

# SET POINT TRACKING OF WIND TURBINE GENERATOR UNDER AGC USING FUZZY LOGIC CONTROL

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**Abstract** - Now a day's wind power is using mostly in several applications. Wind energy converts motion of wind into electricity, thereby sent to consumers by electrical transmission systems. Due to wide range of generation mix in the system, it is necessary to control the wind power under automatic generation control (AGC). This issue conjointly raises another concern on modeling of wind farm under AGC. The aggregated wind turbine model is operated in maximum power point tracking (MPPT) which is not suitable in AGC. The proposed paper illustrates controllability of wind turbines under set-point control using fuzzy controller. Different types of wind farm models are derived and demonstrated using set-point tracking below the intermittent wind conditions. The simulation of wind farm models is developed and its various characteristics were compared in the simulation results.

wind output should trace the native load demand. There may be voltage or frequency excursions due to imbalance power transfer from power plant to grid. This case implies that most of plant is operated in constrained manner rather than operated to trace maximum power point.

These operational cases technically imply that wind farms are possible to operate under set-point mode. So far, the common approach of modeling the large-scale wind farm is to aggregate simplified turbine models. These aggregated models largely assume that wind turbines are operated at fixed power coefficient. This makes the complete power house simulation only hold for case of maximum power point tracking (MPPT). Therefore, these models not applicable for variable power coefficient. These models don't seem to be ready to portray the wind farm output underneath the set-point management.

**Keywords:** Set-point control, variable-speed wind turbine, AGC, wind farm models..

## 2. WIND TURBINE MODEL

## 1. INTRODUCTION

Now a day's renewable energy sources are inexpensive compared to traditional generation. Wind energy is playing a key role on the way towards a sustainable energy in future and wind turbines are mostly using in many applications. In the WTG system, turbine blades convert wind energy into kinetic energy. Wind turbines are often grouped together into a single wind power plant known as wind farm and generate bulk electrical power.

A wind farm is a group of wind turbine in the location used for production of electricity. A large wind farm may consist of several hundred individual wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purpose. For example, Gansu Wind Farm, the largest wind farm in the world, has several thousand turbines.

The large-scale wind farms are committed to grid operation which faces additional challenges. In some cases

According to the aerodynamic rule, the relationship between wind speed and turbine power is approximated by the following equation:

$$P_t = \frac{1}{2} C_p(\theta, \lambda) \rho A V_w^3 \tag{1}$$

Where  $\rho$  is the air density,  $A$  is the blade sweep area,  $V_w$  is the wind speed, and  $C_p$  is the power coefficient. Within,  $\theta$  is the pitch angle of wind turbine, and  $\lambda$  is the tip speed ratio. The tip speed ratio is represented by the following equation:

$$\lambda = \frac{\omega_t r}{V_w} \tag{2}$$

Where  $\omega_t$  is the turbine rotor speed and  $r$  is the rotor radius. Power coefficient  $C_p$  is determined by the aerodynamic design and it represented by the following equation:

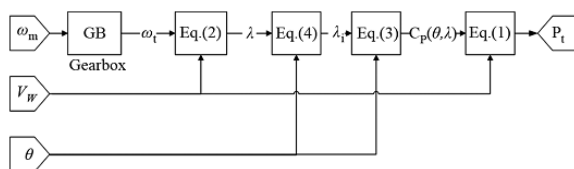
$$C_p(\theta, \lambda_i) = C_1 \left( \frac{C_2}{\lambda_i} - C_3 \theta - C_4 \theta^{C_5} - C_6 \right) e^{-C_7/\lambda_i} \tag{3}$$

Where

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + C_5\theta} - \frac{0.035}{\theta^3 + 1} \tag{4}$$

**Table -1:** Characteristic Parameter of Turbine Blade

Characteristic parameter	Value
$C_1$	0.5
$C_2$	116
$C_3$	0.4
$C_4$	0
$C_5$	2
$C_6$	5
$C_7$	21
$C_8$	0.08



**Fig 1:** Wind turbine model

Combining (1) through (4) together, the turbine model is shown in Fig. 1. The WTG is working at MPPT; an optimal  $\lambda_{opt}$  should be made to keep  $C_p$  at optimal value. Differentiating (3) with respect to  $\lambda$  and equal to zero,  $\lambda_{opt}$  is derived. In order to create the WTG operate at MPPT, the set-point signal for WTG is set as follows:

$$P_{WTsp} = \frac{1}{2} C_{p,max} (\theta = 0, \lambda_{opt}) \rho A V_m^3 \tag{5}$$

