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Original Research Article

Development of a Controlled Output Wind Turbine

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Abstract

The wind turbine is a device that is used to harness one of the most abundant renewable energy sources on the planet: wind. It works on the concept of converting wind kinetic energy to electrical energy. Wind turbines are becoming increasingly popular in today's globe since they provide numerous environmental benefits as well as the ability to create enough power for users. A wind turbine's main functioning principle is that it creates electricity when the wind blows. The wind turbine creates more power when the wind velocity is higher. However, regardless of wind speed variations, the goal of this article is to achieve a consistent or controlled output. The goal is to have a controlled output regardless of how quickly the wind blows. This idea is made possible with the help of a converter that is installed within the wind turbine and converts whatever input it receives into a steady, constant, or controlled output. Numerous tests and simulations back up the methods used for this project. The final results that meet the design specifications are compiled and displayed in figures throughout this publication.

Keywords: Wind turbine, rotor, controller, motor, power.

I. INTRODUCTION

A wind turbine is a machine that transforms wind energy's kinetic energy into electrical energy [1]. Small ones are typically used to charge batteries and are mounted on small boats or yachts, while larger ones are used to power local homes or communities as well as the electric grid [2]. These massive wind turbines are typically found along coastlines, where the wind speed is always high [3]. As previously mentioned, these are the fundamental procedures by which wind turbines convert this kinetic energy into electrical power: flowing air pushes on the turbine blades, turning them.

Fig 1: The wind turbine [image retrieved from energy.gov]

Some of the air's kinetic energy is turned into mechanical (rotational) energy of the rotating blades during this operation [4]. The generator, which is also housed inside the gearbox housing, receives mechanical energy from the blades by shafts and gears. Electricity is generated when the generator is turned on.

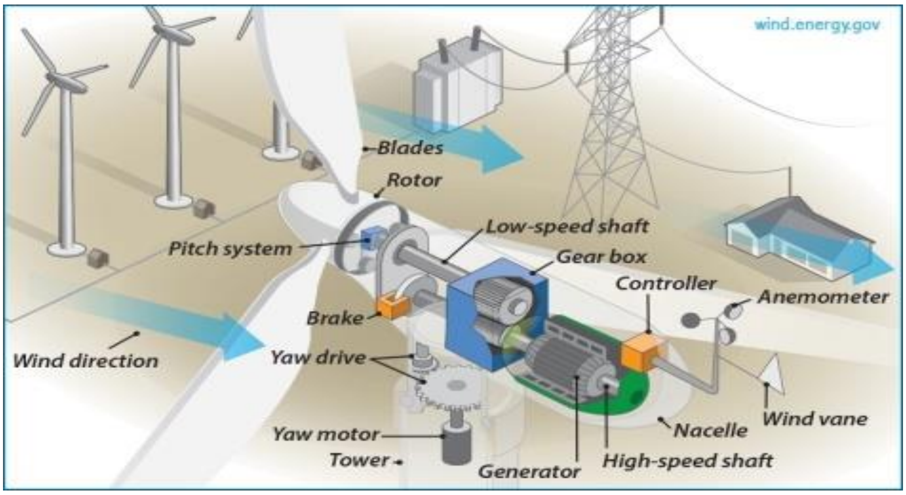

Fig 2: The Wind Turbine block [image retrieved from energy.gov]

The shafts and gears inside the housing of the gearbox transmit the mechanical energy of the blades to the generator that is also inside the housing. When the generator is started, electricity is generated. Wind turbines should be installed in areas with consistent or stable high-velocity winds in order to completely maximize the output. Winds should not, however, blow so hard that they endanger the turbines since smooth (laminar) flow is preferable to turbulent flow for maximum efficiency [5].

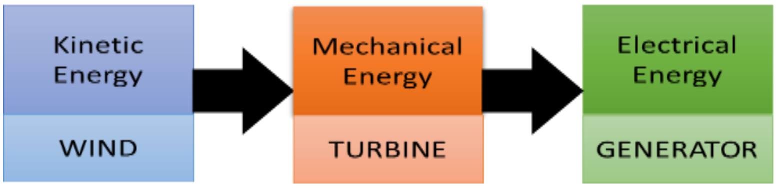

Fig 3: The energy conversion of a typical wind turbine

Therefore, the top of a flat hill or along the shoreline are typically the greatest places to site these turbines. Many other elements, other just wind speed, have an impact on the production of a wind turbine. The number of blades, length of the blades, form of the blades, mass of the blades, pitch angle of the blades (with respect to wind direction), height of the tower, kind of gears used, kind of generator utilized, and micro controller system used to manage the turbine operation are a few of them (if any). Wind turbines have the following benefits: they are a renewable energy source, they don't emit harmful gaseous or other types of pollution, they use less energy than fossil fuel-powered power plants, they cost less than other renewable energy sources (solar, tidal), and they can be installed almost anywhere, including in remote areas.

