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FRESH WATER GENERATION BY WIND ENERGE

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ABSTRACT

The climate change and water scarcity are the most world environmental challenges. Producing fresh water from seawater needs a lot of energy that may be supported by fossil fuel power stations. However, a solution for the challenges is water desalination system that is integrated to the renewable energy. Moreover, there is much energy conversion in these systems that reduce the overall system efficiency. This article introduces a novel Desalination Wind Turbine, and such that it is described and analyzed by nonlinear simulation. In this system, the wind energy transmitted to the water pump by a hydraulic transmission line. The RO module is used for fresh water production. The long-term performance of the system, such as annual water production is calculated and the ability of the system to Maximum Power Point Tracking and the wind turbulence and wind sudden change is analyzed, which shows the system overshoot is less than 6%.

Keywords: Desalination, Wind Turbine, Hydraulic Transition, Maximum Power Point Tracking, RO Module.

أنتاج المياه العذبة بواسطه طاقه الرياح

فؤاد سرحان جواد **عصام مجبل عبد** **مجتبى بهنام تقدسى**

الخلاصة

يعد تغير المناخ وندرة المياه أكثر التحديات البيئية في العالم يحتاج إنتاج المياه العذبة من مياه البحر إلى الكثير من الطاقة التي قد تدعمها محطات توليد الطاقة من الوقود الأحفوري. ومع ذلك ، هناك حل للتحديات يتمثل في نظام تحلية المياه المندمج في الطاقة المتجددة. علاوة على ذلك ، هناك الكثير من تحويل الطاقة في هذه الأنظمة التي تقلل من كفاءة النظام بشكل عام. تقدم هذه المقالة رواية توربينات الرياح لتحلية المياه ، بحيث يتم وصفها وتحليلها عن طريق المحاكاة غير الخطية. في هذا النظام ، يتم نقل طاقة الرياح إلى مضخة المياه عن طريق خط نقل هيدروليكي. يتم استخدام وحدة RO لإنتاج المياه العذبة. يتم حساب الأداء طويل الأجل للنظام ، مثل الإنتاج السنوي للمياه ، ويتم تحليل قدرة النظام على تتبع القدرة القصوى للنقاط والاضطرابات الناتجة عن الرياح وتغير الرياح المفاجئ ، مما يدل على أن التجاوز في النظام أقل من 6٪.

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NOMENCLTURE

Latin Symbols	Description
A	RO module area
Br	Rotor damping
β	Blade pitch angle
Cro	RO module permeability
Cb	Brine water salinity
Cp	Permeate water salinity
Cw	Saline water salinity
Dp	Hydraulic pump geometric displacement
Dm	Hydraulic motor geometric displacement
Dw	Water pump geometric displacement
Jr	Rotor moment of inertia
Ɵ	Swash plate angle
Pb	Brine water pressure
Po	Oil Pressure
Pos	Osmosis pressure
Pp	Permeate water pressure
Pw	Water pressure
PRay	Rayleigh probability function
Qb	Brine water flow rate
Qo	Oil flow rate
Qp	Permeate flow rate
Qw	Water flow rate
Ros	Osmosis pressure constant for salt at 25 oC
Ta	Rotor torque
Tm	Hydraulic motor torque
Tr	Hydraulic pump torque
Tw	Water pump torque
Vw	Wind velocity
ωm	Water pump rotational speed
ωr	Rotor speed

