SPEED CONTROL AND PERFORMANCE ANALYSIS OF SYNCHRONOUS GENERATORS IN A WIND FARM USING FUZZY CONTROL SYSTEM

Tanuj Mishra
Electrical Department, DAVIET,
Jalandhar, Punjab, India

Sudhir Sharma
Associate Professor, DAVIET
Jalandhar, Punjab, India

Shivani Mehta
Electrical Department, DAVIET,
Jalandhar, Punjab, India

Abstract—This paper deals with the execution of a wind farm by using fuzzy control system for productivity advancement and execution. A wind farm comprising of multiple wind turbines associated with a three fuzzy control system which feeds power for distribution system. One fuzzy control is being used for detecting the change in the speed of the synchronous generator with respect to the wind speed for extracting the maximum power out of it. Secondary Fuzzy controller used to detect flux for improving the efficiency during light load. Third fuzzy controller gives vigorous control against turbine oscillation due to wind vortex.

Keywords— Wind, Fuzzy, Synchronous generator, Wind farm, MPPT.

I. INTRODUCTION

The fossil fuels are exhausting. So alternate source ventures are turning out to be more essential now a days. If we compare with fossil fuels and nuclear energy, wind energy conversion system is getting more consideration since it is most cost focused, natural perfect and ecofriendly power source. Late advancement of power devices and control drive innovation has helped the acknowledgment of smooth control of speed during variable input system[1]. While by executing certain calculations and with the assistance of certain control strategies we could enhance the power yield of the wind energy system and in the meantime the productivity of the system can be improved. If we see the statistics as per GWEC, in recent years most of the installations are being done in the wind generation system and countries like china, US, Germany Spain and India has got most of the share[2]. The fundamental issue which happens in the wind energy transformation is that the execution of the wind turbine is exceptionally subject to the force of wind. Regarding ecological conditions in India, consistent stream of wind is startling[3]. During soft start in wind turbine fluctuation happens and because of the change of wind stream the rotational speed changes in the meantime the yield force of generator associated with the turbine is straight forwardly corresponding to the wind speed[4]. The fundamental target is to investigate the execution of a wind farm by utilizing fuzzy controls for improving the efficiency.

II. WIND ENERGY

As long as sun is there, wind energy is there, Wind energy is essentially a type of sunlight energy and brought about because of the uneven warming of the air, abnormalities of the surface of earth[5]. As per Betz's limit the most extreme power extracted from the wind with the assistance of wind turbine is 59.3%
which is a hypothetically demonstrated yet for all intents and purposes it is not accomplished till date. Presently just 25-45% of power can be extracted from the wind.

III. WIND ENERGY CONVERSION SYSTEM

Wind turbines deliver power by utilizing the force of the wind to drive the generator. Airstream passes over the sharp edges, creating boost and applying a rotating power. The pivoting cutting edges turn a pole inside the nacelle, which connects the gearbox. The gearbox builds the revolving speed to what is fitting for the generator which converts the revolving energy into electrical energy[6].

![Wind Turbine Diagram](image)

Fig. 1 Electricity Generation from Wind Turbine [9]

The power confined in the airstream is given by the dynamic energy of the streaming air mass per unit time[7]. Which is

\[ P_{air} = \frac{1}{2} \text{(air mass per unit time)} \times \text{(wind velocity)}^2 \]

Although above equation gives the power accessible in the airstream, the power exchanged to the wind turbine rotor is decreased by the power coefficient, Cp. A most extreme estimation of Cp is characterized by as far as possible, which expresses that a turbine can never extricate over 59.3% of the power from an airstream[8]. As a general rule, wind turbine rotors have most extreme Cp values in the range 25-45%[9]. In the event that the pressure increments by 10% and the temperature diminishes by 15%, the air thickness will increment about 30%. Fig. 2 demonstrates the impact of air density on the power curves. At the point when the air thickness builds, the most extreme mechanical power yield expands, which brings about moving the greatest power point line. Different methods have been proposed to adapt to the

![Power Curves](image)

Fig. 2 The effect of air density on the power curves [7] varieties in the wind speed to guarantee high execution and unfaltering yield for the wind energy system. The change in the power output with respect to wind can be solved by adopting fuzzy logic control. In this paper three fuzzy logic controllers have been employed to control the speed of the synchronous generators used in a wind farm and yields maximum power output.

IV. CONTROLLER

Fuzzy controllers are decide based controllers that utilize “if–then” arrange for the control procedure. In this arrangement, a few factors could be utilized either in condition or conclusion side of the “if–then” rules[10]. Therefore, the scientific model of the system is not required in fuzzy control, so it can be connected to non-linear system.

![Fuzzy Control Diagram](image)

Fig. 3 Fuzzy control structure
For Fuzzification, we ought to have set rules for every information. These sets are somewhat phonetic factors, for example, far, warm, little, high and so forth once the fuzzy set is characterized; level of participation must be ascertained for each info. Least level of enrollment is zero and greatest is 1[11].

