Possibility Application of Stand-alone wind Energy Conversion System under the Climatic Conditions of Iraq

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***Abstract*—The research included a methodology suitable for the use of wind energy in Iraq for the uses of independent loads, by revealing the importance of wind energy, how to exploit it, its most prominent features and the factors that affect it, as well as analyzing the climatic data related to the speed and direction of the wind, which is useful in revealing the amount of electrical energy produced from The wind is measured in watts / square meters.**

In this paper, the optimal location in which wind turbines can be used are studied and proposed based on economic criteria in all locations in Iraq in which wind can be used to generate electricity independently from the national grid to operate loads such as water pumps, or for heating, cooling, or energy storge.

Developing a mathematical model of wind energy conversion system WECS by using (MATLAB /Simulink) consisting of a mechanical system that includes each of the wind turbines with a method of controlling the speed of the turbine rotation while ensuring that the system works at the maximum possible power(maximum efficiency) (maximum power point tracking MPPT) with a gearbox to increase the speed of the turbine connected with a relatively high-efficiency electric generator (parament magnet synchronous generator PMSG) with a power electronics system (Voltage source inverter VSI) with a choice of control method Frequency (Vector control method Field oriented control FOC) to maintain the rotation process while increasing the efficiency of the electrical system.

***Keywords*—wind turbine energy conversion system; Iraq map; mechanical characteristics; PMSG, power coefficient**

I. INTRODUCTION

It is impossible to conceive of a modern society without electricity. When non-renewable energy sources are used up, they are completely depleted. Hence, to provide the requisite quantity of power, alternative energy development is an essential step. The relationship between energy consumption and environmental pollution has become clear because of the exacerbation of broad negative results such as climate change, which included a rise in global temperatures and humidity in the atmosphere, the spread of devastating floods and hurricanes, and other changes that are difficult to control. Therefore, it is necessary to shift from the consumption of fossil fuels to alternative or renewable energy sources such as the usage of renewable energy sources, such as wind, solar energy, wave energy, and energy from ebbs and flows, is important right now. The most interesting source of energy is wind, though.

Also, it is unprofitable to include sparsely populated areas remote from large cities in a single energy system. Traditionally, their autonomous power supply is carried out using diesel power plants, and coal/oil boilers. In this case, the supply of fuel occurs intermittently and is accompanied by an increase in the cost of transporting fuel by land or water, and sometimes by helicopter in the Iraqi area or any far zone in the world. The main consumers in such places can be pumps for lifting water, heating systems, thermal energy storage devices, etc. For such consumers, it is permissible to change the power of the supply network. Therefore, it is possible to use wind power plants that generate intermittent instantaneous energy. For autonomous wind turbines, the main problem is economic efficiency; the payback period depends on it.

There are many evidence confirming the presence of dangerous pollution in the environment in Iraq such as temperature increase and dust storms [1], so solutions must be found to reduce this pollution by using renewable energy. There are much scientific research that gave practical studies of wind energy in Iraq, starting in 1986, which estimated the potential wind energy in Iraq using the monthly wind speed [2][3]. In work [4], the possibility of using wind dependence using the Weibull distribution and the feasibility of installing wind turbines in 19 stations in Iraq were investigated. Where the scientific results and dynamic characteristics of winds were presented [4].

Mathematical models have been developed that describe the process of converting mechanical energy into electrical, which constitutes a mathematical model for wind turbines, presented in the form of a simulation diagram. Where the value of the optimal output speed was calculated depending on the wind speed and the corresponding maximum efficiency and mechanical characteristics of the wind turbine [5, 6]. A mathematical model was also represented, and the maximum mechanical power of the displacement turbine was calculated and the possibility of using it in Iraq was studied [7].

The aim of this work will include using the MATLAB /Simulink on a 6 kW wind turbine system, a three-blade turbine of the French brand with a 6 kW synchronous generator PMSG, using a control system with switches for the electric inverter, and obtaining special results for each of the mechanical, electrical and electronic systems, which are used in special sites in Iraq, according to The available information regarding wind speed, which was previously published in previous studies, in addition to the website of the Iraqi Ministry of Science and Technology and the Iraqi Meteorological Department.

