Design and Development of a Hybrid Power Generating System using Solar and Wind Power with a Streetlamp as an Application

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ABSTRACT

Although solar and wind energies are the most variable renewable energy sources. A little research has been done on operating both to take advantage of their complementary characteristics. This work aims to combine these two energy sources and use this energy to generate electricity to light an electric bulb. There are some drawbacks to using only one system for generating electricity because solar panels are of no use after sunset, and wind speed fluctuations may affect the output of a wind system. Solar panels and windmills are used, from which the energy will be stored inside a battery that can be used as required. As an On-Grid system, unused electricity could easily be supplied or sold to the government. A cleaning mechanism also cleans the solar panel with constant output. Experiments on the solar panel were taken with and without dust, mud and talcum powder. It is observed that a clear solar panel surface gives nearly 20% of improved results and without mud and talcum powder, 55% improvement for different wind speed outputs is measured. As the wind velocity increases, power output is also increased.

1. INTRODUCTION

Solar and wind energy sources are freely available, promising power generation sources, omnipresent, and environmentally friendly. The hybrid solar-wind power energy system uses two renewable energy sources, enhances the hybrid system efficiency, and reduces the energy storage requirements for stand-one applications like a street lamps and power reliability[1]. The substantial rise in fossil fuel and coal prices affects electricity generation through non-renewable sources. The solution to this problem is using renewable energy sources[2]–[4]. Climate conditions, solar radiations, and wind power are available everywhere. Due to the increasing population, consumption of electricity is increased drastically. We must focus on renewable energy sources to meet the electric energy demand. The hybrid system will enhance the energy efficiency of solar and wind energy. [5]–[7].

Mei Yi et al., designed an airfoil design for the wind power generation for variable speed at the tip. The computational fluid dynamics approach was used to simulate the wind turbine. Rotor aerodynamic performance with the newly designed rotor is 6.78% higher than the H-type vertical wind turbine[8]. S. Brusca et al., analyzed the effect of aspect ratio on the turbine's performance. Aspect ratio influences the Reynold number consequences power generation. The results revealed that the lower aspect ratio is superior to the higher aspect ratio [9].

R. Maouedj et al., developed the PV- Wind hybrid system for public lighting at night. The daily consumptions were 2640 Wh. The developed system includes the 1 KW wind turbine, a 600 W PV array with a battery storage capacity of 24V/1600Ah. The power generated from solar and wind is 84% and 16%, respectively [10]. Hongxing Yang et al., optimized the size of solar wind power system. A simulation was conducted to determine the relationship with the reliability requirements of the hybrid system [11].

Wei Zhou et al. reviewed the literature on the solar-wind hybrid system power generation. The hybrid solar-wind power system is a viable alternative for electricity generation in remote areas. The inclusion of artificial intelligence in solar-wind power generation is a viable solution in the future[12]. Pragya Nema et al., surveyed the different solar PV- wind hybrid power generation systems. A renewable hybrid energy system consists of a controller, power conditioning equipment, two or more energy sources, and an optional energy storage system. In future hybrid system will be more popular due to its advantages. The price of the petroleum products will be rise day by day and due to free availability of the solar and wind energy. Utilization of the hybrid energy will increase in future. [13]. Binayak Bhandari et al., did a literature survey on the mathematical modelling of the small hydro-wind-solar power generation system. The PV-wind hybrid system required special techniques to extract the maximum power due to non-linear power characteristics. Maximum power tracking systems

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may increase the complexity of the power generation system[1].

Riad Che did et al., developed the decision support system for optimum wind and solar energy design. The analytic Hierarchy Process was used for the solar-wind power generation setup[14]. Marcelo A. Perez and Jaime analysed PV power generation's short-term and long-term characteristics. Correlation between the idea value of solar power obtained from the astronomical and geographical data and the solar power production data. The accuracy and reliability of this data analysis could become significant [15]. Karim Mousa et al., optimized the design of the Solar-wind power plant. The optimization includes the turbine rotor diameter, number of wind turbine, height, and number of PV modules. Sensitivity analysis and simulation studies reveal hybrid power systems complement two energy sources [16]. Since 2006, renewable energy sources are increased rapidly in the Thailand after giving the incentives per unit[17]. Yuttana Kongjeen et al., did the experimentations on solar panel by cleaning it. They got good results after cleaning the solar PV panel. The PV panels are cleaned twice in a month in the rainy season[18]. Few researcher also worked on the wind energy harnessing process and its improvement techniques[19]–[21].

