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Design and Development of an Electrical Power Generating Bridge using Wind Energy from Moving Vehicles

CFP/5080/2023

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ABSTRACT: Electricity and energy are key issues today in Zambia as a developing country. The ultimate function and goal of any electric power supply company anywhere in the world today is to provide a service of supplying reliable and uninterrupted power supply to its consumers at all times. Although, for developing countries like Zambia, the amount of electric power generated is insufficient to meet the demands of the growing consumers of electricity, therefore power outages and instabilities are experienced

This project attempts to explain an innovative method of generating clean wind energy from a fast moving vehicle by various courses. The energy generated from this method is produced as the consequences of human activity. Five methods used to produce energy are from renewable wind sources, solar, hydro, coal and nuclear energy. One of the biggest obstacles to the widespread use of wind power generation is that many areas just aren't that windy. The alternative form of Renewable wind energy produced by trucks is very unique, as it does not depend on any natural energy resource. A moving vehicle like trucks compresses the air in the front of it and pushes the air to its sides thereby creating a vacuum at its rear and its sides as it moves forward. To fill up this vacuum a mass of airflow rushes into the sides and the rear. The kinetic energy of the wind movement thus created pushes the wind turbines and generates electricity. This generated electricity can be further used for various applications

KEYWORDS: HAWT; VAWT; Kinetic Energy; Renewable energy;wind energy; Zambia

I. INTRODUCTION

Electricity and energy are key issues today in Zambia. A moving vehicle compresses the air in the front of it and pushes the air to its sides thereby creating a vacuum at its rear and its sides as it moves forward. To fill up this vacuum a mass of airflow rushes into the sides and the rear. The kinetic energy of the wind movement thus created is used to rotate a vertical wind turbine to generate electricity.

Power and Energy are the basic economic development of a country. Many functions necessary to present-day living may come to a stop when the supply of energy stops. It is practically impossible to estimate the actual magnitude of the part that energy has played in the building up of present-day civilization[1]. The availability of huge amount of energy in the modern times has resulted in a shorter working day, higher agricultural and industrial production, a healthier and more balanced diet and better transportation facilities. As a matter of fact, there is a close relationship between the energy used per person and his standard of living. The greater the per capital consumption of energy in a country, the higher is the standard of living of its people.

Electrical energy is very important form energy. The modern society is so much dependent upon the use of electrical energy that it has become a part of our lives. Recent statistics indicate that there has been an increased population growth in Zambia, which has brought about more infrastructure development, economic and industrial growth which has led to more production of goods and services and a high demand on the amount of electrical energy needs. Our present situation in Zambia has indicated that the state owned electricity Supply Company which is the Zambia Electricity Supply Corporation (ZESCO) has faced quiet a number of challenges in generating and supplying of enough electrical energy to cater for the demand of the growing population and hence companies and individuals have resolved to the use of alternative energy sources for the generation of electrical energy in order to facilitate the continuity in their production of goods and services. Power has been extracted from the wind over hundreds of years with historic designs, known as windmills, constructed from wood, cloth and stone for the purpose of pumping water or grinding corn.

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Historic designs, typically large, heavy and inefficient, were replaced in the 19th century by fossil fuel engines and the implementation of a nationally distributed power network. A greater understanding of aerodynamics and advances in materials, particularly polymers, has led to the return of wind energy extraction in the latter half of the 20th century. Wind power devices are now used to produce electricity, and commonly termed wind turbines [2].

1.1 Motivation and significance of study

Our present day situation in Zambia is faced with power outages in the form of load management due to low water levels in the main reservoirs and controlled water allocation by Zambezi water resources. This has resulted in the use of alternative power sources such as diesel generator sets and solar generated power in Zambia

Load shedding or power outages have a negative effect on the development of both public and private sectors. It reduces investor confidence due to frequent or constant power loss. Hence this hinders the development of the economy of the nation. There are other processes in addition that do not require interruption because of their importance in nature, for example transfer of money from one bank to the other, a surgery in the hospital, a president giving a press statement and many more. Hence the need for this paper to present the need for the design of an electrical generation bridge through Wind turbines

1.2 Scope of Study

The study in this project was limited to Lusaka, Zambia and Makeni Mall Bridge in particular its focus was on the function of road users

1.3 Problem statement

There is an energy crisis in the country such that the utility company has to load shed areas in order to manage the deficit which rose from 690 Megawatt (as of September 2019) to 810 Megawatt (as of March 2020) and have an equal distribution of power across the country, thus the reason for coming up with this renewable energy solution to take a part in ironing out the deficit. Too much reliance of hydroelectric power and an increase in the number of industries and infrastructure development has resulted in this crisis as the change in climate is causing fluctuations in the amount of rainfall received. It is against this background that I was motivated to come up with the design of an electrical generation bridge through wind.

