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Design and Modeling of Vertical axis wind turbine and SolarPV Hybrid Power Generation System

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***Abstract*— Electricity consumption will comprise an increasing share of global energy demand during the next two decades. In recent years, the increasing prices of fossil fuels and concerns about the environmental consequences of greenhouse gas emissions have renewed the interest in the development of alternative energy resources.The design of a hybrid electric power generation system utilizing both wind and solar energy for remote area is today's need. Wind power is the conversion of wind energy into a useful form of energy. Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions. The system has two basic components – one for generation of electricity through Solar Energy and another one for generation from Wind Energy. Even in the case of absence of either of the two sources, the other remaining source could be used to supplement the absence of the former. The solar energy is available throughout year and it is free and clean sources of energy.The power from wind current can be extracted using a vertical axis turbine. Vertical axis turbine is capable of extracting power form wind regardless of the direction of flow. The solar PV cells absorb the radiation of sun and converting it into the electrical power.. The combination of this hybrid system will be beneficial in future aspects. The entire hybrid system is described given along with comprehensive simulation results that discover the feasibility of the system.**

Keywords*— *Vertical axis wind turbine,modelling of PV cell,modelling of wind turbine,DC-DC Boost converter.

I. INTRODUCTION

Due to the critical condition of industrial fuels which include oil, gas and others, the development of renewable energy sources is continuously improving. This is the reason why renewable energy sources have become more important these days. Few other reasons include advantages like abundant availability in nature, eco-friendly and recyclable. Many renewable energy sources like solar, wind, hydro and tidal are there. Among these renewable sources solar and wind energy are the world's fastest growing energy resources. With no emission of pollutants, energy conversion is done through wind and PV. Day-by-day, the demand for electricity is rapidly increasing. But the available base load plants are not able to supply electricity as per demand. So these energy sources can be used to bridge the gap between supply and demand during peak loads. This kind of small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is impractical.

In this paper, a wind-photovoltaic hybrid power generation system model is studied and simulated. A hybrid system is more advantageous as individual power generation system is not completely reliable. When any one of the system is shutdown the other can supply power.The entire hybrid system comprises of PV and the wind systems[1]. The PV system is powered by the solar energy which is abundantly available in nature. PV modules, maximum power point tracking systems make PV energy system. The light incident on the PV cells is converted into electrical energy. The maximum power point tracking system with perturb and absorb algorithm is used, which extracts the maximum possible power from the PV modules.

II. INTRODUCTION TO HYBRID SYSTEM

A. Solar Cell or PV Cell

Solar power is the conversion from sunlight into electricity, either directly using Photovoltaic (PV), indirectly using concentrated solar power, or a combination. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect.

Solar Energy refers to the energy from the sun. The sun has produced energy for billions of years. And it is the most important source of energy for all life-forms. It is a renewable source of energy unlike non- renewable sources such as fossil fuels. The main benefit of solar energy is that it does not produce any pollutants and is one of the cleanest source of energy.

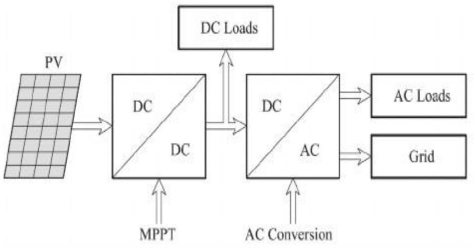

Fig 1 Photovoltaic Arrangement

B. Vertical axis wind turbine

Vertical axis wind turbines, as shortened to VAWTs, have the main shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds. With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawbacks of a VAWT generally create drag when rotating into the wind.It is difficult to mount the vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop.


Fig 2. Vertical axis wind turbine

However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

Types Of Vertical Axis Wind Turbines

a) Darrieus Type
b) Giromill Type
c) Helical Blades Type
d) Cycloturbine type
e) Savonius Type

a) Darrieus Wind Turbine Type

The Darrieus wind turbine is a type of vertical axis wind turbine (VAWT) used to generate electricity from the energy carried in the wind.

