Feasibility Study of Optimization in Renewable Energy Penetration to an Isolated Hybrid Power Plant

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Abstract: The green sources of energy are mortal optimistic to reduce the environmental pollution and the global warming of the planet. An objective of 12% habit of renewable energy has been agreed by the UNO country members to achieve by 2020. So, the power of the renewable energy sources is being used to generate electricity both as grid connected and isolated hybrid power plants. This paper performed a pre-feasibility of renewable energy penetration into an existing diesel plant for powering a village domestic load of 200 kW. The solar radiation data and wind speed data used in this paper are for the place of Ervadi Ramathapuram (District), Tamil Nadu, India which is located 9.25° N longitude and 78.85° E latitude. All the necessary optimization and analysis of cost of energy are carried out using the assessment software package HOMER (Hybrid Optimization Model for Electric Renewable). The outcome is offered and compared the cost of energy for before and after renewable energy penetration.

Keywords: *Renewable energy resources, Solar and Wind Energy, COE, Net present cost HOMER, Hybrid system, Emission.*

I. INTRODUCTION

Energy technologies have a necessary part in socioeconomic development at all scales. Due to a huge magnify in fuel costs and difficulties caused by conventional energy sources, the use of renewable energy resources (RERs) have become compulsory. On the contrary, renewable energy sources are virtually emission free and consequently help the fight against global warming by reducing the amount of carbon dioxide being released into the atmosphere. These energy sources are inexhaustible and clean, and they can be used in a decentralized way. In developing countries like India, renewable energy can play an important role in meeting serious energy deficits. The various Renewable Energy Sources (RES) such as solar energy, wind energy, fuel cells, biodiesel and so on are used for domestic load applications in the developing countries. However, solar and wind are accessible freely and thus appears to be a capable technology to make available reliable power supply in the remote areas of India. The irregular nature of the solar and wind energy under varying climatic conditions requires a feasibility assessment and optimal sizing of hybrid solar and wind energy system. Without proper technical and financial feasibility study, the hybrid alternative energy systems previously installed in the remote areas showed a poor efficient design.

In order to efficiently and economically utilize the renewable energy resources, one optimum sizing method is necessary. The optimum sizing method can help to guarantee the lowest investment with full use of the system component, so that the hybrid system can work at the optimum conditions in terms of investment and system power reliability requirement. Some research use Typical Meteorological Year data [1–2] or long period meteorological data [3] for the hybrid system optimizations. Also many optimum sizing methods were developed based on the worst month scenario [4–5]. There are two sizing methods for stand-alone hybrid wind-solar energy systems. The first method is the ‘‘yearly average monthly method” in which the size of PV panel and wind turbine is derived from the yearly averaged monthly values. Similarly, the load is represented by the yearly mean monthly value. The second method is termed the ‘‘worst months” method, it choose the worst months for solar and wind energy system separately. A similar sizing method, developed by Morgan [6], is the ‘‘worst month” method. Contrary to ‘‘worst months” method, this method chooses the worst month as the one in which the largest total area of PV module and wind turbine occurs. The main object of combining a diesel generator with any of these renewable sources is to ensure minimum diesel fuel consumption, thus minimizing operating costs and carbon footprint of the system [7].The proposed system of this work is intended to provide electricity to a model community of 200 families with five to six family members in each. The community is equipped with a primary load, a deferrable load, a community school and a health post. An electric load which includes lighting, water pumping, a radio receiver, and some clinical equipment has been suggested. Thus, based on the literature reviews, HOMER [8] software is taken for the purposes of this study to carry optimization and analysis of cost of energy in of hybrid renewable energy system. This paper investigates the impacts and integration of renewable energy sources with diesel generator power system. In particular a hybrid renewable energy model has been developed to investigate the necessity of solar and wind power considering pollution, production cost and cost of energy. This paper is organized as follows: Section II discusses mathematical system modeling. Section III presents sample system study setup to build a hybrid renewable energy system. Section IV gives results and discussions energy resources. Cost comparison are described in Section V. Section VI concludes the article.

II. MATHEMATICALSYSTEM MODELING

The mathematical model of the proposed hybrid renewable energy system contains physical modeling followed by cost modeling.

A. Physical modeling

1. Wind Turbine

Wind turbine generation requires a wind turbine which functions as a device to generate AC or DC electricity by converting kinetic energy according to a particular power curve. The power curve set to the standard temperature and pressure conditions and air density of 1.225 kg/m^3, is a power output versus wind speed at hub height. Four steps are involved in the process to determine the output power of the wind turbine for each hour.

First, the average wind speed for a particular hour at the anemometer height is determined using wind resource data. Second, the corresponding wind speed at the turbine's hub height is calculated using power law or logarithm law. Third, the turbine power curve is used to calculate the output power at different wind speed. Fourth, the output power will be multiplied by the air density ratio, the ratio of actual air density to the standard air density, which is assumed to be constant throughout the year.

