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# THE AC SERIES MOTOR AS A WIND TURBINE SIMULATOR

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## ABSTRACT

This paper introduces new wind turbine simulator using Ac series motor (universal motor) to simulate the actual wind turbine in the steady-state mode of operation. Mathematical analysis of proposed model is introduced to compute the performance characteristics at a given wind velocities. The proposed analysis of Ac series motor after applying the control, makes the motor characteristics coincides with the characteristics of the wind turbine in the steady-state mode of operation. Three methods of controlling the ac series motor to simulate the wind turbine are presented for realistic simulation of variable characteristics of wind turbine. The steady state results are highly consistent with theoretical curve, indicating that ac series motor is a new simple, cheap and an excellent method for simulating characteristics of wind turbine.

طاقة الرياح من الطاقات المتجددة التى يتزايد الاهتمام بها لذلك توجد أبحاث عديدة للحصول على أقصى طاقة ممكنة منها. لعمل هذة الأبحاث معمليا يجب أن تتواجد تربينة رياح كذلك رياح بسرعة مناسبة لتوليد الطاقة . هذه الرياح وكذلك التربينة يصعب تواجدهما فى الوقت الذى يتطلبه الباحث. هذا البحث يقدم نموذج جديد يحاكى تربينة الرياح وذلك باستخدام المحرك العام أو محرك التوالى ( ذو التيار المتردد ) حيث أن خواصه تقارب خواص التربينة الهوائية فى حالة التشغيل المستقر. هذاالبحث يقدم نموذج رياضى لحساب خواص الاداء للمحرك والتربينة عند سرعة ما للرياح. التحلبل الرباضى المقترح لمحرك التوالى بعد عمل التحكم جعل خواص المحرك تنطبق مع خواص الترتينة الهوائية فى حالة التشغيل المستقر بما يمكنه من تمثيل تربينة الرياح. تم استخدام ثلاث طرق تحكم بالمحرك لكي تتطابق خواصه مع خواص التربينة الهوائية في حالة الأداء المستقر. هذا التطابق بؤكد أن محرك التوالى ذو التيار المتردد يحاكى التربينة الهوائة بطريقة بسيطة وبتكلفة قليلة وبطرق جيدة للمحاكاة.

***Keywords:*** Wind turbine simulator, AC series motor; control methods.

**List of Symbols**

A Frontal area of the wind, $m^{٢}$
$C_p$ Power coefficient
E Armature back e.m.f., V
I Motor current, A.
N Motor or turbine speed, r.p.m.
$P_w$ Output power of wind turbine, W
$R_a$ Armature resistance, Ω
$R_s$ Field resistance, Ω
r Radius of rotor blade, m
T Torque, Nm.
V Supply voltage, V
$V_w$ Wind velocity, m /s
$X_a$ Armature reactance, Ω
$X_s$ Field reactance, Ω
**ρ** Air density, Kg /$m^3$
**λ** Tip-speed ratio

## 1. INTRODUCTION

Electricity generation from the wind energy has been well recognized as the wind is free, clean, unexhausted energy source (i.e. environmentally friendly). At present, the wind generation is the most mature technology of renewable energy. The cost of wind generation has dropped by large margins which has already approach that of coal generation and economically competitive for many applications.

Due to the uncontrollable nature of the wind speed and large size of wind turbine, the control of wind generation system is so complicated hence; it needs to be studied accurately. Many laboratories haven't had the wind field environment or wind turbine and have brought much difficulty to the experiment study of wind generation technology. So modeling and simulation of wind turbine to study these characteristics are essential in the research works and development. Also, this saves the effort, time and cost for researches.

Simulation of wind-turbine characteristics is mainly about power-speed or torque-speed characteristics in the condition of steady state and dynamic state.

In the past few years, the simulation of wind turbine characteristics is implemented by motors in laboratory. Many researches have been done to develop the wind turbine simulator using permanent magnet synchronous motor, PMSM, [1-2], DC motor [3-5] and induction motor [6-8].