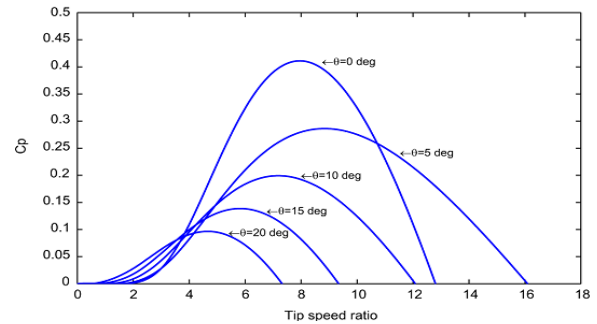
### 3. SET-POINT CONTROL ON THE VARIABLE-SPEED WIND GENERATORS

There are two ways to regulate the wind energy harvesting. One way is to control the rotating speed of the wind turbine

according to its power-speed curve, which is called rotor speed control. The other way is to control the pitch angle of the turbine blades which is called pitch control.

#### 3.1. Set-Point Tracking Using Pitch Angle Control

In the variable speed WTG for providing power regulations or limiting power output at high wind speed pitch angle control (PAC) is an indispensable mechanism.



**Fig 2:**  $C_p$  versus  $\lambda$  curves under various pitch angles.

Fig. 2 clearly shows that every pitch angle has its own  $C_{p,opt}$  and  $\lambda_{opt}$ . Different pitch angle would lead to different peak power when the WTG is working at MPPT. This makes the WTG produce desired power using MPPT operation. Fig. 3 demonstrates power curves of a WTG. At constant wind speed, the peak power decreases along with the rise of pitch angle. Therefore, variable pitch angle will be accustomed to regulate the mechanical power for trailing the set-point command. During this mode,  $C_p$  have different optimal values with relevant to different pitch angles. The power output is given as follows:

$$P_m = \frac{1}{2} C_{p,max} (\theta_v, \lambda_{opt,\theta_v}) \rho A V_\omega^3 \tag{9}$$

where  $\theta_v$  is the feedback signal coming from the pitch angle controller. The pitch angle controller continuously adjust pitch angle in order turbine power closely trace the power command. The proportional-integral (PI) regulator is applied to the control loop for driving the pitch servo system. The schematic diagram of the pitch angle controller under variable pitch mode is shown in Fig. 4. The WTG set-point is give as follows:

$$P_{WTsp} = P_{ref} \tag{10}$$

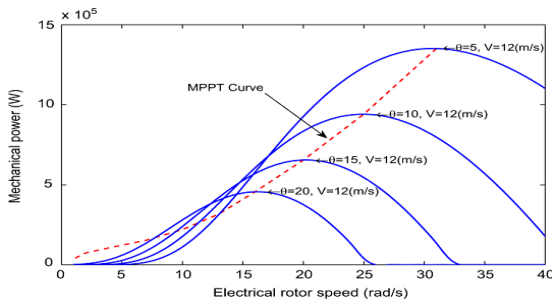


Fig 3: Approximate MPPT curve w.r.t. various pitch angles.

An operating alert should be made if pitch angle control makes the WTG follow the desired command. Fig. 3 indicates that set-point of the WTG should be set equal or less than maximum power available at the same wind speed. Otherwise, moment of inertia releases kinetic energy for compensating power discrepancy.

When the available wind power is less than set-point request, WTG should be operated at zero pitch degree to harness maximum wind speed. At this time, WTG set-point is automatically set to (5). If wind speed is high, pitch angle controller is activated to keep WTG producing the desired power.

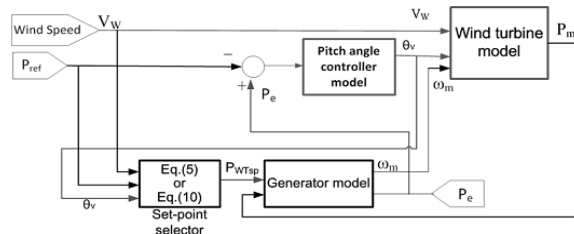


Fig 4: Schematic diagram of the PAC model.

