Performance Enhancement of Wind Energy Conversion System at Low WindSpeeds

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Abstract. This paper is concerned with the design, implementation and monitoring of wind energy conversion system for domestic applications. It is speculated that at most of the places in India, windmills will not be viable due to low wind speed. Hence, a generator with sufficient torque control and having the tendency to produce energy even at very low speed is required. The proposed work has been implemented to generate electricity at low wind speed used for household applications. The main objective intended is to manufacture a cost effective wind turbine and produce effective power when compared to the windmill available in the domestic market. The overall design consists of 3 blades using NACA 63215 profile which is made up of fiber glass material. The permanent magnet synchronous generator with the permanent magnet of alnico type is used to produce the power of 250 W. The power charged in the lead acid battery of rating 24 V; 150 Ah is utilized by the load using power electronic converters. The micro wind turbine operated at wind speed as low as 4.8 m/s and the output power thus obtained was 250 W. The measuring system employs anemometer to measure wind speed, potentiometer to measure wind direction, LM35 sensor to measure generator temperature and hall sensor to measure the generator voltage and load current. All the parameters are monitored continuously to evaluate the performance of the turbine. Since the operating wind speed and production cost is low, the proposed system will serve the basic necessities in meeting the requirements of household appliances. A detailed comparative study is carried out to show the effectiveness of the proposed design.

Keywords: Design, Installation, Low Wind Speed, Performance Improvement Wind Energy Conversion.

1 Introduction

In today's world, power generation is of greatest importance. The amount of traditional energy sources such as coal, oil etc., are depleting drastically. In view of the pending depletion of fossil fuels, developing alternative energy sources is crucial [1]. Among renewable resources, wind power is one of most efficient one [2]. There has been continuous improvement in the establishment of large wind turbines while the small wind turbines suffer few setbacks [3]. The drawbacks of low wind speed turbines are: cost, stumpy energy yield and deprived starting [4-5]. A detailed comparison of six small wind turbines in low-speed areas is given in [6] elucidated that there is significant deviation between manufacturer given specifications and actual estimated energy yield. The system operation at low wind speed is

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highly nonlinear, as the power generation is not significant [7]. A modeling method for wind speeds of the wind turbine generators was proposed in [8].

As the wind power is proportional to the cubic wind speed, the acquaintance of the confined wind circumstances is vital for the energy usefulness of a wind system that they must be taken into contemplation when selecting a site for wind turbine [9].Based on the design, wind mills are classified as horizontal axis and vertical axis. IEC 61400-2 describes the small wind turbine as a turbine with a rotor space of less than 200 m2, providing around 50 kW of power at less than 1000V AC or 1500V DC (IEC 2014) [10]. This specification also illustrates safety for small wind turbines including construction, installation, maintenance costs under specified external conditions.

Small wind turbines have their own set of challenges such as the prerequisite for low wind speed starting torque, responsive to high wind speeds, etc. Mostly housing units and few industrial buildings are the key users of small wind turbines generating power, as the mass development of these turbines is difficult, leading to high cost or high unit production. Consumers are not aware of the wind resource, turbine and load, leading to inadequate use of the turbines. The construction of commercial wind turbines for low-speed generation is an alternative to small wind turbines.

Development of a low cost wind turbine system is elucidated in [11] with maximum power point tracking intended for rural and remote areas. The extraction of power is improved with aid MPPT techniques and the system made use of low cost components to accomplish the task. With the focus on low wind speed speeds, an optimization procedure for generator to rotor ratio based on energy cost is given in [12]. A diode rectifier based system is suggested by [13] as the promising low cost solution for exporting wind power from remote areas. The cost analysis obtained using steady state and dynamic wind turbine models of actual small wind turbines realized in the urban areas of UK are given in [14]. In order to reduce the cost and improve the flux controllability in a low power wind turbine, a generator with magnet less structure is suggested in [15]. The control scheme for doubly fed induction generator for low wind speed power application is presented in [16]. Sensor less speed control using rectifier output voltage ripple is analyzed in [17] for estimating the rotor speed in a low wind speed turbine.

The works reported above stated the importance of low wind speed for WECS and also pointed out the low-cost configuration of such wind turbines. Mainly the cost factor is analyzed based on the available components used for the various geographical locations and for different power ratings. The reduction in cost is mainly achieved by selecting a suitable alternate material and by eliminating unwanted parts. In this paper, a new approach of design and fabrication of windmill for house hold applications is proposed by eliminating a step up gear from an existing model. The advantage of eliminating gear box in windmill head is to reduce the cost of the windmill, weight and power loss due to gear transmission during power generation. A gearless drive system operates the blade and the alternator at the same rpm while the model of gear is influenced by the high initial cost of the installation and the corresponding high maintenance costs.

The proposed cost effective windmill can be used for domestic purposes such as houses, offices and medium industries. The design of alternate blade profile incorporating self starting capacity at low speed is carried out. The design of alternate tower to prevent blades from damaging is also considered. Monitoring system is employed to monitor the parameters such as wind speed, wind direction, generated output voltage and current for analyzing the turbine power performance instantaneously. The data collected are stored such that the past historical data can be used for analyzing the wind turbine system.

This paper is organized as follows: Section 2 describes the modeling of the proposed system. Section 3 discusses the fabrication procedure of gearless WECS. Section 4 confers the design of various components of WECS. Section 5 presents the design of power converter. Section 6 presents the real time monitoring of WECS. Section 7 discusses the results and finally section 8 discusses the conclusions with salient results obtained.

Modelling Of The Proposed Wecs

The mechanical components of WECS are the nose cone, generator casing, pole of the tower, top plate of the tower for holding the turbine generator set, tower base plate for erection and support, vane kit, blade and tower. These mechanical parts are modeled in Solid Work software before fabricating. The modeling parts are shown in Fig. 1.

Blade

Turbines usually have two or three blades mounted horizontally to the ground on a rotor. Whenever the air flows over them the blades lift and rotate. Fig. 1(a) shows the blade model for the system proposed.

Nose Cone

A nose cone as shown in Fig. 1(b) is presented in front of the blades to protect the generator from the rain while allowing airflow for cooling purposes and it streamlines airflow through the blades and rotor section.

Generator Casing

Generator converts the mechanical energy produced by the wind to electrical energy with the help of turbine blades. For proper installation of the generator at the top of the tower, a casing is essential. The generator casing is depicted in Fig. 1(c). Without casing it is very difficult to install a generator at the top of the tower. Casing protects the generator from external disturbances.

Vane Kit

A wind vane tests the wind direction and coordinates with the yaw drive to position the turbine correctly with respect to the wind. Fig. 1(d) shows the modeled vane kit of the proposed system.

Tower

Tower is an essential component which has to be designed for successful implementation of the WECS. Tower has to be built strong enough to bear the entire weight of the turbine, generator, gearbox and vane. Tower is designed with poles and Fig. 1(e) shows its modeled diagram. A tower pole is an important and a mandatory component in WECS. Several poles are arranged in a lattice structure to make a tower which is enlisted as lattice towers, bolted steel towers and steel hybrid towers. Fig. 1(f) shows the modeled tower in solid works software.

Top Plate Tower

The top most layer of the tower is used for installing the generator. Therefore, a square shaped base has to be designed for successful installation of the generator. Fig. 1(g) shows the modeled top plate structure of the tower.

Base Plate Tower

The bottom layer of the tower should be designed in square structured way since the square base provides additional support to the tower during its errection. Fig. 1(h) shows the modeled bottom or base plate of the tower.

