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MPPT of PMSG based Wind System using Fuzzy Logic Algorithm

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Abstract: Permanent magnet synchronous generator (PMSG)-based wind turbine is considered as one of the promising technologies for generating electric power from wind energy. This paper presents an artificial intelligent technique based on fuzzy logic controller (FLC) to enhance the maximum power point tracking (MPPT) of PMSG-based wind turbine. The power output from wind turbines varies nonlinearly with the wind speed, the speed of the turbine blade tips and the blade pitch angle. At a given pitch angle and wind velocity, maximum power is obtained at a specific turbine angular speed. Since wind speeds typically vary over a wide range, the turbine speed needs to be continuously adjusted so that its power output can be maximized. A complete model of Wind turbine, PMSG and Fuzzy logic control MPPT technique is conducted using MATLAB/Simulink platform. On the basis of the results, good tracking with high accuracy and lower oscillation rate are obtained after using FLC.

Index Terms: Wind System, Maximum Power Point Tracking (MPPT), Fuzzy Logic Control (FLC).

I. INTRODUCTION

With the increase of electrical energy demand, wind turbines became one of the important facilities for generating renewable and clean electric power. Mainly, there are many essential reasons for using more wind energy on power grids. For example, wind generation is supported by not only being clean and renewable but also having minimal running cost requirements [1]. The wind turbine control objectives are mainly to optimize wind energy conversion, and to reduce dynamic loads experienced by the plant mechanical structure. Indeed, dynamic loads hardly affect wind turbine lifetime and mainly determine mechanic components design, and consequently their cost.

Fixed-speed wind turbines normally cause a voltage drop during start-up. The voltage drop is mainly caused by reactive power consumption during magnetization of the generator. Another problem concerned to wind turbines with fixed speed is the flicker produced during normal operation of the wind turbine. Once this method the energy extraction is optimized for one point of operating, it means that for only wind speed is achieved the maximum value of extraction.

However, in a wind power generation system, the proportion of available wind power converted to mechanical power of the turbine is largely dependent on the blade-tip speed to the wind speed ratio of the turbine [2]. Consequently, the power generated is a nonlinear function of the turbine angular speed and the wind speed, for a fixed blade pitch angle. With large and abrupt variations in wind speed, it is therefore necessary to extract maximum power from the wind under normal operating conditions. As a result, the generating system is also required to operate at variable speed, giving significant improvements in power efficiency, compared to fixed speed operation. Variable-speed wind turbines operate in two primary region, below-rated power and above rated power. When power production is below the rated power for the machine, the turbine operates at variable rotor speeds to capture the maximum amount of energy available in the wind [3].

This paper present a fuzzy controlled maximum power point tracking system suitable for the PMSG at various speeds. The proposed system uses the generator speed measurements to search for the optimum speed at which the turbine should operate for producing maximum power. The effectiveness of the proposed control scheme is validated through computer simulations under varying wind speeds.

II. MODELLING OF WIND ENERGY SYSTEM

As described in Fig. 1, the rotor blades of the wind turbine convert the kinetic energy of the wind to mechanical energy and the PMSG converts the mechanical power to electrical power. The stator of PMSG is connected to the utility grid through a BTB converter. The BTB converter consists of two parts: the first one is the machine side converter (MSC), which is responsible to accomplish the MPPT strategy. The second part is the grid side converter (GSC) that is connected to the grid through ac filter and is responsible to control the dc-link voltage and the reactive power. Complete configuration of PMSG along with its control system and MPPT techniques are conducted in Fig.1 [4].

