



Fuzzy logic controller based MPPT Micro Wind Power Generation a Case study in Debre Berhan University

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Abstract

(Wind energy is considered to be one of the best sources of renewable energy. Before the implementation of micro wind power generation in the main campus of Debre Berhan University, a potential assessment for the feasibility study was done and it gave an attractive result. In this project micro wind power generation was conducted aiming to generate electricity from wind power at DBU main campus as a pilot project. From the simulation result, we have got the Brushless DC motor (BLDC) motor has been selected as the best alternative for wind power generation. In this site, power is generated from a tower height of 13.5 meters and having five blades, which able to power two 60-watt lamp and booting two 115watt desktop computer. Fuzzy logic controller is used to control the charging and discharging process as well as for maximum power extraction. The electrical circuit including battery, charge controller, inverter, and other accessories are properly installed in the powerhouse near the tower. Before implementing hardware, the proper operation of the system using fuzzy logic controller was tested by using MATLAB/SIMULINK software.

Keywords: BLDC Type Wind Generator, Fuzzy logic controller Abbreviations.

1. Introduction

The demand for electrical energy continuously grows every year, and it was projected that world energy demand would increase by approximately 50% between 2018 and 2050 discussed in [1]. Currently, 85% of the world's energy consumption depends on fossil fuels, the principal CO₂ emission source. Moreover, the fossil fuel industry, as the primary producer and consumer of energy, is the leading contributor to climate change. On the other hand, petroleum-based fuels are nonrenewable, and the reserves are continuously depleted. To fulfill the demand, humans must find other sources of energy that are eco-friendlier to depend on. Electrical generation from renewable energy will be a prospective solution to fulfill the demand since the sources were abundant [2]. Wind energy is one of the fastest-growing energy sources in the world with zero emissions and pollution.

Even though energy from wind has a lot of advantages, this technology is not sufficiently adopted in Ethiopia especially in North Shewa zone and people living here mainly use solid biomass as

a fuel for cooking their food but using this has a lot of disadvantages. For example, as it produces a lot of smoke and soot that is bad for health, it results in deforestation and as a result brings land degradation. Now a days, population is growing rapidly and the area is becoming smaller and smaller, so people may not have the capacity to get fuel wood in the future unless immediate alternative solution is found on biomass. For this, one alternative solution is wind powering because it is a renewable, sustainable and clean source of energy that provides multiple benefits, locally and globally. In this regard, as part of the country to support the work of low carbon development strategies, in reducing greenhouse effect is essential. Hence the research project attempted to address how to generate controllable off-grid electricity using small scale wind generator to power the selected areas. The project is implemented in the main campus of Debre Berhan University, North Shewa zone, Ethiopia for better findings.

Moreover, this project work is implemented to show the visibility of wind power generation in selected site in DBU main campus. The project is implemented using available materials and based

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on the experience in our country. The design, modeling and manufacturing of wind tower structure, wind turbine blades and wind generator based on the available material is developed to provide 380W for demonstration and education purpose. It covers all stages of WECS at micro scale level.

2. LITERATURE REVIEW

Wind turbines play an important role in becoming the alternative technology in the generation of electricity. Since wind is clean and unbounded, wind energy is one of the best renewable sources of energy for the generation of electricity.

Environmentally-friendly renewable energy resources such as wind, hydropower, solar, geothermal, etc. as a replacement for fossil fuels were used as energy security by reducing environmental pollution and global warming. Among those the first wind power which is developed by Chinese were found in the application of wind energy as a sail for their primitive travel from the raft, early about 4000 B.C. So, wind energy was a suitable solution in reducing global energy crises due to climate change and which can be directly used to pump water, grind grain, and also used in sailing ships. Unlike windmills, wind turbines are mainly used to convert the mechanical energy from wind to electricity and the first wind turbine automatically developed for the operation was built in 1888 by Charles Brush with 144 blades having a rotating diameter of 17 meters and a total generating capacity of 12 KW to charge batteries which aid to supply DC supply equipment such as lamps and electric motors [3].

Year to year, wind power generation technology is showing tremendous development, and the researchers' effort for designing and developing wind generator from traditional to recent becomes an advanced and shows good. In [4], the authors in this section present wind turbine generators based on advantages, classification upon the size, and drawbacks. So that synchronous machines, DC machines, and squirrel-cage induction machines are categorized under small scale power generator, while doubly-fed induction generator (DFIG), switched reluctance, permanent magnet (PM), and high temperature superconducting (HTS) are categorized as medium and large wind turbines [4]. Controlling and monitoring wind turbine technology is a must as the wind has an intermittent nature, in [5] monitoring and controlling of wind power systems getting advanced in such a way that wireless sensors which were combined for electrical, mechanical, and environmental monitoring were developed and placed on wind turbine structure. These advanced sensor technologies are also currently improving the blade design efficiency.

A buck-type DC-DC converter control unit with a high-efficiency type equipped with an MPPT system

driver is developed by applying mathematical modeling to drive BLDCM in the electric vehicle using wind energy, modeling and simulating which was performed by using MATLAB/SIMULINK software [6].

The design of a brushless type DC permanent magnet generator for micro wind application is proposed to obtain the advantage of the lack of brush for the improvement of efficiency, for better reliability, less maintenance, for longer life, higher torque to weight ratio and for higher power density. A single optimization process based on modeling is done to calculate the performance of the generator [7]. The author in [8], discussed the optimal combination PV/Wind/Diesel Battery Hybrid Energy System for household energy requirement, under the climatic conditions in Jordan, the economic analysis and system modeling is checked using HOMER software. For the integration of the PV/wind and diesel system power system, power electronic devices are needed and such materials are costly and economic analysis of such hybrid system is not visible. If the average annual wind speed is capable for the production of electricity there is no need to combine them.

DFIG generator used in Off-Grid wind turbine and frequency and power fluctuation due to load mismatch is solved using mutual inductance change, and d-axis and q-axis current and pitch angle control was discussed in [9]. The DFIG as generator needs excitation in the rotor part to produce an electric field in the stator part. This is one of the difficulties of using this generator in an off-grid wind turbine system.

According to the Authors' study of micro wind turbine fed BLDC motor electric vehicle drive application, BLDC motor is used as wind generator and maximum energy extraction is done by MPPT was discussed in [10].

In paper [11], the authors used permanent magnet brushless dc motor as a generator and used buck-boost DC-DC converter for speed control of permanent magnet brushless DC (PMBLD) generator, and they have also used a control algorithm for controlling a buck-boost converter to control over the PMBLDC generator power and to control of single-phase Voltage source inverter to regulate load voltage and frequency. In [12] the authors discussed the size of batteries based on wind speed rather than the demand of the load. But the author didn't explain the effect of the load demand on the batteries and, inverter sizing, charge controller, number of blades, and types of generator. In [13] the authors optimized the power loss of the wind energy system for long-term wind speed profile. However the authors didn't discuss the simulation result and checked it with experimental work.

The advantage of the low-cost installation of micro wind turbine for the application of homes villages is briefly discussed [14]. In [14] the potential resource of wind power in Bangladesh is well described.

The proposed system was designed based on the wind power potential assessment data obtained in [15], and the recorded data using data logger from the site of this micro wind power generation, a potential assessment of wind power was performed at Debre Berhan University of the main campus in [15].

In [16] the authors designed MPPT for a variable speed for small scale wind turbine system using fuzzy logic controller have been designed and simulated.

Change in mechanical power, change in rotor speed and sign of the ratio of mechanical power to rotor speed were considered as input variables and reference generator current was the output variable for fuzzy logic design.