Fig 3. Darrieus Wind Turbine

b) Giromill Wind Turbine Type

Due to the several limitations of the Darrieus wind turbine, several modifications have been made to improve productivity, efficiency and design downtime. Giromill is a subtype of Darrieus turbine with straight blades, as opposed to curved. It uses 2 or 3 straight blades individually attached to a vertical axis.


Fig 4. Giromill Wind Turbine

c) Helical Blades Wind Turbine Type

Another type of Darrieus design is called Helical Blade Vertical- Axis Wind Turbine. This idea firstly inspired by Gorlov Helical Water Turbine. By replacing the blades of a Giromill with helical blades attached around a vertical axis (as DNA structure), it is possible to minimize the pulsating torque that can cause the main bearings to fail on Darrieus-derived designs. Helical blade design is used by the Turby, Urban Green Energy, Enessere and Quiet Revolution brands of wind turbines

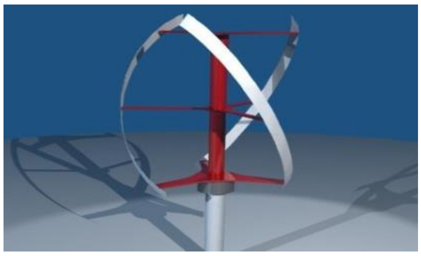
Fig 5. Helical Blades Wind Turbine

d)Cycloturbine Type

Blades around the vertical axis are embedded in this design, which allows them to be appropriately pitched so they always have an angle of attack and are Self starting, a distinct advantage over the original Darrieus design. This change increases the overall efficiency of the turbine, but increases its complexity. In the beginning, the Blade angle changes and reduces the startup torque required and avoids the need for a starter.

e) Savonius Wind Turbine Type

Another type of VAWT was invented in 1922 by Sigurd Johannes Savonius from Finland. It is called Savonius type VAWT. It is a drag based VAWT which operates in the same way as a cup anemometer. However, Savonius wind turbines efficiency is around 15%. That meansjust 15% of the wind energy hitting the rotor is turned into a mechanical energy. It is much less than Darrieus type.

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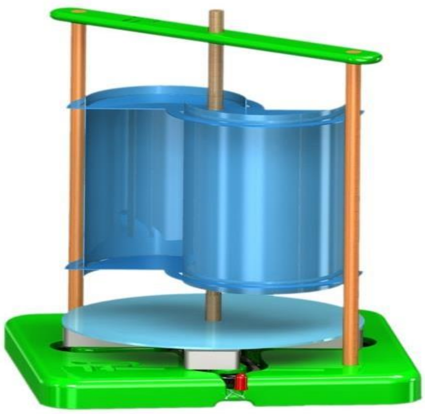
Fig 6. Savonius wind turbine type

III. MODELLING OF RENEWABLE ENERGY SOURCES

A. MODELLING OF PV CELL

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. manifests the equivalent circuit of PV cell [1]. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.

$$I = I_{pv} - I_o\left[\exp\left(\frac{V+R_sI}{V_t a}\right) - 1\right] - \frac{V+R_sI}{R_p}$$

(1)

Where
I_{PV}–Photocurrent current,
I_O–diode's Reverse saturation current,
V–Voltage across the diode,
a– Ideality factor
V_T –Thermal voltage
Rs– Series resistance
Rp–Shunt resistance

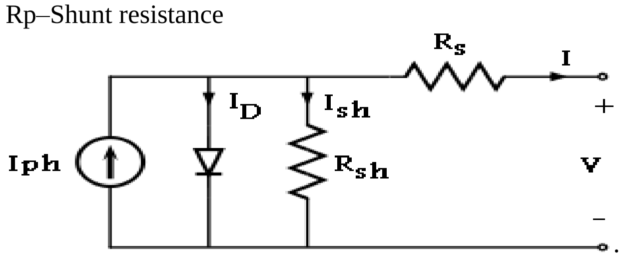

Fig 7. Equivalent circuit of Single diode modal of a solar cell

PV cell photocurrent, which depends on the radiation and temperature, can be expressed as.