Fig. 1(a) Blade

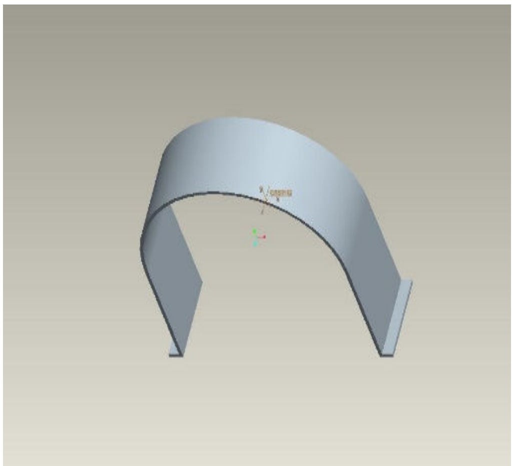


Fig. 1(b) Nose Cone

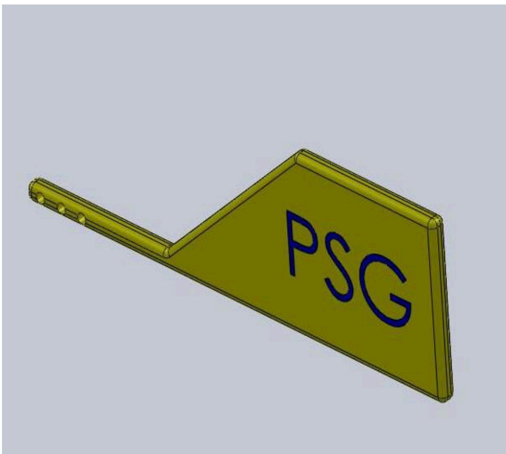


Fig. 1(c) Generator Casing

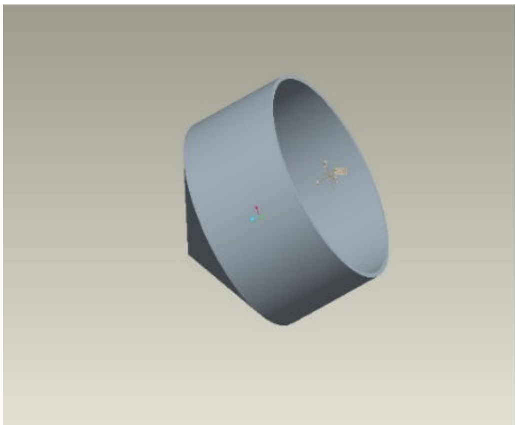


Fig. 1(d) Vane Kit

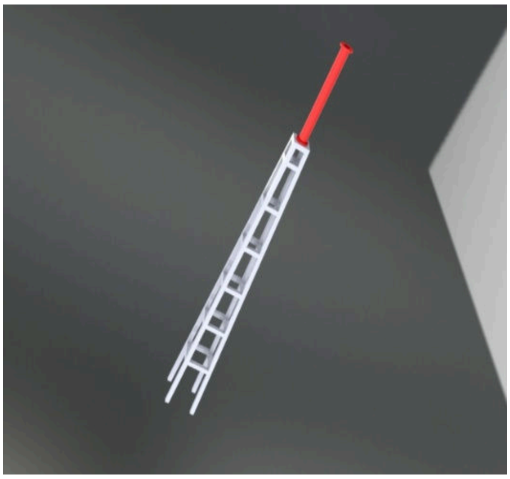


Fig. 1(e) Tower

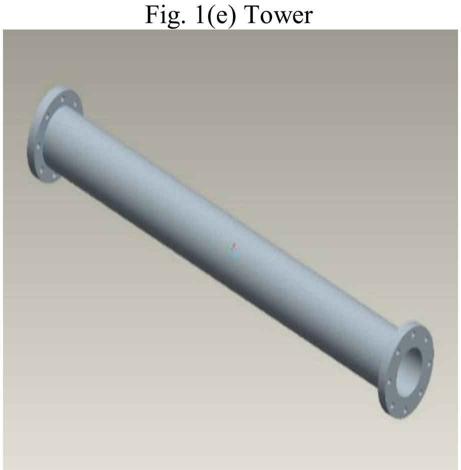


Fig. 1(f) Pole Tower

Fig. 1(g) Top Plate of Tower

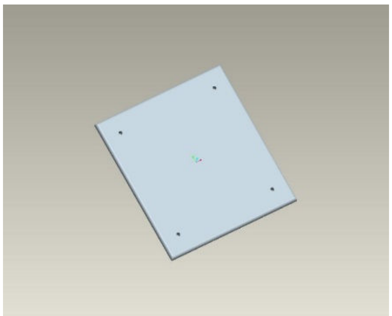
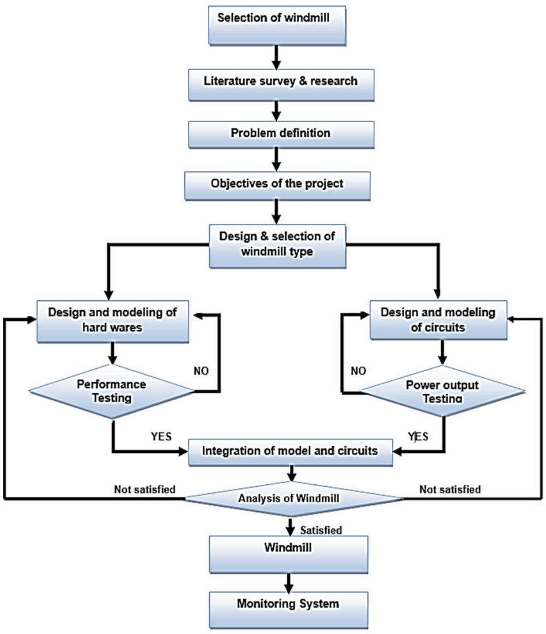


Fig. 1(h) Base Plate of Tower

Fabrication Of The Proposed System



For the calculated chord length values and twist angle for each section, NACA 63215 profile curve diagram is drawn for sections using AutoCAD software. Fig2 shows the flowchart of the proposed methodology. Initially, the profile curve diagram for sections is taken print out. The printed sheets are laminated and profile curves alone are taken out. These laminated sheets of sections are pasted perpendicularly on a cardboard in a regular space of calculated values. With these cardboards, male and female die were made in glass fiber. Glass fiber mat were cut according to size of the cavity on die. The mixture of accelerator and catalyst was applied on surface of the cavity, which is used to melt glass fiber mat. Next, the mat is fixed on mixture which is applied on the cavity. Similarly, the same procedure is followed for the opposite die. Then, both die's were mated each other and a blade is manufactured. With aid of the same procedure other two blades are manufactured.

Fig. 2. Flow Chart of the Methodology

For the required dimension, hub is casted from purchased aluminum materials. The three blades are fixed to hub by fasteners and this setup is known as rotor. Balancing of blades was done and rotor is ready for coupling. Rotor is coupled to alternator shaft with the help of keyway. Nose cone is fixed to front of the hub. The whole setup is kept on the base plate and the alternator is covered using alternator casing. The tail vane is welded to the base plate. This setup is known as turbine. The turbine is fixed to the bearing block.

Bearing block is coupled to flange and the flange is welded to the tower post. This tower post is fixed to the tower head by a flange. The whole setup is fixed to the pillar by concrete. Monitoring system is used to monitor the various parameters and these parameters are displayed in the LCD display with the help of data logger. Visual Basic program is developed to perform data logging operations.