1.4 Main Objective

The main objective of this research paper is to design an electrical generation bridge through wind energy from moving vehicles.

1.4.1 Specific Objectives

1. To design and simulate an electrical generation bridge through wind.
2. To determine the type of wind turbines to be used.
3. To determine the amount of wind velocity, the turbine needs for efficient generation

1.5 Research Questions

1. What is an electrical generating bridge how does it work?
2. What type of wind turbine would be more efficient in this project?
3. At what speed does the vehicle need to move in order to generate sufficient wind to make the turbine rotate?

II. LITERATURE REVIEW

The use of wind turbine which goes back to 7th century in the region of Middle East. Lapointe et al (2016), states that High speed vehicle motion on the highways produce localized winds whose energy can be harnessed. Previous Studies As mentioned before, the produced localized wind energy as the result of high-speed moving vehicles has a very appreciable potential considering the traffic flow, especially on express-ways. In this regard, the implementation of vertical axis wind turbines for the energy recovery from this source is a new concept. Apart from some designs and concepts which still are in progress, the amount of available data in the literature is very scarce and is only limited to some conducted numerical works with so many assumptions. For instance, a multi-stage Savonius rotor combined with a solar panel was proposed by Taskin et al. which can be planted in the median strip of expressways. In another effort by Krishnaprasanth et al (2012), a maglev turbine was designed specifically for the power generation from expressways. These works did not include any insights regarding the performance of rotors either analytically, numerically or experimentally. This study provides no information regarding the conditions of conducted tests

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including traffic regime, rotor properties, highway's specification and etc. with very simplified assumptions. It should be noted again that the idea of harvesting energy from the vehicular traffic has been proposed for around a decade with some patented designs. Due to the lack of any detailed investigations regarding the characteristics of this energy source, the international market is still hesitant towards this source. In order to amend this issue, Morbiato et al, conducted, presumably, the first detailed experimental study regarding the characteristics of generated flow field by heavy trucks in the Venice A4/E70 highway, Italy. One of their aims was to reconstruct the wind profile along the lane axis of motorway on top of the trucks. The reason for that particular position has been attributed to the significant net flow in the trailing direction rather than side faces of a truck which are affected by high turbulence level caused by the rotational motion of wheels. These local winds have less variability especially if the highway traffic is constant. The idea of extracting energy from highway winds has been conceptualized in many studies before. However, the feasibility of this idea has never been tested using analytical, computation or experimental methods. In this study, we numerically compute the amount of power that can be extracted from local highway winds due to vehicular motion. Numerous vehicle motion scenarios were compared to the case of an isolated wind turbine. The initial results show a significant increase in the power that can be extracted by these turbines. The extracted power increases about 200% when compared to the case without any vehicular motion. Field measurements or wind tunnel studies are required to provide validation for the computations and to determine if more advanced turbulence modeling methodologies have to be employed for these studies. They had a very small efficiency and operated on horizontal axis. The first wind turbine to generate electricity was developed in the early 90s.

Gorgen Marvin (2016) agrees that renewable energy can be a promising approach to supply energy, address price volatility of fuels, hedge against supply insecurities, and reduce CO2 emissions. Wind is the continuous movement of atmospheric air masses and is determined by its speed and orientation. This movement derived from the changes and the different values of the atmospheric pressure while these values are the result of the solar heating of different parts of the earth's surface. It might seem obvious, but an understanding of the wind is fundamental to wind turbine design [4]. The power available from the wind varies as the cube of the wind speed, so twice the wind speed means eight times the power. By extracting power, the turbine itself has an effect on the wind downwind of the turbine the air moves more slowly than upwind. The wind starts to slow down even before it reaches the blades, reducing the wind speed through the ―disc(the imaginary circle formed by the blade tips, also called the swept area) and hence reducing the available power. Some of the wind that was heading for the disc diverts around the slower-moving air and misses the blades entirely [5].

