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An Intelligent Maximum Power Point Tracking Algorithm for Wind Energy System

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ABSTRACT

To obtain the maximum power from the variable speed wind generator, fuzzy logic controller is used. Hill-Climbing Search (HCS) technique is used to track the maximum power point. The maximum power is tracked for different wind speeds and load impedance variations. The measurement of wind speed, and rectifier output voltage are applied to fuzzy logic controller to estimate and control the optimal of maximum output power. The inputs to the FLC are the normalized values of error and variation of error. Triangular membership functions are used for input and output variables. The performance of both the schemes are simulated and a comparison is made. The simulation work is done in MATLAB 2010 environment.

Keywords

Maximum Power Point Tracking (MPPT), Permanent Magnet Synchronous Generator (PMSG), Fuzzy Logic Control (FLC), Variable-Speed Wind Turbine (VSWT), power converters.

1. INTRODUCTION

The diminishing reserves of fossil fuels, together with the associated environmental effects are encouraging more research in renewable clean energy. These renewable clean energy alternatives include solar energy, hydro energy and wind energy. The need to extract the maximum power available in the wind, research is taking place in numerous fields related to wind energy production. Intelligent control techniques are considered among the most important dimensions for the turbine efficiency and hence the control techniques enhancement has direct contribution to the better performance of wind turbines [1].

Variable-Speed Wind Turbines (VSWT) is advantageous mainly for their potential capability of extracting more energy from wind resources. To extract maximum energy from wind, a Maximum Power Point Tracking (MPPT) control is necessary to adjust the turbine rotor speed according to the variation of wind speed the Tip Speed- Ratio (TSR) is maintained at its optimal value [2]. Among previously developed wind turbine MPPT strategies, the TSR direction control method is limited by the difficulty in wind speed and turbine speed measurements [2][3]. Many MPPT strategies were then proposed to eliminate the measurements by making use of the wind turbine maximum power curve (or optimal torque curve), but the knowledge of the turbine's characteristics is required. In comparison, the Hill Climbing Searching (HCS) MPPT is popular due to its simplicity and independence of system characteristics [7]-[10].

2. MODELING OF THE SYSTEM

Figure 1 represents the wind energy conversion system used for the verification of the algorithm. A three-phase boost rectifier is used to simplify the control process and thus allows easy verification of the algorithm [6][8]. As for the generator, a Permanent Magnet Synchronous Generator (PMSG) is used due to its high efficiency, small size and no slip rings are necessary [3]. In Figure 1, *ωgen* is the generator angular speed; *dcycle* is the duty ratio, *Vdc* and *Idc* are the average voltage and current of the boost converter respectively. The MPPT control in this system is therefore obtained by changing the duty cycle of the switch of the boost converter. The use of the boost converter in Fig. 1 also allows Power Factor Correction (PFC) to be achieved at the output terminals of the PMSG.

For wind turbine, the static characteristic of the turbine (output as a function of wind speed) is described by the relationship between the total power and mechanical energy of the wind.

$$P_{wind}=\frac{1}{2}\rho\pi R^2_{turbine}v^3_{wind} \qquad (1)$$

Where ρ is the air density (1,225 kg/m3), $R_{turbine}$ is the rotor radius (m), v_{wind} is the wind speed (m/s),C_p is the power coefficient, P_m is the mechanical power.

$$P_m=\frac{1}{2}\rho\pi R^2_{turbine}v^3_{wind}\,C_p \qquad (2)$$

If Ω is the rotor speed, the reduced speed λ is defined:

$$\lambda = \frac{\Omega\,Rturbine}{Vwind} \qquad (3)$$

The output torque of the turbine is calculated:

$$T_m = \frac{Pm}{\Omega} \qquad (4)$$

The PMSG has been modeled in the rotor reference frame under the assumption of zero sequence quantities are not present and applying park's transform, the terminal voltage of PMSG in the rotor reference frame is expressed as,

