Optimization of Solar and Wind Hybrid System

Shashi Shanker[1], BSSPM Sharma[2]

[1]Integrated M.Tech. Scholar, Mewar University, Rajasthan, India

[2]Assistant Professor, Mewar University, Rajasthan, India

Abstract: ***With the advent of new technologies demand for energy is increased rapidly which makes us to seek the more importance towards renewable sources of energy. The very important of which are solar and wind energy as they are abundant, freely available, environment friendly and they are considered as the fuel of tomorrow. Solar and Wind energies are available at most of the remote areas which increases its usability. However, it is notable neither Solar nor Wind energy can provide continuous supply of energy when stand-alone due to seasonal and periodical variations. Therefore we use Hybrid Power System. Hybrid system is used widely to fulfill energy needs in remote areas which are far from the mainstream and out of grid network. The paper presents the simulation of Hybrid Solar and Wind system in MATLAB and cost optimization. We compare stand-alone Solar, stand-alone Wind and their Hybrid in term of their coat. For purpose of optimization purpose we choose Jodhpur (Raj.), India and studied three different plant size i.e. 1kWh/day, 10lWh/day and 100kWh/day and compare the cost of Solar, Wind and Hybrid power system and proved that Hybrid is more feasible then both standing alone.***

Keywords: Solar, Wind, Hybrid, MATLAB, Optimization, Cost.

1. Introduction

Over the years it is become evident that fossils fuels are near to an end. There are some estimation about the ending of various recourses of energy like it is estimated that oil and gas can end in roughly 40 to 60 years respectively wile estimated end of coal reservoirs is around 200 years. The fast depletion of the fossil fuel sparks the need to find the next source of energy to carter the demand of today's energy requirement. Another, fact that reduces our interest in fossil fuel is the pollution and raising the problem of global warming. There are numerous renewable energy sources like Wind, Solar, Tidal, Geo-Thermal, Hydro everyone has its merits and demerits. Out of many alternatives Solar and Wind are one of the promising alternatives to fossil fuels.

The Photo-voltaic (Solar) and Wind energies are freely available; cause no pollution, no green house effect. Both are good complementary to each other and used as Hybrid source to distribute electricity in remote areas which are cut from grid networks. They used together provide a lucrative offer to use them but due to many facts like environmental and other there is fluctuations in the availability of both the resources therefore we need to choose wisely Photo-voltaic panel, Wind turbine and storage unit. We simulate our system with MATLAB/Simulink[1].

2. Solar Power Stand-alone

The most effective way of using solar energy is to directly convert the sun light into electricity and this is accomplished by Photo-voltaic cells. When sunlight falls on them they generate the DC electricity without involvement of any mechanical system. The Photo voltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by the use of photovoltaic effect are called Solar cells [2].

In actual usage, the Solar cells are inter connected in certain series /parallel combinations to form modules. These modules are hermetically sealed for protection against corrosion, moisture, pollution and weathering. A combination of suitable modules constitutes an array. A general data for 1m^2 of a fixed array kept facing south yields nearly 0.5 kWh of electrical energy on a normal sunny day. If it is required to be used during non-shiny hours a storage system is required.

2.1 Photo-voltaic Module

Photo-voltaic consists of PV generator (panel array). A solar cell consists of P-N junction fabricated over a wader of silicon. When the solar photons hots the solar cells with the energy greater than the band-gap of semiconductor electrons got knocked off from atoms and start travelling with a velocity and thus creating the potential difference [1].

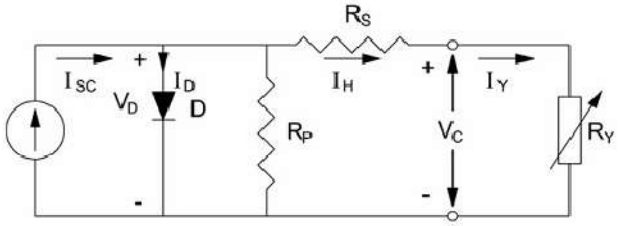

Figure 1: Equivalent circuit of PV-module

Photo-voltaic module can be mathematically modeled as four blocks given below follows:

a) Module photo current

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \frac{\lambda}{1000} \quad (1)$$