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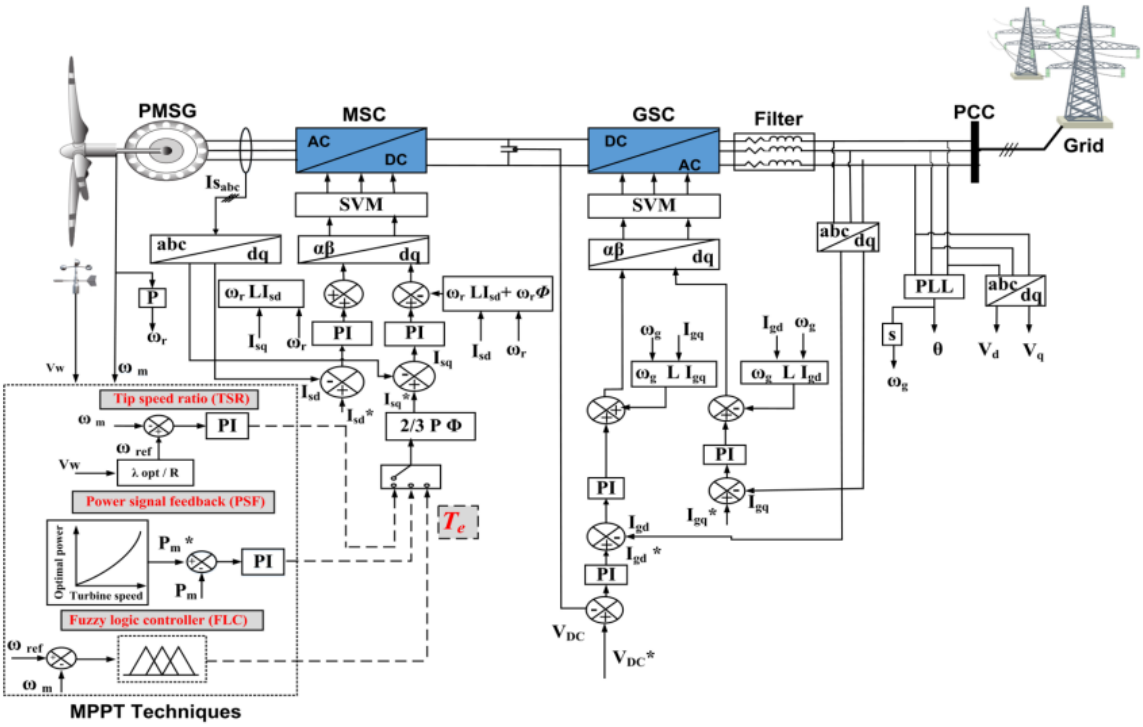

Figure 1 The configuration of PMSG based wind turbine with the control system.

A. Mathematical Modelling Of Wind Turbine

The wind turbine rotor converters the kinetic energy of wind into mechanical energy. Equation (1) follows the mechanical behaviour of the wind turbine. The supply of maximum power that can be cull from wind energy conversion system (WECS) and fed to the permanent magnet synchronous generator is dependent on rotor swept area, performance coefficient or power coefficient, wind speed and air density [5-7].

$$P_{Turbine} = \frac{1}{2}\rho\pi R^2 C_P(\lambda, \beta) v^3 \quad (1)$$

where,
ρ = *air density* (kg/m^3)
R = *radius of the rotor blade* (m)
β = *pitch angle of the rotor blade* (*degree*)
C_P = *performance coefficient of the wind turbin*
v = *wind speed* (m/s)
The performance coefficient value, Cp, is reliant on two variable components : tip speed ratio (TSR) and pitch angle. The TSR indicates the proportion of the tip speed of the turbine blade over the wind speed and is given as equation (2). The pitch angle indicates the angle in which the turbine blades are aligned with respect to their longitudinal axis [8]. Here we have considered pitch angle as zero degree.
The tip speed ratio λ is given by:

$$\lambda = \frac{\omega_m R}{v} \quad (2)$$

where,
ω_m = *wind turbine rotor speed* (rad/sec)
The mechanical torque (T_m) obtained from the wind turbine is given by:

$$T_m = \frac{1}{2}\rho\pi R^2 C_P(\lambda, \beta) v^3 \frac{1}{\omega_m} \quad (3)$$

The coefficient of power conversion $C_P(\lambda, \beta)$ is given as:

$$C_P = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\left(\frac{21}{\lambda_i}\right)} \quad (4)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (5)$$

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B. Mathematical Modelling Of PMSG

