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FEASIBILITY OF HARNESSING WIND ENERGY USING SMALL WIND TURBINE ALONG HIGHWAY IN SOKOTO STATE, NIGERIA.

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Abstract
This research proposes to study the feasibility of harnessing and utilizing the usually unused vehicle-induced turbulence wind energy along some selected highways in Sokoto State, Nigeria. The methodology adopted is to average wind speed obtainable some distances away from the selected highways, and to investigate a suitable placement position of wind turbines using three (3) positional parameters. These are: lateral distances from the road edge; the heights above the ground level; and the orientation of the wind turbines relative to the road. The two initial parameters are set at $0.5\ m$, $1.0\ m$ and $1.5\ m$ for each position, where the later parameter is varied at $45°$, parallel and perpendicular to the road. These measurements were conducted using three (3) digital anemometers. The collected data were plotted for wind velocity versus time and were analysed to determine the most suitable position for sitting the small wind turbine for maximum wind energy extraction from force induced wind speed from accelerating vehicles. The identified optimum positions were: at side distance of $1.0m$ from the road edge, $1.0m$ distance height above ground level and at $45°$ orientation relative to the road. Percentage difference between force induced wind speed and normal wind speed were also determined which proved that the recorded highest wind speeds at the considered roads are utilizable for power generation. These wind speeds, if properly harvested could provide a considerable amount of electricity that could power the highway street lights, roadside sign posts, machines for watering roadsides farms and telecommunication signalling.
Keywords: *wind turbine, wind speed, renewable energy, power generation, vertical axis wind turbine (VAWT), horizontal axis wind turbine.*

Introduction

Renewable energy sources of recent are being earnestly sort for their environmental and economic sustainability. These are some renewable energy sources: solar desalination (Bani-Hali et al, 2016); geothermal energy (United Nations, 2020); bio energy (United Nations, 2020); and wind energy (Bani-Hali and Abidoye, 2016). Wind energy is a viable most rapidly on the rise source of clean energy round the world. Energy consumption across the globe is persistently rising, reasons of which are not unconnected with these factors: urbanization; rising living standards; and increasing population (Mobil Exxon, 2016). The world seems to be in its first global energy crises – activated by Russia's invasion of Ukraine – according to (International Energy Agency, 2022) based on the recent energy data and transaction developments explores the questions about the crises, if it will be a setback for clean energy transitions or a catalyst for greater action. Also, the report (International Energy Agency, 2022) observed as one of the key findings, that the world has not been investing enough in energy in recent years, a fact that left the energy system much more vulnerable to the sort of shocks seen in 2022. A smooth and secure energy transition will require a major uptick in clean energy investment flows. Renewable energy provided 28.3% of global electricity consumption in 2021, irrespective of the progress of renewables in the power sector, the increasing global energy demand was mostly met with fossil fuels (REN21, 2022). Wind energy can be harnessed to generate electrical power to save high cost of fossil fuels (European Wind Energy Association, 2014). According to (REN21, 2022), it was estimated that $102\ GW$ of wind power capacity was installed globally in 2021 of which over $83GW$ is onshore and almost $19GW$ offshore, making total addition around 7% relative to 2020 of which is the highest level to date. This information is an evidence and indication of the relevance of researching in this field of study. Wind turbine use in electricity generation is usually affected by wind direction, wind force and the sufficiency of accessible wind through the year (Bharath and Balaji, 2012). Inconsistency of wind source is a major setback in wind energy technology. However, there is a close constant source of wind power on the major highways in Nigeria emanating from moving heavy vehicles and speeding vehicles, though low wind classes, could be utilized where less energy is needed for instance, in lighting the highways, powering signal signposts, and powering telecommunication signalling. Highways need adequate illumination to provide clear vision and security to road users at night. The infrastructure to provide the needed low energy for this purpose would be less economical in the long run compared to using fuels. Therefore, the use of small wind turbine (SWT) to harness the amount of energy from the moving vehicles would seem advantageous. The number of middle classes is on the increase in Nigeria, with this the number of vehicles is expected to increase as well, this will result to increased use of personal cars on the highways, therefore increasing unused induced wind energy on the roadsides. The huge potentiality accessible wind energy across Northern Nigeria remained significantly not utilized (Ben et al, 2021). This is why this research is aimed at assessing the potentiality of applying SWT on some selected highways in Sokoto State, Nigeria to generate sufficient wind energy that could power street lights, telecommunication signalling, traffic lights and guiding signs. This could be achieved through carrying out wind speed measurements on the selected highways and its surroundings using some positioning parameters for suitable placement of a wind turbine. The measurements are conducted using digital anemometers. The vehicular force induced averaged wind speed obtained from the various parameters used is compared to normal averaged wind speed to observe the percentage wind speed difference between the two. The result proved the potentiality of provision of efficient renewable clean energy that could save the State Government the financial cost of using fuels.

