

# MODELING OF DOUBLY FED INDUCTION GENERATOR FOR VERTICAL AXIS WIND TURBINE

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Global energy demand forms the challenge of selecting a proper power source. The choice is either to continue using traditional fossil fuels, projected to expire in 50–70 years, or to speed up the development of renewables, which could be used considerably longer. Today the advanced choice is the second option. Hence, the new methods and approaches have to be developed, diversified, and/or improved. The paper presents a new MATLAB Simulink simulation model used to estimate the integrated power generated by Vertical Axis Wind Turbine (VAWT). The material presents a step by step description of the model development. The value of generated power fluctuations is accounted for and verified in accordance with the grid capacity available at the moment. The parameters under analysis are as follows: Efficiency, Cost, and System Response Time. The benefits are comprehensively analyzed against disadvantages. A special advantage is considered as a combination of two systems, getting high performance and power stability.

*Keywords: integrated power, power stability, VAWT response, wind power.*

## Introduction

Wind power is the most rapidly developing renewable power source. Electricity is generated by an electromechanical device without any fossil fuel, generating no impact on the environment. However, not all of the wind turbines are cost- and otherwise efficient. The 3 bladed Horizontal Axis Wind Turbines (HAWT), also known as traditional, are efficient enough, but there are new products on the market, called Vertical Axis Wind Turbines (VAWT), which have the same power coefficient along with other advantages worth to explore. However, we have not located any acceptable VAWT mathematic model, which objectively compares VAWTs against HAWTs. Thus, we have started the analysis of these two types based on the energy production research. As a rule, the turbines today are connected with the grid and therefore all computational models should permit a combination with the grid parameters [1]. The simulation model presented in this paper was intended to estimate VAWT blade physical design, analyze the rotor speed, capacity, and load of the grid. Also, the generator type was analysed, estimating the rotor parameters through the tip speed ratio and power coefficient. We have found out that the other known simulation tools do not have these sufficient parameters. Instead, the VAWT simulation is usually presented as the efficiency response versus the average power production in accordance with the instantaneous power load demand in analogue with [2].

## Model description

The wind energy converter (WEC) converts the kinetic wind flow energy to the electric one, pumping it

into the electric grid in accordance with the requirements for the load. Some autonomous or standalone equipment configurations also feature the integration of diesel power plant with VAWT, using the grid as an uninterrupted power supply or vice versa, using it as a consumer of extra load during the peak consumption hours [3]. Today, most HAWTs have three blades, so do VAWTs. The most WECs include a gearbox to minimize or maximize the generator torque based on the blade size and angle. Thus, the analytic wind energy transformation has to be analyzed with account to the gearbox serving as a multiplier on low wind speed. The electric connection should be based on the hybrid grid connection strategy [4–8].

## Methodology and model

Modeling is a cost-effective comparison, featuring a construction of a physical model [10]. Hence, modeling has economic advantages in engineering design and development.

### A. The advantage of the suggested VAWT for modeling

- The major advantages of VAWT are the ability of operation in all wind directions and the installation on the roof top. These features provide less area for standalone turbines and wind farms in contrast to the HAWT systems.
- The blade size and vertical orientation of axis in VAWT cause less strength stresses in the mechanical structure.
- The generator could be located on the ground for better maintenance and repair.
- The HAWT production costs are higher than those of VAWT because of the entire design of

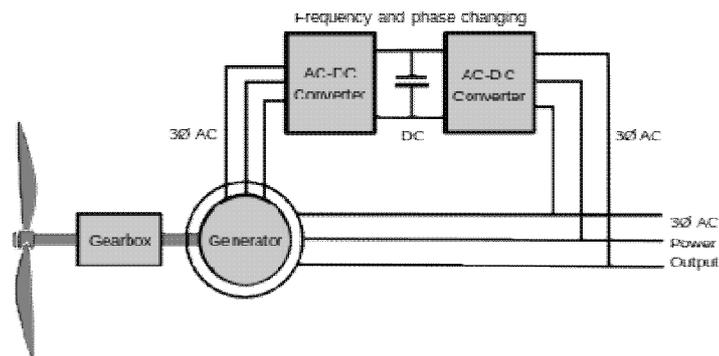


Fig. 1. Configuration of grid tied turbine with DFIM generation

the turbine: HAWT blades are more complex in fabrication and require extra tooling; the generator should be minimized to save the swept area; a gearbox is required in most cases.

