Adaptive Fuzzy Controller Design for Solar And Wind Based Hybrid System

M.Rathaiah¹, P.Ram Kishore Kumar Reddy², P.Sujatha³

¹Research Scholar, Department of Electrical Engineering, INTUA, Ananthapuramu
²Professor,Department of Electrical EngineeringMGIT, Hyderabad
³Professor,Department of Electrical Engineering,INTUACEA, Ananthapuramu

Abstract

Renewable Energy Resources plays an active role in standing against global warming and reduce the use of conventional energy sources. Hybrid systems formed by combining the renewable energy sources are efficient relatively. The intent of this paper is to furnish endurable power for frontier and far-off places with hybrid-system of architecture. The intended system embodying DFIG and solar PV based wind turbine. In solar systems, control mechanism is essential for improving the performance. This paper proposes a method of incremental conductance approach based MPPT Adaptive Fuzzy Logic Controller for grid connected PV system which is composed of a boost converter and a three phase inverter. Adaptive Fuzzy Logic Controller provides fast response and better %THD compared to Fuzzy and PI controllers. In solar system, MPPT will magnify solar output power value. The DFIG has two controllers Grid-Side Control (GSC) and Rotor-Side Control (RSC). The rated rotor speed and DC-link voltage are regulated by RSC and GSC through PI, Fuzzy Logic Controller and AFLC strategies. By using simulation studies performed by three control strategies, %THD analysis is carried out.

Keywords: PV panel, Double –Fed –Induction Generator (DFIG), Wind Energy Conversion System (WECS), Rotor Side Control (RSC), Grid Side Control (GSC), AFLC, %THD.

1. Introduction

Because of exhaustion of the fossil fuel and pollution, renewable energy utilities have been developed recently. The diminutiveness discrete wind power systems with a battery bank as an storage integrant is prevalent and it is imperative to a firm and endurable power in rural and remote areas [1]. The solar and wind energy are irregular and unreliable which are the main drawbacks. By combining both, steadfastness of system can be intensified. Efficient energy can be generated by using combination of energy sources. Hybrid-energy systems (HES) have more ambit in frontier and far-off areas as they cannot get supply from the grid. Renewable energy sources are preferable due to increased demand and diminution of conventional energy sources. Though there are many hybrid systems, solar and wind energy gives better results among them [2]. As solar energy is pollution free, cost effective and readily available source, it is considered as the best among the all renewable energy sources. Wind energy is hugely available in rural areas. For larger scale power generation [5], DFIG based Wind turbine is used. The mainstream high-power WECS uses DFIG. The back- to- back converters are RSC and GSC which are connected back-to-back. In order to keep the voltage variation in the dc-link [6].The main advantages are reduced power rating, less cost, less power loss and improved efficiency. In this work, A mandani model based FLC is contrived in the place of PI controller to control DFIG [7]. Controllers for non-linear systems [13-18].

2. Proposed System

The block diagram of the proposed system is shown in fig.1.

Fig.1: Block Diagram for the proposed system

2.1. Mathematical model

The equivalent circuit of a solar cell is shown in fig.2. By using photovoltaic effect, the light energy of the sun is directly converted to electricity in PV system. By using the temperature and irradiance, the PV cell current is controlled. If the irradiation is high, then the current produced is also high. A current source with a parallel diode [2], [6] is taken as model of an ideal solar cell. Any practical system has some losses and to represent these losses we
use series resistance (Rs) of small value and a shunt resistance (R_s) of high value.

\[ I = I_l - \left( I_0 \left( V + \frac{1}{R_s} \right) - 1 \right) \left( V + \frac{1}{R_p} \right) \]  

(1)

here

- \( I_l \): Light generated current
- \( I_0 \): Reverse saturation current
- \( V_T \): Thermal voltage
- \( V \): Solar cell voltage
- \( I \): Solar cell current

**2.2. MPPT Evaluation algorithm**

The major importance in PV system is given to the operation of system at MPP. Steps are:

1. The outputs are taken from solar panel and are given to MPPT controller.
2. The present, past V & I values are dissected and provides \( \Delta V = V_{max} - V_{old} \), \( \Delta I = I_{old} - I_{new} \)
3. The tracing of MPPT is calculated by \( \Delta I / \Delta V \) gradient.
4. The error is obtained by adding IntCond \( di/dv \) and instant cond \( i/v \) which is \( e = i/v + di/dv \).
5. This error is given to PI controller which minimizes its value \( e \) to zero.
6. The duty ratio is produced by PI controller. It is used to produce PWM pulses by giving it to comparators and these pulses are given to boost converter for switching purpose.
7. All the above steps are repeated until the system reaches MPP.

**2.3 DC-DC Boost Converter**

The Boost Converter is a step up DC-DC converter and BJT, MOSFET, TGBT etc., are the switches used. To maintain constant output voltage the switching pulses are given by MPPT controller.

![Fig. 2: One diode model of solar cell.](image)

**Table 1: Parameters used in modeling the simulation system**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power</td>
<td>3000W</td>
</tr>
<tr>
<td>Voltage ( V_{max} )</td>
<td>300V</td>
</tr>
<tr>
<td>Current ( I_{max} )</td>
<td>8.9A</td>
</tr>
<tr>
<td>( V_{oc} )</td>
<td>37.3V</td>
</tr>
<tr>
<td>( I_{sc} )</td>
<td>8.71A</td>
</tr>
</tbody>
</table>

![Fig. 3: Block diagram of Boost converter](image)

**3. Wind Turbine modeling**

In this modeling, wind turbine transforms wind’s kinetic energy into mechanical energy. Based on this, the following correlations are used for modeling. The output power of the wind turbine is given by eq [9].

\[ P_m = \frac{1}{2} C_p(\lambda, \beta) \rho A v^3 \]  

(2)

Here, \( \rho \) is the air density, \( v \) is wind speed.

The normalized form of eq(2) in P.U system is:

\[ P_m(\text{pu}) = k_p C_p v^3 \]  

(3)

A generic eq is used to model \( C_p(\lambda, \beta) \).

\[ C_p(\lambda, \beta) = c_1 \left( \frac{C_2}{\lambda^2} - c_3 \beta - c_4 \right) e^{-c_5/\lambda} + c_6 \lambda \]  

(4)

Where,

\[ \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08 \beta} - 0.035 \frac{\beta}{\beta^2 + 1} \]

The three inputs are the generator speed in pu, pitch angle \( \beta \) in degrees and wind speed in m/s. The output is torque in Nm.

**4. Modeling of DFIG**

The equations DFIG in dq reference frame are[10]:

\[ V_{qs} = R_s I_{qs} + \frac{d\phi_{qs}}{dt} + \omega_x \phi_{ds} \]  

(5)

\[ V_{ds} = R_s I_{ds} + \frac{d\phi_{ds}}{dt} - \omega_x \phi_{qs} \]  

(6)

\[ V_{qr} = R_s I_{qr} + \frac{d\phi_{qr}}{dt} - \omega_x \phi_{dr} \]  

(7)

\[ \phi_{qs} = L_s I_{qs} + L_m (i_{ds} + i_{dr}) \]  

(8)

\[ \phi_{ds} = L_s I_{ds} + L_m (i_{qs} + i_{qr}) \]  

(9)

\[ \phi_{qr} = L_r I_{qr} + L_m (i_{qs} + i_{qr}) \]  

(10)

\[ \phi_{dr} = L_r I_{dr} + L_m (i_{ds} + i_{dr}) \]  

(11)

**4.1 Rotor side controller**

Vector control principle is used in this scheme.

\[ I_{qr} = - \frac{l_m}{l_s} I_{qs} \]  

(13)