Design of the proposed wecs

The components needed to be designed for installation of WECS are: Rotor- Fan/Blade – 3nos (1m each, fiber glass material), hub, nose cone, generator (250 W), vane controller (with built in rectifier), battery (12 V, 40 Ah), inverter and tower. WECS are essentially available with and without gearbox. The gear model transforms the rotation of the blade to a 1200 rpm alternator speed. In the modeled rotor, it is connected to the gear box and then to the generators. The advantages of this model are its small alternator size, which makes mounting and transportation easy. The complex equipment design, however is costly to produce, susceptible to maintenance costs, and creates excessive noise.

To overcome these problems gearless model design has been approached. In this, gearbox which is used to connect the rotor and the generator is eliminated. Hence the rotor is directly connected to the generator. The transmission without gear presents a unique direct drive system where the blade and the rotor turn at the same velocity. The drive system is much more reliable and much cheaper because it is gearless. In order to produce the same output as the equipment model, on the other hand, it needs a massive housing and a huge generator with many poles. Fig 3 illustrates the detailed design workflow.

Design of Blades

Blades are crucial element to wind turbines functionality, converting energy produced by the wind into kinetic energy. The rotor has a high starting torque vertical axis mechanism with acceptable peak power. Until now its use has been limited because of its wide surface area.

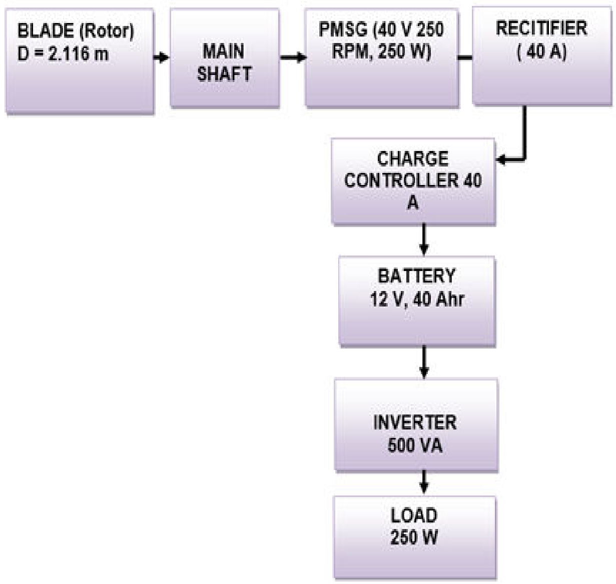
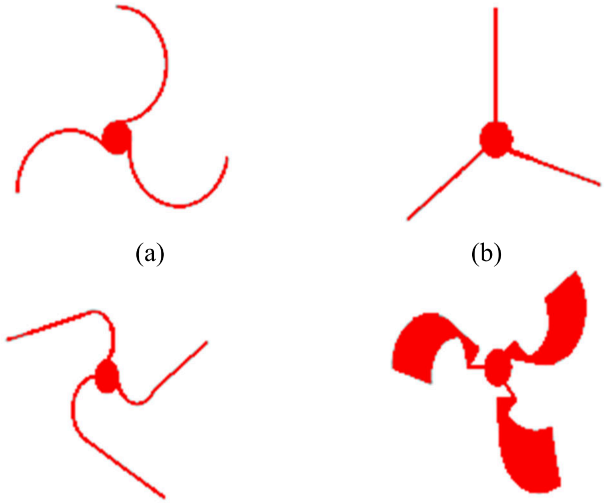


Fig. 3. Design Work Flow

Wind turbines cannot cope with high-speed propellers and conventional wind turbines from the point of view of aerodynamic performance. Rotor has low power per rotor capacity, weight and expense, making it less effective. Nevertheless, these types of turbines are simple to construct, insensitive to wind direction and self starting. In the proposed design, two separate rotor blades were produced and their output against traditional straight and curved rotor blades in terms of rotary speed is analysed. Fig 4 depicts the blade types and Table. 1 shows the specifications of the blade.



(a) (b)

(c) (d)

Fig. 4. a) Curved Blade,b) Straight Blade,c) Aero Foil Blade,d) Twisted Blade

Table. 1. Specifications of the Blade

Parameters	Specifications
No. of blades	3 (1m each)
Sweep area	3.5 m
Material	Fiber glass
Design type	Up wind design
Twisted angle	θ=18.4^0
Blade profile	NACA 63215

Blade Desgin Calculation

Swept area calculation: Swept area is the area through which rotor blades of the windmill rotates. Swept area for 250W windmill is 3-4 m. Swept area =πr2 where r = radius of rotor

Take swept area = 3.5 m

∴ Radius of rotor = 1050 mm

Length of the blade = r – radius of hub, where radius of hub =160 mm

= 1050 – 160= 890 mm = 900 mm

Length of the blade = 900 mm, Angle of twist = 0 – 25.4°

Fig. 5(a) shows the die set up used for manufacturing the wind blades and Fig. 5(b) indicates the final manufactured blade.

Fig. 5(a) Die Setup Used For Manufactruing Blades

Fig. 5(b) Finished Blade

Design of Hub

The windmill's hub is the component that links the blades to the DC generator. It is necessary for the smooth operation of the windmill that the diameter of the hub is equivalent to the generator diameter. To connect the blades to the hub, a six-inch diameter pulley is required with a shaft equal to the engine diameter. A wind turbine hub which is a very basic wind system mechanism connects the engine with the blades with an engine gear. While it is an easy operation, a turbine hub will present some hazards, since the blades will start to spin quickly if the wind blows.

The appropriate size hub is cast from aluminum materials obtained. The three blades are connected by fasteners to the hub and this arrangement is known as a rotor. To repair the generator shaft and hub securely, the key and slot are given. Fig 6 shows the designed hub with Cast iron material with hub radius=160 mm.

Fig. 6. Designed Hub

Design of Nose Cone

The cone of the nose protects the generator from rain while supplying cooling ventilation, streamlining the airflow through the blades and rotor portion. The essential features of implementing nose cone are: reduces the wind resistance, eliminates vortexes, has greater stability, increases the swept area with 10"diameter, precisely machined, wobble-free, automatically secures hub onto turbine and it is excellent for permanent magnet alternators. The specifications of the nose cone are given in Table 2. The designed nose cone is shown in Fig 7.

Table. 2. Specification of Nose Cone

Material	fiber glass
Diameter	160 mm
Thickness	0.5 mm
Mounting	3 blades

Fig. 7. Designed Nose Cone

Design of Generator

The generator is responsible for taking the power from the blades and converting it into usable energy. The generators generate AC current. A 250 W generator shown in Fig8 is used which has a production capacity of 250 W/h. Permanent Magnet Synchronous Generator (PMSG) is a type of synchronous generator where a permanent magnet instead of a spool provides the excitation area. Synchronous generators are the main source of all energy sources, widely used to turn the mechanical power outputs of steam turbines, gas turbines, reciprocal engines, hydro turbines and wind generators into the grid. The generators are known since synchronous, as they run at synchronous speed, which is the same operating principle as a synchronous engine. The rotor speed with a constant magnetic field often matches the stationary winding supply frequency. The constant magnetic field of the armature is generated by a continuous magnetic field of a permanent magnetic rotor assembly or by direct current control in the rotor field (i.e., electromagnet) fed by a slip ring mount or brushless media.

Fig. 8. Permanent Magnet Synchronous Generator

The generator specifications are: 3 phase permanent magnet generator, Power output= 500W/hr, Voltage output= 40 V (can produce 250W at 250 rpm), pole=24 and gauge=19. Meanwhile, in the low wind speed region of the wind turbine, the main control objective is to control the generator torque to have the generated power maximized. The control variable is the generator torque load [18-19]. In the controller design, it is highly essential to consider this context for maximizing the power generated.