Fig 4: The blade configuration

Researchers are currently working at how to best harness energy from renewable sources like wind, solar, and tidal because of the destructive effects and quick depletion of conventional fossil fuels. Due to its cheaper setup costs compared to the other possibilities, wind power is the energy source that is expanding the fastest and is predicted to overtake the others in the near future. It has been discovered that wind energy is a very dependable source of power, and its capacity appears to be growing globally each year. As of 2014, a total of roughly 296225 MW of power was produced globally using wind energy conversion systems. China, the United States, Germany, Spain, and India are currently the top 5 countries driving the global wind energy market. A wind turbine uses the wind's kinetic energy to turn a generator, which generates electricity at the output side. As briefly mentioned in Chapter 1 of this paper, the aerodynamics of the device itself is clearly intimately tied to a number of concerns and challenges for the wind energy conversion system. However, in this specific case, the fundamental difficulty in dealing with the wind turbine is that it constantly relies exclusively on the wind's speed for power. When the wind speed is low, the output might not be able to meet the consumer's or the power grids required power needs. As a result, the concept of a wind turbine with a steady or controlled output appears. This idea would enable the turbine to generate power regardless of changes in wind speed, eliminating the requirement for a significant reliance on the wind to create a good amount of power. A turbine and generator are assembled in Figure 4.

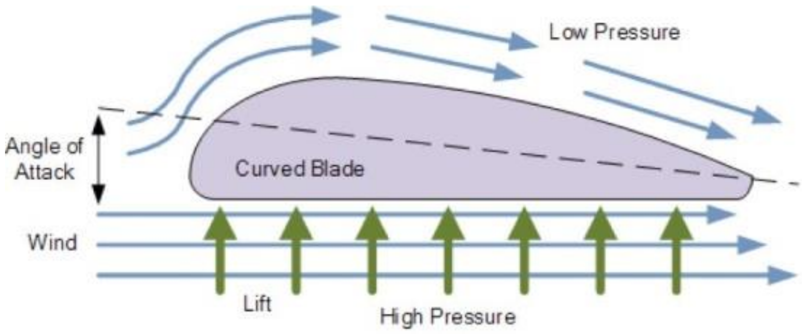

Fig 5: The blade design [image retrieved from valuewalk.com]

Applying a rotor speed control in any strategy to control the performance of wind turbines when exposed to wind changes is one way to realize this concept. Numerous investigations and studies have been conducted to compare the mechanical, electrical, and financial elements of various wind energy system configurations. However, studies have shown that variable speed wind turbine systems typically produce more energy than ones with constant speed. This is a downside of the concept. The wind turbine model is created using the following equations:

$$D = 1 - \frac{Vi \times \eta}{Vo} \quad \ldots\ldots (1)$$

$$\Delta I\iota = 1 - \frac{V i \times D}{fs \times L} \quad \ldots\ldots (2)$$

$$L = 1 - \frac{Vi \times (Vo - Vi)}{\Delta I\iota \times fs \times Vo} \quad \ldots\ldots (3)$$

Where- D= Duty cycle, Vi= Input voltage (min), Vo= Desired output voltage, η = efficiency (estimated to be about 70-80 percentage), fs= switching frequency of the converter, L= Inductor value and I= Inductor ripple current.

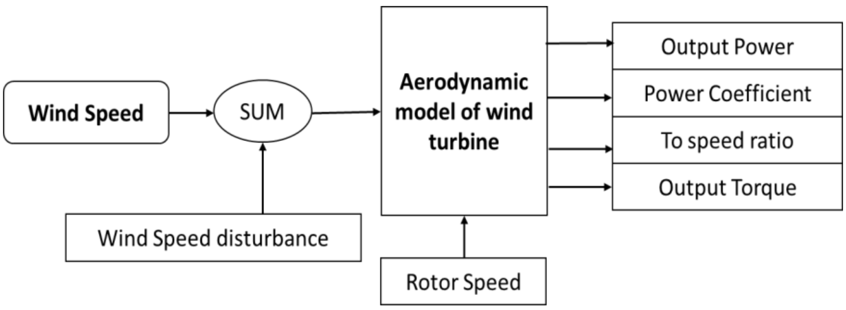

Fig 6: Block diagram of the wind turbine model

Many thousands of power turbines are currently situated offshore, particularly close to the European coasts. It is necessary to create fresh concepts and ideas that satisfy the needs of such offshore power grids due to the maritime environment. A dependable, low maintenance system is one of the most important requirements, which drives the goal of minimizing the amount of components on the wind turbine itself.

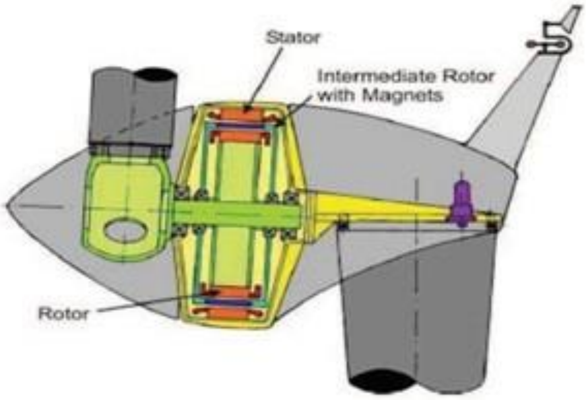

Fig 7: The blade design [image retrieved from valuewalk.com]

