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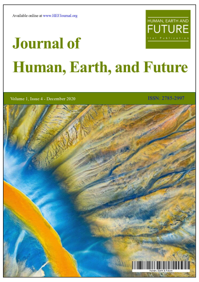

Analysis of the Generated Output Energy by Different Types of Wind Turbines

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Abstract

This study intends to analyse the generated individual output energy by different types of wind turbines. Focusing on estimating the total energy output generated by a wind farm utilizing three distinct wind turbines, Siemens Gamesa SG 3.4-132, Vesatas HTq V126, and Lagerwey L100, with rated powers of 3.465 MW, 3.45 MW, and 2.5 MW respectively. Sixty turbines of each type will be installed at the elevations of 97 m, 87 m, and 99 m consecutively. For the purpose of the study, the Sorochi Gory region was chosen as an eligible location for the farm due to its physiographic location and desirable forestry. A virtual experiment will be conducted by testing different possible wind turbine configurations and calculating their gross energy output, considering the output wind speed is in the ideal case, while the output energy includes the wake effect, using WindFarmer analyst software. Then, the results will be presented, including the optimal wind turbine configuration for the wind farm, in terms of efficiency, stability, and economy.

Keywords: Wind Turbines; Wind Farm; Renewable Energy; Lagerwey.

1. Introduction

Sorochi Gory is located in the center of Tatarstan republic, where the wind turbines will be installed; for the purpose of this study, a mast is placed on the site to measure the wind speed from July 2018 until July 2019, to estimate the turbines' energy output. The results of this study lead to the conclusion that the chosen wind turbines are optimal for this farm [1, 2]. Three types of turbines could be used. The first one is (Siemens Gamesa SG 3.4-132 3.465 MW) where its rated power is 3.465 Mw, and it can function at the air temperature range of -20 to 40°C when the average air density is about 1.24 kg/m^3. The peak power coefficient of the first type is 0.46, and the recommended height of the hub installation must be at an elevation of 97 m [3]. The second type is (Vestas V126-3.45 MW HTq) which is able to give the rated power of 3.45 Mw and can function at the air temperature range of -20 to 45°C when the average air density is about 1.25 kg/m^3. The peak power coefficient of this type is 0.45 and is designed to be installed at 87 m [4]. The third type is the Lagerwey L100-2.5 MW, which gives a rated power of 2.52 Mw, but the acceptable temperature is limited to the range between (-30 to 30°C) when the average density of the air is about 1.225 kg/m^3. The peak power coefficient of this type is 0.48 and the appropriate elevation is 99 m [5]. Three types of wind turbines will be used in a specific configuration, sixty turbines of each type will be installed.

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To achieve the goal of this study, a virtual simulation will be conducted by calculating the gross energy for each turbine individually. The simulation will be carried out using WindFarmer Analyst. WindFarmer Analyst is a software that uses the association method to give the wind flow modelling results, present the data of each configuration, estimate the individual output, and calculate the total energy configuration.

2. Turbines' Farm Location

The wind farm is set to be located in the Sorochi Gory region, south of Kazan, the capital of Tatarstan. It is worth noting that a river passes near the farm. The surrounding area is relatively smooth and unpopulated. The following figure (Figure 1) presents the location of the farm, Kazan, the river, and the distance between Sorochi Gory and Kazan (68 km).

Figure 1. A bird view of the farm's location

Figure 2, shows a closer view of the terrain and the surrounding of the farm's location.

