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Article

Emulator of Wind Turbine by using DC Motor

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Abstract: The development of wind energy conversion systems requires tools like a emulator for a wind turbine. Meanwhile the speed of wind differs erratically in an actual windmill; it suggested a controlled testing setting that enables the assessment and development of regulator systems for electric generators. In this project, an emulator of wind system is modeled and simulated using MATLAB. One may replicate a wind turbine and estimate the rotor's theoretical rotational velocity by using the DC motor. A regulator is employed to match the features of separately excited DC motor with the typical wind turbine curves. The speed of wind and a certain reference rotor speed established by the wind turbine's rotor characteristics generate mechanical wind power. An independently stimulated direct current motor running with a chopper circuit and a proportional integral controller are used in the design of the wind turbine emulator to adjust the errors. In order To check the system, if the induction generator can deliver the required rated voltage for a certain load, it is then instantly connected to the wind turbine emulator.

Keywords: wind turbine; emulator; DC Motor; wind speed; Proportional Integral Derivative controller

1. Introduction

The globe has begun to use renewable energy sources more often during the past twenty years. Renewable energy is clean and environmentally friendly compared to non-renewable fossil fuels, making it a major contributor and encouraging wind-based research [1-3]. It produces no greenhouse gas emissions, making it a green energy source. Since wind is widely available, it is sustainable. As a result, it is trustworthy and can be relied upon. For the research on maximum power point tracking algorithms [4-6] and evaluating advanced control approaches [7-9], the availability of a controlled experiment platform independent of natural wind resources is of utmost importance.

The change from constant to variable speed operation has been one of the most significant developments in wind generator technology [10-13]. Operating at a variable speed leads to increased energy output while lowering drivetrain torque and power variability. This adjustable speed operation of a system for converting wind energy, produce variable output voltage and frequency depend on the speed of the wind. Since a steady DC voltage or an AC voltage with a constant voltage and frequency is required for practical application. Several power electronics controller algorithms [14-16] have been developed to produce constant DC voltage for electric vehicles [17], micro and nano grid [18,19], battery charging application [20,21] etc.

In the laboratory, experimental research in wind energy conversion technologies cannot be done with actual wind turbine. Therefore, research on the power electronic converters and generators used in WECS may be done in-depth by including a wind turbine (WT) emulator to a test bench inside the laboratory. The emulation should operate the wind turbine generator similarly to a real wind turbine. Wind turbine emulator that replicates the torque generated for a specific speed of wind. The literature has a good overview of the fundamental components for modeling wind turbine behaviour. The output power and torque created by the turbine are represented by the connection between density of air, speed of turbine spinning, swept area, and speed of wind. The development of a WT emulator is based on wind curve characteristics [22]. The procedure of an electric drive straightly linked to the generator slide is the most practical method for simulating the performance of a wind turbine in a workshop. For a virtual wind turbine, the DC motor is typically a superior option because it can be regulated by the motor current, which is inversely proportional to the machine's torque.

Using a DC motor, Ovando, R., et al. (2007) created a wind emulator. In a system for converting wind energy, a DC motor is linked with a doubly fed induction machine that functions as a generator [23]. By using an armature controlled independently excited dc motor that is powered by a thristor chopper drive cascaded by a PI controller with closed loop operation, Mahdy, A. et al. imitated the characteristics of a tiny wind turbine. A compact analogue electronic circuit is created that creates a rotor reference speed while taking into consideration the characteristics of wind turbines at a certain wind speed [24]. The wind emulator was created by Kumsup et al. (2010) and consists of a real-time interface card, an induction motor, and a torque inverter. On a 1 kW independently stimulated dc generator, the test was conducted in a lab setting. Wind speeds may be set manually or automatically, and the emulator's power and torque response was adequate [25].

The primary goal of the study is to use chopper circuits in the Matlab/Simulink application to model the characteristics of a wind turbines with individually stimulated dc motors. The hardware implementation is designed with Arduino uno board.

2. Wind Turbine Model

A wind turbine consists of a tower with two blades, a rotor linked to a nacelle, and one or more electric generators mechanically connected to it. The wind's slower rotating speeds are modified by the mechanical component, the turbine of the electric generator to more rapid rotational speeds. The electric generator's rotating shaft produces power, the response of which is sustained by a number of controls. It consist of two different wind turbine strategy models. Vertical axis wind turbines (VAWT) and Horizontal axis wind turbines (HAWT) are the two classifications of wind turbines based on the axis around which they rotate. In honor of its creator, Darrieus, the VAWT is also known as a Darrieus rotor[6]. HAWT can capture the most wind energy possible given the days' time and weather condition, and its edges may be changed to prevent strong wind storms. There are two operating modes for wind turbines: constant speed and variable speed. A constant speed turbine maintains a constant angular speed independent of changes in wind speed.

