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# Evaluation of best value of wind speed for maximum wind energy output in Nigeria using neural network

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## Abstract

The outcome of the study, evaluation of best value of wind speed for maximum wind energy output in Nigeria using neural network was successfully achieved. Wind speed for various months and elevation data gotten from NASA were prepared in excel and imported into neural network toolbox in MATLAB for training and analysis using levenberg maquardt and scaled conjugate gradient algorithms to determine the best performance value. Furthermore, training of the data using levenberg marquardt algorithm at 70% training data, 15% test data and 15% validation data respectively revealed that the best performance level was 1.9046 m/s at 7 epochs and this matches elevation of 7. 24meters. In addition, training of the same data using scaled conjugate gradient algorithm with the stated conditions above, revealed that the best performance level was 9.0376 m/s at 182 epochs and this matches elevation of 34.35meters. Also, training fit coefficients were found to be 0.99984 and 0.99804 respectively which indicated that there is a close and positive relationship between wind speed and wind turbine hub height. Results revealed that the best value of wind speed and elevation for maximum wind energy output in Nigeria ranges from 1.9046 m/s to 9.0376 m/s and 7.2 meters to 34.35 meters respectively. The researchers made the following recommendations: Wind turbine tower and blades should be designed to have wind impact speed capacity beyond the estimated values; further research can also be done in future to establish a more accurate mathematical model between wind speed and wind energy output with other advanced program for generalization, etc.

**Keywords:** Wind speed; Wind energy; Elevation; MATLAB; Algorithm; Training data

## 1. Introduction

AWS Scientific (1997) stated that wind speed data of a site is the first parameter to be considered in the harvest of wind energy source in any location. It is necessary to determine the adjusted average wind speeds at a raise wind turbine hub height. This is essential as wind speed significantly increases with height above the earth surface with respect to terrain roughness.

Bethany (2010) opined that as the demand for more environmentally-friendly energy resources grows, energy providers have recognized the importance of wind power and have invested in the development of wind turbines. In fact, wind energy is the only renewable resource that has grown faster than predicted. The primary reason behind the recent peak of wind energy capacity is due to improved turbine technology.

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Several components of a wind turbine must be taken into account, including the tower, blades, nacelle, and foundation designs. New developments in the construction of taller structures using better, lightweight materials, and improved turbine design techniques have allowed today's taller turbines to tap better winds at higher elevations for reduced costs. As a result of the improved turbine designs using lighter-weight steel for the tower, smaller, lighter foundations can be used and in turn reducing costs. It is imperative to continue improving the design of the wind turbine in order to harvest better energy and optimize its cost (American Wind Energy Association, 2009).

Malhotra (2001) stated that wind turbine towers and foundations must be designed to withstand heavy loads and moments due to extreme wind conditions to prevent failures, as well as other forces that are introduced with alternative site designs. The forces that the tower and foundation must resist are wind loads, ice loads, and the self-weight of the tower. The tower structure must also resist earthquake loads, which can be designed based on checking resistance in the steel's plastic range.10 In addition, the soil has to have adequate bearing capacity to resist the loads on the tower and weight of the foundation.

Njoku et al. (2022) explained that wind turbines are usually classified based on the axis about which the turbines rotate; Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). However, wind turbines that have rotor swept area of 200 $m^2$ or less and a power rating range of 1 kW to 100 kW are classified as small wind turbine.

Best value here represents a numerical value of wind speed at which installed wind turbine would develop maximum power with zero tower displacement. Hence, the paper aimed at evaluating the best value of wind speed for maximum wind energy output in Nigeria using neural network.