This model takes the given inputs and outputs photocurrent I_{ph}

- Insolation $\frac{G}{1000} 1kW/m^2 = 1$
- Module operating temperature $T_{ak} = 30^oC$ to 70^0C
- Module reference temperature $T_{ak} = 25^oC$
- Short circuit current I_{sc} at reference temperature=2.55 amp.

b) Reverse saturation current

$$I_{rs} = \frac{I_{scr}}{[e^{\frac{q*V_{oc}}{(N_s*K*A*T)}} - 1]} \qquad (2)$$

c) Saturation Current

$$I_o = I_{rs} * [\frac{T}{T_r}]^3 * [e^{\frac{q*E_{go}}{(B*K)}*(\frac{1}{T_r}-\frac{1}{T})}] \qquad (3)$$

d) Module Output Current

$$I_{pv} = N_p * I_{ph} - N_p * I_o[e^{\frac{q*(V_{pv}+I_{pv}*R_s)}{(B*K)}} - 1] \qquad (4)$$

Software simulation of the PV-array consists of four blocks the diagram of the module shown below:

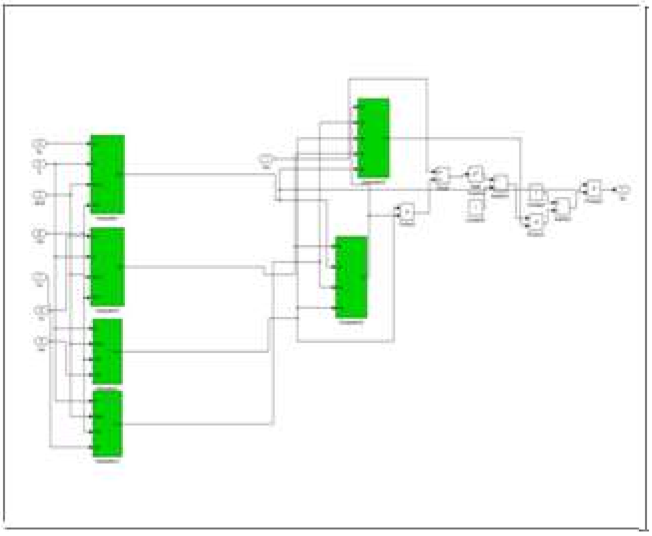

Figure 3: Photo-Voltaic array module

The I-V and P-V Characteristics under constant irradiance with varying temperature are presented respectively. When the operating temperature increases, the current output increases marginally but the voltage output decreases drastically, which result in net reduction in power output with a rise in temperature.

3. Wind Power Stand-alone

Wind energy is a renewable energy source. In it wind turbines converts the wind energy to electricity by rotating wind turbine. The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind power is used to feed both energy production and consumption demand, and transmission lines in the rural areas.

Practically it is observed that the flexible three blades propeller about 35 m in diameter, in a 60 Km/hr wind pressure with a rotation speed of 47 rpm produce maximum power 12 MW. For small wind power generation system, multiple blade type (3 to 5 number blades) or Darrieus type (Curved Blade 3 to 5 numbers) is highly suitable. The main problem with this system is that the speed of wind is not constant and very fluctuating hence the electric power generated also fluctuated. Thus, it is always a wise to supply the wind electricity to a storage unit like battery and then apply load at storage unit [3].

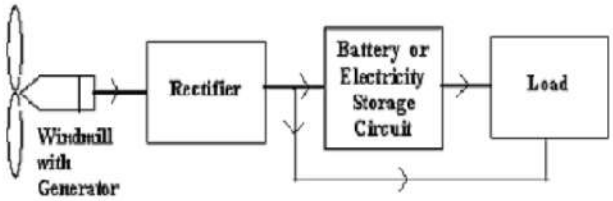

Figure 2: Basic Wind Power System

3.1 Power generated in Wind System

The amount of power transferred by a wind turbine is directly proportional to the area swept out by rotors, to the density of air and the cube of the wind speed.
The power P is given by:

$$P = 0.5 * C_p * \rho * A * V^3 \qquad (5)$$

Where C_p=Turbine power coefficient
ρ=Air density(kg/m^3)
A=Rotor swept area(m^2)
D=Rotor blade diameter(m)
v=Mean wind speed(m/s)
MATLAB simulation[4,5] of wind turbine shown below:

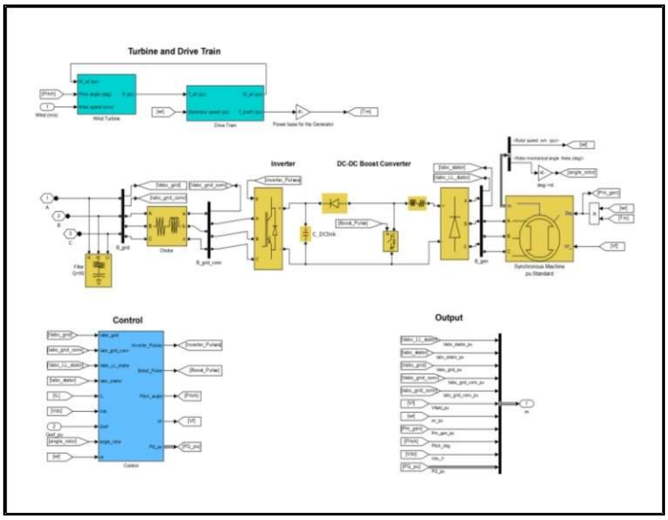

Figure 4: Wind Turbine Module

The stator winding is connected directly to the grid and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. DC-Voltage output characteristic of wind turbine shown below:

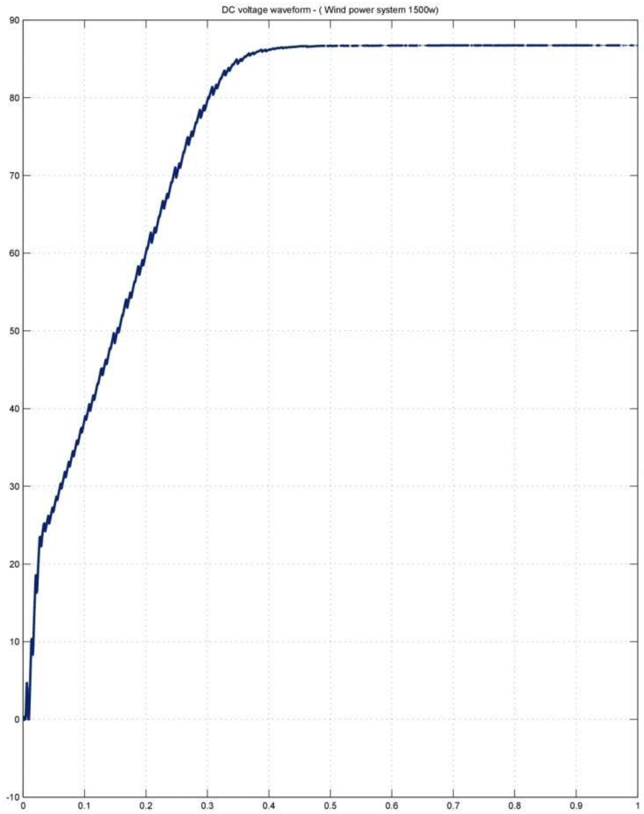

Figure 4: DC-Voltage output waveform

3.2 Dc-Dc Boost Converter

The boost converter configuration shown in fig. consists of DC input voltage source Vs, boost inductor L, controlled switch S, diode D, filter capacitor C, and load resistance R

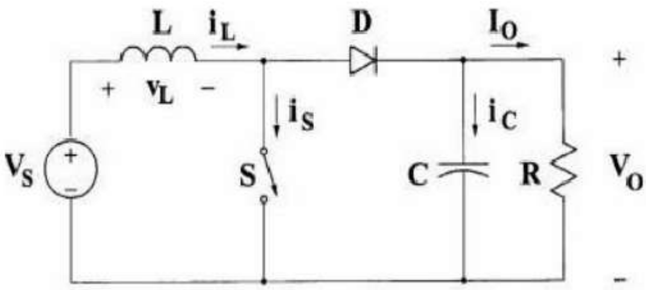

Figure 5: DC to DC boost converter

If the switch operates with a duty ratio D, the DC voltage gain of the boost converter is given by [6].

$$M_v = \frac{V_o}{V_s} = 1/(1-D) \qquad (6)$$

4. Hybrid Power

Wind-solar Hybrid Generating System is considered to take full advantage of renewable energy so greatly as to improve the stability and reliability of the power system, and save the cost of the electricity to a certain extent by reducing the capacity of the battery and extending the life of the battery. The system is mainly made up by the wind turbine, solar photovoltaic batteries, controllers, batteries, inverter, DC load as well as the exchanger of DC/AC parts. DC was generated from wind turbines and solar panels, respectively, then changes to AC by the inverter for users. In order to meet the regulation of the electricity in different time the batteries charging in peak period and discharging in trough.

