American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-3, Issue-9, pp-177-184
www.ajer.org
Research Paper Open Access

A fuzzy-logic based MPPT method for stand-alone wind turbine system

Huynh Quang Minh, Ngo Cao Cuong, Tran NguyenChau

ABSTRACT : *In this paper, a fuzzy-logic based maximum power point tracking (MPPT) method for a stand-alone wind turbine system is proposed. Hill climb searching (HCS) method is usedto achieve the MPPT of thepermanent magnet synchronous generator (PMSG) driven wind turbine system. Simulation results will show the effectiveness of the proposed method in various operating conditions.*

KEYWORDS: *wind energy conversion system; permanent magnet synchronous generator; stand-alone; maximum power point tracking; hill climb searching; fuzzy logic control;*

I. INTRODUCTION

In recent years, the use of renewable energy resources is more and more increased due to the increasing need for energy and the shortage of traditional energy sources in the near future [1]. The literature review shows that, renewable energy systems are not cost competitive against conventional fossil fuel power systems, but the need for cleaner power and improvements in alternative energy technologies make a wide-spread use and application of such systems [2].

Many research and development in wind energy conversion system (WECS) have shown their excellent potential for remote areas located far from power stations and distribution networks which are uneconomical to install [3]. Among those, PMSGs are oftenchosenfor stand-alone WECS because of its advantages: higher reliability, less maintenance and more effectiveness. Besides, it is suitable for variable speed operation, which provides 10-15% higher energy output, lower mechanical stress and less power fluctuation compared withconstantspeedoperation. A system of variable speed PMSG wind turbine has more flexibility because it can adapt wind variations [4].

In this paper, a direct searching MPPT controller is designed for variable speed PMSG driven wind turbine. With this proposed method, wind generator gives maximum power without any knowledge about generator's characteristic or ambient condition. Control algorithm is independent, achieving the fast dynamic responses for the complex nonlinear system.

II. SYSTEM DESCRIPTION

The WECS consists of a wind turbine coupled to a PMSG to power a stand-alone system. A three-phase diode bridge rectifier is used for the AC/DC conversion. A boost converter (DC/DC 1) is used to vary the rotor speed. A FLC is designed to track the MPP of the WECS by adjusting the duty ratio of this converter. The proposed control algorithm is independent on turbine characteristics, achieving the fast dynamic responses. Another DC/DC converter (DC/DC 2) is used to boost the system’s voltage to a sufficient value for a voltage source inverter which provides a sufficient voltage to load. A battery bank is also used to store surplus power and recompense when wind power is not enough for load demand (Figure 1).

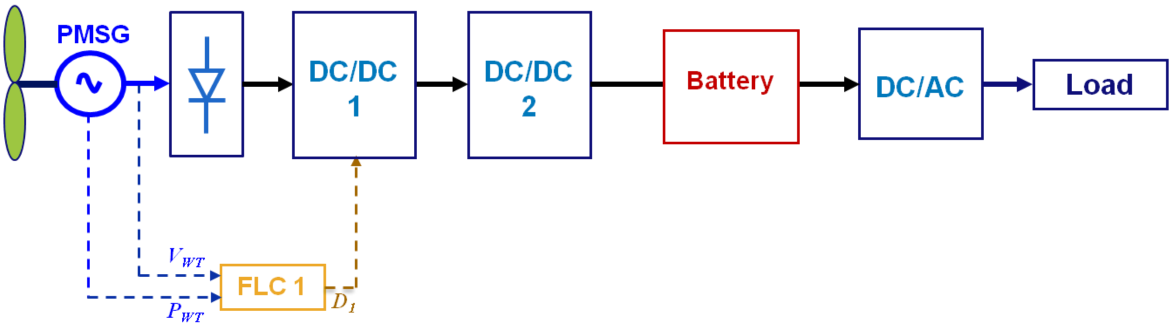

Figure 1. Stand-alone WECS.