A. BLOCK DIAGRAM REPRESENTATION WITHOUT FUZZY CONTROL

A rearranged model of wind farm as appeared in fig. 4 is recommended in which the variety in yield power is seen as for the variety in the wind energy. A Wind farm comprising of five 2 MW wind turbines associated with a three phase load and export power for distribution purpose.

![Wind farm block diagram](image)

**Fig. 4 Control system for Wind farm without fuzzy controller**

Wind turbines utilizing a synchronous generator comprises of variable speed pitch control framework and an Ac to DC and DC to AC IGBT-based PWM converter. The parameters of the synchronous generator are reported in the given table.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nominal Power output</td>
<td>2 MW</td>
</tr>
<tr>
<td>2</td>
<td>Nominal Phase to phase voltage</td>
<td>575 Volt</td>
</tr>
<tr>
<td>3</td>
<td>Rotor resistance in p.u</td>
<td>0.006</td>
</tr>
<tr>
<td>4</td>
<td>Base frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>5</td>
<td>Pair of poles</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Inertia constant</td>
<td>0.62</td>
</tr>
<tr>
<td>7</td>
<td>Friction factor</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The sample time used to discretize the model (Ts=50 microseconds) is determined in the initialization capacity of the model properties. The Simulink model designed for the wind farm without using fuzzy control is shown in fig. 5.

![Wind farm Simulink model](image)

**Fig. 5 Simulink model for 10 MW wind farm without fuzzy logic control**

The Simulink design of the wind farm system without using fuzzy control is appeared in fig.5. This design incorporates the control of frequency and voltage created by the machine is corrected by using rectifier that further supplies excitation current to the generator. Output of the rectifier is reversed to ac through inverters and supplied to the grid at ideal power factor. Both the converters i.e. generator side and line side are vector controlled. Expansion of the output power reduces the dc connection voltage.

A. BLOCK DIAGRAM REPRESENTATION WITH FUZZY CONTROL

The heuristic method for seeking the greatest can be founded on a control called as "Fuzzy Meta-rule", which is given as follows: “On the off chance that the last change in the variable (a) has created the yield variable (b) to build, keep moving the info variable in a similar manner; on the off chance that it has made the yield variable drop, move it the other way”. The current wind energy farm is modified by using three fuzzy logic controllers.
a. Fuzzy Logic Controller 1 (Generator speed following controller)

The function of the FLC1 is that for a specific wind speed, this function will seek the speed of the generator until the framework stops at the most extreme power yield condition. The Simulink model for the FLC1 is shown in fig. 7.

In the fig. 7 we can see that FLC1 will assess an increment (on the other hand decrement) of speed, the relating increment (or decrement) of yield power. In Fuzzy controller-1, there are two information variables at the input i.e. \( \Delta P_0 \) and \( L \Delta \omega_r \) and one output \( \Delta \omega_r \) as shown in fig. 8.

The table 2 says, “If \( \Delta \omega_r \) is N (Negative) AND \( \Delta P_0 \) is NVB (negative value big), THEN \( \Delta \omega_r \) is PVB (positive value big).” The participation capacities for every one of the factors are not symmetrical. Membership functions for FLC1 are shown in the figure 9. In the execution of controller, the input factors are Fuzzify, the considerable control principles are assessed and joined and at long last the output is change over to the crisp values.
Membership function for input variable i.e. ldeltawr

Membership function for the input variable i.e. deltapo

Fig.9 Membership functions

b. Fuzzy Logic Controller 2 (Flux current controller)

The capacity of FLC - 2 is to program the machine rotor flux for light load effectiveness change. The system power control Po(k) is examined and contrasted and the past esteem Po(k-1) to decide the augmentation ΔPo. In expansion, the last excitation current decremented is audited. In FLC2, there are two input variables ldelta and delta_po and one output variables delta_ids as shown in fuzzy window in fig. 10.

TABLE 3
Fuzzy rules for FLC2

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Fuzzy Rules for the FLC 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>If (Ldelta is N) and (delta_Po is PB) then (delta_ids is NM) (1)</td>
</tr>
<tr>
<td>2</td>
<td>If (Ldelta is N) and (delta_Po is PM) then (delta_ids is NS) (1)</td>
</tr>
<tr>
<td>3</td>
<td>If (Ldelta is N) and (delta_Po is PS) then (delta_ids is NS) (1)</td>
</tr>
<tr>
<td>4</td>
<td>If (Ldelta is N) and (delta_Po is NS) then (delta_ids is PS) (1)</td>
</tr>
<tr>
<td>5</td>
<td>If (Ldelta is N) and (delta_Po is NM) then (delta_ids is PM) (1)</td>
</tr>
<tr>
<td>6</td>
<td>If (Ldelta is N) and (delta_Po is NB) then (delta_ids is PB) (1)</td>
</tr>
<tr>
<td>7</td>
<td>If (Ldelta is P) and (delta_Po is PB) then (delta_ids is PM) (1)</td>
</tr>
<tr>
<td>8</td>
<td>If (Ldelta is P) and (delta_Po is PM) then (delta_ids is PS) (1)</td>
</tr>
<tr>
<td>9</td>
<td>If (Ldelta is P) and (delta_Po is PS) then (delta_ids is PS) (1)</td>
</tr>
<tr>
<td>10</td>
<td>If (Ldelta is P) and (delta_Po is NS) then (delta_ids is NS) (1)</td>
</tr>
</tbody>
</table>

This rule says, “if Ldelta is P (positive) and delta_Po is PB (Positive Big) then delta_ids is PM (Positive Medium).”