The controller performance was analyzed and validated by digital simulations and the controller tracks the MPPT for variation of wind speed with respect to change in turbine parameters.

System Design and Concept Selection

Wind speed Data and Site Selection

The project site stated in Debre Berhan university compass is located at a latitude of N 9.664910 and longitude of E 39.622410 [16]. The site has an average wind speed of 7.78m/s at a hub height of 78m . The average hourly wind speed measurement at 10 meters above the ground was taken and it was extrapolated to the height of 13.5m for horizontal axis wind turbine. In addition to the above wind data, the measurement data from NASA Surface meteorology and solar energy database was used for comparison purpose.

On the specified site, the wind data has also been collected from the site since 2013 using the NRG data logger. The data indicate that the monthly average wind speed data ranges from 2.8 m/s to 4.8 m/s at 14 meters above the surface of the ground. The slowest average hourly wind speed experienced in August which has an average speed of 2.82m/s . Both data confirmed that it is feasible for electricity generation. In general, 3m/s is the typical cut-in speed so that the electric power can be generated from wind and if the speed is maximum, the power generation is also maximum as discussed in [17]. Based on Debre Berhan University's monthly average wind speed, the designed wind velocity is 4m/s . From these wind speed data analyses, it is clear that the turbine extracts a minimum of 39.2W/m^2 for 4m/s .

Load Estimation for Selected Site

The primary load input, which is taken as a sample, is estimated for modeling and analysis of micro wind system as shown the Table 1 below. In this project, the modeling energy system should meet the load demand of 4 lamps of each has 9W , and for using of computer PC which is having 115W rating power.

Table 1. Power demand and energy consumption for sample size

Electrical Loads	Rating (W)	Qty	Total (w)	Hourly used per day	Consumption (kWh/day)
Incandescent Lamp	9	4	36	12	0.432
Desktop Computer	115	2	230	18	4.14
Total power(w)			266		4.572

Design of a Wind Turbine

Micro wind turbines have great potential in developing countries but they have not been pursued. This is because it can be implemented in several circumstances which are great for the micro grid and off-grid implementations. In this paper, micro wind generation implementation real application was done in Debre Berhan University main campus. The site is located in Debre Berhan City which is approximately 130 Kilometers away from Addis Ababa, the capital city of Ethiopia.

The power generated by the wind power generator is directly proportional to the wind speed since there is no pitch control or turbine speed control technique. Due to this reason, the generated output voltage from a wind turbine is converted to DC using a rectifier, stored in a storage device (battery), and then converted to suitable AC voltage using an inverter. When batteries are full, the excess power should be diverted to separate load so that the wind turbines will not go into high-speed freewheeling in heavy winds. That is where a dump load (also called a divert load) comes in. The MPPT charge controller will switch from battery charging to sending power to the dump load to keep the wind turbine under load. Not using a reliable dump load, or no divert load at all, can cause serious heat build-up in the wind turbine generator which could ultimately cause the generator to overheat, seize up, and burn out the stator.

The overall electrical circuit diagram of the system is composed of seven main components, as shown in **Fig 1**.

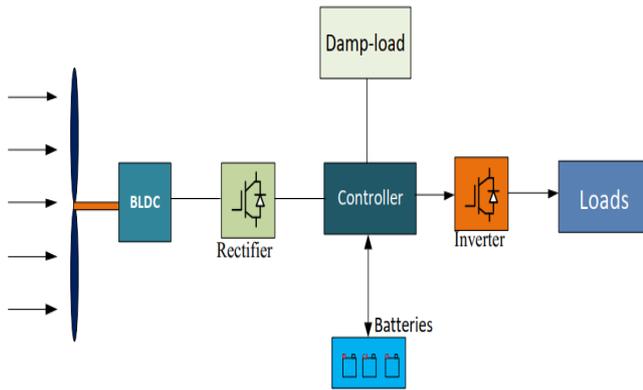


Fig. 1. Overall Electrical Circuit Diagram of Micro Wind Energy Conversion System

Design of wind turbine blades

Recently used turbines are generally categorized into two parts: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs).

- i. Horizontal axis wind turbines are unlike vertical axis wind turbines which have the main rotor shaft on the top of the tower oriented perpendicular to the ground. The main advantages of HAWTs are its fully automated control system, and its efficient power usage.
- ii. Vertical axis wind turbines are oriented so that the main rotor shaft is trans-versed to the wind and the majority of the components are the base of the turbine. The blades are oriented vertically which allow them to catch the wind from any direction.

Assuming V , is the uniform wind speed passing through the turbine rotor, V_1 is upwind, and V_2 is downwind wind speed at a distance from the rotor. Extraction of mechanical energy by the rotor occurs by reducing the kinetic energy of the air stream from upwind to downwind, or simply applying a braking action on the wind. This implies that:

$$V_1 < V_2 \tag{1}$$

Consequently, the air stream cross-sectional area increases from upstream of the turbine to the downstream location:

$$S_1 > S_2 \tag{2}$$

If the air stream is considered as a case of incompressible flow, the conservation of mass or continuity equation can be written as:

$$\dot{m} = \rho SV \tag{3}$$

Equ.3 expresses the mass flow rate is constant along the wind stream. Continuing with the derivation, Euler’s Theorem gives the force exerted by the wind on the rotor as:

$$F = \rho SV(V_2 - V_1) \tag{4}$$

Similarly, the incremental work in the wind stream yields the power content of the wind stream as:

$$P = \rho SV^2(V_1 - V_2) \tag{5}$$

The wind velocity at the rotor may be taken as the average of the upstream and downstream wind

velocities. It also implies that the turbine must act as a brake, reducing the wind speed from V_1 to V_2 , but not reducing it to zero. At this point, the equation is no longer valid. To extract energy from the wind stream, its flow must be maintained and not stopped. One can write expressions for the force F and power P in terms of the upstream and downstream velocities by substituting for the value of V as:

$$F = 0.5\rho SV(V_2^2 - V_1^2) \tag{6}$$

$$P = 0.25\rho S(V_1^2 - V_2^2)(V_1 - V_2) \tag{7}$$

Where, b can be introduced as the ratio of the downstream speed V_2 to the upstream speed V_1 as:

$$b = \frac{V_2}{V_1} \tag{8}$$

From Eqn 6 and Equ 7 the force F and P can be further expressed as:

$$F = 0.5\rho SV_1^2(1 - b^2) \tag{9}$$

$$P = \rho SV^3(1 - b^2)(1 - b) \tag{10}$$

One can observe from Equ. 10 is that the extractable power from the wind is proportional to the cube of the upstream wind speed V_1^3 and is a function of the interference factor b . The power density (p) is defined as:

$$p = \rho SV_1^3 \tag{11}$$

The kinetic power content of the undisturbed upstream wind stream with $V = V_1$ and over a cross-sectional area, S becomes:

$$W = 0.5\rho SV_1^3 \tag{12}$$

The performance coefficient, C_p is the dimensionless ratio of the extractable power P to the kinetic power W available in the undisturbed stream. It is defined as:

$$C_p = 0.5(1 - b^2)(1 + b) \tag{13}$$

When $b = 1$, $V_1 = V_2$, and the wind stream is undisturbed, leading to a performance coefficient of zero. When $b = 0$, and $V_1 = 0$, the turbine stops all the airflow and the performance coefficient is equal to 0.5. It can be noticed that the performance coefficient reaches a maximum at $b = 1/3$. It gives C_p becomes 0.59259.

