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MAXIMUM POWER POINT TRACKING OF WIND TURBINE CONNECTED TO DC GENERATOR USING FUZZY LOGIC CONTROLLER

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Abstract: This paper presents the fuzzy logic control based maximum power point tracking of wind turbine by operating the wind turbine at optimum speed. The optimum speed can be obtained from the power conversion coefficient versus tip speed ratio characteristics. There are many control algorithms available speed based control, torque based control, fuzzy logic control and neuro fuzzy control. Apart from the induction generator and permanent magnet synchronous generator one can also use DC generator. In this field control method is applied to control the speed of the DC generator and intern wind turbine. The maximization problem has been solved by genetic algorithm. This forms the input for the maximum power point tracking(MPPT) algorithm and at different wind velocities the turbine need to be rotated at optimum speed for extracting maximum power from the wind turbine.

Keywords- ***MPPT, power conversion coefficient, tip-speed ratio (TSR), fuzzy logic controller***

I.INTRODUCTION

Electricity generation using wind energy has been well recognized as environmentally friendly, socially beneficial, and economically competitive for many applications. Because of crucial fossil energy resources shortage and environmental issues the wind energy is very important resource for electricity production. Small wind turbines, photovoltaic systems, fuel cells and pump as turbines (PAT) in small scale are main resources for distributed generation systems. Meanwhile, for remote areas wind energy beside photovoltaic system can combine as a hybrid system to provide necessary electric power of users. This system should be designed in such a way that the load demand of remote areas be provided with maximum reliability. Usually Direct coupled axial flux permanent magnet synchronous generator (AFPMSG), self-excited induction generator with gear box and permanent magnet synchronous generator (PMSG) with gear box can be used to connect to small wind turbine. In the past few years, there have been many studies on small scale wind energy conversion systems.

Power available from wind varies as the cube of the wind speed. If the wind speed doubles, the power of the wind (the ability to do work) increases 8 times. One of the effects of the cube rule is that it has an average wind speed reflecting wide swings from very low to very high velocity, and may have twice or more the energy potential of a site with the same average that experiences little variation. The doubly-fed induction generator (operating at constant rotor speed) is being popularly used for wind power generation since the rotor circuit can be controlled in order to give the constant output voltage of the stator. However this system has a disadvantage of slip ring and the operating range is rather limited for a constant speed operation [1]-[2]. On the other hand the permanent magnet synchronous generator is presently too expensive for the high power level even though it has been already designed for commercial purpose. However it is preferable to the low power generation system since no external excitation is required [3]. For low rating wind turbine DC generator is best suitable and speed control for DC generator can be easily mplemented.

Due to the nonlinear characteristics of wind turbine there is particular operating speed at which the output power of the system is maximum for a given wind speed. This has led to the development of control techniques to control the power conditions, in such a way to extract the maximum available wind energy at any given time. There are several ways deal with the maximum output power control using machine parameters and the wind speed measurement [4]. In this paper Genetic Algorithm(GA) is used to find the generator speed which gives the maximum output [power by perturbing the generator sped reference according to the wind speed.

II. WIND TURBINE CHARACTERISTICS

The power generated by the kinetic energy of a free flowing wind stream is given by:

$$P=0.5*\rho*S*V^3 \text{ watt} \quad \text{------------ (1)}$$

The cross sectional area, S of the turbine in terms of its blade radius "R" is given by

$$S=\pi*R^2 \text{ m}^2 \quad \text{------------ (2)}$$

From 1 and 2

$$P=0.5*\rho*\pi*R^2*V^3 \quad \text{----------- (3)}$$

The power conversion coefficient, Cp is defined as the power extracted by the turbine relative to that available in the wind stream.

$$Cp=Pt/P=Pt/0.5*\rho*\pi*R^2*V^3 \quad \text{--------} \ (4)$$

The maximum achievable power factor is 59.26% and is designated as Betz limit. In practice, values of obtainable power coefficients are in the range of 45%. This value below the theoretical limit is caused by the inefficiencies and losses attributed to different configurations, rotor blades and turbine designs.