Literature Review

The use of wind energy is as long as the ages. Ever since its discovery till date it has being an interesting and promising area of research. The first accounted use of wind energy was in 1,700 BC when Hammurabi employed windmill to irrigate plains in East (Gasch and Twele, 2012). Vertical-axis windmills were most common right from the twelfth century, though Horizontal-axis windmills were used in Europe to perform diverse tasks (Shepherd, 1994). Wind turbine generates electricity through two processes, it first converts kinetic energy of the wind into a mechanical energy using the turbine rotor, then the second process is using a generation to convert the converted mechanical energy to electrical energy (Manwell et al, 2010) (Camm et al, 2009). The conversion process of wind energy to mechanical energy is on the bases of fundamental of conversion of mass, energy and momentum (Al-Shemmeri, 2010). The use of SWT in highway is found in literature. Few of the established studies depicted the possibility of implementing the idea and its implementation advantages, one of which is provision of clean energy harnessed from unused wind energy along the roadways (Wiegel and Stevens, 2006) (Gene and Fein, 2014).

Research finding has it that harnessing wind energy for power generation is tied to some of its advantages such as; sustainability, impressive availability, energy security, minimized greenhouse emission among others (Patidar et al, 2022).

Akporhonor et al (2023), evaluates the present status of wind energy in Nigeria, in a bid to provide accurate information to enable exploitation and exploration of wind energy in cities across the country. Conclusion revealed huge potential wind energy in cities across the country, that the number of installed wind capacity is not impressive and also that the country's renewable energy policies depict poor interest in wind energy compared to other renewable energy sources.

Onea and Rusu (2022), research the potentiality of offshore wind energy across Island close to the Mediterranean Sea, discovered that suitable areas in term of wind conditions are located near Sardinia with an average wind speed of about $9m/s$. The work also revealed that best performance of wind turbine is located in the North-Western part of the parameters.
Fagbenle et al (1980) observed based on 9 years (1951-1960) wind data from twelve meteorological station that the mean wind speed across Nigeria is $3\ m/s$. Also, they discovered that the Northern region usually have high wind speeds compared to that in Southern region which is low. Further, they revealed the highest wind speed of $3.6\ m/s$ is recorded in Jos.

Olomiyesan et al (2017) research revealed the highest and lowest annual wind speeds at $10\ m$ AGL (above ground level) as recorded in Kano and Yelwa are $9.27\ m/s$ and $3.48\ m/s$ respectively, where the annual mean value of wind speed of the region is $6.79\ m/s$, at $30\ m$ AGL the wind speed increased by $17\ \%$ in all the locations studied. In conclusion, the study disclosed that Kano, Sokoto and Katsina are viable for economic large-scale wind power generation, where Gusau is suitable for small-scale wind power generation.
To establish the wind energy potentiality for power generation in Knjazevac, Serbia, Potić et al (2021), investigated six locations using multi-criteria analysis method, three best locations for sitting of energy farm for power generation were identified.

Placing a vertical axis wind turbine (VAWT) along a highway is an idea that could generate electricity, when placed on the divider of the highway would receive more wind speed from two sides than it would receive when placed on one side of the road. The generated electrical energy stored in a battery could be utilized to power street light and any other appliances along the road. There are pertinent factors to consider when designing an efficient wind turbine that is not limited to selection of blades which includes: length and shape of the blade, speed of the wind, height and design of the tower, surface treatment and the tip speed ration (TSR) (Sathyanarayanan et al, 2011). Figure 1. Shows the location of the proposed VAWT on the divider of the highway.

Figure 1: VAWT on highway divider (Sathyanarayanan et al, 2011)

Wind energy application in Nigeria requires a continuous assessment of the wind distribution in the country for provision of accurate data. The obvious need to meet the demand of electricity of the growing population is a huge challenge confronting Nigerian government. There was a peak demand forecast in the country as on June 16, 2017 of $17{,}720\ MW$, where the overall power generation capacity is $6969\ MW$, the peak generation output $4240\ MW$

(Transmission Company of Nigeria, 2017). It can be observed that the peak generation is less than one-quarter of the peak demand forecast. Also, it was revealed that 85% of the overall installed capacity is gas-powered (thermal) while, the remaining 15% is hydro-generated. The country's most percentage power generating source has environmental consequences coupled with lots of issues such as insufficient gas infrastructure and vandalism of gas pipelines contributing to poor power generation. Therefore, there is need to cover the gap in power generation in the country through renewable sources, this is driving the motivation to assess the potentiality of harnessing turbulent kinetic energy of moving vehicles in some selected highways in Sokoto State. The wind energy if harnessed would be utilized in powering street lights, telecommunication signalling stations, and roadside signposts. Wind energy is the cleanest source of renewable energy, and efficient as well.