This system produces energy by converting the flowing wind speed into mechanical and then electricity. The power enclosed in the wind kinetic energy is given in Equation (1).

$$P = \frac{1}{2} \times \rho \times A \times v^3 \qquad (1)$$

where A is the area traversed by the wind turbine (m^2), ρ are the air density (1.225 kg/m^3) and v the wind speed (m/s).The electrical power is given in Equation (2).

$$P_W = \frac{1}{2} \times \rho \times C_e \times A \times v^3 \times 10^{-3} \qquad (2)$$

where C_e is the coefficient of the wind turbines performance, according to Bertz $C_{e-Limit} = 0.593$.Therefore, the energy produced by the wind turbine is given in Equation (3).

$$E_W = P_W \times \Delta t \qquad (3)$$

2. PV Generator Model

The PV generator contains modules which are composed of many interconnected solar cells in series/parallel to form a solar array. The energy generated from the PV generator is given in Equation (4).

$$E_{PV} = A \times \eta_g \times P_f \times \eta_{PC} \times I \qquad (4)$$

where A is the total area of the photovoltaic generator (m^2), η_g is the module efficiency (0.111), P_f is the packing factor (0.9), η_{PC} is the power conditioning efficiency (0.86), and I is the hourly irradiance (kWh/m^2).

The derating factor is the effect of which will cause the output power to deviate from the ideal performance of PV array. For example, wire losses, dust on PV panel, and increased temperature and so on into consideration. Therefore, if the temperature of the PV panel increases, the derating factor can be reduced to get a more accurate result. The PV array rated capacity or peak capacity is the power. A PV array would generate under standard conditions: 25° C panel temperature.

3. Battery System

The battery considered in the model systems of this work are rated by the amount of current produced over a period of hours (in Ah). The storage capacity of the battery (C_{wh}) is calculated using Equation (5).

$$Cwh = E_L A \times AD / (\eta_v \times \eta_B \times DOD) \qquad (5)$$

Where DOD is allowable depth of discharge of the battery, *AD* is number of autonomy days, and η_B is battery efficiency.

4. Diesel Generator System

The rated power of the generator and the actual power output affects the fuel consumption of the diesel generator. The fuel consumption of the diesel generator (F_{CG}) in (1/h) is given by Equation (6).

$$FC_G = A_G \times P_G + B_G \times P_{R-G} \qquad (6)$$

Where P_G, P_{R-G} are the output power and the rated power of the generator in kW. A_G and B_G are the coefficients of the consumption curve in (1/kWh), where A_G = 0.246 1/kWh and B_G = 0.08145 for the diesel generation.

5. DC/AC inverter

Inverters convert electrical energy from the DC form into the AC form with the desired frequency of the load. The efficiency of the inverter is assumed to be roughly constant over the entire working range (e.g. 90%) [27].The optimum criteria, including economic, technical and environmental feasibility parameters, were analyzed using the HOMER software package developed by the National Renewable Energy Laboratory (NREL).

B. Cost Modeling

1. Net present cost (NPC)

NPC is used in calculating the life-cycle cost of the project, in which the future cash flows of total costs and revenues discounted back to the present using discounted rate. Inflation can be taken into account by using the real interest rate rather than the nominal interest rate. The cash flow begins with year zero where the initial capital cost takes place, and the replacement cost takes place at the end of the component lifetime while the operation and maintenance (O&M) cost is recorded every year of the project. The formula for salvage value is given in Equation (7).

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \qquad (7)$$

C_{NPC}	=	Net present cost (INR)
$C_{ann,tot}$	=	Total annualized cost (INR/Yr)
CRF	=	Capital recovery factor
i	=	Interest rate (%)
R_{proj}	=	Projected life time

2. Cost of energy (COE)

The cost of energy is calculated as given in Equation (8).

$$COE = TPV * CRF / E_{load} \quad (8)$$

Where, E_{load} is the yearly output in kWh, TPV and CRF are the total present value of actual cost of all system components and the capital recovery factor, respectively, which can be given in Equations (9) and (10).

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (9)$$

$$TPV = C_{PV} + C_{wind} + C_{bat} + C_{con} \quad (10)$$

where, i is the annual discount rate, n is the system life in Yrs, C_{PV} is the sum of present value of capital and maintenance costs of the PV module in system life; C_{wind} is the sum of present value of capital and maintenance costs of the wind turbine in system life; C_{bat} is the sum of present value of capital and replacement costs of battery bank in system life; C_{con} is the sum of present value of capital and replacement costs of converter in system life.

III. SAMPLE SYSTEM STUDY (ERVADI, TAMILNADU, INDIA)

Ervadi (9.25° N longitude and 78.85° E latitude) is situated along southern India. In the area of Ervadi there is a small community of 200 houses, which do not have access to the main electricity grid. This community has been electrified by local village governorate for a period of 8 hours per day, in the context of which an autonomous power system based on a diesel generator has been developed. In more detail, the nominal capacity of the diesel generator is 30 kW. The profile of electricity demand in Ervadi for a day is presented in Fig.1 with daily variation of 5% and hourly variation of 5%. The daily average of the electric load for this community is in the region of 421 kWh/day, the annual peak of the load is 37 kW.