II. THE LOCATION OF THE REPUBLIC OF IRAQ ON THE MAP

Wind speed in Iraq has located in the southwest of the continent of Asia, north of the Arab world. Where it is bordered to the north by Turkey and to the east by the Islamic Republic of Iran, at the time of the west it is bordered by the

Syrian Arab Republic, Jordan, and the Kingdom of Saudi Arabia. It is located between latitudes 29 50 and 37220 north, and longitudes 38450 east and 48450. The total area of the Republic of Iraq is 435,052 square kilometers. There are many high mountains in the northern regions, where the days are not sunny in these areas, especially in the winter season. In central and southern Iraq, it is a flat land between two major rivers, the Tigris and Euphrates [8] shown in Fig. 1. below.

Fig. 1. Iraqi map [9]

Where the Republic of Iraq is located in relation to the seas located in the southwestern part of the continent of Asia, in the second rank in importance, as it is a basic factor and a factor controlling the climate, as it is known that the indication of the seas depends mainly on the distance from the water bodies and the intensity of the wind depends on the control of the terrain as well. As the Mediterranean Sea and the Arabian Gulf are closer to Iraq than other countries, while there are also near it both the Caspian Sea and the Red Sea [10].

III. SOURCE AVAILABILITY POTENTIAL IN IRAQ

In Fig. 2, the spatial distribution is calculated to obtain the wind speed in Iraq, where the study included that the western and southern regions are among the best areas that can be used to obtain electric energy, due to their relatively high wind speed.

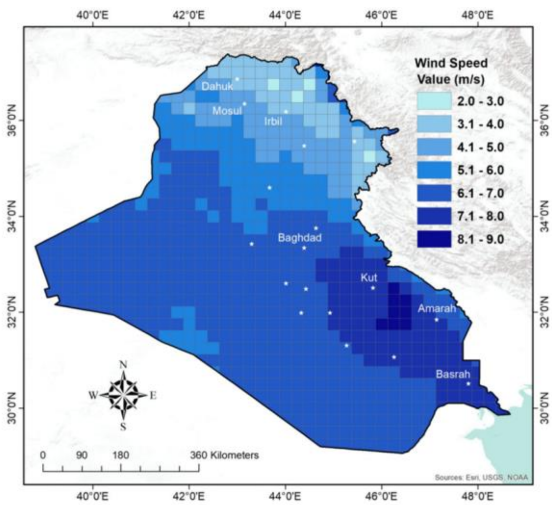

Fig. 2. Map of wind resource potential in Iraq [11]

Where the wind speed exceeded 7 meters per second. As the wind speed in the Iraqi city of Kut and the city of Amarah 9 m/s is the highest average wind speed in Iraq. Followed by the Iraqi city of Basra, then Mosul, with an average wind speed of 6.5 m/s. As for the northern regions, the wind speed for the governorates of Dohuk and Erbil (Kurdistan Region of Iraq) was as low as possible, from 2 m/s to 4 m/s.

Mathematical models have been developed that describe the process of converting mechanical energy into electrical, which constitutes a mathematical model for wind turbines, presented in the form of a simulation diagram. Where the value of the optimal output speed was calculated depending on the wind speed and the corresponding maximum efficiency and mechanical characteristics of the wind turbine [6, 12, 13]. A mathematical model was also represented, and the maximum mechanical power of the displacement turbine was calculated and the possibility of using it in Iraq was studied [6]. To ensure the validity of previous studies [7, 14], studied the wind speed of Basra Governorate, and the result was as shown in the following Fig. 3. Fig. 3, can be see notice the wind speed for at least one governorate for the months of the year. It shows that the month of May (the fifth month in Iraq) has the highest wind speed, approximately 6 m/s.