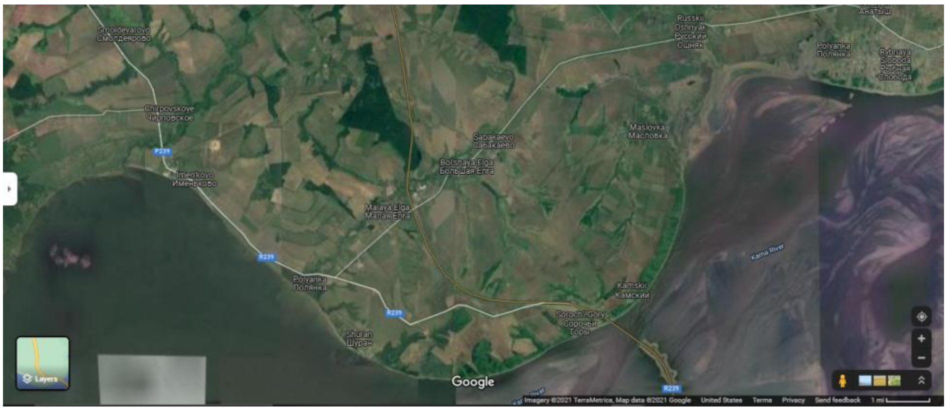

Figure 2. A closer look of the farm's location.

Figure 3, shows a satellite view of the Farm and its surrounding.

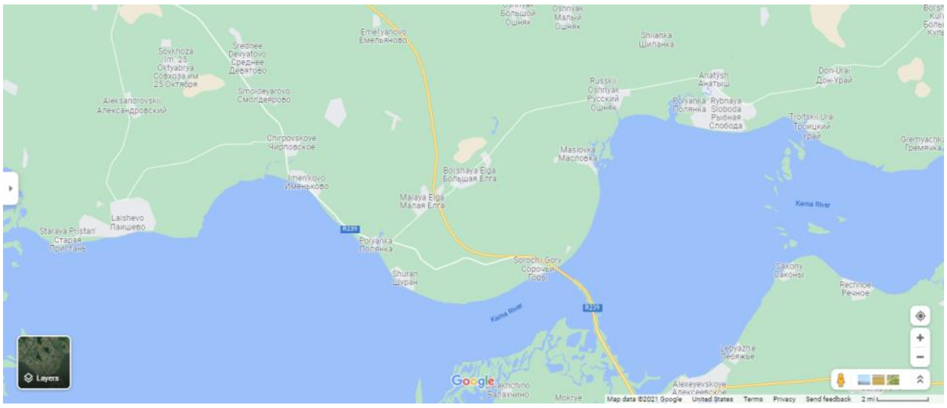

Figure 3. A satellite view of the farm's location.

3. Methodology and Apparatuses

3.1. Wind Turbines Specifications

This study utilizes three types of turbines.

- The first type is the Siemens Gamesa SG3.4-132, 3.465MW. Its technical specifications are shown in Table 1. The resulted power from this turbine depends of its working conditions, where the elevation, directing and the local wind properties, strongly affect on the power generation [6, 7];
- The second type is Vestas V126-3.45 HTq. Its technical details are shown in the Table 2. This type is smaller than the first one. While its capacity is about the same of the first one, the maximum permissible wind speed of the second type is less than that of the first one [8];
- The third type in this study is Lagerwey L100-2.5 MW. Its technical specifications are shown in the Table 3 [9].

The turbines will be configured as follows, SG3.4-132, V126, and then L100.The technical specification of each is presented in the following tables.

Table 1. The technical specifications of Siemens Gamesa SG3.4-132, 3.465 MW turbine

Manufacturer	Siemens Gamesa
Turbine	SG3.4-132 3.465MW
Rated power	3465 KW
Diameter	132 meters
Hub height	97 meters
Rotor speed	6.7 rpm to 10.7 rpm
Air density	1.24 Kg/m^3
Turbulence intensity	Variable
Peak Cp	0.46
Cut-out 10-minute mean wind speed	25 m/s
Restart 10-minute mean wind speed	Unknown
Temperature operational range	-20 °C to +30°C/ +40°C

Table 2. The technical specifications of Vestas V126-3.45 HTq turbine

Manufacturer	Vestas
Turbine	V126-3.45 HTq
Power control	Pitch
Rated power	3450 KW
Diameter	126 meters
Hub height	87 meters
Rotor speed	5.9 rpm to 16 rpm
Air density	1.25 Kg/m^3
Turbulence intensity	6 % to 12 %
Peak Cp	0.45
Cut-out 10-minute mean wind speed	22.5 m/s
Restart 10-minute mean wind speed	20.5 m/s
Temperature operational range	-20°C to +30°C/ +45°C