A. Electrical load calculation

The following loads are considered for this paper, five water pumps, one for the school and one for health-care clinic and the remainder for household use, are assumed. Each water pump has a 200 W power rating. The average load (3x200W =600W x 6 hours usage so, the total consumption of electricity by the pumps) is calculated to be 3.6 kWh/day for the households and 200W x 6 hours =1.2 kWh/day for the school and health post each, the totaling 2.4 kWh/day. (approactemately 3kWh/day).The proposed primary load per household is a 5 W night light, a 5 radio receiver and four 60 W light bulbs to be used between 18:00 pm and 23:00pm in the evening and the daily consumption is calculated to be approximately 400 kWh/day. Electric lighting for the school in the morning (09:00 am-05:00 pm) for those who wish to pursue basic education is suggested. For 4 classrooms with 4 lamps (energy saving type) of 40 watt capacity in each classroom and a lamp for a toilet is calculated to 5.12 kWh/day. A typical two-room healthcare facility (4 bulbs x 40x10hrs : 2 fan x 60x10hrs) is calculated to be 2.8 kWh/day, equipped with vaccine refrigerator (1x80x10hrs), light bulbs (2x20x10hrs), freezer , vaporizer (1x50x3hrs), TV set (1x150x10hrs) is suggested. The most basic health equipment is proposed and the daily consumption is calculated to be just 5.6 kWh .The sum total of the daily energy consumption of the community is approximately 421 kWh.

B. Energy resources hybrid renewable energy system

The setting up of renewable energy system completely depends on the resources available for the given site. That includes wind speeds, average daily surface solar insolation, and their timely variation. The meteorological data of wind speed and solar insolation for Ervadi (9.25° N longitude and 78.85° E latitude) was taken from the NASA surface meteorology and solar energy website [18]. Monthly solar radiations for the site are shown in Figure 2. There are 3 constituents of solar radiation reaching the ground: global radiation, diffused radiation, and direct radiation [19]. Global and diffused radiations are usually measured, while the direct component is estimated. The average daily solar radiation for the site is 5.11 kWh/m2 and average clearness index is 0.608. These insolation levels peak from February to November and are the lowest for the months of January and December. The monthly wind speed variations are shown in Figure 3 and from these values the average wind speed for the area is found to be 5.711 m/s.