The dynamic model of the PMSG has been presented in [9-12]. The stator voltages V_{sd} and V_{sq} relating to dq reference frame can be described in Eq. (6) and (7):

$$v_{qsn}{}^{r} = (R_{sn} + \frac{L_{qn}}{\omega_b} p)\, i_{qsn}{}^{r} + \omega_{rn}(L_{dn} i_{dsn}{}^{r} + \lambda_{afn}) \quad (6)$$

$$v_{dsn}{}^{r} = -\omega_{rn} L_{qn} i_{dsn}{}^{r} + (R_{sn} + \frac{L_{dn}}{\omega_b} p)\, i_{dsn}{}^{r} \quad (7)$$

where,

$v_{qsn}{}^{r}$, $v_{dsn}{}^{r}$ = *quadrature axis and direct axis stator voltage*

$i_{qsn}{}^{r}$, $i_{dsn}{}^{r}$ = *quadrature axis and direct axis stator current*

L_{qn}, L_{dn} = *quadrature axis and direct axis inductance*

R_{sn} = *stator resistance*

λ_{afn} = *flux induced by the permanent magnet*

ω_{rn} = *speed of the generator*

ω_b = *base speed*

p = differential operator, $\frac{d}{dt}$

The normalized electromagnetic torque T_{en} (in per unit) is given by:

$$T_{en} = i_{qsn}{}^{r} [\lambda_{afn} + (L_{dn} - L_{qn}) i_{dsn}{}^{r}] \quad (8)$$

where, $$\lambda_{afn} = \frac{\lambda_{af}}{\lambda_b} \quad (9)$$

The electromagnetic torque, T_e is described in Eq. (10)

$$T_{en} = \frac{3}{2} P\, I_{qsn} ((L_d - L_q) I_{dsn}) \quad (10)$$

The normalized electromechanical dynamic equation is given by:

$$p\omega_{rn} = \frac{1}{2H}(T_{en} - T_{mn} - B_n \omega_{rn}) \quad (11)$$

where, $$H = \frac{1}{2}\left(\frac{J\omega_b^2}{P_b(\frac{P}{2})^2}\right) \quad (12)$$

is known as the inertia constant, the normalized friction coefficient is,

$$B_n = \frac{B\omega_b^2}{P_b(\frac{P}{2})^2} \quad (13)$$

where, T_{mn} is the normalized mechanical torque, J is the moment of inertia, P is the number of poles and B is the friction coefficient.

III. Fuzzy Logic MPPT Control

Performance enhancement of the complex and nonlinear wind system for variable wind speed profile constitute the main contribution of this research. This goal is achieved by using the proposed FLC, which tracks the MPP from the WT system with good dynamic behaviour in terms of steady and dynamic response of the system under fluctuating wind conditions and ensures efficient and reliable grid integration of the wind turbine. The proposed FLC is illustrated in Fig. 2 [13].