Solar energy has a great potential to charge the battery in the daytime; however, combination with wind power gives better results. Very few researchers have worked on the effect of solar and wind power energy on charging the battery pack. There are so many sunshine days in India with good solar radiation intensity in the summer season; however, the wind velocity is less. In the winter and rainy season, the solar radiations are less; however, the shortage could be fulfilled with the combination of wind energy. The solar intensity is not constant throughout the year so we could not get better results from the solar energy only. The wind velocity is also fluctuating. During the research, we found that we could get tremendous benefits by using both sources together so that the output is not dependent on only one source. This product could replace a standard streetlamp, where electricity from conventional sources is unavailable, or as a backup in an emergency. The research paper aims to present and discuss the results of the solar and wind power energy available to charge the battery and operate the street light. The solar radiation intensity, atmospheric temperature, and wind air velocity data were measured and used for the experimental results. This project not only useful for streetlamps but also it may use for various applications like LED bulb charging, mobile battery charging station, EV vehicles charging, and many more.

2. METHODOLOGY

The following methodology was used to develop the solar-wind hybrid power plant.

- Design the street lamp, taking appropriate height of the post by considering the size and weight of objects which are to be mounted on it, such as solar panels, wind turbines, lamps, and a battery.
- Estimating the positions of the lamp would not cause any obstruction in the path between the sun rays and the solar panel, which will also not affect the Ergonomics of the product.
- Design a solar panel mounting structure or frame considering the size of the solar panel to be used.
- Calculate the height and radius of the windmill, which is selected according to the wind speed, which varies depending upon various geographical locations stated by NACA (National Advisory Committee of Aeronautics), and design the windmill.
- The street lamp, solar panel, battery, generator, etc., were selected per the specifications.
- Design of reservoir and piping arrangement.
- A cleaning mechanism is added for solar panels to increase power generation efficiency.

3. DESIGN AND CALCULATIONS

3.1 Parts and Calculations

3.1.1. Solar Panel

Solar energy can be used as solar thermal energy and solar electric energy. The new photovoltaic cells are made up of semiconductors structure. These semiconductors absorb the Sun rays and electrons are emitted from the atoms. It causes the electric current flow into the wiring. The photoelectric principle converts the solar energy into the electric energy.

The calculation for Solar Panel

For street light applications, bulb wattage is 15 W; we have considered the same load for the design.

1) Daily Energy Consume (For 8 Hrs)

$$Energy\ Consume = Load*Amount\ of\ Hrs$$

$$= 120Whr/day$$

2) Effective Solar Energy Available for 6 Hrs in the Day

$$Solar\ Panel\ Voltage\ Required = \frac{\text{Total Load}}{\text{Eff.Solar energy available}} = 20\text{ V}$$

3) Solar Panel Efficiency = 90%

$$Solar\ Panel\ Voltage\ required = \frac{\text{Solar Panel Wattage}}{\text{Panel Efficiency}}$$

$$= 23\text{W}$$

4) *Wire and Generator efficiency* = 90%

$$\text{Total Wattage Required} = \frac{\text{Solar Panel Voltage required}}{\text{efficiency of Wire}} = 24.69 \text{ W}$$

As per the above calculations, we require a 25W solar panel. 10W, 20 W, and 40W solar panels are available from the market survey. So we selected a 40W solar panel for our study instead of a 20W and 10W combination. Following are the details of the solar panel.