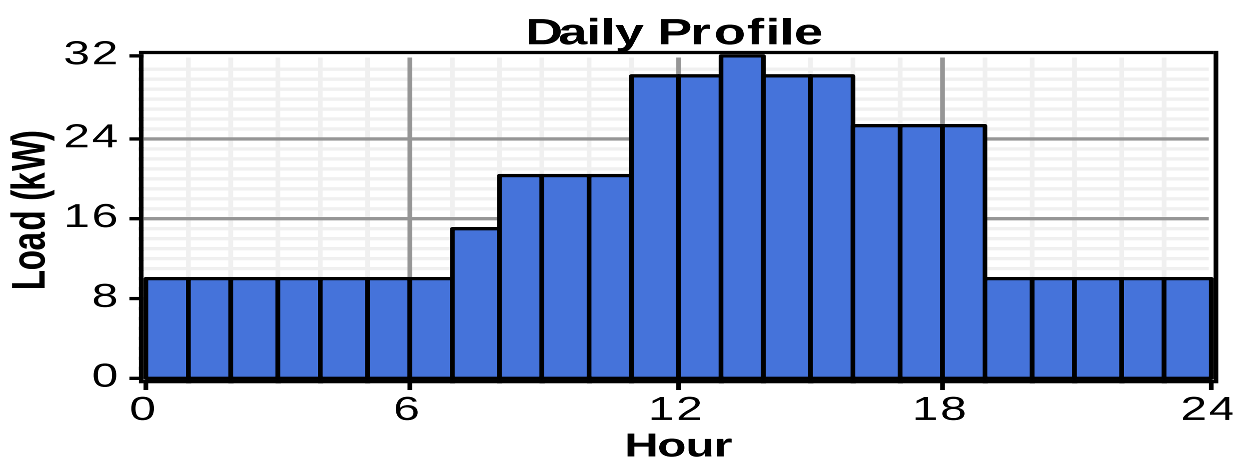

Figure 1: The primary electrical load data for the village

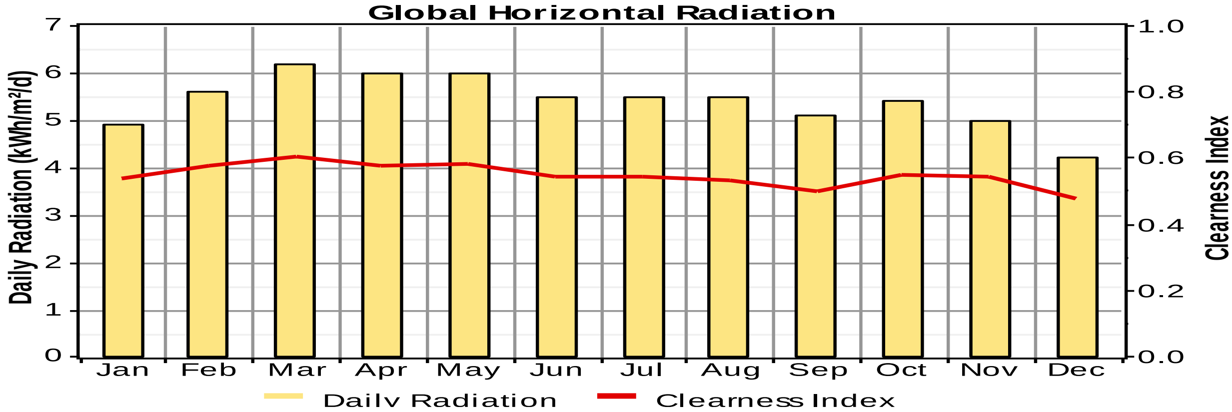

Figure 2: Monthly solar resources

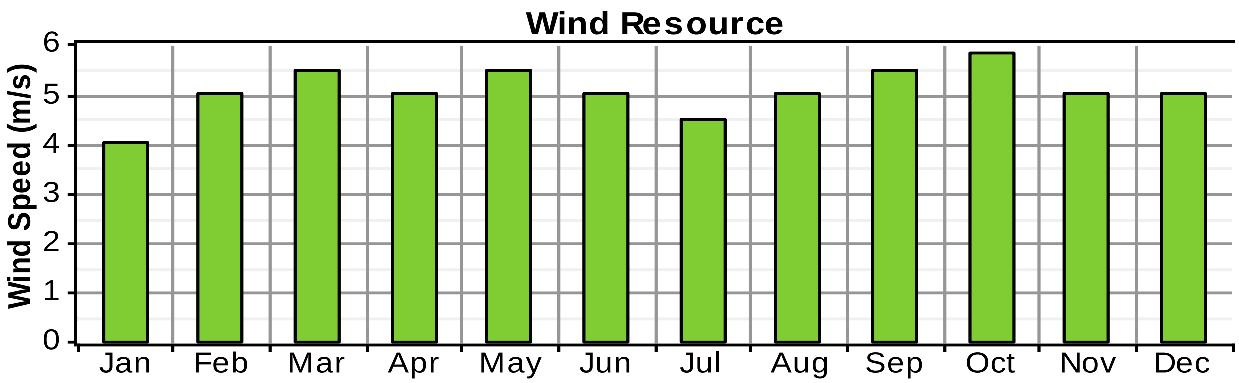

Figure 3: Monthly wind speed variations.

C. Hybrid system components

Summary of initial system costs, Replacement costs and operating & Maintenance costs are shown in Table 1.The PV array, Wind turbine, diesel generator, inverter and battery maintenance costs are estimates based on approximate time required and estimated wages for this sort of work in a remote area of Ervadi. All initial costs including installation and commissioning, replacement costs and operating & Maintenance costs of the site are summarized in Table 1.

D. Hybrid System Control Input

The specifications of system control inputs for this analysis are shown in Table 2.

E. Economics and Constraints

The project lifetime is predictable at 20 years. The annual interest rate is fixed at 6%. There is no capacity shortage for the system and operating reserve is 10% of hourly load. The operating reserve as a percentage of hourly load was 10%. Meanwhile, the operating reserve as a percentage of solar power output was 25%. Operating reserve at 10 % is the safety margin that helps ensure reliability of the supply despite variability in electric load and solar power supply.

Table 1: Components cost

Item	Initial System Costs	Replacement Costs	Operating & Maintenance Costs
PV modules	120 INR/W	100 INR/W	5000INR/kW/yr
Wind turbine	1,24,000 INR/kW	1,00,000 INR/kW	50/W
30kVA Diesel Generator	9,00,000INR	7,00,000INR	30INR/Hr
Surrete 6CS25P battery	2,00,000 INR	1,50,000 INR	100INR/Yr
Converter	10,000 INR	08,000 INR	500/kW/yr

Table 2 system control inputs

Control inputs for optimization	
Simulation time step (minutes)	60
Check load following:	No
Check cycle charging:	No
Set point state of charge:	80 %

IV. RESULTS AND DISCUSSION

A. Simulation Results

The outcome of the paper are provides the results in terms of compared the COE for five different combinations of hybrid renewable energy system components with renewable energy penetration. The optimization results are presented categorically

Case 1 Base diesel generator (existing system)
Case 2 Base diesel generator + battery
Case 3 Base diesel generator + PV +Wind turbine + battery
Case 4 PV +Wind turbine + battery
Case 5 Penetration of renewable energy resources + Base diesel generator + battery is presented in the forthcoming paragraphs.

Case 1: Base diesel generator

At present, a diesel generator is existing power plant for the total responsibility of load demand is mentioned early. For remote homes having an energy rating of 421kWh/d (37 kW peak) should include one 30 kW diesel generator with fuel consumption of 59,058 Lit and the COE is INR 18.10/kWh (COE $/kWh is 0.292, INR Equivalent to $ is 62 as an 2015) The optimization results and various cost indices for a diesel price of 0.67 $/Lit, are summarized in Table 3.