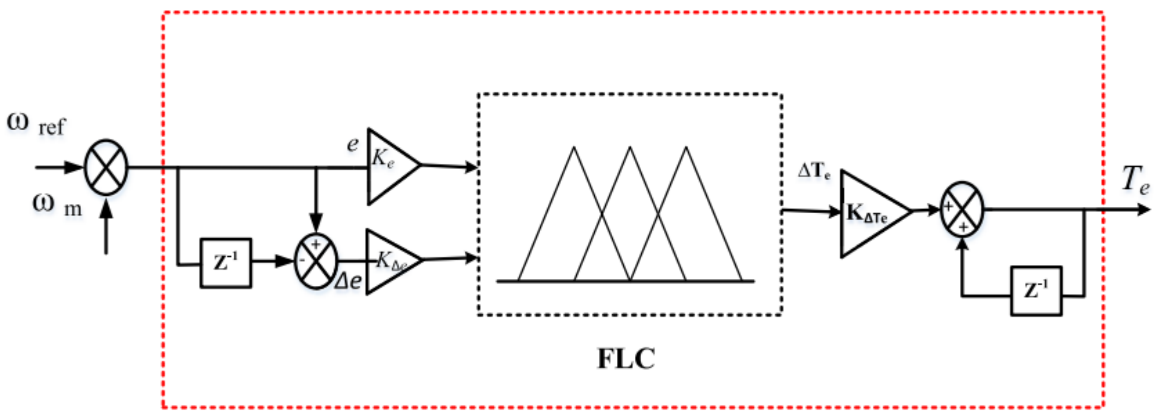

Figure 2 FLC structure

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The input quantities of FLC are the mechanical speed error (e) and the change of this error (Δe), the unit time delay is represented by the symbol (Z −1), and the change in electromagnetic torque (ΔT_e) is the output. The input and output signal scaling factors are, K_e, $K_{\Delta e}$ and $K_{\Delta Te}$, respectively. There are many methods to implement the scaling fuzzy controller. In this study, the trial-and-error method is applied. Input and output signal scaling factors of K_e, $K_{\Delta e}$ and $K_{\Delta Te}$, respectively, are used to alteration the sensitivity of the FCL according to the random change of the wind without causing any modification to the control unit structure. There is always an input limitation for FLC so that inputs and output are normalized within [1; −1] interval, by dividing them by the set point value. The values of scaling gains are: $K_e = 0.1$, $K_{\Delta e} = 0.969$ and $K_{\Delta Te} = 5$.

The FLC inputs are determine by using the following equations [14]:

$$e = \omega_{ref} - \omega_m \qquad (14)$$

$$\Delta e = (1 - Z^{-1})\, e \qquad (15)$$

As demonstrated in Figure 3, FLC composed, in general, of three sections: 1) fuzzification, 2) knowledge base (fuzzy rule base, data base), 3) defuzzification. In the fuzzification process, the input crisp values are converted to fuzzy values, which are realized by linguistic variables, e.g., high, big, medium, slow etc. The fuzzy rules are depended on a set of rules, which depend on IF–THEN rule [14], [15].

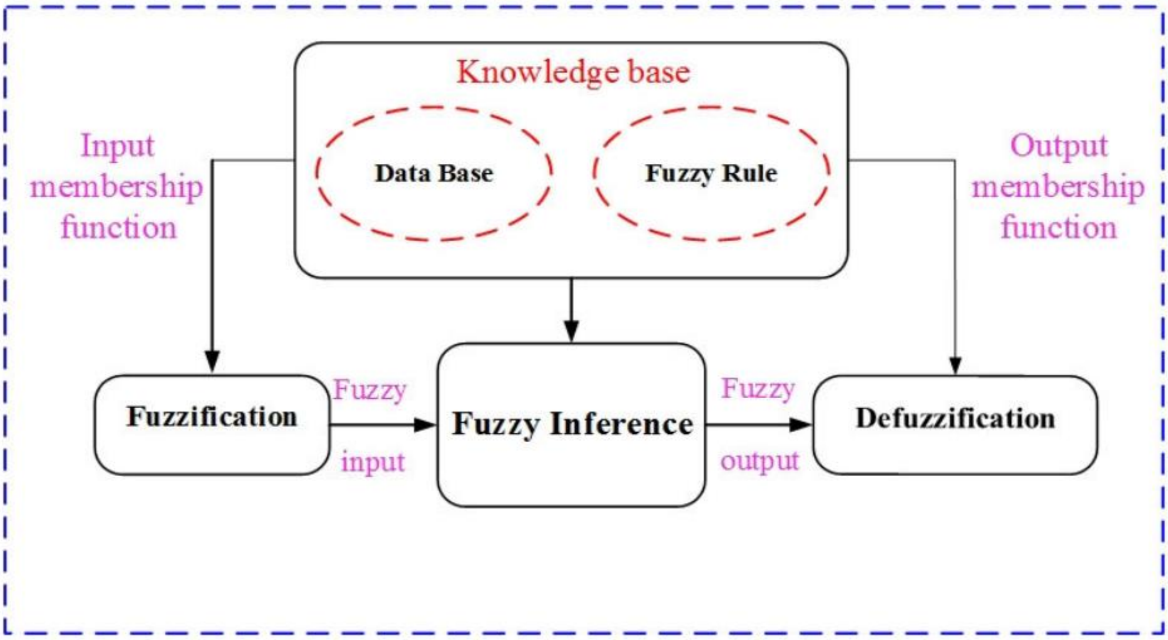

Figure 3 Fuzzy MPPT structure

As conducted in Table 1, the required signals are based on 25 rules of matrix inference, where the membership function determines the relevance between these rules. PS, NS, NB, PB and ZE are abbreviations for Positive-small, Negative-Small, Negative-Big, Positive-Big and Equal-Zero, respectively. The membership functions of the input and output are depicted in Fig. 4.