DC motor has simple control method and fairly good speed regulation performance but its structure is complicated and easy to get damage due to the presence of brushes. Smooth reactance must be used in series with the armature windings to get better torque characteristics. This yields to reduce the dynamic response and less slightly simulation accuracy [3-5].

The induction motors have the advantage of large power and low price, but the control method is complicated and rotor parameters are easy to change hence speed or torque regulation and simulation accuracy is reduced [5-7].

PMSM (permanent magnet synchronous motor) is used to simulate the wind turbine characteristics in laboratory. Its characteristics are better than those of DC motor and induction motor in steady state and dynamic state conditions.

In this paper, a novel model using ac series motor is developed for simulating the actual wind turbine in steady state mode of operation. This stable region is suitable and required for wind turbine operation with any load.

The torque speed characteristics of universal motor are better than those of DC motors and induction motor where its characteristics is near to wind turbine characteristics in stable region. Hence the wind turbine simulation mainly requires motor control. Three methods of controlling the ac series motor are provide a novel method for simulating wind turbine characteristics in laboratory at different rotor speed and load torque.

The performance characteristics of the proposed model are mathematically analyzed at different rotor speed and load torque. The proposed analysis is verified experimentally for characteristics of ac series motor when operates as a wind turbine. Good agreement is obtained which verify the validity of the proposed analysis. This method provides a simple, safe and comfortable operation with low cost for the researches inside the laboratory, where the research work to develop the wind energy conversion system can be made at any time without waiting the presence of wind which has bad effect on the researchers health.

## 2. ANALYSIS OF WIND TURBINE OPERATION

The wind Turbine under study is uncontrolled propeller type windmill (horizontal axis wind turbine) of diameter 2.7 m through step up gear ratio 1 : 30 [9].

The output power of wind turbine is defined as:

$$\mathbf{P_w = 0.5\, C_P\, \rho\, A\, V_w^3} \qquad (1)$$

$$C_p = \frac{\text{power available at turbine shaft}}{\text{power available in wind}}$$

Also $C_p$ is non linear function in tip-speed ratio, $\lambda$ where the blade pitch angle $\beta$ is constant.

For the wind turbine under study, the relation between $C_p$ and $\lambda$ is obtained by a curve fitting equation as:

$$\mathbf{C_p = 0.0003\,\lambda^7 + 0.0009\,\lambda^6 - 0.0543\,\lambda^5 + 0.1951\,\lambda^4 - 0.31921\,\lambda^3 + 0.2282\,\lambda^2 - 0.0266\,\lambda + 0.0002} \qquad (2)$$

Where $\lambda$ is the ratio of linear speed at the tip of the blades to the wind velocity and is defined as

$$\mathbf{\lambda = (2\,\pi\, N / 60)\, r / V_w}$$

The torque developed by the turbine is given by:

$$\mathbf{T = 0.5\, \rho\, A\, r\, (\, Cp / \lambda\, )\, V_w^2} \qquad (3)$$

## 3- WIND TURBINE CHARACTERISTICS

For the given wind turbine with horizontal axis, the torque of turbine with rotor speed (after gear box) characteristics can be obtained using the previous equations at two values of wind velocity. The characteristic is shown in Fig. (1).