Similarly \( I_{dr} \) is written in terms of \( I_{ds} \) and \( \phi_{ds} \)

\[ I_{dr} = - \frac{l_s}{l_m} I_{ds} + \frac{l_m}{l_s} \phi_{ds} \]  

(14)

From DFIG modeling

\[ \phi_{qr} = L_r I_{qr} + L_m (\phi_{qs} + \phi_{qr}) \]  

(15)

\[ \phi_{dr} = L_r I_{dr} + L_m (I_{ds} + I_{dr}) \]

Substituting the values of \( I_{dr} \) and \( I_{qr} \) in the above equation.

\[ \phi_{dr} = L_r \sigma_I_{dr} + \frac{l_m}{l_s} \phi_{ds} \]  

(16)

\[ V_{qr} = R_s I_{qr} + (\omega_e - \omega_r) \sigma L_r I_{dr} + \sigma L_r \frac{d\phi_{qr}}{dt} + (\omega_e - \omega_r) \frac{l_m}{l_s} \phi_{ds} \]  

(17)

\[ V_{dr} = R_s I_{dr} - (\omega_e - \omega_r) \sigma L_r I_{qr} + \sigma L_r \frac{d\phi_{dr}}{dt} + \frac{l_m}{l_s} \phi_{ds} \]  

(18)
Control eq (17) and (18) are expressed with compensating terms as
\[
\begin{align*}
V_{dr} &= (k_{p3} + k_{i3})(I_{dr}^* - I_{dr}) - (\omega_e - \omega_r)L_rI_{qr} \\
V_{qr} &= (k_{p4} + k_{i4})(I_{qr}^* - I_{qr}) + (\omega_e - \omega_r)L_rI_{dr} + \\
& \quad (\omega_e - \omega_r) \frac{L_m}{L_e} \varnothing_{ds}
\end{align*}
\] (19) (20)

4.2 Grid Side Controller

DC-link capacitor can be expressed as:
\[
\frac{dC_{dcs}}{dt} = i_{ds} - i_{qr}
\] (21)

Aligning the d-axis of the reference frame along the stator-voltage position i.e \( V_{dcs} = 0 \).
\[
v_{d1} = -\left( R_{Ld} + L_{dss} \frac{dv_{d}}{dt} \right) \omega e L_I d + v_d
\] (22)
\[
v_{q1} = -\left( R_{Lq} + L_{qss} \frac{dv_{q}}{dt} \right) \omega e L_I d
\] (23)
The controller eq of the grid-side converters are:
\[
v^*_{q1} = - (k_{p2} + k_{i2})(I^*_q - I_q) + \omega e L_I q + v_q
\] (24)
\[
v^*_{d1} = - (k_{p1} + k_{i1})(I^*_d - I_d) + \omega e L_I q + v_d
\] (25)

4.3 Pitch angle controller

To accelerate turbine faster, restrict the rated power at high and low wind conditions and for that Pitch angle controller is required. To retain esteem value, pitch control come into picture and the speed of generator overreach rated speed. \( \omega_{ref} = 1 \text{pu} \).
\[
\frac{d\beta}{dt} = \frac{\beta_{ref} - \beta}{\tau \beta}
\] (26)

Where, 
\( \beta \) is the pitch angle

5. Control strategies

5.1 PI Controller

It is widely used for wind turbine control applications. PI controller involves the proportional gain \( K_p \) and integral gain \( K_i \). The error signal goes to PI control loop where it gets multiplied by the proportional constant \( (K_p) \) and integral constant \( (K_i) \).

For a PI controller,
\[
G_c(s) = K_p + \frac{K_i}{s}
\] (27)

Where

\( K_p \) = Proportional gain
\( K_i \) = integral gain

5.2 Fuzzy Logic Controller

FLC is a control method where linguistic variables are used to govern the circuit rather than mathematical values. This method is more robust than the classical controllers and can work with less data [11].

