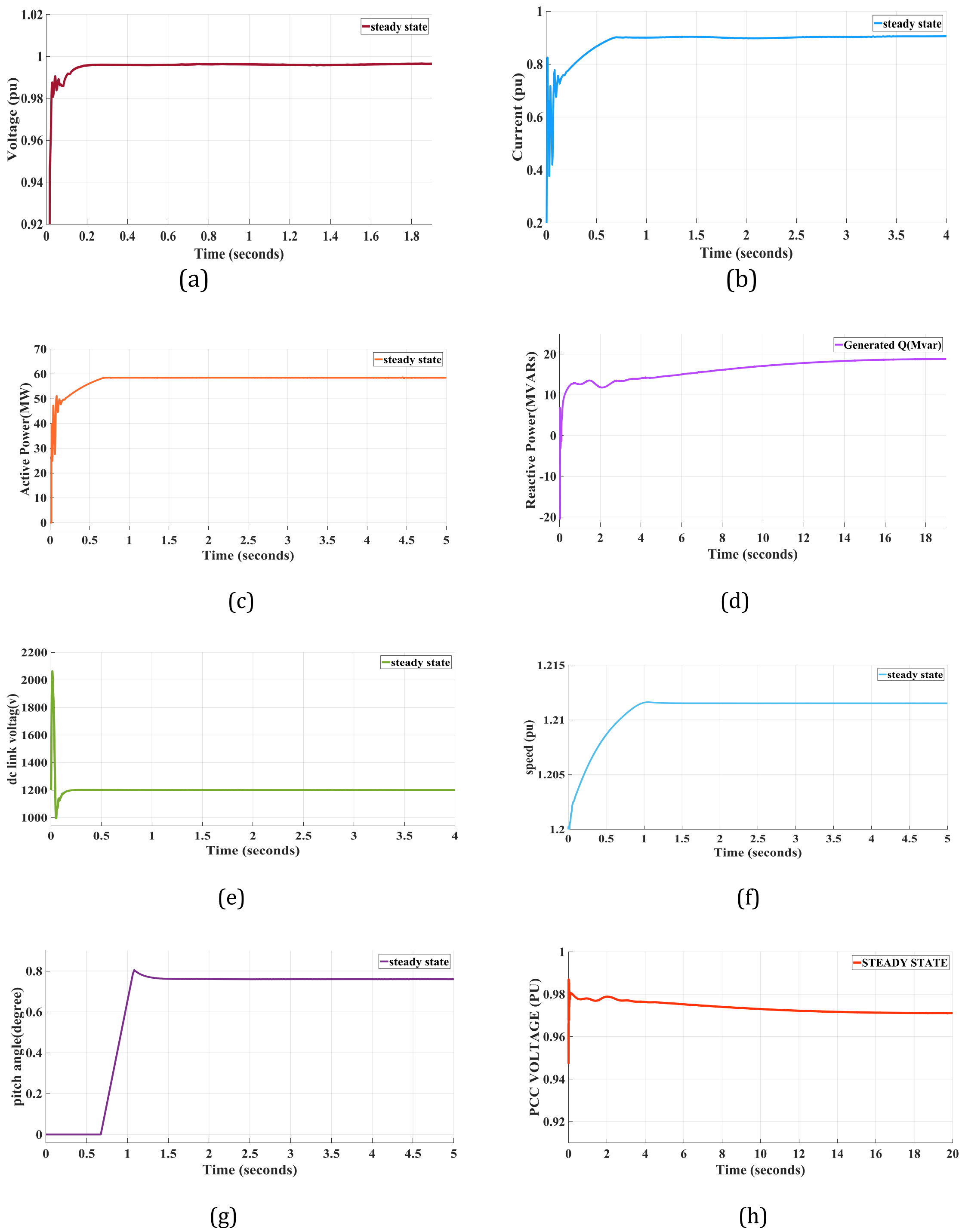


Fig. 13 Wind farm 3 under normal conditions

- From the above waveforms we get that the generated power is not exactly equal to 60 MW, for which it is designed. The generated active power is equal to 58.5 MW; the rest of the active power is dissipated into losses of the DFIG.
- The grid side converter of DFIG maintain the DC link voltage to almost constant i.e. 1200V under normal operating condition. Speed of wind turbine is 1.211 pu at steady state.
- Reactive power of wind farm 3 is 18.7 MVARs at steady state or normal conditions.

