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Improved Fuzzy Logic MPPT Controller of Stand-alone WECS-based PMSG under Stochastic Wind Environment

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Abstract

This paper discusses the modeling and control of a Standalone WECS-based PMSG, the aim is to achieve an optimal operation of the studied WECS under a typically stochastic wind environment. The Maximum Power Point Tracking (MPPT) is guaranteed through the tracking of an optimal generator speed using an Improved Fuzzy Logic Controller (IFLC) based on intelligent algorithms. The effectiveness and the benefits of the proposed approach are demonstrated by numerical simulation using Matlab/SIMULINK. The obtained results indeed confirm a good tracking performance of the proposed controller.

Keywords: PMSG, WECS, Standalone, MPPT, Fuzzy Logic, VSC.

1. Introduction

Nowadays, the world knows a real fast increase of the wind energy installed capacity; so it is expected that the global total wind power generation will supply around 12% of the total world electricity generation at the end of 2020 [1,2]. However, the irregular character of the wind speed (primary source) which has a stochastic nature is considered as the main problem regarding wind power systems designs. Hence, within the technical standards imposed by the energy market, the mitigatation of this problem without the contribution of the advanced control techniques is certainly not possible [3-5]. Thus, researchers have conducted over the past few years a lot of researches and significant contributions aiming to achieve the maximization of the power capture facing to a varying wind conditions [6-8]. Even though the wind power is an abundant source of energy, the power that can be obtained from it changes throughout the day as wind speed changes continually. The maximum power which a wind turbine can deliver at a certain wind speed depends upon certain optimum value of the speed at which the rotor rotates. Extracting maximum possible power from the available wind power is of utmost importance, therefore, MPPT control is an active research area. In order to have maximum possible power, the wind turbine should always operate at optimum tip speed ratio. This is possible by operating the turbine at the optimal rotation speed where the tip speed ratio is optimum [9]. In this paper, an MPPT control of a standalone WECS-based PMSG using an Improved Fuzzy Logic Controller based on intelligent algorithms has been proposed. The MPPT Fuzzy Logic Controller is designed in order to drive the Wind Turbine at the optimal speed. Indeed, the application of FLC is enhanced by two intelligent algorithms "Input_Intell & Output_Intell", by means of those blocs it can be easily transform with accuracy the data from and to the FLC controller.

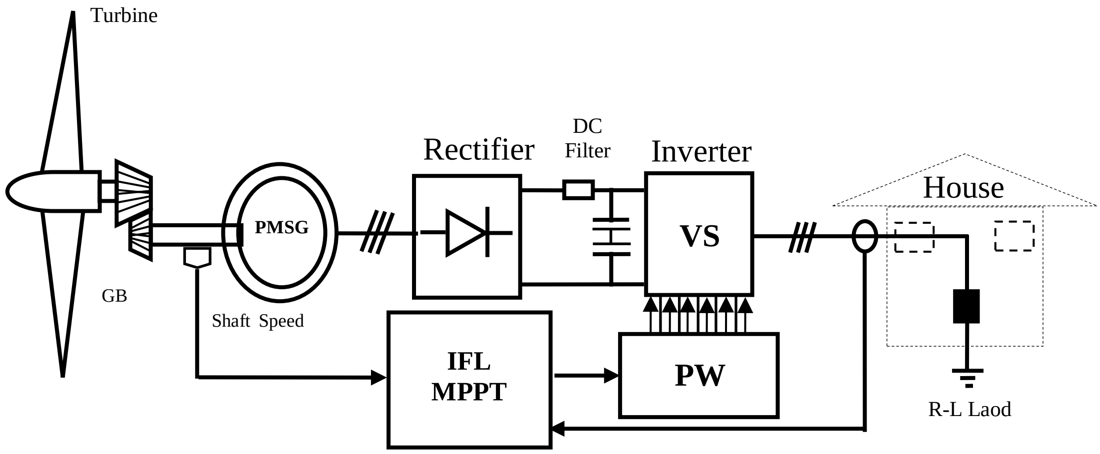

Fig.1. Stand alone WECS-based PMSG Topology

2. System Modeling

2.1 Wind Speed Modeling

A typical wind speed is a high non-stationary random process that can be modeled as the superposition of two components as follow:

$$v(t) = v_s(t) + v_t(t) \tag{1}$$

Vs(t) represents the low frequency long-term variations and Vt(t) stands for the high frequency turbulence.

