Modeling Approach To Evaluate Wind Turbine Performance: Case Study For a Single Wind Turbine of 1.65 MW In Dernah, Libya

Zakariya Rajab[a], Mohamed Almaktar[b] , Naser Al-Naily[c], Saad.M. Saad[d], and Faisal A. Mohamed[e],
[a,c]Electrical and Electronic Engineering Department
Faculty of Engineering, University of Benghazi
[b,d]College of Electrical and Electronics Technology
Benghazi, Libya
[e]Authority of Natural Science Research and Technology
Tripoli, Libya

zakreia.hassan@uob.edu.ly, mohakadroon@gmail.com , naseralnaile222@gmail.com, smuftahndi@gmail.com, elabdli@hotmail.com,

***Abstract*—Various techniques can be used to investigate the performance of mechanical-to-electrical energy conversion. These techniques vary from one to another, owing to their characteristics, complexity, performance, cost, etc. Besides, they are suitable for a wide range of energy sources and applications from very low to very high power levels. In this paper a mathematical model for a 1.65MW Squirrel Cage Induction Generator (SCIG) wind turbine installed in Derna, Libya is tested in Matlab/Simulink and was validated using Alternative Transient Program- Electromagnetic Transient Program ATP-EMTP software through which its dynamic behavior can be accurately predicted. Power coefficient, active power, reactive power, and electromagnetic torque under two proposals are investigated, variable speed and fixed speed. It is noticed that there is a good agreement between the values predicted by the ATP-EMTP and the ones obtained from the Matlab/Simulink simulation. The model is useful for analyzing the behavior and performance of wind turbine in medium voltage power network.**

Keywords— ATP software; Derna; Matlab/Simulink; Renewable energy; SCIG; Wind turbines.

I. INTRODUCTION

Libya is located in the central of North Africa with 1,750,000 km^2 total land area. One of the largest oil producer countries in Africa, gifted with 1900 km coastline along Mediterranean. The country current population is around 6,273,000, majority of them live in the coastline area [1]. Generation of electrical energy in the country is mainly dependent on fossil fuels, oil and gas. The destruction in Libya infrastructure occurred during 2011 civil war reduced the production of oil and gas, the main income source for the nation. This has led to drastic reduction in the country revenue as well as electricity shortage. Furthermore, the energy demand will significantly increase in the near future as a consequence of the economic development and rebuilding new infrastructure [2]. Taking into consideration the present status of electricity generation in the country in terms of energy shortage, its complete reliance on fossil fuels and its harmful emissions makes the utilization of renewable energy urgent.

Nonetheless, the renewable energy has been used in Libya back to the seventies; the main applications are for powering small remote loads. Since 1976 the use of photovoltaic (PV) systems have started to supply electricity for a cathodic protection station for the oil pipe line connecting Dahra oil field with Sedra Port. Moreover, in 1979 four experimental stations in communication field was installed. In 1983 solar water pumping projects were started, where water was pumped for irrigation at EL-Agailat city. On the other hand, wind energy is considered new technology in Libya. In 2010 projects in the scale of 60 MW wind farms was installed in Al-Fattaih, in the city of Dernah, eastern Libya. Dernah has high potential of wind and solar energy. The average wind speed is roughly between 6 m/s and 7.5 m/s at 40 m height [1-4].

This paper is organized as follows; section II presents a potential of wind energy in seven cities in Libya. In section III, the specifications of wind turbine installed in Derna is introduced. The mathematical model of a SCIG is introduced in Section IV, while section V analyzes the wind turbine performance in two cases, fixed speed and variable speed. Finally, section VI concludes the work of this paper.