$$I_{PV} = (I_{PV\_STC} + K_I\Delta T)G/G_{STC} \qquad (2)$$

Where
K_I– cell's short circuit current temperature coefficient
G–solar irradiation in W/m2
G_{STC}–nominal solar irradiation in W/m2
I_{PV_STC}– Light generated current under standard test condition

The reverse saturation current varies as a cubic function of temperature, which is represented as

$$I_O = I_{O\_STC}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \qquad (3)$$

Where
I_{0_STC}– Nominal saturation current
Eg – Energy band gap of semiconductor
T_{STC}–temperature at standard test condition
q – Charge of electrons
The reverse saturation current can be further improved as a function of temperature as follows:

$$I_O = \frac{\left(I_{SC\_STC} + K_I\Delta T\right)}{\exp\left[\frac{\left(V_{OC\_STC} + K_V\Delta T\right)}{aV_T}\right] - 1} \qquad (4)$$

I_{SC_STC}- short circuit current at standard test condition
V_{OC_STC}– short circuit voltage at standard test condition
K_V– temperature coefficient of open circuit voltage

B. MODELING OF WIND TURBINES

Mechanical work is a form of energy, which is given by force multiplied by distance

$$E = W = Fs$$

Force is given by mass multiplied by acceleration

$$F = ma$$

$$E = mas \qquad (5)$$

From kinematics of solid motion, $v^2=u^2+2as$

$$a = \frac{v^2-u^2}{2s}$$

Substituting (2) in (1), we get

$$E = \frac{1}{2}mv^2$$

The power P in the wind is given by the rate of change of kinetic energy

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt}v^2$$

Mass flow rate $\frac{dm}{dt}$ is given by

$$\frac{dm}{dt} = \rho Av$$

Therefore,

$$P = \frac{1}{2}\rho Av^3$$

The actual mechanical power Pw extracted by the rotor blades in watts is the difference between theupstream and the downstream wind powers

$$P = \frac{1}{2}\rho Av(v_u^2 - v_d^2) \qquad (6)$$

From the mass flow rate,

$$\rho Av = \frac{\rho A(v_u+v_d)}{2} \qquad (7)$$

From the mass flow rate,

$$P_w = \frac{1}{2}\rho A(v_u^2 - v_d^2)\frac{(v_u + v_d)}{2}$$

$$P_w = \frac{1}{2}\rho A\left\{\frac{v_u}{2}(v_u^2 - v_d^2) + \frac{v_d}{2}(v_u^2 - v_d^2)\right\}$$

$$P_w = \frac{1}{2}\rho A\left\{\frac{v_u^3}{2} - \frac{v_u v_d^2}{2} + \frac{v_u^2 v_d}{2} - \frac{v_d^3}{2}\right\}$$

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$$P_w = \frac{1}{2}\rho A v_u^3 \left\{\frac{1}{2}\left(1 - \frac{v_d^2}{v_u^2} + \frac{v_d}{v_u} - \frac{v_d^3}{v_u^3}\right)\right\}$$

$$P_w = \frac{1}{2}\rho A v_u c_p$$

Where, coefficient of performance $c_p = \frac{1}{2}\left(1 - \frac{v_d^2}{v_u^2} + \frac{v_d}{v_u} - \frac{v_d^3}{v_u^3}\right)$

IV. BOOST CONVERTER

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage[4]. A schematic of a boost power stage is shown in Figure 8.

When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be. As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load.

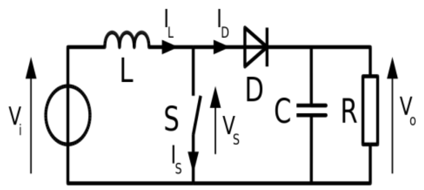

Fig 8. Boost converter schematic

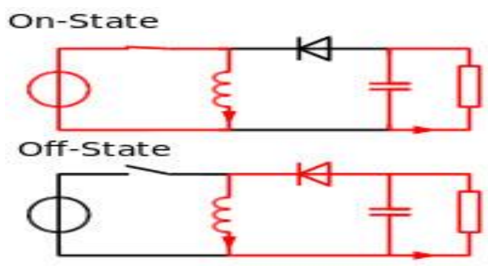

Fig 9. State of the switch

V. WORKING MODELS OF HYBRID SYSTEM

The vehicle moves on the both sides of the highway divider, then some pressurized air is produced to the speed of vehicle. This air is strikes on the turbine blades and turbine makes rotation.The shaft of VAWT is connected to generator with help of gear mechanism.The generating electricity in alternating quantity, the output of the generator is rectified by rectifier and stored in battery the solar system is mounted on the upper part of the vawt; the position of solar plates is in inclined nature at an angle of 45 degrees