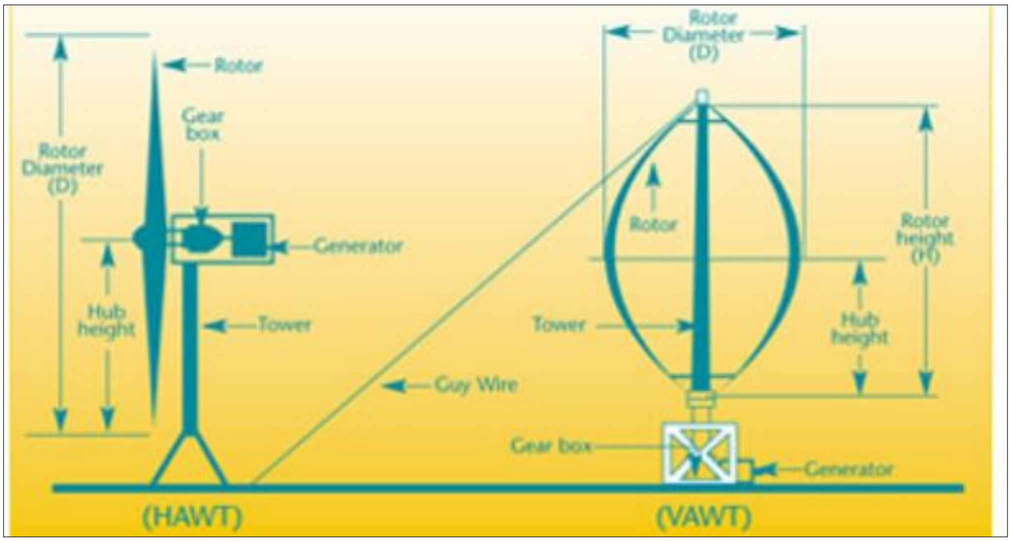


**Figure 1** Types of Wind Turbine (Source: Bethany, 2010)

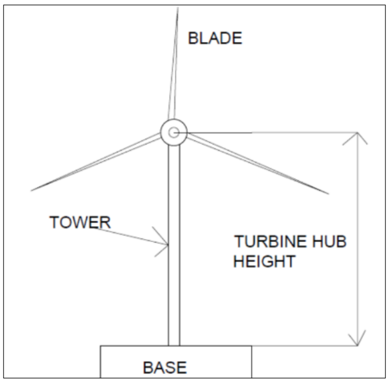


**Figure 2** Wind Turbine Hub Heights

## 2. Material and methods

According to Federal Ministry of Environment (2019), Nigeria is one of the countries in the West Coast of African, with human population around 216.7 million as at 2022 and lies between latitude 3°15’ to 13°30’N and Longitude 2°59’ to 15°00’.

The seasonal period Nigeria is commonly divided into two major areas: Dry season which usually commence from November and end in April when cold dry and dusty north-east trade winds from Sahara Desert keep the atmosphere heavily overcast by dust for many days with characteristic hazy weather conditions and rainy (wet) seasons that start from May to October during which each part of the country experience different levels of rainfall. In this study, the average monthly wind speed data from 1981 -2021 (40 years) for fourth-seven (47) study locations are sourced from National Aeronautics and Space Administration (NASA) website (NASA, 2023). These study locations have been chosen to cover all the major cities in Nigeria as the values of the wind data can be applicable to nearby communities.

The wind speed data was prepared in excel and imported into neural network toolbox in MATLAB and trained using levenberg maquardt and scaled conjugate gradient algorithms to determine the best operational value.

### 2.1. Design analysis

The wind power the wind turbine blade must experience is given as below.

$$P_w = \frac{1}{2}\rho U_w^3 \text{..... (1) (Spera, 1994)}$$

Where $P_w = wind\ power$ , $U = wind\ speed\ and\ \rho = density\ of\ air$

The power output from a wind turbine is given as below.