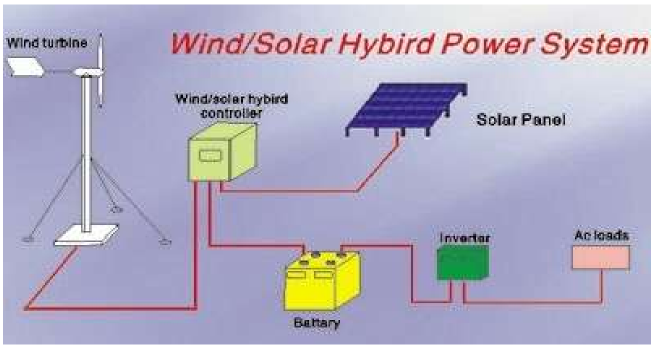

Figure 6: Hybrid Wind and Solar Power System

The topology of Hybrid energy system consisting of variable speed WT coupled to a doubly fed induction generator (DFIG) and PV array. The two energy sources are connected in parallel to a common dc bus line through their individual dc-dc converters. The load may be dc connected to the dc bus line or may include a PWM voltage source inverter to convert the dc power into ac at 50 Hz. Proposed hybrid systems shown below:

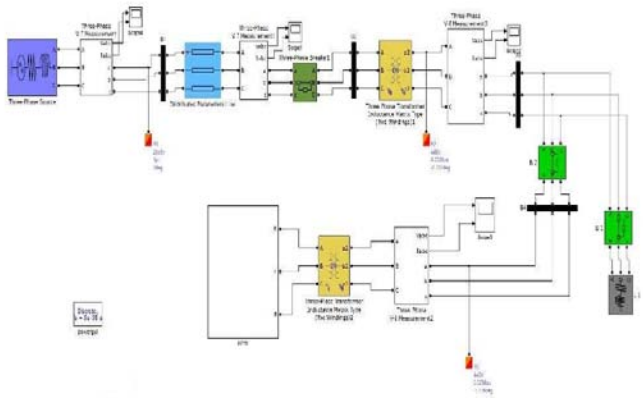

Figure 7: Hybrid System Layout

The outputs by the hybrid system have the following waveform output shown below:

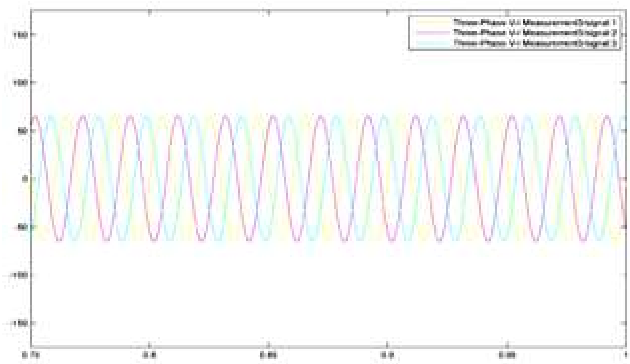

Figure 8: Hybrid Output Waveform

5. Optimization Technique

We select the Jodhpur, Rajasthan for our technique to test as it is rich in both solar and wind resources. Solar insolation and Wind speed is obtained from SYNERGY website. Solar insolation and wind speed data given below [7, 8]:

Table 1: Solar Radiation and Wind Speed Data

Month	Daily Solar Radiation(kWh/m²/day)	Clearness Index	Wind speed(m/s)
Jan	4.35	4.2	3.97
Feb	5.30	4.2	4.24
Mar	6.30	4.1	4.17
Apr	6.98	4.0	4.63
May	7.45	3.9	5.25
Jun	6.86	4.1	5.51
Jul	6.02	2.9	4.55
Aug	5.64	2.7	3.89
Sep	6.10	3.6	4.04
Oct	5.64	4.1	3.70
Nov	4.67	4.2	3.79
Dec	4.11	4.0	3.90

5.1 Size Calculation

Photo-voltaic array size required

PVarraysize=$\frac{TP}{SH}$

Where,

TP=Total Power Requirement

SH=Sunshine Hours

Battery Bank Size=$\frac{5*TP}{Battery\ Voltage}$

5.2 Calculation of Stand-alone PV/Wind Hybrid Power System

- Determine daily load requirement in kW and kWh.Mu3ltiply daily load by a fudge factor of 1.5. This accounts the system efficiencies, including wire and interconnection losses as well as the efficiency of the battery charging and discharging cycles.
- Determine daily sunshine hours and decide battery voltage.
- Calculate power generated by Wind turbine using average daily wind speed and rotor diameter using above equation d. Calculate total power required by PV panel by subtracting power generated by wind turbine from daily load required.
- Determine PV array size
- Determine battery bank size
- Determine inverter size that is almost equals to PV array size.