INTRODUCTION

Fresh water scarcity is one of the most challenging in the world now, and in the future (Alkaisi et al. 2017) and Hatami, and (Imani 2016). The wastewater treatment and the seawater desalination plants are used to produce clean water. Today, most of the desalination power plants are supported by fossil fuel power stations. This means, producing more fresh water causes to more CO_2 emission in the atmosphere. Another serious world challenge is the climate change Currently, burning more fossil fuels for generating more electrical energy is not a good solution, because it will be accelerating climate change phenomena. Therefore, renewable energy is very popular in the world, and wind energy is one of the important sources of clean energy. A wind turbine converts wind energy to the electrical energy, which is transmitted to the consumers by using transmission power lines (Rajanbhandharaks(2014). This electrical energy may be consumed to produce fresh water (Masters 2017) . Such that, the energy conversion has an efficiency which means a lot of energy is dissipated during the energy conversion. In classical wind turbines, drive train consists of main shaft, gearbox and couplings. Wind turbine gearboxes are expensive and its failure has a long down time , One of the ideas to solve this problem is hydraulic transmission system (Kucera 2015) and (Lewabrane 2013). These systems consist of the hydraulic pump in the nacelle, a variable displacement motor and the electrical generator at the ground and other auxiliary component, such as relief valves, heat exchanger, filters, accumulator and etc. The details of these systems are described in (Yang 2014) and (MacKay 2017). However, the main advantages are:

- Reduction of the nacelle weight that can be reduce the tower weight and cost
- Easy maintenance of the generator and other components at the ground

These features are more valuable for float offshore wind turbine that lightweight tower and nacelle caused a great reduction in the foundation costs. The reverse osmosis (RO) method is the most usual technology for producing clean water. The RO system needs a high-pressure water pump (more than 30 bar) for producing fresh water from seawater , The details for these systems are described in (Ahmadv et al.2019) Usually, these systems need electrical motor to drive water pump. However, another solution is to drive the pump directly with a diesel engine or a hydraulic motor, which eliminate electrical generator and motor, therefore increased efficiency of the system. In this configuration, the drive system and water pump should be near each other. The objective of this article is to introduce a "desalination wind turbine" concept. This system converts wind energy to the fresh water without producing electrical energy. The main reasons of this elimination is to avoid energy waste from the energy converter and reduce the overall cost (See figure (1) for descriptions and schematic representation).

Desalination Wind Turbine modeling

The fluid power transmission system is designed for wind turbine has many details(burton et al.2011), It is consisting of many check valves, pressure control valves, accumulators etc. For describing the concept, main components, which have important functions in the dynamic response of the system, are modeled in figure (2) below. The wind energy is converted to the mechanical energy by Rotor. The rotor speed (ω_r) is a function of the Rotor torque (T_a) and hydraulic pump torque (T_r) and based on the Newton second law, it can be written as :

$$T_a - T_r - B_r\omega_r = J_r\dot{\omega}_r \qquad (1)$$

The rotor torque has a nonlinear and complex function as follows :

$$T_a = function(\omega_r, \beta, V_w) \qquad (2)$$

Rotor torque is calculated for different blade pitch angle (β), which is angle between the upcoming wind velocity and the chord line in the wind turbine blade , wind velocity (V_w) and rotor speed. Then T_a can be calculated by a 2D- table interpolation. In this Article. The wind turbine specification is from (Zhanget al. 2016), and presented in Table 1 below. The other parameters are defined in Table 1. More details of these equations can be found in the. The main shaft, which is connected to the rotor, drives a hydraulic pump. The relation between pump and main shaft torque and speed can be defined as :

$$T_r = D_p(P_o - P_r) \qquad (3)$$

$$Q_o = D_p\omega_r \qquad (4)$$

Po is the hydraulic high pressure and Pr is the hydraulic low pressure, Dp is the pump geometric displacement (cc/rev). The pressurized oil, transmitted energy to the hydraulic variable displacement motor. The relations are presented in equations (5) and (6) , The water pump is driven by this motor and pressurized seawater. By neglecting these pump and motor inertia, compare to the wind rotor moment of inertia, the second Newton law for hydraulic motor can be written as equation (5) and (6) and for water pump can be written as equation. (7) and (8) .