- Point of common coupling voltage of wind farm 3 is 0.97.
- Voltage across the terminals of DFIG is 0.995. Current through the DFIG is 0.91 pu.
- Pitch angle of the DFIG is also be normal in steady state that is 0.76 degree.
- Voltage across the DFIG terminals in steady state is 1pu.

(b) Case 2: DFIG based wind farms integrated in 39 bus power system results with and without fuzzy coordinator

The system is subjected to single phase to ground fault at (t = 5 sec) with fault impedance (Z_f = 0.001Ω) and ground impedance (Z_g = 0.01Ω). The L-G fault is given at the bus no.17 because of it is in the middle of whole system. Line to ground fault is the most severe fault in the power system that occurs in the transmission line of the system. The fault is cleared in 0.2 sec. Now we obtain the waveforms of the DFIG based wind farm and PCC voltages, that is presented below. These results are based on the conventional AVR & PSS with fault conditions. The fault time between 5 to 5.2 sec, the waveforms of parameters of DFIG and PCC voltage of DFIG are mainly dominating in this case. Waveforms for system subjected to fault is known as the waveforms without fuzzy coordinator.

As discussed above, fuzzy logic control performs the coordinator function of AVR and PSS to compensate for these two conventional controls. The main purpose of this coordination is to reduce the voltage at a wind turbine terminal built by DFIG in the event of faults and improve the performance of DFIG-based wind farms. According to the normalization procedure for the terminal voltage and angular deviations of the generator rotor, performed by the normalization method described above. The IEEE 39-Bus power system has been selected in this study as a large-scale power supply frame with 10 generators. Given the optimal need, the creation of an fuzzy coordinator for all synchronous generators in a multi-machine feed structure seems unreasonable. In this way, the fuzzy coordinator is installed to be introduced into the system's influential generators. Generators with the greatest generational limit can be considered the right alternative to providing a fuzzy coordinator. The control frame with 39 buses has three control areas; A large generator must be selected at each area installation. Generator number 1 in area 1, generator number 9 in area 2 and generator number 6 in area 3 have the highest production limit in each zone. In this way, the diffuse coordinator is introduced into these three synchronous generators. The results of the reconstruction show that the power of the panel voltage and the DFIG parameters has been improved due to the introduction of the fuzzy Coordinator in generators n. 1, 6 and 9. In these generators, the fuzzy coordinator rationalizes the amplification of AVR and PSS in fault situations by accepting the standard deviations of the terminal voltage and the rotor angle of the synchronous generator.

DFIG-based wind farms are equally divided into all aspects of the 39-bus power system. It is believed that only a few DFIGs are combined to buy each wind farm in the system. These wind farms are connected to the system via transformers and transmission lines. In the event of a fault, voltage drops are shown in the wind farms' PCC. These voltage drops or drops in DFIG wind farms can disconnect them from the system or destroy their power converters. As a result, the voltage drop after an event must be reduced by additional controls to ensure the wind farms and the grid safely. Fuzzy rules or rules are balanced so that the coordinator generates the increased gains for AVR and PSS to reduce the voltage effect in the PCC for DFIG-based wind farms and their parameters. Fuzzy rules and membership function are discussed earlier of Fuzzy Coordinator. After installing the fuzzy coordinator in the generator section, we achieve better results compared to failure situations.

There is waveform of wind farms without fuzzy coordinator associated with the conventional AVR and PSS (in the event of a fault) and with the fuzzy coordinator associated with AVR and PSS are shown below.

(a) Wind Farm 1

DFIG terminal voltage in p.u. [fig.14(a)], current through DFIG terminals in p.u.[fig.14(b)], Active power of WF in MW [fig.14(c)], reactive power of WF in MVAr [fig.14(d)], Voltage across dc link capacitor of DFIG in Volt [fig.14(e)], wind turbine speed in p.u [fig.14(f). and pitch angle in degree [fig.14(g)] waveforms are shown in Fig.14 with and without fuzzy coordinator. This wind farm integrated into the system at bus no.11 in area 1 voltage across the bus no.11 or point of common coupling voltage wave form shown. in the fig.14(h).