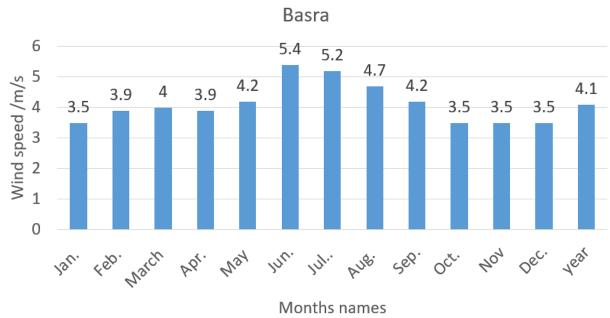

Fig. 3. Average wind speed in Basra city

To verify the possibility of winds in Iraq for the purposes of producing electric energy, wind energy data approved by the Iraqi Meteorological Authority and the article [29] were selected and analyzed for all selected stations in Iraq as in the table below [7, 15].

Through Fig. 4 and 5, changes were observed in the recorded wind speeds, which were taken from the wind speed sensors. Can be see noticed that the wind speed increased with distance from the Turkish borders and mountain ranges with the flattening of the land. Also, Kirkuk stations recorded the lowest wind speed in Iraq, while in the central and southern regions, moderate wind speeds were recorded, as it is possible to use wind stations there.

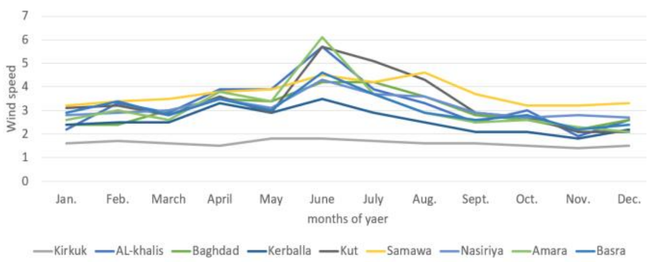

Fig. 4. Average wind speed in Iraq

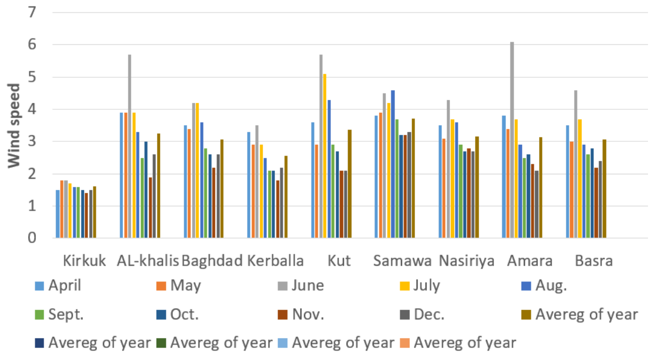

Fig. 5. Wind speed in Iraq.

A high wind speed was recorded in Iraq in 2015 in most of Iraq's stations, with a height of 10 meters, as shown in the following figure, in Baghdad, the capital of Iraq, where the highest value was 30 meters/s. The lowest value was m/sec. The value of the annual average wind speed for the group of governorates included in the study is shown in the following Fig. 3, 4 and, 5.

By studying the possibility of obtaining electricity in Iraq, can be see found many provinces in which it is possible to establish wind energy units in them due to the presence of winds throughout the year, as in Baghdad, Basra, Amarah, Nasiriyah, Al-Khalis, Kut and Samawah and more cities.

In the study [14] proposed a hybrid system between wind energy and solar energy connected to the national grid using the MATLAB program, for only three stations, where the study used selected meteorological information and data. Where the study gave confirmation to the study [7] and the study that carried out that it is possible in Iraq to use wind energy to produce electric energy, and the study confirmed what was obtained in our study. The study also indicated a recommendation that the province of Basra be one of the sites that were obtained in our study and the studies that suggested that.

IV. Mechanical Model of Horizontal Wind Turbines in Mathematics

Aerodynamic, mechanical, and electrical models may all be used to mathematically represent horizontal wind turbines. The aerodynamic model is in charge of depicting the energy conversion from a moving air mass traveling at a specific speed, which generates the turbine's rotational movement, into mechanical energy at the generator's shaft. The speed and torque of the system's shaft are directly related to the mechanical power provided. At the generator output, mechanical torque is transformed into electrical energy according to the electrical model.