Table 3 Optimization results for Base diesel generator with diesel price of 0.67 $/Lit,

Generator (kW)	Initial cost(INR)	Operating cost(INR))	Total NPC(INR)	COE (INR)	Capacity shortage(%)	Diesel (Lit)	Working hour (hrs)
30	4,05,790	27,18,514	3,51,57,906	18.10	0.04	59,058	8760
40	5,41,074	32,05,834	4,15,22,578	21.08	0.02	68,660	8760

Table 4 Optimization results for Base diesel generator with battery

Generator (kW)	Battery	Convertor (kW)	Initial cost (INR)	Operating cost(INR)	Total NPC(INR)	COE (INR)	Capacity shortage (%)	Diesel (Lit)	Working hour (hrs)
30	-	-	4,05,790	27,18,514	3,51,57,906	18.10	0.04	59,058	8760
40	-	-	5,41,074	32,05,834	4,15,22,578	21.08	0.02	68,660	8760
30	1	1	5,42,576	32,06,000	4,16,21,654	23.08	0.06	70,760	8760
40	2	2	5,45,074	32,07,834	4,15,40,508	26.08	0.08	78,680	8760

Case 2: Base diesel generator + battery

The system shown in Table 4 reflects that the same COE is retained by battery along with base generator. Furthermore, same size of the generator is retained the similar COE. In term of fuel consumption and working hours for generator is same for the base cases.

Case 3: Base diesel generator + PV +Wind turbine + battery

The optimization results for specific wind speed (5.67m/s), solar irradiation (5.68 kWh/m^2/d), and diesel price (0.67 $/Lit) are illustrated in Table 5. It is seen that, a hybrid renewable based power system is economically more feasible with a minimum COE of INR 12 /kWh than base diesel generator + battery; however the economic performance of a base diesel generator + battery system is almost similar to the base diesel generator only system. In term of fuel consumption 137 Liters is saved.

Table 5 Optimization results for Base diesel generator **+ PV +Wind turbine + battery**

PV (kW)	Wind turbine	Generator (kW)	Battery	Convertor (kW)	Initial cost (INR)	Operating cost(INR)	Total NPC(INR)	COE (INR)	Renewable fraction (%)	Capacity shortage	Diesel (Lit)	Working hour (hrs)
80	4	5	120	30	1,57,80,302	5,70,462	2,30,72,370	12.00	0.92	0.04	5,821	4.856
0	4	6	100	30	1,54,35,458	6,10,452	2,32,38,902	12.09	0.90	0.04	7,005	4.896
80	4	5	120	50	1,65,55,302	5,35,122	2,33,96,320	12.27	0.93	0.05	4,671	3.625
80	4	6	120	30	1,57,93,818	6,01,152	2,34,78,346	12.15	0.91	0.03	6,498	4.531
80	4	6	100	25	1,52,41,708	6,45,296	2,34,90,436	12.21	0.89	0.05	7,853	5.568
80	4	6	100	50	1,62,10,458	5,74,740	2,35,57,210	12.33	0.92	0.05	5,848	3.863
80	4	6	120	50	1,65,68,818	5,59,984	2,37,27,152	12.33	0.92	0.04	5,225	3.406
80	4	6	120	25	1,56,00,068	6,37,918	2,37,54,99	12.27	0.90	0.04	7,385	5.257
65	4	8	80	30	1,37,09,130	7,96,638	2,38,93,002	12.46	0.82	0.05	1,173	5.740

Table 6: Optimization results PV +Wind turbine + battery

PV (kW)	Wind turbine	Battery	Convertor (kW)	Initial cost (INR)	Operating cost(INR)	Total NPC(INR)	COE (INR)	Renewable fraction (%)	Capacity shortage (%)
80	8	120	50	21,44,766	4,48,012	2,71,74,724	14.32	1.00	0.05
80	8	120	60	21,83,536	4,57,498	2,76,83,372	14.57	1.00	0.05
80	10	120	30	23,15,266	4,90,854	2,94,27,618	15.31	1.00	0.04
80	10	100	50	23,56,930	4,95,690	2,99,06,258	15.68	1.00	0.04
80	10	100	60	23,96,680	5,05,178	3,04,14,906	15.93	1.00	0.04
80	10	120	50	23,88,860	5,09,826	3,04,44,852	15.81	1.00	0.03
80	10	120	60	24,31,516	5,19,312	3,09,53,500	16.12	1.00	0.03
20	35	120	30	48,57,266	12,11,914	6,40,65,344	33.72	1.00	0.05
20	35	120	50	49,34,766	12,30,886	6,50,82,578	33.22	1.00	0.05

Case 4: PV +Wind turbine + battery

The Table 6 represent optimization result for without base diesel generator that is hybrid PV +Wind turbine +battery. As illustrated in Figure 13, the scenario for the minimum COE (INR 14.32/kWh) is 80 kWp PV panel with 8 Wind turbines and 120 battery unit. Due to increased more number of Wind turbine

Case 5:25 % Penetration of renewable energy resources + Base diesel generator + battery (proposed system)

The Table 7 shows that for 25% of renewable energy resources penetration with base diesel generator. The very low COE INR 9.73/kWh is obtained. This shows that cost saving is 50% in COE, a 25% of renewable energy resources penetration could be achieved compared to base diesel generator only. Furthermore, the diesel generator is consumed 59,058 Liters of diesel annually while the hybrid power system with 25% renewable energy resources penetration resulted into 887 Liters diesel consumption i.e. a reduction of 20.83% in diesel consumption.