III. WIND ENERGY CONVERSION SYSTEM

1.Wind aerodynamic

Mechanic power of a wind turbine can be expressed in terms of the air densityρ, the blade radius R_{blade}, and is the wind speed v_{wind}[9]:

$$P_m=0.5C_p\rho\pi R_{blade}^2\ v_{wind}^3 \qquad (1)$$

where C_p is the power coefficient. This coefficient is also known as Betz limit. It can be expressed in terms of reduced velocity λ and blade angleθ. If Ω is the rotor speed, the reduced speed λ is defined:

$$\lambda = \Omega\ R_{blade}/v_{wind} \qquad (2)$$

A generic equation is used to model the power coefficient $C_p = C_p(\lambda,\theta)$, based on the modeling turbine characteristics described in [10]:

$$C_p(\lambda,\theta)=0.5(98/\lambda_i - 0.4\beta - 5)e^{-(16.5/\lambda_i)} \qquad (3)$$

where:

$$\lambda_i = \frac{1}{\frac{1}{\lambda+0.089} - \frac{0.035}{\beta^3+1}} \qquad (4)$$

The characteristic function C_p vs. λ, for various values of the pitch angle β, is illustrated in figure 2. The maximum value of C_p is achieved for $\beta=0^0$. This particular value λ_{opt} results in the point of optimal efficiency where the wind turbine captures the maximum power [10]. In this work, a typical small-sized three-bladed horizontal-axis wind turbine generator with no blade pitch angle control is considered, so that $\beta=0^0$ at all times.

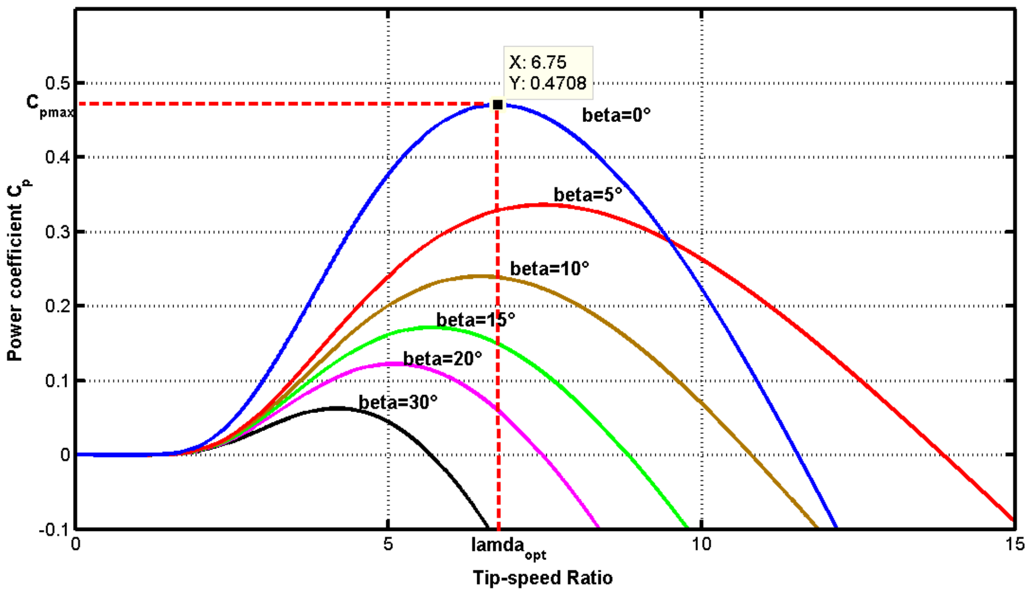

Figure 2. C_p vs λ, for various pitch angles β

For each wind speed v_{wind}, there is a maximum rotor speed Ω_{opt}(or ω_{opt})which made a maximum power recovered from the wind turbine (Figure 3).