Table 3. The technical specifications of Lagerwey L100-2.5 MW turbine

Manufacturer	Lagerwey
Turbine	L100-2.5 MW
Power control	Pitch
Rated power	2520 KW
Diameter	100 meters
Hub height	99 meters
Rotor speed	Unknown
Air density	1.225 Kg/m^3
Turbulence intensity	Unknown
Peak Cp	0.48
Cut-out 10-minute mean wind speed	25 m/s
Restart 10-minute mean wind speed	Unknown
Temperature operational range	-30°C to +30°C

The WindFarmer analysis requires the coordinates of the wind farm, the configuration of the turbines, wind data (speed distribution) and the turbulence intensity.

The considered coordinates are the location of the mast (431079, 6137641), the configuration of the three mentioned turbines (Siemens Gamesa SG 3.4-132, Vesatas HTq V126, and Lagerwey L100) was taken independently. The accumulated wind data was used in estimating the wobble distribution and wind rows, and calculated throughout two years (2018-2019) using four anemometers at several heights (99, 94.8, 75, and 55m), with two wind vanes at 75m, 55m. The turbulence intensity is taken into consideration. The output gross energy calculated is shown in the Table 4.

Table 4. Turbine layout configurations and gross energy

Configuration Id	Turbine type	Hub height [m]	Number of turbines	Rated power [MW]	Average wind speed [m/s]	Gross energy output [GWh/annum]
1	Siemens Gamesa SG 3.4-132 3.465MW	97	60	207.9	7.2	848.9
2	Vestas V126-3.45 MW HTq	87	60	207	7	763.3
3	Lagerwey L100-2.5 MW	99	60	150	7.2	532.9

3.2. The Curve Properties of the Wind Turbine

The terminology of this paper includes: thrust force, which is the propulsive force on the wind turbine, and it's correlated to wind velocity [10], turbine swept area, air density and thrust coefficient as shown in the following formula [8]:

$$\mathrm{T} = \frac{1}{2} C_t.\rho.AV^2 \tag{1}$$

where: T – thrust force, C_t – coefficient of thrust [11], which is also in function of wind speed and turbine geometry, ρ – air density, A – swept area of the turbine, V – wind speed.

The other parameters that must be illustrated, is the power coefficient, Cp– efficiency of the turbine. In addition, can be written as [12]:

$$C_\rho = \frac{\mathrm{P}_a}{\mathrm{P}_w} \tag{2}$$

where: P_a –the actual power from the turbine, kW; P_w – the wind power acting on the thrust force, and can be written as [13]:

$$\mathrm{P}_w = \frac{1}{2} \rho.AV^3 \tag{3}$$

Calculating the actual power of each turbine will be universal, as it depends on the average wind speed at various times. The output power, thrust coefficient and power coefficient are three terms linked together when studying the wind turbines [14]. The optimal wind speed in this situation ranges between (12 – 19) m/s, then the turbine reaches maximum power [15]. While the wind speed that achieves maximum power coefficient ranges between (6 – 8) m/s. The maximum thrust is at 3 m/s wind speed [16].

It is clear, that the maximum output power from the turbine will be achieved when the wind speed is between (11 – 23) m/s. When the wind speed exceeds 23 m/s, the turbine shuts down, because that will damage the turbine itself. The power coefficient starts to increase when the wind speed exceeds 3 m/s. When the wind speed exceeds 9 m/s, the power coefficient starts to drop gradually [17]. The maximum thrust coefficient also takes place at 3 m/s wind speed.

3.3. Turbines' Gross Energy Analysis

This study analyses each turbine individually as well as a part of the whole wind farm. When it is working individually, the output energy from the turbine is called gross energy. In this study, there was no turbulence caused by the other turbines [18]. Constructing the wind farm using the computer program WindFarmer analyst allows visualization of the data as in the following graphs. The gross energy for each configuration is also calculated using the WindFarmer analyst.