OUTPUT		**e(t)**				
		NB	**NS**	**ZE**	**PS**	**PB**
Δe(t)	**NB**	**NB**	**NB**	**NS**	**NS**	**ZE**
	NS	**NB**	**NS**	**ZE**	**ZE**	**PS**
	ZE	**NB**	**NS**	**ZE**	**ZE**	**PS**
	PS	**NS**	**PS**	**PS**	**PS**	**PB**
	PB	**ZE**	**PS**	**PB**	**PB**	**PB**

Table 1 Rule base of FLC

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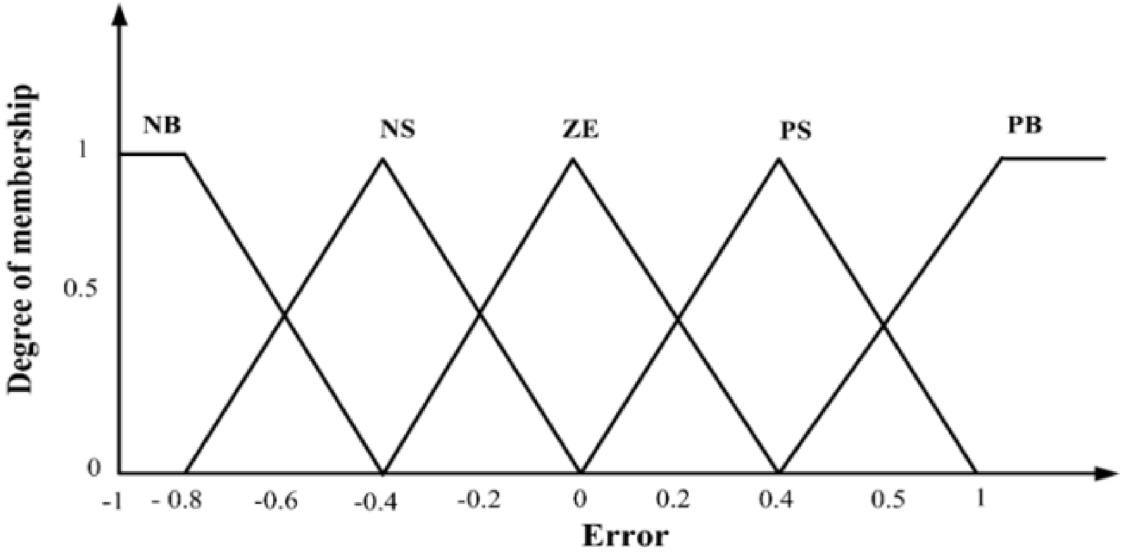

Figure 4 The inputs and output of the membership function

The defuzzification process is responsible for converting the fuzzy quantity to exact quantity. This process depends on the center of gravity technique to realize the crispy output variable (ΔT_e) and the reference electromagnetic torque as shown in the following equations.

$$T_e(k) = T_e(k-1) + \Delta T_e \quad (16)$$

IV. SIMULATION RESULTS

A wind turbine model and a PMSG model with parameters shown in Table 2 is constructed and used to test the performance of the proposed fuzzy logic control system.

Parameters	**Value**
Air density	1.08 kg/m^3
Rotor blade radius	3.1905 m
Base wind speed	12 m/s
Pitch angle	0 degree
Generator stator resistance	0.985 Ω
Generator stator q-axis inductance	0.01 H
Generator stator d-axis inductance	0.01 H
Flux induced by the permanent magnet	0.9 Wb
Moment of inertia	25 $kg \cdot m^2$
Pole pairs	3
Generator rated power	10 kW

Table 2 The PMSG and wind turbine parameters

Fig. 5 shows a wind speed profile, Fig. 6 shows a wind turbine power with and without MPPT. Fig. 7 shows a generator speed with and without MPPT. Fig. 8 shows a power conversion coefficient with and without MPPT. Fig. 9 shows a electromagnetic torque in p.u. with and without MPPT.