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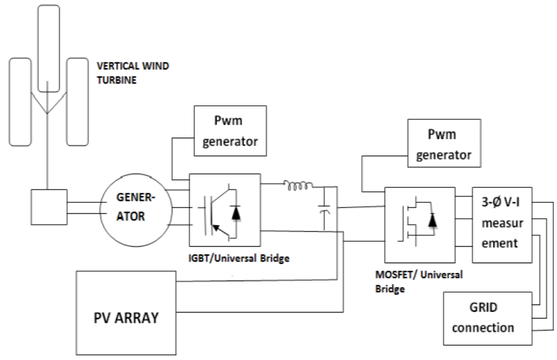


Fig 10. Block diagram of hybrid system

5.1. MODELING OF SOLAR PV MODULE

STEP I

This subsystem is calculates the short circuit current (ISC') with inputs of

Solar Insolation/irradiance (S) = 900w/m2,

Ambient temperature (Tamb) = 28°C,

Short circuit current (ISC) = 3.02A,

Reference temperature (Tref) = 60°C.

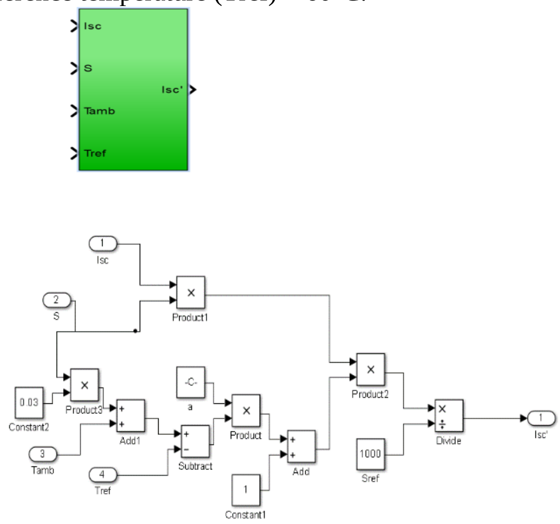


Fig 11. Circuit of subsystem to calculate Isc'

STEP II

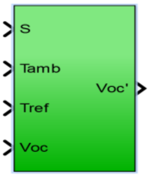
This subsystem is calculates the open circuit voltage (Voc') with inputs of

Solar Insolation/irradiance (S) = 900w/m2,

Ambient temperature (Tamb) =28°C,

Open circuit voltage (Voc) = 2.93A,

Reference temperature (Tref) = 60°C.



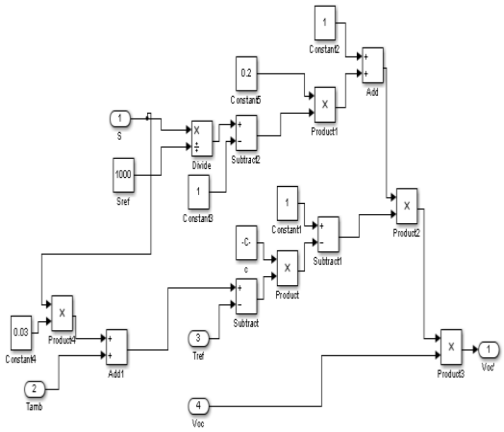


Fig 12. circuit of subsystem to calculate Voc'

STEP III

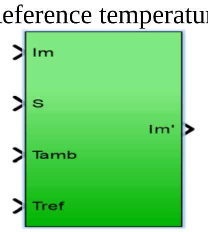
This subsystem to calculate the current at Maximum power (Im') with inputs of