Methodology

The key steps adopted in this research includes: determining the wind speed some distances from the selected highways; determining the appropriate positioning of wind turbine using some measurement parameters for maximum extraction of wind energy from moving vehicles along the highways; and comparing the obtained averaged wind speed as a result of moving vehicles to the ordinary averaged wind speed obtained from data as collected from Sokoto Energy Research Center, Usmanu Danfodiyo University, Sokoto State. The three (3) selected roads are; Gusau Rd. leading to Gusau, Katsina, Zaria etc, Western Bypass Gidan Dare connecting Birnin Kebbi Rd. and Abdullahi Fodio Rd. leading to Usman Danfodiyo University permanent campus, all of which are dual carriage roads. Figure 2 depicts the positional setup of the anemometers at the road edge and the force induced wind direction.

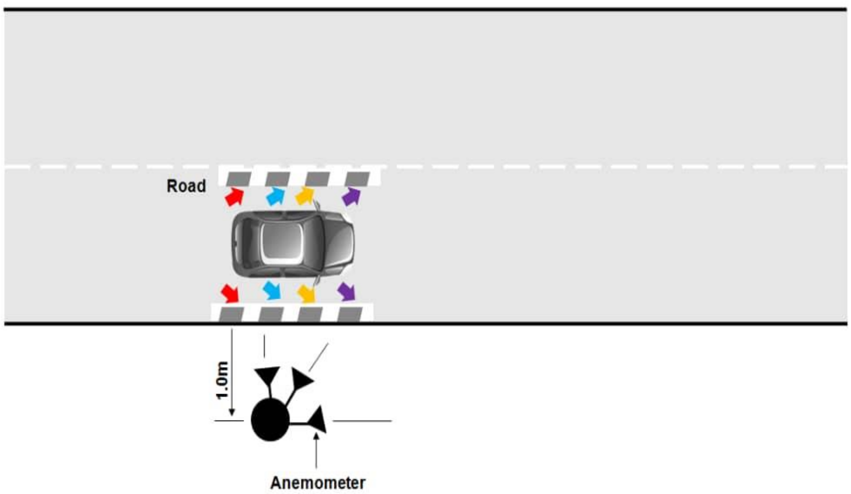

Figure 2: Positioning of the Anemometers at Various Orientations.

To achieve an efficient extraction of induced wind energy due to moving vehicles on the highways, turbine is to be positioned in a location with optimum lateral distance from the road where the induced turbulent wind air flow is strongest and at a suitable ground level. In addition, for Horizontal Axial Wind Turbine (HAWT) use, an orientation measurement would be performed to identify suitable direction for maximum harnessing of induced turbulent wind flow. To this effect three (3) digital anemometers are set up at different locations each time to measure and record the velocity of the wind induced by moving vehicles. The parameters considered are the lateral distances from the road edge, to investigate the maximum vehicle induced turbulent wind at the distances, the heights at ground level, to find out the optimum height from the ground for the turbine positioning, and then the orientation of the turbine relative to the road. The two previous parameters are to be set at $0.5\ m$, $1.0\ m$ and $1.5\ m$ for each position at the sampling time of $1\ second$ for an average duration of $5\ minutes$. Figure 3 depicts the positioning of the various anemometers and the varying heights for the considered measurements. A wooden rack is constructed to hold the digital anemometers at the desired locations and heights. The picture content of Figure 4 is showing one of the wooden racks used in positioning the anemometers.

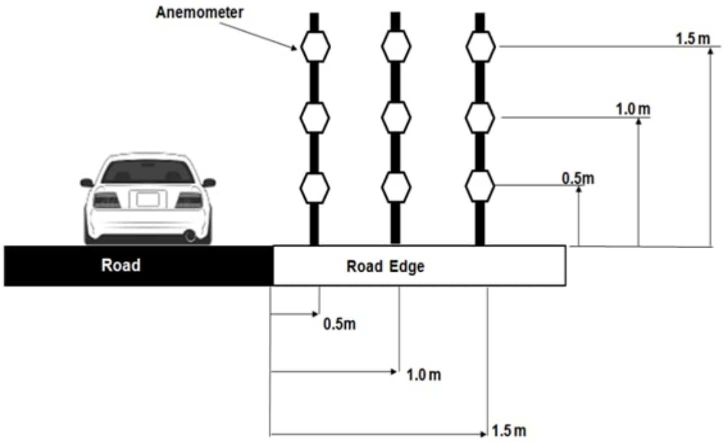

Figure 3: Description of the Framework of the Anemometers to the Edge of the Road.