$$P_T = A\frac{16}{27}(\frac{1}{2}\rho U_w^2) \text{..... (1) (Spera, 1994)}$$

$$A = \pi(D/2)^2$$

Where $D = rotor\ diameter$

**Table 1** Average monthly wind speed for study locations at 10m/s from 1981-2022 (NASA, 2023)

| Locations | Lat. (°N) | Long. (°E) | Elev. (m) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abakaliki | 6.33 | 8.12 | 88.44 | 2.77 | 2.54 | 2.7 | 2.84 | 2.67 | 2.88 | 3.16 | 3.21 | 2.76 | 2.26 | 1.84 | 2.4 | 2.67 |
| Abeokuta | 7.15 | 3.37 | 80.92 | 2 | 2.23 | 2.44 | 2.44 | 2.26 | 2.42 | 2.84 | 2.94 | 2.45 | 1.99 | 1.65 | 1.73 | 2.28 |
| Abuja | 9.08 | 7.4 | 406.97 | 2.9 | 2.75 | 2.56 | 2.48 | 2.2 | 2.19 | 2.42 | 2.45 | 1.99 | 1.77 | 2.12 | 2.67 | 2.37 |
| Ado-Ekiti | 7.62 | 5.24 | 379.21 | 2.14 | 2.2 | 2.39 | 2.46 | 2.23 | 2.28 | 2.62 | 2.68 | 2.11 | 1.75 | 1.64 | 1.88 | 2.2 |
| Akure | 7.26 | 5.21 | 379.21 | 2.14 | 2.2 | 2.39 | 2.46 | 2.23 | 2.28 | 2.62 | 2.68 | 2.11 | 1.75 | 1.64 | 1.88 | 2.2 |
| Asaba | 6.21 | 6.7 | 103.94 | 2.53 | 2.43 | 2.56 | 2.64 | 2.5 | 2.79 | 3.19 | 3.28 | 2.81 | 2.3 | 1.86 | 2.14 | 2.59 |
| Awka | 6.23 | 7.09 | 103.94 | 2.53 | 2.43 | 2.56 | 2.64 | 2.5 | 2.79 | 3.19 | 3.28 | 2.81 | 2.3 | 1.86 | 2.14 | 2.59 |
| Bauchi | 10.31 | 9.83 | 518.79 | 4.11 | 4.18 | 3.83 | 3.47 | 3.28 | 3.01 | 2.59 | 2.3 | 2.3 | 2.63 | 3.28 | 3.82 | 3.23 |
| Benin-City | 6.34 | 5.61 | 93.92 | 1.76 | 1.71 | 1.74 | 1.74 | 1.64 | 1.8 | 2.06 | 2.13 | 1.83 | 1.5 | 1.29 | 1.5 | 1.73 |
| Bida | 9.08 | 6.01 | 126.59 | 2.26 | 2.21 | 2.23 | 2.35 | 2.17 | 2.14 | 2.34 | 2.36 | 1.89 | 1.66 | 1.71 | 2.05 | 2.11 |
| BirininKebbi | 12.44 | 4.2 | 241.96 | 3.64 | 3.64 | 3.24 | 3.08 | 3.27 | 2.99 | 2.43 | 1.96 | 1.75 | 1.89 | 2.54 | 3.29 | 2.81 |
| Calabar | 4.98 | 8.35 | 39.48 | 2.08 | 2.25 | 2.38 | 2.43 | 2.41 | 2.72 | 2.99 | 3.07 | 2.76 | 2.39 | 1.97 | 1.88 | 2.45 |
| Damaturu | 11.75 | 11.97 | 402.61 | 4.81 | 4.94 | 4.62 | 4.06 | 3.96 | 3.94 | 3.38 | 2.74 | 2.39 | 2.58 | 3.86 | 4.54 | 3.81 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duste | 11.75 | 9.34 | 465.94 | 3.02 | 3.11 | 3.07 | 2.98 | 2.79 | 2.61 | 2.17 | 1.8 | 1.77 | 1.99 | 2.39 | 2.78 | 2.53 |
| Enugu | 6.46 | 7.55 | 151.33 | 2.78 | 2.61 | 2.74 | 2.85 | 2.67 | 2.91 | 3.28 | 3.32 | 2.81 | 2.3 | 1.88 | 2.37 | 2.71 |
| Gombe | 10.28 | 11.18 | 381.62 | 4.47 | 4.62 | 4.12 | 4 | 4.06 | 3.76 | 3.27 | 2.76 | 2.36 | 2.32 | 3.08 | 4.01 | 3.56 |
| Gusau | 12.17 | 6.68 | 529.87 | 4.92 | 4.82 | 4.28 | 3.84 | 3.61 | 3.51 | 3.08 | 2.61 | 2.31 | 2.68 | 3.74 | 4.53 | 3.66 |
| Ibadan | 7.38 | 3.95 | 188.89 | 2.17 | 2.31 | 2.6 | 2.71 | 2.52 | 2.65 | 3.08 | 3.16 | 2.53 | 2.03 | 1.71 | 1.89 | 2.45 |
| Ijebu-Ode | 6.83 | 3.92 | 90.82 | 1.77 | 1.94 | 2.12 | 2.14 | 2 | 2.17 | 2.54 | 2.63 | 2.2 | 1.78 | 1.46 | 1.54 | 2.02 |
| Ikeja | 6.61 | 3.36 | 25.49 | 2.48 | 2.9 | 3.24 | 3.21 | 2.98 | 3.36 | 3.92 | 4 | 3.54 | 2.88 | 2.29 | 2.15 | 3.08 |
| Ikom | 5.97 | 8.73 | 116.85 | 2.16 | 2.31 | 2.51 | 2.58 | 2.48 | 2.74 | 3.01 | 3.12 | 2.73 | 2.29 | 1.82 | 1.9 | 2.47 |
| Ilorin | 8.48 | 4.55 | 344.93 | 2.72 | 2.96 | 3.51 | 3.84 | 3.4 | 3.21 | 3.47 | 3.51 | 2.62 | 2.25 | 2.14 | 2.4 | 3 |
| Jalingo | 8.9 | 11.38 | 251.79 | 3.51 | 3.5 | 3.61 | 4.1 | 3.67 | 3.49 | 3.45 | 3.16 | 2.4 | 2.08 | 2.32 | 3.13 | 3.2 |