### 3.2. Set-Point Tracking Using Rotor Speed Control

In generating the desired electrical power rotor speed control is to make the most of inertial response within the WTG. Due wind variability it is not easy to keep turbine power closely tracking the commanded power like it is done with electrical generating system. The operation principle of RSC is described as follows.

When the wind speed is high  $P_m$  becomes higher and the excessive KE produced from the wind turbine would be stored into inertia by accelerating the rotor speed. On the other hand, the decreasing wind speed may make  $P_m$  less than  $P_e$ .

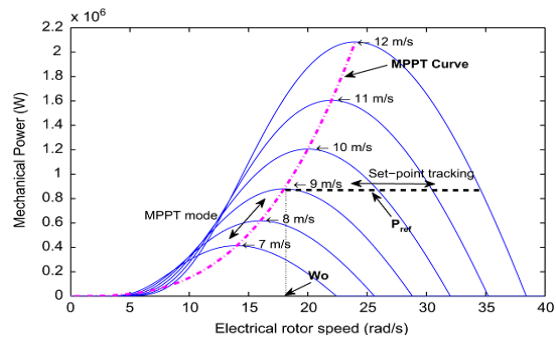


Fig.5: Operating d\states of the set-point tracking and MPPT.

The WTG operates in the set-point tracking mode only when the instant rotor speed is higher than  $\omega_0$ .  $\omega_0$  can be found at the optimal tip speed ratios, where pitch angle is fixed to zero degree. Therefore, is denote by following equation:

$$\lambda_{opt,\theta=0} = \frac{\omega_o \cdot T}{V_o} \tag{11}$$

Where  $V_o$  is the wind velocity base value.  $V_o$  can be obtained from the following relationship:

$$P_{ref} = \frac{1}{2} C_p (\theta = 0, \lambda_{opt,\theta=0}) \rho A V_o^3 \tag{12}$$

When wind speed is low WTG cannot follow the set-point command, MPPT is activated to harvest maximum power for preventing rotor speed to run below lowest stability margin.

RSC focuses on the control of rotor speed range; rotor speed is the controlling variable in pitch angle controller. When speed is about to reach the highest limit, rotor speed is compared with its safe margin. Then error signal is sent to proportional (P) controller which gives pitch angle as reference for adjusting the power output. The block diagram of pitch angle control for RSC is shown Fig. 6.

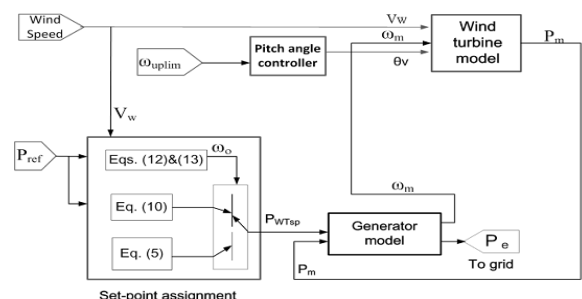


Fig 6: Schematic diagram of the RSC model.

#### 4. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

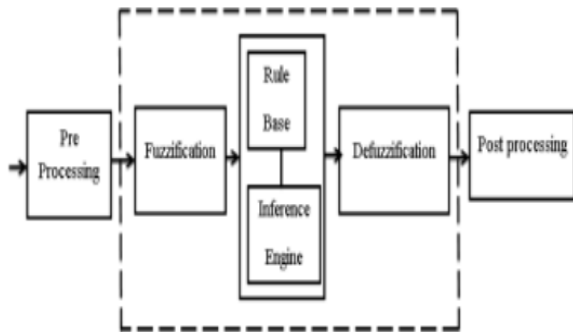


Fig 7:Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mandeni's, 'min' operator. v. Defuzzification using the height method.

Table 2: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

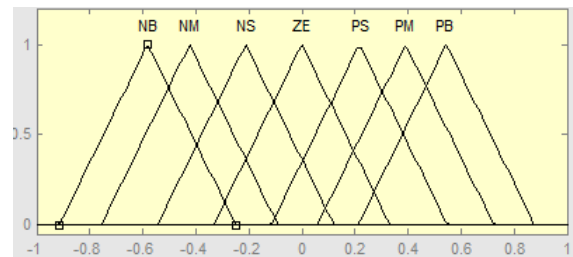


Fig 8: Input power error membership functions

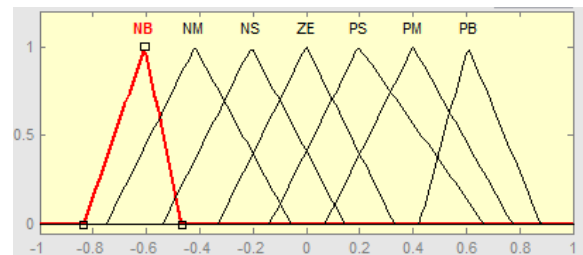


Fig 9: Changing power error as input membership functions.

