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Cost Effective Analysis of a Stand-Alone Distributed Generation and Grid Connected Generation System

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***Abstract*—On account of depleting fossil fuels and certain environmental constraints, use of renewable energy is rapidly increasing in all areas. However implementing such system for extracting this free power is a complex task as well as highly expensive in comparison to the load. This paper proposed a comparative case study of a stand-alone and grid connected hybrid energy system for a remote community in India. Wind generation system and Solar Photovoltaic generator have been are considered as the feasible renewable energy resources for this location. Sizing & cost analysis have been performed for both grid connected as well as stand-alone system using HOMER software. At last a comparative cost effective analysis has been carried out considering the results of both the scenarios.**

***Index Terms*— Renewable Energy system, Hybrid Energy System, Stand-Alone, Grid Connected, HOMER.**

I. INTRODUCTION

Over the past few years there has been drastic increase in energy consumption by the world and India in particular. This increase can be accounted by the rapid growth shown by the country. This has led to more dependency on conventional fuels which are fast depleting and also have drastic environmental impact. After the resent World Climate Summit 2016 in Paris it has become mandatory for all countries to reduce their carbon foot print. One way of doing that is to reduce the dependency on conventional fuels for electricity production via penetration of renewable energy systems.

The most common renewable energy resources are wind and solar. But there main drawback is the energy density of these resources is very less, meaning a large area is required to produce the same amount of electricity[1]. The other issue is non reliability of electricity production. This can be overcome using energy storage units to store electricity during off peak time and using it during off production time.

A system consisting of many energy sources is considered as a hybrid energy system[2].

The hybrid system considered here consists of a Wind Generation System (WGS), Solar Photo Voltaic Generation (SPVG) and a battery bank for electrical energy storage. The power through Solar-wind system can fulfill the demand of power in the future as it can generate thousand of megawatt without actually causing any emission. This way it is becoming a sustainable. Pollution free and independent source of power [3] .

Since the limitation with wind energy system alone is that wind doesn't flow continuously. Likewise solar energy can be at-max present for 8 to 10 hours. Thus a hybrid system is becoming popular as it can easily mitigate such issues as electrical power is required continuously for all applications.thereby issue likes power surge and energy crisis can be dealt with ease with hybrid system[4]. The main issue to be considered for a

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stand-alone hybrid system catering to a load center is its cost. For a developing country like India high cost of such hybrid systems is the main hindrance in there practical application.

A small community in Mumbai, India is considered for case study for this paper. A hybrid system with Wind generation system (WGS) and Solar Photovoltaic generator (SPVG) with battery is used to cater to this load. The main reason for choosing a city like Mumbai is that it is a coastal city where the scope wind production is substantially high. The climate of this city is moderate throughout the year and hence load profile of this area remains almost similar year long.

Cost and Sizing analysis of the stand-alone system is performed using HOMER software. The results show that due to the high Net Present Cost (NPC) and larger installation area of a stand-alone system a grid connected system is proposed which has lower cost and rating of equipment making it more viable prospect for physical implementation.

In recent past also attempt were made to carry out similar type of simulation at technical university of Mombasa. The system showed that power generation though wind and solar PV-System is a better alternative over generating syste via fossil fuel. The result were demonstrated using Homer software[5]. In another model as suggested by [6] for supplying electrical energy to industry, a PV solar cell array in combination with a wind generator and battery system has been proposed. The entire system do comprises of inverter allowing conversion of Direct Current into Alternating current, several fuses, lighting load junction box, electrical heating load and testing instruments for observation and testing the magnitude of current, harmonic contamination, power factor & voltage of the system. The proposed scheme also make use of battery storage system, control system & power electronics. To carry out simulation MATLAB was used for 10kW wind /BESS/PV output, though it has been observed that the peak rated output comes at 8.5 kW [7].

II. STAND-ALONE SYTEM

As mentioned above a stand-alone system is designed as shown in Fig 1.It can be seen that the Wind turbine produces the AC power and the solar panels produce DC power, the load which normally works on Alternating current consumes power from both solar and wind with a help of the converter allowing conversion of DC power into AC for consumption by load center and also during excess power production converts to dc for storage in battery bank.