| Jos | 9.9 | 8.86 | 980.85 | 4.3 | 4.2 | 3.82 | 3.43 | 2.89 | 2.68 | 2.54 | 2.49 | 2.41 | 2.71 | 3.45 | 4.06 | 3.24 |
| Kaduna | 10.52 | 7.42 | 623.54 | 4.77 | 4.49 | 3.67 | 3.18 | 2.85 | 2.73 | 2.61 | 2.47 | 2.09 | 2.23 | 3.46 | 4.43 | 3.24 |
| Kano | 12.01 | 8.6 | 442.08 | 2.84 | 2.89 | 2.78 | 2.64 | 2.51 | 2.39 | 1.94 | 1.52 | 1.44 | 1.69 | 2.16 | 2.58 | 2.28 |
| Katsina | 12.97 | 7.63 | 474.54 | 5.05 | 4.93 | 4.54 | 4.03 | 3.77 | 3.85 | 3.46 | 2.72 | 2.45 | 2.94 | 4.02 | 4.7 | 3.86 |
| Lafia | 7.81 | 6.74 | 167.21 | 2.38 | 2.54 | 3.01 | 3.23 | 2.82 | 2.71 | 2.88 | 2.84 | 2.32 | 2.03 | 1.89 | 2.12 | 2.57 |
| Lokoja | 7.81 | 6.74 | 167.21 | 2.38 | 2.54 | 3.01 | 3.23 | 2.82 | 2.71 | 2.88 | 2.84 | 2.32 | 2.03 | 1.89 | 2.12 | 2.57 |
| Maidugri | 11.84 | 13.16 | 318.25 | 4.57 | 4.78 | 4.65 | 4 | 3.77 | 3.98 | 3.64 | 2.88 | 2.57 | 2.79 | 3.91 | 4.34 | 3.82 |
| Makurdi | 7.74 | 5.54 | 373.17 | 2.53 | 2.65 | 3.01 | 3.16 | 2.83 | 2.82 | 3.14 | 3.19 | 2.52 | 2.12 | 1.97 | 2.23 | 2.68 |
| Mbaise | 5.54 | 7.29 | 92.75 | 2.34 | 2.28 | 2.35 | 2.41 | 2.33 | 2.6 | 2.92 | 3.02 | 2.65 | 2.21 | 1.79 | 1.98 | 2.41 |
| Minna | 7.61 | 8.09 | 149.83 | 3.02 | 3 | 3.3 | 3.42 | 2.98 | 2.97 | 3.18 | 3.14 | 2.57 | 2.17 | 1.98 | 2.59 | 2.86 |
| Nguru | 12.88 | 10.46 | 345.61 | 4.94 | 4.95 | 4.75 | 4.07 | 3.57 | 3.62 | 3.39 | 2.7 | 2.52 | 3.1 | 4.33 | 4.75 | 3.89 |
| Onitsha | 6.14 | 6.8 | 103.94 | 2.53 | 2.43 | 2.56 | 2.64 | 2.5 | 2.79 | 3.19 | 3.28 | 2.81 | 2.3 | 1.86 | 2.14 | 2.59 |
| Oshogbo | 7.79 | 4.55 | 337.39 | 2.43 | 2.6 | 3.03 | 3.23 | 2.91 | 2.9 | 3.31 | 3.38 | 2.55 | 2.06 | 1.89 | 2.13 | 2.7 |
| Owerri | 5.47 | 7.02 | 62.54 | 2.26 | 2.18 | 2.22 | 2.25 | 2.16 | 2.44 | 2.77 | 2.87 | 2.52 | 2.1 | 1.72 | 1.9 | 2.28 |
| Port-Harcourt | 4.34 | 7.05 | 6.8 | 1.65 | 1.77 | 1.76 | 1.66 | 1.62 | 1.86 | 2.17 | 2.29 | 2.03 | 1.71 | 1.5 | 1.45 | 1.79 |
| Potiskum | 11.7 | 11.09 | 411.77 | 4.36 | 4.47 | 4.13 | 3.56 | 3.43 | 3.33 | 2.8 | 2.27 | 2.06 | 2.25 | 3.38 | 4.06 | 3.34 |
| Sokoto | 13.01 | 5.25 | 276.18 | 4.51 | 4.42 | 3.94 | 3.59 | 3.8 | 3.71 | 3.12 | 2.44 | 2.19 | 2.38 | 3.3 | 4.14 | 3.46 |
| Umuahia | 5.53 | 7.5 | 92.75 | 2.34 | 2.28 | 2.35 | 2.41 | 2.33 | 2.6 | 2.92 | 3.02 | 2.65 | 2.21 | 1.79 | 1.98 | 2.41 |
| Uyo | 5.04 | 7.92 | 39.48 | 2.08 | 2.25 | 2.38 | 2.43 | 2.41 | 2.72 | 2.99 | 3.07 | 2.76 | 2.39 | 1.97 | 1.88 | 2.45 |
| Warri | 5.55 | 5.57 | 9.6 | 1.36 | 1.41 | 1.4 | 1.3 | 1.2 | 1.36 | 1.64 | 1.79 | 1.58 | 1.28 | 1.07 | 1.15 | 1.38 |
| Yelwa | 10.84 | 4.75 | 257.74 | 3.94 | 3.89 | 3.36 | 3.35 | 3.15 | 2.9 | 2.65 | 2.48 | 2.07 | 2.05 | 2.81 | 3.54 | 3.01 |
| Yenegoa | 4.93 | 6.28 | 17.26 | 2.08 | 2.15 | 2.23 | 2.19 | 2.09 | 2.37 | 2.72 | 2.87 | 2.56 | 2.14 | 1.78 | 1.77 | 2.25 |
| Yola | 9.04 | 12.5 | 344.13 | 2.48 | 2.82 | 3.36 | 3.55 | 2.94 | 2.68 | 2.59 | 2.36 | 1.91 | 1.91 | 2.05 | 2.21 | 2.57 |
| Zaria | 11.13 | 7.73 | 646.9 | 4.86 | 4.67 | 3.97 | 3.5 | 3.23 | 3.11 | 2.82 | 2.53 | 2.2 | 2.39 | 3.51 | 4.45 | 3.43 |
| | | | Ave | 3.01 | 3.05 | 3.04 | 2.97 | 2.77 | 2.82 | 2.88 | 2.76 | 2.36 | 2.18 | 2.33 | 2.71 | 2.74 |
| | | | Max | 5.05 | 4.95 | 4.75 | 4.1 | 4.06 | 3.98 | 3.92 | 4 | 3.54 | 3.1 | 4.33 | 4.75 | 3.89 |
| | | | Min | 1.36 | 1.41 | 1.4 | 1.3 | 1.2 | 1.36 | 1.64 | 1.52 | 1.44 | 1.28 | 1.07 | 1.15 | 1.38 |

