Hybrid Test Bed of Wind Electric Generator with Photovoltaic Panels

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Abstract—Driven by the increasing costs of power production and decreasing fossil fuel reserves with the addition of global environmental concerns, renewable energy is now becoming significant fraction of total electricity production in the world. Advancements in the field of wind electric generator technology and power electronics help to achieve rapid progress in hybrid power system which mainly involves wind, solar and diesel energy with a good battery back-up. Here the discussion brings about the installation of real time test bed with a small electric generator and dynamic solar panels with battery backups.

Keyword- PMAC Generator, performance co-efficient, TSR, insolation, photovoltaic, WEG

I. INTRODUCTION

Renewable energy comes from natural sources that are constantly and sustainably replenished. The technologies featured in recent times make the homes healthier, more secure and more prosperous by improving the air quality, reducing reliance on fossil fuels, limiting global warming, adding suitable jobs to public, and above all protecting the environmental standards. Wind energy systems can also operate in parallel with diesel sets or solar PV systems. Induced by ecological issues, alarming threats of carbon footprint and passion for green future all set a initiative efforts to build a hybrid test bed which comprises a small capacity wind electric generator, two photovoltaic panels and a suitable battery back-up.

The organization of the paper begins with the introductory comment on renewables as a good reliable resource for better future; Section II discusses the issues related while constructing the hybrid power system particularly, a wind electric generator with photovoltaic panels. Mechanism and machinery used in small scale energy production has been explained in Section III. Section IV describes about the experimental set-up through real time implementation. Results and future extension is brought out in Section V. References and the specification sheets are pinned in the appendix.

II. ISSUES ON INTEGRATION

With new technology and new materials, modern wind turbines are being used to generate clean electricity for all types of needs. Power can be extracted from the kinetic energy of air mass available in atmosphere. As power is the product of energy within a given time frame, the power obtained from wind [1, 2] can be estimated by the formula given in Equation 1 as

$$P_{wind} = \frac{1}{2}\rho A V_w 3 \quad (1)$$

where ρair =1.25 kg / m3 the air density, A the rotor swept area, Vw the velocity of wind. The amount of energy in wind increases by a factor of two as its speed increases and is proportional to the mass of air that passes through the area swept by the rotors, especially for a horizontal axis wind turbine. As a result, if the diameter of the rotor blades is doubled, the power increases by a factor of four. If the wind speed then doubles, power increases by a factor of eight. Albert Betz [3] demonstrated in his theory of closed stream tube that a wind turbine can only convert a maximum of 16/27 or 59% of the energy in wind into electricity in 1920. This optimum performance Cp is attained only when a wind turbines' rotor slow the wind speed by one third. As the wind blow is intermittent and stochastic in nature, various technologies have been implemented right from the selection of site unto the implementation of wind power. About 50% of the entire energy is spelled out in just 15% of the operating time. Small wind electric systems can make a noteworthy contribution to our nation's energy needs nowadays.

A. Large area scanning and micro siting

The meteorological and geographical issue is first considered in selection of the best site for installing wind turbine or wind farms in case of small scale and large scale energy production respectively. The site chosen for installing the wind mill should not have any land dispute and free from environmental impacts. Compared to all other types of energy production wind power consume no fuel and hence emit no air pollution. But still the noise created near the site is horrible and reports of negative effects from the people who live very close to wind turbines never ended. Apart from zoning problems, it also affects bionetwork to a great extent. The area selected must be very large to accommodate multiple numbers of wind turbines without affecting one another while in operation [4]. Areas where wind speed is stronger and more constant, such as offshore and high altitude sites are the mostly preferred locations for raising wind farms.

B. Unpredictable wind blow

Another factor is forecasting of wind blow to get a better production of electricity. A good location for extracting wind energy should have an average wind speed of at least 12 miles/hour or 5.36 m/s. Wind strengths may vary and thus cannot guarantee continuous power. The lowest wind speed of about 3m/s at which a wind turbine starts producing utilizable power is called cut-in speed. The highest wind speed of about 30m/s called cut-out speed at which it is advisable to stop the turbine rotation and hence the power production. The optimum value of rotational speed of rotor is 1800 rpm which is the safe operating region of wind turbine.