The wind energy derived from the air as a result of its movement which is about 0.2%, of the solar radiation that reaches the surface of the earth. The wind power around the globe is estimated in 3.6×109 MW while, according to valid estimations of the world meteorology organization, the percentage which is available for energy exploitation in various parts of the world is only 1% and it is estimated around 0.6Q (175×1012 KWh) [6].

Many scientists support that the proper exploitation of the wind energy can resolve in a way the world's energy problem. For instances, the energy needs in here hardly constitute the one tenth of the wind energy potential of the country. Nowadays a total of 59,100 MW of wind generated capacity is installed around the world, with an average annual growth rate of 29 percent over the last ten years. Although each coin has two sides and thus wind energy can't be easily predicted neither can its continuous operation. Wind is a form of energy with low density, something which implies that large structures have to be made for its exploitation [7].

Undoubtedly the wide use of the wind energy and its efficient exploitation is going to improve the global energy balancing without overloading at the same time the environment with dangerous gases.
According to the meteorological department the wind data Zambia has a national average Wind Speed of 3.4 m sec-1.

2.2 Types of Wind Turbine

The machines which are proposed to harness the wind energy are considered as wind turbines. The two commonly used wind turbines are:

- HAWT (Horizontal Axis Wind Turbine)
- VAWT (Vertical Axis Wind Turbine)

2.2.1 Horizontal Axis Wind Turbine

Horizontal axis wind turbines utilize wind energy through blades directed on a horizontal axis parallel to the ground. HAWT faces wind perpendicularly so that wind turbine blades turn following an aerodynamic lift. Horizontal axis WTs prevail in the wind energy market as their construction design allows to obtain more energy through full rotation of

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blades in terms of consistent wind flow. What is more, horizontal axis wind turbines are resistant to backtracking which is also beneficial in this type of power generation [6]. To reach the utmost efficiency, horizontal axis wind turbines must be placed in the wind direction. If the wind direction is versatile, energy generation efficiency may drop down significantly at times. However, this drawback is eliminated when a horizontal axis wind turbine farm is located in a properly selected area with the consistent, same-directional wind flow. A small wind turbine often has a wind vane to align with the wind direction while large wind turbines include a yaw meter to correct the wind turbine position to keep aligned with the wind stream. Consistent, stable wind flow is important to have when an operator is looking for a cost-effective solution [6][7].

2.2.2 Vertical Axis Wind Turbine (VAWT)

Vertical Axis Wind Turbines are designed to be economical and practical, as well as quiet and efficient. They are great for use in residential areas whereas the HAWT is best for use at a business location. There are two different styles of vertical wind turbines out there. One is the Savonius rotor, and the second is the Darrieus model. The first model looks like a 55-gallon drum that is been cut in half with the halves placed onto a rotating shaft. The second model is smaller and looks much like an egg beater. A wind turbine secures air into a hub, which them turns into a generator. The air that passes through the blades of the wind turbine is spun into the generator through rotational momentum[8][9]. The VAWT, as the turbines are oftener shortened, feature the following qualities:

- Two to three blades with a vertically operating main rotor shaft – the more blades that you have on the unit, the more wind energy it will receive and the more efficiency it will offer
- Used less frequently than a horizontal wind turbine

The position of the blades is different in the VAWT. On this model, the base of the tower holds the generator, and the blades then wrap themselves around the shaft. People use the VAWT because they can be placed closer to the ground, which makes them acceptable and effective for use at a residential location.

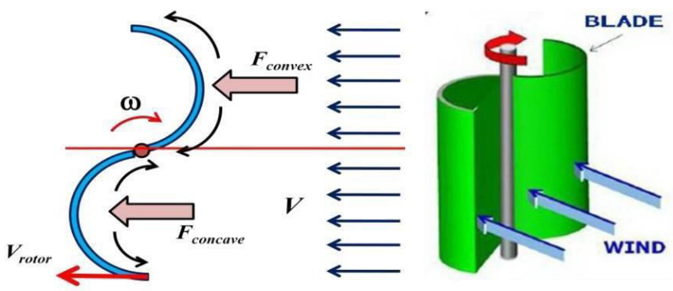
- With the vertical axis wind turbine, the rotor shaft is arranged in a vertical pattern
- The VAWT are easier and more affordable to maintain than horizontal units

a) Darrieus Wind Turbine

Darrieus Wind Turbine is commonly known as an Eggbeater turbine. It was invented by Georges Darrieus in 1931. A Darrieus is a high speed, low torque machine suitable for generating alternating current (AC) electricity. Darrieus generally require manual push therefore some external power source to start turning as the starting torque is very low. Darrieus has two vertically oriented blades revolving around a vertical shaft.