*Panel Dimensions (L*W*H): - 440mm*670mm*34mm*

Panel weight: - 3.82Kg

1. Monocrystalline Solar Panel
2. Model - SLP018-12
3. Rated Power - 40W
4. Rated current - 2.12A
5. Rated Voltage - 18.90V
6. Open circuit voltage - 22.64V
7. Short circuit current - 2.26A
8. Standard test conditions (STC) - 1000W/ m2, AM1.5And 25°C

3.1.2. Storage Battery

The energy generated by the PV panels are need to store in the battery. The batteries are used for the storage of the electric energy. There are several battery chemistries are available to store the more energy in the system. The battery used in this project is dry maintenance free type and it utilizes special electrolytes. These types of batteries will give the better performance for the long discharge.

Calculation for Battery

Total Watt Hour =120Whr
Available Battery Capacity = 12 V

1) $\text{Battery Capacity} = \frac{\text{Total Watt Hrs}}{\text{Available Battery Capacity}}$

= 10 Ahr

2) Battery Discharge Upto 80%
Considering Battery Discharge Loss

$$\text{Battery Capacity} = \frac{\text{Battery Capacity}}{\text{Battery discharge}}$$

= 12.5 Ahr

3) Generator and Wire Loss = 90% Efficiency
Considering Generator and Wire Losses

$$\text{Battery Capacity Required} = \frac{\text{Battery Capacity}}{\text{wire loss and DC to AC loss Eff.}} =$$

13.88 Ahr

From the above calculations and market survey for batteries, we have selected 15 Ampere hour Batteries for our research work. The following are the battery specification:

1. Lead Acid battery (SMC)
2. Voltage-12V
3. Current-15 AH
4. Life-5 Years.

3.1.3. Lamp

For this research work we have selected 15 W 12V LED lamp, which will transform the electric energy into the visible electromagnetic radiation (Lumens). The rate at which LED lamp convert electrical energy into visible light is called “Luminous efficiency”. An LED lamp with the following specification are used in this research work:

1. Voltage - 12V
2. Power - 15W
3. Lumen (LM) - 1600-1650lm
4. Current - 0.836A
5. Lifetime - 50000hrs

3.1.4. Charge controllers

For limiting rate of electric current drawn or added to the batteries, a battery regulator or charge controller is used. The charge controller prevents the overheating, overcharging of the batteries and enhance the battery life along with the performance. The charge controller will also help to maintain the minimum level of the battery voltage (Deep battery discharge). This is battery powered device is used for the protection of the battery charge, discharge.

Table 1 Vertical axis blade design values

SR. NO.		Values
1	Power (kW)	0.5
2	Airfoil	NACA 0018
3	Wind speed (m/s)	2.5
4	Air density (kg/m^3)	1.225
5	Kinematic air viscosity (m^2/s)	1.46 $*10^{-5}$
6	Rotor aspect ratio (h/R)	0.4
7	Number of blades (Nb)	3
8	Reynold number	5 $*10^6$
9	Cpmax, Ϭ cpmax, λ cpmax	0.51, 0.3, 3.0
10	Rotar Radius (m)	0.3578
11	Angle Between two Blades (Degree)	120

3.1.5. Windmill Design

Different researcher uses different windmill blades for their applications. Carbon-fiber girders are used to reduce the weight of the blade, having several advantages. The angle between the three blades is 120 degrees. The highest and lowest daily wind speed was 4 m/s and 1 m/s. The average daily wind speed was observed at 2.5 m/s. The wind turbine's design is done according to NACA 0018 (National Advisory Committee for Aeronautics). The power of a wind turbine with a vertical axis can be estimated using the following formula:

$$P = \frac{1}{2} * \rho * Vo^3 * 2 * R * h * Cp$$

For power 500 W:

Power (P) = 500 W

$$P = \frac{1}{2} * \rho * Vo^3 * 2 * R * h * Cp$$

R * h = 0.051224

3.1.6. Wiper Mechanism

A wiper mechanism is used to clean the solar panel. A power window motor is used as s driving member for a wiper. Power window motor is connected to 12v dc power supply. As power is given, the motor starts and mechanical power is given to the regulator, composed of a worm gear and several spur gears. These gears produce enough torque to move wiper over solar panel. This produced torque drags the wiper through cable and pulley arrangement. Wiper moves in the slot of bracket. Wiper is pivoted using nut and bolt arrangement. Hence it wipes out dust, dirt, bird droppings, etc.