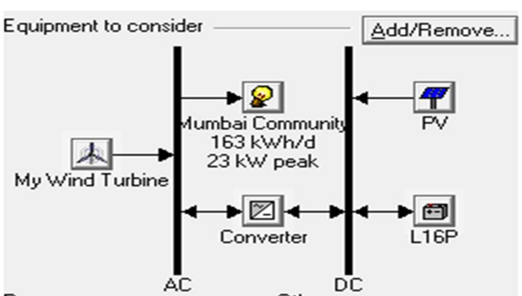


Fig. 1. System Implemented in HOMER

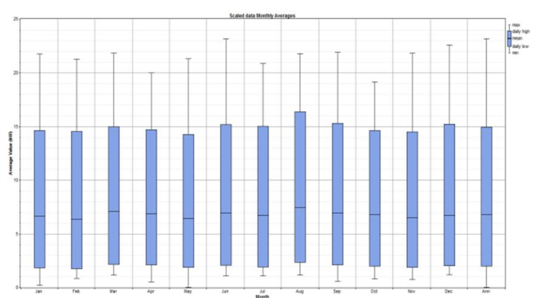


Fig.2 Scaled Monthly Average of Load Demand

A. Electrical Load

The electrical load of the community has a peak load of 23kW with a daily energy consumption of 163 units (kWh). The load profile is almost similar for all the months throughout the year because of moderate costal climate of the location[8]. The average load demand for each month is presented in Fig.2.It should be noted that since the peak load demand of the load is 23kW which has to be catered by the renewable energy system therefore the sizing of the system has to be done accordingly.

B. Renewable Resource

The two main resources are wind and solar energy. The wind energy data of Mumbai which is at an altitude of 14m above sea level is considered for 2014-2015 which shows that an average annual speed of 4.3m/s with the wind profile[9] as shown in Fig.3. The other resource is solar energy. The solar energy data is obtained from NREL site [10] for the year 2014-2015 which shows an average irradiance level of 4.98kWh/m^2 /d with clearance index and irradiance level as shown in Fig.4.

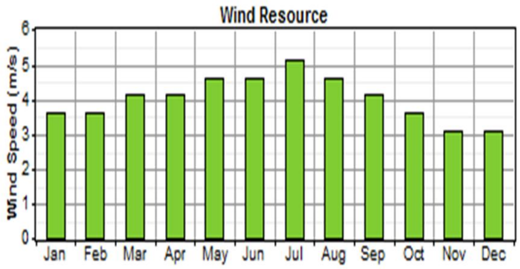


Fig.3 Average Wind Speed for Mumbai

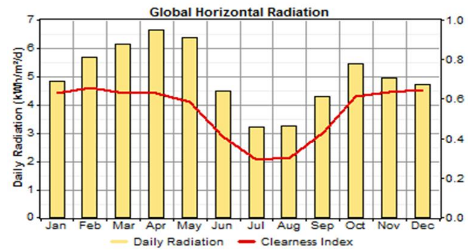


Fig.4 Solar Irradiance level and Clearance index

C. Power Generation System

The hybrid system designed using HOMER consists of a wind turbine generator, a solar PV generator, battery bank, converter, the primary load as discussed above and a grid. The grid is used in the latter part of the paper to show a comparative study of the hybrid system in grid connected and islanding mode.

Wind Power Generator

The wind turbine and generator set used is from manufacture Polaris America.The output is expressed as [11]

$$P_t = \frac{1}{2} C_p(\lambda)\rho A V^3 \qquad (1)$$

Where, Pt =Output power, Cp–Power Co-efficient, λ=Tip speed ratio, ρ= Air density inKg/m3, A=Frontal area of wind turbine, V=Wind Speed. It is a 20kW AC WPG with the power curve as shown in Fig.5. The technical specification of the turbine generator set can be found from manufacturer website[12]. The cost of buying and installing this wind turbine Rs 22 lakhs. The power curve shows a cut in wind speed of 2.6m/s and a cut out wind speed of 25m/s. the survival wind speed of the turbine is 59m/s.

Hub height of 21.3 m is the most optimized height for the turbine as simulated by HOMER. The life expectancy of the WPG is assumed to be 25 years which can increase on proper maintenance.