$$V_d = \frac{-Rsid-Lddid}{dt+\omega Lqiq} \qquad (5)$$

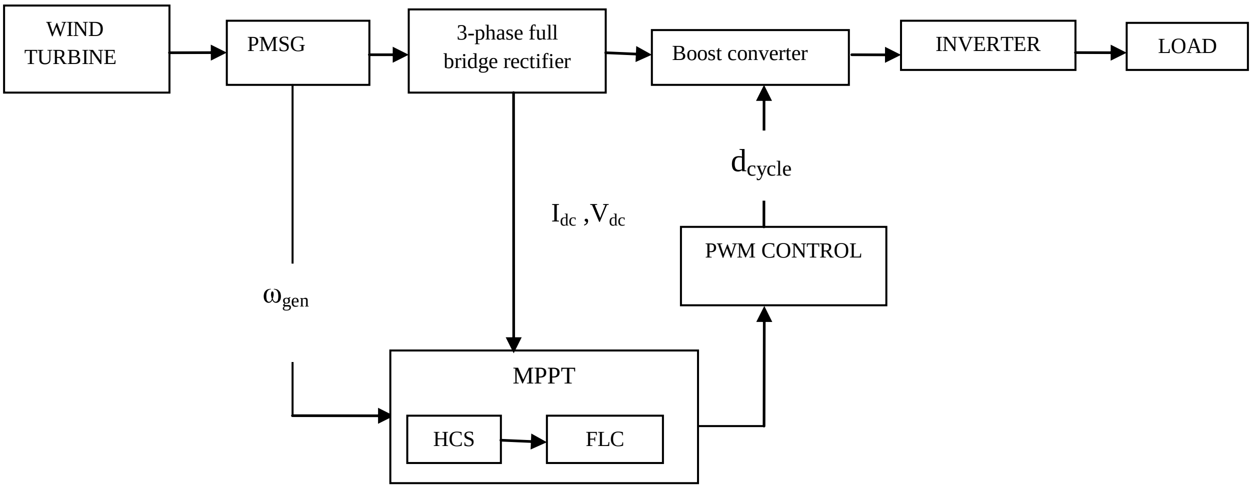


Fig 1: Block diagram of Variable speed wind turbine generation system

$$V_q = \frac{-\mathrm{Rsid}-\mathrm{Lddid}}{\mathrm{dt}-\omega \mathrm{Lqiq}+\omega\lambda \mathrm{m}} \qquad (6)$$

The expression of electromagnetic torque in the rotor is given by:

$$T_e=\frac{3}{2}\, p[(L_d-L_q)i_q i_d-\lambda_m i_q] \qquad (7)$$

where *p* is the number of pole pair, λ_m is the magnetic flux, L_d is the direct axis inductance, L_q is the inductance in quadrature, R_s is the stator resistance and ω is the electrical angular frequency[4].

Since the output of PMSG is AC,it is converted into DC for 3 phase full-bridge diode rectifier. The average value of Vdc is

$$\mathrm{Vdc}=(3\sqrt{2}\ V_L)/\pi \qquad (8)$$

V_L=line to line voltage of PMSG.

For boost converter, the relation between the input and output voltage and current are,

$$V_{dc\text{-}out}=\frac{1}{(1-D)}V_{dc\text{-}in} \qquad (9)$$

D is the duty ratio of boost converter

$$I_{dc\text{-}out}=(1\text{-}D)I_{dc\text{-}in} \qquad (10)$$

$$D=1-\frac{\mathrm{Vdc-in}}{\mathrm{Vdc-out}} \qquad (11)$$

The peak to peak ripple of the output dc voltage ΔVdc-out is

$$\Delta\mathrm{Vdc\text{-}out}=\frac{\mathrm{Idc-out\ D}}{\mathrm{C\ Fsb}} \qquad (12)$$

C=capacitance of the boost converter.
Fsb=switching frequency of boost converter.

For inverter, the PWM scheme may be evaluated under a certain switching frequency and reference signal frequency ratio, and the input and output voltage ratio. The definition of the modulation index m_a is

$$m_a=V_{LL}/V_{dc\text{-}out} \qquad (13)$$

V_{LL}=peak value of the line to line voltage.

The frequency modulation ratio m_f is

$$m_f=fs/f_1. \qquad (14)$$

fs and f_1 is the switching and modulation frequency.