Vane

Vane calculates the wind direction and communicates with the yaw and drive to better align the turbine to the wind. It helps to shape the tail so that the blades transform into the wind using a strong aluminium sheet (tail shape varies by preference). Above the mount, the generator and tail are installed. It is essential to make sure that blades are working and still windward. It is required to build a bearing that makes wind current mobility. Moreover it should be light weight, so that it can turn the generator by yawing according to the wind direction.

Fig. 9. Vane (Tail)

Controller

When the wind generator is used for charging batteries, a controller with built-in rectifier should be used. This device tests the charge level of the battery and recognizes the total charge of the battery. The controller includes a bridge rectifier that converts alternating current (AC) into direct current (DC) for battery charge from the wind generator. Controller is employed to control the current fluctuations due to variable wind speed and also serves as allowing the required current to the battery in case of excessive power generation. It can be employed up to 350 watts as given by manufacturer.

Battery

A battery is a device that stores and electrically distributes chemical energy [20]. Electrochemical equipment like one or more electrolytic cell, fuel cell or flow cell compose batteries. It is used for the conservation of electricity. The electrode is immersed in an electrolyte. This triggers a chemical process that releases electrons to generate electricity through the conductors. The battery used in the proposed system is 40 Ah.

Tower

It supports rotor and generator and raises the whole configuration to a higher level. The towers are made up of tubular steel, concrete or stainless steel. Since wind speed increases with height, higher towers allow turbines to produce more energy and electricity. Tower plays very important role in windmill arrangement. Tower is designed such that it should be rigid and fix firmly in the ground. It should arrest the vibration created by generator during rotation.

Tower Design

The tower has been designed with the combination of both lattice and pole. One meter of pole is used to prevent the blade from rotation during heavy wind. Total height is calculated by 4m (3+1) where lattice= 3m and pole=1m. Fig 10 shows the designed tower.

Fig. 10. Desgined Tower

Tower Erection

Tower erection is one of the most important works to be done in the windmill set up. Tower is erected by welding the bottom plate of the tower in to another plate which is bolted on the floor so that it can withstand maximum load of 1 ton. It is needed to arrest the vibration produced during the rotation. After welding the tower in to the bottom plates in the floor now it is further provided by concrete so that it fixed firmly in the floor. Tower should be placed horizontal to the ground without any slanting and it is then checked by sprit level.

Before the erection of tower it is indispensable to conduct the wind velocity test to find the availability of wind source in the particular location. Anemometer is the measuring instrument used to measure the wind speed as shown in Fig 11. Test should be conducted in different places and at different timings and values to be noted down for analysis. It is essential to select the place which has more wind source to erect the tower.

Fig. 11. Anemometer

Sprit level test is conducted to ensure that the tower has placed at flat horizontal surface without any slanting effect. It is also necessary to make sure that the base was tightening very firmly on the floor. Fig 12 depicts the erection of tower which shows the sprit level test conducted for erecting the tower that is to be bolted.

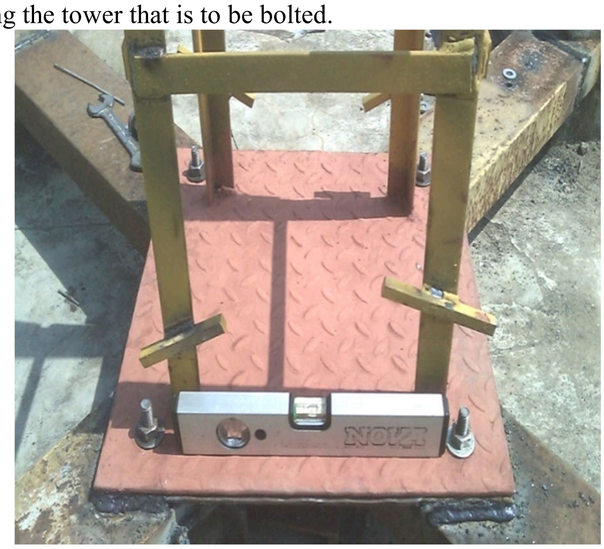


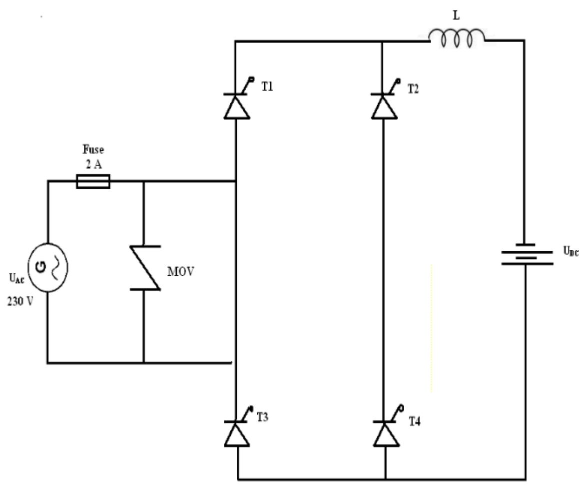
Fig. 12. Erection of Tower

Design of inverter

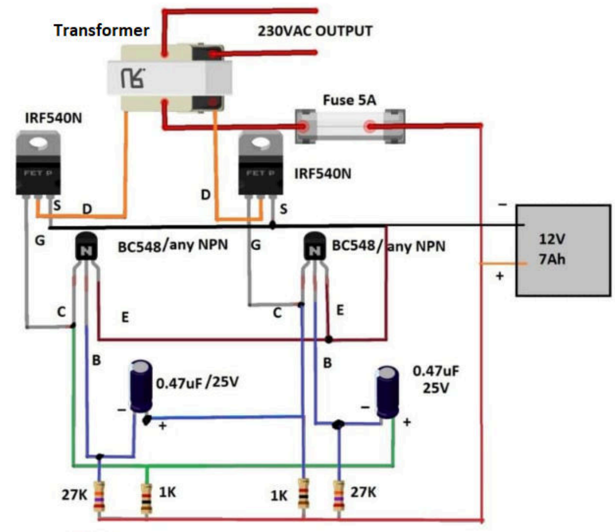
The purpose of an inverter is to convert DC power of DC bus to an output AC power, fed to load [21]. A nominal DC voltage of 12 V can be applied as an input to the inverter. Here the inverter output is connected to the load. The inverter circuit used in the Uninterruptible power supply in conversion of 12V DC to 230V AC is used. By suitable firing of the power device, the amount of power transferred can be varied and total harmonic distortion can be a limited to safer value. The power circuit consists of SCR where the switches T1 and T3, forms one leg of the converter and T2 and T4, forms another leg of the converter. The input DC supply is given to the inverter through an inductor L1. The anode of T1 and cathode of T4 are connected to grid. DC supply is given to cathode of T2 and anode of T4 through an inductor. Gate pins of the power switches are connected to the driver circuit and are triggered by high frequency triggering signal generated by micro controller. Due to higher EMF induced in the inductor which may try to turn off the thyristors. In order to prevent this continuous triggering has been used. Design consideration of the inverter involves only the selection of power devices and their ratings. The power devices can be switched in a complementary manner (if Q1 is on, Q2 is off, and vice versa). The schematic diagram for the inverter is shown in Figure 13 (a) and (b) while the nominal specifications are listed in Table 3.