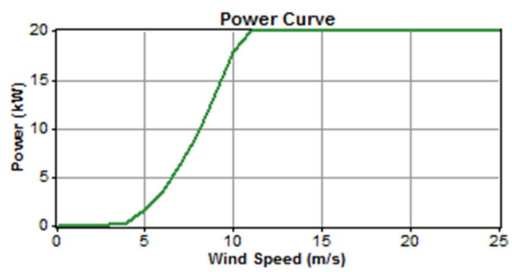


Fig.5 Power Curve for 20kW Polaris America WPG

Solar Photovoltaic Array

The flexibility of choosing a photovoltaic array has increased because of the recent advancement in its technology. Basically PV is a physical process through which solar energy is converted to electrical energy. The solar cell basically acts as a p-n junction diode governed by the following equation[13]

$$I = I_L - I_O[e^{\frac{V+IR_S}{\alpha}} - 1] \qquad (2)$$

Where IL is the light current of the PV cell in amperes, Io is the saturation current, I is the load current, V is PV output voltage (in volts), Rs is the series resistance of the PV cell (in ohms) and 휘 is the thermal voltage timing completion factor of cell (in volts). The solar module considered for the purpose of this case study is STP280-24/Vd solar module[14]. This module can produce a power of 280W at a voltage of 24V. Hence the DC bus voltage is also fixed at 24V. The costing of these panels has been normalized [15] because of variety of modules present in the market and considered as Rs 38,500 per kW. Lifespan of these modules is 20 years with a derating factor of 80%. A horizontal axis tracking system is considered with monthly adjustment cycle.

Battery Bank

The batteries used for the system are Trojan LP16. The battery model can be represented by the dynamic equation based on the charge storage process and the electrolyte heating [16].

$$Q_e(t) = \int_0^t -I_m(\tau)\, d\tau \quad (3)$$

$$C_\theta \frac{d\theta}{dt} = \frac{\theta - \theta_e}{R_\theta} + P_s \quad (4)$$

Where Qe is Extracted charge,C= Battery thermal capacitance, R = Battery thermal resistance, Ps = Heating power. The details of the battery can be obtained from the companies site [17]. The battery has nominal voltge of 6V with a capacity of 2.16kWh. Since the DC bus voltage is fixed at 24V therefore 4 battery are connected per strings. The cost of these batteries is Rs 8,500 per battery.

Converter

The converter connected basically facilitates the power transfer between the AC bus and the DC bus. The rectifier used here has a cost of Rs 50,000/kW. The life expectancy of the converter is 15-18years with an overall efficiency of 90%.

Grid

In this case study we have also considered a grid connected system. The current pricing and scheduling of the utility in Mumbai is shown in Fig.6 as obtained from [18].The tariff for extracting power from utility during peak power is Rs 5.5/kWh, base price Rs 3.7/kWh and off-peak tariff is Rs 3/kWh. The simulation of the hybrid system is performed keeping in mind the life span of the project as 25 years. It is obvious that the tariff rates will not remain during this period therefore an annual variation of 0.01% in tariff rates is assumed.

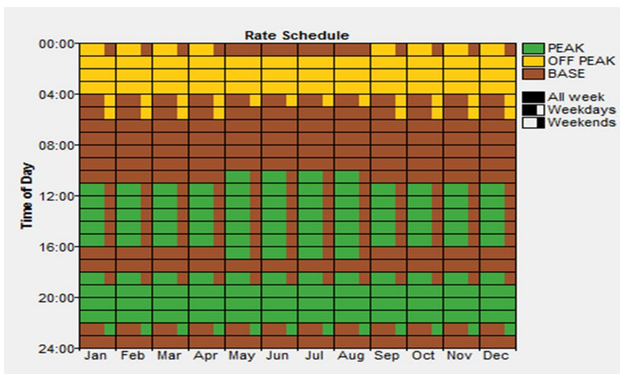


Fig.6 Rate Scheduling of Utility in Mumbai [18]

In India there is still no provision provided by the utility companies for selling excess power produced by the hybrid system back to the grid. But policies are being formulated [19] and it is proposed to be implemented in future years. Therefore a sell back rates is extrapolated form the recent trends in the world. The sell back tariff during peak hours is Rs1.65/kWh and of Rs 0.88/kWh during base time. Sell back during off-peak is zero as it leads to swell in the voltage of the grid which has to avoided. A dummy load can be used if excessive power is produced during off peak time or an extra storage capacity can be thought of which leads to further increase in capital cost [20].