Neglecting the friction losses, the mechanical power available to be converted by the generator is given by

$$P_M=0.5*P*\Pi*R^2*V^3*C_P \quad \text{-----------} \ (5)$$

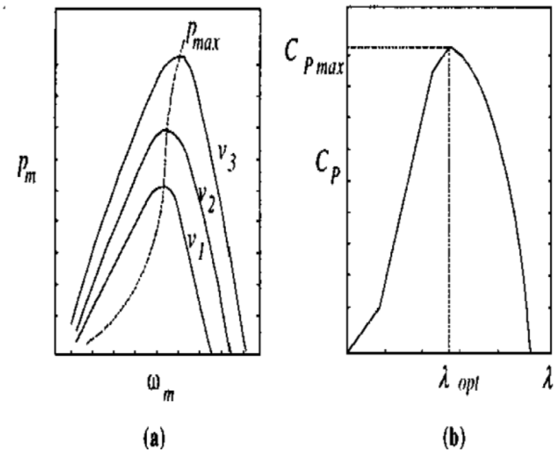


Figure 1: (a) Variation of wind turbine mechanical power with sped (b) Variation of power conversion coefficient Cp with tip-speed ratio λ

The power conversion coefficient is a function of the tip-speed ratio λ which is defined as

$$\lambda = \frac{\omega_m R}{\upsilon} \quad \text{---------------} \ (6)$$

Where ω_m and R are the rotor speed and radius of the turbine blade, respectively. Fig 1(a) shows that the power converted from the turbine blade is a function of the rotational speed and that the power converted is maximum at the particular rotational speed. Fig1 (b) shows that the average power conversion coefficient Cp is maximum at a particular λ

Hence to fully utilize the available wind energy to obtain the maximum output power, λ should be maintained at its optimum value λ_{opt}. In this case the maximum available power at any wind speed is given by

$$P_{max} = 0.5.\rho.C_{p\,max}.\upsilon^3 \quad \text{------------} \ (7)$$

And the reference speed in the control scheme is determined according to the optimum tip-speed ratio

$$\omega_m^* = \frac{\lambda_{opt}}{R}\upsilon \quad \text{--------------} \ (8)$$

III. WIND TURBINE MODEL

The model is based on the steady-state power characteristics of the turbine. The output power of the turbine is given by the following equation.

$$P_m = c_p(\lambda,\beta)\frac{\rho A}{2}\upsilon_{wind}^3 \quad \text{.................} \ (9)$$

Where,

Pm-Mechanical output power of the turbine (W)

Cp-Power Conversion coefficient of the turbine

P-Air density (kg/m3)

A-Turbine swept area (m2)

Vwind-Wind speed (m/s)

λ-Tip speed ratio of the rotor blade tip speed to wind speed

ß-Blade pitch angle (deg)

A generic equation is used to model Cp(λ,ß).This equation, based on the modelling turbine characteristics of [5], is:

$$c_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda$$

with

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad \text{......} \ (10)$$

The coefficients c1 to c6 are: c1 =0.5176, c2 = 116, c3 = 0.4, c4 =5, c5 = 21 and c6 = 0.0068 and β= 0°.

In order to obtain the maximum power from the wind turbine, wind turbine has to rotate at optimum speed and we need optimum tip-speed ratio. The power conversion coefficient equation (10) is maximized using Genetic Algorithm and optimum tip-speed ratio is obtained. This forms the input for MPPT algorithm.

IV. Maximum power point tracking using fuzzy logic controller

The fuzzy logic control is applicable search the generator speed reference which tracks the maximum output power point at varying wind speeds [5]-[6]. The FLC (fuzzy logic controller) block diagram is shown in figure 2. The FLC doesn't require any detailed mathematical model of the system and its operation is governed simply by a set of rules.

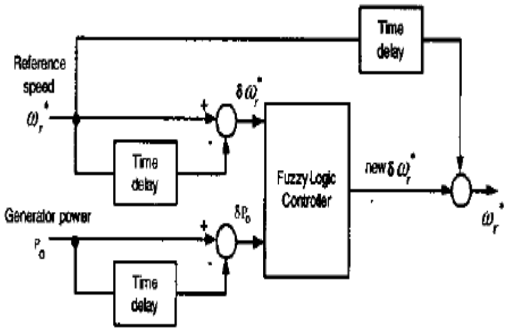


Figure 2: Input and output of fuzzy controller

The principle of the FLC is to perturb the generator reference speed ω_r* and to estimate the corresponding change of output power Po. If the output power increases with the last increment, the searching process continues in the same direction. On the other hand, if the speed increment reduces the output power, the direction of the searching is reversed. The fuzzy logic controller is efficient to track the maximum power point, especially in case of frequently changing wind conditions.