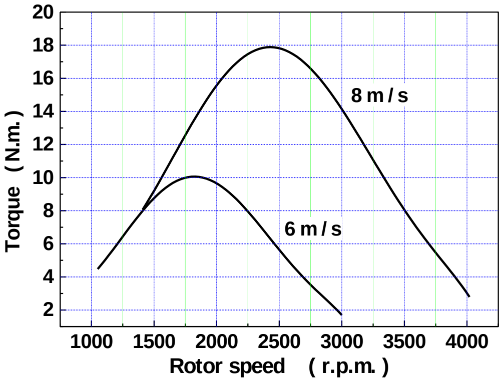


**Fig. (1)** Turbine torque variation with speed after gear box

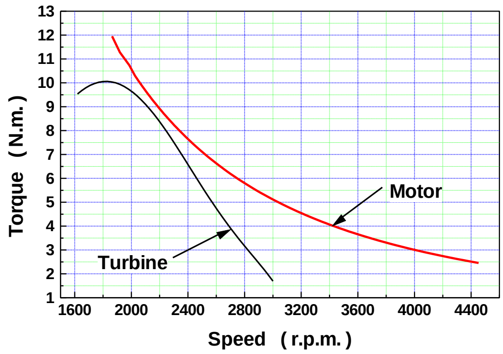


**Fig. (2)** Turbine torque / speed curve and uncontrolled motor torque /speed curve.

## 4- ANALYSIS OF THE MOTOR AS A SIMULATOR

Computer program is used to compute the motor characteristics as follows:

The motor parameters used in this paper are R = 2 Ω and X = 3.5 Ω with a rated voltage of 220V and rated current of 11.5 A. Neglecting the effect of iron loss resistance .

The motor induced e.m.f., E, is given by:

$$E = V \cos\varphi - I R \quad \text{or}$$
$$E = K I N$$

Where, K is e.m.f. constant and depends on motor specification,

$$\varphi = \tan^{-1} ( I X /( I R + E ))$$

and $R = R_a + R_s$ , $X = X_a + X_s$

The input power to the motor, $P_i$, is

$$P_i = V I \cos\varphi \quad , \quad V \cos\varphi = E + I R$$
$$P_i = E I + I^2 R$$

The output power

$$P_o = E I$$

Motor efficiency, $\eta = E I / P_i$

The developed torque $T = E I / \omega$

## 5- Universal motor characteristics

Using the previous analysis of universal motor, the torque versus rotor speed is obtained at rated voltage as shown in Fig. (2).

The current variation of the AC series motor with rotor speed at rated voltage is shown in Fig. (3).

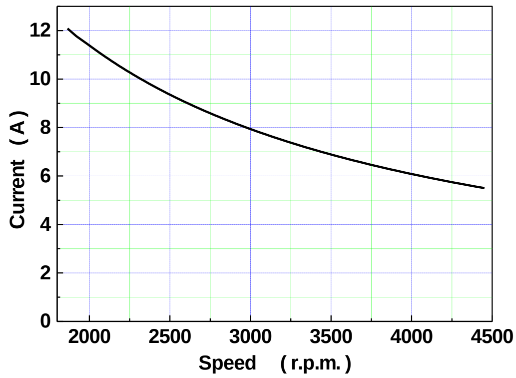


**Fig. (3)** Motor current variation with rotor speed

## 6- The Control Methods of the motor to suite the Wind turbine

Three methods of control are used to make the characteristics of AC series motor is similar and coincide with the characteristics of wind turbine at a given wind velocity.

1- Voltage control
2- Reactance control
3- Resistance control

The first method of control to make the AC series motor suite the wind turbine in steady-state region is changing the applied voltage on the motor. It is found that when the applied voltage on the motor is changed in the speed range of 1850- 3000 rpm, the torque versus rotor speed characteristics of the wind turbine and motor are coinciding as shown in Fig.(4).

The variation of the applied voltage on the AC series motor within the mentioned region of speed is given in Fig. (5). Also this figure shows the changes in induced e.m.f. with the rotor speed.

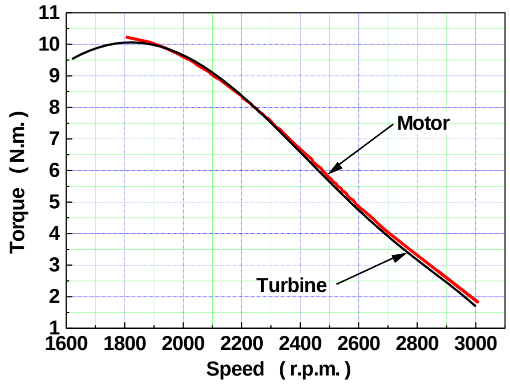


**Fig. (4)** Turbine torque and motor torque versus rotor speed when the applied voltage is changed.

The second method of control to make the AC series motor suite the wind turbine is adding external reactance in the rotor circuit.