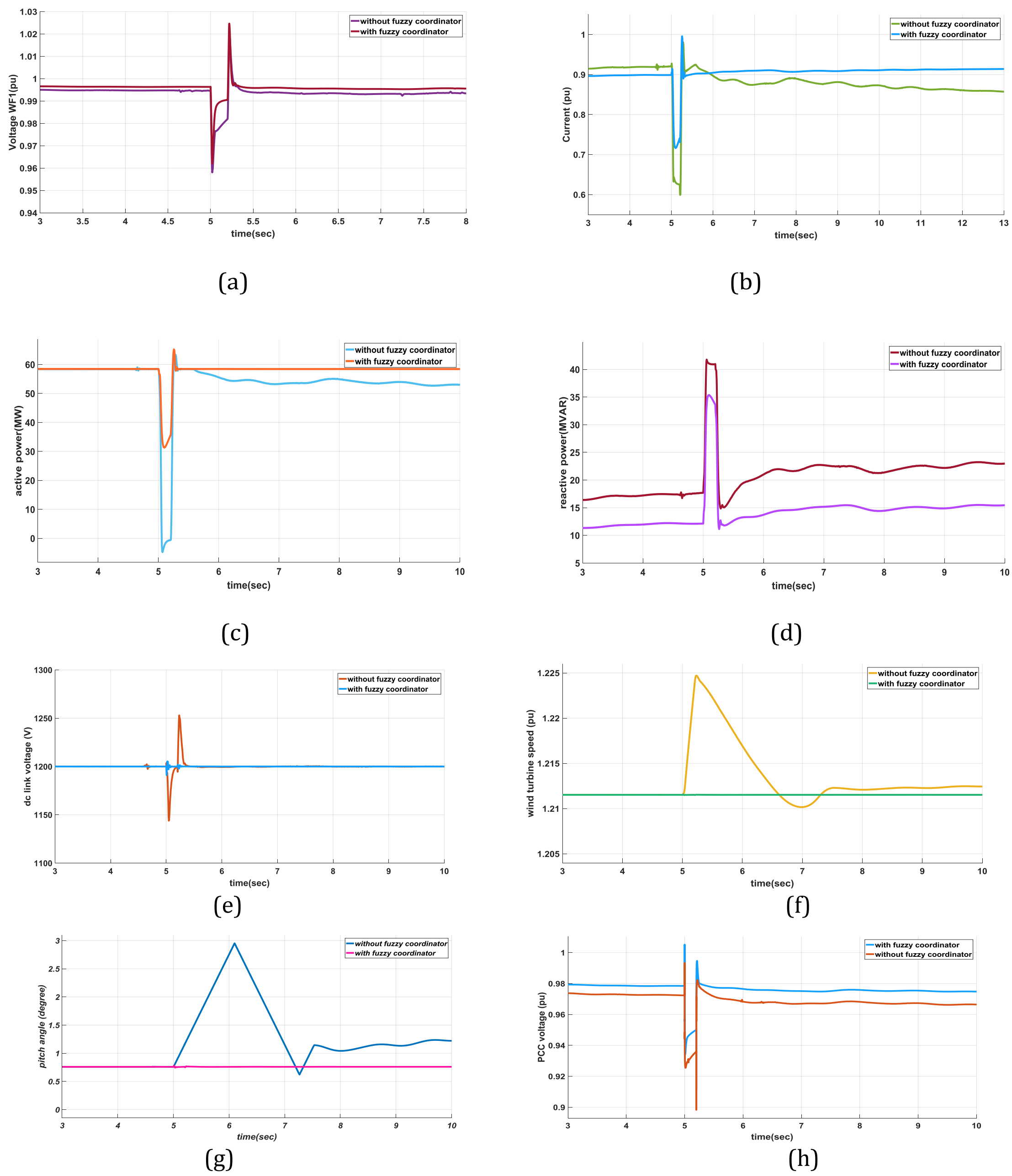


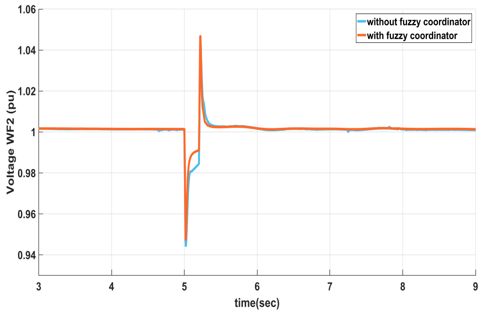
Fig. 14 Waveforms of wind farm 1 with and without fuzzy coordinator