The input (Po and ω_r*) and output (ω_r*) membership functions are shown in Fig 3. Triangular symmetrical memebership functions are suitable for the input and output, which give more sensitivity especially as variables approach to zero value. The width of variation can be adjusted according to the system parameter.

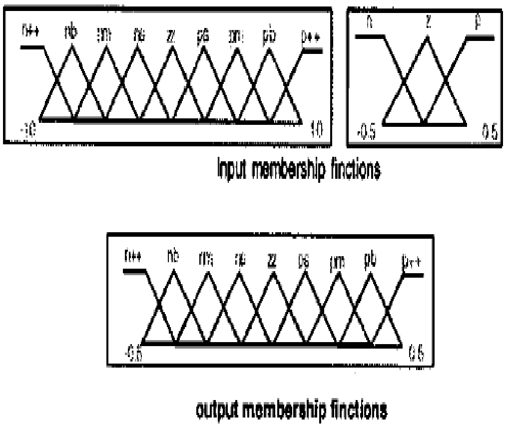


Figure 3: Membership functions of fuzzy controller

The input signals are first fuzzified and expressed in fuzzy set notation using linguistic labels which are characterized by membership functions before it is processed by the FLC. Using set of rules and a fuzzy set theory, the output of the FLC is obtained [8]. This output, expressed as a fuzzy set using linguistic labels characterized by membership functions, is defuzzified and then produces the controller output.

Table I lists the control rule for the input and output variable. The next fuzzy levels are chosen for controlling the inputs and output of the fuzzy logic controller. The variation step of the power and the reference speed may vary depending on the system. In Fig 3, the variation step in the speed reference is from -0.5 [rad/s] to 0.5 [rad/s] for power variation ranging over from -10 [W] to 10 [W]. The membership definitions are given as follows: n(negative), n++ (very big negative), nb(negative big), nm(negative medium), ns(negative small), z(zero), p(positive), ps(positive small), pm(positive medium), pb(positive big), p++(very big positive).

V. RESULTS

The parameters of wind turbine are listed in Appendix table II. The equation (10) has been optimized (maximized) with the given turbine parameters using genetic algorithm. The actual and maximum power conversion coefficients are 0.375674, 0.48001 respectively. The results of the genetic algorithm are shown in table II

Figure 4 shows wind turbine DC generator setup for maximum power point tracking using fuzzy logic controller.