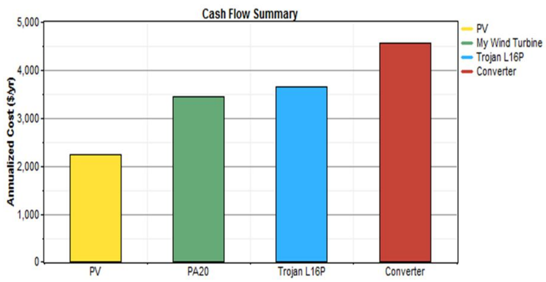
III. Optimized Results Stand-Alone System

HOMER software performs several iteration considering several sensitivities and gives an optimal solution for designing the system. The software considers the most cost effective iteration as the most optimized result which also caters to the load. For this case study the sensitivities considered are wind speed, solar irradiance and projection of load variation. A total of 95,000 sensitivities cases were evaluated and the most optimized result thus obtained is shown in Fig.7. The life span of the project is fixed at 25years with an annual rate of interest of 7% is considered for cost estimation.

				PV (kW)	PA20	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
				39	1	220	23	$ 123,300	5,141	$ 195,764	0.234	1.00

Fig.7 Optimized Result for Stand-Alone System

It shows an initial capital cost of Rs 68 Lakhs, with an Annual Operating Cost (AOC) of Rs 2.86 Lakhs. Total Net Present Cost (NPC) is Rs 1.076 Crores, which gives a cost of electricity (COE) Rs 12.86 per kWh. The annualized cost of hybrid system components is shown in Fig.8 and the net production of power by each component of the hybrid system is shown in Fig.9.



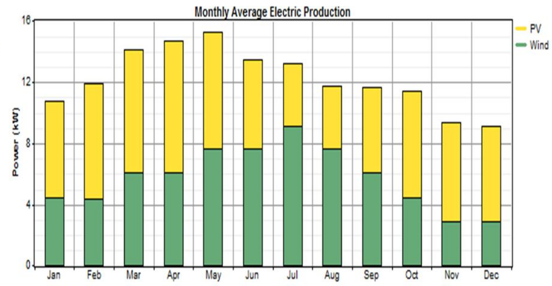
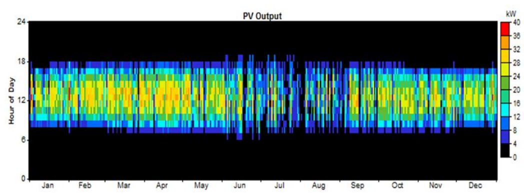


Fig.8 Annualized cost of system components

Fig.9 Monthly Electricity production by WPG and SPV

After optimization is performed the rating of equipment so decided is as follows: PV array of 39kW, one wind turbine of 20kW, 220 batteries with 4 batteries in each string and a converter with 23kW rectifier rating and 23kW of inverter rating. The higher rating of the converter which is the most cost hungry component of the hybrid system is justified by the 23kW peak load demand and 20kW rating of the wind turbine used.The annualized cost of the proposed system comes out to be Rs 7.7 lakhs. Fig.9 shows the power generation data of each month divided between the PV and Wind. The total electricity produced by PV is 56,629kWh/yr (53%) and by wind is 50,437kWh/yr (47%). Fig.10 and Fig.11 shows the amount of electricity produced wrt time of the day.



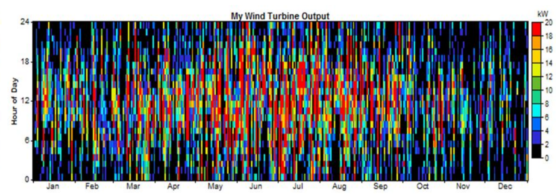


Fig.10 PV output Vs Time for one year

Fig.11 Wind Turbine output Vs Time for one year

As seen from the Fig.1 the load demand is of 163kWh/day which converts to 59,595kWh load demand per year. This is far less than what is generated by the hybrid system. This leads to an excessive energy production of 39,889kWh/yr (37.3%) as shown in Fig.12.