Table. 3. Specifications of the Inverter

Parameters	**Values**
Input voltage minimum U_{DC} (min)	11.4V
Input voltage maximum U_{DC} (min)	14.6V
Nominal output apparent power S_{out}	500 VA
Maximum output current I_{out}	2 A (RMS)
Switching frequency f_{sw}	2 kHz



(a)



(b)
Fig. 13. (a) Basic Block Diagram of Inverter Circuit
(b) Components Used For 12V DC To 230V AC

Selection of SCRs

In order to meet the above requirement, power SCR of type TYN 616 is chosen for the proposed design application. These SCRs are designed as consolidated strip layout-based MESH OVERLAY process; since these devices are suitable for high frequency switching applications typically of 100 kHz. Table 4 shows the parameter description of the SCR.

Table. 4. Parameter Description of TYN 616

Parameters	**Values**
Anode to cathode Voltage	600 V
Anode to Cathode Resistance	<0.27 Ω
Average on-state current (I_{AVG})	10 A
RMS on –state current (I_{RMS})	16 A
Average gate power dissipation	1 W

Desgin of Snubber Circuit

Snubber is used to suppress electrical transients which are created due to the presence of inductor. Due to inductor, the sudden interruption of current flow led to a sharp rise in voltage might lead to a transient or permanent failure of the device. The value of R (100Ω) and C (0.1µF) are obtained from the data sheet of the SCR.

Schematic Diagram of Driver Circuit

Driver circuit is entirely made up of small signal devices such as diodes, NPN transistors, resistors, capacitors and isolation transformers. Fig 14 represents the driver circuit configuration. Isolated transformers are used for separation of higher power section with lower power section. Transistor BD 139 is used for this application which has higher current gain and diode is used for suppressing negative pulses and providing path for positive pulses.

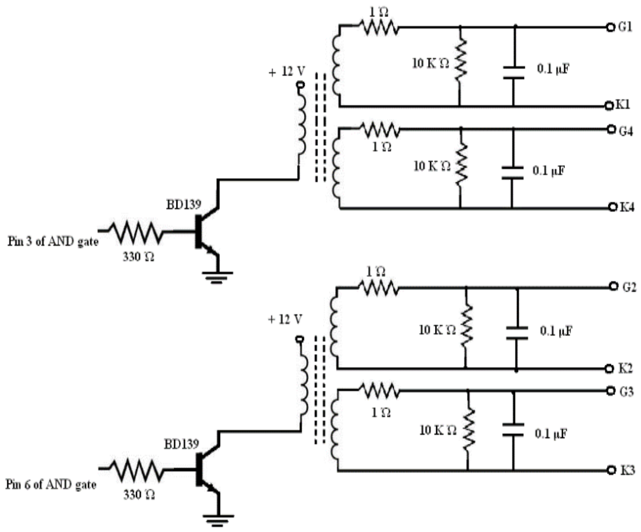


Fig. 14. Inverter Driver Circuit

Filter Components

In DC / AC power section, the major filter component is an inductor. Here the inductor performs two actions: One is to reduce current ripple and another is to boost the voltage in DC section. Without the inductor power transfer will not occur in the system.

Design of Choke

The inductor current contains a high frequency ripple and the inductance is used to filter it. By trial-and-error method the value of the inductance is calculated. Table 5 represents the filter inductor parameters for nominal conditions.

Table 5 Inductor parameters

Parameters	**Values**
Inductance (L)	120 mH
Maximum current I_{max}	2 A
Core Type	Ferrite

Design of Charge Controller

The main task of the wind turbine charging regulator is to charge and protect the battery from deep discharge. Due to overcharging the electrolyte boiling, the battery could be damaged or even destroyed. Deep discharge could damage the battery as well. If battery is fully charged then charge controller will connect the generator output to the dummy load. At low wind speed the generated voltage will be low and also load utilizes power from the battery will be reduced. If deep discharging happens, then the load should be disconnected from the system. When the wind speed reaches the cut-out velocity, then the charge controller makes a decision to apply break i.e., by making generator output terminal short circuited resulting in electromagnetic braking.

Pluse Width Modulation Charge Controller

PWMs help to regulate the often-inconsistent voltage put out by power sources. They protect the system batteries from overcharging. The PWM charge controller shown in Fig15 performs this by checking the state of the battery to determine both how long the pulses should be as well as how fast they should come. This type of charge controller provides several key benefits such as higher charging efficiency, rapid recharging and healthier batteries that operate at full capacity. The technology is important for systems that can go days or weeks with excess energy during periods when very little of the wind energy is consumed. Table 6 gives the specification of the charge controller.

The wind turbine is connected to the controller in operation and lines then run from the battery controller. All loads are taken from the battery directly. If the voltage of the battery falls below 11.9 V, the controller switches the power of the turbine to charge the battery. If the voltage level rises to 14 V, the control system switches into the dummy load to dump the turbine power. The voltage levels are adjusted by trimmings pots at which the controller switches back and forth between the two states. The battery voltage is between 11.9V and 14.8V.

The process can be switched between either charging or dumping whenever the battery voltage is between 11.9V and 14.8V and the system usually runs automatically. When the battery is charged, the yellow LED is lit. The green LED is lit when the battery is loaded and power is dumped to the dummy load.

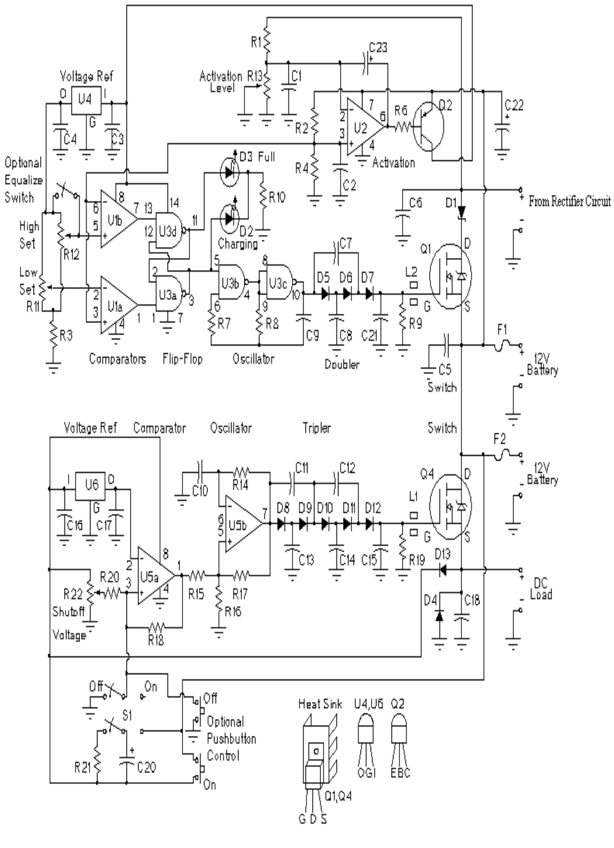


Fig. 15. Circuit Diagram of PWM Charge Controller

Table. 6. Specifications of Charge Controller monitoring of wind turbine parameters

Specifications	Range
Charge current max.	40A
Load current max.	40A
System voltage	12 V
Self-power consumption	< 4mA

To continuously analyses the performance of the wind turbine system and to monitor the system parameters a monitoring system is used. Parameters monitored are wind velocity, wind direction, temperature of the generator, output voltage of the generator. One of the objectives of the monitoring system is to measure the turbine power curve and the performances of the turbine-generator assembly with the charge and verify the design method for maximum load power. Most small wind turbines are direct drive types with permanent magnets synchronous generators for battery charging applications. Fig16 gives the general block diagram used for the monitoring system.

