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Fuzzy optimum opertaing of a wind power pumping system

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***Abstract*—The efficiency of wind water pumping system depends on the availability of the wind energy and the level of pumped water. This paper develops a water-level control of a water pumping system based on a fuzzy logic algorithm . The proposed controller consists of computing forecasted wind velocity and tank water level instantaneously in order to run out a speed reference needed to a DTC of moto pump drive. The validity of the simulation results has been investigated under Matlab-Simulink.**

keywords: Wind pumping system, Fuzzy logic, DTC-SVM, Volume water.

I. INTRODUCTION

During the last decades, the challenge of producing electricity in the world has undergone a great difficulty, especially with the primary energy sources. Thus the growing rate of depletion of conventional sources has given a great importance of renewable sources such as photovoltaic, wind energy and biomass sources. The availability of this renewable energy provides a suitable solution for energy related problems in remote areas [1]. The substantial wind potential exists in the most rural and remote area. Besides, due to the pain of the availability of water in this area, wind pumping systems (WPS) is an attractive alternative for this deficiency of water supply [2]. Thus, water supply presents one of the most important applications in the growth of remote regions. The pumping of water through a wind turbine has been reported and highlighted by reviewers and well developed for irrigation applications [3]. Many works dealt with the ways to control and optimize the feasibility of wind powered water pumping system such as Parikh and Bhattacharya [4] . Others have estimated the cost of water pumping wind turbine for irrigation applications such as Sinha and Kandpal [**?**]. Researchers have published in wind water pumping system are interested essentially in water pump modeling and control in order to bring a contribution to the study of the behaviors of the variable speed turbine used to feed a centrifugal pump system. In fact, many researchers have established an explicit algorithms to fix the IM speed reference without taking into account the level of water in the tank to fill.

This paper presents a novel pump control drive powered by a wind turbine system. An IM fed centrifugal pump is controlled by a conventional DTC. The algorithm is consisting of fuzzy logic technique which computes IM speed reference taking into account the wind velocity and provides an optimum water pumping. Following section 2 presents the water pump wind turbine model. In section 3 the control strategy is outlined. Then the the optimum pump WT algorithm is presented and discussion are shown in section 4. Finally, the conclusion was drawn in section 5.

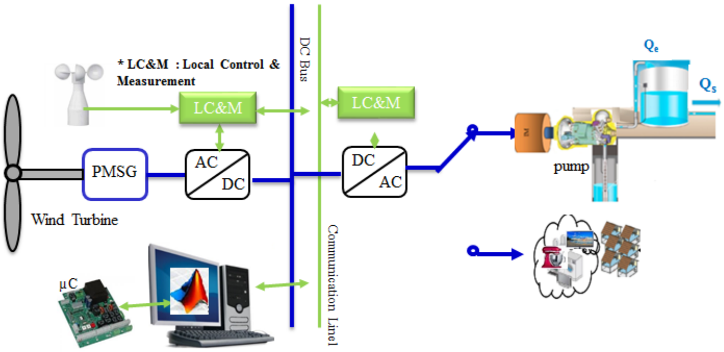

Fig. 1. Simulation results for the network.

II. MODELING OF THE PROPOSED SYSTEM

The WT pump system is composed by a variable speed wind turbine with PMSG supplying a moto-pump system as shown in Fig 1. The system includes a centrifugal pump fed tank water to provide autonomy for any water requirement.

A. Wind turbine model

The aerodynamic power captured by the wind turbine can be described by the following equation [5]

$$P_{aeor} = \frac{1}{2}\rho S C_p(\lambda,\beta) V_w^3 \tag{1}$$

Where ρ is the air specific density (Kg/m^3) , S is the Area swept by the rotor (m^2) and V_w is the wind speed (m/s). The power factor C_p linked The tip speed ratio λ and the pitch angle β. According to Betz theory, it cannot exceed the max value which is 0.593. It is given by the equation as follows:

$$C_p(\lambda,\beta) = 0.53\left[\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right] e^{\left(\frac{-18.4}{\lambda_i}\right)} \tag{2}$$

where

$$\lambda_i = \frac{1}{\dfrac{1}{\lambda - 0.02\beta} - \dfrac{0.003}{\beta^3 + 1}}$$