The line to line rms voltage at the fundamental frequency is

$$V_{LL}=\frac{\sqrt{3}}{2\sqrt{2}}\, m_a\ \mathrm{Vdc\text{-}out}. \qquad (15)$$

3.FUZZY LOGIC CONTROLLER

As shown in Figure 2, the FLC system consists of 3 components. They are fuzzification, the rule base, and defuzzification. Fuzzification, the first component of the FLC, converts the exact inputs to fuzzy values. These fuzzy values are sent to the rule-base unit and processed with fuzzy rules, and then these derived fuzzy values are sent to the defuzzification unit. In this unit, the fuzzy results are converted to exact values using centre of area method.

In Figure 3 and 4, the error and the error variation of the input data of the FLC's input variables areshown. Triangle membership functions were used. These functions are called NB, NM, S, PM, and PB, and the data vary between –1 and 1, as seen in the Figures [5]. The triangle membership function is defined as,

$$\mu_{MU(x)} = \max(\min(\frac{x-x1}{xT-x1}, \frac{x2-x1}{x2-xT}),0) \qquad (15)$$

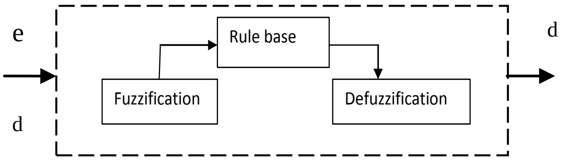


Fig 2: Basic configuration of a FLC

In Figure 5, the output space of the FLC is shown. These data also vary between –1 and 1. In Table 1, the rules of the FLC are given. Due to the 5-ruled input variables, there are 25 rules in total.

Table 1. Fuzzy rule base

e/de	**NB**	**NM**	**S**	**PM**	**PB**
NB	NB	NB	NM	NM	S
NM	NB	NM	NM	S	PM
S	NM	NM	S	PM	PM
PM	NM	S	PM	PM	PB
PB	S	PM	PM	PB	PB

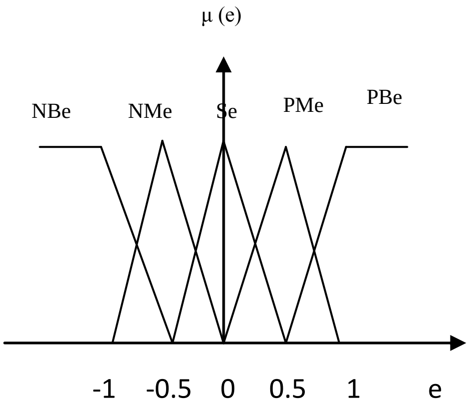


Fig 3: Error membership functions

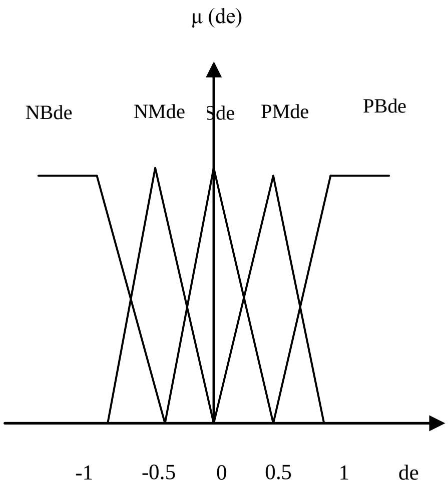


Fig 4: Variation of error membership functions

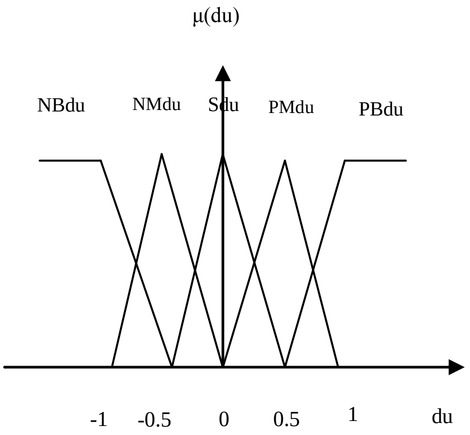


Fig 5: Output space

4. SIMULATION AND RESULTS

In Figure 6, the wind turbine is designed according to the wind characteristic equation. The wind turbine output power is given into the PMSG .In Figure 7, the FLC is designed with the help of fuzzification, fuzzy rule table and defuzzification model. It is designed to be 5-ruled. The minimum of the error and its variation to the input variables are calculated here. The centre of the area method is used in the defuzzification.