In a practical wind turbine system, taking into account the loss in the gearbox, bearings, generator, and so on, only 10 – 30% of the power of the wind is actually converted into usable electricity. This is referred to as the Betz Criterion or the Betz Limit since it was first formulated in 1919. The power extracted by the rotor blades may be expressed as follows [12][17], [18]:

$$P_T = 4a(1 - a)^2 \left[\frac{1}{2} \rho A U_o^2 \right] \tag{14}$$

where a is the perturbation factor, ρ is the density of the air, A is the swept area of the blades and U_o is the speed of the upstream wind. The blade profile has been chosen whose specification is given in Table 2.

Table 2: Choice of the design tip speed ratio and selection of the number of blades [19]

Design tip speed	ratio, λ_d Number of blades, B
1	6-20
2	4-12
3	3-6
4	2-4
5-8	2-3
8-15	1-2

The power coefficient varies with the tip speed ratio of the turbine. The tip speed ratio is defined as:

$$\lambda = \frac{\text{Blade tip speed}}{\text{wind speed}} = \frac{\omega_m r}{V_1} \quad (15)$$

The radius of wind Turbine is, $r = 4m/2 = 2m$, as the tip speed ratio-is $\frac{V_{tip}}{V_1}$ (Velocity at tip)/ (upwind velocity) = 2.09. Up wind velocity = $2/3 \times$ undisturbed wind velocity (V). Therefore, $V_{tip} = 2.09(2/3) V = (4.18/3) V$. Angular velocity of the wind turbine is related to velocity at the tip of the blade is $V_{tip} = \omega_m r$. The angular velocity at the cut in speed, $V_c = 3m/s$, $3(4.18/3) = 2\omega_m \Rightarrow \omega_m = 2rad/sec$. This is the minimum wind speed at which the turbine blades overcome friction and begin to rotate [20].

Table 3. Project Design specification.

No	Item	Value
1	Tower Height	13.5 m
2	Rotational wind speed in revolution per minute	10rpm
3	Value of λ	0.29
4	Number of Blade	5
5	Expected power generated, P	284 Watts
6	The average prevailing wind speed ,V	4m/s.
7	Density of the wind at height of the tower of 13.5m	$\rho = 1.22k g/m^3$
8	Swept area	15.4 m ²
9	Radius of the rotor, r	2m

Particularly, for this project, the tower height is 13.5m, the rotational wind speed in revolution per minute is 10rpm, the value of λ is 2.09. Using Table.2, the number of blade for our data can be selected from 4 to 12 blades. Therefore, 5 blades were selected for the work. The power coefficient is affected by the profile drag via the C_d/C_l ratio. The reduction of the maximum power coefficient is proportional to the tip speed ratio and the C_d/C_l ratio.

The wind turbine designed should be able to generate minimum electricity power of 284 welts at an average prevailing wind speed of 4m/s, the height of 13.5m, with 1.225kg/m³ density of air. Designing of a wind turbine was done based on the following parameters. The blade area was calculated by the following equations [21] and [22]

To extract 380W power from a wind turbine with an air density of 1.225kg/m³, $C_p = 0.59$, and overall turbine system efficiency of 0.8, requires a swept area of 15:3577m². This leads to a rotor radius of 2m.

The physical significance of solidity is solid blockage area. Solidity is generally defined as the function of the circumference of the rotor blocked by the blades. For the horizontal axis wind machine, solidity (σ) is defined as following using equ 16:

$$\beta C_\sigma = 2\pi R \quad (16)$$

In Fig 2.the relationship between the cord length and the ratio of blade radius with each airfoil radius is shown. This relation is used to design the airfoil structure of the blade.

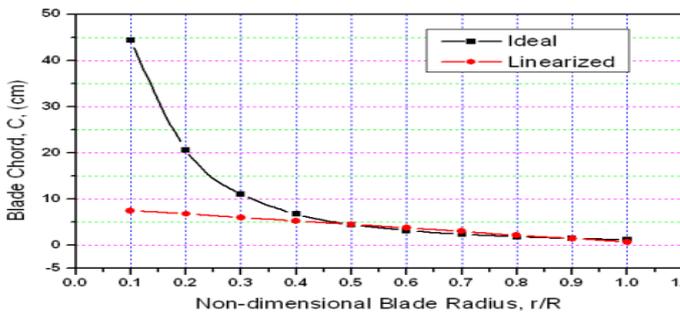


Fig. 2. Optimum and linearized blade chord distribution Where B is the number of blades, C is the blade chord, R is the radius of the rotor. As the solidity increases, the starting torque increases but the RPM and coefficient of performance usually decrease. Solidity increases with the increase of the number of blades. So, for the selected site, the wind turbine has 5 blades and a solidity of 0.028 [20].

Blade surface finish is critical from the performance point of view and any deterioration causes drastic shaft power reduction. So drag produced by the blade surface friction is very important. The cost of the blade materials and their availability are also critical factors to determine the type of blade used for the given project works. In this consideration, Poly Vinyl Chloride (PVC) maintains its surface highly finished and hence, selected for this work.

Tower design

The supporting tower for the turbine is very important in ensuring the stability and strength of the turbine over its life span. By keeping the turbine in the small scale range, the cost of the tower and visual impact on the area was reduced while making installation and maintenance on the turbine much easier. Considering available materials and the need to place the turbine higher than the coastal foliage, metal poles were used and the turbine was placed at a height of 13.5m.

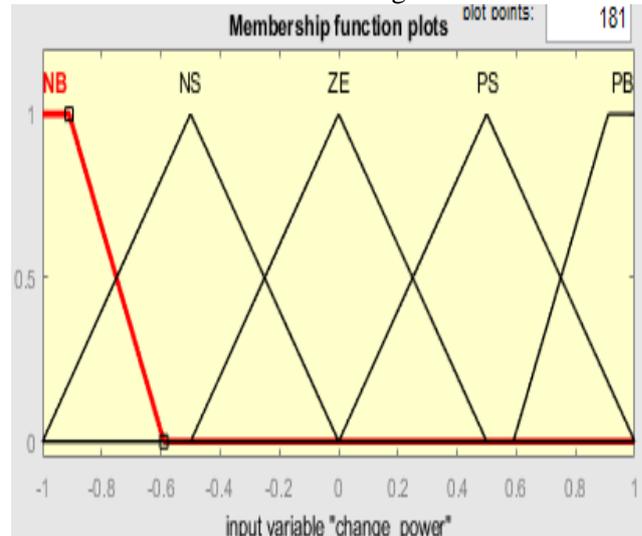
CONTROLLER DESIGN

The selection and design of the controller for a wind turbine were based on the characteristics of wind speed variation during each season. For off-grid wind turbine generators, extracting the maximum power and storing energy is necessary.