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and

$$\lambda = \frac{R_t \Omega_t}{V_w} \tag{3}$$

Besides, the mechanical speed of the shaft turbine is extracted from the fundamental equation of dynamics as follows:

$$J\dot{\Omega}_t = T_t - T_{em} - f\Omega_t \tag{4}$$

Where Ω_t(rad/s) is the mechanical speed of the rotor torque(Nm), J is the moment of inertia (Kgm^2), f is the coefficient of the viscous friction ($Nmsrad^{-1}$) , T_m is the turbine torque and T_{em} is the electromagnetic torque defined by [6]:

$$T_{em} = p\phi_m I_{sq} \tag{5}$$

The model commonly used of the PMSG in the park reference frame is given by the following equations:

$$\begin{aligned} \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} &= -R_s \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} - \frac{d}{dt}t \begin{pmatrix} L_d I_{sd} \\ L_q I_{sq} \end{pmatrix} \\ &+p.\Omega_t \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} L_d I_{sd} + \phi_m \\ L_q I_{sq} \end{pmatrix} \end{aligned} \tag{6}$$

B. Pumping Unit Model

1) Model of IM: The dynamical behavior of induction machine is represented by several mathematical models. A state space model represented in the frame is considered as follows [7]:

$$\begin{cases} \dot{I}_{s\alpha} = -(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_r})I_{s\alpha} - \omega_r I_{s\beta} + \frac{R_r}{\sigma L_s L_r}\phi_{s\alpha} + \frac{\omega_r}{\sigma L_s}\phi_{s\beta} \\ +\frac{1}{\sigma L_s}U_{s\alpha} \\ \dot{I}_{s\beta} = -(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_r})I_{s\beta} + \omega_r I_{s\alpha} + \frac{R_r}{\sigma L_s L_r}\phi_{s\beta} - \frac{\omega_r}{\sigma L_s}\phi_{s\alpha} \\ +\frac{1}{\sigma L_s}U_{s\beta} \\ \dot{\phi}_{s\alpha} = U_{s\alpha} - R_s I_{s\alpha} \\ \dot{\phi}_{s\beta} = U_{s\beta} - R_s I_{s\beta} \\ \dot{\omega}_r = \frac{np}{j}(\phi_{s\alpha} I_{s\beta} - \phi_{s\beta} I_{s\alpha}) - \frac{T_l}{j} \end{cases} \tag{7}$$

where

$I_{s\alpha}, I_{s\beta}$: stator current,

$\phi_{s\alpha}, \phi_{s\beta}$,$\omega_r$, $U_{s\alpha}, U_{s\beta}$ denotes stator fluxes, electrical rotor speed and the stator voltages respectively.

With $\sigma = 1 - \frac{M^2}{L_r L_s}$ is the redefined leakage inductance.

The electromagnetic torque can be derived from stator flux and stator currents in the fixed coordinate system $\alpha\beta$ and given by:

$$T_e = \frac{3}{2}np(\phi_{s\alpha} I_{s\beta} - \phi_{s\beta} I_{s\alpha}) \tag{8}$$

2) Pump Model : Several pumps are used with wind pumping system. In this study, we use a centrifugal pump applies a load torque proportional to the square of the rotor speed [8].

$$T_l = K_l \Omega^2 \tag{9}$$

Where K_l is the proportionality constant.

Given the performance of the centrifugal pump ($Q,\ H\ and\ P$) for the speed N the performance ($Q^{'}, H^{'}, andP^{'}$) for the speed $N^{'}$ is evaluated by the following relationships :

$$Q^{'} = Q\frac{N^{'}}{N}, H^{'} = H\left(\frac{N^{'}}{N}\right)^2, P^{'} = P\left(\frac{N^{'}}{N}\right)^3$$

where

Q and $Q^{'}$: respectively corresponding to the flow speed N and $N^{'}$,

H and $H^{'}$: the total discharge heads,

P and $P^{'}$: the powers of the IM also respectively corresponding to the speed N and $N^{'}$.