Following wiper, mechanism is selected for our application.

Specifications:

1. Voltage-12V
2. Current- 1.2 Amps
3. Working Speed-26RPM
4. No-load Speed-30RPM
5. Noise-55db

4. WORKING

When the solar rays are incident on the solar PV panel it will generates the electricity. The generated solar energy is stored in the battery through the charge controller. Meanwhile the small wind turbine also generates the electric energy and stores the energy in to the battery through charge controller. Solar and wind hybrid power systems are designed to generate electricity using solar panels and small wind turbine generators. Generally, these solar-wind hybrid systems are capable of small capabilities. Solar wind hybrid systems' typical power generation capacities range from 1 kW to 10 kW. The following block diagrams explain the working of the system. The stored energy into the battery will be utilized by connecting to the electric load (LED bulb).

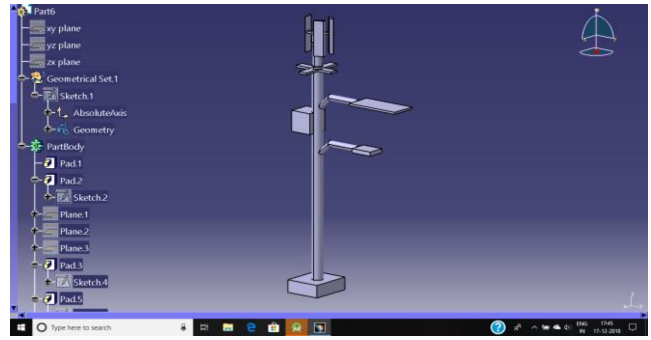

Fig. 1. 3D CAD model

Fig. 2. Experimental setup.

Fig. 3. Solar panel with cleaning mechanism.

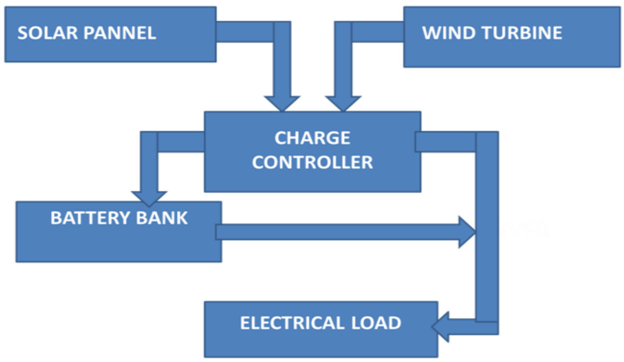

Fig. 4. Hybrid Solar-Wind Solar System.

In the solar PV panel, it comprises the solar cells which is used to convert the solar energy into the electric energy. The electrons produced in the N-type material are passed to battery through the wires and electrodes. Output of the solar panel is in the electric energy form and it is measured in the Watt. The different solar panels are designed for the various output rating. Based on the application/requirements we can use the different solar panel. A 12 volt 15 Watt solar panel produce around 1 Ampere current during the normal sunshine day. The life of the solar panel may vary from the manufacture to manufacture however the average life is around the 22 years. Efficiency of the solar panel may enhance by keeping the solar panel always normal to the Sun rays. The surface of the solar panel needs to clean at regular interval of the time.

5. ANALYSIS OF SYSTEM USING DIFFERENT PARAMETERS

5.1 Effect of cleaning

The efficiency of the solar panel is determined by using the following equation:

$$\text{Efficiency} = \frac{\text{Output Energy Generated}}{\text{Total Solar Radiation}} = \frac{Vp*Ip}{Ps*A}*100$$

where, V_p is the Electrical voltage produced by the Solar PV panel; I_p is the electrical current produced by the solar PV panel; P_s is the power of the incident solar radiation (W/m²); A is the exposed area of the solar cell.

The above equation is intended for use under standard test conditions, i.e. under the temperature of 25°C and an irradiance of 1000 W/m² with an air mass of 1.5 (AM1.5) spectrum.