5.3 Calculate Data for the load of 10kWh/day

To calculate the sizing data for load requirement of 10 kWh/day the calculation has been done as per given procedure. The results are shown in tables below:

Data required for 10kWh/day:

Table 2: Data Required for calculation of 10kWh/day

	March-June	July-Oct	Nov.-Feb
Load Req.	10kWh/day	10kWh/day	10kWh/day
SH	10 h/day	8 h/day	7 h/day
Battery Voltage	48V	48V	48V
Wind Speed	4.89m/s	4.045m/s	3.975m/s
Rotar Dia.	2.8m	2.8m	2.8m

Data using fudge factor of 1.5, actual requirement and calculation of PV size given below

Table 3: Calculation of Sizing and Power Generation

	March-June	July-Oct	Nov.-Feb
Actual Load Req.	15kWh/day	15kWh/day	15kWh/day
Power Generated by wind Turbine	885.15Wh/ day	501.01Wh/ day	475.45Wh/day
Power Req. by PV Panel	14114.85Wh/ day	14498.99Wh /day	14524.55Wh/day
Req. Array Size	1411.48W	1812.37W	2074.93W
Battery Bank Size	1470.30Ah	1510.31Ah	1512.97Ah

5.4 Calculate Data for the load of 100kWh/day

To calculate the sizing data for load requirement of 100 kWh/day the calculation has been done as per given procedure. The results are shown in tables below:

Data required for 100kWh/day:

Table 4: Data required for calculation of 100kWh/day

	March-June	July-Oct	Nov.-Feb
Load Req.	100kWh/day	100kWh/day	100kWh/day
SH	10 h/day	8 h/day	7 h/day
Battery Voltage	96V	96V	96V
Wind Speed	4.89m/s	4.045m/s	3.975m/s
Rotar Dia.	8m	8m	8m

Data using fudge factor of 1.5, actual requirement and calculation of PV size given below

Table 5: Calculation of Sizing and Power Generation

	March-June	July-Oct	Nov.-Feb
Actual Load Req.	150kWh/day	150kWh/day	150kWh/day
Power Generated by wind Turbine	7225.72Wh/ day	4089.88Wh/ day	3881.20Wh/ day
Power Req. by PV Panel	142774.28Wh /day	145910.12Wh /day	146118.80Wh/ day
Req. Array Size	14277.4W	18238.7W	20874.1W
Battery Bank Size	7536.16Ah	7599.48Ah	7610.35Ah

5.5 Calculation for Cost of Electricity

To calculate Cost of electricity, Capital cost and life time of equipment should be known.

Normally 50 kW PV panel generates 200 units per day and 50 kW wind turbine generates 150 units per day.

- Decide components, its Capital cost, life time of each equipment.
- Calculate cost per year of each equipment by dividing capital cost of that equipment to the life time of that equipment.
- Calculate electricity generation over year.
- Cost of electricity is the summation of cost per year of all equipment divided by electricity generation over year.

For this calculation we will consider three plant size i.e. 1kWh/day, 10 kWh/day, 100 kWh/day.

5.5.1 Case-I Solar Power System

We will consider 1st 50 kW PV panel, 50 kW Inverter, battery of 200Ah. As 50 kW PV panel generates 200 units per day so this system should be used for loading condition of 200 kWh/day.