This mode has the benefit of doing away with pricey power devices like inverters and converters. However, it has the drawback of limiting rotor speed, which prevents the turbine from operating at maximum efficiency at all wind speeds. Consequently, a turbine with a constant wind speed turbine, which is made to run at a rotor speed proportionate to the breeze, provides lesser power at low wind speeds. Several factors affect a wind turbine's output power or torque aspects such as speed of the turbine, pitch angle and tilting of rotor blade, shape, area and size of turbine and the kind of rotor and wind speed. The output power and numerous other factors are correlated to form the wind-turbine mathematical model. A wind-related mathematical model analyze the performance of the wind turbine requires a modeling. The performance of wind turbines may be controlled by modelling, over its operating zone. A portion or all of these broad goals of wind turbine modelling are attempted in this paper.

The turbine's mechanical output power P is expressed as

$$P = \frac{1}{2}\rho V^3 A\, C_P \tag{1}$$

where: A is the region that the rotor blades sweep$(A = \pi r_t^2)$, ρ is the density of air, V is the wind speed, and CP is the WT power constant $(C_P = C_T\lambda)$. For each kind of turbine, a distinct CP value applies. Turbine manufacturers often provide it as a curve or in a look-up table.

The wind turbine's aerodynamic torque T_t is calculated as

$$T_t = \frac{1}{2\omega_t}\rho V^3 A\, C_P \tag{2}$$

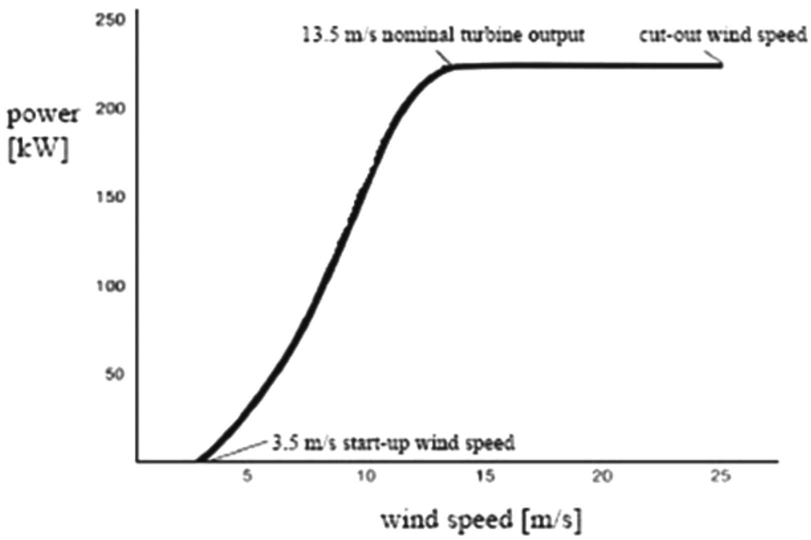

Figure 1. Wind turbine characteristics curve

A wind turbine's power production varies with wind speed, and each one has an own power performance curve, as shown in figure 1. Without taking into account the specific technical specifications of its many components, it is possible to anticipate the energy output of a wind turbine using such a curve. As a result, the power curve of a wind farm is a graph that shows how much electrical power the turbine will produce at various wind speeds. It shows three crucial characterizing velocities: The wind speed at which the turbine begins to produce power is known as the cut-in speed. The wind speed at which a wind turbine generates its maximum power is known as the "rated speed." This is frequently the strongest power, though not always. The wind speed at which a wind turbine switches off to prevent dangerously high loads and generator power.

3. Block diagram for wind turbine emulator

The project aims to replicate a wind turbine component. We'll use a 3.5 m/s input speed as an example. One DC motor may be connected to produce an output of 5N/s. The differential pattern of wind speed must be achieved in both the positive and negative directions. For instance, we can generate 25KW from wind turbines at 7M/s of wind speed. Now, using a current sensor, we'll measure any loads more than 12 KW. We're using the present sensor's additional input as a measurement for that. Now that the potentiometer has been adjusted to 7 MPH, we are providing the same input, verifying the output for the same value, and repeating the process. The input energy is obtained by pulsing this instant value, but we are unable to obtain an accurate value. To do this, we must turn on and off the driving circuit in order to obtain the appropriate PWM. Anemometer, wind sensor, and one Arduino are all being placed.