- From the above waveforms of the wind farm 1 under fault conditions or without fuzzy coordinator we get the dips in the voltage at the PCC and DFIG terminals at fault between 5 to 5.2 sec. Voltage at bus 11 or PCC voltage is the reduce at time of fault that is 0.929 pu. When system is subjected with fuzzy coordinator the PCC voltage at fault is raise to 0.945 pu and dip can be mitigated that can be enhanced the voltage when subject to fault.
- Voltage at DFIG terminals is also be reduced at time of fault that is 0.96 pu. Both voltages are the interrupted the system at time of fault. When system subjected with fuzzy coordinator the voltage is 0.966 pu at time of fault.
- Active power of the wind farm 1 under fault condition is dipped and reach to14.1 MW (at 5 sec.) and during fault interval it is reach to zero and no real power in DFIG at fault time and after fault it regain the active power but reduced from steady state value and reach to 50.4 MW. But the system with the fuzzy coordinator the real power is enhanced and reach to 42.3 MW.
- Reactive power of the wind farm is increased by huge amount at time of fault 39 MVAR. This type of reactive power effect to reduce the system efficiency. But the system with the fuzzy coordinator the reactive power is reduced and reach to 30.4 MVAr.

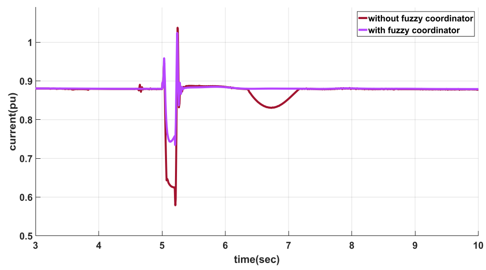
- Pitch angle be more than the normal conditions at time of fault that is 0.8 degree and its high at instant of fault and reach to almost 3 degree this gives the less effective control to pitch. Peak of the pitch angle is high in fault as compare to normal condition. By the using fuzzy coordinator the pitch angle be almost normal at time of fault that is 0.78 degree.
- Current through the DFIG and dc link voltage be also dipped and reduced at fault to 0.8 pu, 1143.9 volt. Whenever using the fuzzy coordinator current through DFIG is enhanced to 0.88pu an dc link voltage is reach to 1180.3 volt. Wind turbine speed of wind farm is also improved by using fuzzy coordinator.

(b) Wind Farm 2

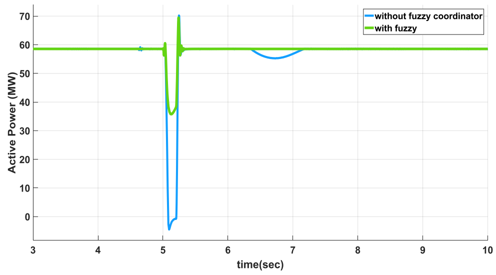
DFIG terminal voltage in p.u. [fig.15(a)], current through DFIG terminals in p.u.[fig.15(b)], Active power of WF in MW [fig.15(c)], reactive power of WF in MVAr [fig.15(d)], Voltage across dc link capacitor of DFIG in Volt [fig.15(e)], wind turbine speed in p.u [fig.15(f)] . and pitch angle in degree [fig.15(g)] waveforms are shown in Fig.15 with and without fuzzy coordinator. This wind farm integrated into the system at bus no.2 in area 2 voltage across the bus no.2 or point of common coupling voltage wave form shown. in the fig.15(h).



(a)



(b)



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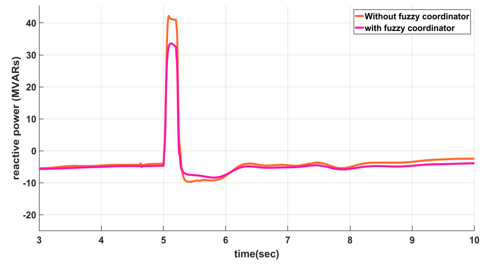

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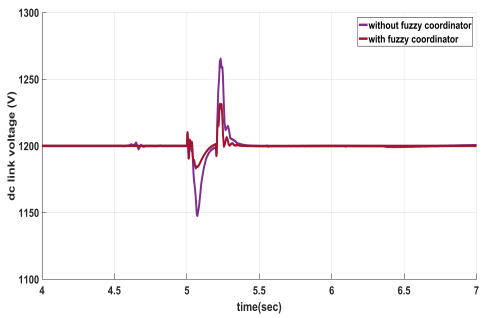