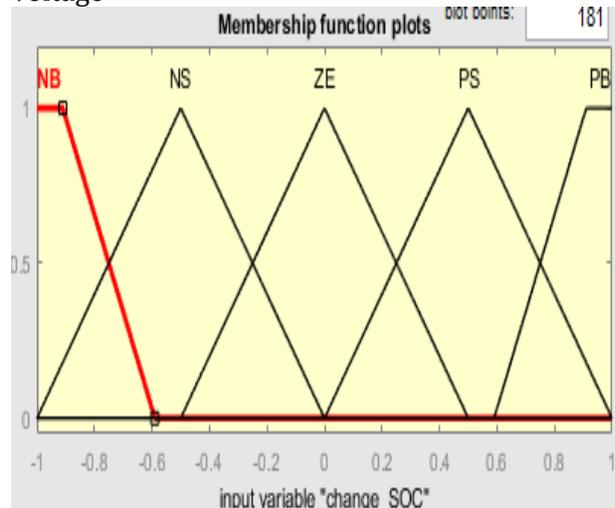
Fuzzy based maximum power tracking

The power generated from the wind turbine varies during each time and season due to the high variation of wind speed, and even the variation of wind speed is not linearly determined. To extract the maximum power at each time, a nonlinear controller was designed. The fuzzy logic controller is one of the best controller selections for this type of system because the variation of the wind is not easily modeled mathematically. The voltage and current being sensed using the current and voltage sensor and calculating

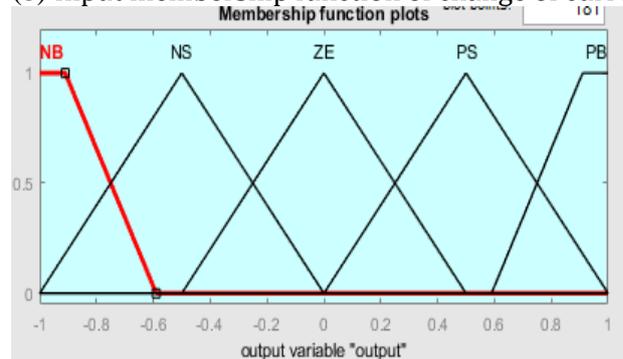
the power and change of power which is used as an input to the fuzzy logic controller. The membership function, input and output function of Matlab Simulink model are shown in Fig 3.



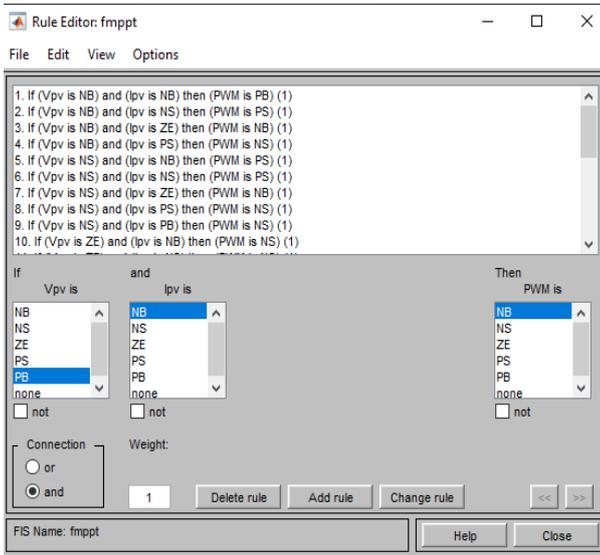
(a) Input membership function for change in voltage



(b) Input membership function of change of current



(c) Output membership function



(d) Fuzzy rules for maximum power tracking
Fig. 3 a,b,c,d fuzzy logic controller

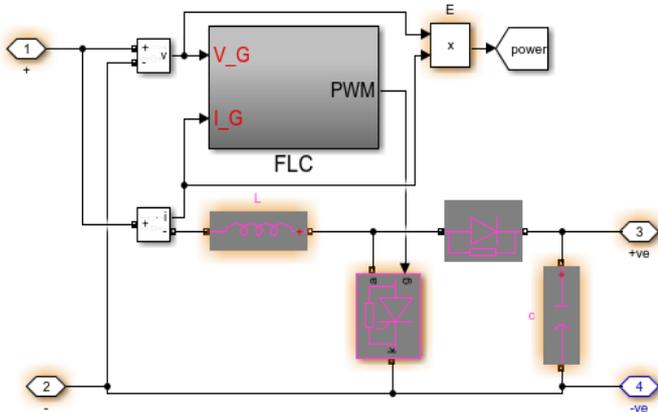
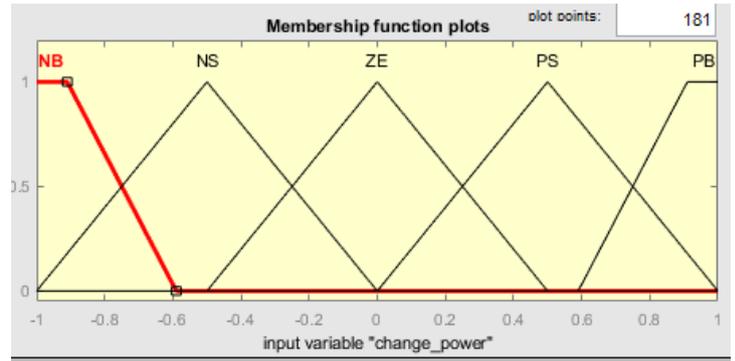


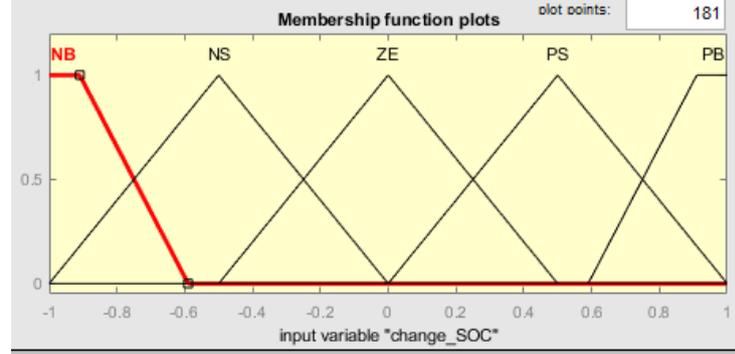
Figure 4 Simulink model of Maximum power point tracking

Battery management system

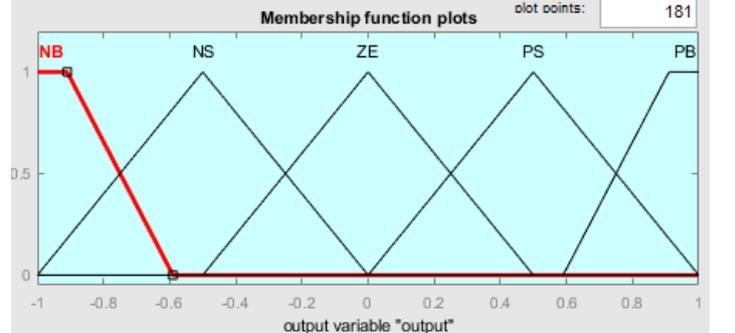
For the off-grid system, the energy storage is a difficult work even if the wind power in Debre Berhan is visible for electrical energy production. Simulink model of the battery management system is shown in Fig 6. Lithium-ion battery is selected due to its performance. Due to nonlinear characteristics of charging and discharge behavior, fuzzy logic controller was used to the controller its charging and discharging rate. The power and state of charge were used as an input to the fuzzy logic controller.
 Change of power = load power - generated wind power
 Change of state of charge (SOC) = command state of charge - new state of charge
 The input, output membership function and the rule based battery management of the wind turbine is shown in Fig.5.