II. WIND ENERGY

Libya is blessed with perfect condition for the renewable energy sources, mainly the solar and wind energy. Wind energy is an indirect shape of solar energy. About 1-2% of the solar radiation that reaches the Earth is changed into wind energy [5]. Winds are produced from an unequal heating of different parts of the Earth's surface, resulting in cooler dense air that circulates to a warmer, lighter air. Whereas some of the sun's energy is absorbed directly by the air, the majority of

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the energy in the wind is primarily absorbed by the plane of the Earth and then transferred to the air by convection. As the height increases the wind speed increases due to the frictional drag of the ground, plants and buildings. It is clear that any plans to harness the wind must take into account these variables [6]. The average wind speed in Libya is roughly between 6 m/s and 7.5 m/s at 40 m height [1,2,4,5]. Table I shows the average wind speed in some selected cities in Libya. Previous study [6] reported that the possibility of utilizing wind energy in electricity generation in some locations and connecting it with the nation grid is high as in case of Benina, Sirt, Dernah, Sebha and Tolmetha, whereas in other areas such as Ejdabia and Sorman it is more favorable to use wind energy for water pumping and other applications.

TABLE I. THE AVERAGE WIND SPEED IN LIBYA CITIES

Station	**Average Wind speed (m/s)**
Benina	5.32
Ejdabia	2.78
Sirt	6.3
Sorman	3.38
Dernah	7.5
Sebha	6.63
Tolmetha	5.9

III. THE WIND TURBINE IN DERNAH-LIBYA

The wind turbine located in city of Dernah in the north east of Libya. A 1.65MW wind turbine is taken as a case study in this work. All the system parameters are shown in Table. II.

Table. II. Parameters Of Power System Equipment According To IEC 60909

Parameter	**Value**
Network Feeder	Isc-3= 6.74 ∠-83.5° Isc-1= 3.3 ∠-78.9° Z_0/Z_1=4.1272727 R_0/X_0=0.1961922 R_1/X_1=0.113956
30/0.69 KV 2 MVA Transformer	Positive Sequence data: Copper Losses=0.4% Impedance Voltage=6.5% Zero Sequence data: Copper Losses=0.45% Impedance Voltage=6.5%

As depicted in Fig. 1 a 1.65MW wind turbine is connected to the grid via step up transformer to the 30kV bus bar.

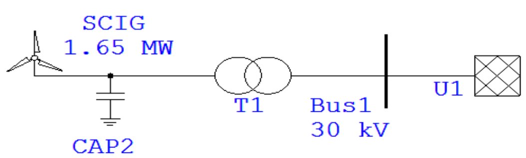

Fig. 1. Block diagram of a 1.65MW wind turbine

Since wind turbines capture the kinetic energy of the wind and convert it into a usable form of energy. The kinetic energy from wind rotates the blades of the wind turbine. The blades are connected to a shaft. The shaft is coupled to an electric generator. The generator converts the mechanical power into electrical power [7,8].

$$P_m = 0.5\rho A C_p v_w^3 \qquad (1)$$

where P_m the mechanical power in watts, ρ is the air density (Kg/m^3), A is the swept area (m^2) and C_p is the power coefficient of the turbine, v_w is the wind speed (m/s). The power coefficient C_p represents the conversion efficiency of the turbine. If the pitch angle β=0, C_p is function of the tip speed, λ, of the turbine and is given by [9]:

$$C_p(\lambda) = c_1(\frac{c_2}{\lambda} - c_4)e^{-c_5/\lambda} + c_6\lambda \qquad (2)$$

Where $\lambda=\omega R/v_w$, ω is the rotational speed (rad/s), R is the radius of the blades. The maximum power can be extracted from the turbine can be achieved when c_p=0.42 and λ=6.5. The coefficients c_1 to c_6 are: c_1 = 0.5176, c_2 = 116, c_3 = 0.4, c_4 = 5, c_5 = 21 and c_6 = 0.0068 [10]. The wind turbine used in the simulation has the following specification: power rating, 1.65 MW, the rated wind speed 12 m/s, cut-in and cut-out speeds are 3 and 25 m/s respectively, blade diameter is 40 m. The power of the wind turbine versus wind speed and aaerodynamic coefficients are shown in Fig 2.