### B. Doubly Fed Induction Motors (DFIM)

Asynchronous machines called Doubly Fed Induction Motors (DFIM) or Generators (DFIG) are used for the most wind turbine applications as they operate in the wide speed range. This approach allows for a considerably smaller turbine size [10–11]. It is especially feasible for variable-speed condition generation as the value of power could be controlled by the torque of rotor by controlling the voltage and current response, which is presented by formula:

$$T_{em} = \frac{3p}{sw_s} [R][I]^2 - V_{load}I \cos [\phi], \quad (1)$$

where:

$T_{em}$ : Torque generated by rotor/DFIM;

$sw_s$ : Switch converter when load increase;

$P_{rotor}$ :  $[R][I]^2$  shows current fluctuations in accordance with rotor speed variations;

$P_{reactive}$ :  $V_{load}I \cos [\phi]$ .

The simulation model contains a static part and a dynamic part classified as:

1) Steady-State Simulation Circuit;

2) Dynamic Simulation Circuit.

Fig. 1 presents the optimal control strategy using the grid load, approaching the charging control by rotor voltages of DFIM at operating points as well as controlling converters by the grid loading [9, 12].

### Steady-State Simulation Circuit

The VAWT simulation approach uses another strategy comparing with the HAWT as it does not use pitch control for power regulation. The energy output is controlled by controlling the rotor state and its rotation frequency according to the load. This method is similar to the control of diesel generator electric station and could be presented by the following formula [10, 11, 13, 14]:

$$\omega_s = \omega_r + \omega_m, \quad (2)$$

where:

$\omega_s$ : Stator frequency of voltages and currents;

$\omega_r$ : Rotor frequency of voltages and currents;

$\omega_m$ : Rotor electrical speed.

When the rotor speed is changing according to the shaft load, the pole displacement is represented by formula:

$$\omega_m = p \Omega_m, \quad (3)$$

where:

$p$ : Electromagnetic pole;

$\Omega_m$ : Angular velocity of rotor shaft.

Formula (2) presents the variable signal, which could be divided into three modes of the rotor slip [15].

$$s = \frac{\omega_s - \omega_m}{\omega_s} = \frac{\omega_r}{\omega_s}. \quad (4)$$

The operation of VAWT depends on the wind speed but does not depend on wind direction. In such approach the blades design and the calculation of profile parameters are the most important but the most complex at the same time [16]. Fig. 2 shows the aerodynamic design of VAWT, where:

$L$ : Length of the blade;

$\omega$ : Angular velocity;

$t$ : Blade thickness;

$\phi$ : Maximum deviation angle for blade;

$U$ : Wind speed;

$C$ : Width blade maximum chamber (chord);

$D$ : Axis of rotation.

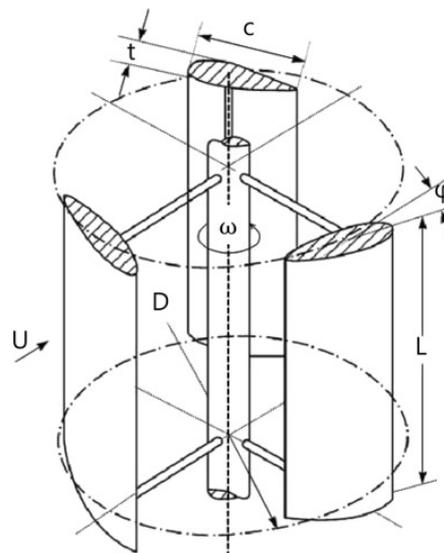


Fig. 2. Aerodynamic design of VAWT

**Simulation Algorithm**

The simulation model development is based on the integration and coordination of the VAWT power generation with the grid requirements to compensate the fluctuating demands of load in the grid and/or on VAWT output. The main goal is the determination of maximum VAWT power production, acceptable for the grid at the moment. In such approach the turbine model generates the values of voltage and current before and after the moment of time when the rotor generation is almost reaching the steady-state mode. During the model initialization, the MATLAB/Simulink program reads the stator voltage and current, speed or frequency of rotor rotation and reference value of parameters in analog with [17–19].