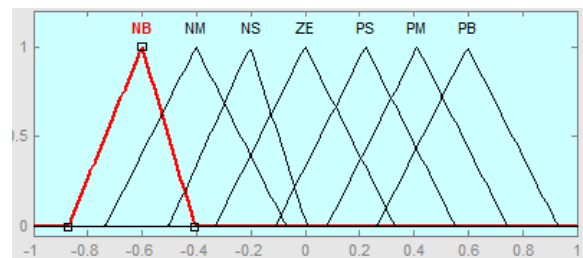


Fig 10: Output variable membership functions

**Fuzzification:** Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). Referred from [11], The Partition of fuzzy subsets and the shape of membership  $CE(k)$  and  $E(k)$  function adapt the shape up to appropriate system. The value of input power error and change in power error are normalized by an input scaling factor.

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular  $E(k)$  input there is only one dominant fuzzy subset. The input power error for the FLC is given as

$$E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \tag{16}$$

$$CE(k) = E(k) - E(k-1) \tag{17}$$

**Inference Method:** Several composition methods such as Max-Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator. Table 1 shows rule base of the FLC.

**Defuzzification:** As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, height method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u = -[\alpha E + (1-\alpha)C] \tag{18}$$

Where  $\alpha$  is self-adjustable factor which can regulate the whole operation. E is the power error of the system, C is the change in error and u is the control variable.