Area of solar panel exposed to solar radiation-

Area = Width * Length = 0.30016 m²

As per specification-

Vm(Rated) = 18.90 V

Im (Rated) = 2.12 Amp

Power (Rated) = 40 W

5.1.1 When panel is clean

V=18.90 V

I =2.12 Amp

Power = V*I

= (18.90*2.12)

= 40.068 W

$$\text{Efficiency} = \frac{\text{Output Energy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{40.068}{1000*0.30061} * 100$$

= 13.34 %

5.1.2 When dust is applied over Panel

V = 18.32 V

I = 1.8506 Amp

Power = V*I

= (18.32*1.8506)

= 33.7379w

$$\text{Efficiency} = \frac{\text{Output Energy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{33.7379}{1000*0.30061} * 100$$

= 11.24%

Fig. 5. Dust applied to Solar Panel.

5.2.3 When dust is wiped out from a panel

V = 20.06 V

I = 1.96 Amp

Power = V*I

= (20.06*1.96)

= 39.3509 W

$$\text{Efficiency} = \frac{\text{Output Enegy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{39.3509}{1000*0.30016} * 100$$

$$= 13.11\%$$

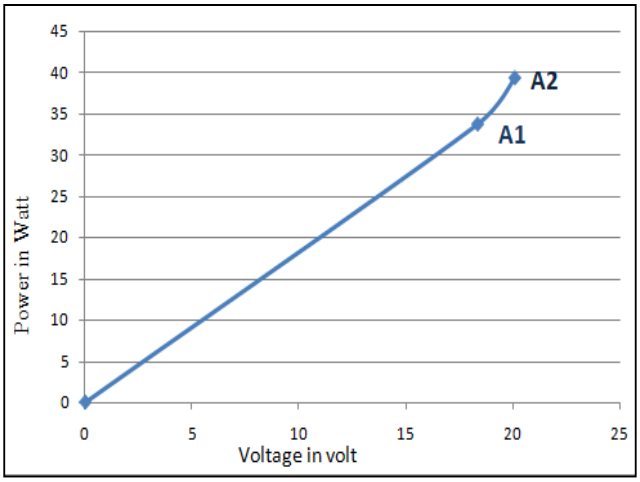

Fig. 6. Graph for dust applied and wiped out.

A1 = When dust is applied over panel; x axis = Voltage in Volt; A2 = When dust is wiped out from panel y axis = Power in Watt.

5.3 When talcum powder is applied over Panel

V = 18.98 V

I = 1.1829 Amp

Power = V*I

= (18.98*1.1829

= 22.45 W

$$\text{Efficiency} = \frac{\text{Output Enegy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{22.45}{1000*0.30016} * 100$$

$$= 7.485\%$$

5.3.1 When talcum powder is wiped out from solar panel

V = 19.7 V

I = 1.977 Amp

Power = V*I

= (19.7*1.977)

= 38.96 w

$$\text{Efficiency} = \frac{\text{Output Energy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{38.96}{1000*0.30016} * 100$$

$$= 12.98\%$$

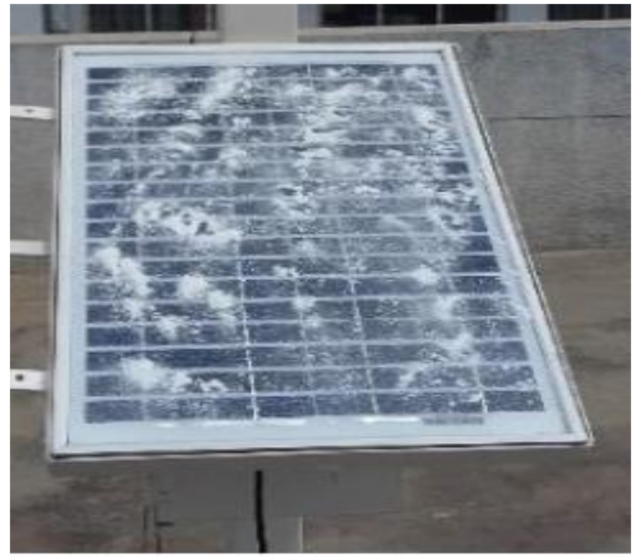

Fig. 7. Talcum powder applied on solar panel.