The idea in this study uses a permanent magnet induction generator instead of a gearbox or frequency converter, which unintentionally reduces the overall number of parts and eliminates the requirement for maintenance oil, making the system lubricant free. The direct drive permanent induction generator is depicted in figure 7 in the section after this one. When connected directly to the grid, this type of turbine operates at a constant speed because it currently lacks a gearbox or converter. The disadvantage of this design is that the pitch control is not usable, and a lower output power is anticipated because the rotation speed control cannot be adjusted to the wind velocity, resulting in a lower power coefficient. The novel control idea uses just one central converter to manage the frequency and indirectly the turbine's rotational speed in order to increase power yield and enhance power coefficient. A system with variable frequency is produced based on this specific arrangement. In order to properly optimize or maximize the energy yield, the system's frequency is adjusted. When using an HDVC link, the converter may either be installed onshore or on a platform. The concept is shown in the following figure:

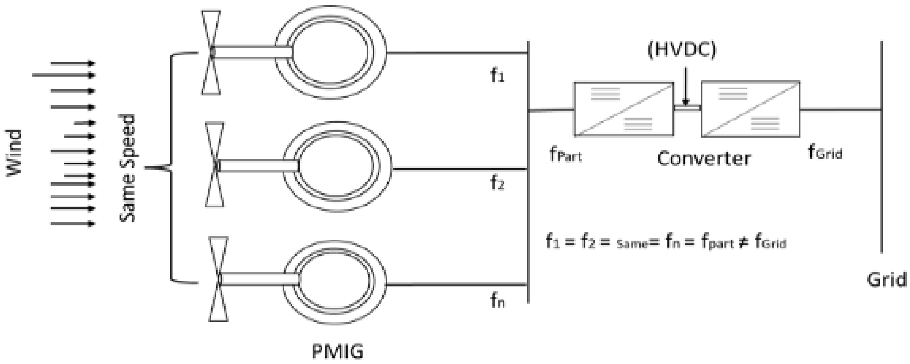

Fig 8: The blade design [image retrieved from valuewalk.com]

In the event of a conversion issue, both of the previously mentioned places are conveniently accessible. Furthermore, a high compliance with the criteria for grid connection can be attained. Investigated at rated load are the active stall and pitch controls. For constant speed turbines, active stall is typical. Using a unique frequency control, pitch control is made possible. However, this control has its own disadvantages, one of which is the need to reduce mechanical power in order to prevent frequency power dips. Lowered mechanical power will result in a decreased yield of output power. The model that is being provided is based on Hoffman's research and examinations. By using a scale that is predetermined and slightly altered to reflect the actual performance of the power plant, Hoffman's model is able to produce this conclusion. The model has been developed to a full wind park model, which has a total of ten separate wind turbines and is managed by a single central frequency converter. Although the mean wind speed and turbulence are the same for all turbines, each one is evaluated with a distinct wind contact period. Deviations in the results can be significantly influenced by a change in wind flow. In general, large changes in the data are caused by strong turbulence, but minor changes are only caused by low turbulence. The best frequency (which results in the best power output) must be identified in order to adjust the speed of the turbines in accordance with the available wind speed. Maximum Power Point (MPP) Tracking is used to make this achievable. Currently, two methods have been developed for MPP tracking. The first method is based on relative comparison. To boost the power, the frequency is altered in one direction. The ensuing frequency change may persist if the power is sufficiently increased. The frequency must be altered in the opposite way in the event of a power reduction, though. Working with absolute values is the second technique. To find the point of highest power, the entire frequency spectrum is sensed. The frequency is then altered to reflect this value. Both of the aforementioned methods have advantages and disadvantages. Although the relative comparison technique is fairly simple to use, it only finds local maximum values. The other method cannot be used directly since it is impossible to periodically pass through all frequencies in each turbine in order to achieve a maximum power output. However, a wind turbine model can be used to implement this strategy. The frequency can then be varied across a wide range to determine the maximum power output only then. The simulation's output can be used as a standard input for applications in real life. These tools are not flawless, though. They also have some drawbacks, such as the fact that the amount of electrical power delivered is dependent on wind speed, that extremely strong winds could destroy them, that some towers are erected very high, and that they might be quite expensive if connected to a major electricity grid. A controlled or constant output wind turbine must be properly built and developed in order to minimize the issue of electrical power delivery variations, which is listed as one of the drawbacks of wind turbines [6].

This merely implies that the power produced by the turbine should not be impacted by fluctuations in the wind. Utilizing a controller to maintain the output given any input is one technique to realize this concept and achieve this goal. Two categories will be used to discuss the project's components [7, 8]. The following conclusions can be drawn for Example as increased dependability and decreased cost based on this study [9, 10]. The experiment was successfully carried out under ideal circumstances [11, 12]. The invention has been discussed with reference to what is currently regarded as the most useful and preferable embodiment [13, 14]. Here is the proposed system's block diagram [15, 16]. The conclusion and advice are offered along with hardware materials for future work [17–19]. An innovative technique for managing the energy system has been established in this study [20, 21]. The report's findings are listed [22–24]. The information was evaluated and categorized in MATLAB [25, 26]. The goal of this project is to develop the invention, as stated in this paper [27, 28]. Instead of concentrating on the mechanical construction or aspect, the major goal of this project is to create a wind turbine with a regulated output utilizing a converter or controller [29, 30]. The project should result in a wind turbine with a controlled output that is not overly impacted by wind changes. Mechanical and electrical parts make up the two categories into which components are classified.