However, [5] offer a detailed expression of the wind speed.

2.2 Turbine Modeling

For a fixed pitch variable speed WECS, the interaction between the air mass (aerodynamic part), the turbine's rotor and gear box (mechanical part) and the PMSG (electrical part) yields a system of equations as following:

$$\begin{cases} P_{turbine} = \frac{1}{2} C_p(\lambda)\rho\pi R^2 v^3 \\ C_p(\lambda) = q_2\lambda^3 + q_1\lambda^2 + q_0\lambda \\ \lambda = \frac{\omega_t R}{v} \\ J_{eq}\frac{d\omega_g}{dt} = \frac{\eta}{G}\Gamma_t - \Gamma_g \\ \omega_g = \omega_t \times G \end{cases} \tag{2}$$

Pt is the wind turbine power, ρ is the air density, R is the wind turbine radius, CP, λ, ωt are respectively the power coefficient (see Appendix), the tip speed ratio (TSR) and the wind turbine speed (low speed shaft). Jeq is the equivalent inertia rendered at high speed shaft, Γt , Γg and ωg, are respectively the wind turbine mechanical torque, the generator electromagnetic torque and the generator speed, and finally G and η are respectively are the gearbox ratio and its efficiency.

The schematic diagram that describes the wind turbine model is presented in figure (2).

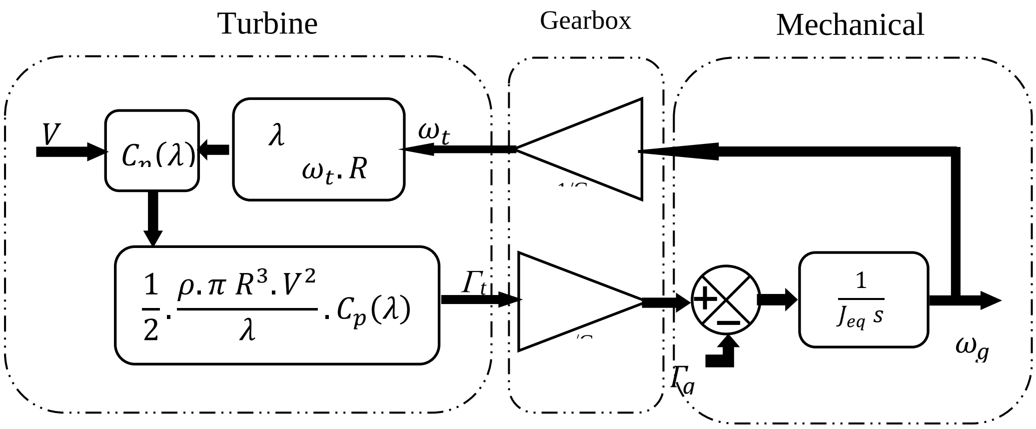

Fig.2. Wind turbine model

2.3 PMSG Modeling

The mathematical model of a PMSG is usually defined in the rotating reference frame d-q as follows:

$$\begin{cases} v_d = -R_s i_d - L_d \frac{d}{dt} i_d + L_q i_q \omega_g \\ v_q = -R_s i_q - L_d \frac{d}{dt} i_q - L_q i_d \omega_g + p\Phi_m \omega_g \end{cases} \tag{3}$$

Where V_q and V_d are the quadrature stator and direct stator voltage, respectively. i_q and i_d are the quadrature stator and direct stator current, respectively. R_s is the stator resistance, L_q and L_d are the inductances of the generator on the q and d axis, ϕ_m is the permanent magnetic flux.
The electromagnetic torque can be expressed as:

$$\Gamma_g = p\Phi_m i_q \tag{4}$$

2.4 R-L Load Modeling

In the studied case (Figure (1)), the adopted configuration is almost commonly used nowadays for small standalone wind turbine applications. This choice is basically judged by the control scheme simplicity of the wind energy conversion system [10,11].

2.5 DC Filter Modeling

The filter is added to improve the form quality of the dc voltage.