3) Tank: Q_e and Q_s represent the water flow rate of the input and output of the storage tank respectively. The water flow Q_e is proportional to the speed rotor of the IM, however, the flow rate Q_s varies according to the need of the user.

The liquid height in the tank, H, is given by the differential equation as follows:

$$\dot{V} = S\dot{H} = Q_e - Q_s \tag{10}$$

Where V is the volume of liquid in the tank, S is the cross-sectional area of the tank. The equation describes the height of liquid, H, as a function of time, due to the difference between flow rates Q_e and Q_s of the tank.

III. CONTROL STRATEGY

The first part of control consists of maximizing the generated power from WT. In order to capture the maximum power, the power coefficient C_p must be tracked to its maximum value $C_{p.max}$ for corresponding tip speed ratio λ_{opt} and a pitch angle β_{ref} for each value of wind speed. In addition, Equation 6 shows the dependence of the wind generated power to the reference signals V^*_{sd} and V^*_{sq} . Each signal is used to the vector control of PMSG. In fact, this classical strategy imposes a direct current I^*_{sd} equal to zero and a quadrature current I^*_{sq} reference related to the electromagnetic torque as follows:

$$I^*_{sq} = \frac{T^*_{em}}{p\phi_m} \tag{11}$$

In the second part, we choose the direct torque control strategy as a control technique for the IM. In our study, the DTC offers a direct torque control which achieves an effective control of the torque and stator flux by using the adequate selection of the inverter switching states. With this technique, only the $(\alpha - \beta)$ plane is used to estimate the torque and the stator flux as follows: At a stationary reference axes $\alpha\beta$, The stator flux is then, given by:

$$\begin{cases} \overline{\phi_s} = \int_t^0 (\overline{V_s} - R_s \overline{I_s})dt \\ \phi_s = \sqrt{(\phi_{s\alpha}^2 + \phi_{s\beta}^2)} \\ Arg(\phi_s) = arctg(\frac{\phi_{s\beta}}{\phi_{s\alpha}}) \end{cases} \tag{12}$$

where

$$\begin{cases} \phi_{s\alpha} = \int_t^0 (V_{s\alpha} - R_s I_{s\alpha})dt \\ \phi_{s\beta} = \int_t^0 (V_{s\beta} - R_s I_{s\beta})dt \end{cases}$$

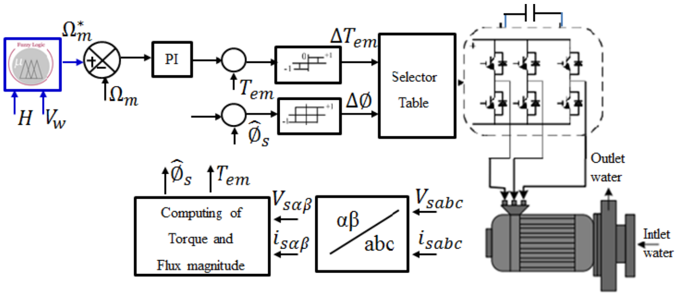

Fig. 2. Schematic diagram of the DTC for the IM.

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TABLE I
SWITCHING TABLE

		Switching table				
$\Delta\Phi$	ΔT_{em}	Sector I	Sector II	Sector III	Sector IV	Sector V
1	1	$V_2(110)$	$V_3(010)$	$V_4(011)$	$V_5(001)$	$V_6(101$
	0	$V_7(111)$	$V_0(000)$	$V_7(111)$	$V_0(000)$	$V_7(111$
	-1	$V_6(101)$	$V_1(100)$	$V_2(110)$	$V_3(010)$	$V_4(011$
0	1	$V_3(010)$	$V_4(011)$	$V_5(001)$	$V_6(101)$	$V_1(100$
	0	$V_0(000)$	$V_7(111)$	$V_0(000)$	$V_7(111)$	$V_0(000$
	-1	$V_5(001)$	$V_6(101)$	$V_1(100)$	$V_2(110)$	$V_3(010$