C. Design of blades

The efficiency of power extraction from wind depends on the proper choice of blade numbers and blade materials. Also it depends on the tip speed ratio of blades. Mostly three blade turbine is preferred rather than two blade or multi-blade turbine assembly. In order to have highly stabilized system, the blades are usually 120° apart which provides dynamically balanced structure. Blade failure can be avoided simply by ensuring a high tensile strength along the direction of blades by choosing materials like glass fibre reinforced plastic (GRP), or epoxy materials, or even the aluminium metal.

D. Tower elevation

The installation of tower is a herculean task compared to all other jobs involved in the erection of wind turbines. The wind surveillance mainly depends upon the type of the tower and the pose it is been laid over. Whenever the blades cross the tower, the shadowing caused by the tower prevent the free wind blow ultimately decreases the energy production. Prestressed concrete towers are nowadays used in the erection of wind mill.

E. Economic factors

Lastly the energy generated by a wind turbine can meet the energy consumed to manufacture and transport the materials used to build a wind power turbine within a few months. Wind turbine manufacturer Vestas claims that the initial energy ‘pay back’ is within 8.6 months of operation for a small say, 2.0MW wind power plant under low wind conditions. Though the cost of extraction of wind power has decreased dramatically, the technology requires a higher initial investment than fossil-fuelled generators. Roughly 80% of the cost is devoted for machinery, the balance being committed to site preparation and installation.

F. Technical complexities

When all these above cited causes are somehow managed, it is increasingly becomes difficult to solve the technical complexities arising while operating the wind electric generators. As the wind power increases, the reactive power drawn from the grid also increases; accordingly capacitor banks or power capacitors are switched in or not to obtain the reactive power compensation; the R/X ratio should be close to unity. Flicker emission due to voltage fluctuations and frequency deviations are also a major issue causing power mitigation. Short circuit level and fault ride through recovery system should be increased.

The careful integration of renewable sources and superior interconnection standards can guarantee better output. Short duration voltage variations such as sag, swell, and interruption and transients can be avoided by introducing active filters and suitable controllers in affordable cost [5]. Power control and braking can be done by aerodynamics; Yaw motor control and pitch angle control with suitable drives align the wind turbine assembly to the predominant wind direction. The other notable factors include vibration and conditional monitoring, over speed control, cable twist limits, temperature control and load impacts on wind turbine might be of static, dynamic and fatigue and maintenance of all electrical and mechanical components.

III. Mechanism and Machinery

A. Components of Small Wind Electric System

A wind electric system is made up of a wind turbine mounted on a high altitude tower with wind masts to provide better access of stronger winds. In addition to the turbine and tower, small wind electric systems also require balance-of-system components which are otherwise, the accessories.

(i) Turbine

Mostly small wind turbines are of horizontal-axis, upwind machines that have two or three blades. These blades are usually made of composite materials such as fiber glass, aluminium metal. The turbine's frame is the structure onto which the rotor, generator, and tail are attached. The amount of energy a turbine will produce is determined primarily by the diameter of its rotor. The diameter of the rotor defines its "swept area," or the quantity of wind intercepted by the turbine. The tail keeps the turbine facing into the wind.

(ii) Tower

Since wind speed increases with higher altitude, more power can be produced if the tower height increases. Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, to raise a 10-kilowatt generator from a 60-foot tower height to a 100-foot tower involves a 10% increase in overall system cost, but it can produce 25% more power.

Generally there are two basic types of towers namely self-supporting (free-standing) and guyed. Most home wind power systems use a guyed tower, which are least expensive and are easier to install than the self-supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height, guyed towers require enough space to accommodate them. Tilt-down towers can also be lowered to the ground during hazardous weather conditions like hurricanes.