$$T_m = D_m\theta(P_o - P_r) \quad (5)$$

$$Q_o = D_m\theta\omega_m \quad (6)$$

$$T_w = D_w P_w \quad (7)$$

$$Q_w = D_w\omega_m \quad (8)$$

θ is the motor angular that is varies from 0 to 1 and is related to the swash plate angle. P_w is water pressure which is set by the brine relief valve and is a design parameter and constant, D_m is the motor geometric displacement, T_w is the water pump torque and ω_m is water pump rotational speed. By using equations (1) to (8), the dynamic relation of the wind turbine is:

$$T_a - P_w \frac{D_p}{D_m} D_w\theta - B_r\omega_r = J_r\dot{\omega}_r \quad (9)$$

The seawater is purified with the RO module and the relation between RO module variables can be written as mentioned in the Table 2 below:

$$Q_w - Q_b - Q_P = 0 \quad (10)$$

$$C_w Q_w - C_b Q_b - C_P Q_P = 0 \quad (11)$$

$$Q_p = (P_w - P_{os})C_{RO}A \quad (12)$$

$$P_{os} = R_{os}\left(\frac{C_b + C_w}{2}\right) \quad (13)$$

Qw is the saline water flow rate, Qb is the brine flow rate, Qp is the permeate flow rate and the equation. (10) is the water mass balance law , Cw is the salinity of the saline water, Cb is the brine salinity, Cp is the permeate salinity and the equation (11) is the salt mass balance law , Po is the osmosis pressure of the saline water, Cro is the Ro module coefficient, which is find in the catalogue, A is the RO module area and equation (12) is related to the RO membrane permeate flux (Boudewijin 2013) and (Cabrera et al. 2018) . Ros is the pressure constant for the solvent salt in the water at 25 C and the equation. (13) is the osmosis pressure relation. The system parameters are selected to be consistence with the wind turbine specifications (Table 1) and listed in the Table (2). The saline water is considered to have sea water specifications.

Steady State Analysis

For assessment of the Desalination Wind Turbine concept, steady state condition of the system is calculated from equation (9). The Ta is a nonlinear function of the rotor speed, wind velocity and pitch angle, therefore this equation is nonlinear. The right side of this equation is set to zero and the nonlinear equation is solved for different wind speed, from cut in 3.5 m/s to cut out 18 m/s by using MATLAB software functions. The aerodynamic power, pitch angle and rotor speed is plotted in figures (3), (4) and (5) respectively. The wind turbine rotor starts to rotate from 3.5 m/s wind velocity (Cut-in). The rated power is 3600 kW at 7.5 m/s wind velocity (Table 1). In this band, Zone II, the pitch angle is zero and rotor speed should be controlled to be increased from 12 rad/sec to the 15 rad/sec, linear with wind velocity, to have best aerodynamic performance. From the rated to the cut-out wind velocity, Zone III, the rotor speed is constant and pitch angle is increased to regulate rotor speed. In this zone the aerodynamic power should be constant. The hydraulic oil pressure, hydraulic oil flow and the motor angular is shown in Figure (6), (7) and (8) respectively. By increasing rotor speed in Zone II, the oil flow is increased from 20 to 50 lit/min. In order to track best aerodynamic performance conditions (rotor speed), the water pump angle should be increased (Figure 8). Then the oil pressure increased consequently. The permeate water flow is calculated based on Equations (10) to (13) as shown in Figure (9). At rated wind velocity, the rated permeated flow is 550 liters per day. The important parameter for a classical wind turbine is the annual power production. For this concept, the Annual permeate Water Production (AWP) is important. The AWP for different annual wind speed based on the Rayleigh distribution function is calculated similar to annual power production and reported as in Table (3).

$$Annual\ Water\ Production = 8760 \times \int_{Vw(Cut-in)}^{Vw(Cut-out)} Q_p P_{Ray.}(V_w) dV_w \quad (14)$$

P_{Ray} is the Rayleigh probability function and 8760 is the hours in one year.