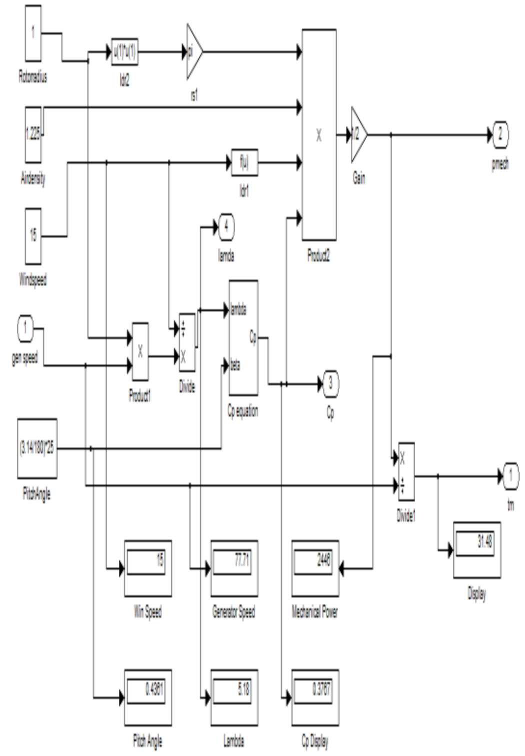


Fig 6: Simulation of wind turbine

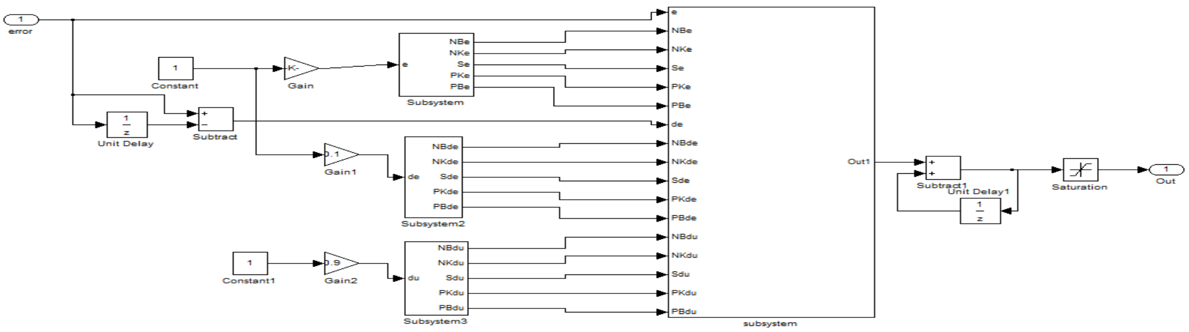


Fig 7: Simulation of fuzzy logic controller.

In order to verify control principle given in this paper, detail model of the system in MATLAB/Simulink has been developed. Figure 8 is the simulation waveform of stepwise wind speed. Figure 9 shows PWM signal and duty cycle variations are fed into the boost converter.

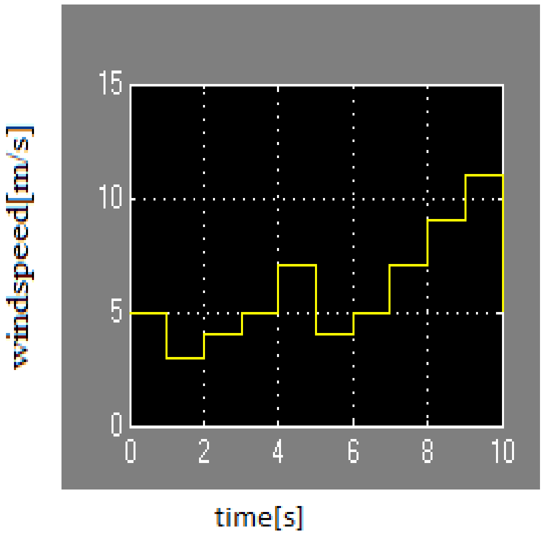


Fig 8: Stepwise wind speed profile.