Using measuring tape, measurements for placement of the wooden racks were taken, after which they are placed together with the anemometers and readings are taken for 20 $minutes$, this procedure is repeated for all the considered parameters, after which data gathered were Tabulated. A graph of wind velocity (m/s) versus time (s) using the data collected for the various parameters considered is plotted to determine: optimum position and most suitable lateral distance from the road edge when positioning the wind turbine; and to obtain the highest, average and least wind speed for the individual parameters considered. A graph of wind velocity (m/s) versus time (s) is also plotted for ordinary wind speed using data collected from Sokoto Energy Research Centre, to enable obtain the percentage difference between the two.

Figure 4: Picture of one of the Wooden Rack.

Results and Discussion

The experimental and numerical processes involved in this work are to affirm the optimum position for the wind turbine placement along the selected highways to extract maximum wind energy from force turbulent airflow from moving vehicles that could generate sufficient electricity to power highway street lights, to water farms on roadsides, roadside sign posts and telecommunication signalling. Apart from investigating the appropriate distance from the road edge and height above ground level for sitting the wind turbine, some orientation measurements were done to identify the accurate direction in which the force induced wind flow can be directed toward the wind turbine. All these were achieved using digital anemometers placed at different locations to read and store wind velocity for sampling time of 1 second for an average duration of 5 minutes. Data recorded were extracted and used to plot graphs of wind velocity verses time. The Figure 5- Figure 10 contains the graphs plotted which is used to discuss the research results in accordance with the used parameters. It is important to state here that there about twelve (12) graphs plotted, however, the selected ones is because of their vital points for emphasis and available limited space. Each Figure of graph has an attached Table of descriptive statistics of the graph

A. Side Distance from the Road Edge

To dictate the maximum force induced wind velocity from the side of the roads, measurements were made at distances of $0.5\ m$, $1.0\ m$ and $1.5\ m$ at the same ground level from the side of the road, and wind velocity readings taken at changing anemometer heights of $0.5\ m$, $1.0\ m$ and $1.5\ m$ respectively for the three investigated roads.

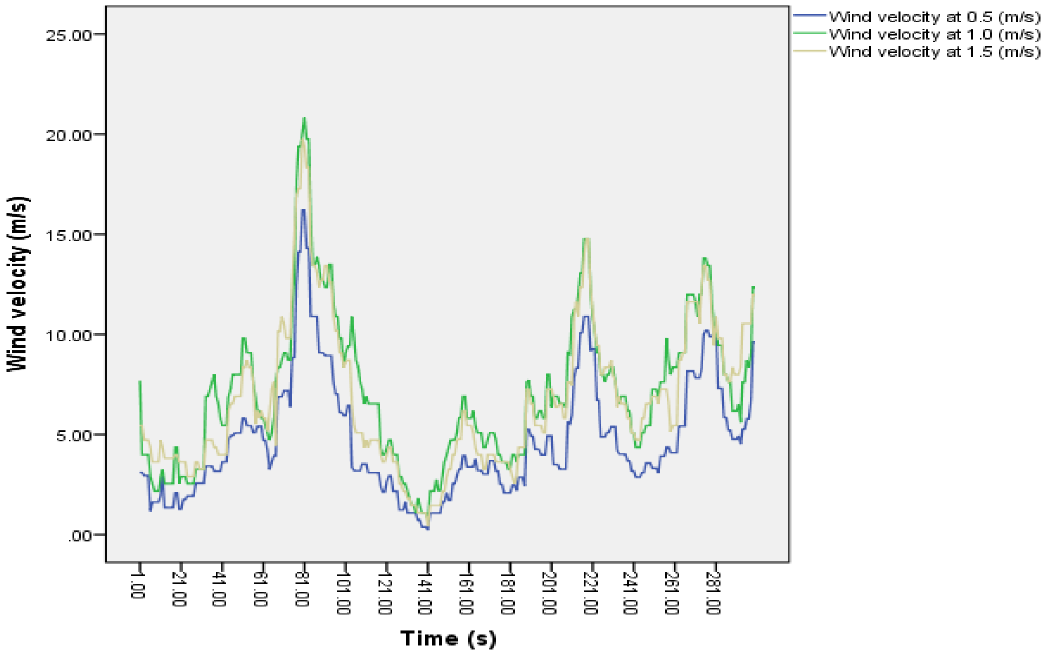

Figure 5: Wind Velocity at ($0.5\ m$, $1.0m$, $1.5\ m$) Lateral Distances at$1.0\ m$ above the Ground Level in Gusau Rd. Sokoto State, Nigeria.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wind velocity at 0.5 (m/s)	300	16.00	0.21	16.21	4.6564	2.94407	8.668
Wind velocity at 1.0 (m/s)	300	20.11	0.72	20.83	7.1121	3.75338	14.088
Wind velocity at 1.5 (m/s)	300	19.34	0.41	19.75	6.7579	3.68966	13.614