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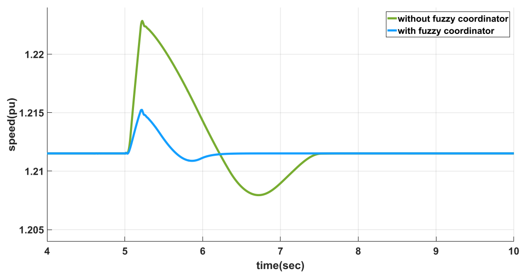
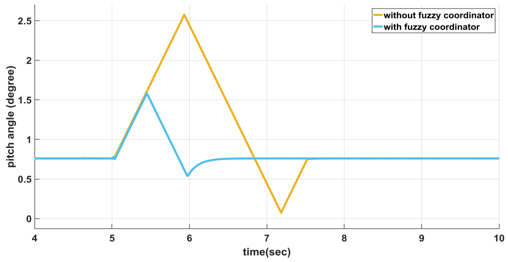
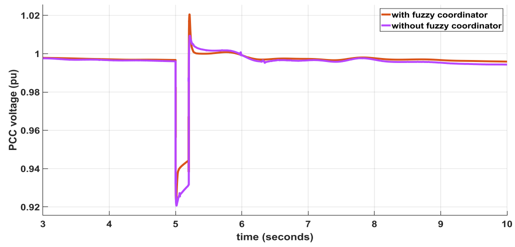


(f)



(g)



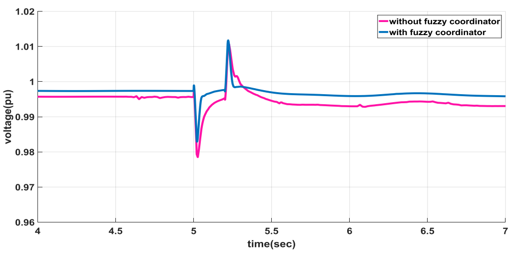
(h)

Fig. 15 Waveforms of wind farm 2 with and without fuzzy coordinator

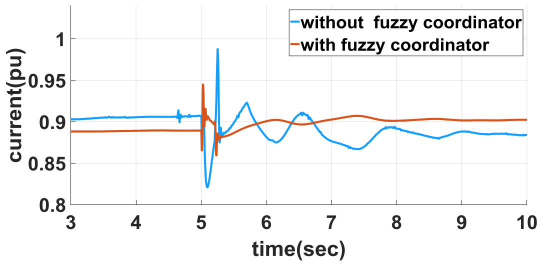
- From the above waveforms of the wind farm 2 under fault conditions or without fuzzy coordinator we get the dips in the voltage at the PCC and DFIG terminals at fault between 5 to 5.2 sec. Voltage at bus 2 or PCC voltage is the reduce at time of fault that is 0.921 pu. When system is subjected with fuzzy coordinator the PCC voltage at fault is raise to 0.939 pu and dip can be mitigated that can be enhanced the voltage when subject to fault.
- Voltage at DFIG terminals is also be reduced at time of fault that is 0.96 pu. Both voltages are the interrupted the system at time of fault. When system subjected with fuzzy coordinator the voltage is 0.98 pu at time of fault.
- Active power of the wind farm 2 under fault condition is dipped and reach to14.1 MW (at 5 sec.) and during fault interval it is reach to zero and no real power in DFIG at fault time. But the system with the fuzzy coordinator the real power is enhanced and reach to 42 MW.
- Reactive power of the wind farm is increased by amount at time of fault is 26.1 MVAR. This type of reactive power effect to reduce the system efficiency. But the system with the fuzzy coordinator the reactive power is reduced and reach to 22.2 MVAr.
- Pitch angle be more than the normal conditions at time of fault that is 1.34 degree. Peak of the pitch angle is high in fault as compare to normal condition. By the using fuzzy coordinator the pitch angle be almost normal at time of fault that is 0.92 degree.
- Current through the DFIG and dc link voltage be also dipped and reduced at fault to 0.94 pu, 1173.4 volt. Whenever using the fuzzy coordinator current through DFIG is enhanced to 0.96pu an dc link voltage is reach to 1189.6 volt. Wind turbine speed of wind farm is also improved by using fuzzy coordinator.