Fig. 3 shows the VAWT and grid integration when the load has reached the value of  $(T_{em} * 0.5)$ . The rotation speed is being increased as well as the torque, until it reaches the synchronization required by the grid [16]. In Fig. 3:

- Ir: Rotor current;
- Vs: Stator voltage;

- Tita: Rotation angle;
- Omega\_m: Rotor speed;
- $T_{em}$ : Electromagnetic torque.

Fig. 4 shows the oscilloscope registered measurement parameters, where:

- Omega\_ref: Reference rotor speed;
- iqr: The q component of rotor current;
- iqr\_ref: Reference q component of rotor current;
- idr: The d component of rotor current;
- idr\_ref: Reference d component of rotor current;
- vdr\_ref: Reference d component of rotor voltage;
- vqr\_ref: Reference q component of rotor voltage;
- Is: Stator current.

DFIM power stability mode provides the information about the rotor speed and load fluctuations. Then according to [20–22], the stator power ( $P_s$ ) and wind turbine power ( $P_r$ ) are equal, i.e. when  $(\omega_m = \omega_s)$  is reaching the  $\omega_r = 0$ , and the mechanical power on the shaft is equal to  $(P_m)$ . The situation is illustrated by formula (5), and Fig. 5–7.

$$\omega_m = \omega_s; \omega_r = 0; s = 0. \tag{5}$$

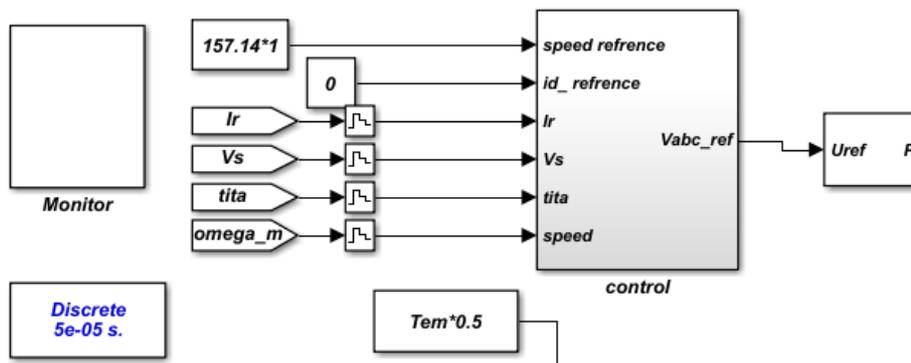


Fig. 3. Control part of Simulink model when VAWT is integrated with the grid

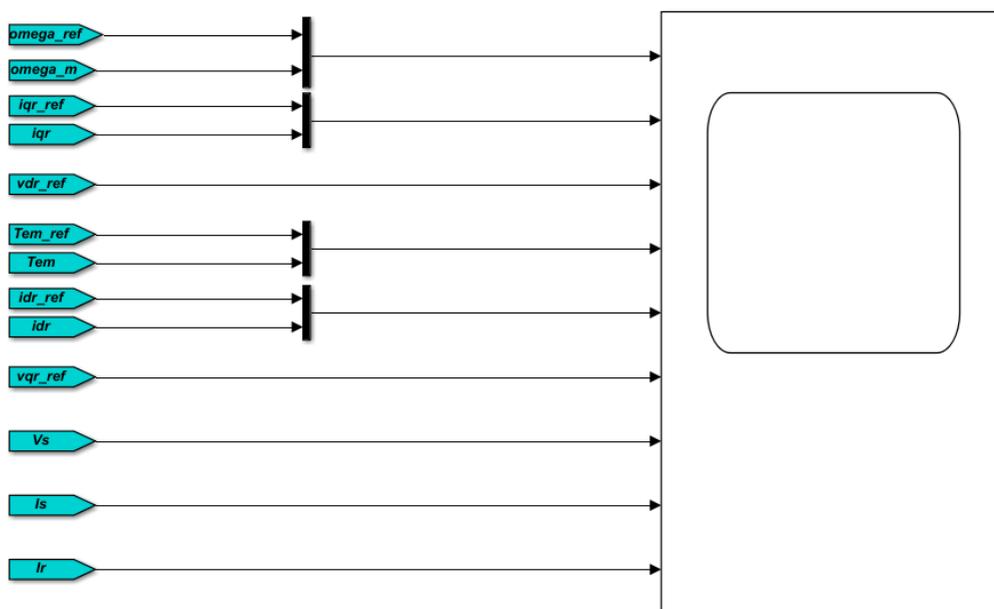


Fig. 4. Oscilloscope registered measurement parameters

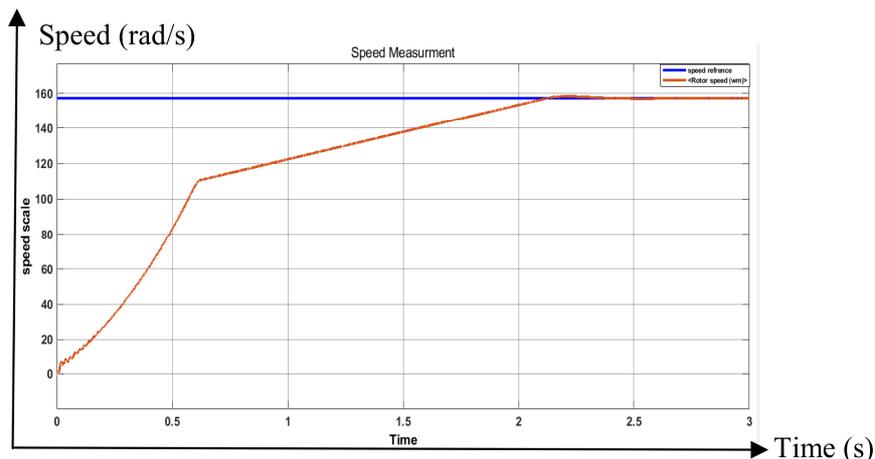


Fig. 5. The measured rotor speed increasing due to load fluctuation

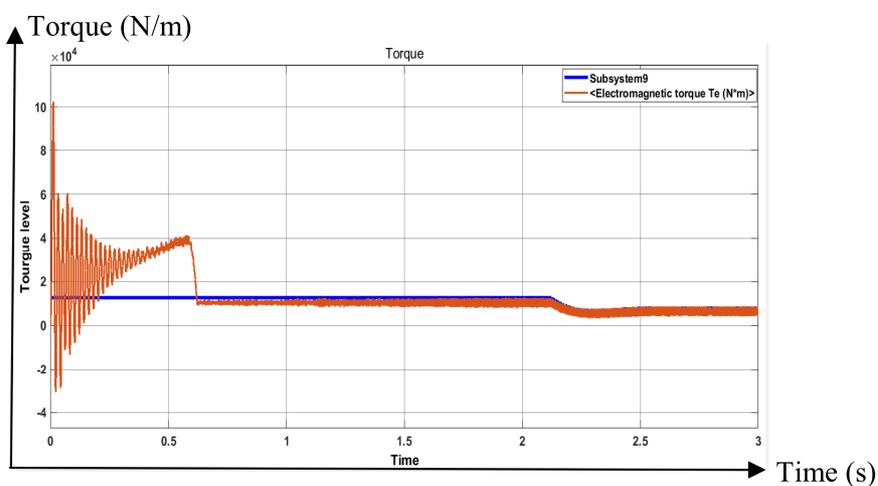


Fig. 6. The measured rotor torque as the response on the load changing

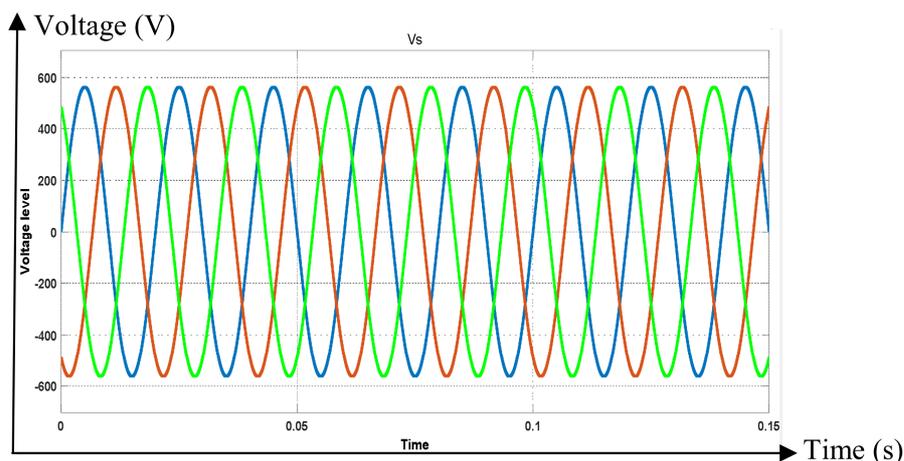


Fig. 7. The stator voltage response on the load change

The control of the DFIM response during the stator voltage and current fluctuations is provided on the basis of measurement of the rotor current increment level, reaching the steady-state. The stability of the current response is shown in Fig. 8. However, the re-

sult of simulation should be divided into two different scenarios [23]:

- a) Grid tied operation (GCO);
- b) Standalone operation (Isolated or Autonomous mode).