The block diagrams of the proposed emulator are shown in Figure 2. Analog input from the wind sensor is provided to the Arduino. By turning the driving circuit ON or OFF, the wind speed is regulated and the required output, either positive or negative, is obtained. The speed torque will also fluctuate automatically for 3.5KW output plus or minus. Then, the potentiometer's input and ground pins are adjusted to alter the speed. Input values also vary when machine speed is altered. Speed Torque characteristics will be attained in this way. As a result, the wind blows differently depending on where you are. For this, the switching pattern is altered in accordance with the wind speed.

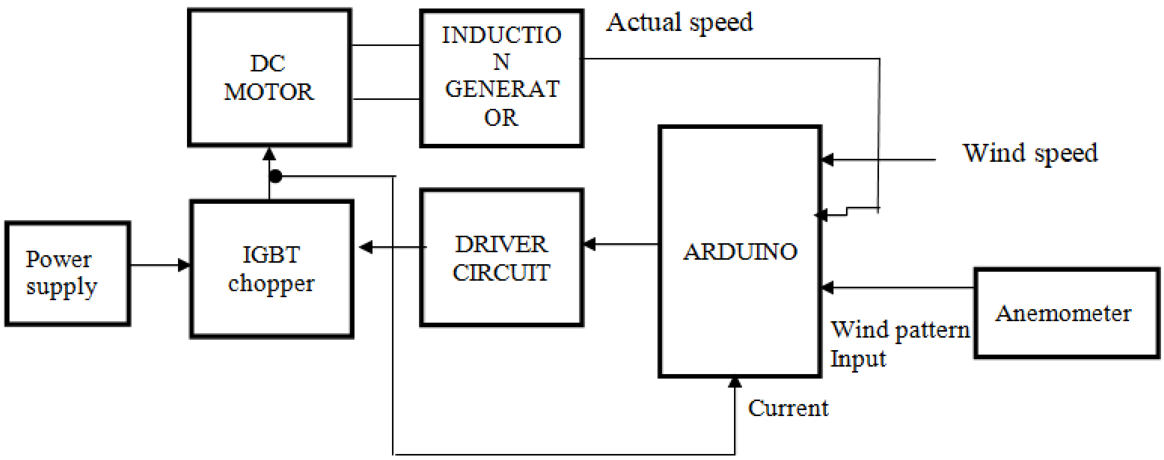

Figure 2. Block diagram for wind turbine emulator

4. Simulation circuits and results

The mathematical model is discussed in the earlier section are used to create a MATLAB/ SIMULINK model of a wind turbine emulator, which is seen in Figure 3. It includes a DC motor, fully controlled converter, PI controller and generator.

