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Optimization and Cost of Energy of Renewable Energy System in Health Clinic Building for a Coastal Area in Tamil Nadu, India Using Homer

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Abstract: The renewable energy potential of coastal areas of Tamil Nadu, India ranks among the highest in the world. The annual solar energy received is 5.0 kWh m^{-2} and the wind energy received is at a moderate speed (4-6 m sec^{-1}). This study proposes optimization and cost of energy of different hybrid renewable energy system to power a health clinic in that building. The total daily health clinic load is 34.9 kWh and detailed loads are listed. The National Renewable Energy Laboratory (NREL) optimization computer model for distributed power, homer is used to estimate the optimization and its cost of energy. The implementation of RE systems to supply rural health clinics will contribute to reduce both electricity generation cost and CO_2 emissions while improving health care and quality of life in these isolated coastal regions.

Key words: Renewable energy systems, wind energy, PV, diesel generator, hybrid system, rural health

INTRODUCTION

Most of the coastal areas in Tamil Nadu are still under developed and in a chaotic state after the commandment of development activities and there is a need to provide these areas with electricity. Small standalone hybrid renewable energy systems can play a strategic role in the region's balanced and sustainable development. The region enjoys a huge amount of renewable energy sources during the entire year. Although, capable of providing plentiful and reliable electricity this resource is presently remaining untapped. The renewable energy sources (NASA, 2012) can satisfy the electrical needs of clinics, schools and other social places in a way that can positively affect health care and education, ensuring adequate services for the population. An excellent application of these systems is in health clinics. The relation between health and energy is compounding and as interdependent factors, they largely determine the progress of rural development. Reliable electricity generation on site is capable of delivering high-quality electricity for vaccine refrigeration, lighting, communication, medical appliances, clean water supply and sanitation (Lambert, 2000).

FEASIBILITY OF THE PROPOSED SYSTEM

The design of the proposed system to power the health clinic is done, according to medical equipments installed in the clinic. The total load capacity is found to be 34.9 kWh day^{-1}. The system consists of wind turbine, PV modules, diesel generator, batteries, charge controller, inverter and the necessary wiring and safety devices. The system feasibility analysis was performed using the homer software developed by the National Renewable Energy Laboratory (NREL) to evolve the design of micropower systems. Homer is a computer model that simplifies the task of evaluating design options for both off-grid (Jennings and Green, 2000) and grid-connected (Bakos *et al*., 2003) power systems for remote, standalone and distributed-generation applications (Cetin *et al*., 2009).

Homer's optimization and sensitivity analysis algorithms allow one to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. Homer models (Ramakumar *et al*., 1992) both conventional and renewable-energy technologies. Homer models a power system's physical behavior and its life-cycle (Kabouris and Contaxis, 1992) cost which is the total cost of installing and operating the system over its life span. Homer allows the modeler to compare many different design option based on their technical and economic criteria (Privitera *et al*., 2011). It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

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ASSUMPTIONS AND HOMER MODEL INPUTS

Clinic load analysis: The typical clinic building comprises the following rooms; administration room, doctor room, nurses' room, waiting room, 2 treatment rooms, small pharmacy and 2 rest rooms (Jimenez and Olson, 1998). The medical equipment, lighting and other devices used in this clinic are the following; refrigerator (80 W), freezer (80 W), vaporizer (50 W), oxygen concentrator (300 W), electric sterilizer (1500 W), water pump (100 W), color TV set (130 W), 15 florescent lamps (20 W each), 7 ceiling fans (60 W each) and 3 evaporative coolers (500 W each). The estimated daily working hours of the medical equipment and other devices are as follows: Fluorescent lamps (exteriors and interiors) (12 h day^{-1}), TV set (6 h day^{-1}), refrigerator and freezers (14 h day^{-1}), ceiling fans (12 h day^{-1}), vaporizer (3 h day^{-1}), oxygen concentrator (2 h day^{-1}), electric sterilizer (3 h day^{-1}) and water pump (6 h day^{-1}). The system is assumed to work for 6 days a week. The analysis found that the total connected wattage is 4460 W and the total average daily load is 31.6 kWh. The load analysis calculation is listed in Table 1. A small base load of 0.18 kW occurs from 5 p.m. until 7 a.m. This load is for outside lighting and some insidelighting whereas the majority of the load occurs during the day time (8 a.m. to 5 p.m.) (Fig. 1).