4. Results and Discussion

The CFD simulation of the farm in three different configurations, where each wind turbine is processed individually, leads to the results shown in the following graphs. Configuration 1, Siemens Gamesa SG3.4-132, 3.465MW: In this configuration, the hubs of the turbines are installed at an elevation of 97 meters. The total energy output of this configuration is 614.5 GWh/annum.

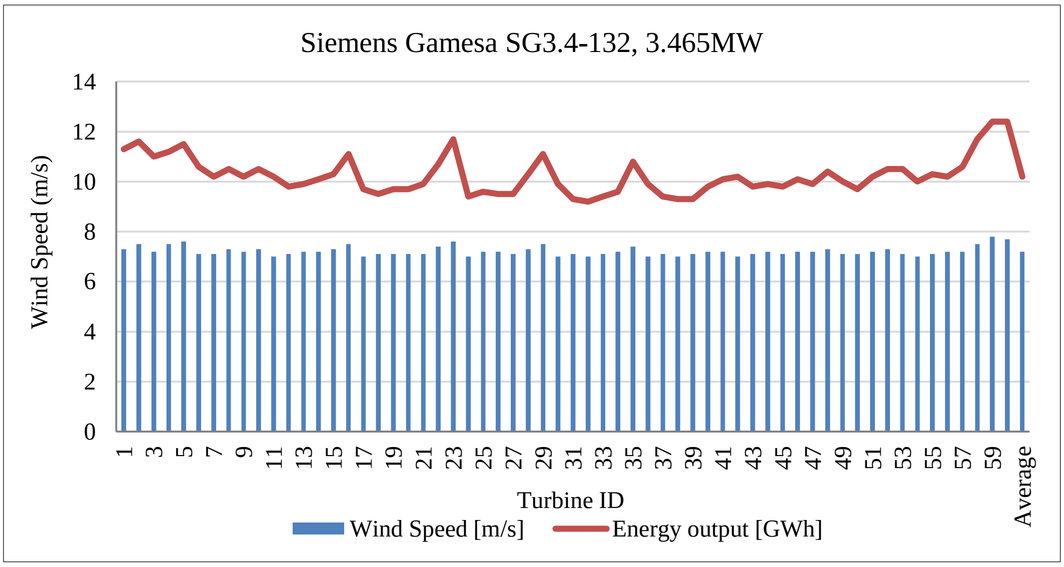

Figure 4. Energy results for configuration 1, Siemens Gamesa SG3.4-132, 3.465MW

- Configuration 2, Vestas V126-3.45 HTq: In this configuration, the hubs of the turbines are installed at the elevation of 87 meters. The total energy output of this configuration is 551.9 GWh/annum.