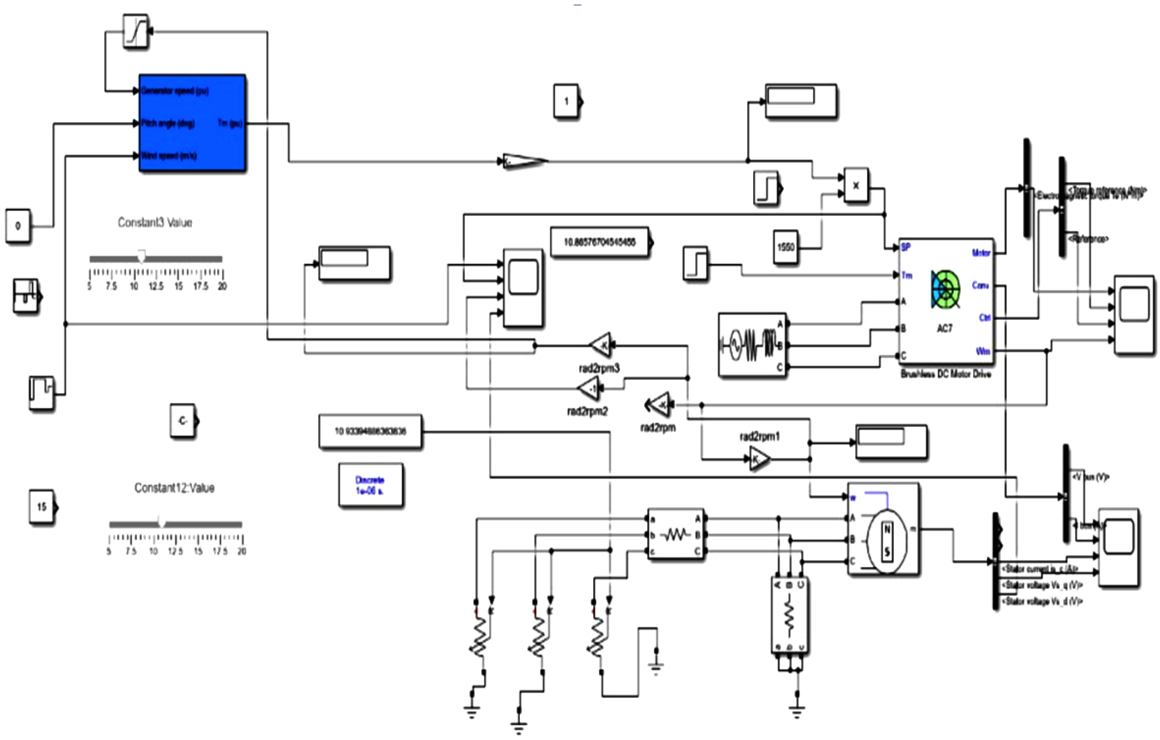

Figure 3. Simulation model of the proposed emulator

The DC motor model's inputs consist of the excitation voltage, practical armature voltage, inertia of motor, and load torque. The outputs are electromagnetic torque, armature current and rotor speed. The reference current is calculated as a gathering of wind turbine speed in accordance with the control scheme of the windmill simulation system to produce the mean aerodynamics torque of the wind.