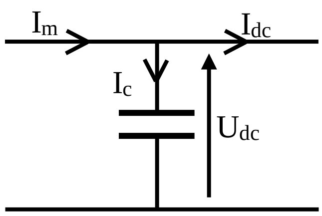

Fig.3. DC bus Filter

The filter can be modeled by the following equations:

$$\begin{cases} U_{dc} = \dfrac{1}{C}\int i_{dc}dt + U_{dc}(t_0) \\ i_{dc} = i_m - i_c \\ i_c = C\dfrac{d}{dt}U_{dc} \end{cases} \tag{5}$$

2.6 DC/AC Converter Modeling

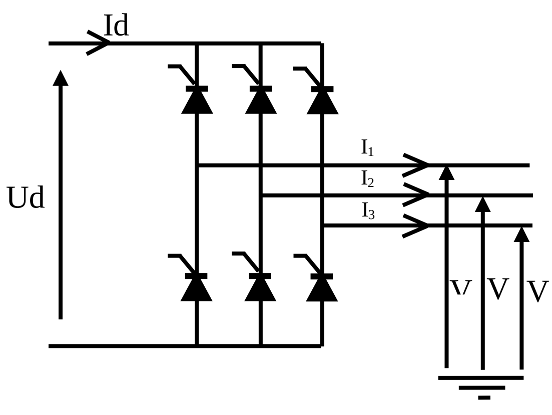

Fig. 4. DC/AC Converter.

The DC/AC is a three-phase inverter. Following to the switch's state *Si* generated from the PWM bloc; the converter model can be expressed as follows:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \frac{U_c}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} \quad (6)$$

Furthermore, the DC current can be calculated from the switch's state *Si* as follows:

$$i_{dc} = S_1 i_1 - S_2 i_2 + S_3 i_3 \quad (7)$$

2.7 AC Load Modeling

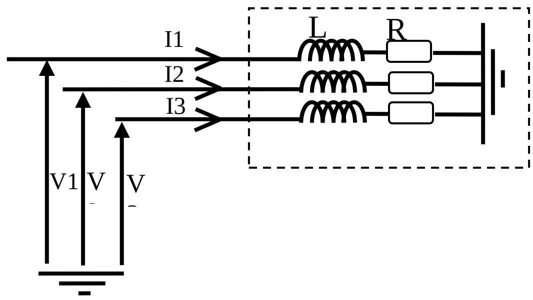

Fig.5. AC Load

For the one-phase balanced Load current; its expression is similar to the others, it is obtained as follows:

$$\begin{cases} i_1(t) = \dfrac{1}{L_f} \int v_L(t)dt + i_1(t_0) \\ v_R = Ri_1 \\ v_L = v_1 - v_R \end{cases} \quad (8)$$

2.8 PWM Control Strategy

In the studied case, the aim is to control the currents that can be fed the load by means of the DC/AC converter.

The PWM signals *Si* represents the switch's states, they are binary numbers that take two values, 1 (the switch is closed) or 0 (the switch is opened). However, the PWM bloc generates those signals through a hysteresis comparison between the generator output currents and their references as follows:

If $i_{iref} - i_i \rangle \Delta i$ so $f_i = 0$ and if $i_{iref} - i_i \langle -\Delta i$ $f_i = 1$

where Δi is the hysteresis bandwidth.

2.9 MPPT Strategy

The two following figures depict the wind turbine characteristics taking into account the turbine Power, wind speed, and turbine speed, in which the region of interest in this paper is the region I, in that region, there are slight wind speeds and the wind turbine nominal power could not obtain, so the objective is to extract maximum power (Maximum Power Point Tracking) from any wind speed by driving the turbine with an adequate speed (λ^*, C_{pmax}) (references).