(iii) Balance of System Components

The balance-of-system parts which is needed for a small wind electric system in addition to the wind turbine and the tower depend on the application where it is been used. It also depends on whether the particular system is grid-connected, stand-alone, or hybrid. For example, a simple residential grid-connected wind turbine includes accessories like charge controller, storage batteries, an inverter, the power conditioning unit, wiring cables, electrical disconnect switch or relay, grounding system and the foundation for tower.

(iv) Braking methods

Braking of a small wind turbine can either be done electrically or mechanically. Electrical braking can be done by dumping energy from the generator into a resistor bank, converting the kinetic energy of the turbine rotation into heat. The turbine's rotation can be kept at a safe speed in faster winds while maintaining the nominal power output. This method is usually applied on small scale wind turbines.

In mechanical braking, a mechanical drum brake or disk brake is used to stop turbine in emergency situation such as extreme gusts or over speed prevails. This brake is also used to hold the turbine at rest for maintenance as a secondary cause, primarily acts as a rotor lock system. Such brakes are usually applied only the turbine speed reduces to ½ the rotor speed as the mechanical brakes can create a fire inside the nacelle if used to stop the turbine from full speed. Either turbine blades pitch control or yaw control mechanisms can be used as a brake under extremely strong wind conditions.

(v) Battery back-up

Deep cycle batteries are preferably suggested to store the excess power when the energy generated is surplus in standalone systems. The load demand can be met by sharing the generated power with grid power if there is a lack of power in generation, usually in a grid connected systems.

IV. TEST RIG ARRANGEMENT

Here, this test bed is made considering the abundant availability of non-conventional energy sources like wind and solar sources to obtain continuous power output round the clock even if only one source is available. The area has been chosen after carefully studying the availability and accessibility of the particular site which is having ample amount of sun light and an average wind speed of 5m/s. The site suited for erecting this experimental set-up has been located in our university campus.

The proposed hybrid model includes the combination of wind electric generator with photovoltaic panels raised over a single pole. A small wind electric generator of capacity 600 W is being put together with the two solar panels of each 80 W capacity. Each panel is laid over the pole about 10 feet above the ground level from the basement. They are tilted at 45° from the pole side and facing each other in order to trap the sun energy effectively. The tower constructed here is of a guyed type.

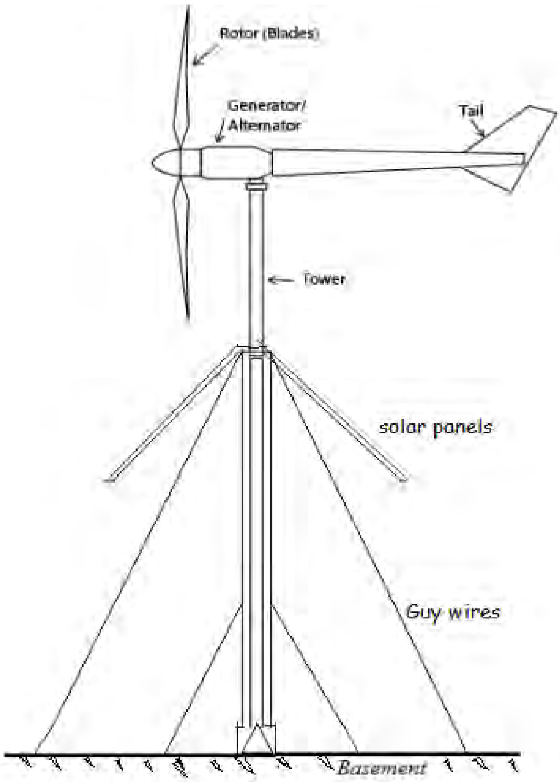

Fig.1 Lay-out of hybrid test-rig

The generation of electric power from the experimental set-up shown in Fig.1 depends upon airstream around the turbine, pitch angle control, dimension of blades and the blade material. The turbine rotor blade assembly is important in bringing the output power optimum. Since aluminium metal is weather resistant and resilient, it is suitable for small scale wind turbines. The set of three aluminium blades been bolted with the hub at the centre against each other. They are set dynamically 120° apart. The rotor blade converts the kinetic energy of the wind into rotational force that drives the turbine generator. The blade assembly is attached to the shaft of an alternator with the help of coupler as in Fig 5e.