b) Savonius Turbine

Savonius is a type of VAWT, which uses a rotor that was introduced by Finnish engineer S. J. Savonius in 1922. Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices. In its simplest form it is essentially two cups or half drums fixed to a central shaft in opposing directions. Each cup or drum catches the wind and so turns the shaft, bringing the opposing cup or drum into a flow of the wind. This cup or drum then repeats the process, so causing the shaft to rotate further and completing a full rotation. This process continues all the time the wind blows and the turning of the shaft is used to drive a pump or a small generator.



$$P = 1627\times12\times\rho\times v3\times A$$
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Where
ρ is the density of air,
A is effective area of disk,
v is wind velocity, and
P is power.

2.3 Related Works

DESIGN AND IMPLEMENTATION OF VEHICLE MOUNTED WIND TURBINE
Md Rabiul Awal1, Muzammil Jusoh1
2018

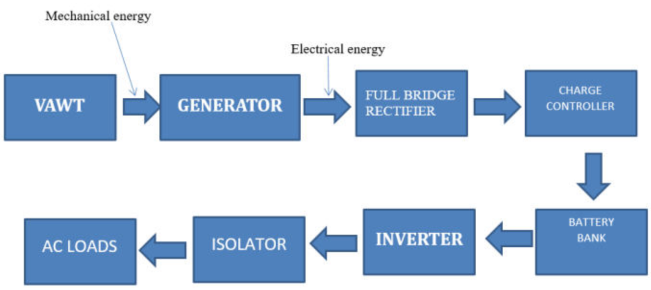
Vehicle Mounted Wind Turbine (VMWT) is a mounted horizontal axis wind turbine system for vehicles. This paper presented design and implementation of VMWT to generate electricity from vehicle. VMWT has several smart features including high rpm turbine, convenient weight, practical shape and portability. In addition, this paper evaluates the VMWT performance in terms of power generation. It is shown that, with proper designing, VMWT can generate approximately 200 W of power at vehicle speed of 80 km/hr. A number of design considerations have taken into account for designing VMWT to ensure its proper functionality in practical environment.

GENERATION OF ELECTRICAL POWER BY A WIND TURBINE FOR CHARGING MOVING ELECTRIC CARS
Stephen Kwasi Adzimah
2019

This research targeted the design of a wind turbine that will be mounted on the electric car to generate electrical power to charge the car batteries when in motion. The turbine is positioned on the roof of the car near the wind screen, where the velocity of air flowing around the car is highest due to its aerodynamic nature. A portable horizontal axis diffuser augmented wind turbine is adopted for the design since that is able to produce a higher power output as compared to the conventional bare type wind turbine. The air current is generated by the car when it begins to move. A frame is provided on the roof of the car to serve as a support for the turbine. Through the theoretical calculation on the power generated from the wind, a significant amount of electrical power (about 3.26 kW) is restored to the batteries when the car is moving at a speed of 120 km/h.

III. METHODOLOGY

The design and simulation were done using done using sketch up software and proteus version 8.0 professional. Proteus is a systems modeling and tool used for circuit simulation



1. Wind Turbine Generator Block
One of limiting factors in wind turbines lies in their generator technology. Traditionally, there are three main types of wind turbine generators (WTGs) which can be considered for the various winds turbine systems, these being

- Direct current (DC).
- Alternating current (AC) synchronous and
- AC asynchronous generators.

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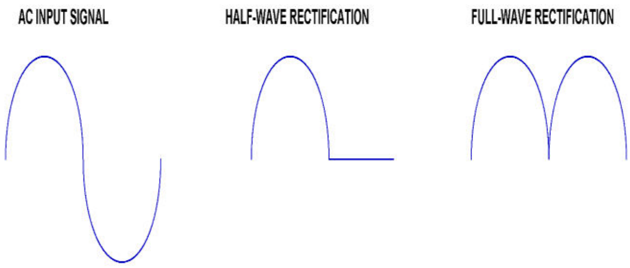
In principle, each can be run at fixed or variable speed due to the fluctuating nature of wind power.