Solar Insolation/irradiance (S) = 900w/m2,

Ambient temperature (Tamb) =28°C,

Maximum current (Im) = 2.93A,

Reference temperature (Tref) = 60°C



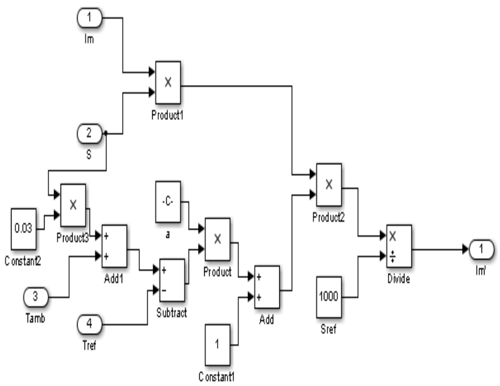


Fig 13. Circuit of subsystem to calculate Im'

STEP IV

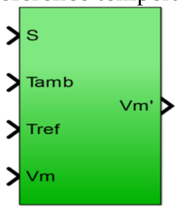
This subsystem to calculate The Voltage at Maximum power (Vm') with inputs of

Solar Insolation/irradiance (S) = 900w/m2,

Ambient temperature (Tamb) =28°C,

Maximum voltage (Vm) = 75.4V

Reference temperature (Tref) = 60°C



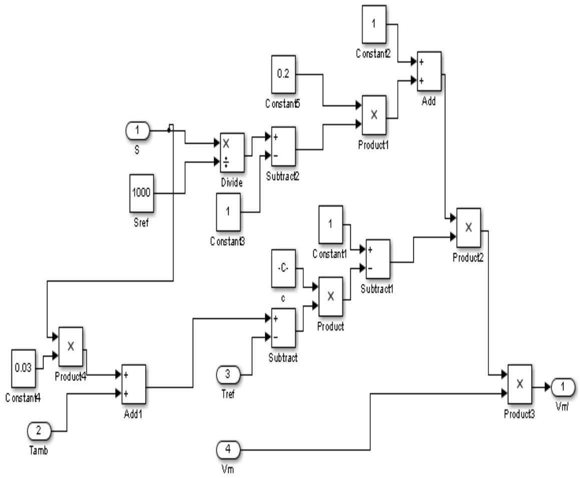


Fig 14. Circuit of subsystem to calculate Vm'

STEP V

A complete connected model of subsystems is shown in fig 5.10. In this figure all subsystems are interconnected to calculate the incident light current Ipv.

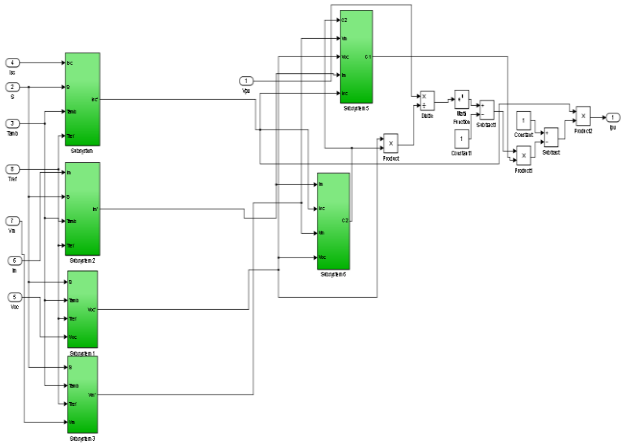


Fig 15. Interconnection of all subsystems

It shows the complete model of PV array, we get after connecting all the subsystems simulated above to calculate the photo current (Ipv).

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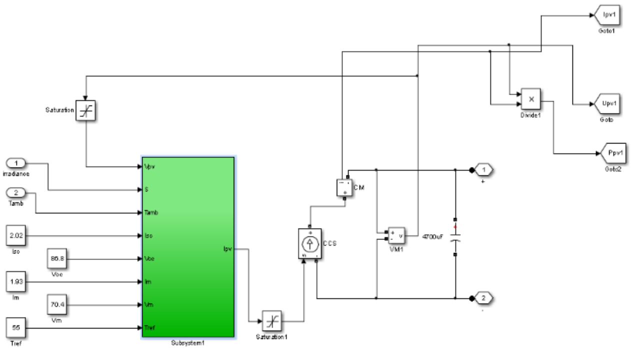