A charge controller or regulator is necessary to charge the battery bank when the voltage approaches the set maximum voltage; then the controller turns on a dump load or shunts which would dissipate the excess power to prevent it from charging the batteries. Continuous over charging of batteries would boil the electrolyte dry and ruin the expensive battery bank. Charge controller connected between the charging source and battery used in conjunction with solar panels monitors the battery voltage, and once it reaches its full charge, the controller shorts the panel leads together and the energy ends up in heating transistors in the controller.

The usage of charge controller has made the battery to work efficiently and hence increases the life span of battery. Shorting the output of wind energy generator while it is spinning at high speed will generate a large current spike, possibly destroying the controller, perhaps even the generator. Also on no load it is not advisable to unhook the generator from the batteries suddenly, it would cause self destruction in strong winds. Hence the batteries are allowed to reach their full charge, and then switch to an alternate load where the energy can be safely handled.

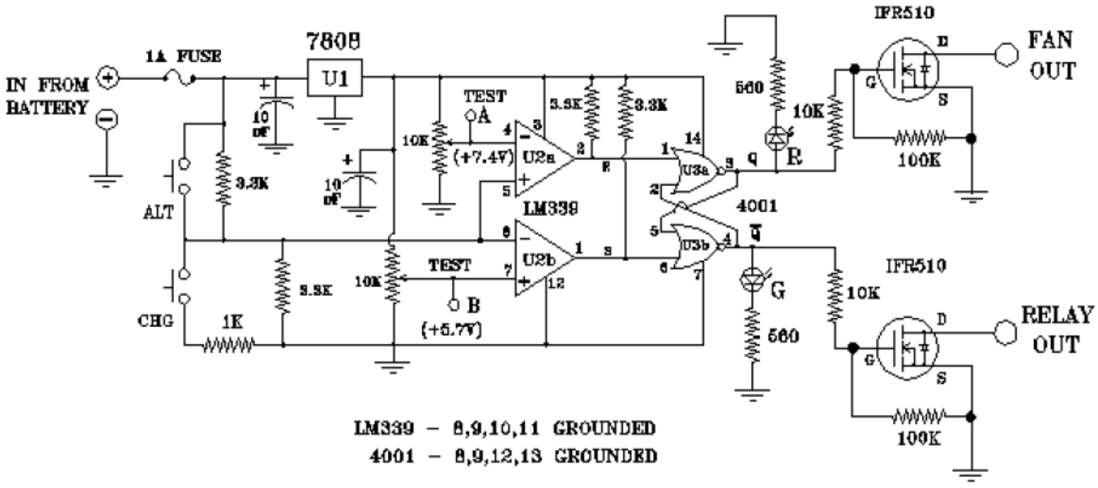

Fig.2 Circuit of charge controller

When the battery voltage measured is fallen below the set threshold value of 0.2-0.5V, below the float voltage the dump load is turned off and the battery charging process restarted.The working of charge controller circuit as in Fig.2 can be summarised as follows: The incoming battery voltage is divided into half by a pair of 3.3KΩ resistors, so the trip points are being adjusted to one half of the desired levels. The voltage ranges lies in between 14.5V and 11.8V for full charge state and discharge state respectively. The trim pots should be adjusted to read 7.25V at the test point TP-A and 5.9V at test point TP-B. The battery voltage should be monitored through several charge and discharge cycles to determine the perfect trip points for a particular system. The output of the controller is latched to drive a pair of IRF510 power FETs, which serve as relay drivers.

The two push buttons provide a way to toggle the output manually when the battery voltage lies in the null zone between the trip points. By momentarily pressing one of the buttons, the output state would reverse and latch. A 1KΩ resistor prevents a dead short, in case someone accidently presses both the buttons simultaneously. The charge controller is built on a small printed circuit board with integrated circuits and capacitors. Terminal blocks are soldered to the board for the incoming 12V and for connections to the relay coil.