Simulink model for the FLC2 controller is also shown in Fig.11

Fig 11. Simulink model for FLC2

Modelling is done by using triangular function and defuzzification is done with the centroid function. Membership functions are shown in fig. 12(a)-(c)
and change in speed deltaEw and output variable is delta_TE. The rule table for the FLC 3 is shown in Table 4.

TABLE 4 Fuzzy Rules for FLC 3

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Fuzzy Rules for the FLC 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>If (Ew is NVL) and (deltaEw is PS) then (delta_TE is NL) (1)</td>
</tr>
<tr>
<td>2</td>
<td>If (Ew is NVL) and (deltaEw is PM) then (delta_TE is NM) (1)</td>
</tr>
<tr>
<td>3</td>
<td>If (Ew is NVL) and (deltaEw is PL) then (delta_TE is NS) (1)</td>
</tr>
<tr>
<td>4</td>
<td>If (Ew is NVL) and (deltaEw is PVL) then (delta_TE is ZE) (1)</td>
</tr>
<tr>
<td>5</td>
<td>If (Ew is NL) and (deltaEw is ZE) then (delta_TE is NL) (1)</td>
</tr>
<tr>
<td>6</td>
<td>If (Ew is NL) and (deltaEw is PS) then (delta_TE is NM) (1)</td>
</tr>
<tr>
<td>7</td>
<td>If (Ew is NL) and (deltaEw is PM) then (delta_TE is NS) (1)</td>
</tr>
<tr>
<td>8</td>
<td>If (Ew is NL) and (deltaEw is PL) then (delta_TE is ZE) (1)</td>
</tr>
<tr>
<td>9</td>
<td>If (Ew is NL) and (deltaEw is PVL) then (delta_TE is PS) (1)</td>
</tr>
<tr>
<td>10</td>
<td>If (Ew is NM) and (deltaEw is NS) then (delta_TE is NL) (1)</td>
</tr>
</tbody>
</table>

The rule says, “IF Ew is NVL (Negative very low) and deltaEw is PS (Positive Small) THEN delta_TE is NL (Negative Low). Membership functions for input and output variables are shown in fig. 13 (a)-(c).
Both the speed change and error in speed are processed through the FLC3 and produce torque output component for current. This FLC controller works all the time.

IV. SIMULATION OUTPUT

A. Without Fuzzy Controller simulation results

In comparison with wind farm containing fuzzy logic controller, the system without fuzzy results in following outputs. The major concern is about the three main quantities i.e. Generator speed, power output, and flux current. The simulation results between generator speed and wind velocity shows in fig. 14

Fig. 14 Generator speed w.r.t Wind velocity

The simulation results between generator speed and output power can be compared in fig 15

Fig. 15 Output power w.r.t speed

In the event that we check the rotor flux current for this model it will demonstrate that amid light load its value is more and results in increment in the losses. This further diminishes the efficiency of the engine.

Fig. 16 Flux Current Vs Time

B. Inner Loop FLC Control Simulation Results

Yield result uncovers that for a specific speed of generator, if the airstream is expanded its related turbine torque is additionally expanded. As we realize that if torque increased with speed than output power
will increase. This outcome uncovers that for a specific speed of generator, if the airstream is expanded, its comparing turbine created power is likewise expanded. This can be approved from the fig. 17

![Fig. 17 Generator Speed w.r.t Wind Velocity](image1)

**DISCUSSIONS**

In both the models the output results are compared with the same input which is the variable wind velocity as shown in fig. 14. FLC-1 will follow the speed of the generator with the adjustment in wind speed to concentrate greatest control. So as the speed of airstream increments, speed of generator is additionally expanded by primary fuzzy controller. As an aftereffect of which the line power is additionally expanded. Comparable is the case for the abatement in wind speed. This can be visualized in Fig. 20.

![Fig. 18 Output power w.r.t speed](image2)

![Fig. 19 Flux current w.r.t speed](image3)

**VI. CONCLUSION**

The FLC based Wind farm framework has been examined and Simulink exhibitions has been considered to approve all the hypothetical ideas. The primary fuzzy controller looks on line the ideal speed so that the streamlined productivity of the wind turbine is most extreme. The secondary fuzzy regulator lineup the rotor flux by seeking online in order to enhance the machine effectiveness. Against Turbines oscillations third fuzz controller is used which works all the time.

- By the use of the fuzzy system performance of the wind farm has been increased.
- The fuzzy rules utilized as a part of the framework are widespread and can be implemented for numerous systems.
- Fuzzy system helps in predicting human problems and model imprecise information.
VII. REFERENCES