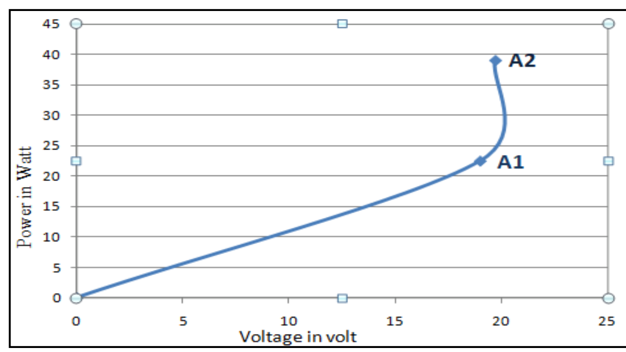

Figure 8 Graph for Powder applied and wiped out

A1 = When talcum powder is Applied on solar panel; x-axis = Voltage in Volt; A2 = When talcum powder is Wiped out from solar panel; y-axis = Power in Watt

5.4 When crushed soil applied on solar panel

V = 18.68 V

I = 0.922 Amp

Power = V*I

= (18.68*0.922)

=17.2291 W

$$\text{Efficiency} = \frac{\text{Output Enegy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{17.2291}{1000*0.30016} * 100$$

$$= 5.74\%$$

5.4.1 When crushed soil is wiped out from solar panel

V = 19.6 V

I = 1.946 Amp

Power = V*I

= (19.6*1.946)

= 38.1503 w

$$\text{Efficiency} = \frac{\text{Output Enegy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{38.1503}{1000*0.30016} * 100$$

= 12.71%

Fig. 9. Crushed soil applied on solar panel.

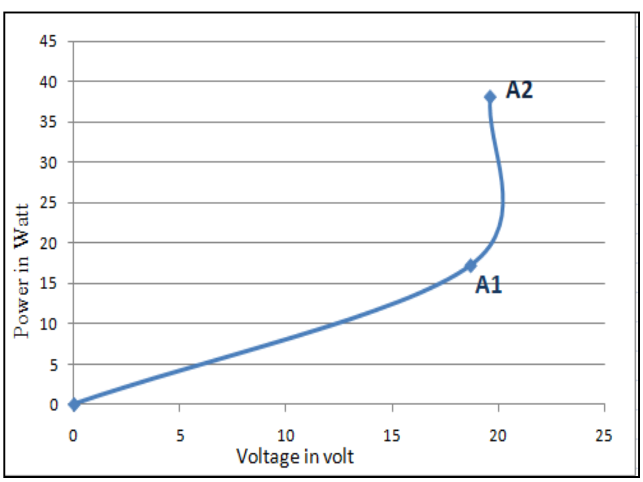

Fig. 10. Graph for crushed soil-applied and wiped out.

A1 = When crushed soil is Applied on solar panel; x-axis = Voltage in Volt; A2 = When crushed soil is wiped out from solar panel; y-axis = Power in Watt.

5.5 When mud is applied on Solar panel

V = 18.81 v

I = 0.5776 Amp

Power = V*I

= (18.81*0.5776)

= 10.8657 w

$$\text{Efficiency} = \frac{\text{Output Energy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{10.8657}{1000*0.30016} * 100$$

= 3.62%

5.5. 1 When mud is wiped out from a panel

V = 19.56 v

I = 1.8614 Amp

Power = V*I

= (19.56*1.8614)

= 36.409 w

$$\text{Efficiency} = \frac{\text{Output Energy Generated}}{\text{Total Solar Radiation}} * 100$$