When the battery is charging, each source is pulled down to the battery terminal voltage, such that each source contributes whatever current it can able to generate. Each blocking diode has to be sized for the rated current. The negative lead from each source is connected to ground. High current MOSFETs are used instead of relays making them highly reliable and robust. Light emitting diodes are used to indicate the current charging status: Green LED glows when the battery is fully charged, dumped load is ON and Red LED glows when the batteries are ready to be charged.

Additionally three 12V batteries are used to store the energy and intended to meet the load whenever none of the source is strong enough to produce sufficient amount of energy. Battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. The battery selected is of model No.6ELF39 to store energy. The improved version of this model has been designed for frequent deep discharge cycles during power cuts while retaining the excellent original features of highly discharge and good runtime [6].

The real time test model includes a number of procedures to install a hybrid prototype of 600W wind electric generator with two photovoltaic panels of capacity 80 W. The observations of wind speed at the particular site have been obtained at an altitude of 30 feet by means of a handheld wind anemometer positioned at different angles and is given by in Table.1 The motor speed is also tested at different speeds from 600 rpm to 200 rpm and different voltages at OCC and load test is obtained shown above. Also at about 600 rpm of rotor speed, motor is tested with different voltages and different current is obtained.

TABLE 1. WIND SPEED AT CHOSEN SITE

Altitude in feet	**Angle in deg**	**Wind speed in m/s**
30	45	8.1
30	60	8.3
30	90	8.7

It also includes the model of a solar photovoltaic array, maximum power point tracker (MPPT), battery, charger, DC/DC converter and load. The complete model is simulated under various testing conditions including sunny and cloudy periods for constant and varying loads can be combined effectively and every system is integrated to get a complete simulated model. The simple PVA model as in Fig.3 and the governing equations are listed.When sunlight falls on solar cells, a voltage is generated across its terminal and every solar cell acts like a charged battery. Generally 36 solar cells are connected together to get minimum of 12 volt from a single solar panel and 18 cells to 6 volt output. On average silicon solar PV module of one square feet gives peak output power of 10 to 12 Watt. The output current from the PV cell can be found using the equation (2)

$$I = I_{sc} - I_d \tag{2}$$

where,

Isc – short circuit current

Id –shunted current through intrinsic diode

And also the diode current is given by the Shockley's diode equation in (3)

$$I_d = I_0 (e^{\frac{qV_d}{kT}} - 1) \tag{3}$$

where,

Io-Reverse saturation current of the diode.

q-electron charge ($1.602*10^{-23}$C)

Vd-Voltage across the diode (V)

K-Boltzmann's constant ($1.381*10^{-23}$ J/K)

T-junction temperature in Kelvin (K)

Combining equation (2) & (3)

$$I = I_{sc} - I_0 (e^{\frac{qV_d}{kT}} - 1) \tag{4}$$

where

Vd -voltage across the PV cell

I-output current

The more accurate model in Fig.3 includes an extra diode D_2 along with series and parallel resistances.

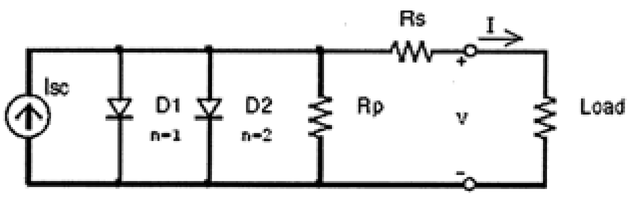

Fig.3.Accurate model of PV cell

The two diodes can be combined giving the equation

$$I = I_{sc} - I_0 [e^{\frac{q(v_d + IR_s)}{nkT}} - 1] - \left[\frac{V_d + IR_s)}{R_p} \right] \tag{5}$$

while n-ideality factor, takes a value between 0 and 1

In the practical PV cell, series resistance accounts for any resistance in the current path through semiconductor material, the metal grid, contacts, and current collecting bus while the effect is less negligible by shunt resistance. These resistive losses are lumped together and its effect becomes very noticeable in PV module that consists of many series connected cells, and the value of total resistance is calculated by multiplying it with the number of cells.