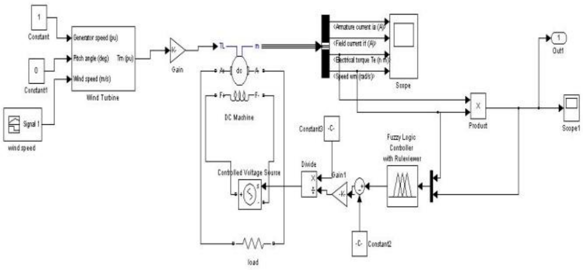
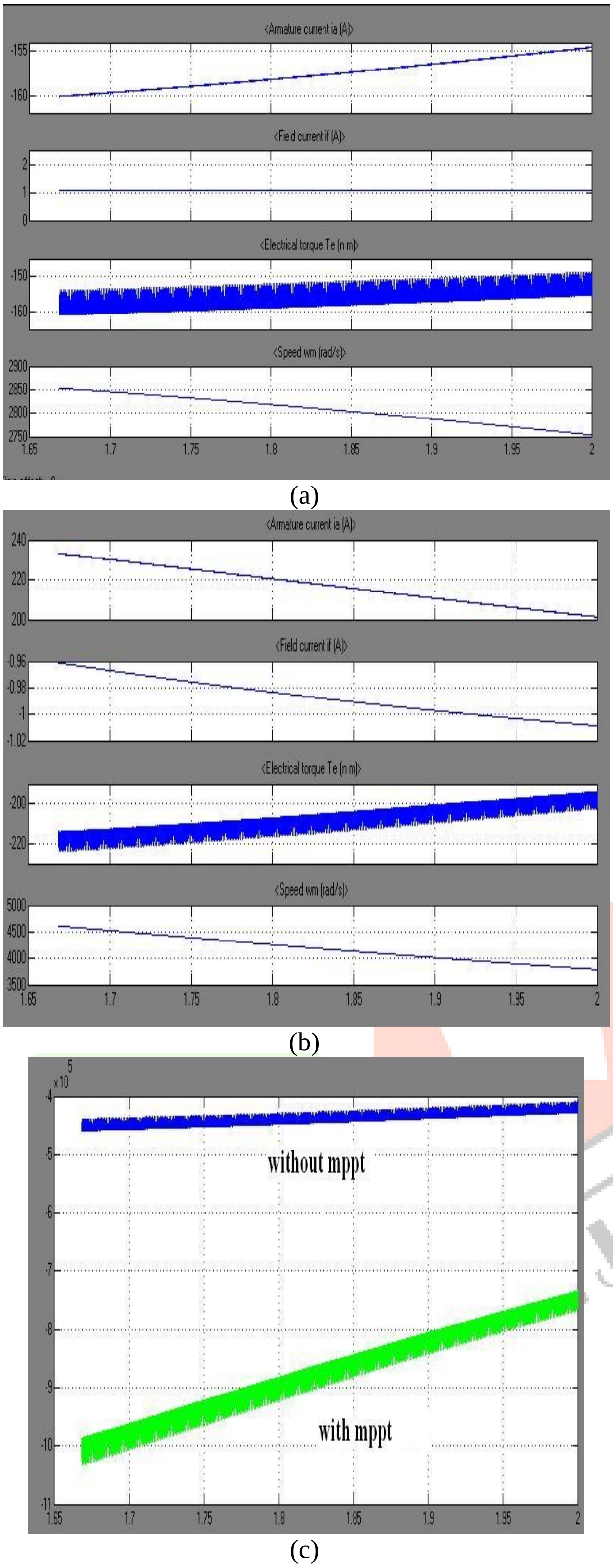


Figure 4: wind turbine DC generator set



(a)

(b)

(c)

Figure 5: DC generator outputs (a) armature current, field current, mechanical speed and torque without MPPT (b) armature current, field current, mechanical speed and torque with MPPT (c) power with and without MPPT

VI. CONCLUSIONS

Fuzzy logic controller based maximum power point tracking has been proposed and demonstrated to extract maximum power from the wind turbine connected to DC generator. The optimum point has been obtained from genetic algorithm. The outputs are tested for different generators connected to wind turbine. The DC generator was controlled in field-control method and its speed reference was determined by fuzzy rules. The wind turbine runs in standalone mode. Power has been enhanced by 27.04% and effective utilization of wind resources. The proposed algorithm was effective in tracking the optimum point.

APPENDIX

The DC generator used for test is 5HP, 240V, 1750 RPM, field-300V, of which parameters are listed in table IV.

Table 1: Rules of fuzzy logic controller

	n++	nb	nm	ns	z	ps	pm	pb	p++
n	p++	pb	pm	ps	z	ns	nm	nb	n++
z	nb	nm	ns	ns	z	ps	pm	pm	pb
p	n++	nb	nm	ns	z	pm	pm	pb	pb

Table 2: Parameters of wind turbine

Air density(ρ)	1.225 [kg/m^3]
Radius of turbine blades	43 [m]
Rated wind speed	20 [m/s]
Tip speed ratio	6
Cut in speed	5 [m/s]
Power conversion coefficient	0.375674
Pitch angle	0 [degrees]

Table 3: Genetic algorithm results

Parameter	Actual	Genetic algorithm
Power conversion coefficient, Cp^{max}	0.48	0.48001
Tip speed ratio, λ_{opt}	8.1	8.110236

Table 4: Parameters of DC machine

Parameters	Value
Armature resistance	2.581[Ω]
Armature inductance	0.028[H]
Field resistance	281.3[Ω]
Field inductance	3.156[H]
Field-armature mutual inductance	0.9483[H]
Total inertia	0.02215 Kg.m^2
Viscous friction coefficient	0.002953 N.m.s
Coulomb friction torque	0.5161 N.m

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