2. Rectifier Block

In the electronics industry, one of the most popular applications of semiconductor diodes is to convert alternating current (AC) signal of any frequency, which is typically 60 or 50 Hz, to a direct current (DC) signal. This DC signal can be used for powering electronic devices, rather than batteries. The circuit which converts the AC into DC signal commonly consists of a particular arrangement of interlocked diodes and is known as a rectifier. In power supply circuits, two types of rectifier circuits are commonly used — half-wave and full-wave. Half-wave rectifiers only permit one-half of the cycle through, whereas full-wave rectifiers permit both the top half and bottom half of the cycle through, while converting the bottom half to the same polarity as the top. This difference between them is shown in figure below.



Difference between outputs of half- and full- wave rectifiers

Between the two types, the full-wave rectifier is more efficient as it uses the full cycle of the incoming waveform. There are two types of full-wave rectifiers

- The center-tapped full-wave rectifier, which requires a centre-tapped transformer, and
- The bridge rectifier, which does not need a center-tapped transformer.

The bridge rectifier was considered for this project as it suits the requirements and is the most popular and usually comes in preassembled modules, making them easier to use.

3. Charge Controller Block

According to Daniel. M. Schwartz(2020) defines a wind charge controller as an electronic device that both ensures that your turbines don't over charge your batteries as well as limit how fast speed the wind turbine blades are able to spin when the batteries are full or in high wind situations. Having a purpose designed charge controller is essential to safely running a wind turbine unless the wind turbine has a built in safety system. Choosing the right charge controller for your system is absolutely essential for safe and efficient functioning of your off grid energy system. When choosing a wind power charge controller, is absolutely essential that you choose a controller that is matched to your system in terms of maximum size and capability. Here is a short list of exactly what you need to compare,

- Input power type (three phase AC vs two phase AC vs DC)
- Maximum power capability in watts (must meet or exceed your wind turbine's capability)
- Supports your battery bank type (sealed, flooded, lithium)
- Supports your battery bank voltage (12V, 24V,48)

4. Isolator block

The isolator part of this circuit is the component that protects the circuit in case of short circuits from the load. The isolator in this case may be a fuse or miniature circuit breaker. Fuse is the simplest current interrupting device for protection against excessive currents.

Wind mills convert Kinetic Energy (KE) of the wind into Mechanical Energy. The total power of the wind stream is equal to the time rate of kinetic energy. The wind mill with large swept area produces more power. Wind velocities below 5 m/s and above 25 m/s are not suitable for wind turbines.

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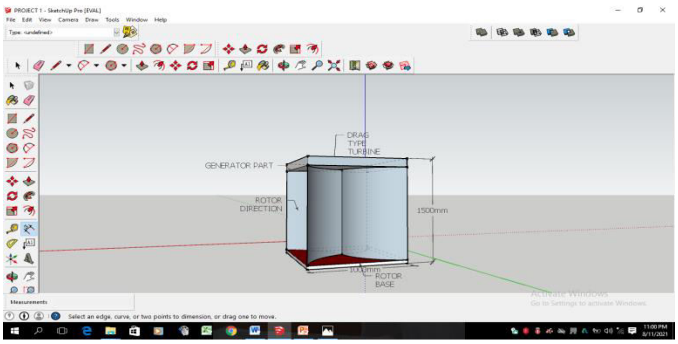
$$K.E = \frac{1}{2} MV^2$$