Controller Structure Design

For wind turbine, capability of Maximum Power Point Tracking (MPPT) is very important. For the Desalination Wind Turbine Concept, the oil pressure is measured easily and it has a relation with a rotor angle (Figure 10). Instead of power measurement of the wind turbine generator, the rotor speed reference can be calculated from the oil pressure measurement and the command signal is send to the hydro motor to set the relative motor angle. The block diagram of the closed loop system is shown in Figure (11). It has two controller block: Pitch controller for rotor speed regulation and Oil pressure controller for MPPT. The algorithm for controller tuning is as follows:

-Step 1: The pitch angle controller strategy is similar to what has been assigned by is chosen. This is a PID schedule gain controller. The controller gains are determined to place the poles in the desire position. More details are described in the (Zhang et al.2016)

- Step 2: the hydro motor controller is designed as follows (Laplace Domain):

$$PI = 0.2 \times (1 + \frac{0.3}{s}) \quad (15)$$

The PI parameters is set such that the closed loop has a fast response to the sudden wind changes and the rotor over speed (speed more than 180 rev/min) is not happened.

RESULTS AND DISCUSSION

The closed loop response to the wind gust and wind variations is plotted in Figure (12) to (14). In Figure (12), the wind turbine response to the wind variation is presented. The wind velocity is changed from 3.5 to 9 m/s, with a Sine wave shape. It is in the Zone II and III. Both the Pitch controller and the Pressure controller are active, but the Pressure Controller has a more significant effect. The maximum over shoot of the rotor speed is 10 rpm, and overshoot of the Oil pressure is 5 bar, which shows the capability of the Desalination Wind Turbine concept for MPPT. In Figure (13), the wind turbine response to the sudden wind changes (wind gust) is presented. The wind velocity is changed from 8 to 10 m/s, just in 10 seconds, in the Zone III. Both Pitch controller and Pressure controller are active, but the pitch angle has a more significant effect. The maximum over shoot of the rotor speed is 10 rpm, which is acceptable. This shows the capability of the pitch controller. In figure (14), the wind turbine response to the wind turbulence is presented. The wind velocity is considered as a white noise which is changed from 4 to 10 m/s. Both Pitch controller and Pressure controller are active. The maximum over shoot of the rotor speed is 10 rpm, which is acceptable. The importance of the compatibility of the Pitch controller and Pressure Controller is shown in this result.

CONCLUSION

In this article, a novel concept for wind turbine system is introduced. The consumer need for energy demand is considered and a Desalination Wind Turbine is established. This concept has a lower component and cost, compared to the Wind turbine with electricity output and a RO system. The value proposition of this concept is highlighted in the off shore wind turbine, which the weight of nacelle and tower is very important. For this concept, an advance control system is introduced that can have a good response to the wind turbulence and gust. In this system, a simple measurement of the oil pressure is used for Maximum Power Point tracking which is more reliable compared to classical solutions. In addition, this concept can be used for stall wind turbine. The controller optimization and modeling details of the system can be performed in the future study.