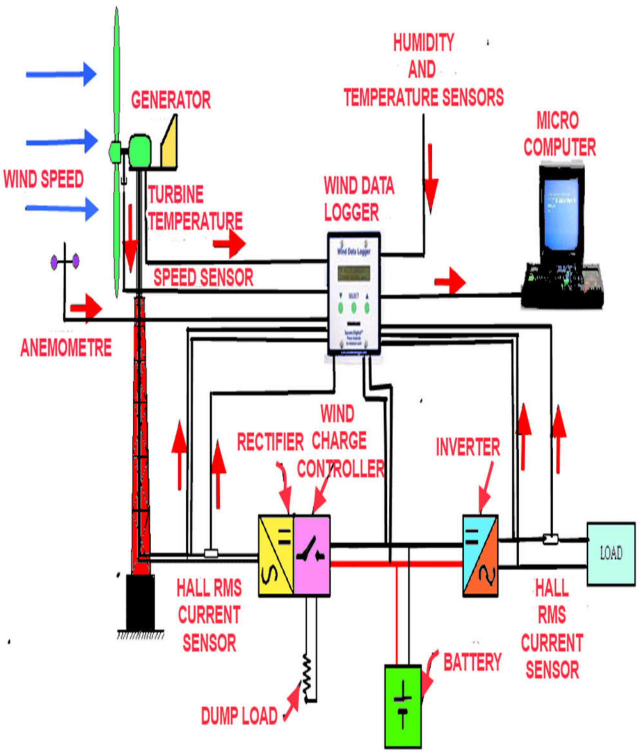


Fig. 16. Schematic Diagram of Wind Turbine Monitoring System

Measurement of Wind Velocity

An anemometer is a wind speed measurement device. The free-flowing wind speed appears as the cube for wind power extraction by rotor and is therefore one of the most important parameters. A small error can lead to a relatively large error in the results. Therefore, the selection of a proper anemometer was crucial. The tool consists of a cup mount (usually 3 or 3 cups) connected to a rotating vertical shaft as shown in Fig17. In fact, it is the most direct application of a wind rotor based on Savories drag. As the wind blows, the thrust is turned into a rotary torque due to the wind pressure. Atransducer, integrated with the instrument and transforming the rotational movement into electronic signals is electronically recorded per minute rotations. The wind speed of these electronic signals is then interpreted.

Fig. 17. Cup Type Anemometer for Measurement of Wind Speed

The anemometer includes a 3-cup rotor fixed to a steel spindle in a unique sensing system in which the rotor is pressed from the top with the spindle. The anemometer must be inverted and the rotor hub pressed up. The steel spindle turns the slotted disc, interrupting the light beam to measure the speed of rotation. This system results in a low threshold and allows highly precise measurements of wind speed. The integrated electrical modules convert the light beam signal into the analogue or pulse output required. The anemometer is attached to a mast with a screw attached to the base.

The IR reflectance sensors include a corresponding pair of infrared transmitters and infrared receivers. These devices measure the amount of light reflected in the recipient. As the receiver is also responsive to ambient light, the device works best when well protected from ambient light, and when the distance between both the sensor and the reflective surface is small. In general, white surfaces are good, while black surfaces are badly reflected. One of these applications is a robot's line follower. This set up used in the lower side rotor of the cup set. Infrared transmitter and receiver unit with comparator is given in Fig18. Whenever the transmitting IR signal is received in the receiver section, the comparator output is low to high. This signal is given to the microcontroller which in turn displays the wind velocity in m/s.

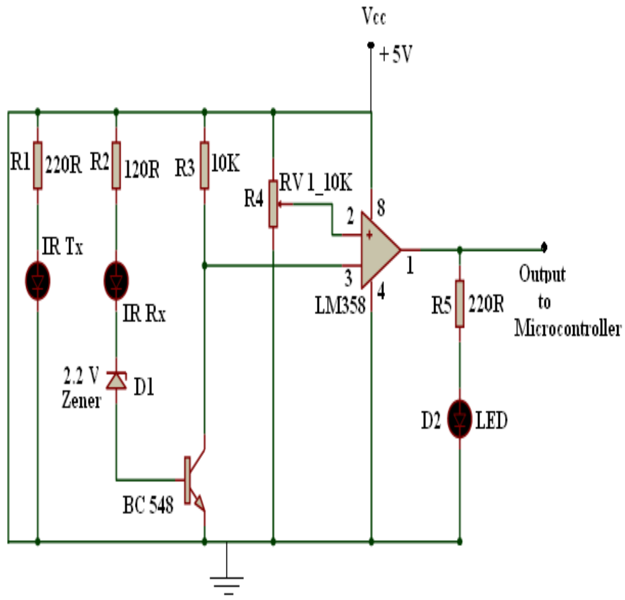


Fig. 18. Infrared Transmitter And Receiver Unit

Measurement of Wind Direction-Wind Vane

A wind vane is used to measure the direction of the wind. It consists of a fin fixed to a horizontal rod on the other side of the rod with a counterweight. The rod is mounted at the point of balance on a vertical spindle. In a horizontal plane, the wind vane can rotate freely. As the wind blows from one direction the wind blow adjusts to the direction of the wind (wind direction is defined as the direction, which the wind is blowing from). The position of the pointer is determined by a transducer that produces an electric signal in relation to a position of reference. A potentiometer is normally used as a transducer.

For measuring the wind direction, the fixed-reference wire-wound potentiometer was selected. Like the wind anemometer, the wind valve has a fastener at the base to mount it to a mast and an arrangement for gravitational sensing fastening to secure the valve arm movement of the spindle. A spindle clamp ensures that the fan arm mount is always mounted at a specific angular position on the spindle.

The stainless-steel spindle is attached to a potentiometer wiper by a rigid plastic upper bearing and a lower thrust bearing. The output of the potentiometer corresponds to resistance factor protected by the wiper, with a slight dead band segment of 3.5° close to the ends due to the small distance between connectors. The gap is filled with an insulator to make the transition from one terminal to the other smooth. As the wind blows from north to east, south and west, the sweater goes from the terminal on the track. Fig19 depicts the measurement of wind direction with aid of wind vane.

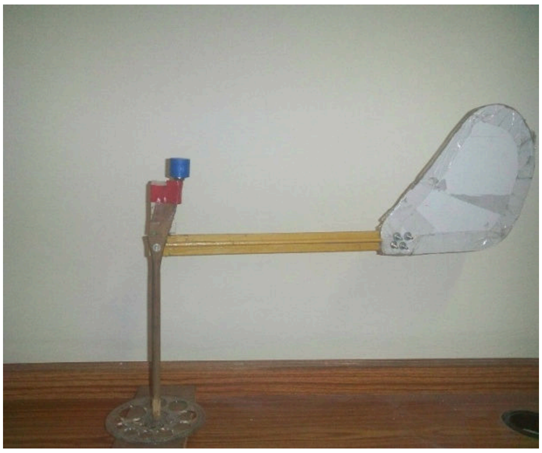


Fig. 19. Wind Vane for Measurement of wind direction

Temperature Measurement

The series LM35 is an integrated precision circuit temperature sensor where the output voltage is uniformly proportional to the temperature of Celsius (Centigrade). The LM35 therefore has an advantage over the linear temperature sensors measured in ° Kelvin, as a convenient Centigrade scaling is not necessary to remove high constant voltages from their output.

The low output impedances, linear output and correct inherent calibration of the LM35 make it particularly easy to communicate with or monitor the circuit. It can be used with single or plus or minus power supplies. Since it draws just 60 µA from its source, it has very low self-heating in still air of less than 0.1°C. The LM35 is classified for a temperature range between -55°C and +150°C whereas the LM35C is rated for a range between -40° and +110°C (-10° with improved precision). Fig 20 shows the graph depicting output voltage Vs temperature.