II. MECHANICAL COMPONENTS

Input, process, and output are the three primary divisions of the controlled output wind turbine construction. The turbine blades' capture of wind kinetic energy serves as the system's input. In a traditional or usual wind turbine, the output is directly and inversely correlated to the wind speed; however, in this situation, because the controlled output of the wind turbine was generated through the use of a converter, the wind speed has very little bearing on the output. The main actions that occur in the element "process" are the activation of the generator by the turbine blades, which converts the kinetic energy of the wind to electrical energy, followed by signal rectification and boosting to obtain a controlled or constant output, which is none other than the electrical power produced in accordance with the desired settings.

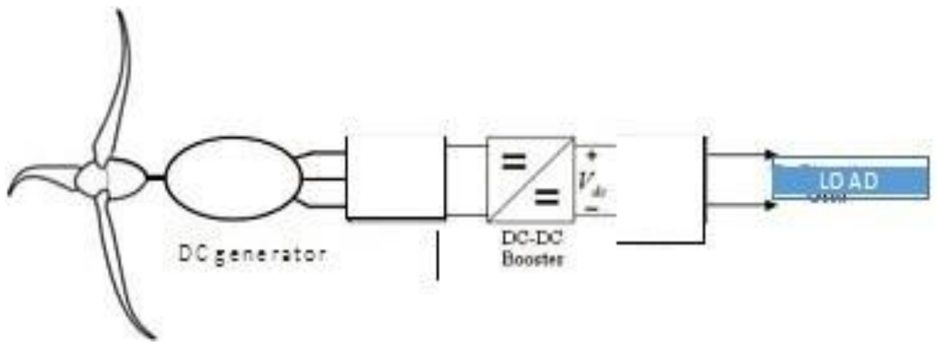

Fig 9: Basic diagram of a wind turbine

A. Motor/Generator and Blade

Kinetic energy is transformed into electrical power using a generator [7]. The wind itself serves as the project's primary source of kinetic energy. There are many other types of generators available on the market that can be utilized for this project, but in order to keep costs low, a DC generator with the simplest design was selected. A DC generator, also known as a DC motor, is preferred because it produces output as direct current (DC), simplifying the system as a bridge inverter is not necessary (that converts AC to DC unlike any other generator). Because the converter selected for this project is a DC-DC (Boost) converter, a DC input is necessary. The figure of a DC generator utilized for this project is provided below. As was previously described in the prior chapter, the blades for any wind turbine play a very important part in determining the power production. To achieve the highest possible power output, the design and materials should be carefully evaluated [8]. Alloys, PVC pipes, and even hard sheets are among the materials used in typical wind turbines (poster boards). The least expensive and easiest to obtain option is picked as mechanical construction is not the project's primary concern. PVC pipe, as depicted in Fig 10, is the material that meets these requirements.

Fig 10: The 12V DC motor and blade made from PVC

B. Mount, Tower and Base

The mount serves the only purpose of supporting the wind turbine blades and ensuring that they face the direction of the wind in order to maximize power output by fully utilizing the dynamics of the blowing wind [9]. The material chooses needs to be sturdy enough to prevent the blades from falling and resilient enough to endure heavy winds. Given that PVC pipes were used as the blades for this project, the mount does not need to be very durable. Consequently, a circular plastic disc (or wheel hub) will do. The system is held upright by the tower, also known as the stand [10]. In order to achieve the best power production, the tower's height is crucial. A medium-sized tower should be sufficient, though, as obtaining the most power production is not the project's primary goal. The material picked out needs to be sturdy enough to support the entire system, which includes the generator, blades, and several other electrical or electronic parts. The chosen base should be substantial enough to support the system's weight. So a sturdy PVC tower with a wooden foundation would be an appropriate material for this use.

Fig 11: The mount, tower and wooden base

III. ELECTRICAL COMPONENTS

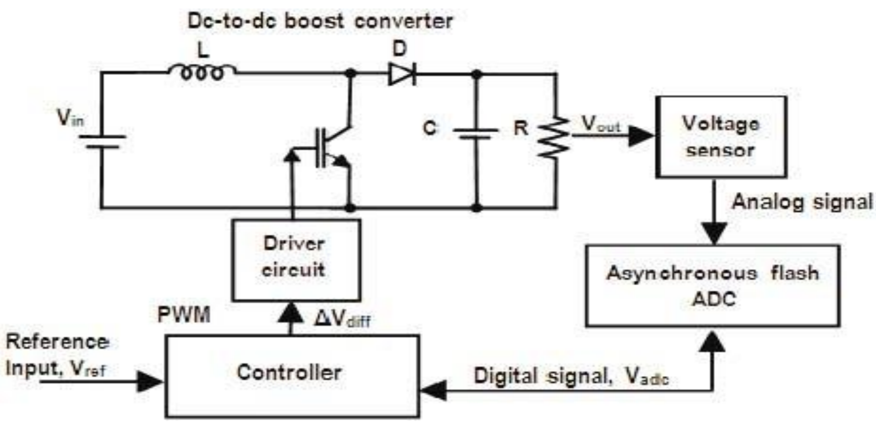

Fig 12: The Converter Circuit and Block diagram

The DC-DC (Boost) converter shown in the diagram below uses the electronics components. The electrical parts needed for this project are readily apparent from the provided diagram. A straightforward boost converter is shown in the above figure. The DC voltage is stepped up using a boost converter, which, as its name suggests, raises the output voltage above the input voltage. Since this converter is directly connected to the wind turbine generator, the wind turbine's output serves as the converter circuit's input. To produce an error feedback amplifier regulator, a suitable integrated circuit switch—the LM555—is chosen and put to the circuit. Due to the 12V DC motor chosen and the electrical component values selected, an output value of roughly 5 times the input voltage is anticipated.