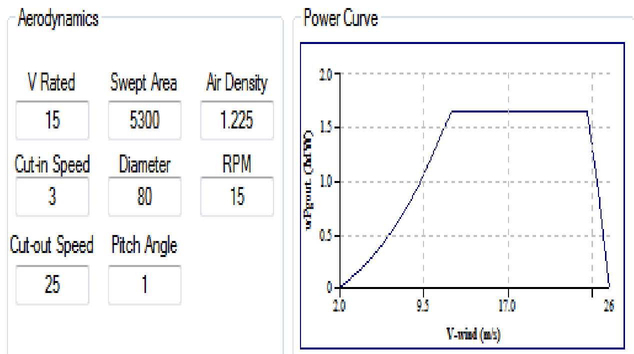

Fig. 2. Wind power versus the turbine speed

IV. SQUAIRREL CAGE WIND TURBINE SYSTEM

The generator is the mechanical-to-electrical energy conversion unit of the system that is driven by the mechanical power of the turbine. The electrical energy output of the generator is connected to a grid or load. There are numerous types of electrical generators. In the work conducted herein, SCIG is used. The mathematical model of the SCIG is given by [11], [12]:

Stator voltage is given by:

$$v_{ds} = R_s I_{ds} - w_s \psi_{qs} + d\psi_{ds}/dt \qquad (3)$$

$$v_{qs} = R_s I_{qs} + w_s \psi_{ds} + d\psi_{qs}/dt \qquad (4)$$

Rotor voltage is given by:

$$v_{dr} = R_r I_{dr} - sw_s \psi_{qr} + d\psi_{dr} / dt \quad (5)$$

$$v_{qr} = R_r I_{qr} + sw_s \psi_{dr} + d\psi_{qr} / dt \quad (6)$$

Flux linkage is given by:

$$\Psi_{ds} = L_s I_{ds} + L_m I_{dr} \quad (7)$$

$$\Psi_{qs} = L_s I_{qs} + L_m I_{qr} \quad (8)$$

$$\Psi_{dr} = L_r I_{dr} + L_m I_{ds} \quad (9)$$

$$\Psi_{qr} = L_r I_{qr} + L_m I_{qs} \quad (10)$$

Electromagnetic Torque is:

$$T_e = 1.5 p(\psi_{ds} I_{qs} - \psi_{qs} I_{ds}) \quad (11)$$

where R_s and R_r are stator and rotor winding resistance; id, iq are d and q axis currents; v_d, v_q are d and q axis voltage; ωs is the synchronous speed; L_m is the mutual inductance and L_s, L_r are the self inductances of stator and rotor. Ψ is the induced flux, p is number of pole pairs, and T_e is the electromagnetic torque. The specifications of the SCIG are shown in Table III:

TABLE. III. SCIG PARAMETERS

Parameter	Value
Number of pole pairs	3
Frequency	50 Hz
Stator resistance	0.0008 ohm
Stator leakage reactance	0.0137 ohm
Rotor resistane (referred to stator)	0.0020 ohm
Rotor leakage reactance (referred to stator)	0.0143 ohm
Magnitazing reactance	0.07783 ohm
Inertia	170 kg.m^2

V. SIMULATION RESULTS

The implementation of Simulink and ATP-EMTP software for the SCIG wind turbine connected to the grid is shown in Fig. 3 and Fig. 4 respectively.