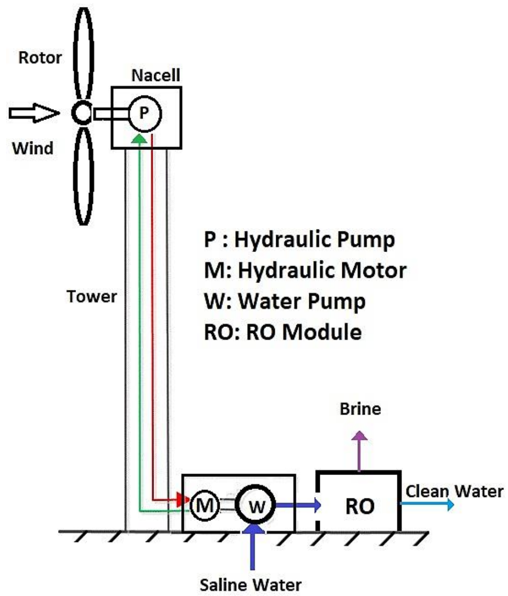

Fig.(1): General View of the Desalination Wind Turbine

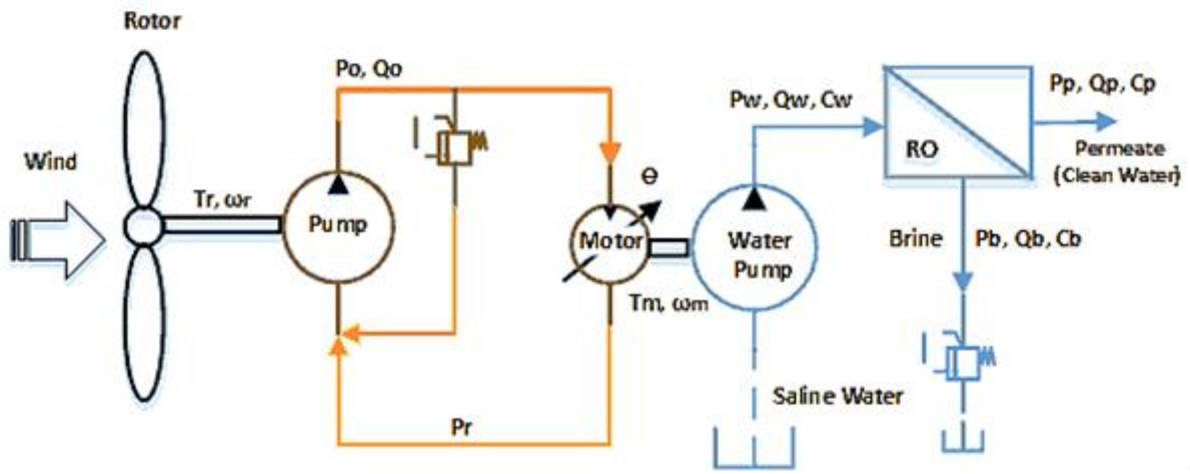

Fig.(2) Desalination Wind Turbine modeling

Table 1: Wind Turbine Specification

Rated Aerodynamic Power	3600 W
Rotor Nominal Speed	145 rpm
Number of Blades	3
Rotor Radius	3.3m
Tip Speed Ratio	6.6

Table 2: Parameters Definition

Variable	Description	Value
Jr	Rotor moment of inertia	38 $kg.m^2$
Br	Rotor damping	0.38 N.m.s/rad
Dp	Hydraulic pump geometric displacement	50 CC
Dm	Hydraulic motor geometric displacement	4 CC
Dw	Water pump geometric displacement	8 CC
Pw	Water pressure	35 bar
Cro	RO module permeability	98.5×10^{-6}
A	RO module area	87.5 m^2
Ros	Osmosis pressure constant for salt at 25 ^oC	0.7835