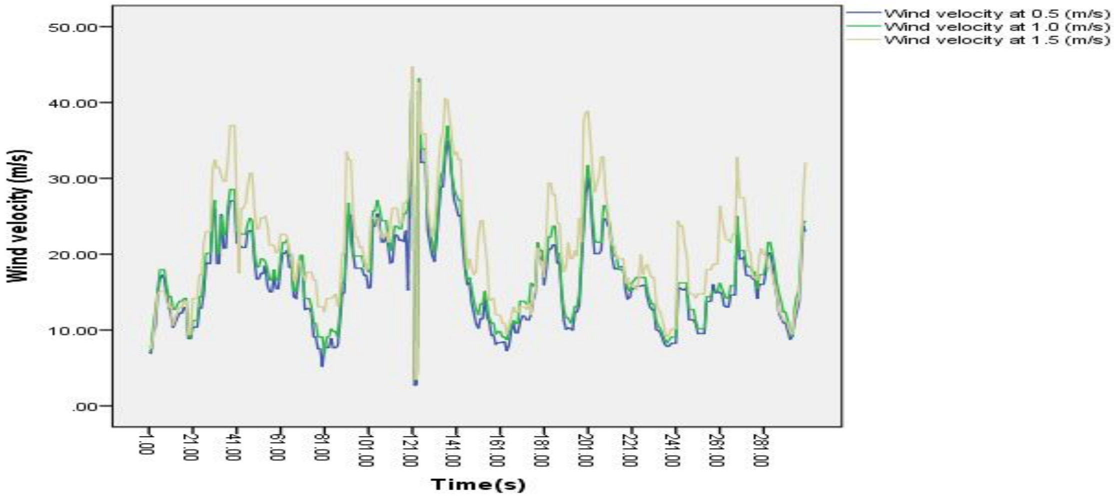

Figure 6: Wind Velocity at ($0.5\ m$, $1.0m$, $1.5\ m$) Lateral Distances at $1.0m$ above the Ground Level in Western Rd. Sokoto State, Nigeria.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wind velocity at 0.5 (m/s)	300	41.15	2.66	43.81	16.4842	6.37541	40.646
Wind velocity at 1.0 (m/s)	300	40.57	3.47	44.04	17.8275	6.50206	42.277
Wind velocity at 1.5 (m/s)	300	41.24	3.52	44.76	20.7083	7.60553	57.844

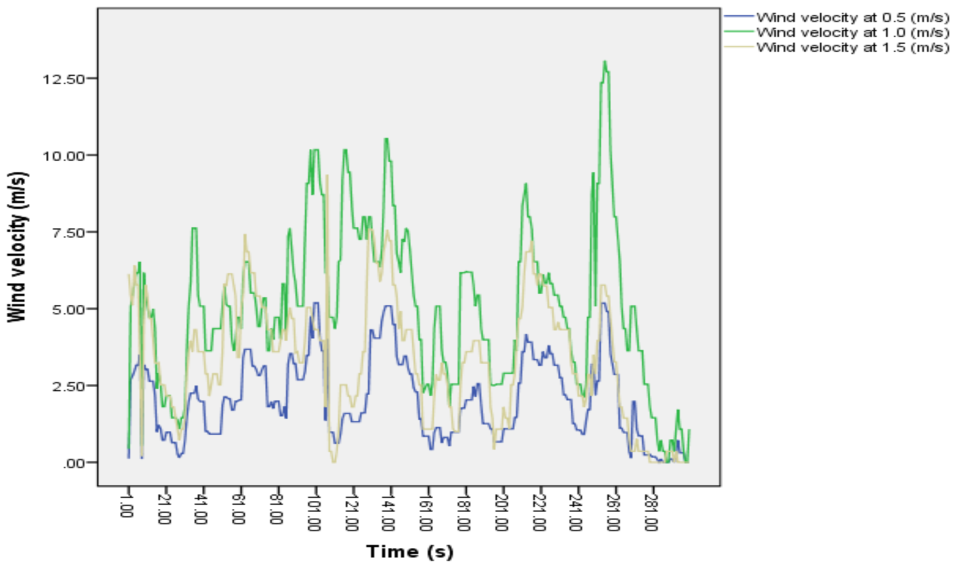

Figure 7: Wind Velocity at ($0.5\ m$, $1.0m$, $1.5\ m$) Lateral Distances at $1.0m$ above the Ground Level in Abdullahi Fodio Rd. Sokoto State, Nigeria.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wind velocity at 0.5 (m/s)	300	5.19	.00	5.19	2.0311	1.33817	1.791
Wind velocity at 1.0 (m/s)	300	13.07	.00	13.07	5.0814	2.62317	6.881
Wind velocity at 1.5 (m/s)	300	9.36	.00	9.36	3.3563	2.02952	4.119