The wind turbine is equipped with 690V/30KV step up transformer. The wind turbine has been tested under different conditions as follows;

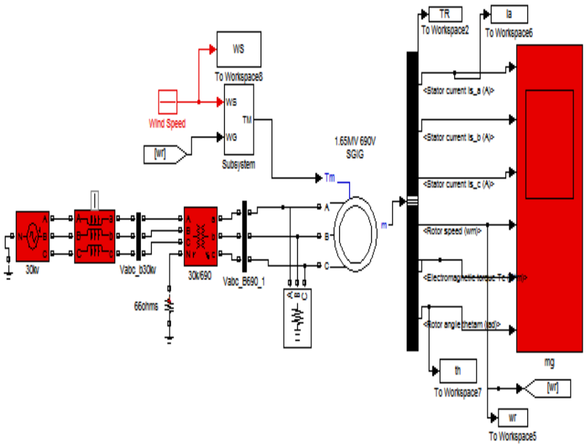

Fig. 3. The SCIG wind turbine model implemented in Simulink

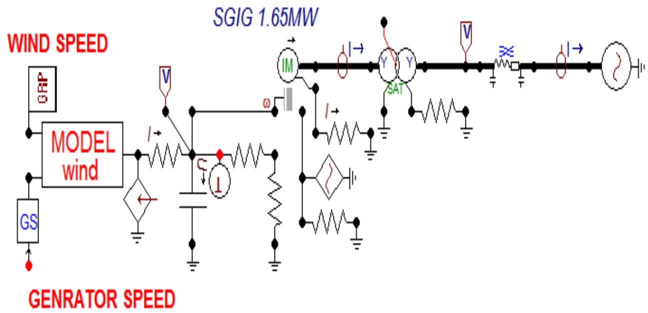

Fig. 4. The ATP model of the SCIG wind turbine

A. *Fixed speed wind turbine*

Typically, it is common to test the behavior of wind turbine under fixed speed. The speed suggested to be 11 m/s and the simulation results are as shown in figures 5-11. Fig. 5 shows a constant wind speed as a function of time. As can be seen in Fig. 6, power coefficient is equal to 0.41 at 11 m/s. The active and reactive power is depicated in Fig. 7 and Fig.8 respectively. Similarly, the electromagitic torque is provided in Fig 10. The rotor speed is roughly 105 rad/sec (1003 rpm) which is shown in Fig. 11

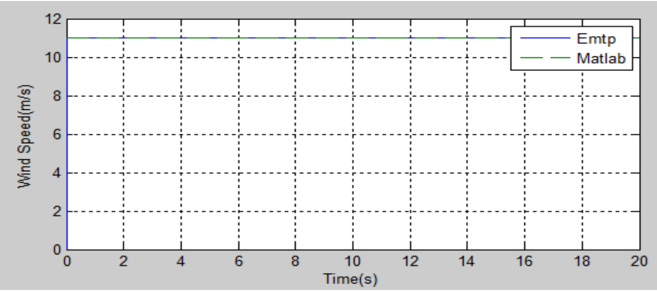

Fig. 5. Constant wind speed at 11 m/s

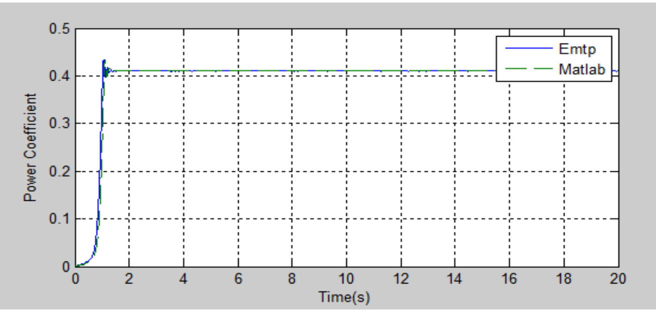

Fig. 6. The power cofficient at 11 m/s

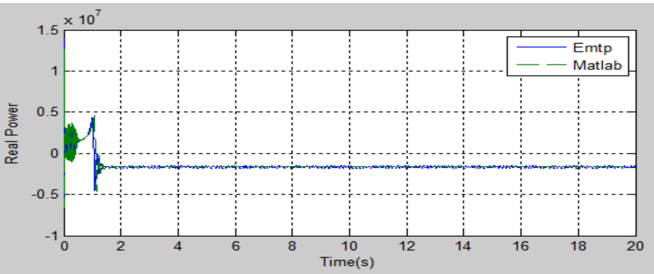

Fig. 7. The active power (Watt)