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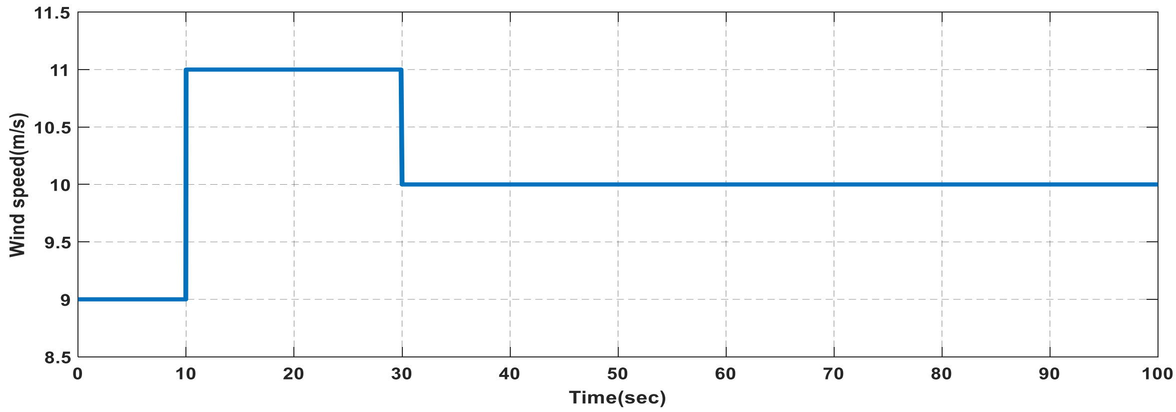