Table 6: Equipment Detail

Equipment	Rating	Cost(INR)	Lifetime(Years)
PV	50kW	120000000	20
Battery	200Ah	20000	3
Inverter	50kW	1000000	20

Calculation:

Total Capital Cost = Cost of PV panel + Cost of Battery + Cost of Inverter

= 120000000 + 20000 + 1000000

= 13020000

Cost per Year $= \frac{Cost of PV\ Panel}{LifeTime\ of\ PV\ Panel} + \frac{Cost of PV\ Battery}{LifeTime\ of\ PV\ Battery} + \frac{Cost of PV\ Inverter}{LifeTime\ of\ Inverter}$

$$= \frac{12000000}{20} + \frac{20000}{3} + \frac{100000}{20}$$

$= 656666.66$

Total Cost per year = Cost per year + Op. and Maintenance cost + Discount rate

= 656666.66 + 65666.66 +65666.66

= 788000

In above equation Operation and maintenance cost and discount cost is 10 % of cost per year.

$$Cost of Energy = \frac{TotalCostPerYear}{GenerationPerYear}$$

$$= \frac{788000}{200 * 365}$$

$$= 11 Rs/kWh$$

Now, considering the different plant size i.e. 1 kWh/day, 10 kWh/day, 100 kWh/day. Same calculation can be done.

Table 7: Solar Power System

Calculation of Standalone Solar PV Power System					
	Unit Sizing	1kWh/ day	10kWh/ day	100kWh/ day	
Cost per year	656666	465833	4625000	35116666	Rs/yr
Operation and maintance	65666	46583	462500	3511666	Rs/yr
Discount rate	65666	46583	462500	3511666	Rs/yr
Total Cost	788000	555000	5550000	42140000	Rs/yr
Cost of electricity	11	16	15	12	Rs/yr

5.5.2 Case-II Wind Power System

We will consider 1st 50 kW PV wind turbine, battery of 200Ah. As 50 kW Wind turbine generates 150 units per day so this system should be used for loading condition of 150 kWh/day.

Table 8: Equipment Detail

Equipment	Rating	Cost(INR)	Lifetime(Years)
Battery	200Ah	20000	3
Wind Turbine	50kW	8750000	15

Calculation:

Total Capital Cost = Cost of Wind Turbine + Cost of Battery

= 8750000 + 20000

= 8770000

Cost per Year $= \frac{Cost of WindTurbine}{LifeTime of WindTurbine} + \frac{Cost of PV\ Battery}{LifeTime\ of\ PV\ Battery}$

$$= \frac{8750000}{15} + \frac{20000}{3}$$

$= 590000$

Total Cost per year = Cost per year + Op. and Maintenance cost + Discount rate

= 590000 + 59000 +59000

= 708000

In above equation Operation and maintenance cost and discount cost is 10 % of cost per year.

$$Cost of Energy = \frac{TotalCostPerYear}{GenerationPerYear}$$

$$= \frac{708000}{150 * 365}$$

$$= 13 Rs/kWh$$

Now, considering the different plant size i.e. 1 kWh/day, 10 kWh/day, 100 kWh/day. Same calculation can be done.

Table 9: Wind Power System

Calculation of Standalone Solar PV Power System					
	Unit Sizing	1kWh/ day	10kWh/d ay	100kWh/ day	
Cost per year	590000	450833	4475000	30033333	Rs/yr
Operation and maintance	59000	45083	447500	3003333	Rs/yr
Discount rate	59000	45083	447500	3003333	Rs/yr
Total Cost	70800	541000	5370000	36040000	Rs/yr
Cost of electricity	13	19	16	13	Rs/yr

5.5.3 Case-III Solar-Wind Hybrid Power System

We will consider 1st 50 kW PV panel, 50 kW wind turbine, 50 kW Inverter, battery of 200Ah. As 50 kW PV panel generates 200 units per day and 50 kW Wind turbine generates 150 units per day so this system should be used for loading condition of 350 kWh/day.

Table 10: Equipment Detail

Equipment	*Rating*	*Cost(INR)*	*Lifetime(Years)*
PV	50kW	120000000	20
Wind Turbine	50kW	8750000	15
Battery	200Ah	20000	3
Inverter	50kW	1000000	20

Calculation:

Total Capital Cost = Cost of PV panel + Cost of Wind Turbine+ Cost of Battery + Cost of Inverter

= 120000000 + 8750000 + 20000 + 1000000

= 21770000

Cost per Year =

$$\frac{Cost of PV\ Panel}{LifeTime\ of\ PV\ Panel} + \frac{Cost of Wind Turbine}{LifeTime of Wind Turbine} + \frac{Cost of PV\ Battery}{LifeTime\ of\ PV\ Battery} + \frac{Cost of PV\ Inverter}{LifeTime\ of\ Inverter}$$

$$= \frac{12000000}{20} + \frac{8750000}{15} + \frac{20000}{3} + \frac{100000}{20}$$

$= 1140000$

Total Cost per year = Cost per year + Op. and Maintenance cost + Discount rate

= 1140000 + 114000 +114000

= 1338000

In above equation Operation and maintenance cost and discount cost is 10 % of cost per year.

$$Cost of Energy = \frac{Total Cost Per Year}{Generation Per Year}$$

$$= \frac{1338000}{350 * 365}$$

$$= 10 Rs/kWh$$

Now, considering the different plant size i.e. 1 kWh/day, 10 kWh/day, 100 kWh/day. Same calculation can be done.