FIG 16. COMPLETE MODEL OF PV ARRAY

5.2. MODELLING OF WIND TURBINE

Wind energy is an environment friendly and endless source. Therefore, a wind energy generation system may be one of the promising sources of alternative energy for the future demand. Wind turbines convert the kinetic energy of wind into mechanical energy. The magnitude of this converted mechanical energy depends on the air density and the wind velocity. The wind power (Pm) that is developed by the turbine is given by the equation:

$$P_m = \frac{1}{2} C_p(\lambda, \beta)\rho A w^3$$

Where

C_p = performance coefficient of turbine
ρ = air density (kg/m3)
A = area of turbine blades (m3)
w = wind velocity (m/sec)
λ = tip speed ratio of the rotor blade tip speed to wind speed
β = blade pitch angle (deg)

The coefficient CP is the fraction of kinetic energy which is converted by wind turbine into mechanical energy. It is related to the tip speed ratio (λ). Wind turbine output torque (Tm) can be calculated using equation:

$$T_m = \frac{1}{2}\rho A C_p \frac{W}{\lambda}$$

Using above equations a Simulink model is implemented as shown in fig 17.

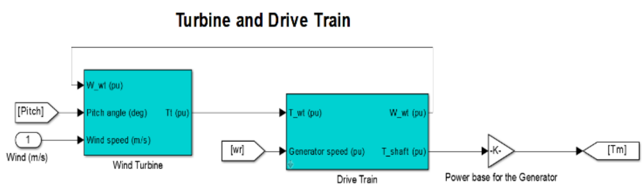

Fig 17. Simulink model of wind turbine

5.3 MODELING OF HYBRID WIND/PV SYSTEM

Complete Simulink Model Of Grid Connected Wind/PV Hybrid System

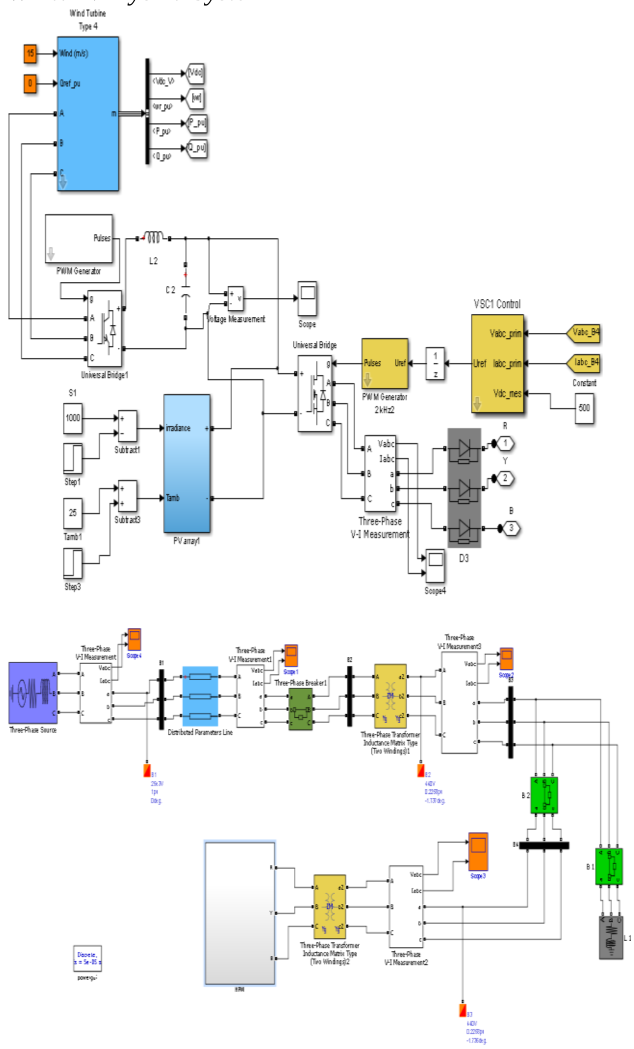

Fig 18. Simulink model of WIND/PV Hybrid system

V.RESULTS

Simulation Result Of Dc Output Voltage Of Wind System

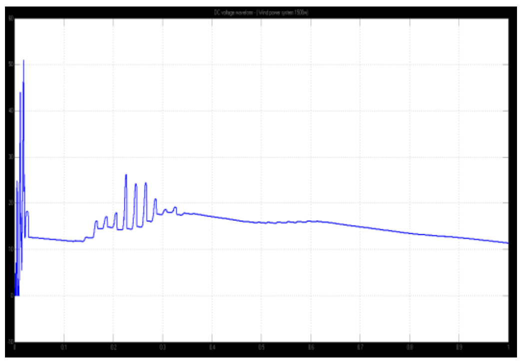

Fig 19. DC OUTPUT VOLTAGE OF WIND SYSTEM

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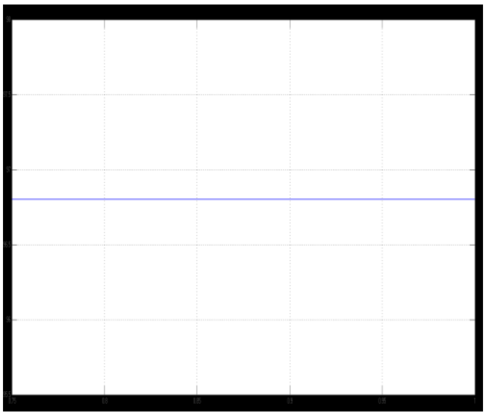

Fig 20. DC Output Voltage of PV System

Simulation Result Of Total Ac Output Voltage Of Grid Connected Both Wind/PV Hybrid System