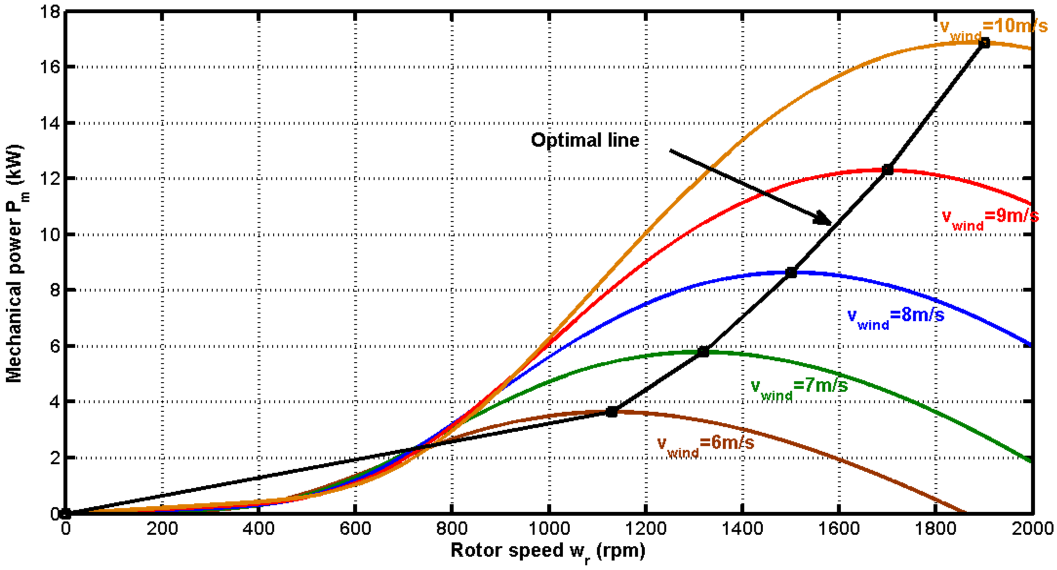

Figure 3.Power versus rotor speed at various wind speeds

2. Electrical system modeling

In PMSG wind generation systems, the output current and voltage are proportional to the electromagnetic torque and rotor speed, respectively [9]:

$$T_e = k_T I_a \quad (5)$$

$$E = k_e \omega \quad (6)$$

where I_a is the stator current, ω is the rotor speed, k_T and k_e is the torque and voltage coefficient, respectively.

Output voltage of the wholesystem[9]:

$$V_{DC} = \frac{1}{1-D_2}\frac{3\sqrt{6}}{\pi}\omega\sqrt{k_e^2 - \left(\frac{T_e L_s}{k_T}\right)^2} \quad (7)$$

So with a specific wind speed, if we vary the system's output voltage by adjusting the duty cycle D_2, rotor speed will be controlled. By applying this strategy,the maximum power of wind energy is achieved when rotor speed achieve its optimum value[11].

3. Proposed fuzzy MPPT controller

AnWECS involves the air masses complex dynamics, the wind regimes tochastic nature and the turbine and generator non-linear behavior. In such kind of applications, the fuzzy-logic based controllershaveshownbetterperformanceandsomeothersadvantages.The mathematical model is not necessary to controller synthesis; it tolerates parameter imprecisions or parameter variations [12].

Koutroulis et al. [13] has proposed a MPPT algorithm which is based on the fact that dP/dD=0 in the MPP, and from that calculate the new duty cycle to track the MPP when wind speed change. Trinh et al. [14] has based on the same equation, but using a FLC to follow the MPP. Both show that neither wind generator'scurves nor actual wind speed is required. However, it just can apply for a constant load demand. If load demand varies while wind speed remains constant, current and voltage of the system will change but dP/dD still remains at the same value so the controller cannot recognize that change, thus the system will not work in the true MPP. So these methods can not apply for a stand-alone system where load demand varies in time.