When the added reactance is varied, it is found that the turbine torque characteristics is coincide with motor torque characteristics in the range of rotor speed 1750-3000 rpm as shown in Fig. (6). The variation in added reactance with rotor speed through the mentioned region is illustrated in Fig. (7).

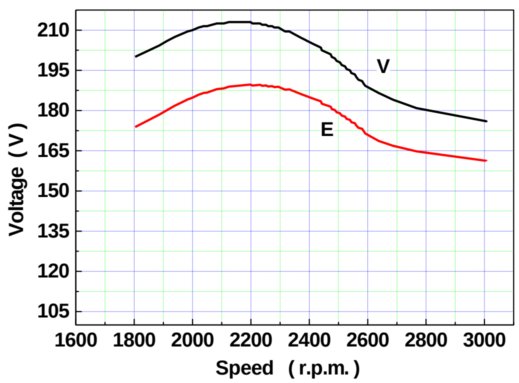


Fig. (5) The variation of the terminal voltage with rotor speed.

The third method of control to simulate the AC series motor with wind turbine is adding external resistance to the motor circuit. By varying the added resistance with the rotor speed, it is found that the characteristics of the motor and wind turbine are coinciding in the same previous speed range as shown in Fig. (8).

The corresponding variation in added resistance with rotor speed is shown in Fig. (9).

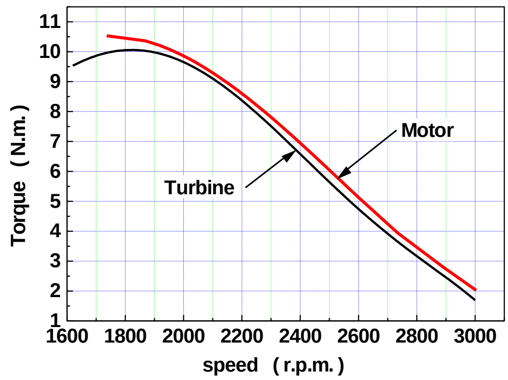


**Fig. (6)** Turbine torque and motor torque versus rotor speed with adding external reactance.

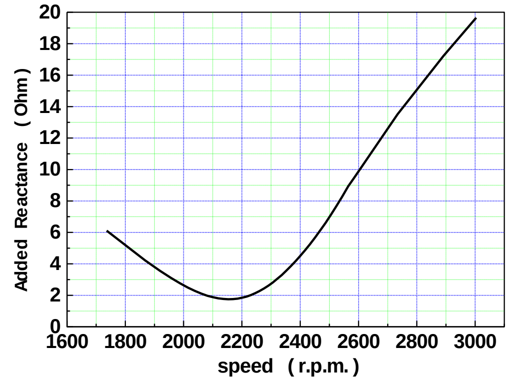


**Fig.(7)** Added reactance versus the rotor speed

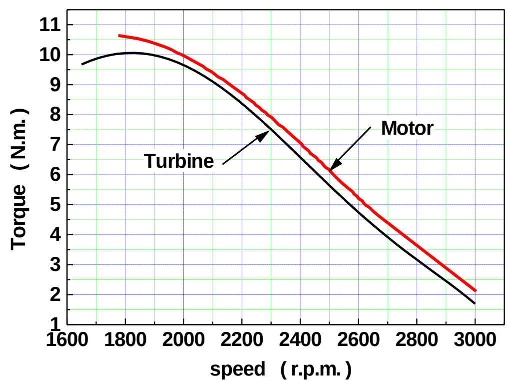


**Fig. (8)** Turbine torque and motor torque versus the rotor speed for adding resistance.

The characteristics of the AC series motor with the three methods of control are shown in the following figures from [10-16].