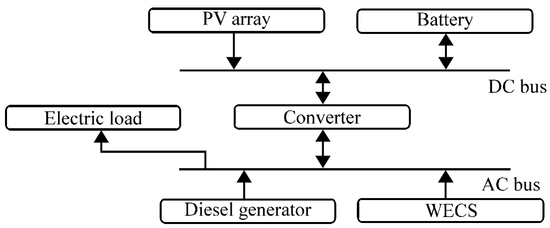

Fig. 1: Block diagram of renewable energy system

Table 1: Electric load worksheet (abbreviated)

Individual load	Qty	Qty/watts	Total watts	Total h day^{-1}	Watts h
Lamps	13	20	260	12	3120
Lamps (out)	2	20	40	2	80
Refrigerator	1	80	80	14	1120
Freezer	1	80	80	14	1120
Vaporizer	1	50	50	3	150
Oxygen conc.	1	300	300	2	600
Elec. steril.	1	1500	1500	3	4500
Water pump	1	100	100	6	600
TV set	1	150	150	12	1800
Ceiling fan	7	60	320	12	3840
Evap. cooler	3	500	1500	12	18000

AC total connected watts = 4380; AC average daily load = 34930 Wh

Table 2: Monthly average solar radiation

Months	Month clearness index	Avg. radiation (kWh/m^2/day)
Jan.	0.61	5.50
Feb.	0.64	6.20
Mar.	0.63	6.50
Apr.	0.58	6.10
May	0.49	5.10
Jun.	0.53	5.50
July	0.50	5.20
Aug.	0.55	5.80
Sep.	0.48	5.00
Oct.	0.47	4.60
Nov.	0.41	3.80
Dec.	0.52	4.60
Average		5.32

Table 3: Monthly average wind energy

Months	Average wind source (m sec^{-1})
Jan.	3.5
Feb.	3.9
Mar.	4.0
Apr.	4.8
May	4.8
Jun.	5.2
July	4.9
Aug.	4.5
Sep.	4.2
Oct.	3.9
Nov.	3.1
Dec.	3.7
Average	4.2

The sample clinic to locate in remote costal area called Kilakarai in Tamil Nadu (State) India, (9.27 N, 79.123 E). The wind data and solar radiation data for this region were obtained from the (NREL, 2011). Table 2 and 3 shows the monthly average solar radiation and wind for this area. The annual average solar radiation is 5.32 kWh/m^2/day and annual average wind energy is 4.2 m sec^{-1}.

SYSTEM COMPONENTS AND ESTIMATED PRICES

The proposed system consists of PV modules **batteries, charge controller, inverter, auxiliary diesel generator (Saheb-Koussa *et al.*, 2009) and the rest of the balance-of-systems (McGowan *et al.*, 1996) which includes** modules structure, wiring, fuses and other system safety devices.

PV array: The PV array is an interconnection of PV modules or panels that produces Direct-Current (DC) electricity in direct proportion to the solar radiation incident upon it, independent of its temperature and voltage to which it is exposed. The suggested PV panels to be used in the system simulation are 500 W (Kaldellis and Ninou, 2011) and 24 V and have estimated capital and replacement cost of Rs. 81,000 and 75,600. This cost includes shipping, tariffs, mounting hard-ware control system, wiring, installation and labour cost. The lifetime is assumed to be 25 years. A derating factor of 90% was (Dalton *et al.*, 2008, 2009) applied to the electricity generated from each panel. The panels were modeled, as fixed and tilted South at an angle equal to the latitude of the site. Capacities of different PV panels (0, 1, 2, 5, 10 and 20 kW) were considered in the analysis.

Batteries: The battery is capable of storing a certain amount of DC electricity at fixed round-trip energy effciency (Garcia-Valverde *et al*., 2009) with limits, as to how quickly it can be charged or discharged without causing damage and how much energy can cycle through it before it needs to be replaced. Homer assumes that the properties of the battery remain constant throughout its lifetime and are not affected by external factors, such as temperature. The chosen battery has a 2-V, 250-Ah capacity. The cost of one battery is Rs. 12,000 with a maintenance cost of Rs. 250/year. Different numbers of batteries (0, 1, 5 and 10) were considered in this analysis.