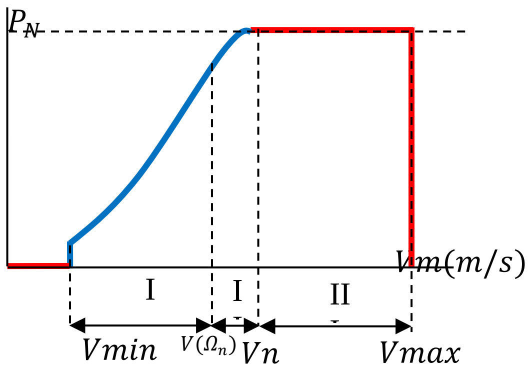

Fig.6. WT Characteristics in (Power, Wind seed)

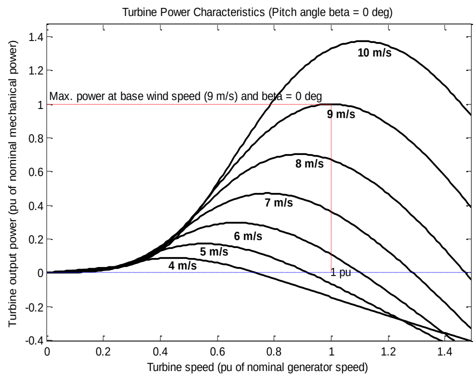

Fig.7. WT Characteristics (Power, Turbine seed)

2.10 Speed Control Based on Improved Fuzzy Logic Controller

As it is shown in figure (6), a fuzzy logic controller (FLC) based on intelligent algorithms is proposed in order to track asymptotically an optimal reference ω_g^* to guarantee the MPPT operation mode of the WECS [12].

The generator speed reference can be expressed as follow:

$$\omega_g^* = \frac{\lambda^* G v(t)}{R} \qquad (9)$$

which λ^* is the optimal TSR, the maximum extracted power of the WT is given as :

$$P_{t\_max} = \frac{1}{2} C_{p\_max} \rho \pi R^5 \left(\frac{\omega_g^*}{\lambda^*} \right)^3 \qquad (10)$$