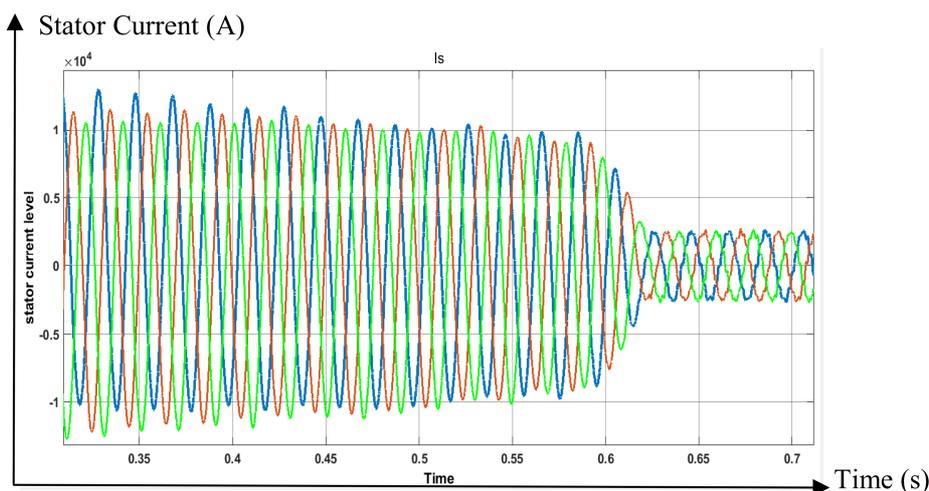


Fig. 8. Stator current response

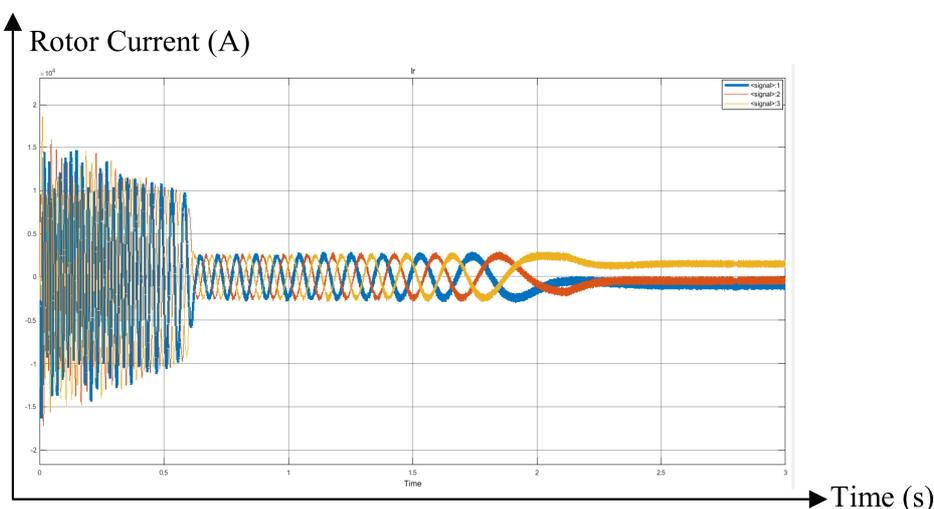


Fig. 9. Rotor current at the moment of reaching the steady state response

Different approaches are based on alternative methods of renewable power generation. However, they all have the same power requirement to meet the grid or consumer load demand. This approach is further being divided into the same concepts of AC/DC/AC or DC/AC converters, as well as using the alternative algorithms of control and conversion. However, for the VAWT with DFIM the simulation can be based on the rotor current loop response control in accordance with increasing rotor speed, supporting the torque stability as represented by formula (6) and Fig. 9.

$$I_{r_{max}} \geq i_{qr}^2 + i_{dr}^2, \tag{6}$$

where:

$i_{qr}^2$ : Axis coordinate;

$i_{dr}^2$ : Vertical coordinate.

The presented simulation model is implemented in the integration of a grid and a VAWT, either grid-tied or standalone [21, 24]. The model may be used to control DFIM equipped 2000–3000 kW VAWT turbines, using the algorithm tested against the presented MATLAB/Simulink model.

### Conclusion

The VAWT design was selected based on the comparison analysis of VAWT and HAWT features and performance quality. The simulation model for wind energy conversion systems has been implemented for the VAWT using MATLAB/Simulink package. This approach allowed measuring different required parameters of the rotor reaching the steady state. The model estimates the current of the rotor, which depends on the load applied to the rotor shaft. The VAWT was considered being connected to the grid having its local requirements. The situation is analyzed in details, including the conditions of rotor and stator at the moment when the system reaches the steady state, measuring rotor speed, torque, coordination of the components current “ $i_{qr}$ ,  $i_{dr}$ ” and synchronization parameters. It is estimated that a VAWT turbine may produce more electricity volume due to the pre-estimation of load during the peak demand periods in the grid.