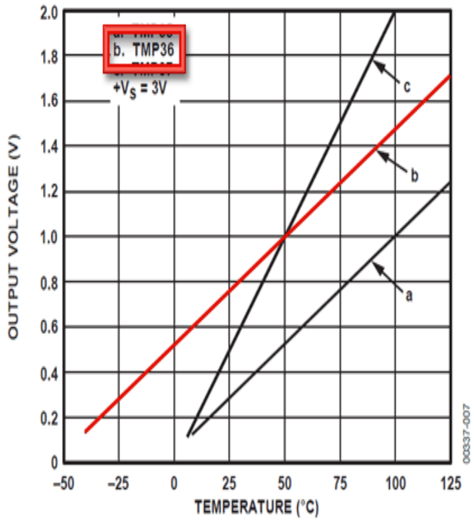


Fig. 20. Graph showing the Output voltage Vs Temperature

To convert the voltage to temperature, the following basic formula is used:

Temp in °C = [(Vout in mV) - 500] / 10

So, for example, if the voltage out is 1V that means that the temperature is ((1000 mV - 500) / 10) = 50 °C

If LM35 or similar is used, line 'a' in the image above is used and the formula is temperature in °C = (Vout in mV) / 10.

Power Measurement

Small wind turbines can be wired to charge batteries with DC or feed inverted AC directly into home. When using a monitor system to track wind power, the generated electricity must be measured at generator output power.

i) Generator Output Voltage:

In real wind speed the wind turbine system generates the output voltage which could be displayed with the help of LEM transducer and displayed in LCD. It is displayed in personal computer using visual basic. The generator output AC voltage and converts it to a standard output signal which is directly proportional to the measured input. The output can be connected to controllers, data-loggers, and recorders for display, analysis or control.

ii) Generator Output Current and Load Current:

The current value can be displayed using current HALL sensor i.e., LEM LTS 25 as shown in Fig 21. The load current value varies corresponding to the system load. The load current value can be displayed using current HALL sensor. This sensor is a single-axis IC magnetic field sensor that is designed for measurement of the AC and DC current applications. The current sensor is manufactured using traditional CMOS with an additional ferromagnetic layer. The ferromagnetic layer is used as an IMC to have a higher magnetic gain than would normally be possible. The circuit therefore has very high magnetic sensitivity with low offset and noise.

Fig. 21.Current HALL Sensor LEM LTS 25

System Controller ATMEGA 8535

The main functions of system controller are converting analog to digital (ADC) of all parameters and displaying parameters in LCD display. Selection of controller depends on various factors like in-build configuration like ADC and PWM modules, instruction execution time, etc. Here a peripheral interface controller of series AVR- AT mega 8535 has been employed as a system controller for this task.

Display Parameters and LCD Interface

The parameters are regularly monitored by the controller. After processing the information of these parameters, it can be displayed by using LCD which has been interfaced to the controller through port B. For this purpose, a dedicated 20 x 4 LCD has employed and it will show the all-condition monitoring parameters. Fig 22 shows the controller interface with the 20 x 4 LCD where pin 15 is for backlight control and pin 2 is connected to VCC supply.

Fig. 22. LCD Display Unit

The port D has 8 pins which is programmable as input /output. While interfacing with LCD all the port B pins are configured as output pins.

Wind Data Logger

Data loggers are programmed with the help of Visual Basic software (shown in Fig23). In this data logger, the various parameters can be monitored and displayed with the help of PC. Past historical data's can be used to analyze the performance of the wind turbine. For several purposes, data loggers may be used such that they can measure and record the parameters as well. The multifaceted capabilities of the data logger include operating as PLCs or RTUs. They have different type of channels that can measure almost all types of sensors on a single unit. If long cable runs are avoided, data loggers can be deployed in the configuration of a wireless network that allows economic monitoring at each stage of the wind evaluation tower.

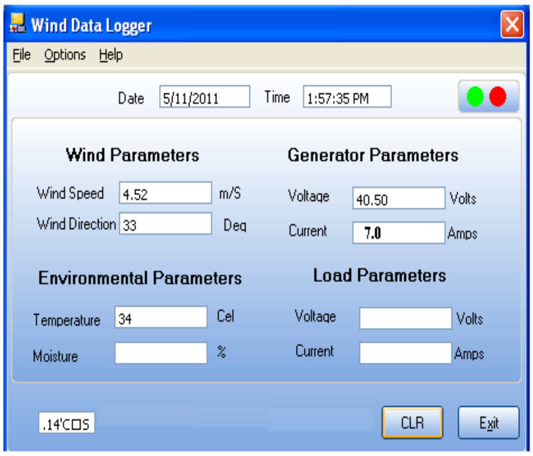


Fig. 23. VB Form With Interfacing of Various Parameters

Even under adverse circumstances, the reliability of data logger systems ensures data collection. Broad ranges of operating temperature and weatherproof boxes allow systems to work reliably in harsh environments. Data loggers continue to monitor and store data and perform control during power outages since they have their own power source (batteries, solar panels). The data is labeled with time and date for the detection and study of past events.

results and discussion

The output load performances of the wind turbine have been measured by using the power quality analyzer [22-23] and digital storage oscilloscope. Fig 24 depicts the graph drawn between wind speed Vs generator speed and Fig 25 shows the graph drawn between wind speed Vs generator output voltage.