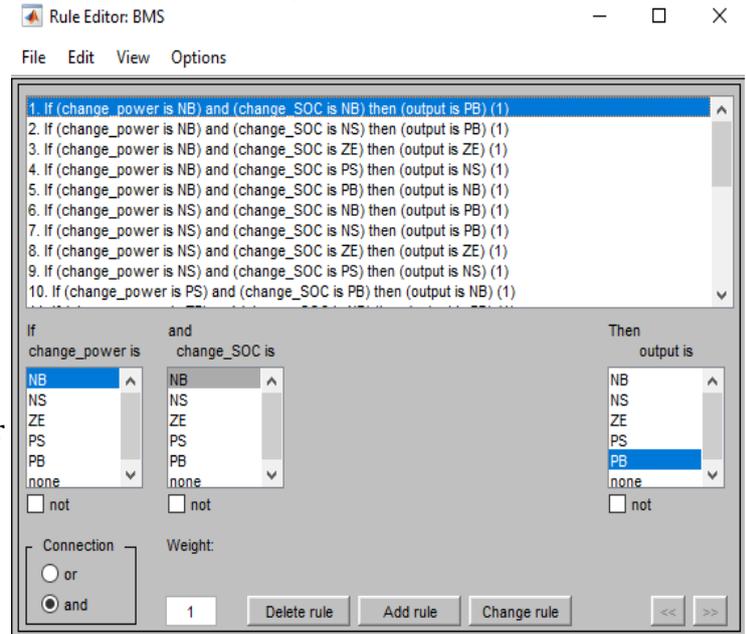
(a) Input membership function for change in Power



(b) Input membership function of change of SOC



(c) Output membership function



(d) Fuzzy rules for battery management system

Fig.5. a,b,c,d, Fuzzy logic controller of the battery management system

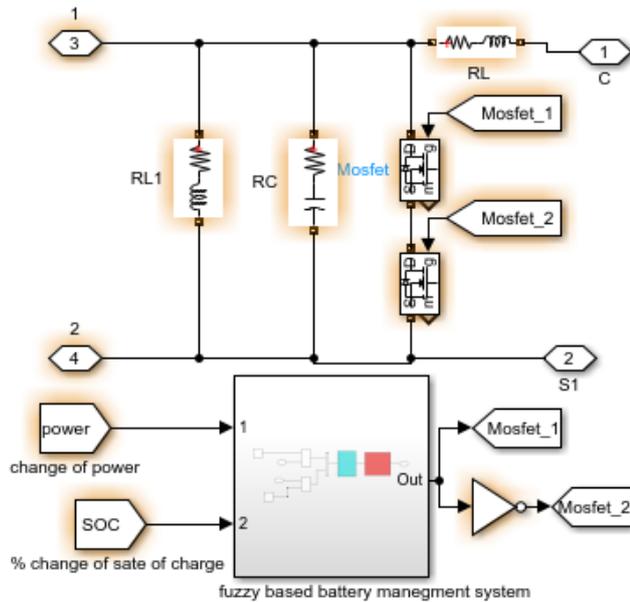


Fig.6. Simulink model of the battery management system

AC-DC CONVERTER

Power converters may consist of the rectifier, boost converter, H-bridge converter [2]. Rectifiers are devices that convert AC into DC and the boost converter boosts up the voltage when there is a decrease in wind energy to the required voltage which is constant. The boost converter is typically voltage step-up power that converts a low voltage input and delivers output at the higher voltage level [23]. The boost converter is a conventional basic DC/DC converter that operates with a single switch.

In this project, the rectifier was used as both since the variable speed wind power system was used to charge the battery and supply ac load at the same time. The generator used in this research project was 72V, 1000 W, 350 rpm brushless DC Electric Scooter Hub Motor (hub generator). The output dc voltage V_{dc} for a three-phase power rectifier was computed with RMS line to line source voltage, V_{LL} as follows:

$$V_{dc} = \frac{3\sqrt{2}}{\pi} V_{LL} \tag{17}$$

The maximum ideal RMS line to line voltage and maximum phase voltage of the generator were 53.29V and 29.035V respectively. The diode should have a voltage rating of at least $2 \times V_{pn} = 60V$ and a current rating of at least $1.25 \times 1000w/72V \approx 17.36A = 20A$. the nominal frequency range is 0.24Hz with a ripple frequency of 1.444Hz and maximum frequency of 17.7Hz for the generated voltage can be determined from the cut-off wind speed and maximum rpm of the hub generator.

The required LC filter was designed for the converter to avoid harmonic. The L and C are computed as:

$$L = \frac{0.013V_{LL}}{2\pi f I_{cri}} \tag{18}$$

$$C = \frac{1}{4\pi^2 f_c^2 L} \tag{19}$$

where f is line frequency and I_{cri} is the value that the inductance is to maintain for continuous conduction mode till 20% of rated load current discussed in [24] . Replacing values $f_c = 50Hz$, $V = 220V$, and $S = 1000V A$, the capacitor capacitance is $3.29\mu F$.

As shown in Fig.7. LCL filters were specially designed to reduce harmonics of current absorbed by power converters, in [25]with a rectifier input stage mainly, the filter was made of a parallel-series combination of reactors and capacitors. The design of the inverter and load side inductor is as follows: Inverter side inductor was determined using:

$$L_1 = \frac{V_{dc}}{4f_{sw}\Delta I_{ppmax}} \tag{20}$$

$$L_2 = \frac{0.1V^2}{2\pi f S} - L_1 \tag{21}$$

Where V_{dc} input dc voltage to the inverter, f_{sw} switching frequency of 1 kHz, considering 20% of maximum inverter current, I_{ppmax} is 3.928A. The value of the inverter side and load side inductor were 0.7637mH and 14.65mH respectively.

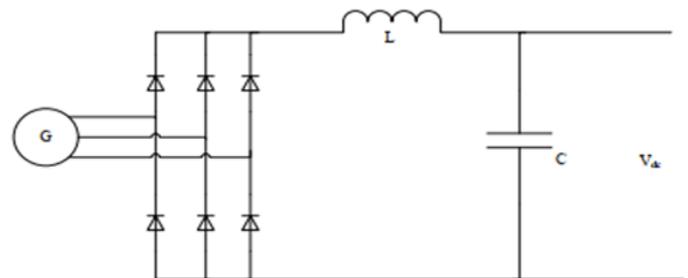


Fig.7. LCL filter topology for harmonic reduction

Sizing and selection of inverter

The size of the inverter was designed for the load power P_L and the inverter output $\eta_{inv} = 50\%$ is defined as:

$$P_{inv} = \frac{P_L}{\eta_{inv}} \tag{22}$$

The controller charge current value, that is, the ratio of inverter power used for wind power generation system to battery voltage:

$$I = I_{charge} + \frac{P_{inv}}{P_{battery}} \tag{23}$$

Sizing and selection of battery

Accumulators are used for surplus electric energy generated from wind turbines. The ratio of electrical power generated by the wind turbine to accumulator voltage expresses the accumulator value used in the unit of ampere-hours [26], [27]. The daily watt-hour of our load (assuming the lamp will be on for 12 hours in

a day) with inverter efficiency of $\eta_{inv} = 80\%$, $W_{Ahr} = 284.5W \times 12hr = 4, 267.5Whr \eta_{inv}$. The battery bank capacity (KBatWhr) in Whr taking into account that the accumulators are discharged down to 20%, with one day of autonomy and 1.19 temperature multiplier for 24oC is 4, 062.66Whr, using equation 3.43 $KBatWhr = PAhr \times Battery Temp. Multiplier \times Days of Autonomy \times Discharge limit$. The battery bank capacity (KBatWhr) in Ampere hour (Ahr) is 338.55Ahr using equation 24.

$$K_{BatAhr} = \frac{K_{BatWhr}}{V_{battery}} \tag{24}$$

The maximum number of parallel-connected battery strings is recommended to be 2, with this in hand the maximum number of series-connected strings should have a 169.2775Ahr rating,

$$N_{series} = \frac{K_{BatAhr}}{2} \tag{25}$$

3. Results and Discussion

In this paper, the power generated by the wind turbine system was analyzed by varying wind speed with constant blade radius and electronic converter. Based on our designed blade radius of the turbine was set and then the circuit was simulated using different wind velocities.