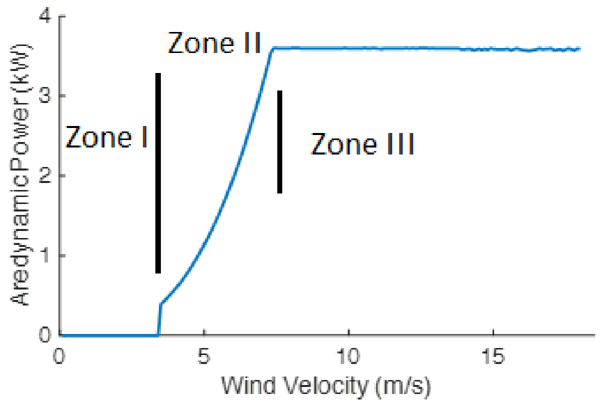

Fig.(3): Aerodynamic power

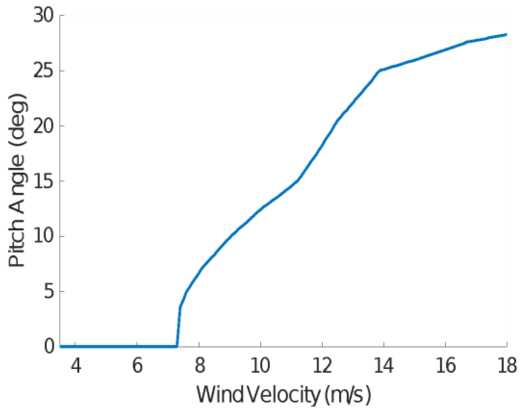

Fig.(4): Pitch angle for wind speed from cut-in to cut-out

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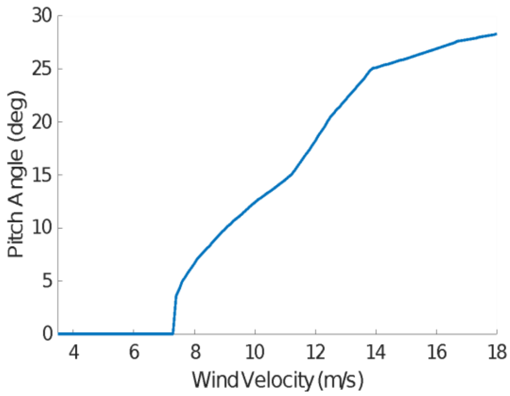