Quantity	kWh/yr	%
Excess electricity	39,889	37.3
Unmet electric load	29.5	0.0
Capacity shortage	51.9	0.1

Quantity	Value
Renewable fraction	1.00

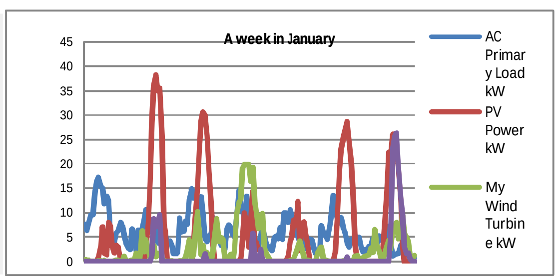


Fig.12 Excess Electricity Production data

Fig. 13 Power production and consumption for a week in January

The unmet electric load and capacity factor is very small and can be neglected. The prime reason for this excess production is the miss match of the power production from PV and Wind and the load demand. As seen from Fig.10 and Fig.11 the SPV produce power during day time when sun is shining and the WPG produces power thought the day but the power generated varies with the wind speed. This miss match can be easily seen from Fig.13 which shows the power production, consumption and excess for a week of January. It is to be mentioned that similar type of mismatch is present in other months as well for visibility of the result only a week is considered.A prospective solution to reduce this excess generation is reducing the rating of the equipment which is not possible as during low production hours the demand increases which can be catered by higher rating equipment. The other proposal is to increase the storage capacity which would incur further increase in cost and installation area. Both these are not feasible as it would increase the cost of an already capital intensive hybrid system. Therefore a grid connected system is proposed in this case study.

IV. Optimization of Grid Connected System

In order to reduce the per unit cost of electricity and making the system viable for an Indian scenario were cost is a very critical aspect considering India is a developing nation. A grid connected system is proposed as shown in Fig.14. The sensitivities of the previous system are retained and a new sensitivity of grid power extraction is incorporated. Since our previous system was completely renewable hence an addition constraint is applied to the system there by making the minimum renewable energy production to 80%. The optimized result thus obtained from HOMER is shown in Fig.15. It shows annualized cost of Rs 5.2Lakhs, an initial capital cost of Rs 44 Lakhs, with an Annual Operating Cost (AOC) of Rs 22.07 Lakhs. Total Net Present Cost (NPC) is Rs73.61Lakhs, which gives a cost of electricity (COE) Rs 8.8 per kWh. The annualized cost of hybrid system components is shown in Fig.16 and the net production of power by each component of the hybrid system is shown in Fig.17. After optimization is performed the rating of equipment decided is as follows: PV array of 18kW, one wind turbine of 20kW, 80 batteries with 4 batteries in each string and a converter with 16kW rectifier rating and 16kW of inverter rating. In addition a 5kW connection from the utility is obtained.
This helps reduce the rating of the components as now during miss match of electricity production and demand, electricity is drawn from the grid. This further help reducing the excess power generated as shown in Fig.18.

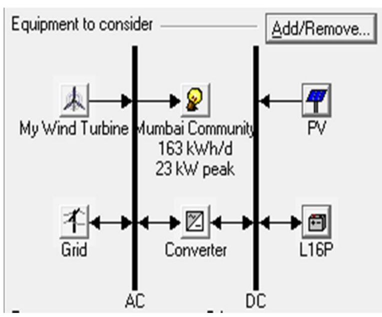


Fig.14 Grid connected System implemented in HOMER

PV (kW)	PA20	L16P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
18	1	80	16	5	$ 80,600	3,778	$ 133,844	0.160	0.82

Fig.15 Optimized Result for Grid Connected System

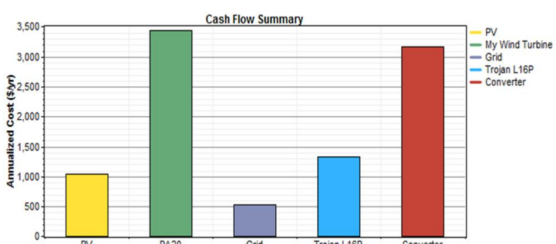


Fig.16 Annualized Cost of System Components

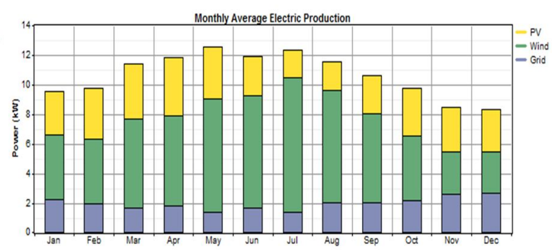


Fig.17 Monthly Average Electric Production

Production	kWh/yr	%
PV array	26,137	28
Wind turbine	50,437	54
Grid purchases	17,032	18
Total	93,606	100