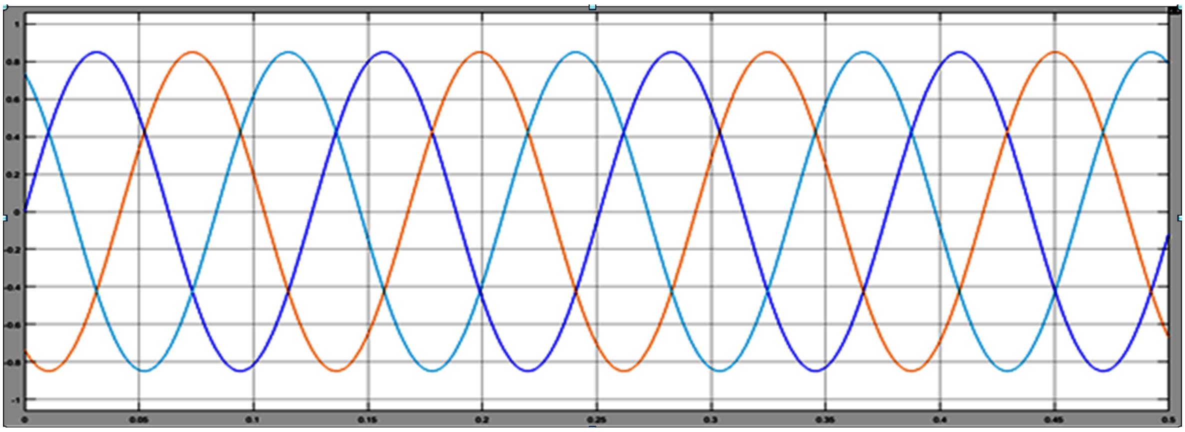

Figure 4. Input voltage waveform of the Rectifier

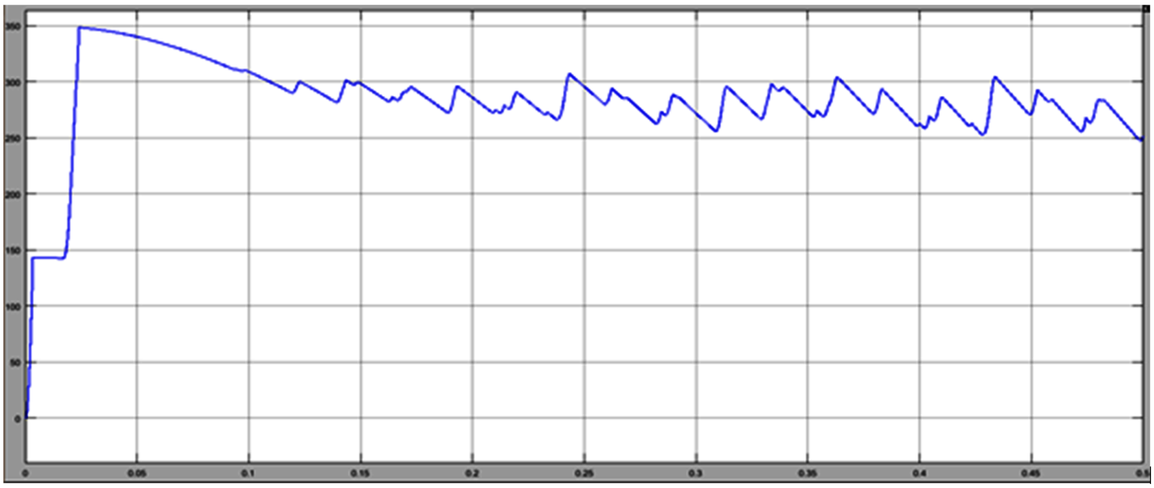

Figure 5. Output Characteristics of Rectifier

The PI controller [26-29] is designed for regulating the voltage of the fully controlled converter and attached to the DC motor's armature. Adjusting the firing of this converter which in turns the regulating the speed of the DC machines coupled to the wind driven generator. The output and input voltage waveform of the controlled system is shown in Figures 4 and 5. The PI controller creates an analogue firing signal as an output after comparing the set point of the armature's real current. The value of Kp and K_I are observed to be 0.09 and 0.325 using Ziegler-Nichols method.This analogue firing signal is coupled to a driver control unit, which transforms it into a train of pulses that regulates the armature voltage.

The amount of electricity a wind turbine will generate at a convinced normal speed of wind cannot be predicted by a power curve. Keep in mind that, as shown on the page Energy of wind, the power existence of the wind fluctuates extremely substantially with the speed of wind. Therefore, how that average was calculated, such as whether winds change greatly or blow somewhat steadily, is crucial. Additionally, keep in mind that the majority of the power exists at wind speeds that are double as fast as the site's average speed of wind. Last but not least, it is important to take into consideration that the system perhaps not operating at normal air density and temperature; therefore it is required to kind adjustments for variations in the air. The look up table for the proposed emulator is exposed in table 1.

Table 1. Look Up Table

Serial No	Torque Nm	Motor Speed RPM	Output Power Pout
1	15	261.5	410.55
2	20	258.9	541.96
3	25	256.3	670.65
4	30	253.7	796.61
5	35	251.1	919.86
6	40	248.5	1040.38
7	45	245.9	1158.18
8	46	245.4	1182.11
9	47	244.8	1195.7
10	48	244.3	1199.9

The outcomes characteristic curve of the system operates under emulation mode shown in Fig 6. The wind profile used to simulate step changes in wind speed from 4 to 12 m/s is shown in (a) together with a load torque of 0.42 Nm, and the dissimilarity in separately excited motor speed demonstrates that it closely matches the speed of the turbine model.

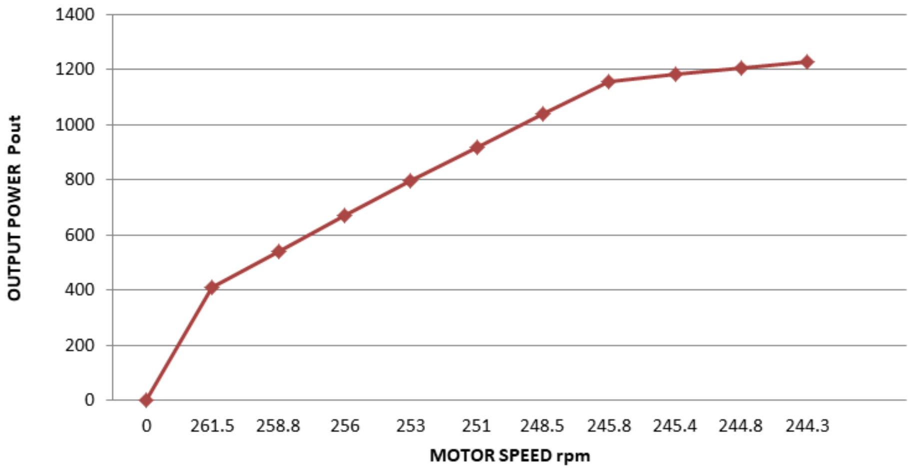

Figure 6. Simulated DC motor characteristic of proposed emulator

5. Hardware implementation

Arduino and an IGBT chopper circuit were used to design hardware setup of a wind turbine emulator using separately excited motor shown in Fig 7. By changing the speed of the separately excited motor, the response was achieved. The system is designed to control the voltage at the motor terminals, while keeping a fixed excitation current in order to manage the motor torque. In accordance with the triggering pulses, the fully converter bridge produces regulated rectified voltage. To modulate torque, this voltage is delivered to the armature of the motor. The regulated mechanical torque produced by the motor in accordance with the formulae for wind turbines serves as the input for the induction generator. Figure 6 display output voltage of the induction generator coupled to the wind turbine emulator.