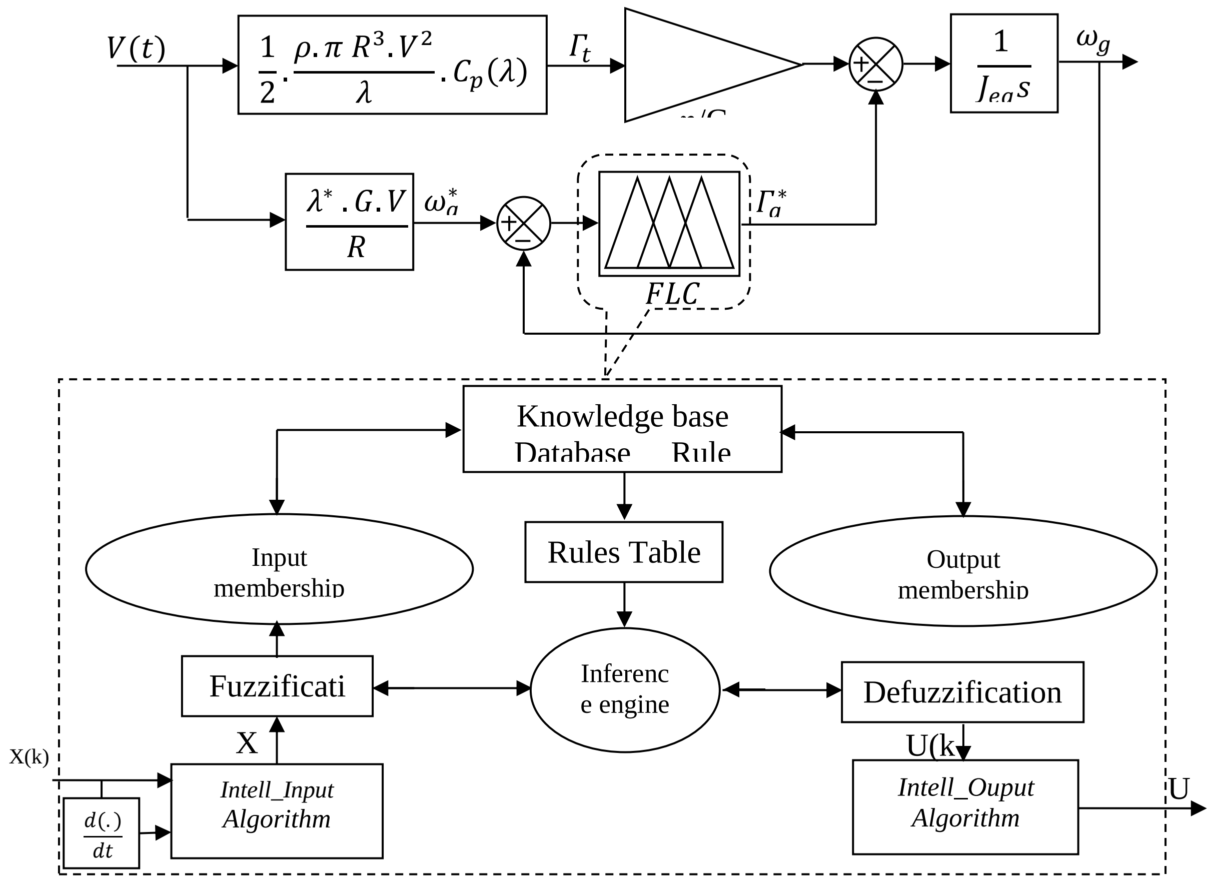

Fig.8. MPPT simplified schematic diagram

2.11 Fuzzy Logic Controller Architecture

Generally a fuzzy logic controller design is based on the choice of the following factors:

- Fuzzification
- Fuzzy variables (linguistic).
- Membership functions.
- Inference method (Inference engine).
- Defuzzification method.

Hence, for the studied case (speed control), as it is shown in figure (5), the FLC is implemented using Fuzzy Logic Toolbox in Matlab (Figure(9)), in which the inputs are the speed generator and its dynamic, the output is the electromagnetic torque. For that, a simplified schematic proposed by *Mamdani* is adopted [13].

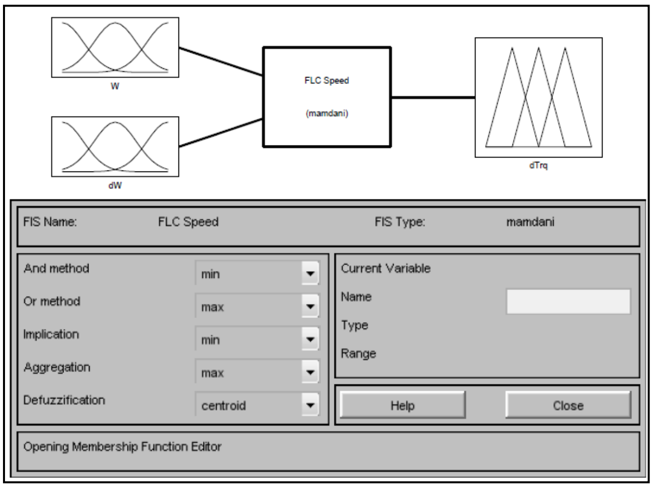

Fig. 9. FLC (Fuzzy Logic Toolbox)

The membership functions form and their distribution on the *FIS range* are selected similarly for the inputs and output as it is depicted below:

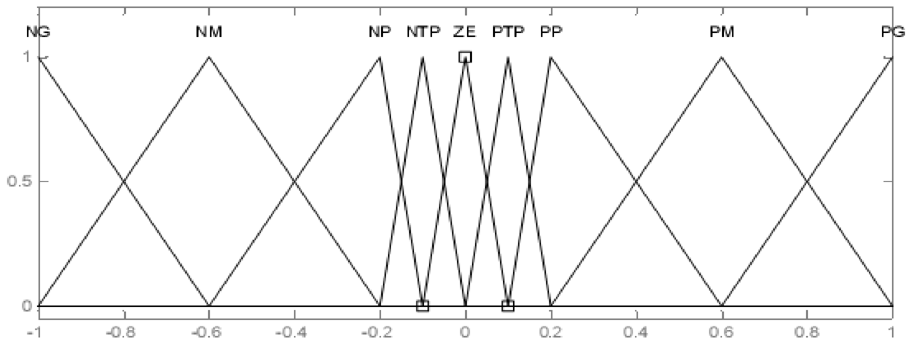

Fig.10. Membership functions form and their distribution on the *FIS range*

However, it is a well-known that the choice of appropriate gains to guarantee a good conversion of the FLC inputs and output is still a main problem in that matter; hence to mitigate this problem; the FLC capability is improved using two algorithms:

- Intell_Input and Intell_Output Algorithms, in which their role is to convert appropriately the FLC input from a real space (environment) to a fuzzy space and vice versa. The following two algorithms show clearly their structures, in which (x(k), u(k)) are the input and output in the real space, (X, U) are the input and output in the fuzzy space, and FIS means Fuzzy Inference System. For a simulation period T=[Start time End time], the *Intell_Input*/*Intell_Output* algorithms are built as following:

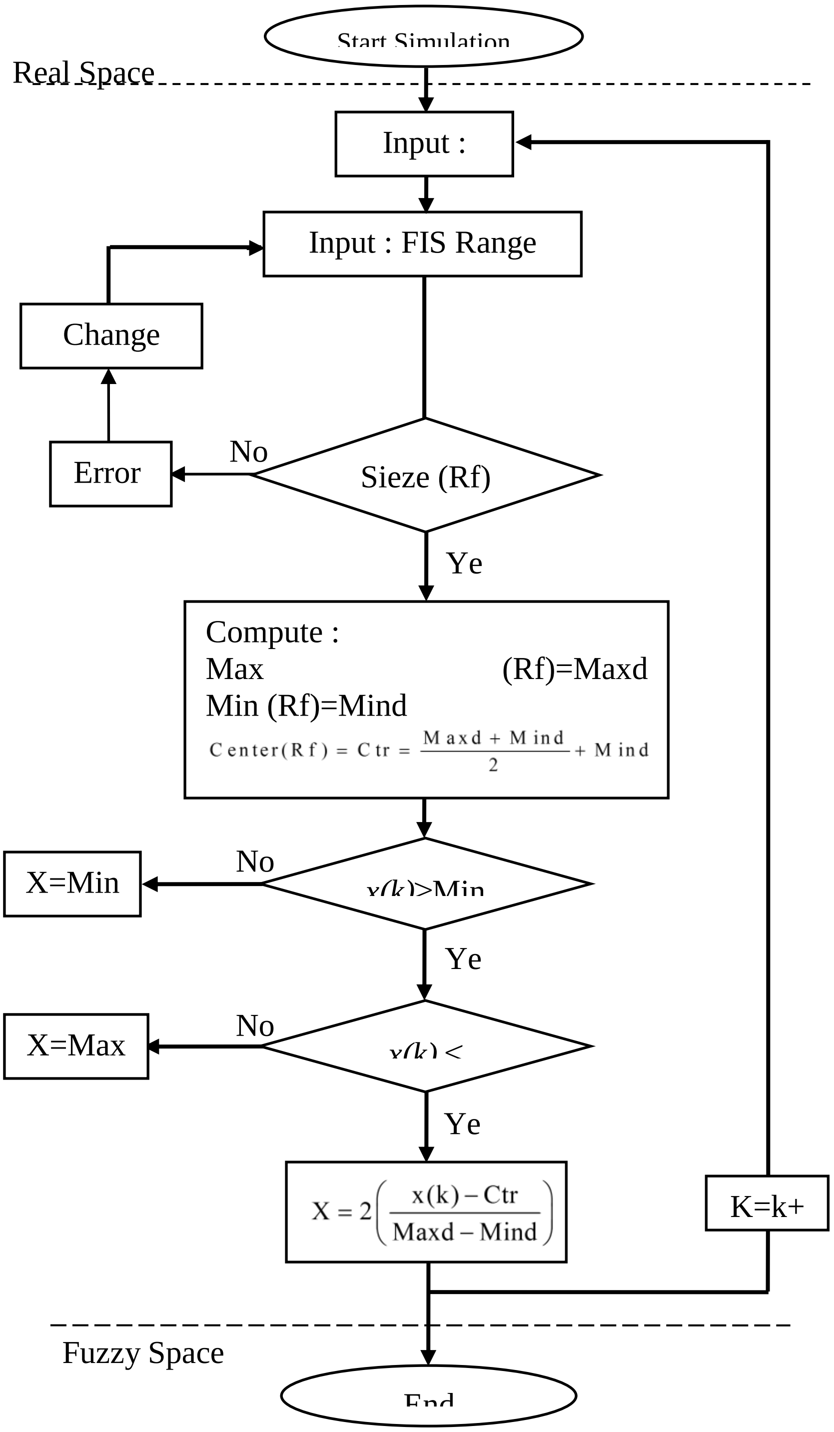

Fig.11. Intell_Input Algorithm

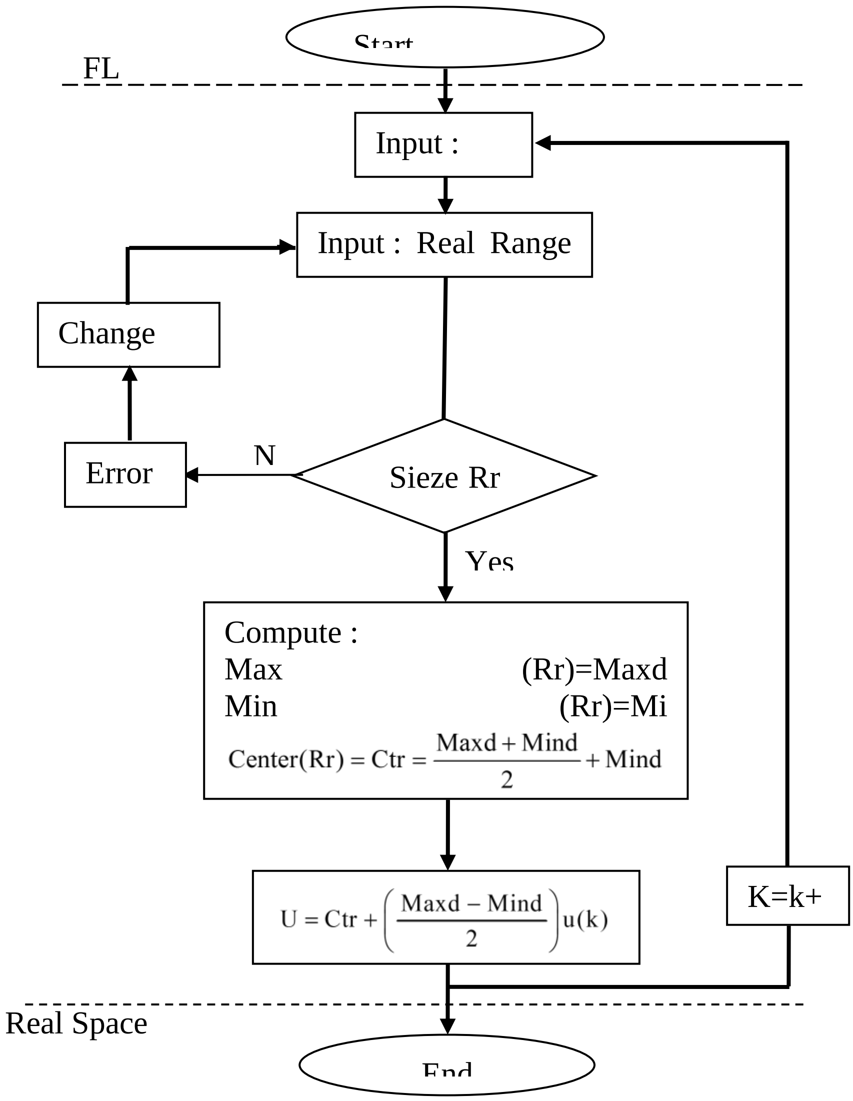

Fig.12. Intell_Output Algorithm

3. Simulation Results