A. *Mathematical model Aerodynamic*

The wind power supplied to the turbine shaft, which transforms it into mechanical power, comes from [27, 28] [16, 17] [5, 6, 13, 18, 19]:

$$P_T = \frac{1}{2}.\rho.A_t.v_u^3 Cp \tag{1}$$

where PT stands for the mechanical power generated by the wind turbine (in Watts), for air density (1.225 kg/m3 at sea level), A for the swept area (in square meters), V_u for wind speed (in meters per second), and *Cp* for the power coefficient. A turbine's power efficiency is determined by its aerodynamic properties and direction in relation to the wind flow. The relationship between the wind speed and the blade speed determines the value of *Cp*. Tip Speed Ratio (TSR) is the name given to this ratio. For further information on this conversion, see reference [5, 6] [16, 17] [18, 19]. The TSR is shown by and described by

$$\lambda = \frac{\omega_t \cdot R}{V_u}, \tag{2}$$

where ω_t is the angular velocity of the turbine shaft (rad/s) and *R* is the radius of the swept area of the turbine (in meters). For any WT model, direct measurements of the turbine in operation may be used to derive the curves that connect *Cp* to various values of pitch angle and TSR λ, β respectively. These curves, sometimes referred to as power curves, can be used to calculate *Cp* at various turbine operating stages. It is difficult to determine Cp precisely, and this requires the use of sophisticated mathematical models. As a result, various estimates based on measurements of and have been provided for the estimation of *Cp* [13, 16, 17] [5, 6, 18, 19]. A phrase that is frequently used to discourage mining Cp is:

$$C_p(\lambda,\beta) = C_1(C_2/\lambda_i - C_3\beta - C_4)^{C_5/\lambda_i} - C_6\lambda, \tag{3}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + C_7\beta} - \frac{C_8}{\beta^3 + 1} \tag{4}$$

where *C1*, *C2*,..., and *C8* are constants that relate to the turbine's aerodynamic properties. The power coefficient *Cp*, the wind speed *Vu* that impacts the blades, and the physical properties of the blades may all be used to represent how much torque the turbine produces. Given is a mathematical connection.

$$T_t = \frac{1}{2\lambda}\rho \cdot A_t \cdot R \cdot V_u^2 \cdot C_p(\lambda,\beta) \tag{5}$$

B. *Modelling of PMSM BASED WECS*

Fig. 6 depicts the equivalent circuit of a permanent magnet synchronous generator in vector coordinates dq. The statement below [5, 13, 16, 19]. determines the constructed mathematical model of a permanent magnet synchronous generator.

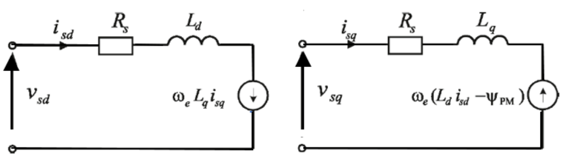

Fig. 6. A permanent magnet synchronous generator's vector equivalent circuit dq [5, 13, 16,19]

$$\frac{d}{dt}i_d = \frac{1}{L_d}V_d - \frac{R}{L_d}i_d + p \cdot \omega_e \cdot i_d \tag{6}$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}V_q - \frac{R}{L_q}i_d - p \cdot \omega_e \cdot i_d + \frac{\psi_r p\omega_e}{L_q} \tag{7}$$

It can be inferred from the formulae and the graphic that the element's EMF has a (sinusoidal) shape since the back EMF depends on the rotor's location and has a distinct amplitude. The electromagnetic torque for a permanent magnet synchronous generator is defined as [5, 17, 18, 19] after that.

$$T_e = 1.5p\left[\psi_r i_q + \left(L_d - L_q\right) i_q i_d\right] \quad (8)$$

where ω_r is the angular velocity of the rotor, L_q is the q axis inductance, L_d is the d axis inductance, R is the resistance of the stator windings, iq is the q axis current, id is the d axis current, vq is the q axis voltage, v_d is the d axis voltage, and ψ_r = amplitude of flux.

where p is the number of pole pairs, L_q is the q-axis inductance, L_d is the d-axis inductance, R is the stator winding resistance, i_q is the q-axis current, i_d is the d-axis current, vq is the q-axis voltage, vd is the d-axis voltage, and R is the rotor's rotational velocity.