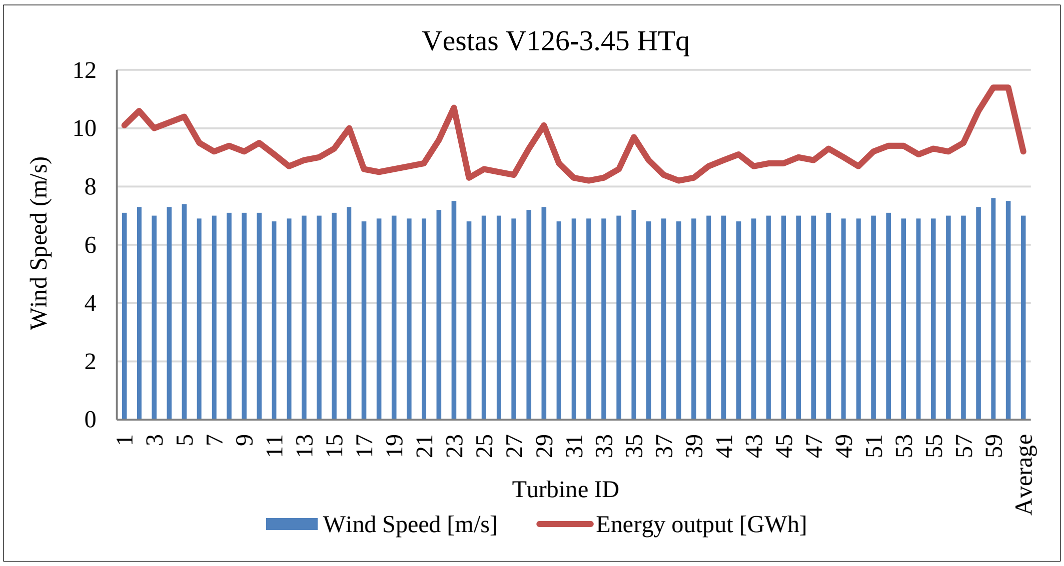

Figure 5. Energy results for configuration 2, Vestas V126-3.45 HTq

Configuration 3, Lagerwey L100-2.5 MW: In this configuration, the hubs of the turbines are installed at the elevation of 99 meters. The total energy output of this configuration 2 is 411.1 GWh/annum.

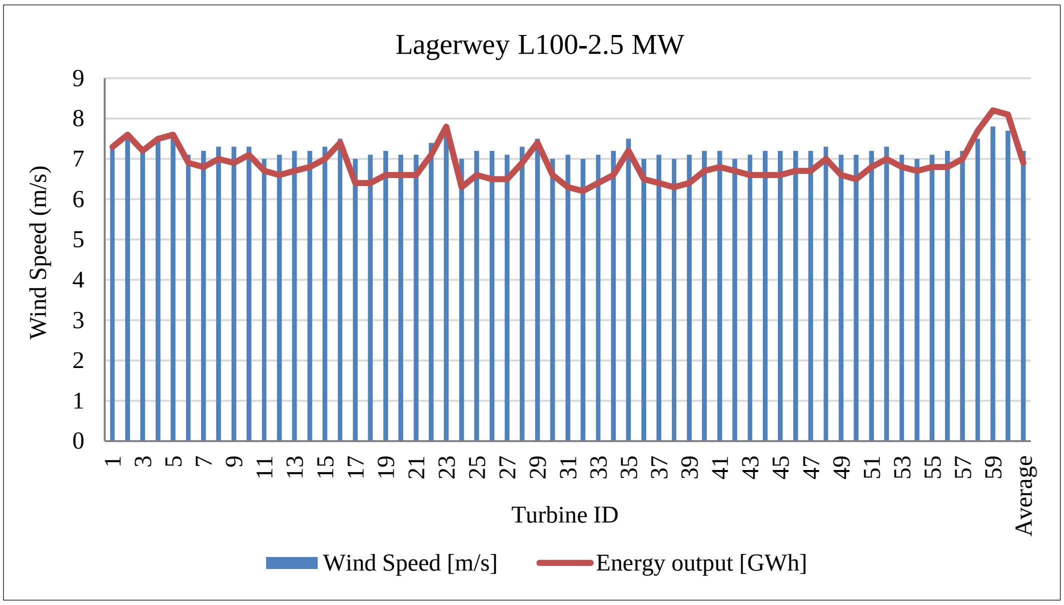

Figure 6. Energy results for configuration 3, Lagerwey L100-2.5 MW

5. Conclusions

Following the results of this study, if a wind farm is to be constructed in the region of Sorochi Gory, Republic of Tatarstan, Russia, the following should be taken into account:

- The Siemens Gamesa SG3.4-132, 3.465MW is the optimal wind turbine to be used to build the wind farm because of its high efficiency, stability, and generated power;
- To achieve ideal results, above 95m is the recommended hub turbine height;
- Lagerwey L100-2.5 MW is the less efficient of the three turbines, due to wake effect. Therefore, it generates less power than the others.

The total generated power of each configuration in this study represents the ideal situation, which gives the maximum amount of energy.

6. Declarations

6.1. Author Contributions

Conceptualization, F.A.H.; methodology, F.A.H., M.M. and O.A.M.A.; formal analysis, F.A.H., M.M. and O.A.M.A.; writing—original draft preparation, F.A.H.; writing—review and editing, F.A.H., M.M. and O.A.M.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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