$$= \frac{36.409}{1000*0.30016} * 100$$

= 12.13%

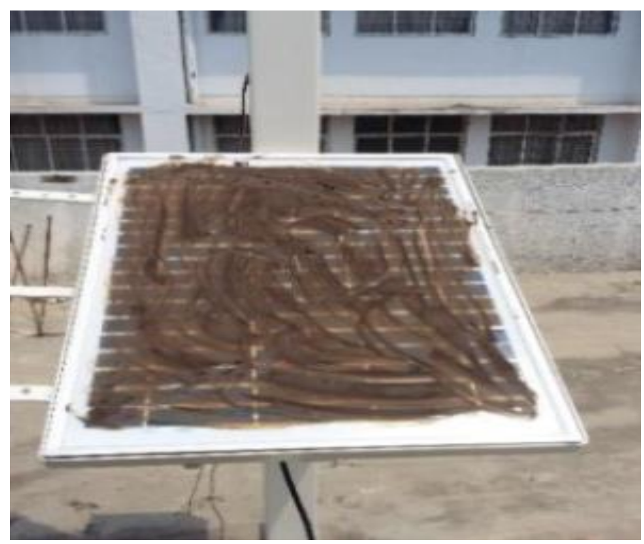

Fig. 11. Mud applied on solar panel.

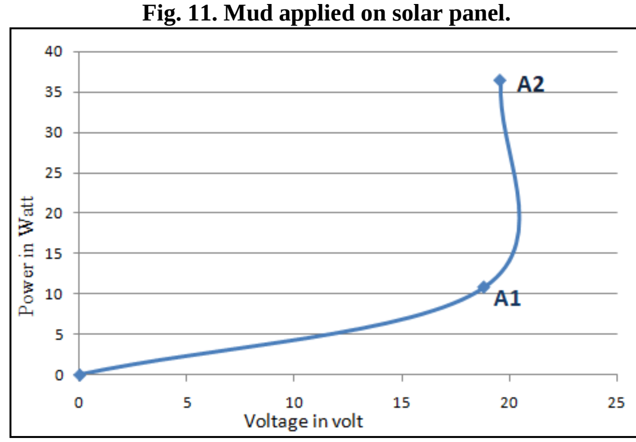

Fig. 12. Graph for mud applied and wiped out.

A1 = When mud is applied over panel; x-axis = Voltage in

Volt; A2 = When mud is applied over panel; y-axis = Power in Watt.

5.6 Overall characteristics of solar panel

Table 2. Overall Characteristics of Solar Panel

SR No.	Conditions	Voltage (V)	Current (I)	Power (P)	Efficiency (η)%
1	Panel is Clean	18.90	2.12	40	13.34
2	Dust Applied on the Panel	18.32	1.8506	33.7379	11.24
3	Dust is wiped out from the panel	20.06	1.96	39.3509	13.11
4	Talcum powder was Applied to the panel	18.98	1.1829	22.45	7.485
5	Talcum powder wiped out from the panel	19.7	1.977	38.96	12.98
6	Crushed Soil was Applied to the Panel	18.68	0.922	17.2291	5.74
7	Crushed soil wiped out from Panel	19.6	1.946	38.1503	12.71
8	Mud applied to the panel	18.81	0.577	10.8657	3.62
9	Mud wiped out from the panel	19.56	1.8614	36.409	12.13

5.6.1 Overall characteristics Curve of solar panel

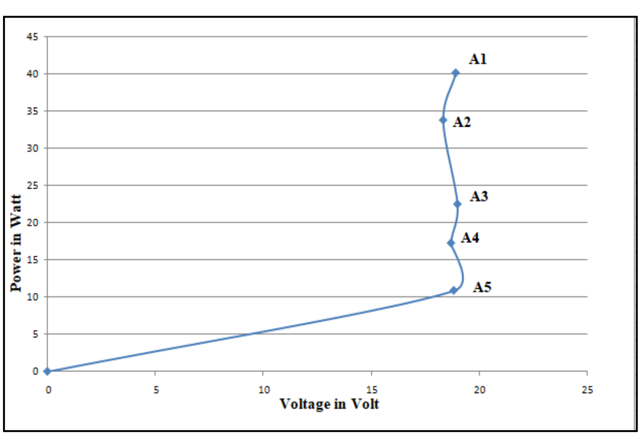

Fig. 13. Overall characteristics curve of solar panel

X-axis = Voltage in Volt; Y-axis = Power in Watt; A1 = When Solar Panel is Clean (18.90, 40.068); A2 = when the dust is applied to the solar panel (18.32, 33.7379); A3 = when Talcum Powder is applied on solar panel (18.98, 22.45); A4 = when crushed soil is applied to the solar panel (18.68, 17.2291); A5 = when mud is applied on solar panel (18.81, 10.8657).