## 3. Results

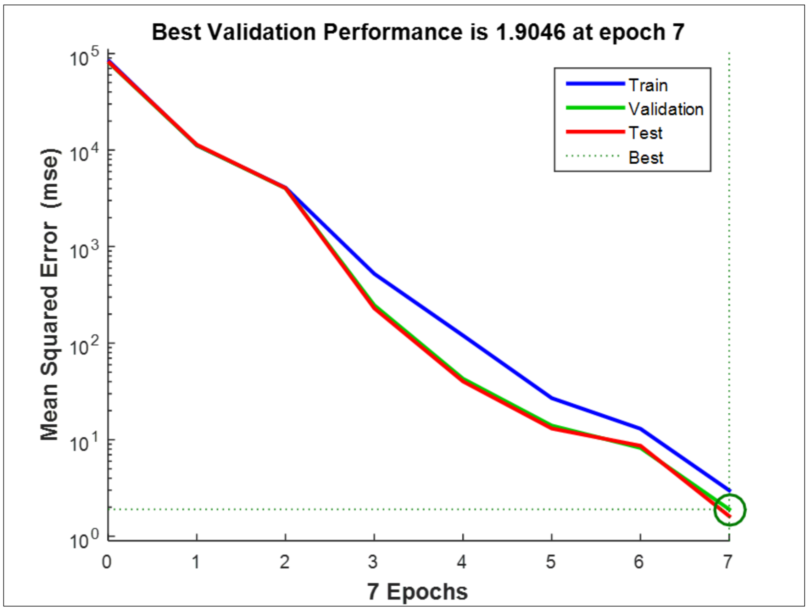


**Figure 3** Best Value of Wind Speed with Levenberg Maquardt Algorithm

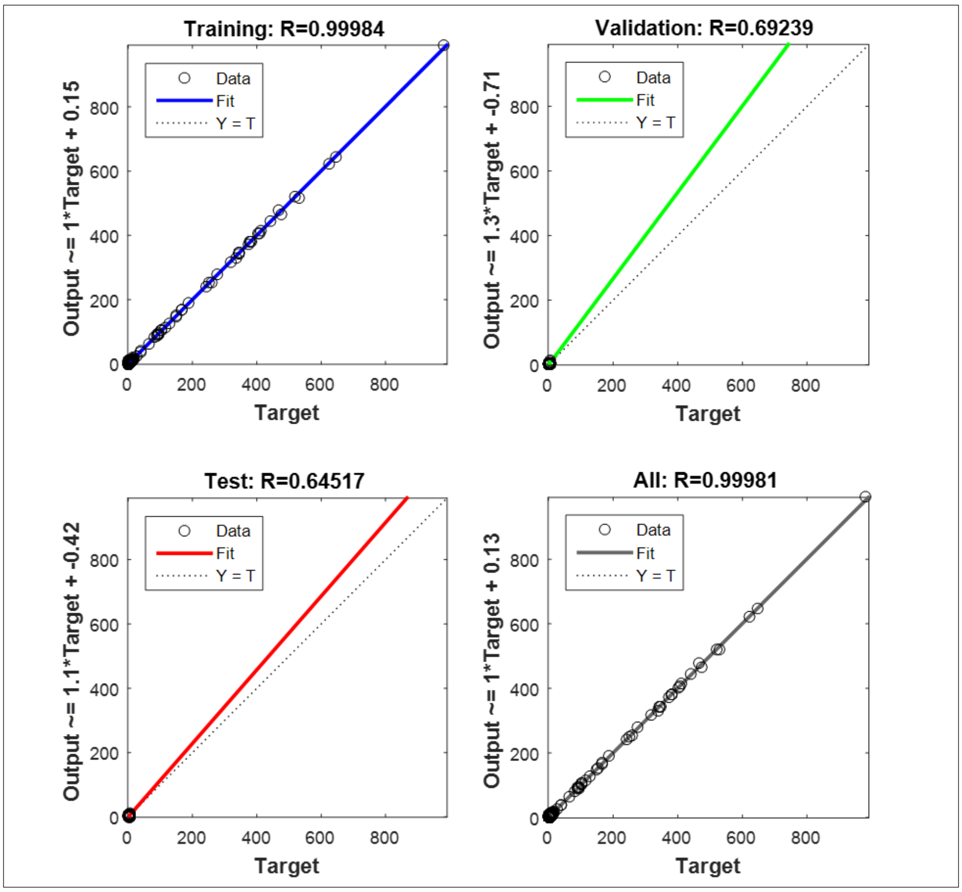


**Figure 4** Training fit of Wind Speed with Levenberg Maquardt Algorithm

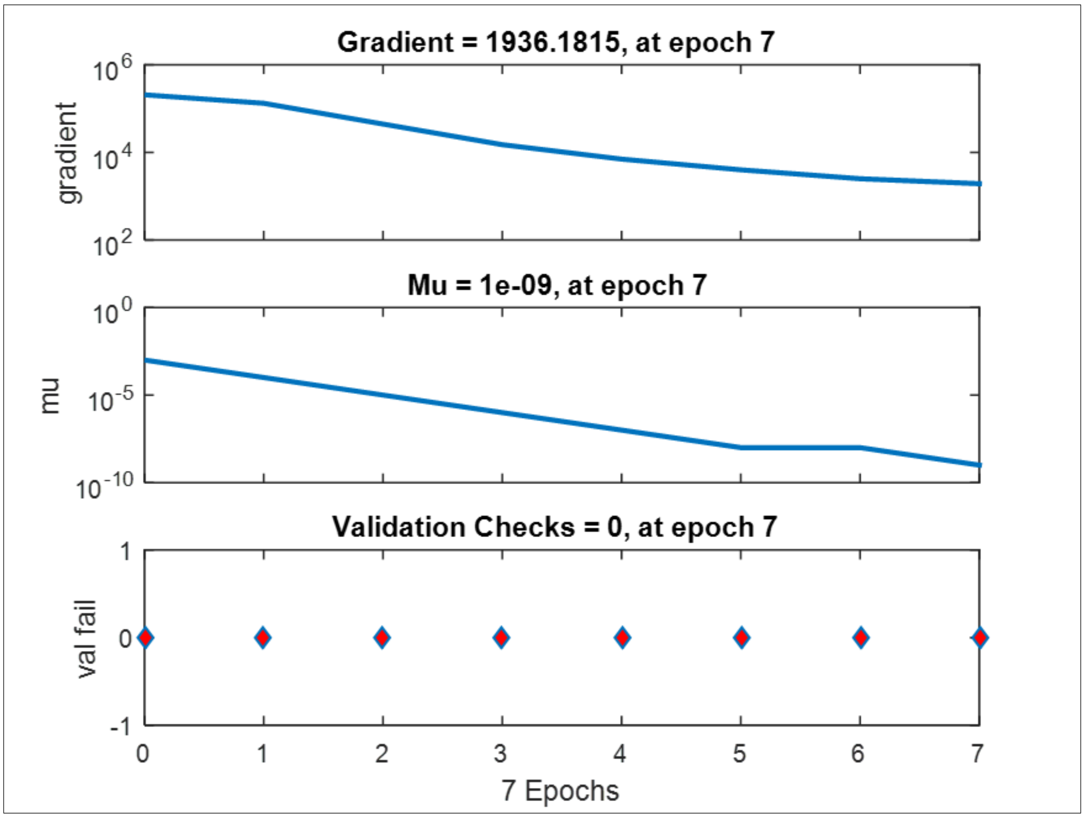


**Figure 5**State Train of Wind Speed with Levenberg Maquardt Algorithm

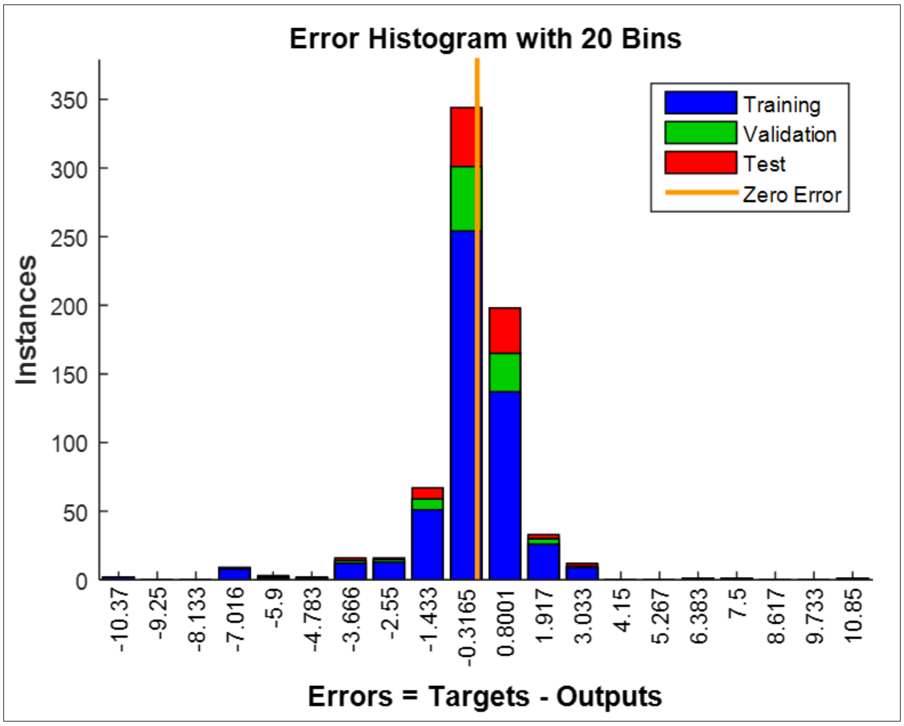


**Figure 6** Error Histogram of Wind Speed with Levenberg Maquardt Algorithm

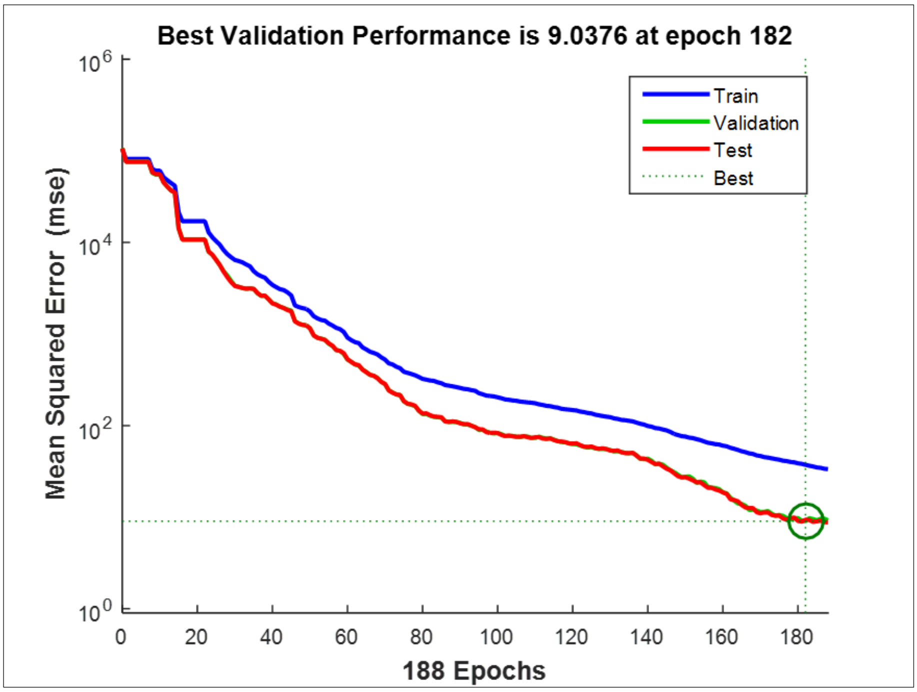


**Figure 7** Best Value of Wind Speed with Scaled Conjugate Gradient Algorithm

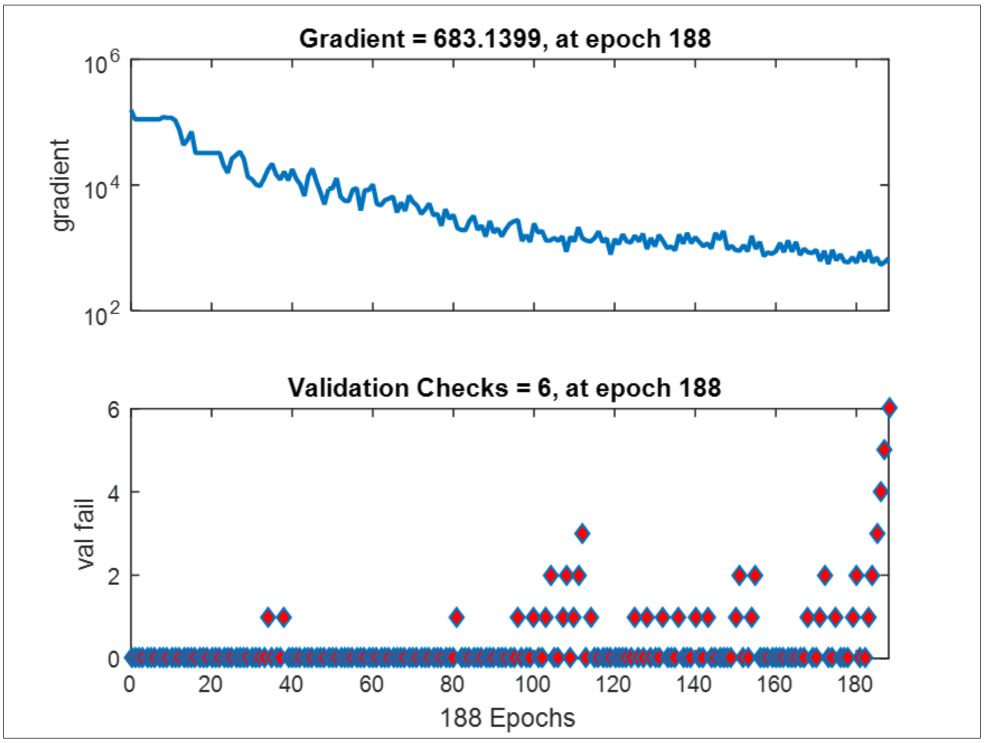


**Figure 8** Training State of Wind Speed with Scaled Conjugate Gradient Algorithm

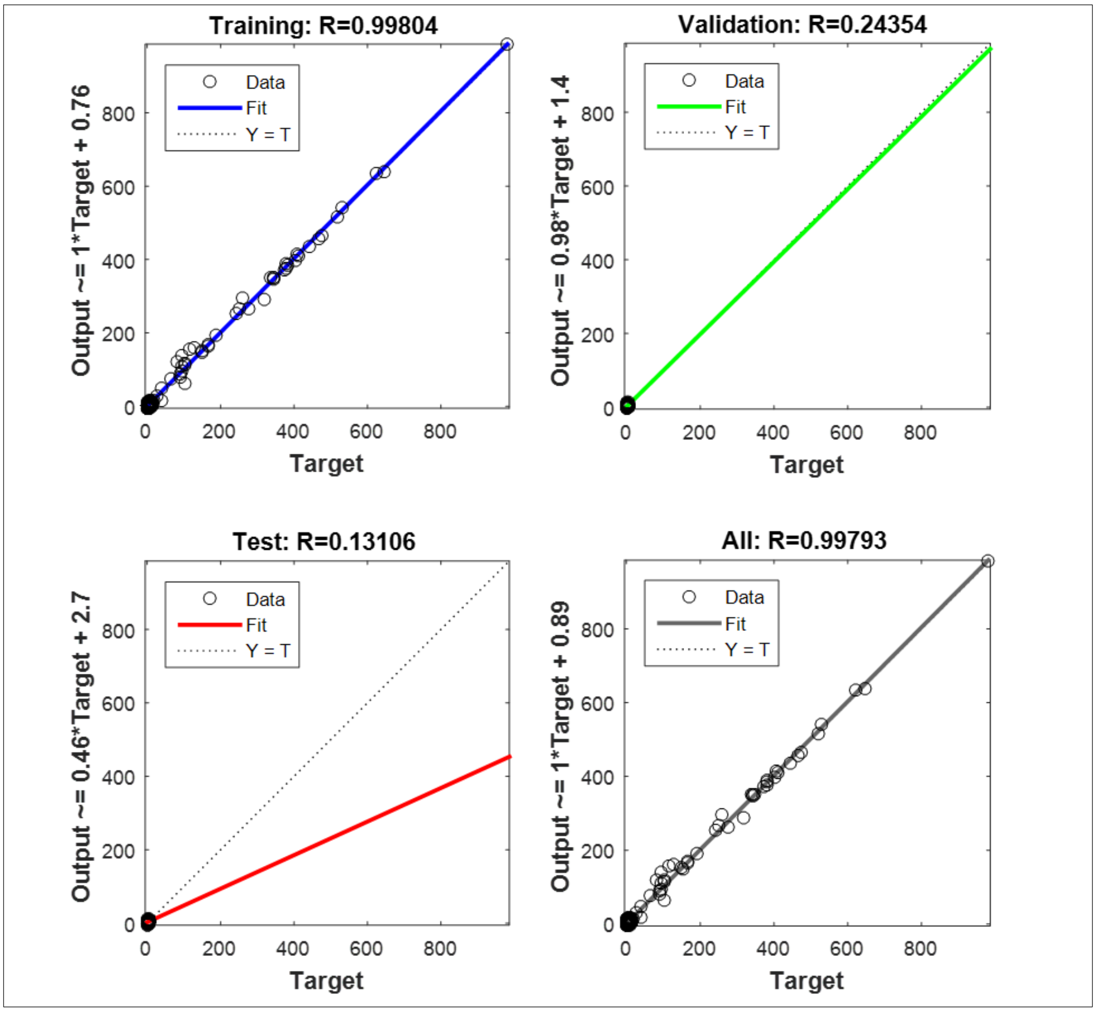


**Figure 9** Training Fit of Wind Speed with Scaled Conjugate Gradient Algorithm

## 4. Discussion

The outcome of the study, evaluation of best value of wind speed