Here we propose a modified HCS method which base on the relationship between wind power and rotor speed at the MPP:

$$dP/d\omega=0 \quad (8)$$

Applying the chain rule, we have:

$$dP/d\omega=(dP/dV).(dV/d\omega) \quad (9)$$

In a PMSG, rotor speed is proportional to the generator phase voltage, so:

$$dV/d\omega>0 \quad (10)$$

Then:

$$dP\backslash d\omega=0 \Rightarrow dP/dV=0 \quad (11)$$

Applying this principle in the HCS algorithm: On the MMP, we have dP/dV=0. If we are in the up-hill region (dP/dV>0), we should increase the voltage to reach the MPP. If we are in the down-hill region (dP/dV<0), we should decrease the voltage to reach the MPP (Figure 4). Thus, whenever wind speed or load demand change, wind turbine power or wind turbine output voltage will vary, so the controller can recognize these change and react to reach the new MPP.

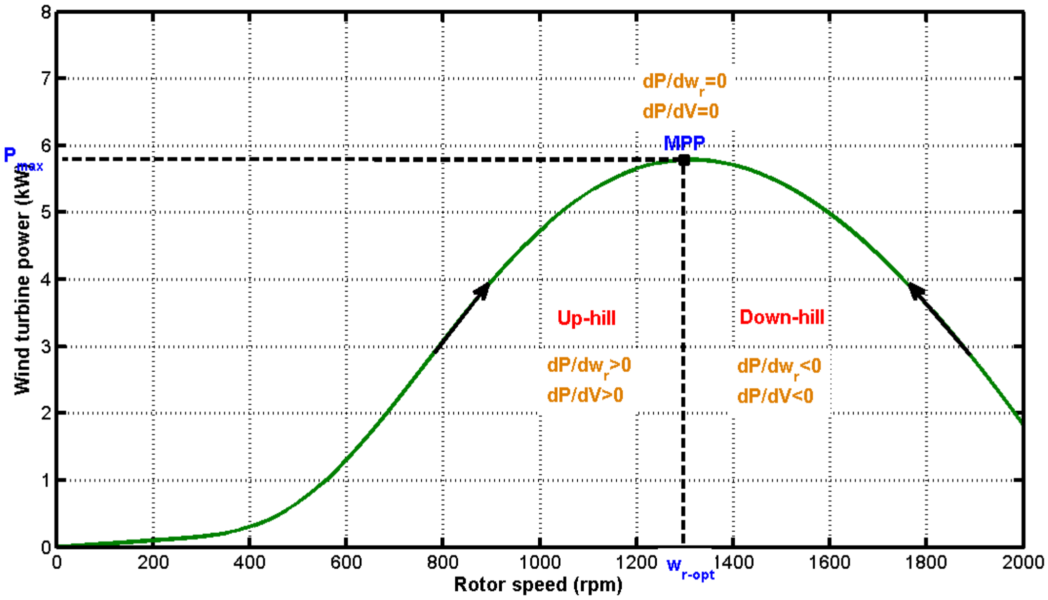

Figure 4. MPP in function of rotor speed

To implement this algorithm in a FLC, we need two inputs: change in wind turbine power (dP/dV) and its derivative, output is duty cycle D_1 of the converter DC/DC 1.

Fuzzy rules are summarized in table 1.

ΔD_1		(dP/dV)'		
		Negative	Zero	Positive
dP/dV	Very Negative	+3%	+3%	+3%
	Negative	+3%	+1%	+1%
	Zero	0%	0%	0%
	Positive	-1%	-1%	-3%
	Very Positive	-3%	-3%	-3%

Table 1. Rules of ΔD_1

IV. SIMULATION AND RESULTS

1. Initial conditions

The system described in section 2 is implemented in Matlab Simulink (Figure 5).