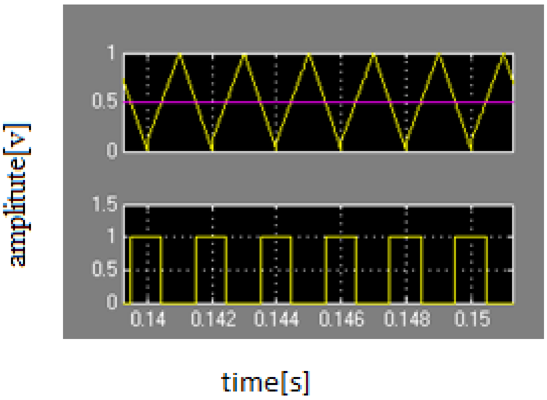


Fig 9: PWM signal and duty cycle.

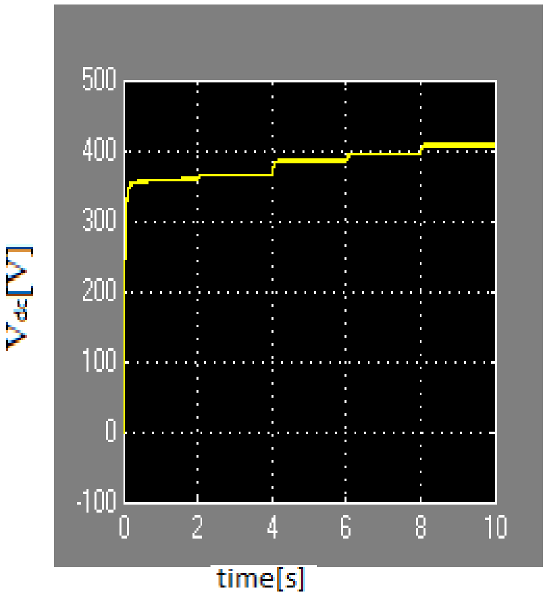


Fig 10: Boost converter voltage with fuzzy

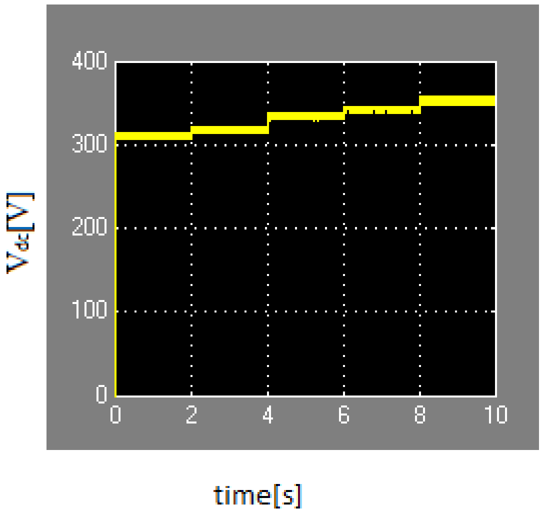


Fig 11: Boost converter voltage without fuzzy

Figure 10 and Figure 11 shows boost converter voltage with and without FLC.On comparison it is observed, fuzzy logic controller is reduces the ripple and increases the voltage to certain level.

Figure 12 shows, under variable wind speed condition voltage and current obtained are 420V, 4.7 amps at the inverter side for a constant load of 1000kW using fuzzy logic controller. Table 2 shows the inverter output for variable wind speeds for a constant load of 1000watts.