Here the membership function considered, is triangular. The membership function values are separated into seven sets and they are named as: Positive Big (PB), Zero (ZE), Negative Small (NS), Positive Small (PS), Negative Medium (NM) and Positive Medium (PM), Negative Big (NB). The controller output \( \Delta \theta \), \( I_d^* \) and \( I_q^* \) for a FLC depends on the fuzzy rules shown in table 2.

The inference method used is mandami method. The defuzzification method used is centre of area method.
5.3. Adaptive fuzzy Logic Controller

The AFLC basically consists of two fuzzy logic controllers which are connected in parallel and the corresponding block diagram shown in Fig.8, Fig.9, and Fig.10. The AFLC input and output membership functions are shown in Fig.11.

In this case, the incremental change in controller output ΔD is given by

\[ ΔD(k) = \{ α(k) × ΔD_N(k) \} \]

6. Simulation results

The responses of the three controllers used, namely, PI, Fuzzy and AFLC are plotted.

PV panel voltage for a change in PV panel irradiance input from 500W/m² to 1000W/m² from these results AFLC gives quick response compared to Fuzzy and PI which is shown in Fig.12. From table 4, AFLC has better tr and ts compared to other two controllers.

Boost converter output voltage for a change in solar panel voltage, when compared with PI and fuzzy, AFLC gives quick response which is shown in Fig.13. From table 5, AFLC has better tr and ts compared to other two controllers.

PV Power, when compared with PI and fuzzy, AFLC give quick response which is shown in Fig.14. From table 6, AFLC has better tr and ts compared to other two controllers.
Table 7: Comparison of $t_r$ and $t_s$ for PI, Fuzzy and AFLC controllers

<table>
<thead>
<tr>
<th>Controllers</th>
<th>$t_r$ (sec)</th>
<th>$t_s$ (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>0.15</td>
<td>0.2</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>AFLC</td>
<td>0.08</td>
<td>0.09</td>
</tr>
</tbody>
</table>

From the table 7, Conclude that AFLC had better $t_r$ and $t_s$ compared to other two controllers.

Fig. 16: Wind speed
Simulation result for a period of 1sec with change in wind speed of 0.5 sec that is up to 0.5 sec 4 m/s after 0.5 sec 14 m/s shown in Fig.16.

Fig. 17: DC link voltage

Table 8: Comparison of $t_r$ and $t_s$ for PI, Fuzzy and AFLC controllers

<table>
<thead>
<tr>
<th>Controllers</th>
<th>$t_r$ (sec)</th>
<th>$t_s$ (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>0.13</td>
<td>0.25</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>0.08</td>
<td>0.2</td>
</tr>
<tr>
<td>AFLC</td>
<td>0.07</td>
<td>0.09</td>
</tr>
</tbody>
</table>

From the table 8, Conclude that AFLC has better $t_r$ and $t_s$ compared to other two controllers. DC link voltage 580 V.
Fig. 20: THD of grid Voltage with (a)PI (b) fuzzy (c)AFLC

Fig. 21: THD of grid current with (a)PI (b) Fuzzy (c) AFLC

THD of grid Current are better in AFLC compared to PI and Fuzzy controllers. From the Fig.21.

Table 9: Comparison performance between PI, Fuzzy and AFLC

<table>
<thead>
<tr>
<th>S.No</th>
<th>Variable Name</th>
<th>PI Controller THD (%)</th>
<th>Fuzzy THD (%)</th>
<th>AFLC THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Grid Voltage</td>
<td>0.17</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>Grid current</td>
<td>2.40</td>
<td>1.58</td>
<td>0.79</td>
</tr>
</tbody>
</table>

The %THD value of AFLC is reduced by 50% approximately when compared to the PI and fuzzy THD values. From the table. It is observed that the AFLC gives better performance than the PI and fuzzy.

7. Conclusion

In this work, an AFLC is used to achieve fast response with change in wind speed. Simulation results show that the proposed AFLC controller gives fast response when compared with PI and fuzzy logic controller. From results it is observed that % THD for grid current and grid voltage are improved when AFLC is used.

References