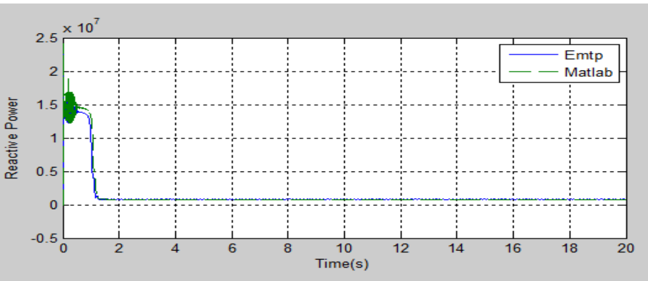

Fig. 8. The reactive power (Watt)

Because of the expected high starting current, the simulation time starts from zero in order to present the transient wave form during stating. As can be seen from Fig. 9, the high inrush current has serious consequences to the network especially that this current is not sinusoidal at starting. This current could result in high losses and high electromagnetic torque oscillation. In order to reduce the starting current, power electronics should be used for soft starting.

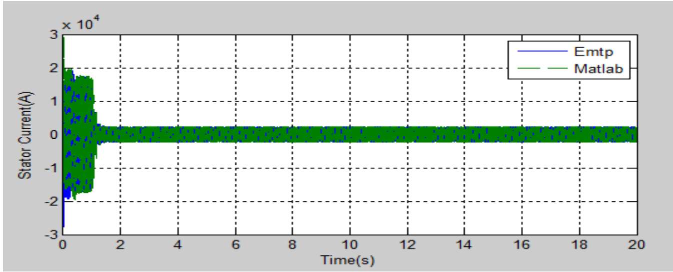

Fig. 9. The stator current

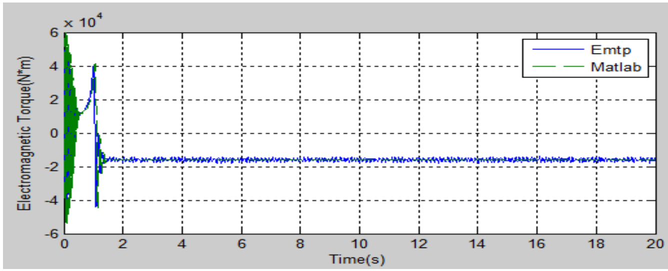

Fig. 10. The Electromagnitic Torque

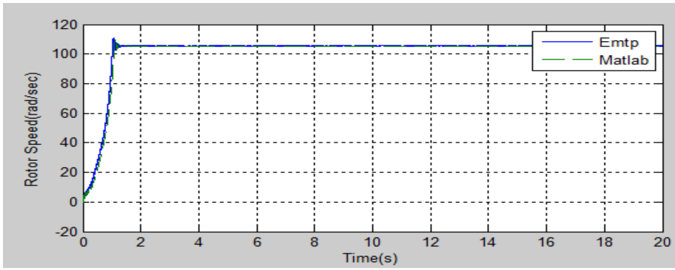

Fig. 11. The rotor speed

B. *Variable speed wind turbine*

To understand the dynamic behavior of the system, the speed should be changing. For the case suggested herein, the speed changes from 11 m/s to 10 m/s for five seconds starting from the tenth second to the fifteenth. The results are as shown in the figures 12 to 18. As can be observed, when the wind speed is reduced from 11m/s to 10m/s the power coefficient, 0.41 the active power, stator current, and the electromagnetic torque increases while the reactive power and rotor speed almost remain constant as shown in Fig. 15 and 17.