For this work, the blade’s radius was two meters and varying the wind velocity from 3 m/s till 12 m/s was simulated. Then, the difference of power generated was calculated and analyzed.

Simulation Results

The simulation result of fuzzy-based MPPT boost converter of the wind turbine was carried out to assess its performance. Knowledge of generator parameters and design characteristics of the blade is important for this simulation, since the power generated is highly dependent on the wind speed variation. The effect of wind speed was tested based on the different conditions that were put on its effects on power generation robustness.

Wind Speed Characteristic Curve from MATLAB Simulation

The Simulink model shown in Fig 12, was simulated for constant pitch and a variable wind speed turbine model. The performance coefficient C_p of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). C_p reaches its maximum value at zero betas. While wind speed increases the power generated as illustrated in Fig 8 and Fig 9

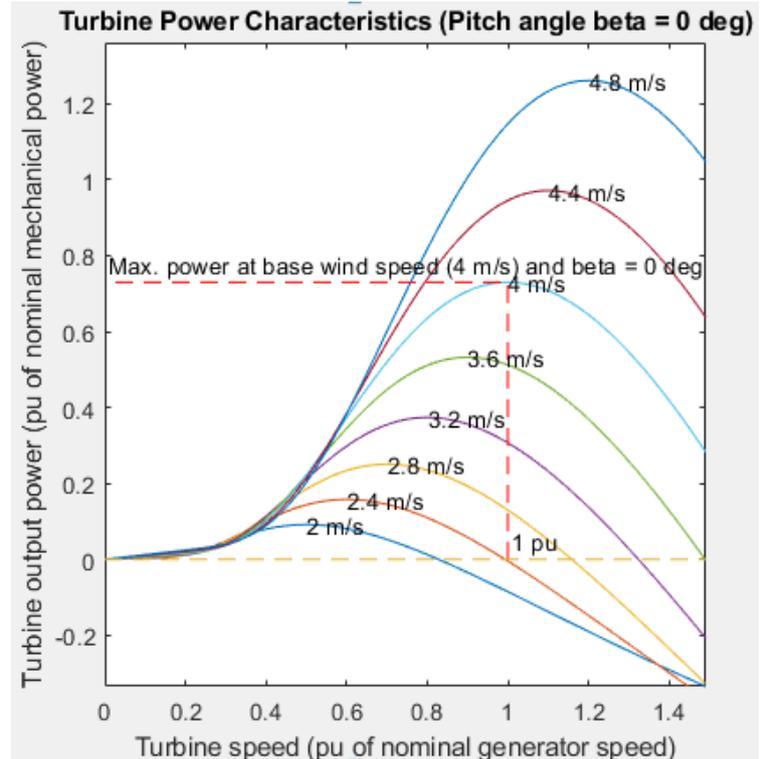


Fig.8. wind speed vs turbine power characteristics for base wind speed 4.5 m/s

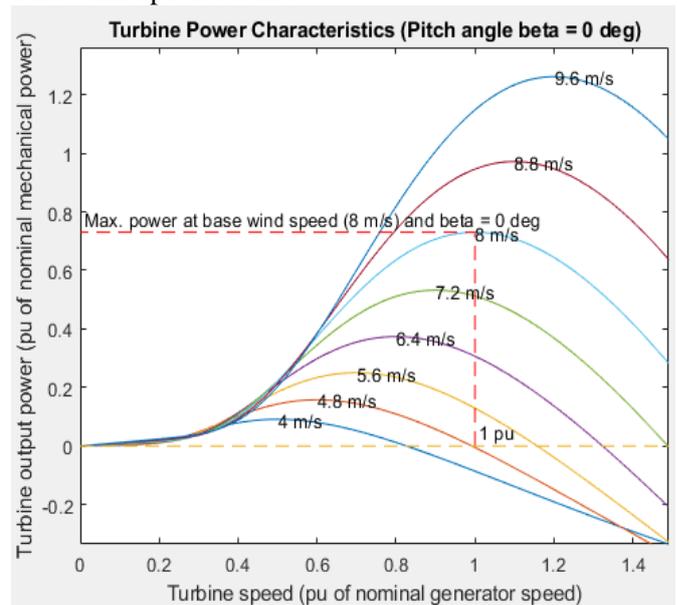


Fig.9. wind speed vs turbine power characteristics for base wind speed 8m/s.

From Fig 8 and 9, we observed that the power generated from the wind speed increased as the wind speed increased till the turbine rated voltage achieved.

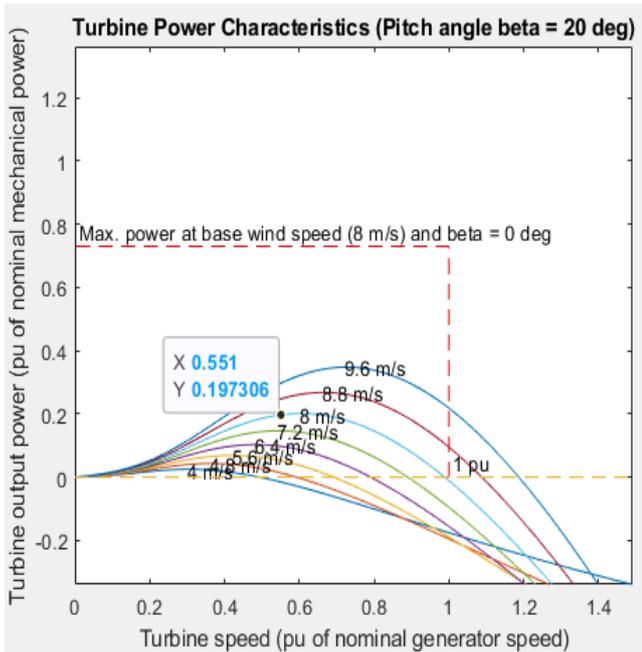


Fig.10. pitch angle vs turbine power characteristics

Fig 10. Illustrated that the pitch angle increased from zero degree to 20 degrees the power generated decreased from 0.73 to 0.1973 pu power. So for maximum power generation, the pitch angle was adjusted based on the wind speed variation to its minimum value using nonlinear control.

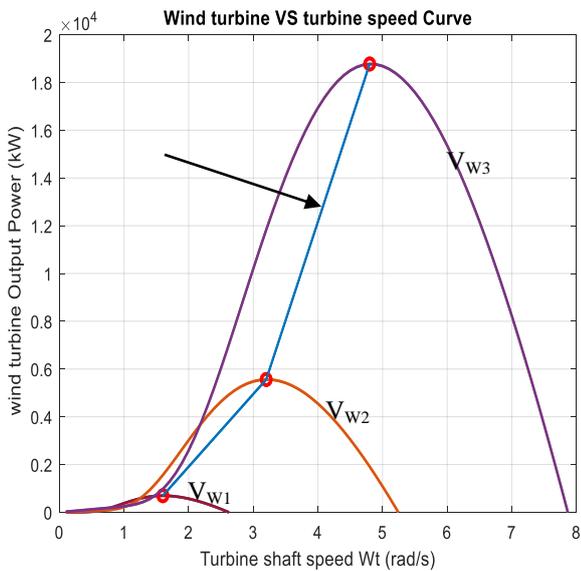


Fig.11. Turbine mechanical power as a function of rotor speed for various wind speeds.

As shown in Fig 11, when the wind speed varies, the rotor speed and the power generated also vary. When the wind speed increases, the power captured increases for certain values, and there is a point when the maximum power is grasped at the optimal rotor speed which is illustrated in the Fig 9. For the different wind speeds, the maximum power is achieved at different rotor speeds.