for maximum wind energy output in Nigeria using neural network was discussed here. The data in table 1 was analyzed using neural network toolbox in MATLAB command window. According to Fig. 3 to Fig. 9, the original data was trained using two training algorithms: levenberg marquardt and scaled conjugate gradient to achieve a network best performance level. Training of data using levenberg marquardt algorithm at 70% training data, 15% test data and 15% validation data respectively revealed that the best performance level was 1.9046 m/s at 7 epochs and this matches elevation of 7. 24meters as shown in table 1.

Training of the same data using scaled conjugate gradient algorithms at 70% training data, 15% test data and 15% validation data respectively revealed that the best performance level was 9.0376 m/s at 182 epochs and this matches elevation of 34.35meters as shown in table 1. According to Fig 4 and Fig 8, training fit coefficients of 0.99984 and 0.99804 respectively from graph indicated that there is a close and positive relationship between wind speed and wind energy output.

## 5. Conclusion

Obviously, results from the study revealed that the best value of wind speed for maximum wind energy output in Nigeria ranges from 1.9046 m/s to 9.0376 m/s with elevation ranges of 7.2 meters to 34.35 meters respectively. This is in agreement with (BWEA Briefing Sheet) that the lowest wind speed value at which small wind turbine produce a net positive power output is approximately 3 – 4 m/s. Although, results disagrees with AWS Scientific (1997) which stated that actual wind turbine elevation is usually in the ranges of 50 m to 65m.

*Recommendations*

- Wind turbine tower and blades should be designed to have wind impact speed capacity beyond the estimated values.
- This study can also be done in future using other training algorithms.
- Further research can also be done in future to establish a more accurate mathematical model between wind speed and wind energy output with other advanced program for generalization.

*Limitation of the study*

In the course of carrying out this research, evaluation of best value of wind speed for maximum wind energy output in Nigeria using neural network, the researchers encountered many encumbrances which might cause deviations from actual results. Some of the hindrances includes: data collection, cost of data analysis, lack of electricity, etc.

## Compliance with ethical standards

*Acknowledgments*

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*Disclosure of conflict of interest*

This research article is original and the corresponding author hereby confirms that all of the other authors have read and approved the manuscript with no ethical issues and with declaration of no conflict of interest.

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