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## МОДЕЛИРОВАНИЕ ИНДУКЦИОННОГО ГЕНЕРАТОРА ДВОЙНОГО ПИТАНИЯ ВЕРТИКАЛЬНО-ОСЕВОЙ ВЕТРОЭНЕРГЕТИЧЕСКОЙ УСТАНОВКИ

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Глобальный спрос на электроэнергию ставит перед человечеством задачу выбора пути использования надлежащего источника, либо для продолжения использования традиционных ископаемых видов топлива, разведанных запасов которых хватит на 50–70 лет, либо для ускорения разработки возобновляемых источников энергии, которые могли бы эксплуатироваться значительно дольше. Сегодня развитое общество выбирает второй вариант. Поэтому необходимо разрабатывать, диверсифицировать и совершенствовать новые методы и подходы. В данной работе представлена новая имитационная модель MATLAB Simulink для оценки интегральной мощности, вырабатываемой вертикально-осевой ветроэнергетической установкой (ВО ВЭУ). В статье представлено поэтапное развитие всех этапов моделирования. Величина колебаний выработки электроэнергии учитывается и контролируется в соответствии с имеющейся на данный момент пропускной способностью сети. Для анализа взяты следующие параметры: эффективность, стоимость и время отклика системы. Преимущества и недостатки анализируются комплексно. Особое преимущество заключается в сочетании или гибридизации двух систем – сетевой и автономной, итогом которого является высокая эффективность и стабильность выходной мощности. Подготовка модели включает все этапы разработки имитационной модели локальной системы электропитания (ЛЭС) на основе ВО ВЭУ. Диапазон изменения мощности соответствует емкости сети.

*Ключевые слова:* интегрированная мощность, стабильность мощности, реакция ВО ВЭУ, энергия ветра.

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