IV. SIMULATION STUDY / EXPERIMENTAL SETUP

LabView from National Instruments is the program used to simulate the controlled output wind turbine for this project. Basically, block diagrams are built in the workspace in accordance with the design specifications, data, and results are obtained depending on the settings and configurations defined in the block diagram. During the course of this research, additional software, such as MATLAB-Simulink, is also employed for the Converter and rotor control simulations. Below is an illustration of the simulation block and result.

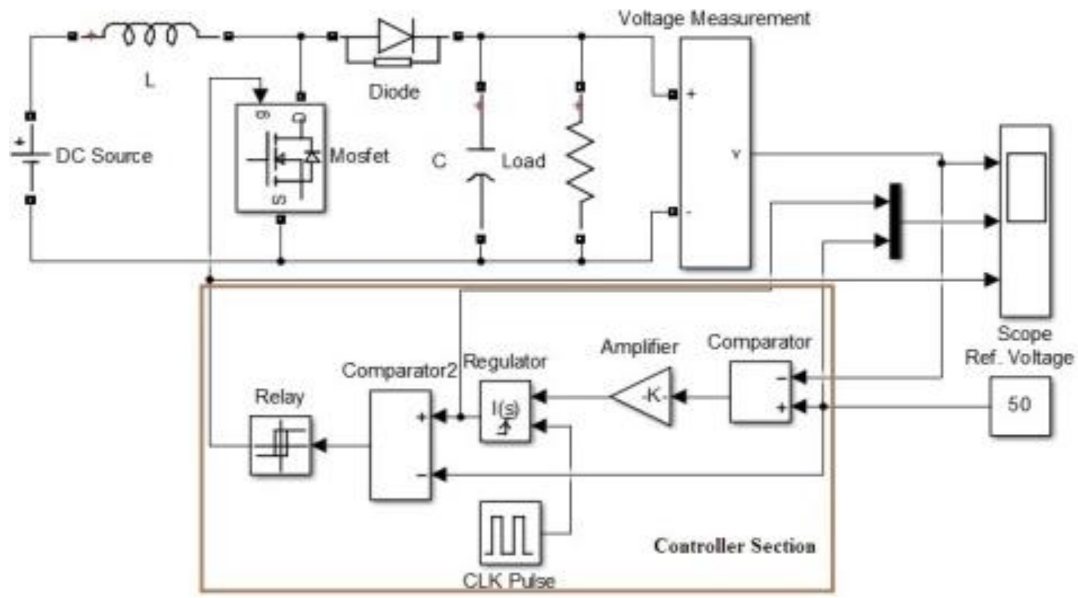

Fig 13: DC-DC Boost Converter Simulation block diagram

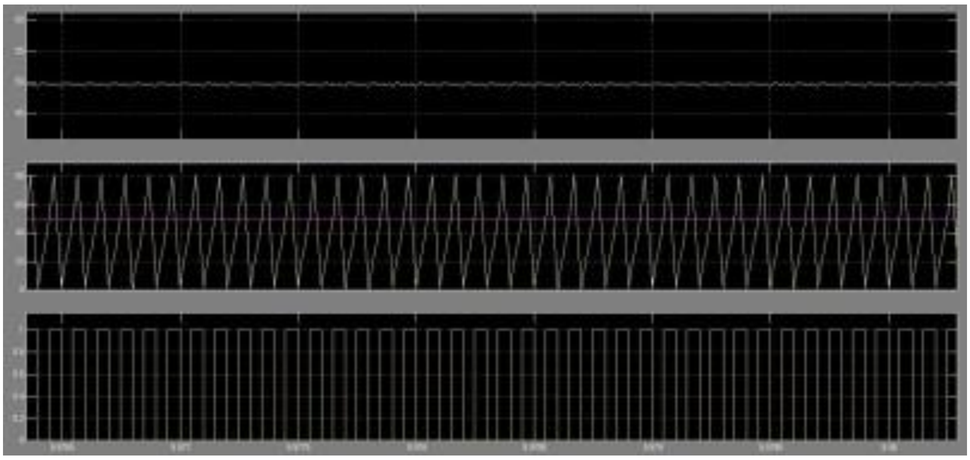

Fig 14: Simulation for 12V DC Input and 50V Ref. source

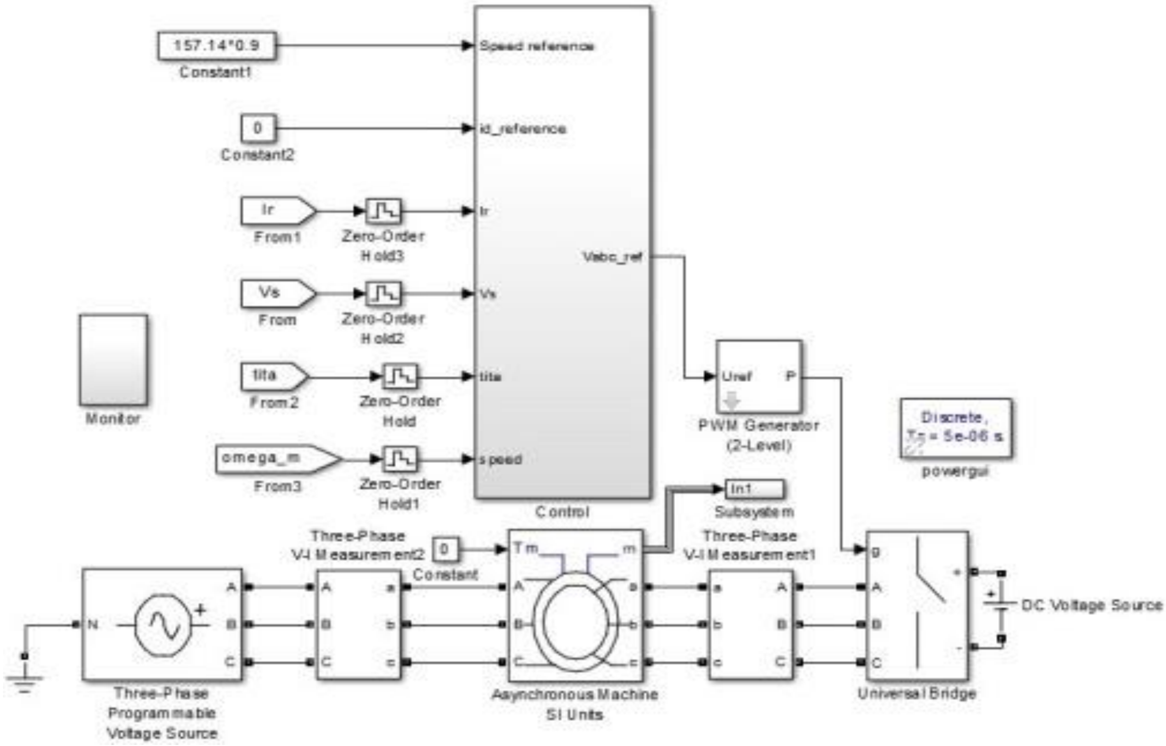