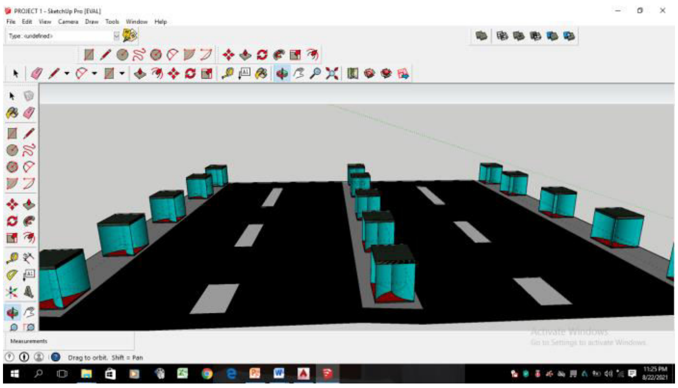
Mass flow rate = ρ × A × Velocity

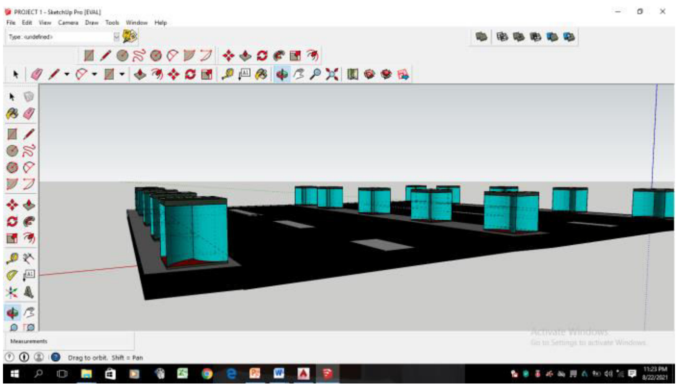
$$\text{K.E per Unit Volume} = \frac{1}{2}\,\rho A \times V^2$$

The Total Power (Pt) in the wind is:
Kinetic energy multiplied by Velocity, that is

$$Pt = \frac{1}{2}\,\rho \times \frac{\pi D^2}{2} \times V^3 = \frac{1}{8}\,\rho \times \pi D^2 \times V^3$$







The vast majority of vehicles on Makeni Mall Bridge are the lightweight vehicles including cars and trucks move at speed of (60-80 km/h). What actually stands out is the significant dissipation in the magnitude and fluctuations of localized wind which increases from the passing trucks than small cars. Therefore, the ideal position of a harvesting energy device should be as close as possible to the moving vehicle positioning on the median and sides of the

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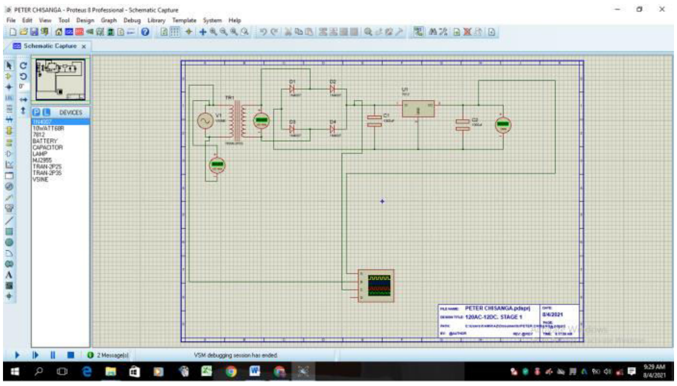
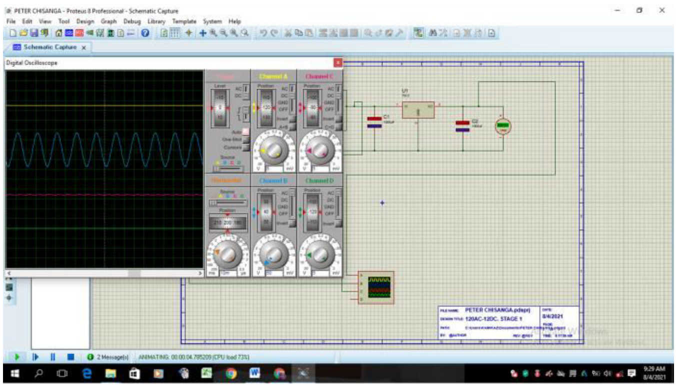
motorway will ensure a safe and constant distant regardless of vehicle type. Since there is no experimental data in regard to the performance of Savonius vertical axis wind turbine (VAWT) on highways and there are tons of vehicles passing through highways and motorways with appreciable speeds. Each of these moving vehicles is a kinetic energy source. Theoretically, a portion of this energy can be harvested by laying a drag based vertical axis wind turbine (VAWT) in the vicinity of passing vehicles. Some studies show that in addition to the kinetic component of this wind, the vortices shed by each moving vehicle can induce the flow field as the figure below. These swirling flow structures can assist the rotor for more torque generation if its blades benefit from an appropriate design. The generated electricity can be utilized in many worthwhile applications.

IV. RESULTS





STAGE 1. CONVERSION FROM 120AC-12DC FOR BATTERY CHARGING.