Periodically the wind speed is noted down and the average wind power density is found to be approximately 28.34 W/m^2 in the chosen site. The power is transmitted from wind turbine to the load through in several steps. In between these steps there are several losses of power. Power generated through wind turbine is passed through shaft of the motor to produce electromagnetic power. This electromagnetic power is given to generator and then this power is given to converter which is again given to the load to meet the required load demands. The performance plot in Fig.4 portrays the power curve for different wind speeds.

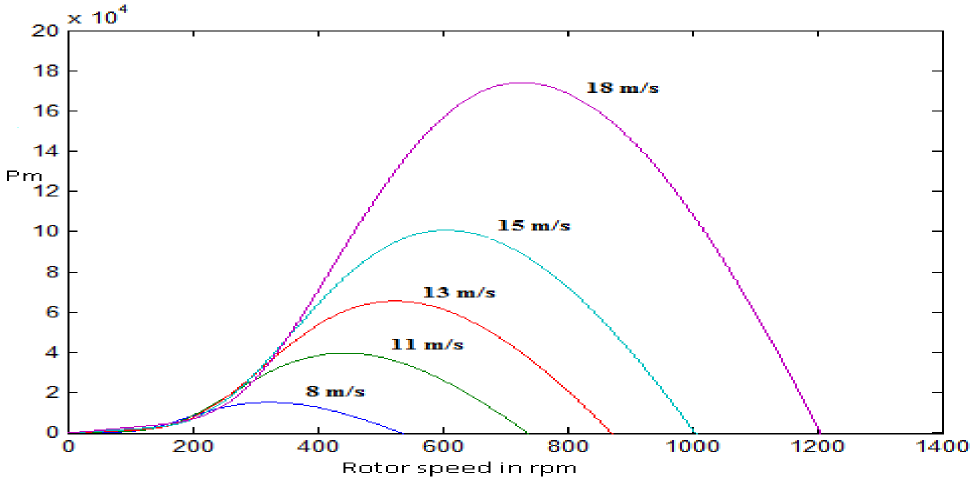

Fig.4 Power curve with rotor speed in rpm

The above curve shows the overall performance of wind turbine electric generator. The consecutive tables labelled as Table 2, 3 and 4 tells about the name plate details, the test report under OCC and load of the selected PM AC generator. The PMAC generator is selected because of its construction-wise merits such as symmetrical stator winding, uniform air gap, negligible magnetic saturation with minimal iron loss and ignorable harmonics in power converters [7]. Again this generator is less affected by rotor parameters and reduction in mechanical constraints eliminates the use of gear box which make the vector control implementation easier. PMSG When the rotor is driven by the wind turbine, electrical power is generated in the stator windings which are drawn through the cable of length down from tower height and then brought to the 3 bridge ac rectifier shown in Fig.5. The ac power is then converted into dc power. The bridge rectifier 16 NSR120 is of uncontrolled rectifier with 6 PN diodes. These are the standard recovery diodes available in normal and reverse polarity in stud version. The maximum average forward current is 16A. For an uncontrolled three-phase bridge rectifier, six diodes are used, and the circuit has a pulse number of six. In this six-pulse bridge, double diodes in series, with the anode of the first diode connected to the cathode of the second, are manufactured as a single component especially for low-power applications.