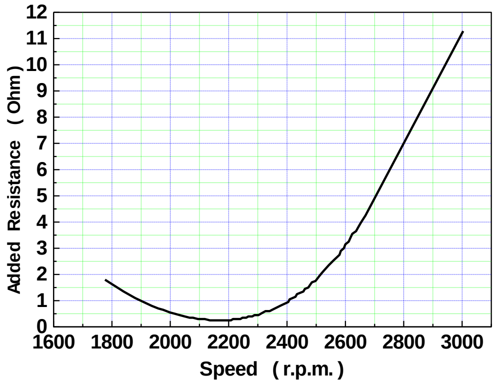


**Fig.(9)** Added resistance versus the rotor speed.

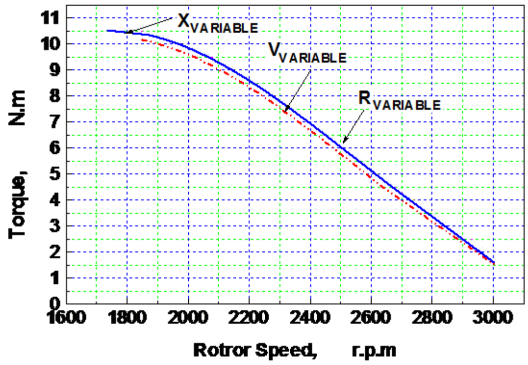


**Fig. (10)** Torque-speed characteristics for voltage, reactance and resistance variations.

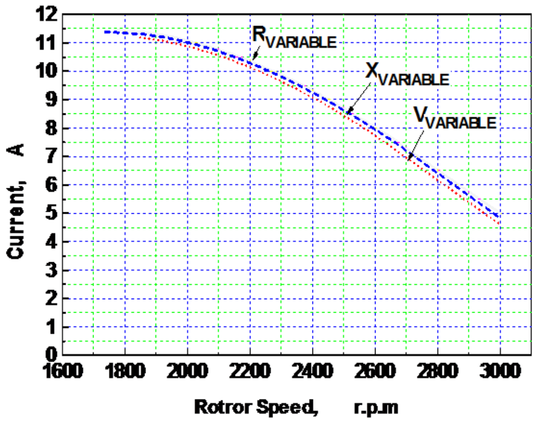


**Fig. (11)** Motor current-rotor speed characteristics for voltage, resistance and reactance variation.

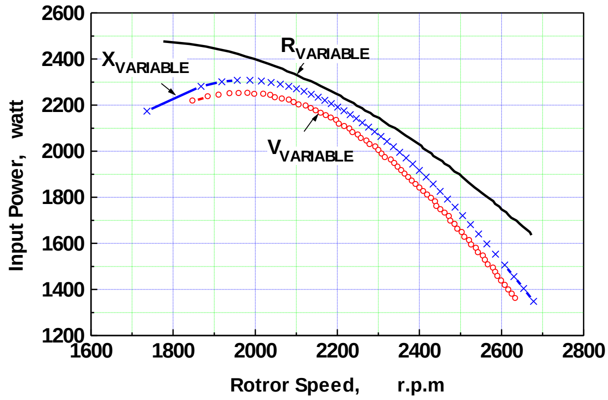


**Fig. (12)** Current-speed characteristics for voltage, resistance and reactance variation.

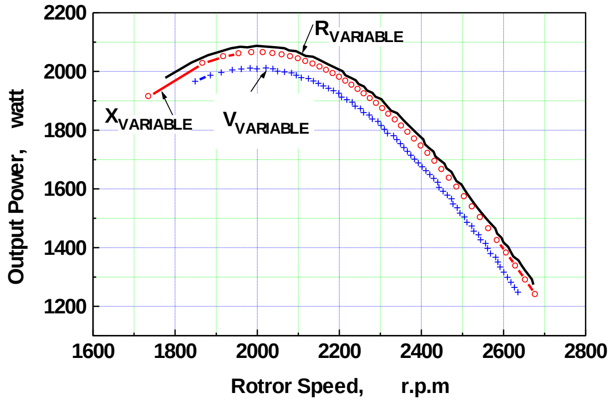


**Fig. (13)** Output power -speed characteristics for voltage, resistance and reactance variation.

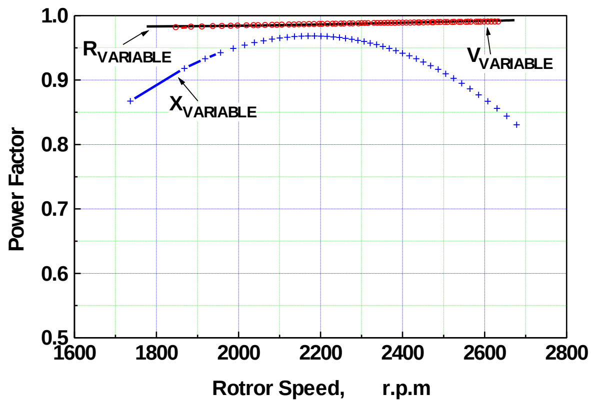


**Fig. (14)** Power factor-speed characteristics for voltage, resistance and reactance variation.

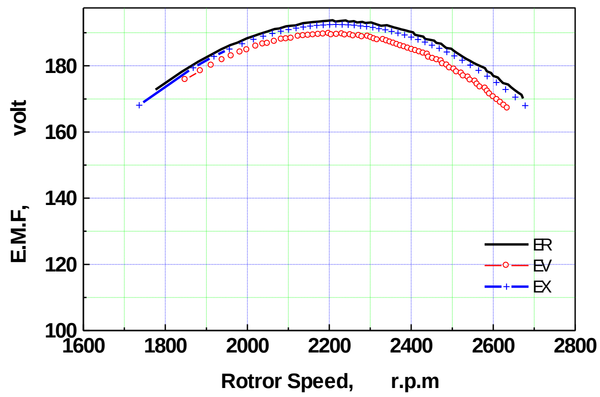


**Fig. (15)** Induced e.m.f.-speed characteristics for voltage, resistance and reactance variation.

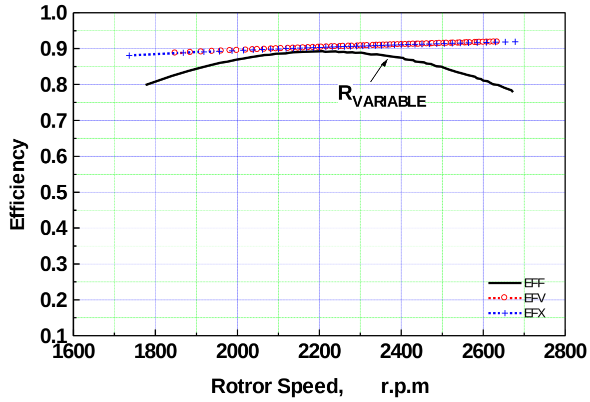


**Fig. (16)** Efficiency-speed characteristics for voltage, resistance and reactance variation.

## 7- CONCLUSIONS

Wind turbine simulation is very important for the development of wind energy conversion system and the health of researchers.

In this paper a new wind turbine simulator using AC series motor (universal motor) is introduced to simulate the actual wind turbine in the steady-state mode of operation.

Mathematical analysis of proposed model is introduced to compute the performance characteristics at a given wind velocities. The proposed analysis of Ac series motor after applying the control, makes the motor characteristics coincides with the characteristics of the wind turbine in the steady-state mode of operation.

Three methods of controlling the AC series motor to simulate the wind turbine are presented for realistic simulation of variable characteristics of wind turbine. The steady state results are highly consistent with theoretical curve, indicating that AC series motor is a new simple, cheap and an excellent method for simulating characteristics of wind turbine.

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