Consumption	kWh/yr	%
AC primary load	59,484	66
Grid sales	30,114	34
Total	89,597	100

Quantity	kWh/yr	%
Excess electricity	0.000222	0.0000
Unmet electric load	11.1	0.0186
Capacity shortage	56.9	0.0957

Quantity	Value
Renewable fraction	0.818

Fig.18 Power Distribution of Grid Connected System

As can be seen the excess electricity has reduced to zero. But we see that electricity produced by SPV and WPG is 26,137 kWh/yr and 50,437 kWh/yr which is still higher than the AC primary load. This is due to the constraint that minimum 80% of energy should be produced by renewable method. After optimization the renewable energy fraction is 81.8% as shown in Fig.18. The excess energy so produced is fed back to the grid. The net grid purchase is 17,032 kWh/yr and net grid sales is 30,114kWh/yr. The purchase and sales are shown graphically for one week in January in F ig.19 and net power production in Fig.20. The sale of electricity back to the grid

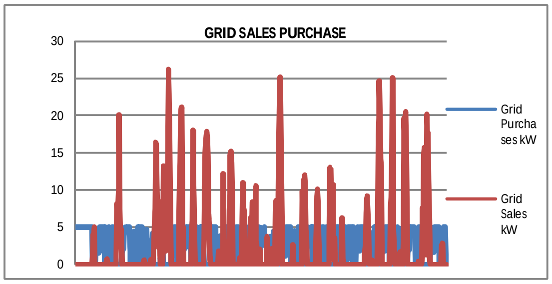


Fig.19 Grid Sales and Purchase for one week of January

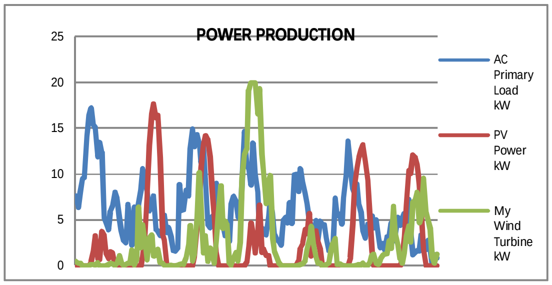


Fig.20 Power Production for one week of January

reduces the utility cost incurred. Hence no electricity is wasted in this proposed system. As seen from the Fig.20 the whenever AC load demand is more power is extracted from the grid and when renewable energy is production more power is given back to the grid. Table.1 shows the comparison between the two systems. It can be conclusively said that not only the grid connected system has lesser cost and installation area but also has more practical and economic viability.

TABLE. I COMPARISON OF STAND-ALONE AND GRID CONNECTED SYSTEMS

PARAMETER	STANDALONE	GRID CONNECTED
SPV(rating, cost)	39kW, Rs68 Lakhs	18kW, Rs44 Lakhs
WPG(rating, cost)	20kW, Rs22 Lakhs	20kW, Rs22 Lakhs
Battery (no., cost)	220, Rs18.15 Lakhs	80, Rs6.60 Lakhs
Converter (rating, cost)	23kW, Rs11.5 Lakhs	16kW, Rs8 Lakhs
Excess Energy	39,889 units	NIL
NPC	Rs107.61 Lakhs	Rs73.61 Lakhs
COE	Rs12.86/kWh	Rs8.8/ kWh
AOC	Rs7.42 Lakhs	Rs8.8 Lakhs
Net Grid Purchase	NIL	+Rs28,930

V. CONCLUSION

Going through the results presented above it can be conclusively said that for penetration of renewable energy into electric energy production hybrid system is the way to go. The two configurations in which a hybrid energy system can be architecture namely stand-alone and grid connected are compared. Due to the very high investment cost Rs 107.6 Lakhs of a standalone system and excess energy production nearly 40,000 units/yr makes it a non-viable prospect. The proposed grid connected system not only reduces the NPC to Rs 73 Lakhs but also reduces the excess electricity production. The system is so optimized that the renewable energy fraction is not less than 80%. The excess energy produces by the hybrid system if sold back to the grid at the proposed prices will not only cover the purchase cost but also salvage a cost of Rs 28,930. This proposal not only reduces the load demand of the grid but also help in increasing the grid capacity for load centers having high demand.

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