### 5. SIMULATION RESULTS

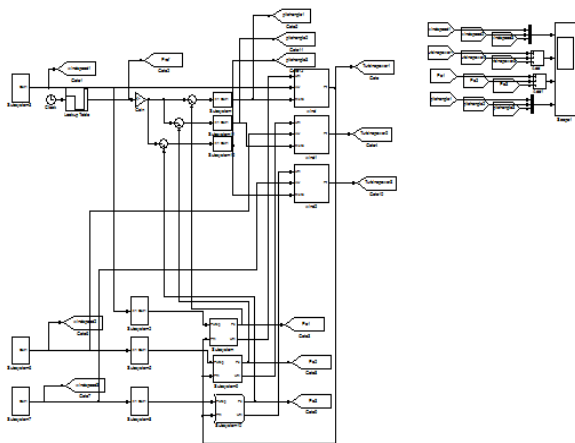


Fig.11. Simulation model of the system

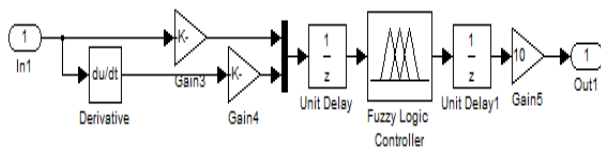


Fig 12: Fuzzy controller block of the proposed system

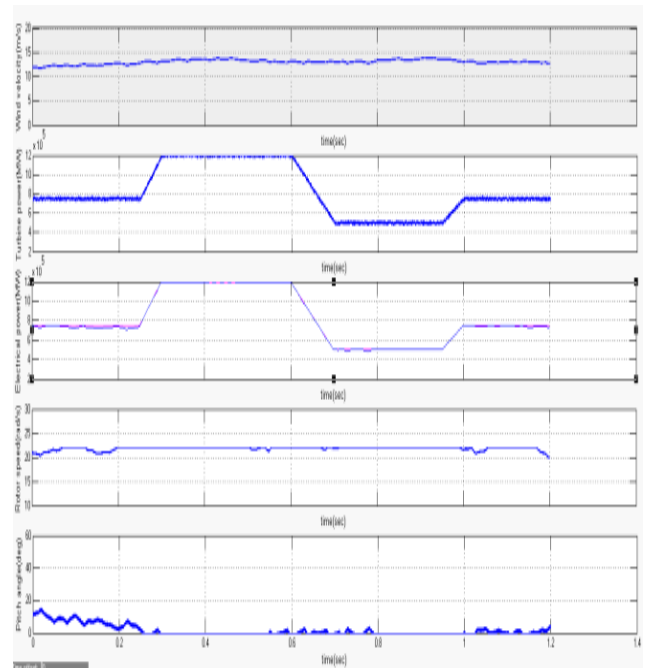
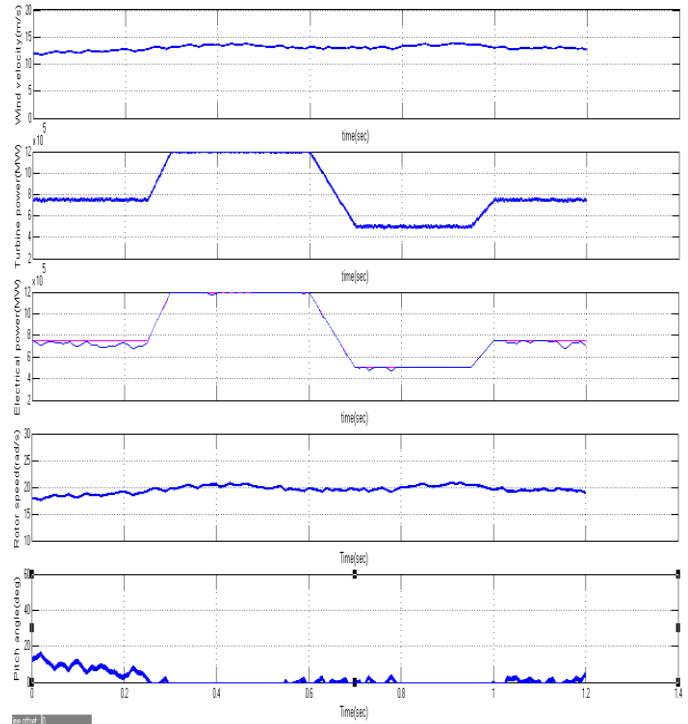
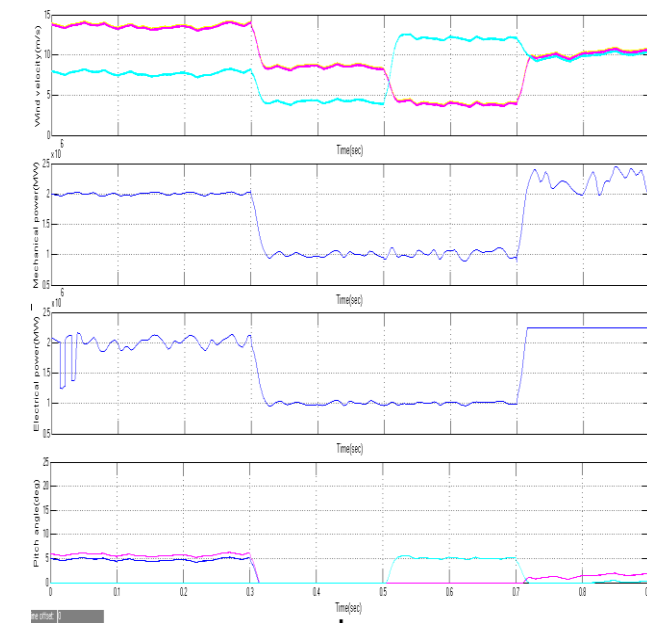
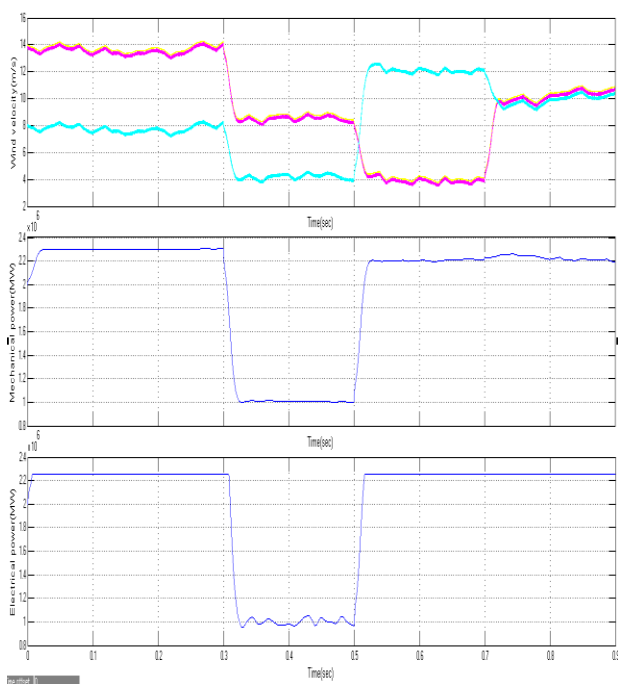