Fig 15: Simulation block of wind rotor control

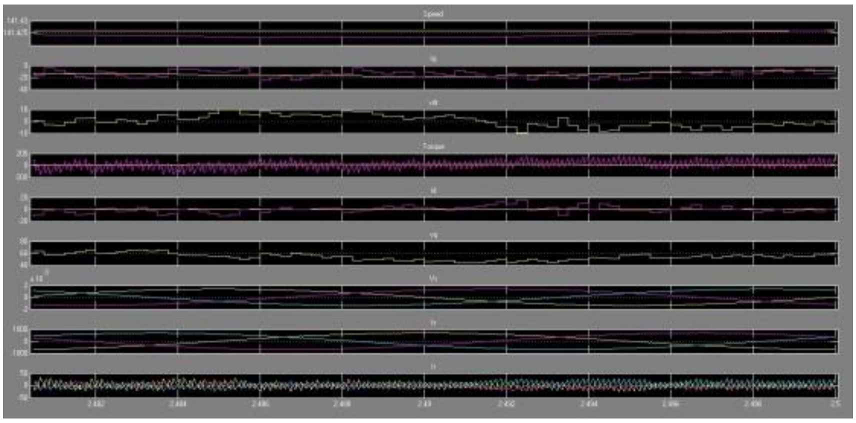

Fig 16: Simulation result

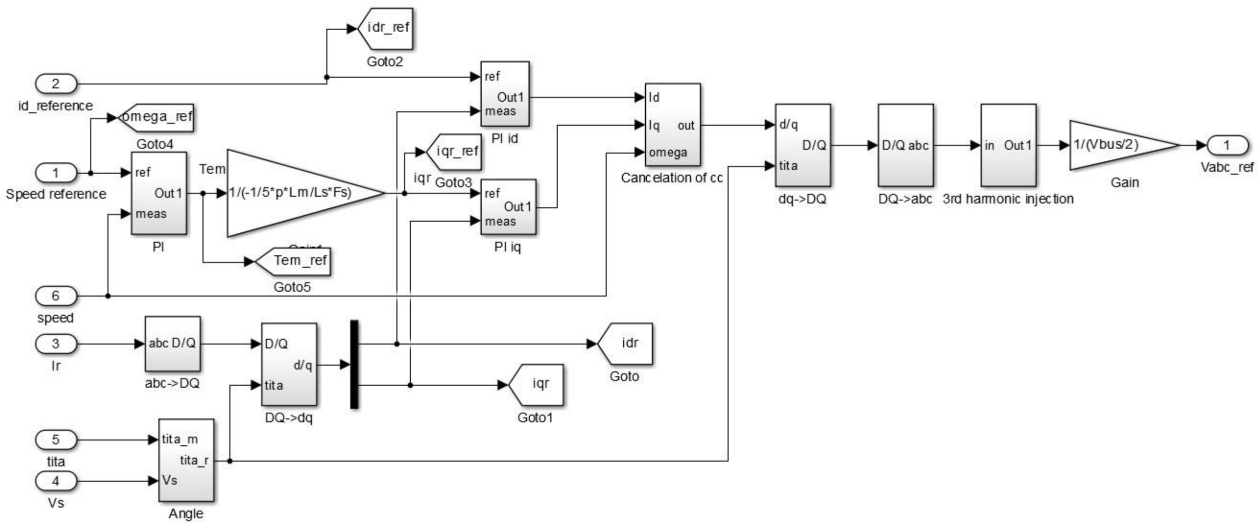

Fig 17: Simulation design of stator controller section

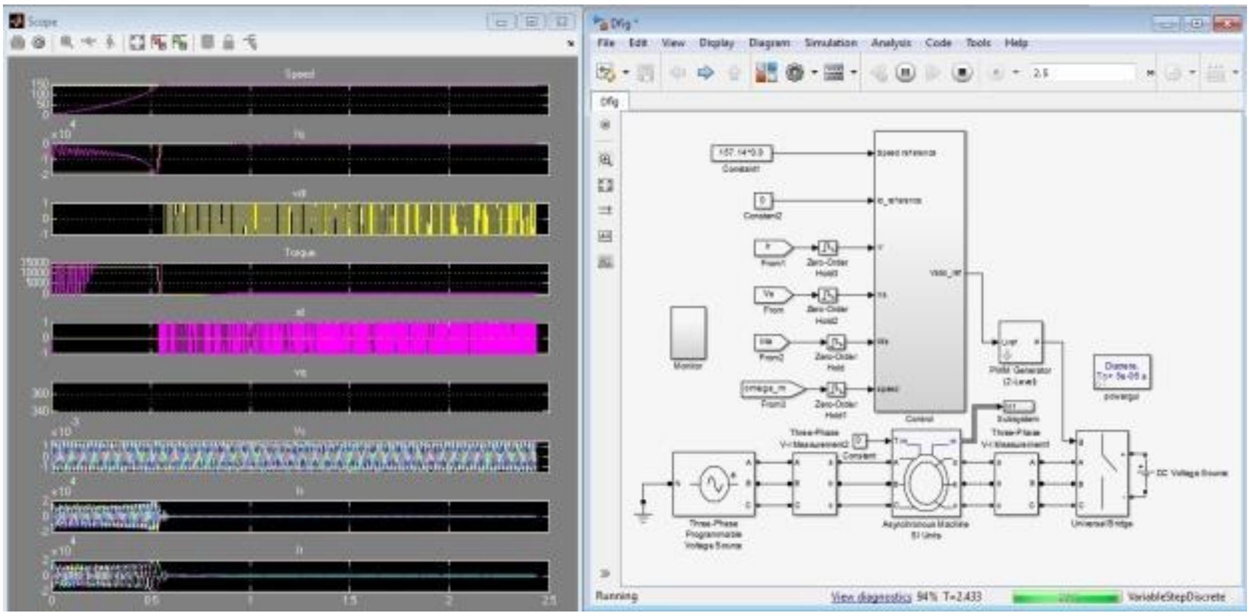

Fig 18: Simulation result running

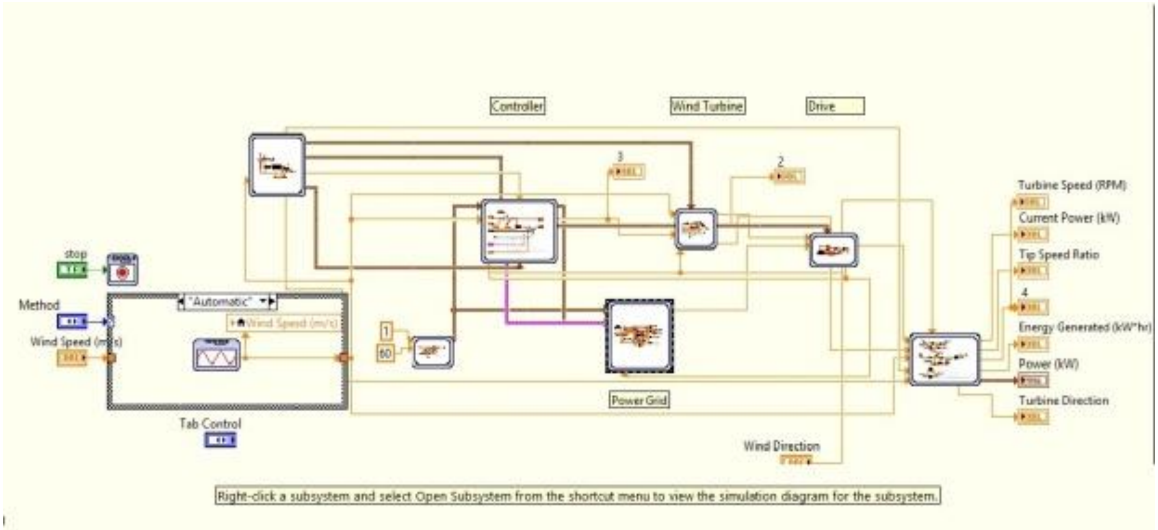

Fig 19: Wind turbine Simulation block diagram

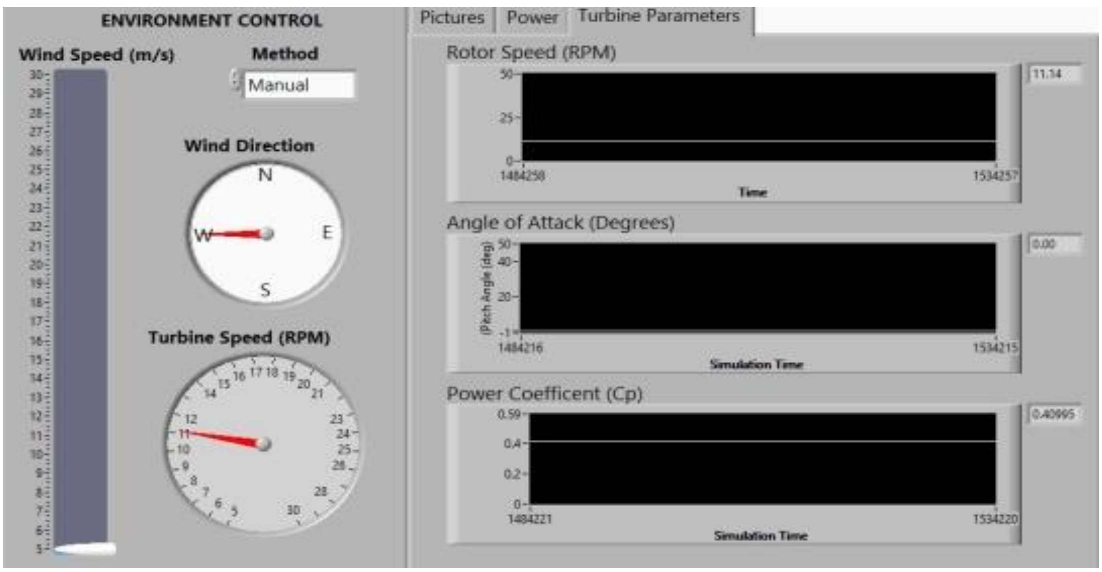

Fig 20: Simulation result of turbine parameters

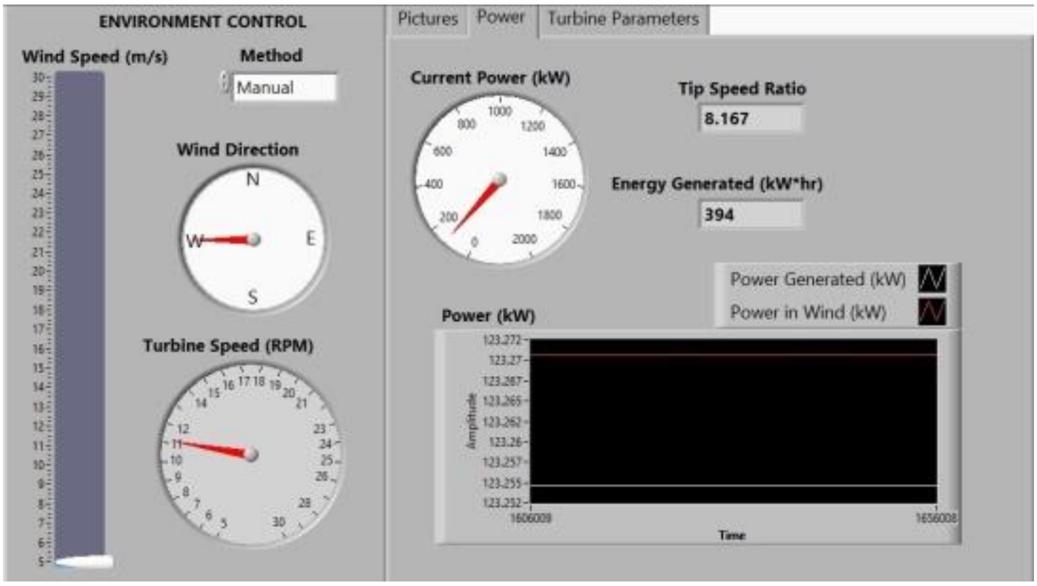

Fig 21: Simulation result of Energy parameters

All of the project's mentioned components have, in the end, been effectively identified. Through the research conducted for this article, the concept and technical requirements for the circuit diagram, which includes various components, have been determined. A simulation in LabView and a rotor controller simulation in MatLab have both been performed in order to actualize the notion of the controlled output wind turbine and make the project's operating principle obvious. As it would simply result in the complete design and development of the electrical components without worrying too much about the mechanical construction, it should be simpler to work on an existing compact wind turbine than to build and develop it from scratch for future work on this same issue. There are a lot of future enhancements that can be made to this project, such adding a solar panel to fully utilize its potential as a green technology or redesigning the blades' aerodynamics for improved wind turbine performance.

CONCLUSIONS

While working on this project, a number of difficulties were faced. Finding a suitable wind turbine design that might serve as the project's foundation was the first difficulty. Without including any additional parts, controllers, or converters, a test and simulation were run to see the actual data of the wind turbine's output. The best way to get a wind turbine with a controlled output is the next problem. According to the research, there are numerous ways to implement this idea, but the most popular one involves employing a converter, rectifier, and booster to produce a constant output without much consideration for the supplied input. Even under turbulent or slow-moving wind conditions, the regulated output wind turbine must be able to maintain a constant power output. The output produced might not be what is expected if the converter or controller design is not correct.

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