B. Costs-Benefit Analysis of HPSS

1. Existing System/Proposed Hybrid System.

The existing diesel generator have worse initial capital cost, higher operating cost, and higher total net present cost for the whole project as shown in Table 8 and as illustrated on chart of Figure 6. This system is produced more carbon monoxide (CO) and NO_2 as a result of high fuel consumption. The proposed hybrid system (25 % Penetration of renewable energy resources + Base diesel generator + battery) was able to satisfy daily energy demand with contribution of 99% of renewable energy sources. The proposed hybrid renewable energy sources has reduced total net present cost as a result of less fuel consumption as shown in Table 8 and displayed in chart of Figure 7.

Table 7: Optimization results 25 % Penetration of renewable energy resources + Base diesel generator + battery

PV (kW)	Wind turbine	Generator (kW)	Battery	Convertor (kW)	Initial cost (INR)	Operating cost(INR)	Total NPC(INR)	COE (INR)	Renewable fraction (%)	Capacity shortage	Diesel (Lit)	Working hour (hrs)
65	4	1	120	30	1,43,31,176	3,32,878	1,85,86,422	9.73	0.99	0.05	887	3.781
80	1	6	120	30	1,20,73,818	5,27,930	1,88,22,580	9.73	0.91	0.03	6,881	5.088
80	1	6	120	50	1,28,48,818	4,79,570	1,89,79,254	9.92	0.92	0.04	5,470	3.736
65	4	-	120	50	1,50,92,660	3,11,488	1,90,78,516	10.04	1.00	0.05	-	-
80	4	-	100	30	1,53,54,300	2,91,338	1,91,67,362	9.92	1.00	0.04	-	-
80	1	6	120	25	1,18,52,168	5,70,090	1,92,63,028	9.92	0.89	0.04	7,898	5.807
80	4	1	90	30	1,51,88,636	3,18,742	1,94,06,992	10.04	0.99	0.04	754	3.423
80	1	8	100	30	1,17,42,490	5,99,540	1,94,20,322	9.98	0.88	0.02	8,722	4.791
65	4	1	120	50	1,51,06,176	3,37,466	1,94,41,003	10.16	0.99	0.04	580	2.282