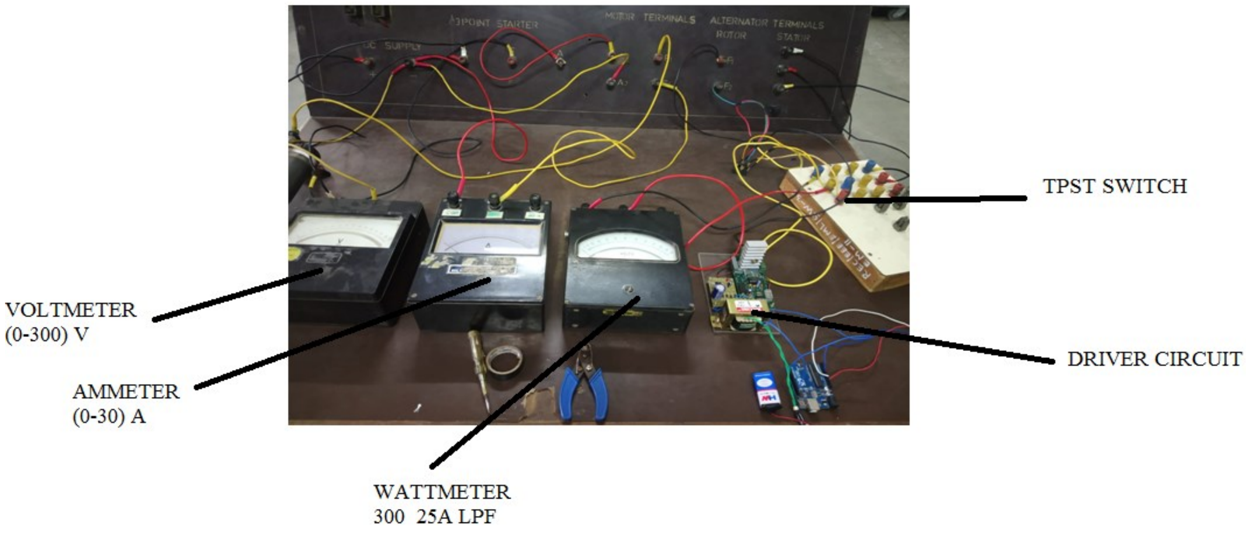

Figure 6. Hardware implementation of proposed emulator

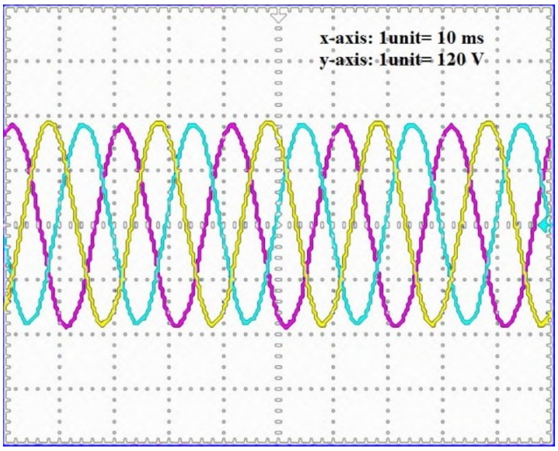

Figure 6. Output voltage of the induction generator coupled to the wind turbine emulator

6. Conclusion

A simulation of a wind turbine simulator has been created in order to faithfully reproduce the performance of a wind turbine using the wind profile as input. The WT emulation is built on a DC motor drive with direct connectivity to the three phase induction generator without a gear box. The model, which was created in the Matlab/Simulink situation, enables reproduction of the functioning of the turbine under various situations, including load torque, changeable wind speed and rotational speed The simulation's findings display that the selected strategy is accurate, and the system is capable of acting like a wind turbine when exposed to demanding and recurrent wind conditions. The hardware setup has been successfully designed using DC motor and arduino based controller.

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