(iii) Wind Farm 3

DFIG terminal voltage in p.u. [fig.16(a)], current through DFIG terminals in p.u.[fig.16(b)], Active power of WF in MW [fig.16(c)], reactive power of WF in MVAr [fig.16(d)], Voltage across dc link capacitor of DFIG in Volt [fig.16(e)], wind turbine speed in p.u [fig.16(f)] . and pitch angle in degree [fig.16(g)] waveforms are shown in Fig.16 with and without fuzzy coordinator. This wind farm integrated into the system at bus no.21 in area 3 voltage across the bus no.21 or point of common coupling voltage wave form shown. in the fig.16(h).



(a)



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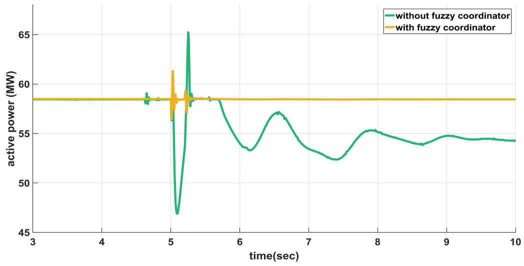

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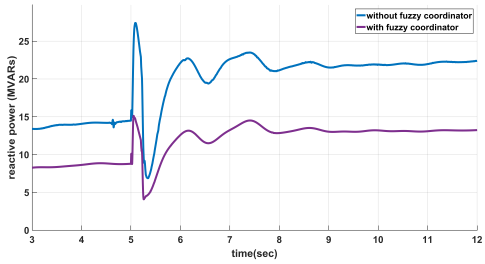

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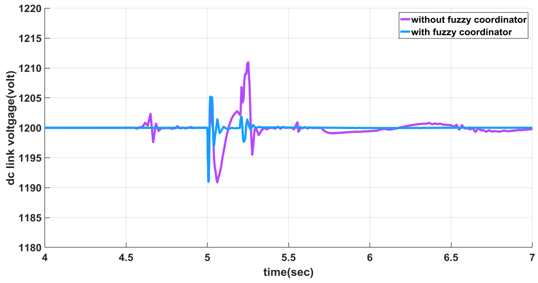

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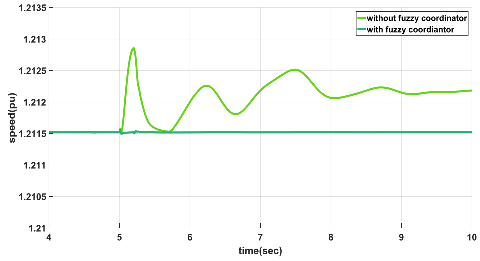

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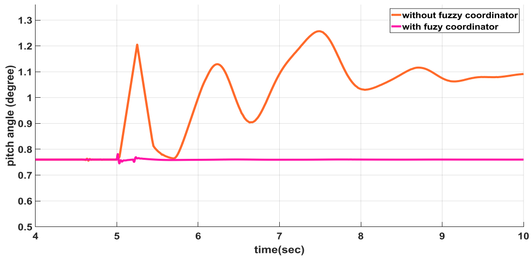

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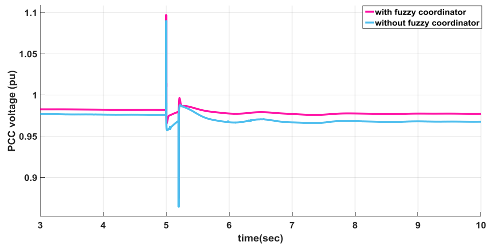

(h)