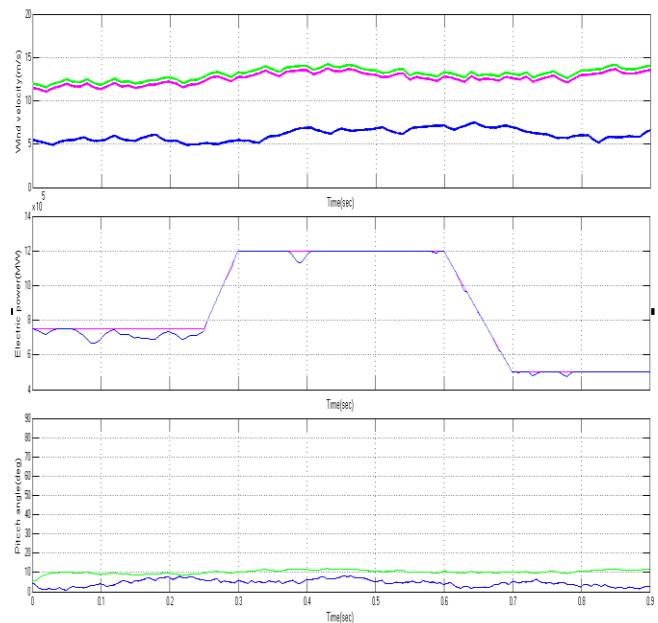
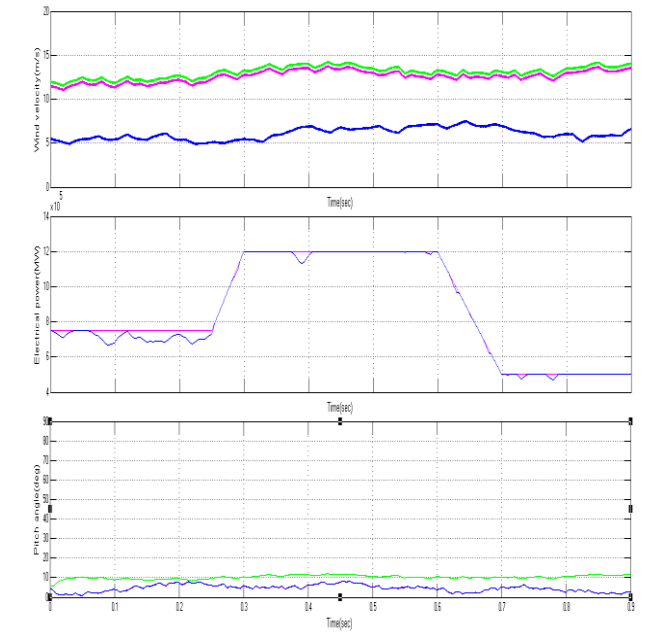
Fig 13: Results of comparative test on PAC and RSC using Fuzzy Logic.