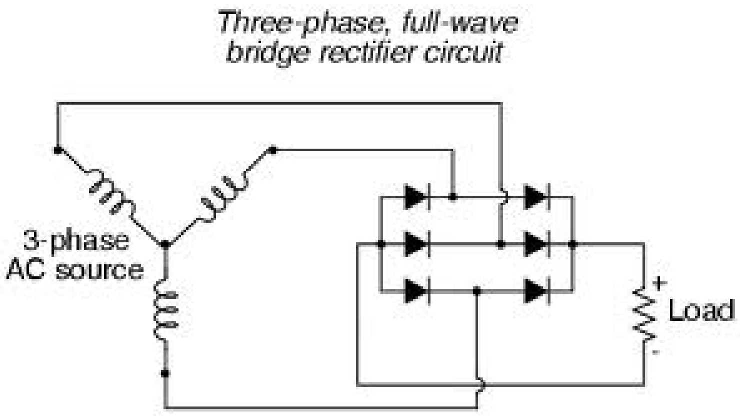

Fig.5 3 bridge ac rectifier

TABLE 2. NAME PLATE DETAILS OF PM AC GENERATOR

Parameters	**Ratings**
Power	500W
Voltage	48V
Current	6A
Rotor speed	600rpm
Winding resistance	3.2Ω
Ball bearing type	Self-Lubricating
Weight	17.57kg

TABLE 3.OCC TEST REPORT

Rotor speed in RPM	**Open Circuit Voltage in Volts**
600	70
500	58
400	47
300	35
200	24

TABLE 4.LOAD TEST REPORT

Speed in RPM	**Output Voltage in Volts**	**Output Current in Amps**
600	70	--
	64	1.2
	59	2.0
	56	2.8
	54	3.7
	50	5.0
	48	6.0

The descriptions of mechanical and electrical components used in this test bed have been given in the Tables 5, 6&7.

TABLE 5. DESCRIPTION OF MECHANICAL COMPONENTS

Description of the items		**Quantity**	**Dimension**	**Material used**
Tower		1	Height-30’3.”	Cylindrical steel tubing
Turbine blades		3	Length-3’1⁄₂”	Fibre Glass
			Weight-1.29 kg each	
			Circumference-6’11.46”	
Hub and coupler	Supporting block	Each of 1	Height-8cm	Mild steel
	Base joint		Width-21cm	
	Base plate		Length-35cm	
	Plate thickness		Thickness- 10mm	
	Innerdiameter		Φ-24mm	
Ball bearings		1	Weight-4.02kg	Mild Steel

TABLE 6. DESCRIPTION OF ELECTRICAL COMPONENTS

Description of the items	**Quantity**	**Components used**
3 bridge ac rectifier	1	Stud version(6 diodes)
3 PMAC alternator	1	--
Wind turbine with charge controller	1	Resistors MOSFETs Op Amps LEDs Wires
Solar panels each with charge controller	2	

The various snapshots of the entire test bed has been depicted in figures from Fig.6a to Fig.6f

a)Blade elements

b) Assembled blades

c)Hub with coupler

d)PMAC Generator

e) Blade assembly connected to the shaft

f) Whole set-up coupled with tower

Fig.6 Various snap shots showing the pre-assembled components of WEG

The entire project lay out has been depicted in Fig.7.The results taken on 30th March 2013 when the wind speed is about 4.8 m/s has been noted with multimeter. The generated output is of 3 ac voltage in all the three phases R, Y and B terminals and tabulated as in Table.7. The solar modules are tested for their electrical performance characteristics and found that the open circuit voltage and the short circuit current are 23.01 V and 4.92A respectively. The unique integrated approach averts the need for the dedicated communication between the two sources for coordination and eliminates the use of a separate boost converter stages required for PV power processing [8].

Fig.7 Real time implementation of hybrid bed

TABLE.7 OBSERVATION

Generator Terminals	**Generated 3 output in Volts**
R	11.39
Y	10.5
B	12.27

V. Results and future trends

This hybrid test model is intended to power the lightings in the laboratory nearby. It is proposed at least 10 fluorescent lamps would be getting a constant supply from this set-up. A 1kVA, 150Ah inverter is needed to supply the required power. This extension of supply to the laboratory is in progress, and further the introduction of bearings near the foot of the alternator to rotate the whole hub around 360° according to the wind direction, to get more output. Braking either disc brake or hydraulic one has to be laid whenever it is necessary to stop the wind turbine; wind speed exceeds the safe limits. All the parameters like wind speed, voltage, current, vibration, temperature and output from each solar panels can be continuously monitored using data logger and updated readings can be sent through messages either by mobiles or by GPS system.