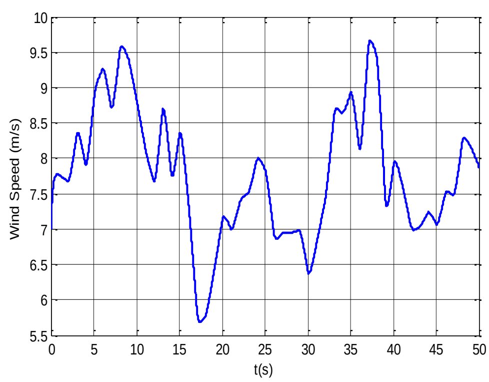

Fig.13. Stochastic wind speed

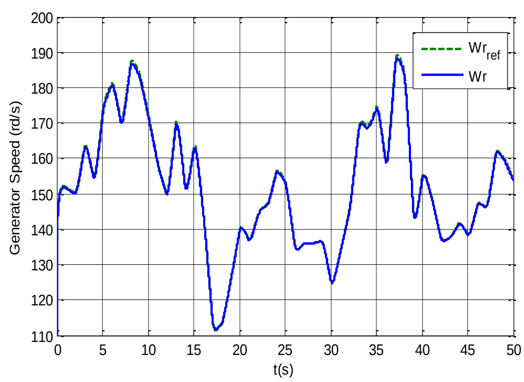

Fig.14. Generator Speed

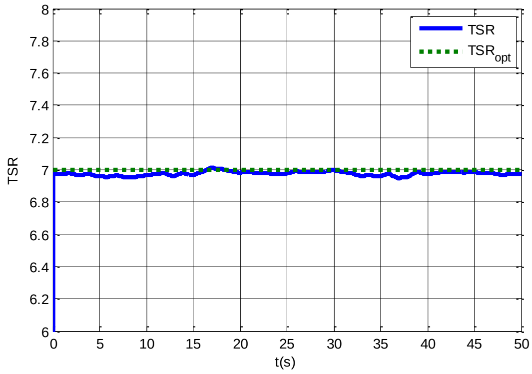

Fig.15. Tip speed ratio

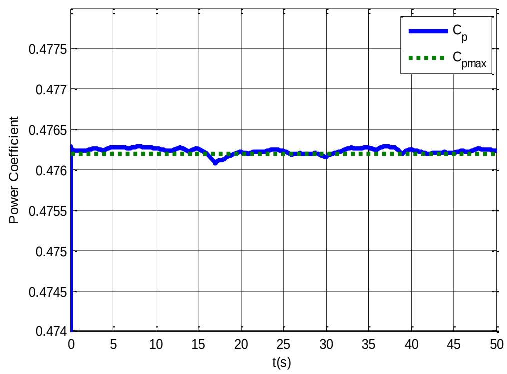

Fig.16. Power coefficient

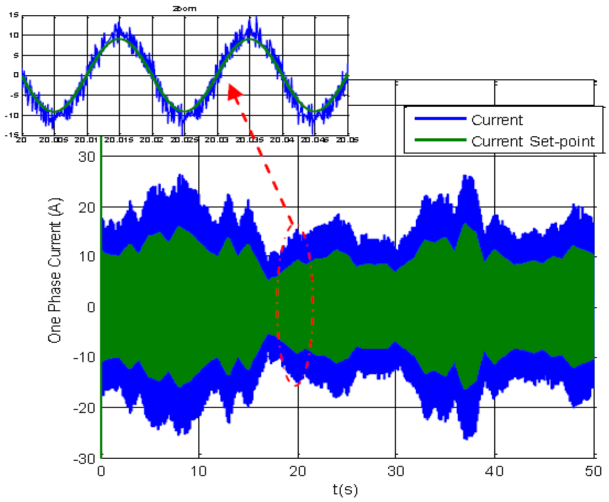

Fig.17. One Phase Current

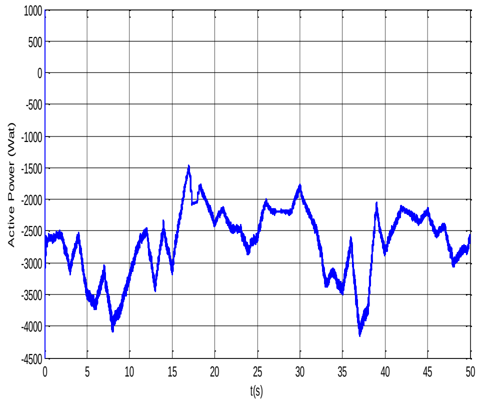

Fig.18. Generated Active Power

4. Conclusion

Recently the standalone WECS application is considered as an important solution of electrification issue in remote areas. The system-based on a small PMSG is being the most adaptable one in that matter. However, the stochastic nature of the wind speed makes the WECS very complicated and very hard to be controlled. Throughout this paper we did the modeling and control of a standalone WECS-based PMSG, in which an optimal operation of the system has been achieved by extracting the maximum power from the wind (MPPT), the MPPT control technique, is based on an improved Fuzzy Logic Controller (FLC) based on intelligent algorithms. The effectiveness and the benefits of the proposed approach are demonstrated by numerical simulation using Matlab/SIMULINK. The obtained results indeed confirm a good tracking performance of the proposed controller.

5. References

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