### B. Lumped Model and Detailed Model



**Fig 14:** Comparative test using the lumped and detailed wind farm models using Fuzzy Logic.

### C. Simulation of Wind Farm Models



**Fig 15:** Wind farm model test using PAC using Fuzzy Logic.

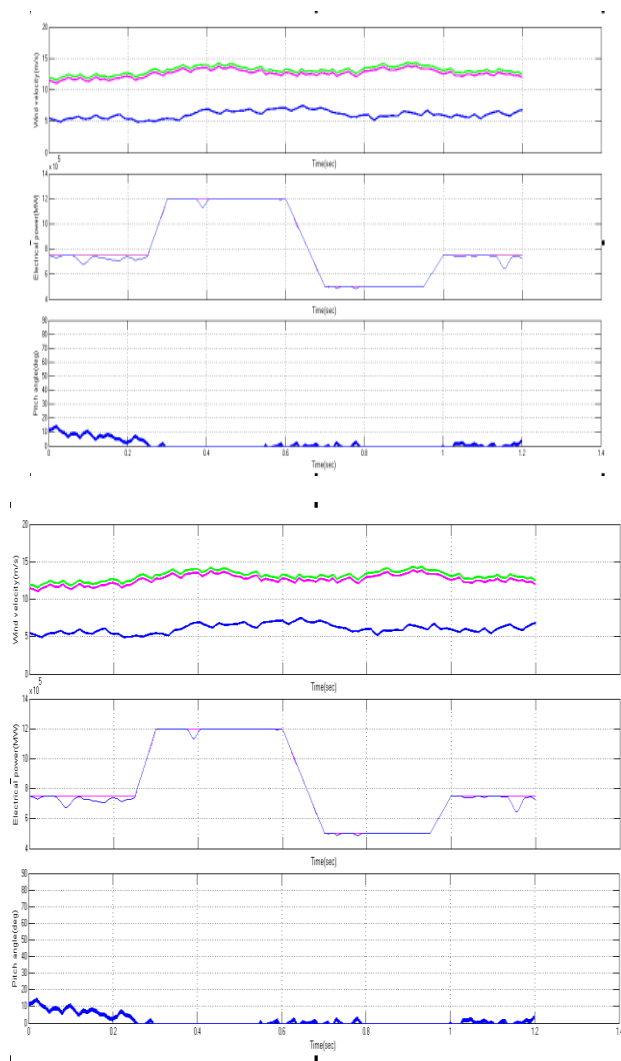


Fig 16: Wind farm model test using RSC using Fuzzy Logic.

## 6. CONCLUSION

This paper explains about the different types of set-point controls for variable-speed wind generators. Both pitch angle control (PAC) and Rotor speed control (RSC) having their own advantages and disadvantages. Compared to PAC, RSC have better inertial effect which leads to better tracking in set-point command. Below set-point management this proposed paper illustrates the controllability of wind kind. However, the sturdiness of inertia impact mainly depends on the allowable rotor speed vary. The projected wind farm models not only ready to portray the set-point management underneath variable wind speed, this gives best solution by reducing the calculation burden which is useful for system analysis. Here we are using the fuzzy controller compared to other controllers. The different characteristics of wind farm and performance are shown in simulation results.

## REFERENCES

- [1] Global Wind Report on Annual Market Global Wind Energy Council, 2010.
- [2] M. D. Esteban, J. J. Diez, J. S. Lopez, and V. Negro, "Why offshore wind energy?," *Renew. Energy*, vol. 36, no. 2, pp. 444–450, Feb. 2011.
- [3] W. Yao and K. Y. Lee, "A control configuration of wind farm for load following and frequency support by considering the inertia issue," in *Proc. IEEE PES General Meeting*, Jul. 2011, pp. 1–6.
- [4] C. M. Colson and M. H. Nehrir, "Load-following for wind turbines with permanent magnet synchronous generators," in *Proc. North Amer. Power Symp. (NAPS)*, Jul. 2010, pp. 1–6.
- [5] L.-R. Chang-Chien, C.-M. Hung, and Y.-C. Yin, "Dynamic reserve allocation for system contingency by DFIG wind farms," *IEEE Trans. Power Syst.*, vol. 23, no. 2, pp. 729–736, May 2008.
- [6] L.-R. Chang-Chien and Y.-C. Yin, "Strategies for operating wind power in a similar manner of conventional power plant," *IEEE Trans. Energy Convers.*, vol. 24, no. 4, pp. 925–934, Dec. 2009.
- [7] J. G. Slootweg and W. L. Kling, "Modeling of large wind farms in power system simulations," in *Proc. IEEE PES Summer Meeting*, 2002, pp. 503–508.
- [8] J. G. Slootweg and W. L. Kling, "Aggregated modelling of wind parks in power system dynamics simulation," in *Proc. IEEE Power Tech Conf., Bologna, Italy*, Jun. 2003, pp. 1–6.
- [9] L. M. Fernandez, F. Jurado, and J. R. Saenz, "Aggregated dynamic model for wind farms with doubly fed induction generator wind turbines," *Renew. Energy*, vol. 33, pp. 129–140, 2008.
- [10] S. Heier, *Grid Integration of Wind Energy Conversion Systems*. New York, NY, USA: Wiley, 1998.
- [11] Shilpy Agrawal, Vijay Bhuria "Shunt Active Power Filter for Harmonic Mitigation by using Fuzzy Logic Controller". Volume 2, Issue 6, June 2013 1950.