5.7 Wind Energy

The power extracted from wind energy with the help of an alternator at different wind velocities.

Table 3. Overall characteristics of wind energy

SR No.	Alternator Speed (RPM)	Wind Velocity (m/s)	Voltage (V)	Current (Amp)	Power = V*I (Watt)
1	40	2.06	4.2	0.190	0.798
2	50	2.33	6	0.250	1.5
3	55	2.57	7	0.305	2.135
4	60	2.65	7.3	0.414	3.022
5	65	2.83	8.84	0.493	4.358
6	70	3.09	9.40	0.562	5.282
7	75	3.35	10.17	0.630	6.407
8	80	3.60	10.72	0.704	7.546
9	85	3.84	11.06	0.784	8.671
10	90	3.96	11.70	0.880	10.296

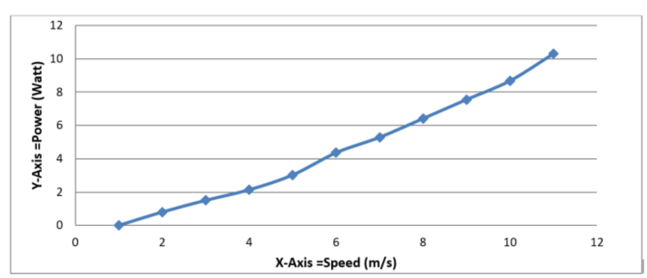

Fig. 14. Wind Power Graph.

5.8 Hybrid Power System

Combine output power from a Wind and a PV module:

PGen(t) = Pwind(t) + Npv* Ppv(t)

NPV = Number of PV panels

PGen(t) = Total power generated

Pwind(t) = Power from wind

Ppv(t) = power from photovoltaic cell

A1= Min combined voltage and power (23.1, 40.778)

PGen(t) = Pwind(t) + Npv* Ppv(t)

= 0.798 + 1*39.98

= 40.778 W

A2= Median combined voltage and power (27.74, 44.338)

PGen(t) = Pwind(t) + Npv* Ppv(t)

= 4.358 + 1*39.98

= 44.338 W

A3 = Max combined voltage and power (30.6, 50.276)

PGen(t) = Pwind(t) + Npv* Ppv(t)

=10.296+ 1*39.98 = 50.276 W

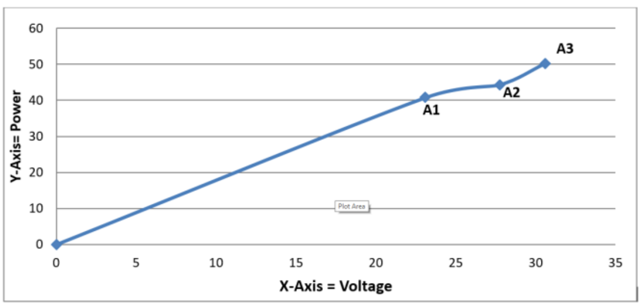

Fig. 15. Hybrid power graph.

6. CONCLUSIONS

The wind, solar, and hybrid system experiments were done under different conditions. The following results were obtained during the experimentations.

- The power output was 14-16W and 40-45W from the Wind power and solar panel under different conditions. From the hybrid system, 50- 55W is generated.
- The system aims to produce and utilize the electrical energy from more than one source, provided that at least one is renewable. The integration of the hybrid is to electrify a street light,
- Residential areas and it's surrounding to reduce the need for fossil fuels leading to an increase in the sustainability of the power supply. Accumulation of dust from the outdoor environment on the solar photovoltaic (PV) system panels is natural.
- Some studies showed that the accumulated dust could reduce the performance of solar panels by up to 50%, but the results were not quantified. This research aims to clean the solar panel using a wind pump and increase efficiency.

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NOMENCLATURE

V_0 = Wind Speed (m/s)

h = Blade Length (m)

P = Power (W)

Nb = Number of Blades

Re = Reynolds Number

ρ = Air Density (Kg/m^3)

Cp = Power Coefficient

c = Airfoil chord (m)

σ = Rotor solidify