Stage 1. Conversion from 120v ac – 12v dc for the charge controller for battery charging

When the simulation is run in proteus it revealed that the source is 120v which is what will be given output from the individual Savonius vertical axis wind turbine on the bridge. The transformer in the circuit is to step down the voltage to something low enough for the bridge rectifier circuit to handle without damaging the diodes of the rectifier circuit. After the rectifier circuit the voltage produced, is a 12V pulsating direct current (DC) which is evident in the digital oscilloscope, the red line shows the pulsating DC current from the bridge rectifier. The yellow line is the one signifying the voltage after the stabilizer has been introduced in the circuit and the blue line in the digital oscilloscope is shows the signal alternating current that will be given from the vertical axis wind turbine. The multimeters in the circuit show the voltage level in the circuit which is then given to the charge controller for charging the battery bank in the circuit. The charge controller in the circuit there so as to charge the battery bank and also isolate the bank whilst the bank is fully charged. After the battery bank is charged the circuit is such a way that the inverter is connected to the robotic and the street lights circuit via an automatic change over switch which detects the utility supply such that if there is an interruption from the main utility line the robotic circuits will continue operating efficiently without any disturbances meaning there will be good floor of traffic at all times and the small buildings close to the production site can also be

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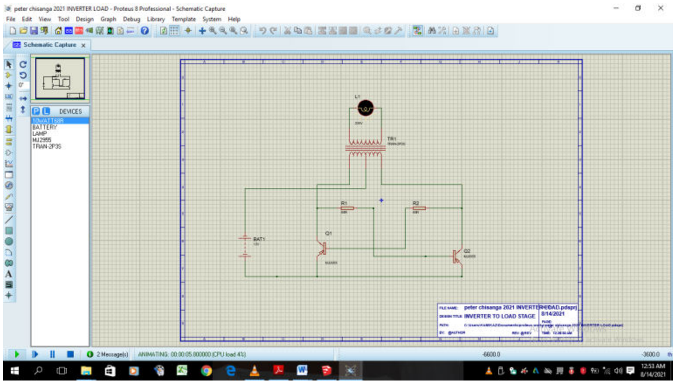
powered by this system. In an event of a short circuit the isolator will protect the rest of the circuit from the high current discharge from the load or vice versa.
The circuit was done in stages and the results were as follows;
Stage 1 which consists of V1= voltage source of 120V, D1-D4=1n4007, U1 7812= 12V voltage stabilizer, C1 and C2= 1000uf capacitors and TR1= 120V- 14V step down transformer in the circuit and steps down the voltage from 120V to 14V AC low enough for the bridge rectifier circuit to handle without damaging the diodes(D1-D4) of the rectifier circuit. After the rectifier circuit the voltage produced is a 12V pulsating direct current (DC) which is evident in the digital oscilloscope, the red line shows the pulsating DC current from the bridge rectifier. The yellow line is the one signifying the voltage after the stabilizer (U1 7812) has been introduced in the circuit and the blue line in the digital oscilloscope is shows the signal alternating current that will be given from the vertical axis wind turbine. The multimeters in the circuit show the voltage level in the circuit which is Then given to the charge controller for charging the battery bank in the circuit. The capacitors (C1 and C2) in this circuit are for (smoothing capacitors). This 12V is fed to the charge controller to charge the battery bank and isolate the bank whilst the bank is fully charged.



This a stage from inverter to load stage

Stage 2, shows the inverter section of the circuit such that if there is an interruption the inverter will start converting the dc 12V DC into 220V AC to power 220V lamp in the circuit. Which consists of the following 12V battery bank, 220V lamp, resistors R1 and R2= 68ohms and transistors Q1 and Q2= MJ2955.

The second part of the circuit is the inverter to load stage after the batteries have been charged via a charge controller it is being used to power alternating current loads through an isolator which is being used to protect the rest of the circuit.

V. CONCLUSION

A sustainable solution is evident that the utilization of wind energy as a permanent resolution to this world energy consideration may well be a property. The resource in its current state of technology is useful enough to be able to support. Wind energy has attracted much attention from research and industrial communities. One growth area is thought to be in the offshore wind turbine market. The on-going effort to develop advanced wind turbine generator technologies has already led to increased production, reliability, maintainability and cost effectiveness. At this stage, the doubly-fed induction generator technology (equipped with fault-ride-through capacity) will continue to be prevalent in medium and large wind turbines while permanent magnet generators may be competitive in small wind turbines. Other types of wind turbine generators have started to penetrate into the wind markets to a differing degree. The analysis suggests a trend moving from fixed-speed, geared and brushed generators towards variable-speed, gearless and brushless generator technologies while still reducing system weight, cost and failure rates.