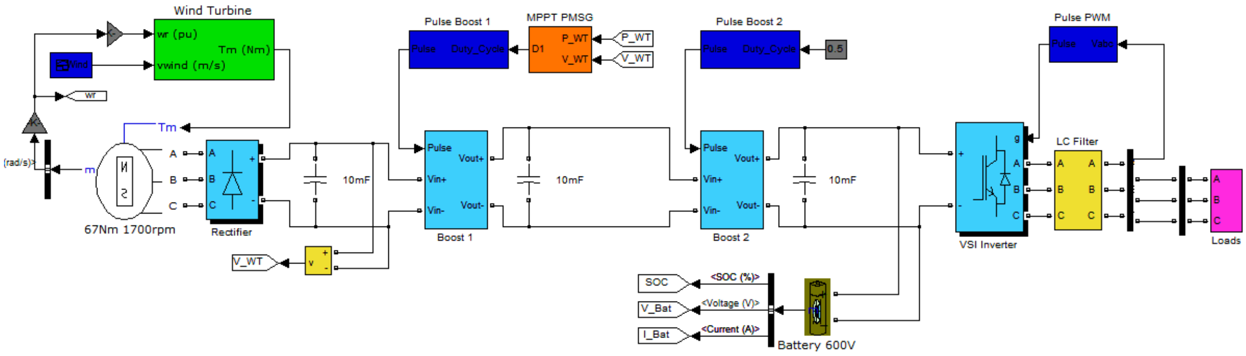

Figure5. Simulation in Simulink Matlab

Wind speed and load demand are varied within 100 seconds to test our controllers in various climatic and operating conditions (Figures 6, 7).