The world is in need of safe, affordable sources of energy. Let’s continue to work together to bring a harmless, fruitful energy efficient green future at right time...

APPENDICES

i. Specification of a battery

Specification	**Range**	
Nominal monobloc unit voltage	12 V	
Charging current for initial charging (Amps)	Starting 2.35V per cell	5.5
	Finishing 2.75V per cell	2.7
Minimum Ah input during initial charge	140 Ah	
Approx battery + weight(1.220 Sp. Gr./cell)	Without acid(kg)+/-2%	3.25kg
	Filled with acid(kg)+/-2%	6.9 kg
Approx+acid quantity	11.2 litres	
Overall dimension	Length	10 mm
	Width	76 mm
	Height	81 mm
Constant potential limiting current	10 Amp	
Trickle charge current	Maximum	60 mA
	Minimum	0 mA

ii. Capacity range of battery

Hours	**Capacity in AMPERE-HOUR at 27° when discharge occurs**
10	39.0
5	33.8
3	30.0
2	27.5
S	23.5

iii. Specification of solar module

Model No	**MS1274**
Voc (Open Circuit Voltage)	22.32 V
Isc (Short Circuit Current)	4.36 A
Vm (Rated Voltage)	18.1V
Im (Rated Current)	4.10 A
Maximum System Voltage	1000V
Maximum Power	74watts
Temperature	25° C
AM	1.5
Tolerance at Maximum Power	±5%

iv. Project expenditure

Description of items	**Cost in Rs**
3 PMAC alternator	18,000.00
Solar panel with charge controller	4000.00
Wind anemometer	3000.00
Wind turbine charge controller	1500.00
3 ac bridge rectifier	1100.00
Hubs and coupler	1000.00
Ball bearings	500.00
Miscellaneous	900.00
Total	30,000.00

*These costs do not include installation cost of tower mountings, blade materials, cables and basement.

REFERENCES

[1] Rui Melício, Victor M. F. Mendes and João P. S. Catalão (2011). Wind Turbines with Permanent Magnet Synchronous Generator and Full-Power Converters: Modelling, Control and Simulation,Wind Turbines, Dr.Ibrahim Al-Bahadly (Ed.), ISBN: 978-953-307-221-0, InTech,
Available from: http://www.intechopen.com/books/wind-turbines/wind-turbines-with-permanent-
Magnet-synchronous generator- and-full-power-converters

[2] Wind Turbine Power Calculations, Royal Academy of Engineering

[3] Magdi Ragheb and Adam M. Ragheb (2011). Wind Turbines Theory - The Betz Equation and Optimal Rotor Tip Speed Ratio, Fundamental and Advanced Topics in Wind Power, Dr. Rupp Carriveau (Ed.), ISBN: 978-953-307-508-2, InTech, Available from: http://www.intechopen.com/books/fundamental-and-advanced-topicsin- IEEE Std. 802.11, 1997.

[4] A Technical note on micrositing of wind turbines, Centre of Wind Energy Technology

[5] Fadaeinedjad Roohollah, Moallem Mehrdad, MoschopoulosGerry.Simulation of a wind turbine with doubly fed induction generator by FAST and Simulink.IEEE Transactions on Energy Conversion 2008; 23(2).

[6] Min Chen, Student Member, IEEE, and Gabriel A. Rincon-Mora, "Accurate electrical battery model capable of predicting runtime and I-V performance", IEEE Transactions on Energy Conversion, vol. 21, No.2, pp. 504-511, June 2006.

[7] Zhonghui Zhang, Jiao Shu, "Matlab-based Permanent Magnet Synchronous Motor Vector Control Simulation"

[8] Jain Sachin, Agarwal Vivek, "An integrated hybrid power supply for distributed generation applications fed by non conventional energy Sources",. IEEE Transactions on Energy Conversion 2008; 23(2):622–31.
Available from: http://www.cwet.tn.nic.in/