Analysis of all plotted graphs show that Gusau Rd. and Abdullahi Fodio Rd. recorded the highest wind speed of $20.83\ m/s$ and $13.07m/s$ and average wind speed of $7.1121m/s$ and $5.0814m/s$ respectively, at $1.0m$ away from the road, at $1.0m$ above ground level, these records are greater to the ones recorded at $0.5m$ and $1.5m$ above ground level, where Western Rd. recorded highest wind speed of $44.04m/s$ and average wind speed of$17.8275m/s$, at $1.0m$ away from the road, at $1.5m$ above the ground level, these records are greater compared to the ones recorded at $0.5m$ and $1.0m$ above the ground level. This can be seen in Figure 5 – Figure 7. This recorded high speeds at this position is characterized to the formation of trailing vortices at the side and behind the region of 1.0m distance from the body of the moving vehicle. It is evident that the side distance of 1.0m provides the optimum position for placement of wind turbine for all the considered heights above the ground level after measurements and analysis of induced wind speed of accelerating vehicles.

Optimum Height Above the Ground Level

Considering the results of the measurement made for side distance from the edge of the road for which 1.0m is optimum location for placement of wind turbine, three anemometers were place at distance of $0.5m$, $1.0m$ and $1.5m$ above the ground level to get the optimum height to sit the wind turbine above the ground. Analysis of Figure 5 – Figure 7 show wind speed of $20.82m/s$ in Gusau Rd., wind speed of $13.07m/s$ in Abdullahi Fodio Rd. all recorded at the height of $1.0m$ above the ground level, these have highest wind speed compared to other distances measured in the same ground level, where at Western Rd. the recorded wind speed is $44.04m/s$ at $1.0m$ distance above the ground, this is highest compared to the other distanced measured in the same ground level. At side distance of $1.0m$ away from the road, and 1.0m height above the ground level, the wind flow could have the maximum wind speed at which a mounted wind turbine can extract maximum energy from force induced wind energy generated by traveling vehicles, for Gusau Rd and Abdullahi Fodio Rd., however, for Western Rd. this could be actualized at a distance of 1.0m away from the road, at $1.5m$ above the ground level.

Orientation Relative to the Roads

There is need to determine the optimum orientation for placement of HAWT since it receives wind flow only in one direction. For this singular reason, three directions were selected, parallel to the road, perpendicular to the road and $45°$ to the road as shown in Figure 2. The three anemometers were set up at a side distance of $1.0m$ on the same ground level away from the road edge, each for one orientation to obtain the most efficient result. The extracted data readings are as indicated in Figure 8 – Figure 10.

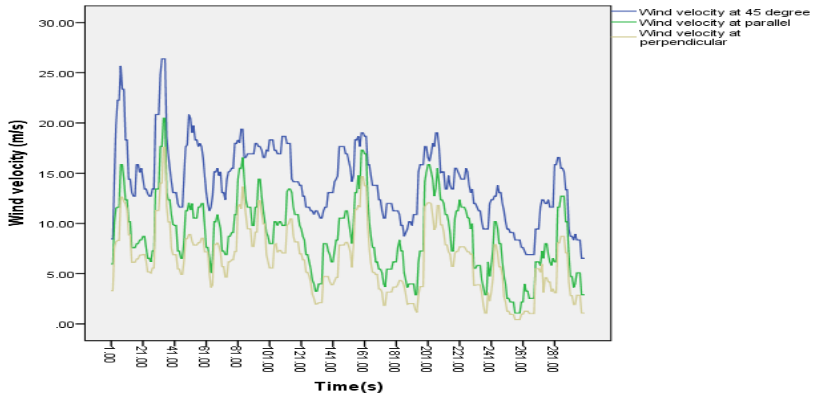

Figure 8: Wind Velocity at (45^{o}, Parallel, Perpendicular) orientations at $1.0\mathrm{m}$ above the Ground Level in Gusau Rd. Sokoto State, Nigeria