$\overline{\phi_s}$ is the stator flux vector, ϕ_s is the amplitude and R_s is the stator resistance.
Using the dc-link voltage V_{dc} and the inverter switch gating signals $S_a,\ S_b,\ and\ S_c$, the stator voltage space vector V_s is computed as follows :

$$\begin{cases} V_{s\alpha} = \sqrt{\dfrac{2}{3}}(S_a - \dfrac{1}{2}(S_b + S_c))V_{dc} \\ V_{s\beta} = \sqrt{\dfrac{1}{2}}(S_b - S_c)V_{dc} \end{cases} \tag{13}$$

$S_i = 1$ the phase i is connected to the supply positive polarity, $S_i = 0$ the phase i is connected to the supply negative polarity The stator-current space vector I_s can be given from the measured currents $I_a,\ I_b\ and\ I_c$:

$$\begin{cases} I_{s\alpha} = \sqrt{\dfrac{3}{2}} I_{sa} \\ I_{s\beta} = \sqrt{\dfrac{1}{2}}(I_{sb} - I_{sc}) \end{cases} \tag{14}$$

The schematic diagram of the conventional DTC IM is shown in Fig 2. The magnitude of stator flux and electric torque estimation are calculated from the IM voltages and currents, then they are compared with their hysteresis band controller. Thus, the appropriate inverter voltage vector is selected from the switching table based on the position of the stator flux. Table 1 summarizes the voltage vector table for the conventional direct torque controller. As a consequence, only one selected vector is applied for the entire sampling time.

The principle of the fuzzy logic controller consists in establishing the speed reference of the moto-pump system. This controller is based on the measured water level in the reservoir and the wind velocity as inputs and the relative calculated speed as outputs. In our study, the fuzzy inference Mam-dani's method is employed with a defuzzification centroid method to compute the reference speed Ω_{ref}. The fuzzy partitions leads to the computing of the membership function $(\mu_{V_w}, \mu_\varepsilon, \mu_H)$ using symmetric triangular given in Fig 3. This controller lead not only to establish the reference speed, but also to control and regulate the water level in the tank which is equipped by a sensor to measure the water level as shown in Fig 4.