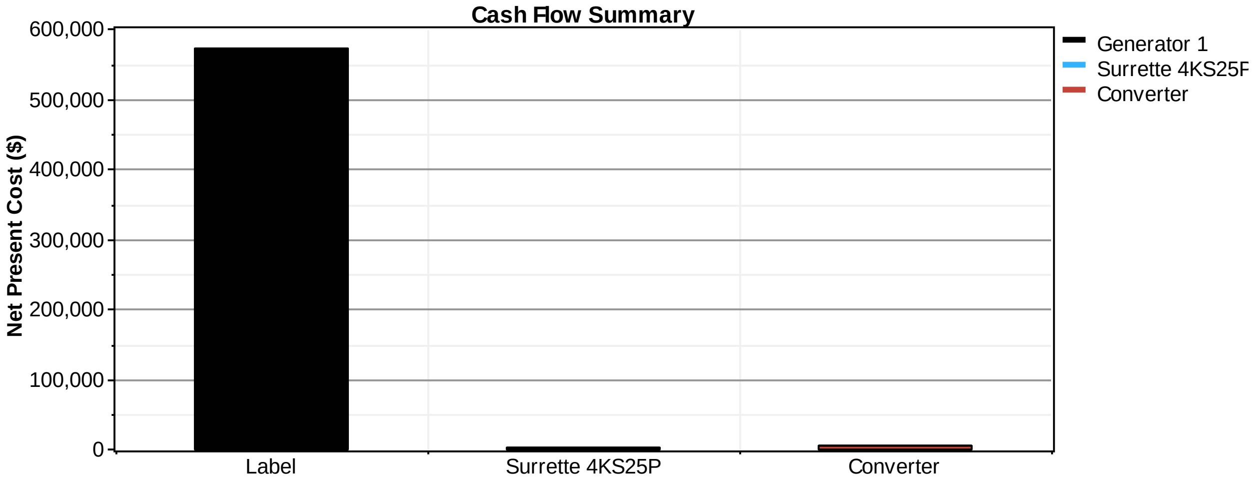

Figure 6: Cost summary of existing diesel-only generator set

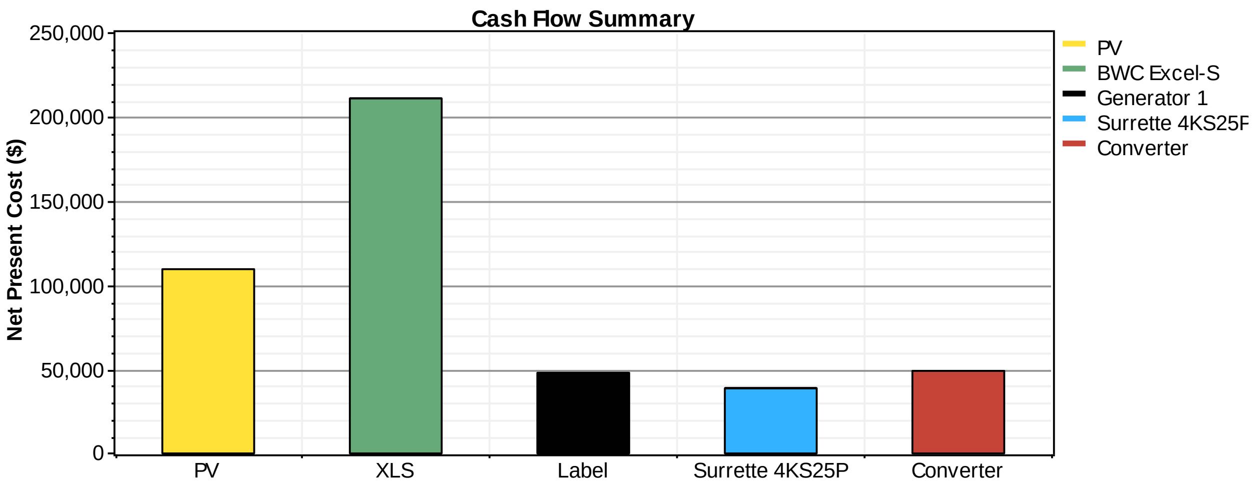

Figure 7: Cost summary of NPC of optimized hybrid energy system

2. Economic Cost

The NPC concerned in the two cases of standalone diesel generator and hybrid systems is displayed in Table 8. Subtracting the hybrid NPC from Standalone diesel NPC, the standalone system is 1,65,71,484 costlier if compared with the newly designed hybrid system NPC. A hybrid system saves cost and allows the station to enjoy optimum economic conditions. Moreover, the operational life of diesel only is low (2 years) as predicted by HOMER software in Table 9, while in Hybrid system its operational life is extended (20 years) as shown in Table 9. Table 8 Comparison of economic results between existing system and a hybrid system (Proposed system)

Parameter Value	Existing diesel-only system	Proposed system
Initial cost(INR)	4,05,790	1,43,31176
Operating cost(INR)	27,18,514	3,32,878
Total NPC(INR)	3,51,57,906	1,85,86,422
COE(INR)	**17.98**	**9.3**
Fuel (Lit)	59,058	887

Table 9 Comparison simulation of existing system (diesel only) and proposed hybrid system

Quantity	Diesel only		Proposed system	
	Value	Unit	Value	Unit
Operational life	2.5	Yr	20	Yr
Capacity factor	15	%	10	%
Hours of operation	8760	Hr	3781	Hr
Fuel consumption	59085	Lit	887	Lit

Table 10: Comparison of electricity production by existing system (diesel only) and proposed hybrid system (kWh/Yr)

Quantit	Diesel only		Proposed system	
	kWh/ Yr	%	kWh/Yr	%
Demand				
AC primary load	1,52,117	100	1,52,117	100
Production				
PV array	None	None	1,10,937	73
Wind turbines	None	None	40,594	26
Generator 1			10,514	1
Total energy	1,52,138	100	1,62,045	100
Excess electricity	21		9,928	

C. Electricity Production

The standalone diesel generator set produces 1, 52,117 kWh/Yr (100%) of the total electricity with a capacity factor of 15% compared to the proposed hybrid system that will produce 1, 10,937 kWh/Yr (73%) from solar PV array and 40,594 kWh/Yr (26%) from Wind turbines with diesel generator with a capacity factor of 10% making a total of 1, 62,045kWh/Yr (100%). The load demand is 1, 52,117kWh/Yr, while excess electricity from the existing system is 21kWh /Yr; the proposed project has excess electricity of 9,928 kWh/Yr as shown in Table 10. This information is displayed graphically in Figures 8 and 9, respectively

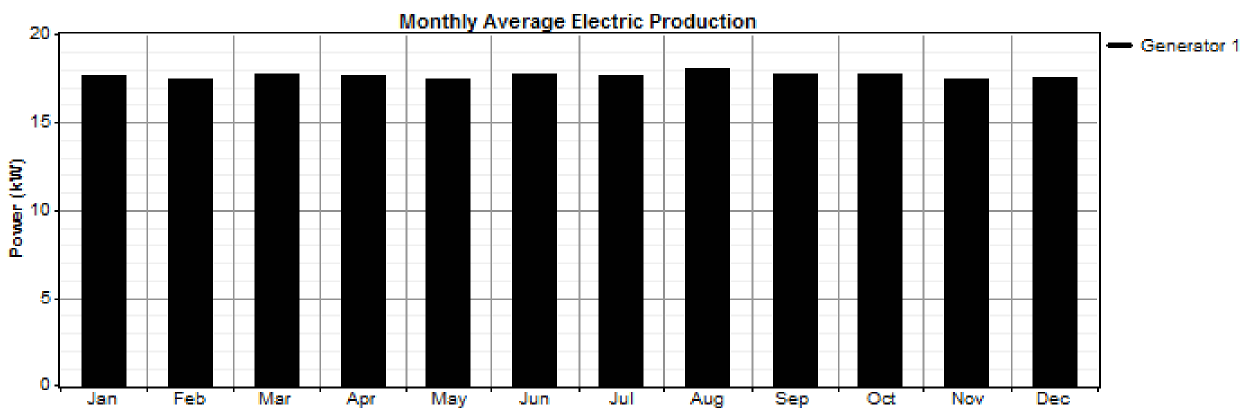

Figure 8 Monthly average of electrical power production of diesel only generator set