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wind velocity at 45 degree	300	19.86	6.53	26.39	14.1578	3.81263	14.536
Wind velocity at parallel	300	19.39	1.08	20.47	8.7376	3.80115	14.449
Wind velocity at perpendicular	300	17.14	0.43	17.57	6.3617	3.41229	11.644

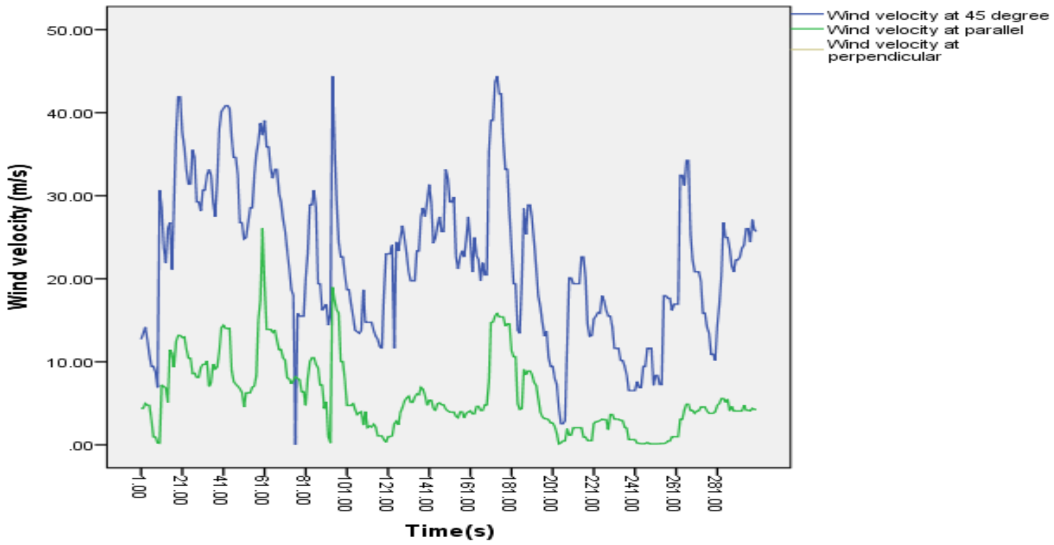

Figure 9: Wind Velocity at (45^{o}, Parallel, Perpendicular) orientations at $1.0\mathrm{m}$ above the Ground Level in Western Rd. Sokoto State, Nigeria.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wind velocity at 45 degree	300	44.40	.00	44.40	22.2355	9.30284	86.543
Wind velocity at parallel	300	34.61	.00	34.61	11.3632	7.19966	51.835
Wind velocity at perpendicular	300	25.98	.11	26.09	5.7647	4.46037	19.895

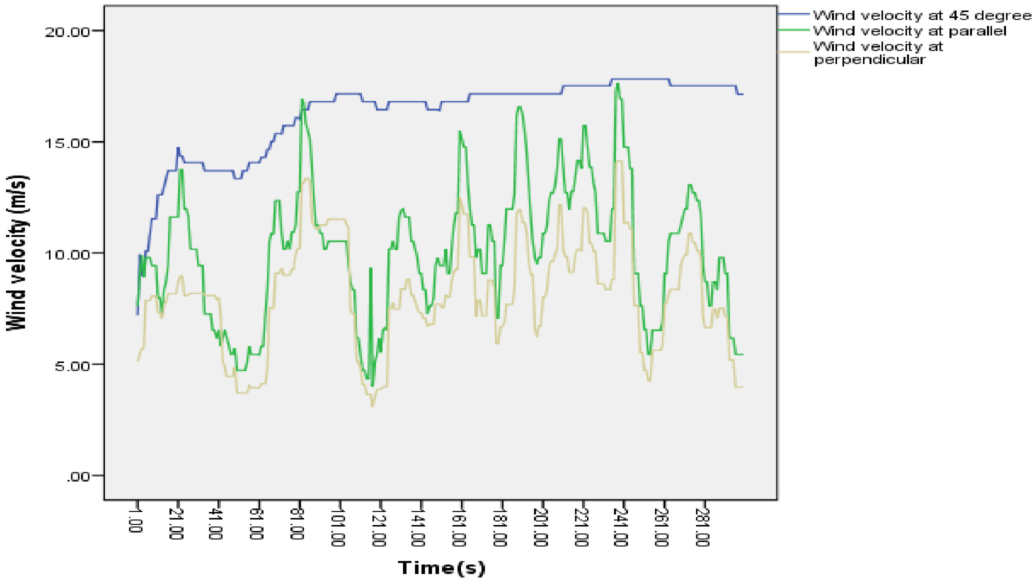

Figure 10: Wind Velocity at ($45°$, Parallel, Perpendicular) orientations at 1.0m above the Ground Level in Abdullahi Fodio Rd. Sokoto State, Nigeria