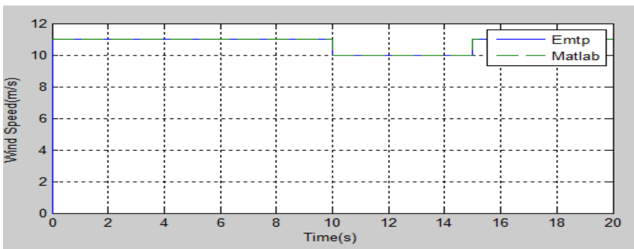

Fig. 12. Wind speed

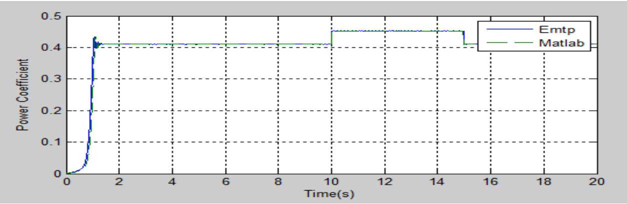

Fig. 13. The cofficient power

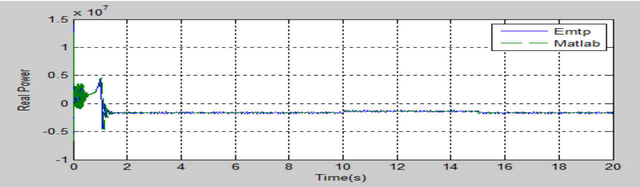

Fig. 14. The active power (Watt)

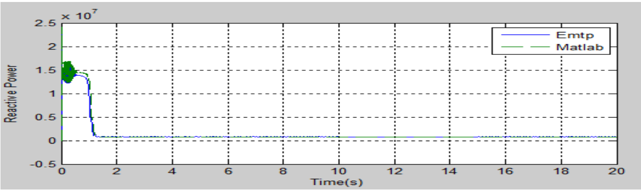

Fig. 15. The reactive power (Watt)

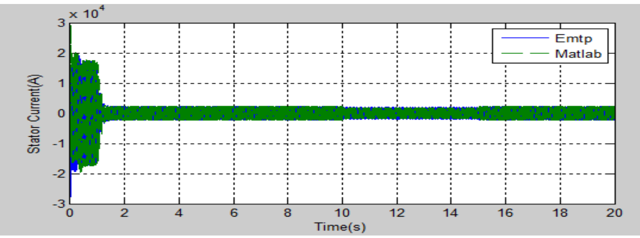

Fig. 16. The stator current

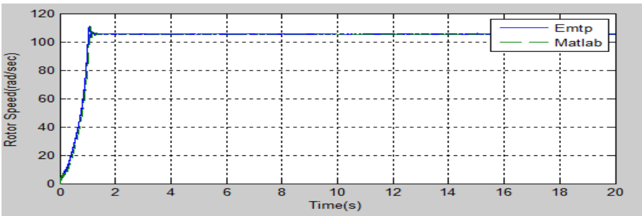

Fig. 17. The rotor speed

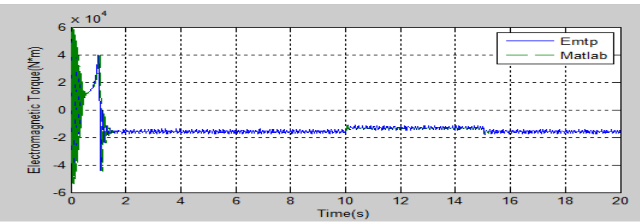

Fig. 18. The elecromagnetic torque

VI. CONCLUSION

In this paper, modeling of a proposed 1.65 MW SCIG wind turbine is reported. The system is modeled and implemented in Matlab/Simulink and validated using ATP software to evaluate the performance of the wind turbine. Two simulation scenarios are carried out to test the performance of the system, in fixed speed mode and variable speed mode. A good agreement between the ATP-EMTP results and the results predicted from the simulation is achieved. The conducted study showed some wind turbine problems such as fluctuation, harmonics and oscillation which are mainly due to the high starting current. To overcome those issues, power electronic circuits are needed.

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