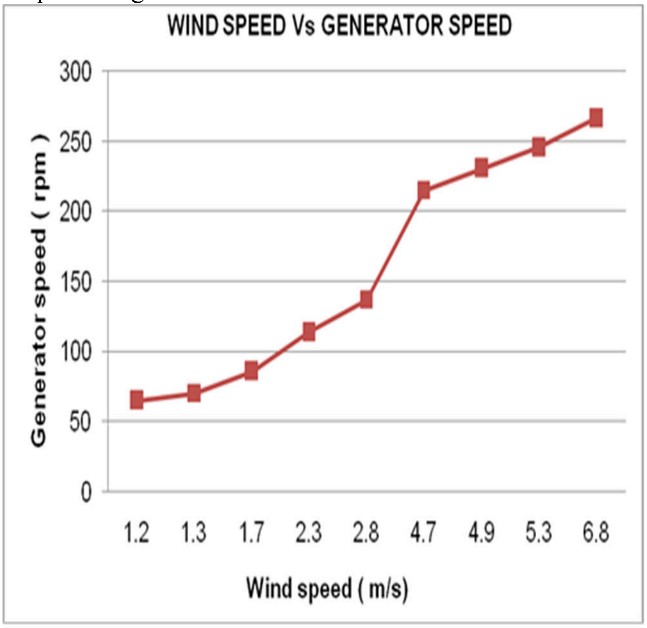


Fig. 24. Graph showing the Wind speed Vs Generator speed

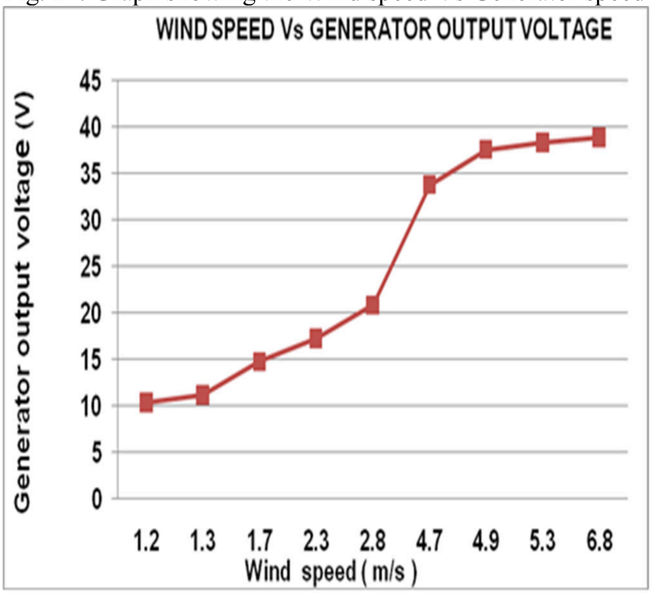


Fig. 25. Graph Showing the Wind speed Vs Generator output voltage

The output performance of the wind turbine is analyzed with the wattmeter, voltmeter and ammeter as shown in the wiring diagram in Fig26. The anemometer is to measure the velocity of the wind and the corresponding open-end voltage to be generated by the PMSG is measured and the readings are tabulated as given in Table 7. The output of the PMSG is directly connected to the lead acid battery. An ammeter (0-15 A) is connected series to the wind generator to measure the generator current. A voltmeter (0-100 V) is connected parallel to the wind generator to measure the generated voltage. A voltmeter (0-15 V) is connected parallel to the lead acid battery to measure the battery voltage. An ammeter is connected series with battery to measure the battery charging and discharging current value.

The output of the battery is connected to the inverter (400 VA) input to convert DC to AC single phase 230 volts. An ammeter (0-5 A) is connected series with inverter to load to measure the load current, and a voltmeter (0-400 V) is connected across the load to measure the load voltage. The wattmeter (400 V/2.5 A) is connected in load side to measure the load output power. The load performance is measured and tabulated. Digital storage oscilloscope and power quality analyzer are connected to the load setup to measure the no-load and various load conditions to measure the voltage, current and frequency readings.

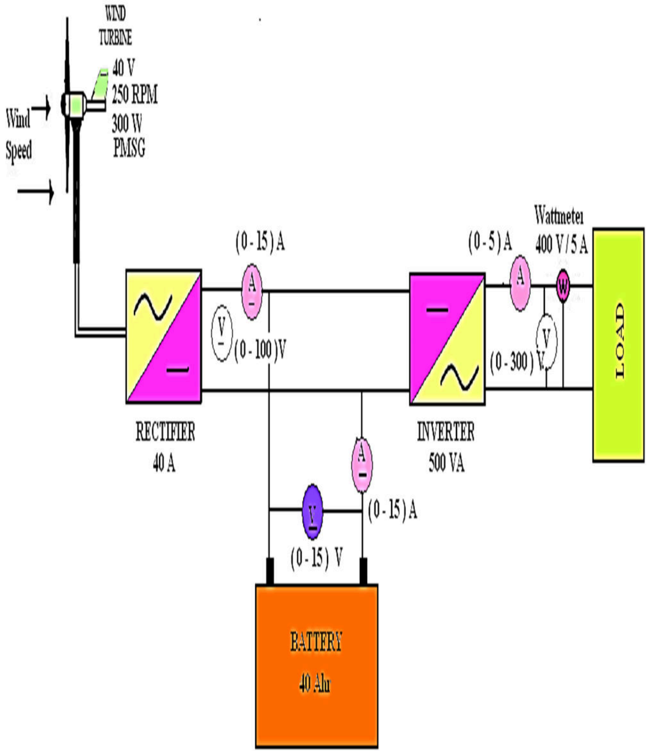


Fig. 26. Wiring diagram for Load Test on Wind Turbine

Total harmonic detections for voltage and current in each loading conditions are observed. The output voltage waveform, power and energy readings for various loading conditions are measured. The output waveforms measured by performance is analyzed and listed in Table 7. The experimental setup depicting the conversion process from AC-DC and DC-AC is shown in Fig 27.

Conclusion

The experimental setup was planned, monitored and verified in the labs of PSG College of Technology which provided useful information on the effective power produced on a small-scale basis. The following conclusions were drawn from the analysis of the field test results: In the case of the blade of the wind turbine (Aero foil Design -NACA4412), it has been designed and manufactured in such a way that even at a cut-in speed of 3m/s, optimum power is generated. This is due to the fact the blades have been manufactured using fiber-reinforced glass which makes the blade light weight and yet break-resistance. It produces rated power more than what is required of a low cut-in speed. The Permanent Magnet Synchronous Generator used in the experimental setup is re-engineered from an induction motor. This rotates at a speed of 250 rpm. The output frequency is of 50 Hz. The specialty with this generator is that it used an induction motor transformed by using 24 poles magnets which in-turn produces required voltage. The power obtained is of 25 watts. This makes the generator so unique given to the fact the cut-in speed is 3m/s and thereby acquiring the rated power. Monitoring system which is used to study the performance of the wind turbine by comparing the various system parameters such as wind speed and direction, generator output voltage and current, temperature information's were successfully implemented with the help of data loggers which can able to store the past data of parameters in the memory and also LCD which displays the present system parameters.

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Table. 7. Power Performance of the Wind Turbine System

Sl. No.	**Connected Load in Watts**	**Battery Voltage in Volts(V)**	**Battery Discharge current in Amps (A)**	**Input Power (W)**	**Output Voltage in Volts(V)**	**Output Current in Amps(A)**	**Output Power in Watts(W)**	**% Efficiency of Inverter (η)**
1	No Load	12.3	0	0	229	`0	0	0
2	100	12.2	10	122	215	0.4	90	73.77
3	160	12.2	14	171	214	0.7	150	87.71
4	200	12.0	17	204	211	0.8	180	88.23
5	260	12.0	21	252	210	1.0	220	87.30
6	300	12.0	26	312	215	1.18	260	83.33
7	360	11.8	35	413	214	1.4	340	82.23

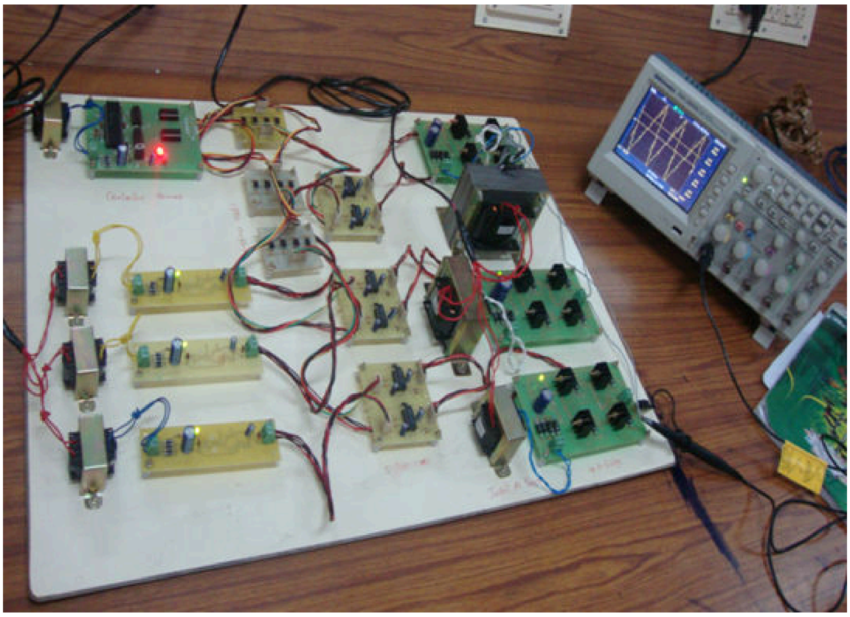

Fig. 27. Experimental Setup

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