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wind velocity at 45 degree	300	10.62	7.21	17.83	16.2514	1.81465	3.293
Wind velocity at parallel	300	13.66	3.99	17.65	10.0744	3.00781	9.047
Wind velocity at perpendicular	300	11.06	3.08	14.14	8.0876	2.48774	6.189

The anemometer at the direction of $45°$ to the road recorded the highest wind speed, followed by the one at parallel to the road, where the lowest recorded wind speed in obtained from the one at perpendicular to the road. Based on this result, HAWT is to be placed at side distance of $1.0m$, at $1.0m$ height above the ground and at direction of $45°$ to the road to gather maximum wind flow energy from accelerating vehicles.

Percentage difference between Force Induced Wind Speed and Normal Wind Speed

Figure 11 is the plotted graph of the normal wind speed based on the data collected from Sokoto Energy Research Center, Usmanu Danfodiyo University, Sokoto State. It is observed from the graph that the highest wind speed is$12.95m/s$, equation 1 is used to determine the percentage difference between force induced wind speed and the normal wind speed.

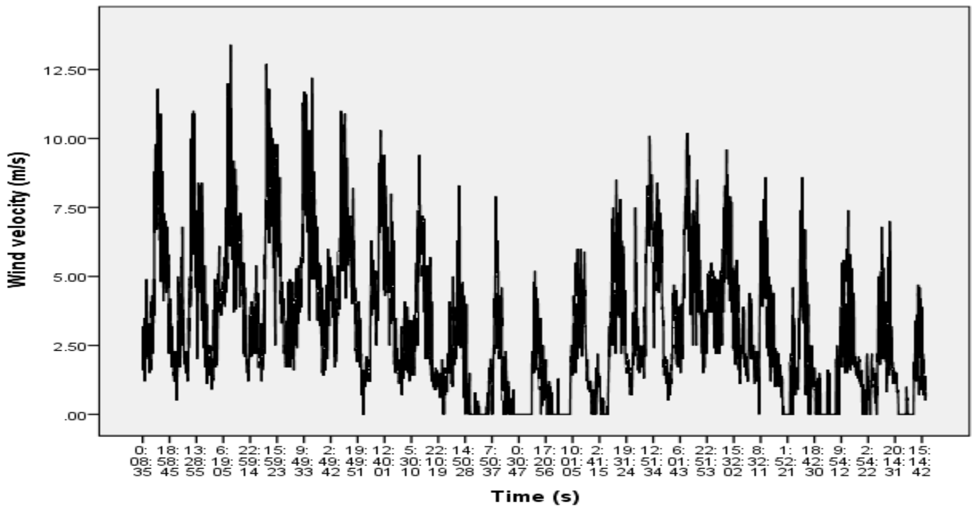

Figure 11: Normal Wind Speed for the Month of February, 2024 in Sokoto State, Nigeria.

$$\text{Percentage difference} = \frac{|A-B|}{\frac{(A+B)}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equ. (I)}$$

The percentage difference of the highest values of force induced wind speed recorded for Gusau Rd., Abdullahi Fodio Rd., Western Bypass Rd. and the highest normal wind speed recorded for the Month of February are $46.61\%, 0.92\%$ and 200% respectively. These values of force induced wind speed are much more compared to the approved research results of utilizable potential wind speed energy for power generation in Nigeria (Ajayi 2009, Ogolo et al, 2020). Based on these facts, it is evident that the force induced wind speed as recorded in the considered roads are utilizable for electricity generation to supply power to highway street lights, water farms on roadsides, roadside sign posts and telecommunication signalling.

Conclusion

This research work is aimed at studying the feasibility of harnessing force induced wind energy by the road side of some selected roads as a result of moving vehicles using wind turbine. By adopting and applying some parameters using digital anemometers this aim and some objectives were achieved. This research has through experiments and numerical processes been able to identify optimum positions for sitting wind turbine beside highways for maximum extraction of wind energy from moving vehicle induced wind speed. The identified optimum positions were: at side distance of $1.0m$ from the road edge, $1.0m$ distance height from ground level and at $45°$ orientation relative to the road. The determined percentage difference of the force induced wind speed to the normal wind speed is a clear approve that these wind speeds are utilizable for power generation in Sokoto state, Nigeria. Therefore, going by the results of this research the attention is sought of the Federal Government of Nigeria and the Government of Sokoto State for implementation consideration. Future work could be done in producing small scale wind turbines with specific performance characterizations and installed at the identified optimum positions for power measurements. Also an hybrid system of wind and solar energy could be developed to support more loads.

VI. Acknowledgement

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