Fig.(5): Rotor speed

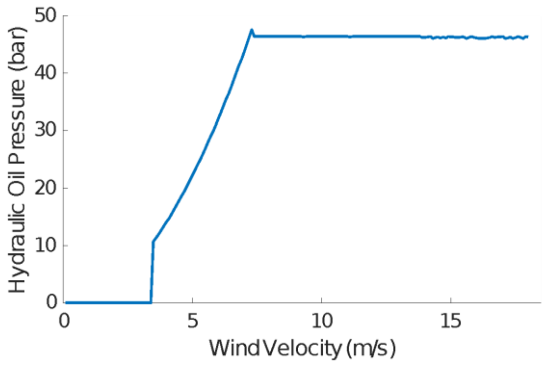

Fig.(6): The hydraulic oil pressure

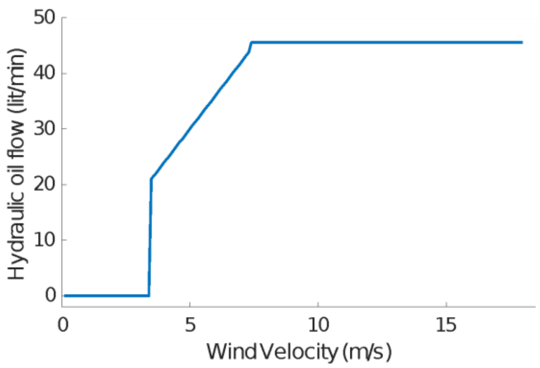

Fig.(7): The Hydraulic oil flow rate

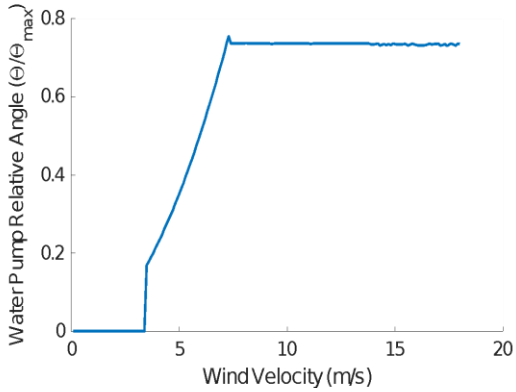

Fig.(8) The motor angle

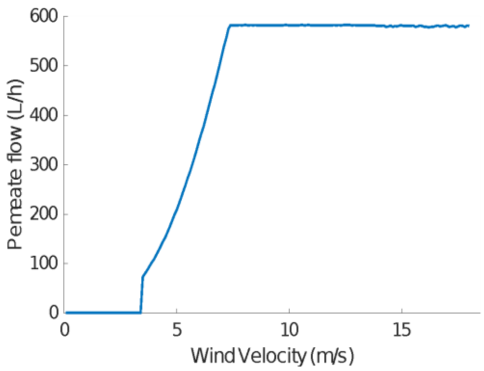

Fig.(9): The permeate flow rate

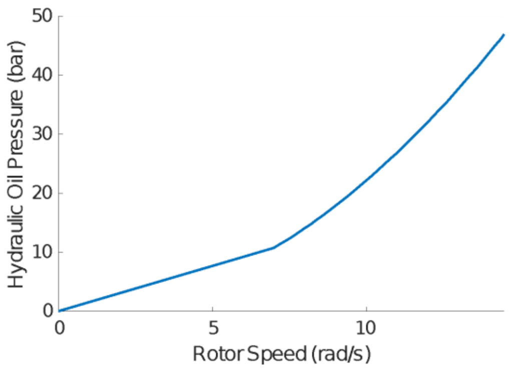

Fig.(10): The Hydraulic Oil Pressure and Rotor Speed relation for MPPT

Table 3: Annual Water Production

Annual Wind velocity (m/s)	5	5.5	6	6.5	7	7.5	8	8.5
Annual Water Production (m^3)	2072	2393	2676	2920	3125	3291	3420	3513