AC output and battery characteristics of the wind turbine project

The general Matlab Simulink model for the proposed system is shown in Fig12, consisted of different blocks and is modeled based on the extraction of maximum power from variable wind speed.

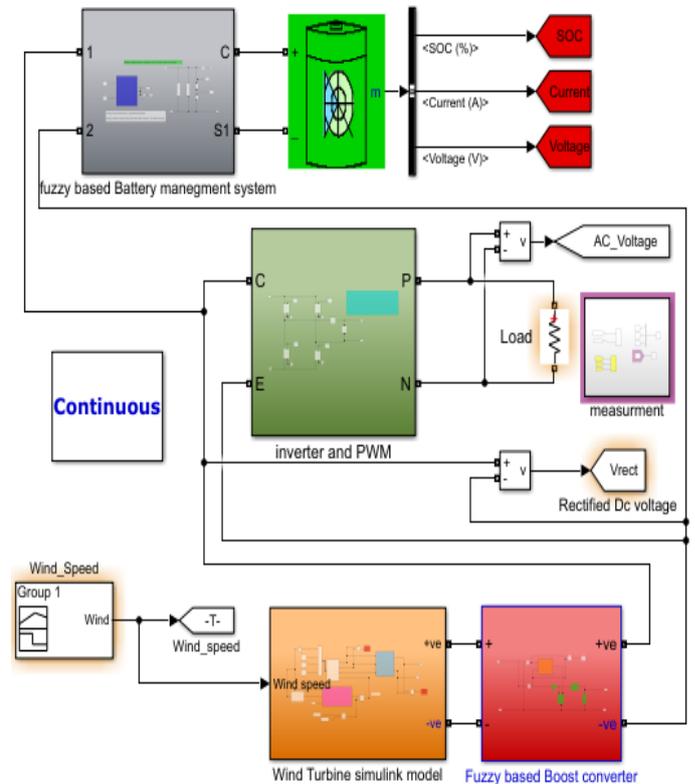


Fig. 12. General block diagram for this project

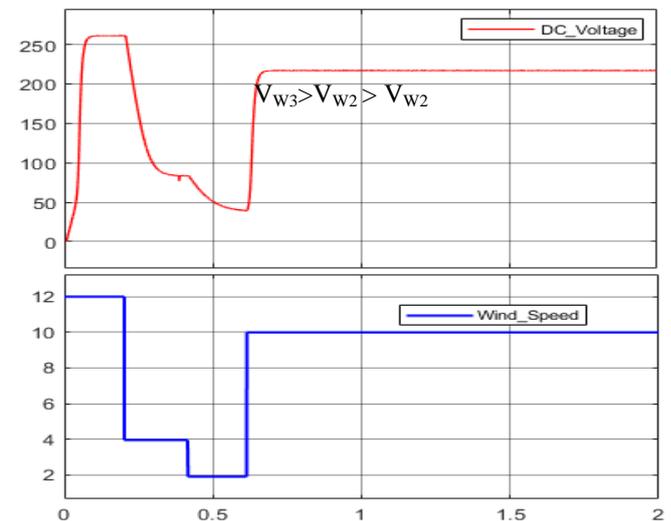


Fig. 13. Wind speed vs DC voltage generated

As shown in Fig 13, the voltage and wind speed are directly proportional. The rectified DC out voltage is shown in **Fig.14**.

As shown in **Fig.14**, the simulation result for the inverter output is stare case like fully square wave. To convert this in to fully sinusoidal at frequency of a 50 Hz, low passed filter was designed and the simulation result is shown in **Fig.15**.

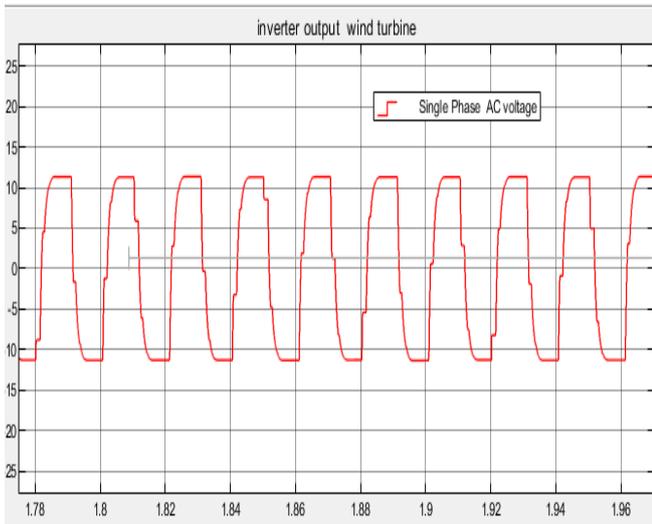


Fig.14 AC output from the inverter

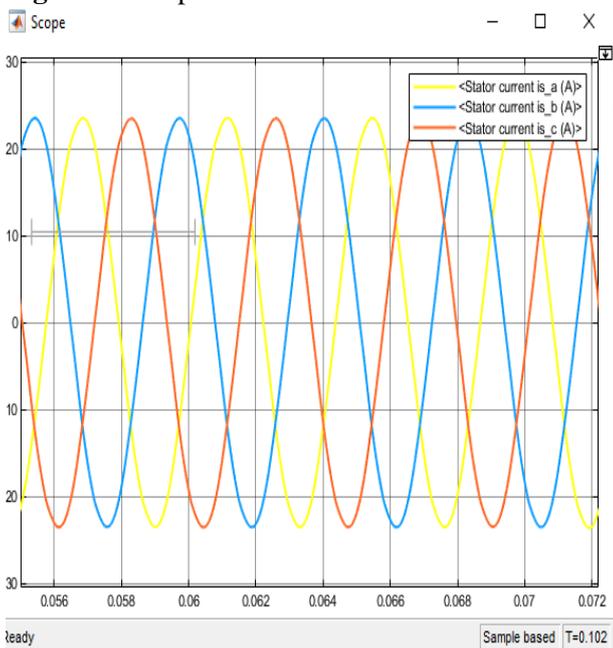


Figure 15 AC output from Low pass filter

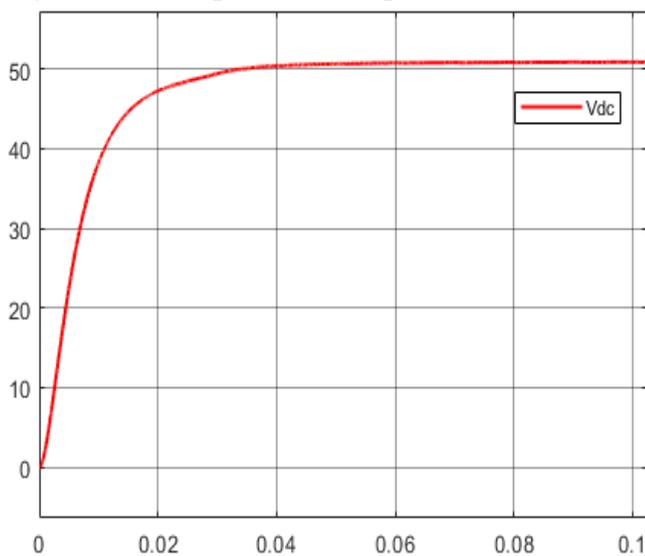


Fig.16. Rectified DC output Voltage at 6m/s
The simulation result for the battery charging and discharging was simulated on MATLAB/SIMULINK

by turning on the battery switch and turning off the battery switch respectively as shown in Fig 17.