Consequently, the following definition applies to the electromagnetic torque produced by the PMSG [5, 13, 16, 19].

$$T_e = \frac{P_{em}}{\omega_e / \frac{P}{2}} = \frac{3}{2}\left(\frac{p}{2}\right)\left[\psi_d i_q - \psi_q i_d\right]$$
$$T_e = 1.5p\left[\psi_r i_q + \left(L_d - L_q\right) i_q i_d\right] \quad (9)$$

C. Vector control method

For a synchronous machine with permanent magnets mounted on the surface of the rotor, the inductances along the d and q axes are considered to be equal to each other: Lq = Ld. (8). In this situation, the equation for the torque may be streamlined and represented as follows.

$$T_e = 1.5p\left[\psi_r i_q\right] \quad (10)$$

The d-axis current reference is set to zero ($i_d{}^* = 0$) to provide the greatest torque. The flux linkage of permanent magnets has a constant value in equation (10). As a result, the electromagnetic torque and q-axis current will have a linear connection, making it simple to regulate the electromagnetic torque by modifying q-axis current. Fig. 7 displays the vector diagram of the PMSM when vector control is used.

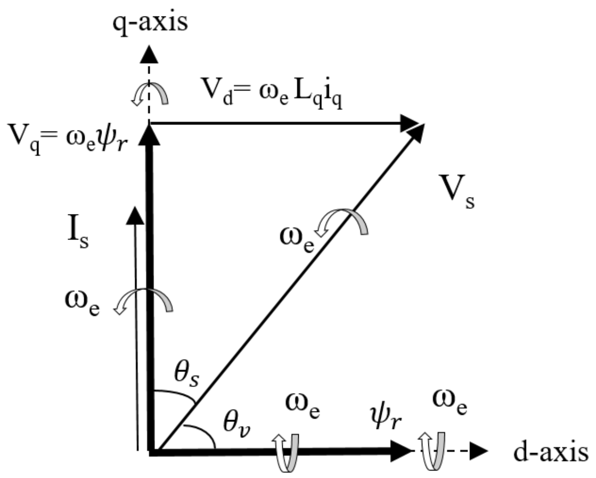

Fig. 7. Vector driven PMSG diagram [5, 13, 16,19].

The value connected to the spinning field must be chosen for vector control of the generator. As a result, as illustrated in Fig. 7, the signal area will be synchronized with the stator flux and the axis will also be aligned with the stator flux vector.

When moving from a three-phase system (ABC) to a two-phase stationary coordinate system (α, β, system), the formulae for changing the number of phases (Clark transform) are as follows [5, 13, 16, 19]:

$$V_\alpha = V_A$$
$$V_\beta = \frac{V_B - V_c}{\sqrt{3}} \quad (11)$$

Equation 12 uses the Park transformation to translate the biaxial stationary values of the number system into rotating values. The following equations represent the Park transform [5, 13, 16, 19]:

$$V_d = V_\alpha \cos(\theta) + V_\beta \sin(\theta)$$
$$V_q = V_\beta \cos(\theta) - V_\alpha \sin(\theta) \quad (12)$$

Fig. 8 depicts the method of vector control for a synchronous generator with permanent magnets.