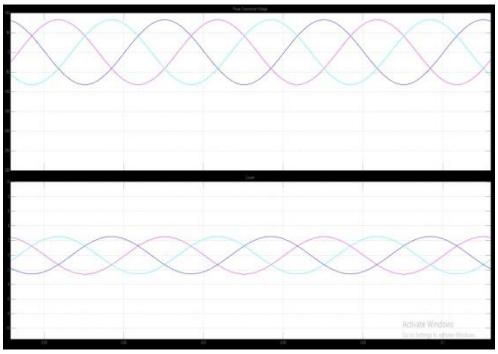

Fig 21. Total AC Output voltage of Grid Connected Hybrid System

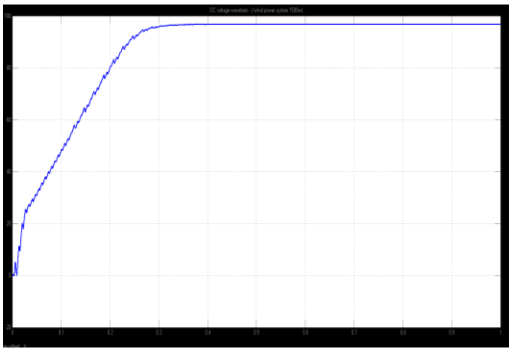

Fig 22. DC Output voltage of Hybrid system

VI. CONCLUSION

The simulation result of implemented hybrid system shows the generated output voltages which can be supplied to the grid. This hybrid system is more reliable as compared to single energy system. Vertical axis wind energy conversion systems are practical and potentially very contributive to the production of clean renewable electricity from the wind There is less scope for an abrupt halt in power generation. This system is quite useful for backward, rural areas which face severe shortage of electricity but have abundant solar and wind energy

The VAWT can be a good alternative source of energy to the non- renewable resources and by using this model all the small villages can be lightened without the use of conventional energy source. Both the systems are integrated and the hybrid system is used for battery charging and discharging This can be implemented instead of single source to gain more power almost at all the times.

VII.FUTURE SCOPE

By modifying the blade area and rotation axis of turbine can be coupled with large rating generator to produce electrical energy in high range.The same model can be installed on buildings and house roof to supply electricity for their need.

With some modifications in wind turbine part and increasing no. of solar panels & wattage this model can be utilized as standalone system specially in off shore-on shore where speed of the wind is adequate.By using Power Converting Unit (PCU) this model can be utilized as a grid tie power system.

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