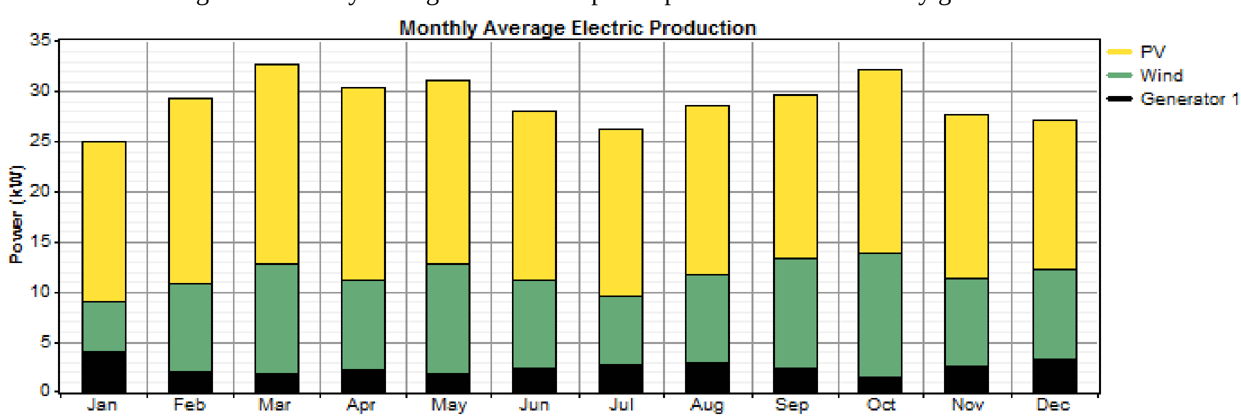

Figure 9: Monthly average of electrical power production of hybrid energy system

D. Environmental Pollution

The standalone diesel generator set operates for 8760hr/ Annum, with total fuel consumption of 59,058 Lit/Annum. It generates 1,80,808 tonnes of CO_2, 446 tonnes of CO, 49.4 tonnes of UHC, 33.6 tonnes of PM, 363 tonnes of SO_2, and 3,982 tonnes of NO_2 as shown in Table 11. In contrast, in 25 % Penetration of renewable energy resources + Base diesel generator + battery for 3.781hr /annum and has a fuel consumption of 887 Lit/ annum as shown in Table 1. This proposed system emits 15,327 tonnes of CO_2, 37.8 tonnes of CO, 4.19 tonnes of UHC, 2.85 tonnes of PM, 30.8 tonnes of SO_2, and 338 tonnes of NO_2 annually. Considering the environmental hazard, the higher the operational hours of a diesel generator, the higher the pollutant emission, and vice versa. Therefore, standalone diesel system is generating lay down poses more danger to the environment if compared with a hybrid system.

Table 11 Comparison of results in emissions from standalone diesel generator set and proposed.

Name of	Emissions(kg/Yr)		
Pollutant	**Existing diesel only**	**Proposed hybrid system**	**Difference**
	(kg/Yr)	(kg/Yr)	(kg/Yr)
Carbon dioxide	1,80,808	15,327	1,65,481
Carbon monoxide	446	37.8	408.2
Unburned hydrocarbons	49.4	4.19	45.21
Particulate matter	33.6	2.85	30.75
Sulfur dioxide	363	30.8	332.2
Nitrogen oxides	3,982	338	3,644

CONCLUSIONS

In this paper pre-feasibility study of renewable energy penetration into an existing diesel plant was proposed to integrate with a diesel power plant of a local site in Ervadi, India. The hybrid system becomes feasible when 25 % penetration of renewable energy resources. The COE for this case is INR 9.30/kWh, which was the most economical system configuration. Hybrid energy systems present many benefits, including reduced COE, and negligible environmental effects as compared to base generator system. The proposed designed hybrid system could be a good alternative for implementation, as the contribution made by renewable resources is quite significant.

Findings:

1. Case 5 offered the lowest COE when compared with remaining cases.
2. The COE per kWh for first two cases was the same as described in Table 3.
3. Case 4 that is pure renewable energy system had the 3rd highest COE because the number of penetration of PV panels and Wind turbines is increased.
4. On the basis of electricity production (kWh/yr), it is clear that last case was the highest production in electricity due to penetration of 25% renewable energy resources.
5. From the optimization results, it can be seen that system 5 was the very low COE, due to the increased renewable energy sources.

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