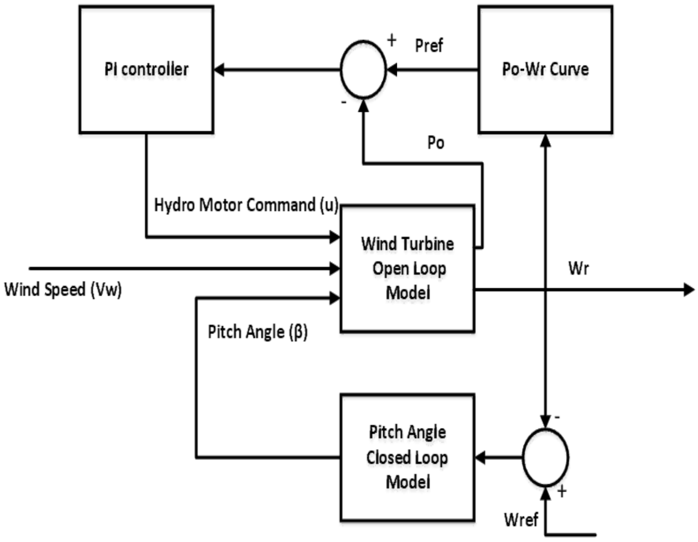

Fig.(11): The Closed loop Structure for Desalination Wind Turbine Concept

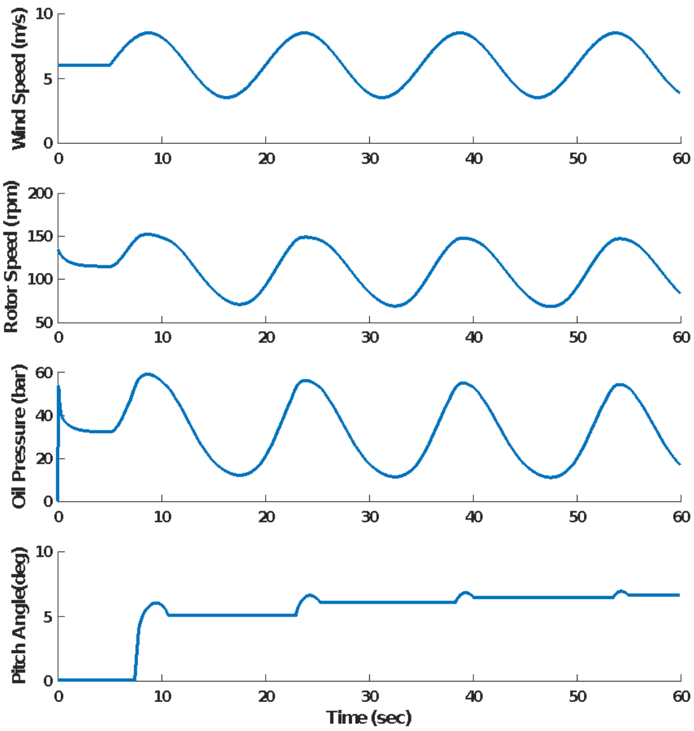

Fig.(12): Response of the Wind Turbine to the Wind speed change

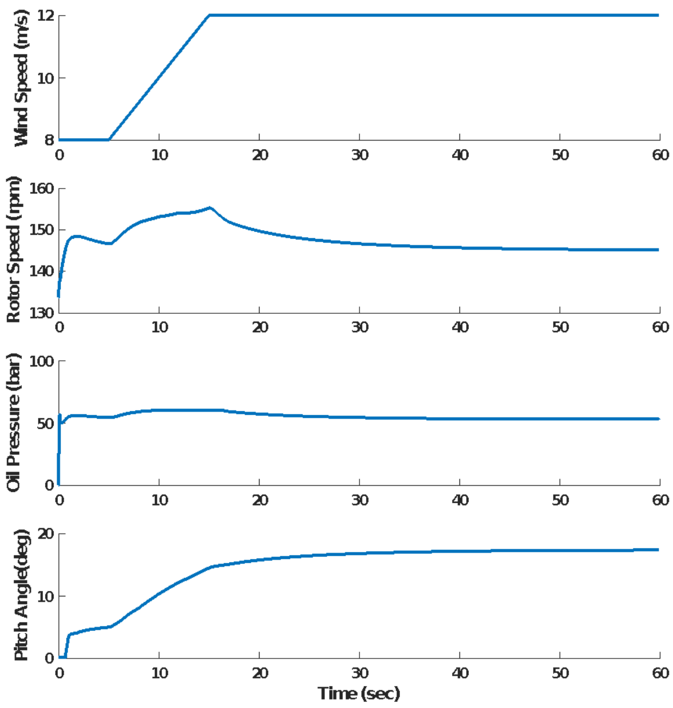

Fig.(13): Response of the Wind Turbine to the Gust

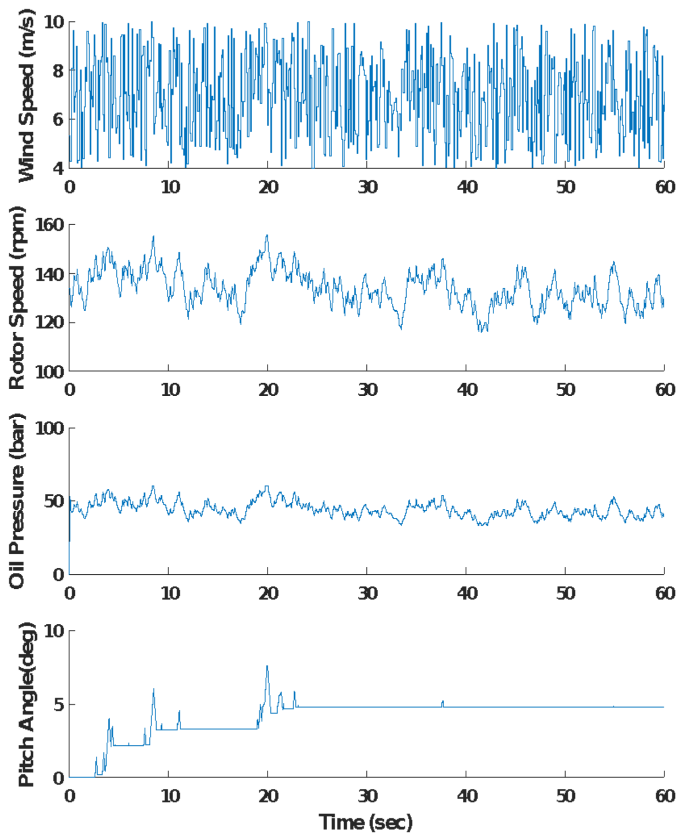

Fig. (14): Response of the Wind Turbine to the Wind Turbulence

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