Inverter: An inverter converts electric power from DC to Alternating Current (AC). Its efficiency is assumed to be 90% (Ibrahim *et al*., 2008) for all sizes considered. The estimated life time is 15 years and various size are s (0, 1, 5 and 10 kW) considered in this study.

Generator: A generator consumes fuel to produce electricity and possibly heat as a by-product. A vast range of generators are available (diesel, gasoline, propane and biofuel) (Ibrahim *et al*., 2008). This analysis, considers a generator producing electricity that operates on diesel fuel because it is more efficient than the others and its lifetime is longer. The estimated price of the generator is Rs. 81 W^{-1} and various capacities sizes are considered (0, 1 and 2 kW) in the analysis.

SYSTEM ANALYSIS

Optimization results: In the optimization process, homer simulates every system conffiguration in the search space and displays the feasible ones in a table, sorted by total net presentcost. Figure 2-5 shows the results of the sample wind-diesel stand alone hybrid renewable energy sources. Each row in the table represents a feasible system conffiguration. The first 4 columns contain icons indicating the presence of the different components, the next 4 columns indicate the number or size of each component and the next 5 columns contain the key simulation results; namely, the total capital cost of the system, the total net present cost, the levelized cost of energy (cost per kilowatt hour), the annual fuel consumption and the number of hours the generator operates per year. The complete simulation results, for different stand alone hybrid renewable system (PV wind-battery, wind-diesel-battery, PV-diesel-battery, PV-wind-diesel-battery) is shown in Fig. 2-5.

PV-wind-diesel-battery: Figure 2 shows that optimization result for PV-Wind-Diesel-Battery Hybrid System. This system consists of one 2 kW PV array, 1 BWC excel-s wind turbine, one 1 kW diesel generator, 1 battery and a 1 kW power converter with lower COE at Rs. 17. This COE remain constant even withchanging of PV, wind turbine, generator and converter but increases when the battery

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

PV (kW)	XLS	Label (kW)	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Capacity Shorta..	Diesel (L)	Label (hrs)
2	1	1.0	1	1	$ 20,700	1,875	$ 44,675	0.323	0.69	0.25	1,221	4,632
2	1	1.0	5	1	$ 22,700	1,858	$ 46,454	0.323	0.69	0.20	1,219	4,335
1	1	1.0	5	1	$ 19,700	2,206	$ 47,905	0.334	0.60	0.20	1,543	5,274
2	1	1.0	10	1	$ 25,200	1,826	$ 48,536	0.337	0.70	0.20	1,165	4,127
1	1	1.0	10	1	$ 22,200	2,105	$ 49,113	0.341	0.62	0.20	1,467	5,057
	1	1.0	5	1	$ 16,700	2,554	$ 49,354	0.354	0.50	0.23	1,863	6,198
	1	1.0	10	1	$ 19,200	2,561	$ 51,936	0.363	0.50	0.21	1,896	6,334

Fig. 2: Optimization for PV-wind-diesel-battery

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

XLS	Label (kW)	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Capacity Shorta..	Diesel (L)	Label (hrs)
1	1.0	5	1	$ 16,700	2,554	$ 49,354	0.354	0.50	0.23	1,863	6,198
1	1.0	10	1	$ 19,200	2,561	$ 51,936	0.363	0.50	0.21	1,896	6,334
1	5.0	1	1	$ 16,300	4,331	$ 71,666	0.452	0.34	0.00	3,516	3,699
	5.0	5	1	$ 6,300	5,203	$ 72,813	0.459	0.00	0.00	4,833	4,015
1	5.0	5	1	$ 18,300	4,312	$ 73,419	0.463	0.35	0.00	3,479	3,629
	5.0	10	1	$ 8,800	5,253	$ 75,946	0.479	0.00	0.00	4,833	4,015
1	5.0	10	1	$ 20,800	4,361	$ 76,551	0.483	0.35	0.00	3,479	3,629