Fig. 16 Waveforms of wind farm 3 with and without fuzzy coordinator

- From the above waveforms of the wind farm 3 under fault conditions or without fuzzy coordinator we get the dips in the voltage at the PCC and DFIG terminals at fault between 5 to 5.2 sec. Voltage at bus 21 or PCC voltage is the reduce at time of fault that is 0.958 pu. When system is subjected with fuzzy coordinator the PCC voltage at fault is raise to 0.975 pu and dip can be mitigated that can be enhanced the voltage when subject to fault.
- Voltage at DFIG terminals is also be reduced at time of fault that is 0.984 pu. Both voltages are the interrupted the system at time of fault. When system subjected with fuzzy coordinator the voltage is 0.996 pu at time of fault.
- Active power of the wind farm 3 under fault condition is dipped and reach to14.9 MW (at 5 sec.) and during fault interval it is reach to zero and no real power in DFIG at fault time. But the system with the fuzzy coordinator the real power is enhanced and reach to 58.5 MW.
- Reactive power of the wind farm is increased by amount at time of fault is 25.3 MVAR. This type of reactive power effect to reduce the system efficiency. But the system with the fuzzy coordinator the reactive power is reduced and reach to 15.1 MVAr.
- Pitch angle be more than the normal conditions at time of fault that is 0.77 degree. Peak of the pitch angle is high in fault as compare to normal condition. By the using fuzzy coordinator the pitch angle be almost normal at time of fault that is 0.75 degree.
- Current through the DFIG and dc link voltage be also dipped and reduced at fault to 0.84 pu, 1195.2 volt. Whenever using the fuzzy coordinator current through DFIG is enhanced to 0.92pu an dc link voltage is reach to 1199.9 volt. Wind turbine speed of wind farm is also improved by using fuzzy coordinator.

(c) Comparison Table

In this section the comparison tables of wind farms are presented. Each table have presents the complete analysis of each cases. Table.2 is represents the all parameters associated with wind farm 1, Table.3 is represents the all parameters associated with wind farm 2 and Table.4 is represents the all parameters associated with wind farm 3. Comparison table is based on total performance analysis of the DFIG based wind farms at every instant of the time. This can be elaborate the different-different studies when wind farms active with normal integrated, with fault situation and with the fuzzy coordinator. In this research the main focus on the enhancement of the performance parameter of DFIG based wind farm, this can be achieved by the using the fuzzy coordinator. Coordinator supports to the power system that can be improve the performance of the DFIG based wind farms. Point of common coupling voltages of each wind farms are enhanced that can be represents in table. By improvement the PCC voltage and the power requirement of DFIG the system efficiency be also improved. Transient stability and the small signal stability be also improved because of the coordination of the AVR & PSS it adjusts their gains by fuzzy logic. Table associated with the wind farms including parameter like as voltage across the DFIG (pu), current through the DFIG (pu), active power (MW), reactive power (MVAr), dc link voltage (V), wind turbine speed (pu), pitch angle (degree) and the PCC voltage (pu).

Table .2 comparison table of wind farm 1

Wind Farm 1		L-G Fault					
Parameters	Steady State	Without Fuzzy Coordinator			With Fuzzy Coordinator		
		Before Fault	At Fault	After Fault	Before Fault	At Fault	After Fault
Voltage across DFIG terminal (in pu)	0.995	0.995	0.977	0.989	0.996	0.981	0.996
Current through DFIG terminal(in pu)	0.918	0.918	0.63	0.83	0.921	0.72	0.922
Generated active power(MW)	58.4	58.4	22.9	50.91	58.52	45.3	58.4
Generated reactive power(MVARs)	21.6	17.4	40.9	25.1	12.1	34.9	16.6
DC link bus voltage (in volt)	1200	1200.5	1143.9	1199.7	1200	1180.3	1200
Wind turbine speed(pu)	1.2115	1.2115	1.2243	1.2132	1.2115	1.2159	1.2115
pitch angle (degree)	0.76	0.76	2.94	1.59	0.76	0.59	0.76
PCC voltage (pu)	0.959	0.961	0.929	0.964	0.978	0.945	0.979

Table. 3 comparison table of wind farm 2

Wind Farm 2		L-G Fault					
Parameters	Steady State	Without Fuzzy Coordinator			With Fuzzy Coordinator		
		Before Fault	At Fault	After Fault	Before Fault	At Fault	After Fault
Voltage across DFIG terminal (in pu)	1	1	0.982	0.998	1.002	0.99	0.999
Current through DFIG terminal(in pu)	0.884	0.88	0.63	0.878	0.881	0.74	0.89
Generated active power(MW)	58.5	58.499	14.9	57.9	58.52	42	58.58
Generated reactive power(MVARs)	0.6	0.599	41.8	-0.3	-5.4	33.1	-2.6
DC link bus voltage (in volt)	1200	1200	1183.1	1199.8	1200	1192.7	1200
Wind turbine speed(pu)	1.2115	1.2115	1.2218	1.2114	1.2115	1.2141	1.2115

pitch angle (degree)	0.76	0.76	2.48	0.757	0.76	0.55	0.76
PCC voltage WF2 (pu)	0.991	0.998	0.921	0.992	0.99	0.939	0.995