This project has provided an overview of different wind turbine generators including DC, synchronous and asynchronous wind turbine generators with a comparison of their relative merits and disadvantages. More in-depth analysis should be carried out in the design, control and operation of the wind turbines. Despite continued research and development effort, however, there are still numerous technological, environmental and economic challenges in the wind power systems.

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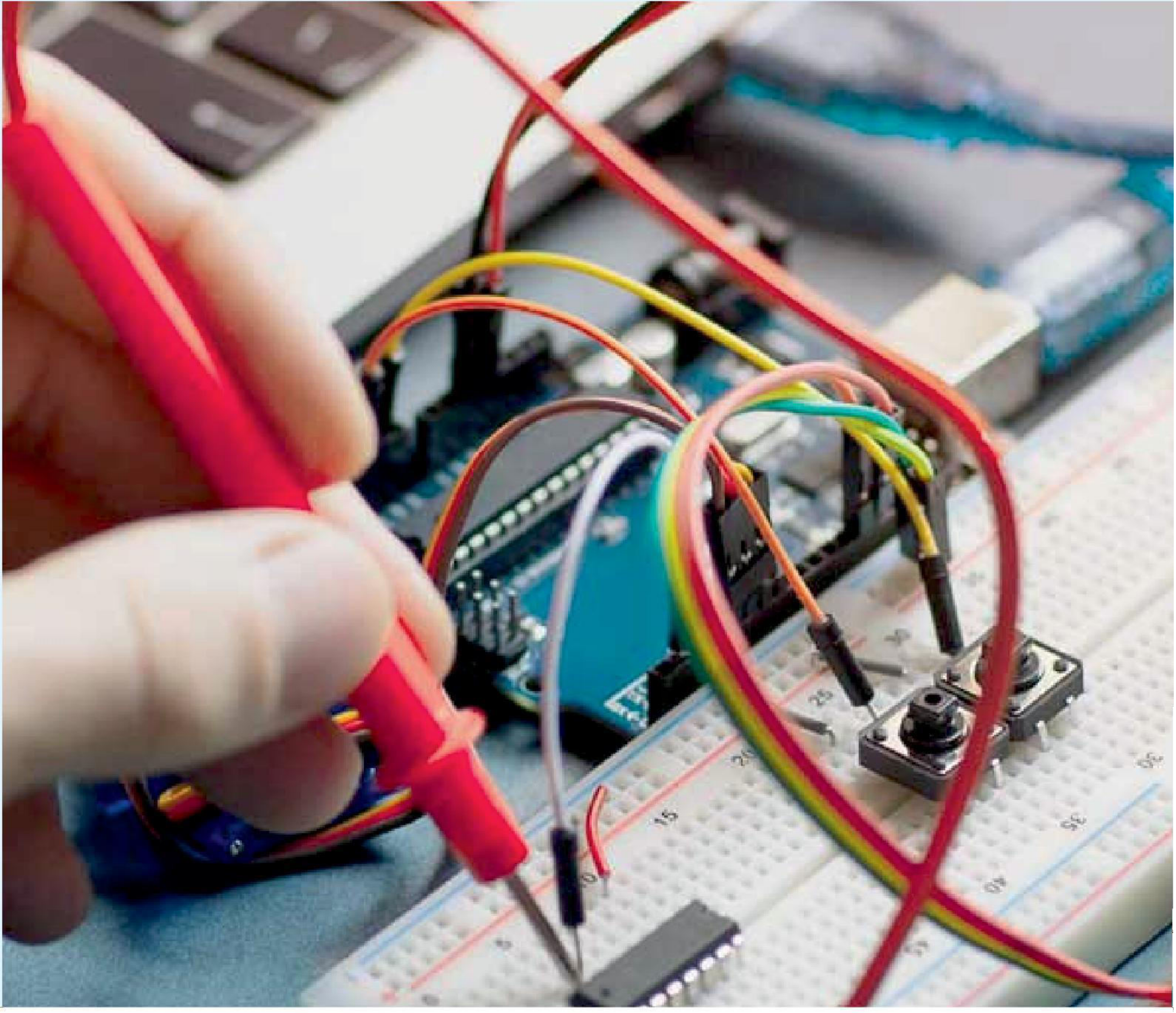

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