Table 11: Hybrid Power System

Calculation of Standalone Solar PV Power System					
	Unit Sizing	1kWh/ day	10kWh/ day	100kWh/ day	
Cost per year	1140000	903333	9000000	60283333	Rs/yr
Operation and maintence	114000	90333	900000	6028333	Rs/yr
Discount rate	114000	90333	900000	6028333	Rs/yr
Total Cost	1338000	1084000	10800000	72340000	Rs/yr
Cost of electricity	10	17	13	11	Rs/yr

6. Comparison

Comparison for Unit Sizing that is PV panel of 50 kW, Wind turbine of 50 kW, Battery of 200 Ah and Inverter of 50 kW between Solar Power System, Wind Power System, and Hybrid Power System. Hybrid Power System initially costs high but it generates more electricity and it also least cost of electricity than Solar Power System.

Table 12: Comparison among Solar, Wind and hybrid Power System

Equipment	Solar PV	Wind System	Hybrid System
Plant Size	200kW/day	150kW/day	350kW/day
Initial Capital(INR)	13020000	8770000	21770000
Electricity-yearly	73000kWh	590000kWh	127750kWh
Energy cost	11Rs/kWh	13Rs/kWh	10Rs/kWh

We can see that from table 1, 2, 3 that using Hybrid System for larger load will cost less than stand alone solar or wind power system.

References

[1] Prof.Pandiarajan.N , Dr.Ranganath Muth, "Development Of Power Electronic Circuit-Oriented Model Of Photovoltaic Module", International Journal of Advanced Engineering Technology, vol. 2, Issue 4. October-December 2011.

[2] B H Khan, "Non-conventional Energy Sources",Tata McGraw-Hill Publication, India,II edition.

[3] RAMADONI SYAHPUTRA , MOCHAMAD ASHARI , IMAM ROBANDI, "Modeling and Simulation of Wind Energy Conversion System in Distributed Generation Units", International Seminar on Applied Technology, ISSN 208-1931, Dec. 2011.

[4] Martin Kanlik , Frantiek Lizk, "Possibilities of Distributed Generation Simulations Using by MATLAB", International Conference, CZ-ERASMUS-IPUC-3,Dec. 2011.

[5] Suman Nath,Somnath Rana," The Modeling and Simulation of Wind Energy Based Power System using MATLAB ",International Journal of Power System Operation and Energy Management, ISSN 22314407,Volume-1, Issue-2,2011.

[6] Ram Mohana Vamsee.B, Prof. D.S.Bankar, Dr. D. B. Talange, "Modelling and Dynamic Behaviour of Variable Speed Wind Turbines Using Doubly Fed Inducstion Generators (DFIG) ", IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 25, NO. 3, SEPTEMBER 2010

[7] Solar insolation . *www.synergyenviron.com* [Online] 25-07- 2014. [Cited: 25-07- 2014.] http://www.synergyenviron.com/tools/solar_insolation.asp?loc=Jodhpur%2CRajasthan%2CIndia

[8] Wind Speed. *www.synergyenviron.com* [Online] 25-07-2014. [Cited: 25-07- 2014.] http://www.synergyenviron.com/tools/wind_data.asp?loc=Jodhpur%2C+Rajasthan%2C+India

Author Profile

Shashi Shanker is currently pursuing Masters Degree in Power System Engineering from Mewar University, Chittorgarh, India.

S S P M Sharma B: Received B.Tech degree from JNTUK and M.Tech degree from VIT University (Vellore Institute of Technology), India. He is currently working toward the Ph.D degree at Mewar University, Department of Electrical Engineering, India. His current Research interest includes the modeling, analysis and control of power converters, application of renewable energy such as photovoltaic grid connected systems and photovoltaic grid connected inverters