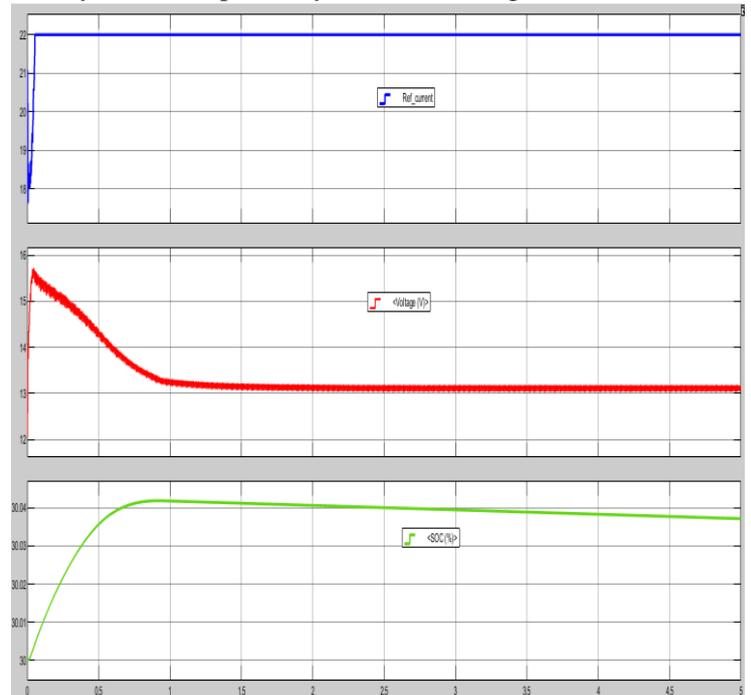


Fig.17 Battery characteristics

Pulse width Modulation is used to keep the output voltage of the inverter at the rated voltage 220V AC irrespective of the output load. In a conventional inverter, the output voltage changes according to the changes in the load. The simulation result for PWM signal generator to turn on and turn off the inverter gate terminals for a duty cycle 95% as discussed in Fig 18.

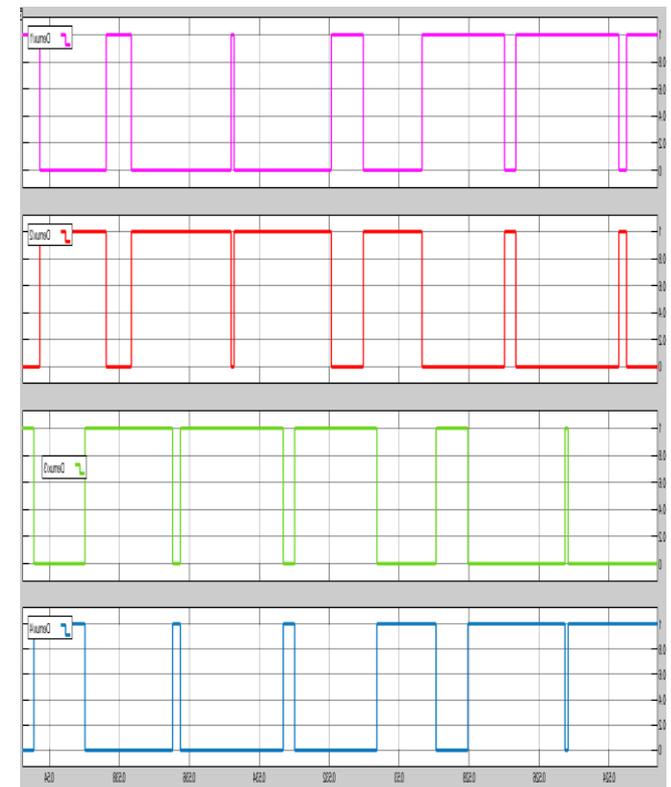


Figure 18 PWM Signal Generator

4. EXPERIMENTAL IMPLEMENTATION

To test the performance of the proposed scheme, experimental work was carried out using a BLDC motor with a horizontal axis wind turbine. For this experimental work, the wind turbine is directly coupled with the BLDC motor, there is no speed multiplication technique is used to multiply the speed of the BLDC motor.

The overall horizontal axis wind turbine system with BLDC generator with its control and protection circuitry developed is shown on the right side of Fig 19. The circuitry includes a protection fuse, AC to DC converter, filter circuit, generated voltage display unit, PWM voltage control, and an inverter and battery management system. To demonstrate that the system was working, two 60W lamp which had the power 115W desk top computer is connected as a load to the system as shown in left side Fig.18. To register the wind speed status, Symphonies' data logger was used to store data from wind vane, temperature sensor and anemometer

The system included a BLDC generator with a horizontal axis wind turbine used to convert mechanical energy to electrical energy (voltage), the voltage produced by the wind turbine generator is 3 phase AC voltage. To regulate the frequency, the 3 phase AC voltage was converted to DC using three phase full-phase rectifier. The magnitude and frequency of the produced voltage depend on the wind speed. To continuous supply the power to the load and regulate the supplied power, battery bank was used to store charge. The PWM charge controller controlled discharging and charging of the battery bank depending on the state of charge of the battery and power generated by the wind turbine generator. The power stored in the battery bank was then converted to single-phase AC power to feed the AC loads through the inverter.



Fig.19. Experimental setup of System Configuration After installing the experimental setup, the recorded data is shown in Table 4.

Table 4. Experimental result of wind speed and output DC voltage

Wind speed (m/s)	DC output voltage (V)
2.33	6.3
2.99	7
4.14	7.27
4.43	8.2
4.52	9
4.9	9.9
5.2	10
5.6	11
5.66	13

5. CONCLUSION

A micro-horizontal wind turbine was designed and implemented with five blades inside the campus of Debre Berhan University. The wind turbine site was selected near the Electrical and Computer Engineering laboratory to utilize the generated power for experimental purposes. The initial wind turbine data were collected from the university using the installed Data Logger since 2013. The Symphonie data logger provided information such as the wind speed, temperature, and humidity for the design of the wind direction, temperature, and humidity for the design of the wind turbine.

A brushless DC motor (BLDC) was used as a wind generator in the modified version. The charging system used was a Pulse Width Modulation (PWM) charge controller and functioned as a 13.8 dc voltage regulator. There are four gel-type battery banks used to store generated voltage with a total capacity of 12 Volts 72 ampere-hour or 864 Watt-hours. The power inverter converts the 12 volts direct current to 220volts alternating current with a maximum load power capacity of 1000 watts. The maximum capacity of the wind generator is 1000 watts. The nominal speed of the BLDC motor is 350 rpm which is suitable for this wind speed without a gearbox. Otherwise, one can notice that gearbox design is mandatory for low-pole generators. The wind turbine can also scan the wind to self-rotate and align the blade to the best direction of the wind speed. The hub generator is a three-phase system with 72V line-to-line voltage. It gives ± 20 phase voltage at normal wind speed. This voltage is

suitable and enough to operate low-voltage three-phase/single-phase loads in the electrical engineering laboratory.

The electromechanical, and power electronics conversion design and simulation were also analyzed in the MATLAB Simulink toolbox. The input and output side of the pulse-width-modulation (PWM) converter was designed with considering 10% current harmonics distortion and 120% over current. Finally, from the experimental and simulation results, the researchers conclude the following points: The research site has wind potential to generate energy from wind for a selected load in the compass.

Low-speed BLDC is suitable for micro-wind generators to reduce the challenge of mechanical gearbox design and associated components. The selection of the wind turbine site can potentially affect the generation capacity.

The experimental and simulation verification indicate that the research can also be further extended in the next phase in the selected area of the university.

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