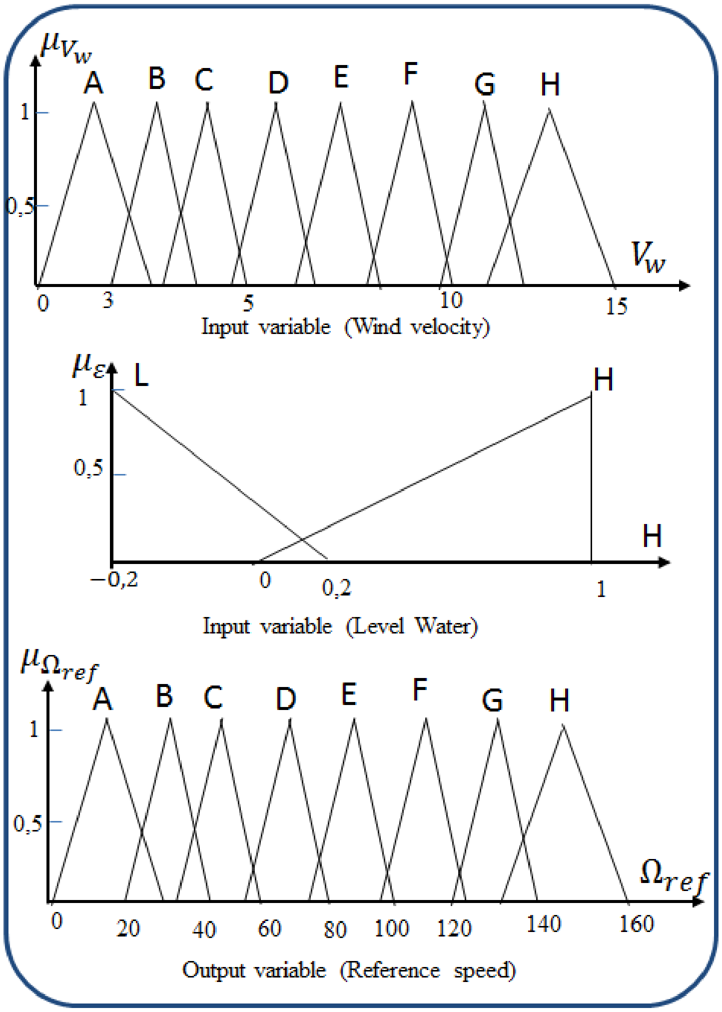

Fig. 3. fuzzy logic membership function

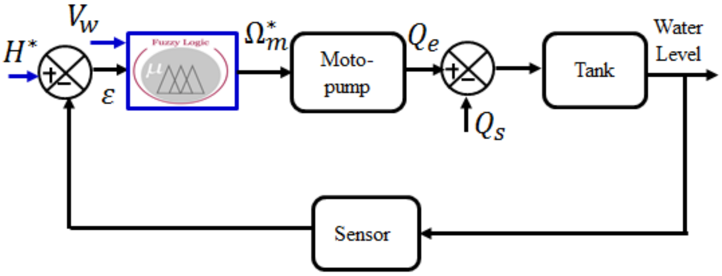

Fig. 4. Schematic diagram of the DTC for the IM.

IV. SIMULATIONS RESULTS

The proposed control has been implemented in Matlab/Simulink environment. As mentioned in section 3, the wind power system is designed to supply and control the water level. To evaluate the performance of the proposed fuzzy controller, the simulations are carried out for a variable wind profile as shown in Fig 5 (a) for 25 s time. Fig 5 (b-d) show the evolution of the mechanical parameters of the WT. It shows that when the wind speed goes beyond its nominal value, the pitch angle β increases thus the power coefficient C_p decreases. Fig 5 (e-f) show the responses obtained with the classical vector control . Figure 6 (a) gives the IM electromagnetic and load torque. Figure 6 (b) shows the pump power evolution according to the demand of water. Figure 7 presents the simulation results under reference speed ramp up, when the need for water increase. This control of mechanical speed allows achieving flow and water level desired as shown in Fig 9.

V. CONCLUSION

A fuzzy logic for the control and regulation of the water level in a wind power pumping system is proposed and validated using a variable profile of wind speed. This algorithm allows to generate the reference speed of the moto pump system taking into account the water level in the tank. Simulation results were conducted to verify the effectiveness of the wind power pumping system without disturbance.