Figure 5 Wind Speed Profile

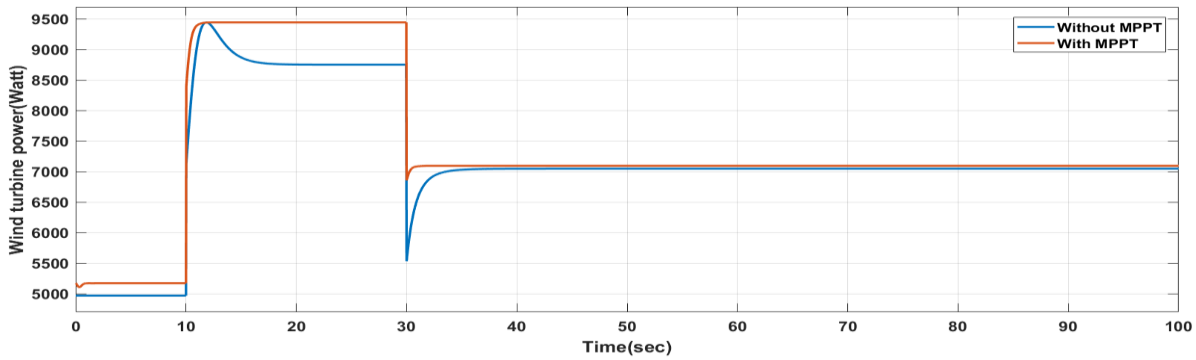

Figure 6 Wind Turbine Power in Watts

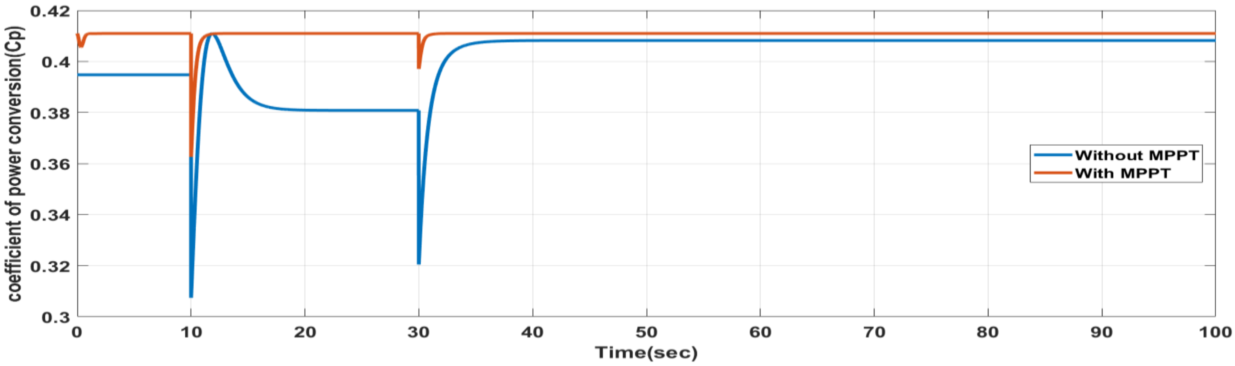

Figure 7 Generator Speed

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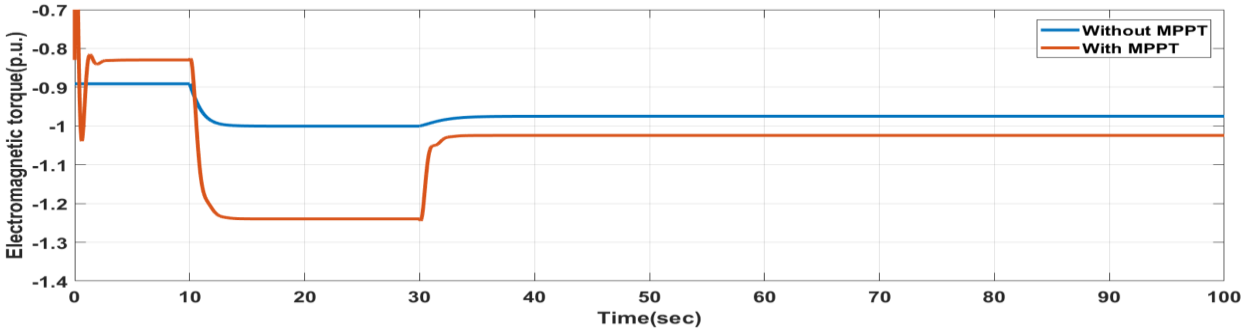

Figure 8 Power Conversion Coefficient

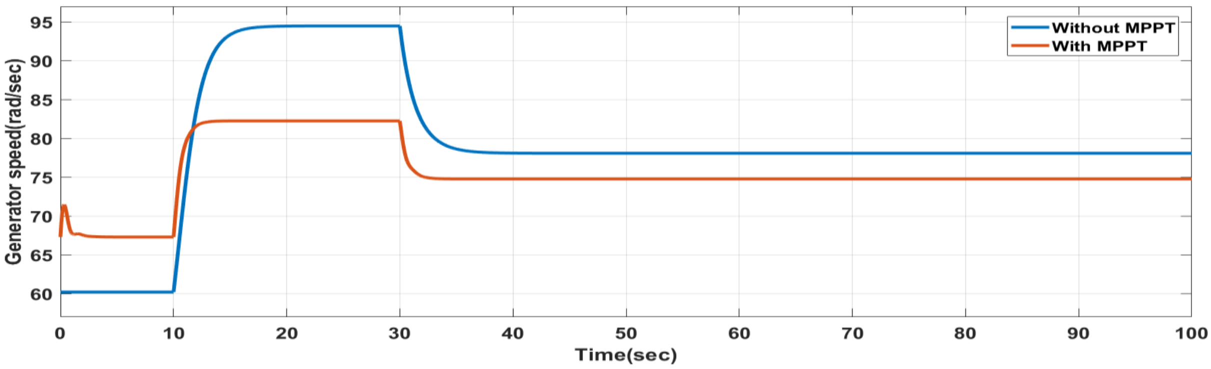

Figure 9 Electromagnetic Torque in p.u.

V. CONCLUSION

A fuzzy logic - based MPPT for PMSG variable speed wind turbine system has been proposed in this paper. It has been shown that the turbine power output non-linearly depends on its rotor speed and the wind speed. Fuzzy control approach is quite suitable for searching the optimal rotor speed at which the turbine operates with the maximum power value. The performance of the proposed system has been verified under the changes of wind. The proposed MPPT algorithm shows good performances under various operating conditions.

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