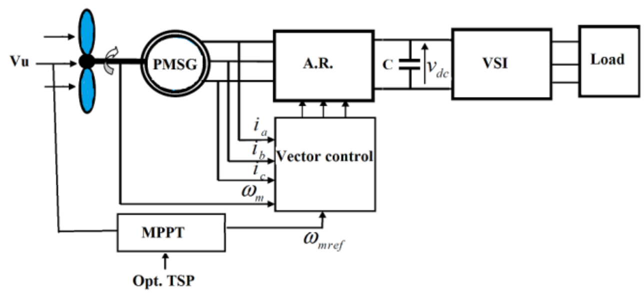

Fig. 8. Vector control of PMSG – control strategies scheme

Where MPPT – maximum power point tracking by tip speed ratio method, A.R – actine rectifier, VSI – voltage source inverter, PMSG – permanent magnet synchronous generator. As was already said, the vector control technique is combined with MPPT control based on the ideal propeller speed ratio as the control algorithm for the generator power converter. Three feedback loops are depicted in Fig. 3.7 of the control system: a speed control loop, a d-axis current control loop, and a q-axis current control loop. The actual speed of the generator, as determined by a rotor position sensor installed on the rotor shaft, is compared to its reference value at each sample interval in the speed loop. The error is then communicated to the PI controller, which produces the q-axis current reference, $i_q{}^*$, from the generation of this value by managing the ideal speed value. The d-axis reference current, $i_d{}^*$, is always set to zero in the meanwhile. The three-phase stator currents are monitored and transformed to the dq coordinate system using the Park transform to provide current feedback signals. The PI controllers in the dq current control loop then do the reference stator voltages.

V. Simulation and Result

Parameters were selected for real models of both the mechanical turbine and the electric generator of well-known and prestigious companies in the manufacture of electric generators and wind turbines. These parameters were also used in studies and research [5, 13, 16, 19]. Fig. 9 shows the changing wind speed for example from the research date. A three-phase sinusoidal waveform of current and voltage was obtained from the generator, as shown in the Fig. 10, 11, 12 and 13 below:

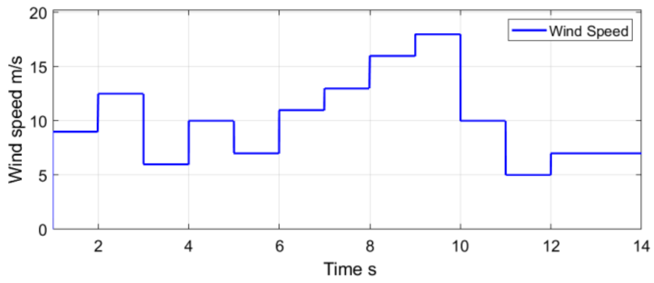

Fig. 9. Wind speed

For example, can be see took a set of wind speed values from the proposed study, where assumed that the wind speed changes from 5 meters per second as the lowest value to 17 meters per second as the highest value, as shown in the above Fig. 10.