Table. 4 Comparison table of wind farm 3

Wind Farm 3		L-G Fault					
Parameters	Steady State	Without Fuzzy Coordinator			With Fuzzy Coordinator		
		Before Fault	At Fault	After Fault	Before Fault	At Fault	After Fault
Voltage across DFIG terminal (in pu)	1	0.999	0.994	0.998	0.998	0.997	1
Current through DFIG terminal(in pu)	0.91	0.91	0.86	0.878	0.902	0.94	0.92
Generated active power(MW)	58.5	58.5	52.4	58	58.52	58.42	58.51
Generated reactive power(MVARs)	18.7	18	7.1	23.5	8.2	4.1	13.9
DC link bus voltage (in volt)	1200	1199.8	1193.2	1199	1200	1198.4	1200
Wind turbine speed(pu)	1.2115	1.2112	1.2128	1.2126	1.2115	1.2115	1.2115
pitch angle (degree)	0.76	0.76	1.13	1.29	0.76	0.75	0.76
voltage across bus 21 (pu)	0.97	0.979	0.958	0.966	0.983	0.975	0.98

V. Conclusions & Future Scope

A strong expansion of DFIG in the power system requires appropriate working conditions. Of the basic needs of DFIG-based wind farms, the voltage execution and wind farms performance parameters, by fault, the most extreme. In this work, the control of synchronous generators is used to improve the voltage performance of the PCC for the DFIG-based wind farms and the performance parameters of the DFIG-based wind farms. An ideal compromise between AVR and PSS with fuzzy logic is this main task for this investigation. AVR and PSS controls improve stability, DFIG power quality, and voltage control through a unit signal. In fault situations, updating one can lead to resolution of the other. In this way, a compromise is made between AVR and PSS to improve the system's voltage performance and the performance parameters of DFIG-based wind farms.

The system is analyzed under different cases and obtained following results-

• Under normal operating condition- Generated active power of three wind farms are 58.4 MW, 58.5 MW and 58.5 MW respectively, reactive power of three wind farms are 21.6 MVAR, 0.6 MVAR and 18.7 MVAR is absorbed. The voltage at the terminals of the DFIG 0.995 pu, 1.002 pu and 1 pu of the three wind farms and the PCC voltage of the DFIGs connected is 0.968 pu, 0.991 pu and 0.97 pu.

• Under line to ground fault condition- In this case we obtained the dips in some parameters waveforms of the DFIGs. All of parameters get affected by the fault. The reactive power is more in the DFIGs i. e, 39 MVAR, 26.1 MVAR and 25.3 MVAR at time of fault. And the active power become zero during fault interval. Pitch angle is also increase at time of fault that is 1.58-degree, 1.34 degree and 1.29 degree with respective 1,2 and 3 wind farms.

• System with Fuzzy coordinator- With fuzzy coordinator the active power of three wind farm is 58.4 MW, 58.53 MW and 58.4 MW and reactive power is 16.6 MVAR, -2.6 MVAR,

and 13.9 MVAR. Speed of wind turbine is 1.2115 pu and pitch angle is 0.76 degree which is near to normal operating condition. PCC voltage of wind farms are 0.979 pu, 0.995 pu and 0.98 pu.

On the other side of the DFIG-based wind farm, replacement efficiency is shown in case 2 because the reactive power is maintained or controlled, which reduces the voltage profile for undershoot recovery and improves stability value. The fuzzy logic method is used to coordinate between AVR and PSS. The fuzzy

coordinator gets the normalized deviations of the synchronous generators voltage and rotor angle and changes the addition of AVR and PSS so that they can give a tempting performance in the event of fault.

- There are many opportunities for future research in DFIG-based wind power applications. The list of future activities is listed below:

(a) More detailed, dynamic, stationary and experimental analysis of fault management systems for DFIG based wind farms. Development of models for DFIG reaction under asymmetric fault conditions.
(b) The improved low voltage transport capacity (LVRT) due to faults and the improved stability and reliability of DFIG wind turbines with an energy storage system can be a significant improvement. Another difficult task that needs to be investigated.
(c) Study the hybrid structure on a micro grid that also contains other energy sources.
(d) Perform an analytical study of the effects of inertia loss when using a power electronics control system.

VI. References

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