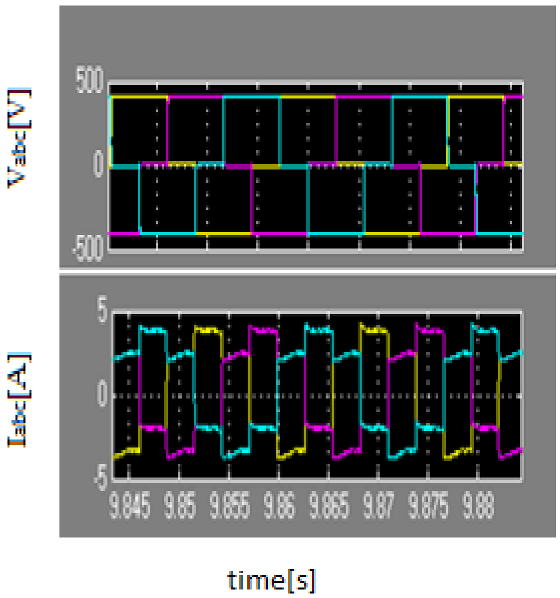


Fig 12: Voltage and current waveform for inverter

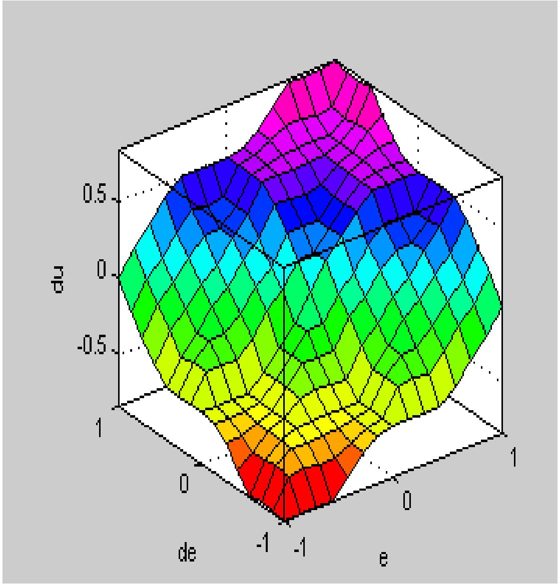
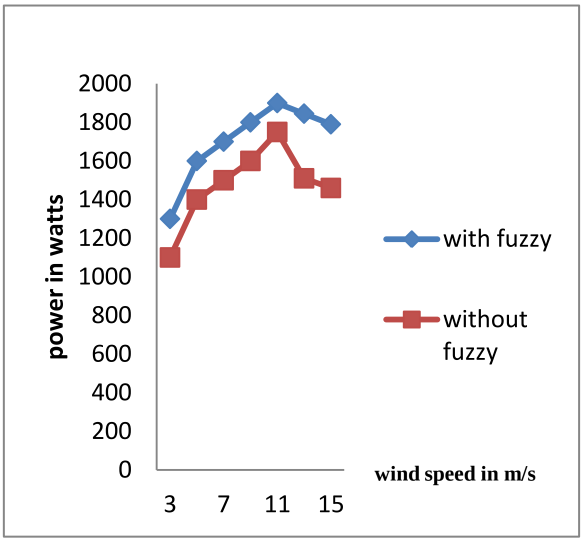


Fig 13: Rule surface of Fuzzy Logic Controller

Table 2. Output of inverter for variable wind speeds

Various wind speed in m/s	**Voltage in volts**	**Current in amps**	**Power in watts**
11	420	4.7	1974
10	420	4.7	1974
9	420	4.7	1974
8	410	4.6	1886
7	410	4.6	1886
5	400	4.5	1800
4	400	4.5	1800
3	560	4.4	1716

Graph 1 shows the comparison for maximum power of the system between with and without fuzzy logic controller under various wind speed condition.



Graph 1: Comparison between with and without fuzzy logic controller.

5. CONCULSION

A variable speed wind generator with fuzzy logic control is presented. The proposed fuzzy logic MPPT control was then combined with 3-phase boost converter. The system performance has been compared with fuzzy logic controller and without fuzzy logic controller. The system shows a fast convergence, accept noisy and inaccurate signals with fuzzy controller. The simulation result shows a stabilized maximum power should be obtained under variable wind speed and load variation with the introduction of fuzzy logic control.

6. REFERENCES

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