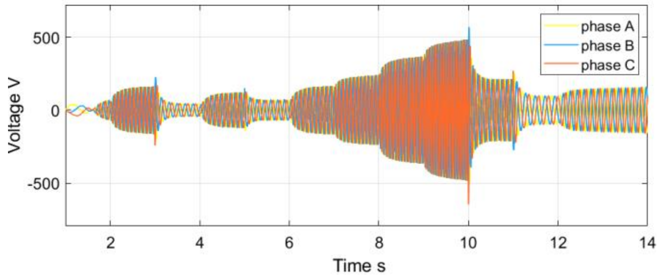

Fig. 10. The phase voltage of the PMSG with varying wind speed

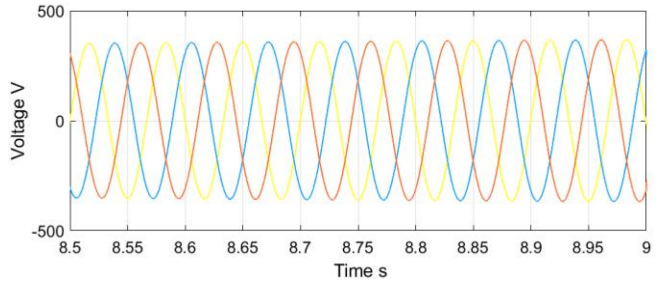

Fig. 11. The phase voltage of the PMSG

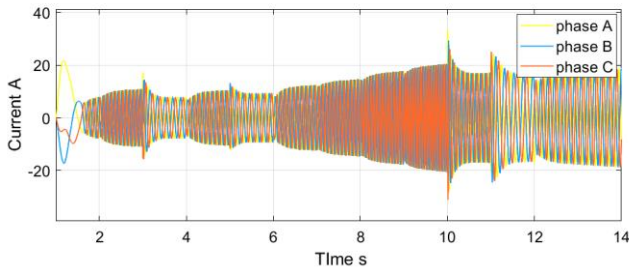

Fig. 12. The phase current of the PMSG with varying wind speed

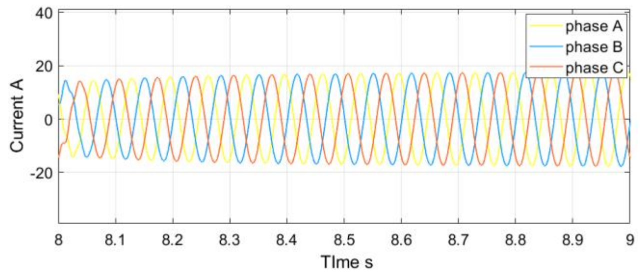

Fig. 13. The phase current of the PMSG

Modeling results the electrical characteristics of the generator were obtained, where in Fig. 10, 12 can be seen notice an increase in both the current and the voltage with the increase in the wind speed. As for the two Fig. 11, 13 depending on a constant wind speed at the bases of wind speed, where the voltage is 380 volts shown in Fig. 11, and the value of the current is estimated at a wind speed estimated at 12 meters per second, 18 A, as shown in the two Fig. 13. The Fig. 14 shows the mechanical characteristics of a wind turbine (dependence between coefficient power and tip speed ratio).

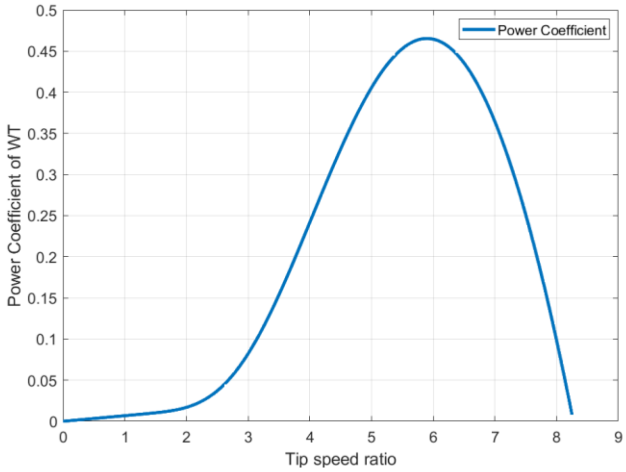

Fig. 14. Dependence between coefficient power and tip speed ratio

From the above Fig. 14, can be see that the highest value of the power factor is 0.48 when the optimal value of the tip speed is 5.7 where the turbine operates at the highest efficiency, where the power coefficient is the total efficiency of the turbine because it represents the value of the total output power divided by the total input power from wind energy. The Fig. 15 below shows a relationship between the torque coefficient and the tip speed ratio.

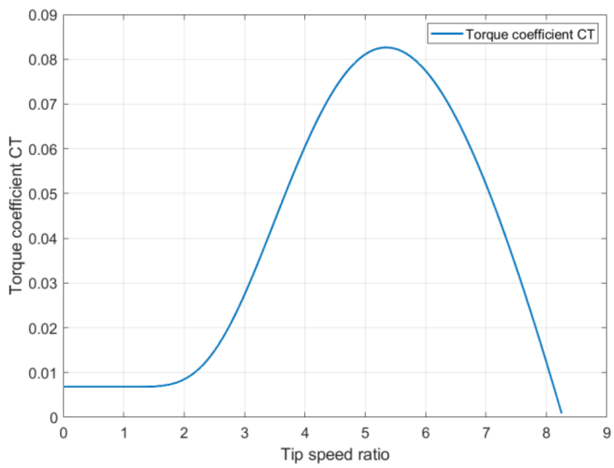

Fig. 15. Dependence between mechanical torque and tip speed ratio.