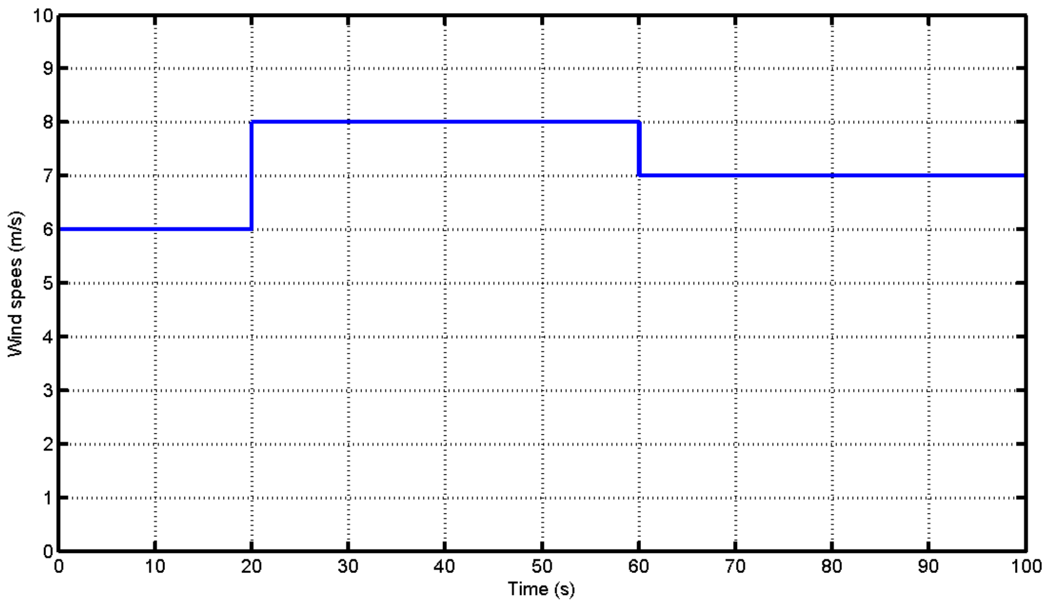

Figure 6.Wind speed

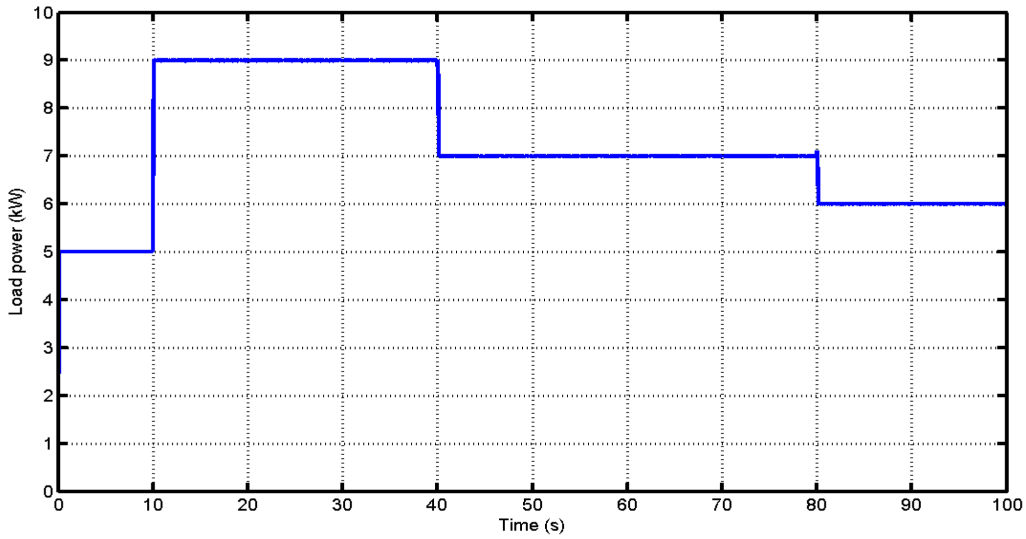

Figure7. Load demand

V. RESULT AND DISCUSSION

In the first ten seconds, load demand is 6 kW and wind speed is 6 m/s. In these conditions, our FLC has chosen the value for D_1 around 0.55 to keep the DC output voltage at 130 V (rotor speed at around 1150 rpm), which make power extracted around 3.1 kW. According to the generator curve in figure 3, we have the optimal rotor speed and the maximum power output is 1130 rpm and 3.645 kW respectively. The 0.545 kW difference between these two values is the power loss. After, when load change from 6 kW to 9 kW, the FLC still keep rotor speed around 1200 rpm to extract the maximum power from wind.

When wind speed change from 6m/s to 8m/s, our FLC decrease the duty cycle to increase wind turbine voltage to 160 V (rotor speed is 1500 rpm), the value of FLC output is kept near 0.35 to achieve the maximum power of 7.33 kW (optimal rotor speed is 1500 rpm and maximum power is 8.64 kW for wind speed 8 m/s).

In the last forty seconds, wind speed drops down to 7 m/s (for a optimal rotor speed of 1320 rpm and maximum power of 5.78 kW). Rotor speed is kept at 1300 rpm now, which make a 5 kW power extracted (Figures 8, 9, 10, 11).