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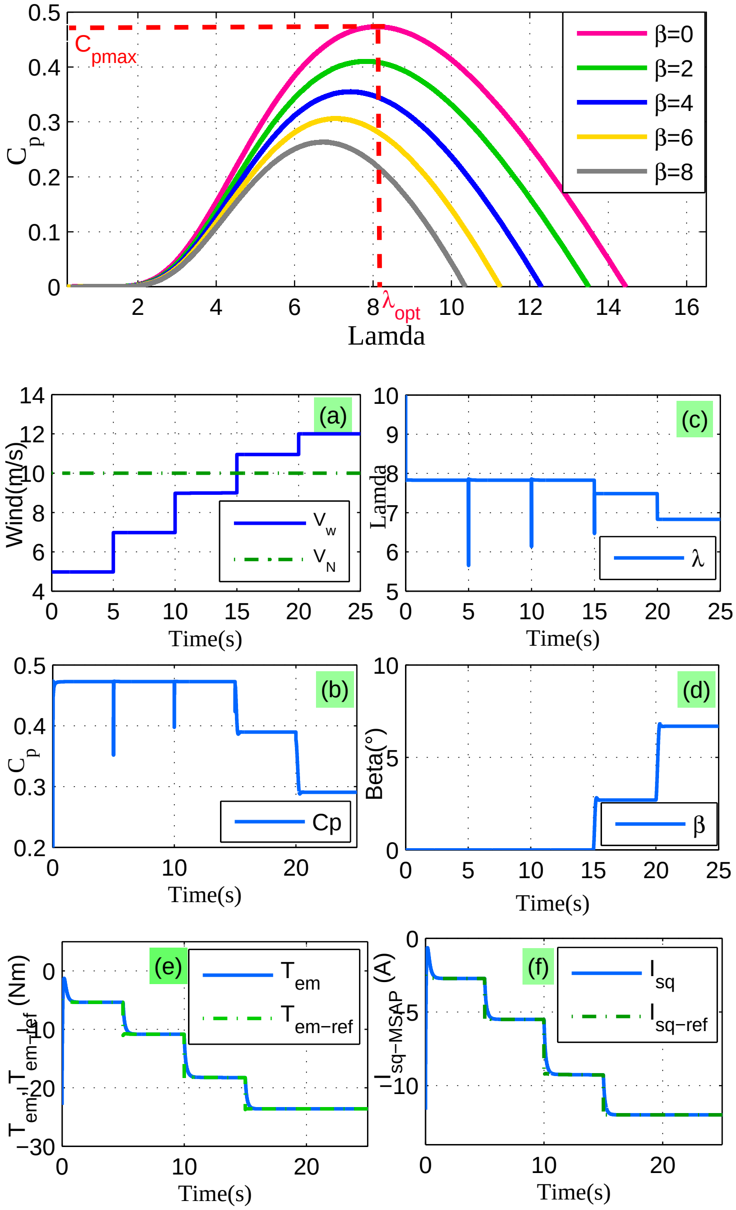

Fig. 5. Evolution of different characteristics of the wind turbine

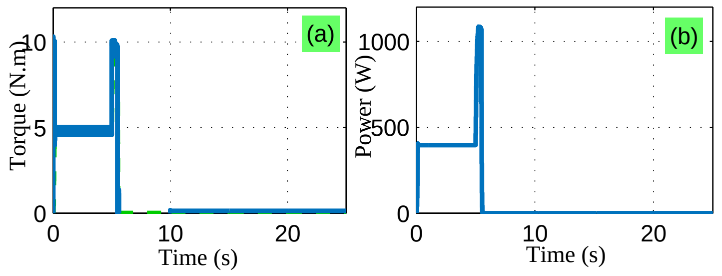

Fig. 6. a) IM electromagnetic and load torque, b) Pump power

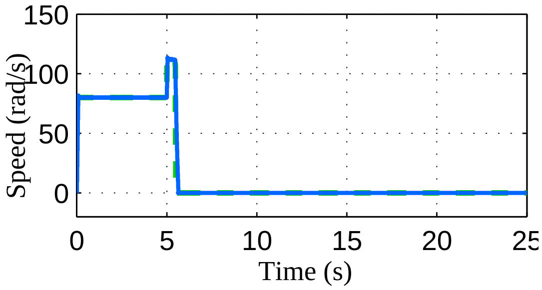

Fig. 7. IM speed variation

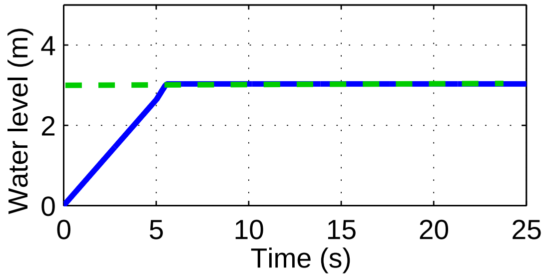

Fig. 8. Water level variation

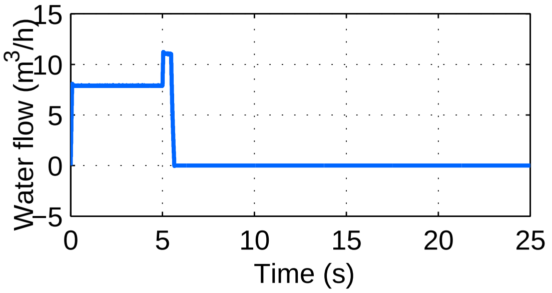

Fig. 9. Flow variation