The value of the torque coefficient was also calculated, which represents the relationship between the upper value of the power constant divided by the optimum value of the tip speed ratio, which gives the maximum value of the tip speed ratio of approximately 5.5 and the torque coefficient value of 0.08. The Fig. 16 shows the mechanical characteristics of a wind turbine (dependence between torque and rotational speed).

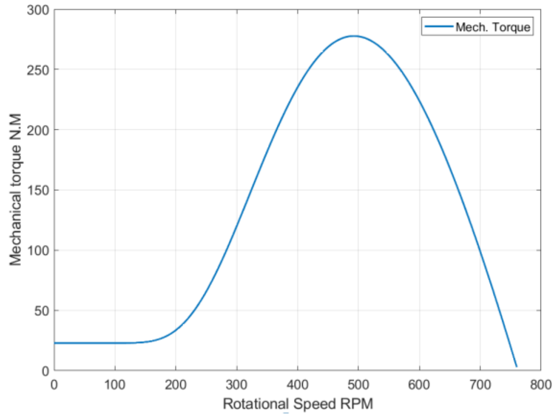

Fig. 16. Dependence between mechanical torque and rotational speed

The highest mechanical torque of the wind turbine is 275 Nm at a rotational speed of 500 revolutions per minute, when the wind speed is constant, as shown in the above figure. The Fig. 17 shows the mechanical characteristics of a wind turbine (dependence between mechanical power and rotational speed).

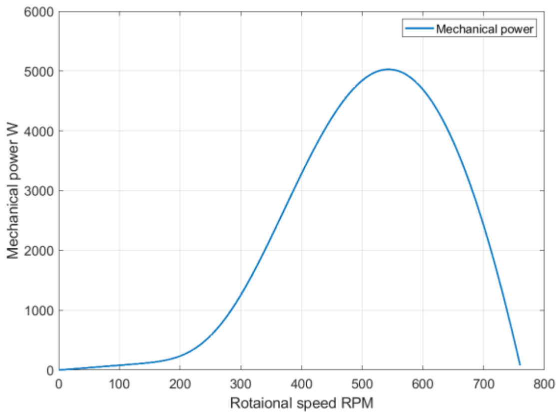

Fig. 17. Dependence between mechanical power and rotational speed

The highest value of the mechanical power of the wind turbine is 5 kW at a rotational speed of 550 revolutions per minute at constant wind speed, as shown in the above Fig. 17.

VI. Conclusion

A special wind system was modeled in the Iraqi airspace, including each of the wind turbines It is connected to an electric generator PMSG, with a power electronics system (voltage source inverter) and a switch control circuit (vector control method) to ensure the continuity of the generator's rotation with the load, with the change in wind speed. The Iraqi regions were also studied for 19 separate stations between the central and southern regions of Iraq, where a comparison was made between the old studies and the proposed study, as it was found that the use of wind energy in Iraq is possible in most of the regions of Iraq spread between central and southern Iraq. Also, the mechanical properties of the wind turbine were studied, represented by the dependence between the mechanical power and the rotational speed, in addition to the dependence of the mechanical torque of the turbine with the rotational speed as well. As for the efficiency of the turbine, the power coefficient and the mechanical torque coefficient were calculated with Tip Speed Ratio, where the turbine efficiency was up to 48 percent with the highest value of the tip speed ratio by 5.8 and the torque coefficient represents 0.08. The electrical characteristics of the electric generator were also studied based on the highest value reached by the wind speed according to the current study or previous studies. The electric current of the generator was calculated with the voltage generated in the stator part of the generator. The electromechanical system was modeled using MATLAB-SIMULINK.

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