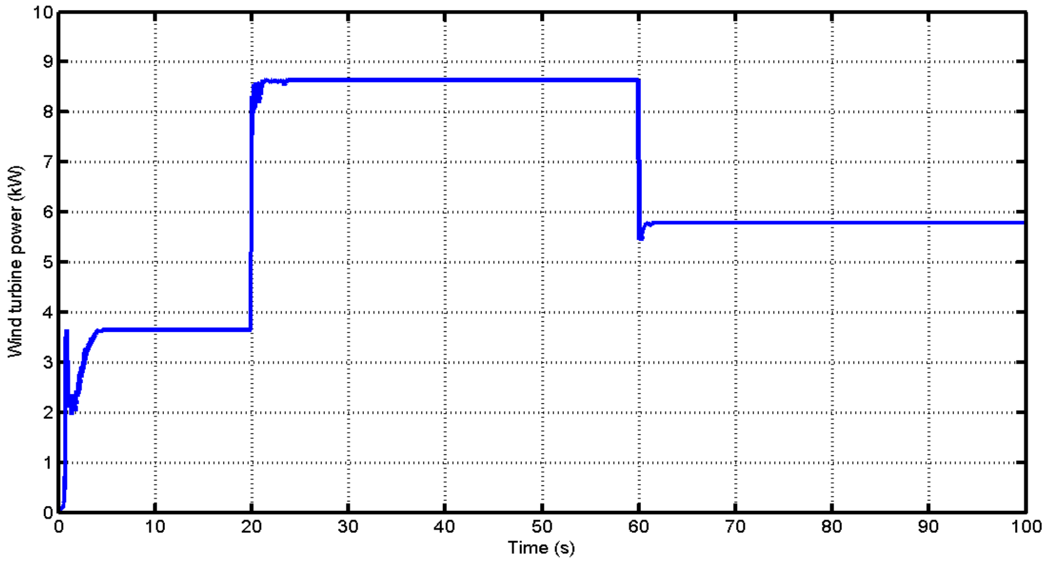

Figure8. Wind turbine power

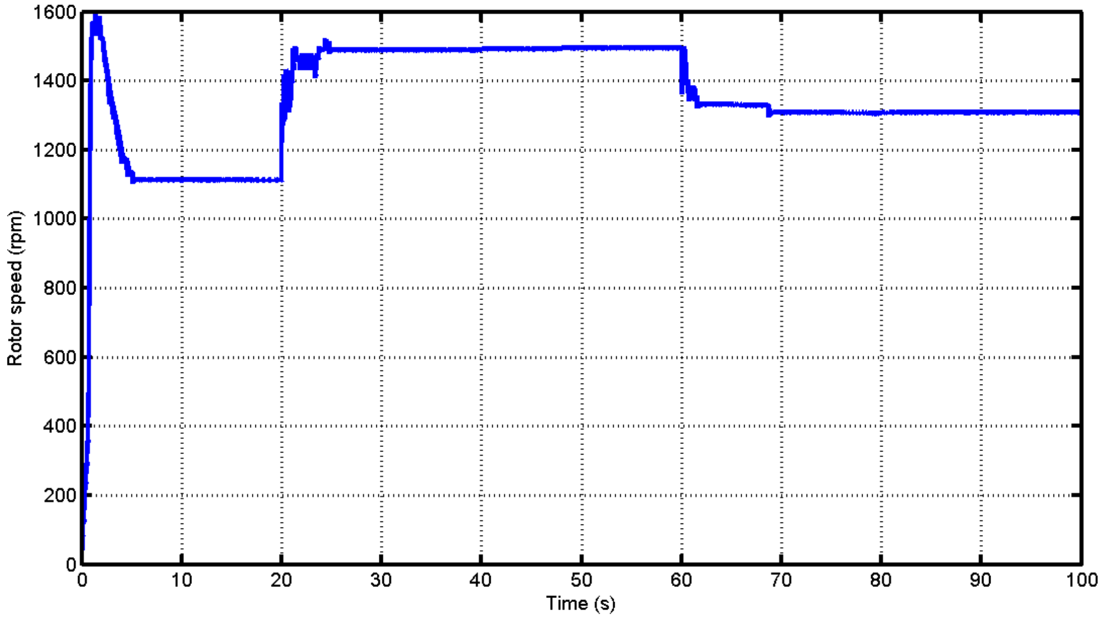

Figure9. Rotor speed

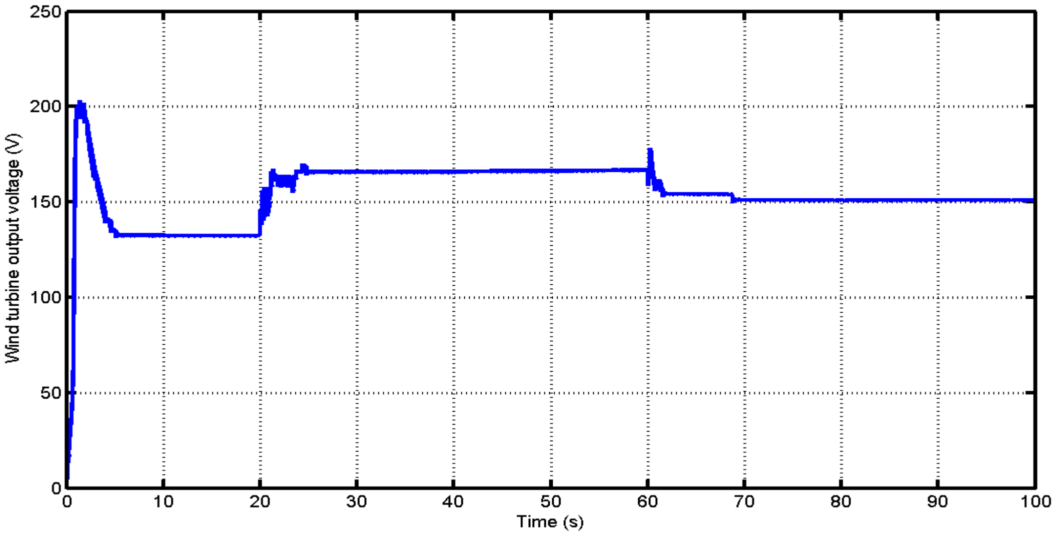

Figure 10. Wind turbine output voltage

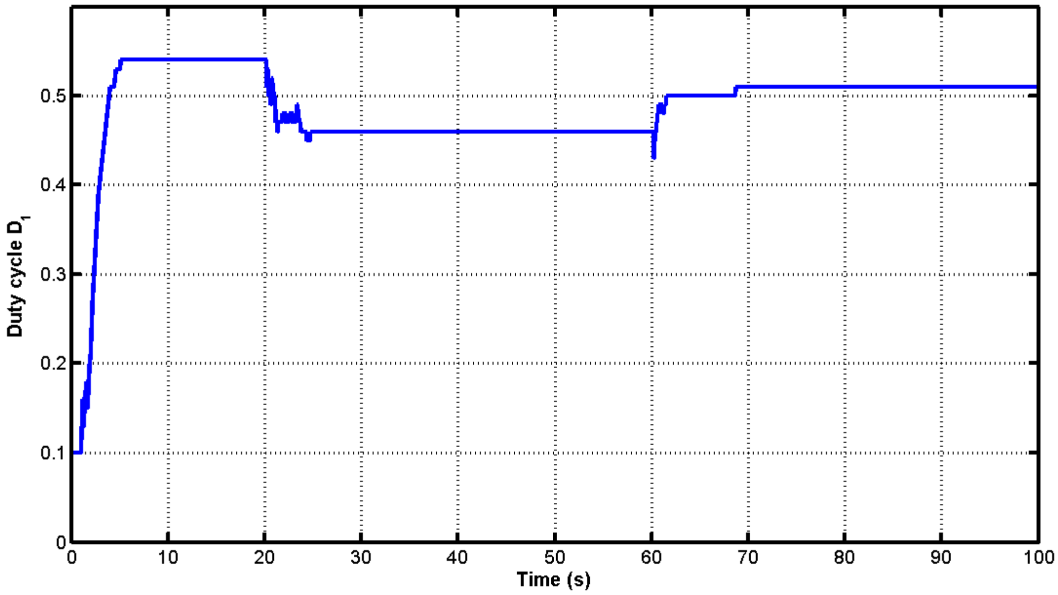

Figure 11.Duty cycle D_1

We can see that our FLC works well to track the maximum power point when wind speed or load demand change. These results still have some oscillation, it is evident because of the complex and nonlinear nature of the WECS, but it does not affect the final objective of our controller.

VI. CONCLUSION

In this paper, a new MPPT method for stand-alone WECS is proposed. Without information of wind speed or generator's power characteristic, control signals were generated to recover maximum power from the wind in any climatic or operating conditions. Simulation result shows good behavior of our controllers to achieve the MPPT. As perspective, experimental result will be carried out to verify the efficiency and feasible of our proposed method.

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