Fig. 3: Optimization for wind-diesel-battery

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

PV (kW)	Label (kW)	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Capacity Shorta..	Diesel (L)	Label (hrs)
5	1	1	5	$ 24,700	2,133	$ 51,972	0.364	0.58	0.17	1,621	5,472
5	1	5	5	$ 26,700	2,337	$ 56,575	0.373	0.54	0.07	1,785	5,423
5	1	10	5	$ 29,200	2,393	$ 59,792	0.386	0.53	0.03	1,882	5,704
2	1	5	5	$ 17,700	3,323	$ 60,184	0.453	0.16	0.22	2,888	8,750
2	1	10	5	$ 20,200	3,265	$ 61,940	0.466	0.16	0.21	2,886	8,746
5	1	1	10	$ 33,700	2,433	$ 64,798	0.453	0.58	0.17	1,621	5,472
5	1	5	10	$ 35,700	2,636	$ 69,401	0.458	0.54	0.07	1,785	5,423
5	1	10	10	$ 38,200	2,692	$ 72,617	0.469	0.53	0.03	1,882	5,704
2	1	5	10	$ 26,700	3,623	$ 73,009	0.549	0.16	0.22	2,888	8,750

Fig. 4: Optimization for PV-diesel-battery system

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

PV (kW)	XLS	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Capacity Shorta..
2		10	3	$ 19,000	228	$ 21,912	0.877	1.00	0.00
2		20	3	$ 26,000	331	$ 30,236	1.207	1.00	0.00
1	1	1	3	$ 21,200	970	$ 33,603	1.359	1.00	0.02
	1	10	3	$ 22,500	1,021	$ 35,552	1.419	1.00	0.00
2	1	1	3	$ 26,200	1,001	$ 38,997	1.568	1.00	0.01
1	1	10	3	$ 27,500	1,053	$ 40,963	1.635	1.00	0.00
	1	20	3	$ 29,500	1,125	$ 43,877	1.751	1.00	0.00
2	1	10	3	$ 32,500	1,085	$ 46,375	1.851	1.00	0.00
1	1	20	3	$ 34,500	1,157	$ 49,288	1.967	1.00	0.00
2	1	20	3	$ 39,500	1,189	$ 54,699	2.183	1.00	0.00
10		10	3	$ 59,000	485	$ 65,201	2.602	1.00	0.00
10		20	3	$ 66,000	589	$ 73,526	2.934	1.00	0.00
10	1	1	3	$ 66,200	1,257	$ 82,268	3.289	1.00	0.00
10	1	10	3	$ 72,500	1,343	$ 89,664	3.579	1.00	0.00

Fig. 5: Optimization for PV-wind-battery

bank increases. The maximum COE is observed for higher rating of battery bank at Rs. 19. The important conclusion is that COE is mainly dependant on battery bank. Figure 2 show that this hybrid system can supply the power to isolated clinic with minimum fuel consumption 1221/year, the reason being that contribution of power from renewable energy sources is 69%.

Figure 6 shows relationship between costs of different components which are associated with PV-Wind-Diesel-Battery System. As can be seen from Fig. 3, the operating cost is very low for this system.

Wind-diesel-battery: Figure 3 reveals, the second economically viable standalone hybrid Wind-Diesel-Battery System which consists of one XLS-turbine, 1 kW diesel generator, 5 batteries and a 1 kW power converter with COE of Rs. 19.11 kWh^{-1}. The COE of this system increases with increase in diesel generator and battery bank.

Figure 7 shows relationship between costs of different components which are associated with Wind-Diesel-Battery System. As can be seen from Fig. 5, the operating cost is low for this type system but there is a reduction in capital cost and an increase in operating cost, as compared to PV-Wind-Diesel-Battery System.

PV-diesel-battery: Figure 4 reveals data on PV-Diesel-Battery System. In this system renewable energy share is 58% of the total energy production, the generator will be running about 5472 h year^{-1} consuming 1621 L of fuel. The system configuration incorporates 5 kW of PV along with a 1 kW generator, 1 batteries and an inverter capacity of 5 kW for an initial cost of Rs. 13,33,800. The NPC over the lifetime of the system is Rs. 28,06,488. As can be seen from Fig. 6, COE increases with decrease in PV module. This is due to the fact that as the PV module decrease, the contribution from renewable energy source decreases with corresponding increase in fuel consumption.

The optimal hybrid power system proposed by homer includes PV, diesel generator, battery and inverter. The components needed to satisfy the demand of 34.9 kWh day^{-1} are 5 kW of PV panel, 1 kW capacity diesel generator, 1 batteries and 5 kW inverter. Figure 8 show that the capital cost of this system is Rs. 13,33,800

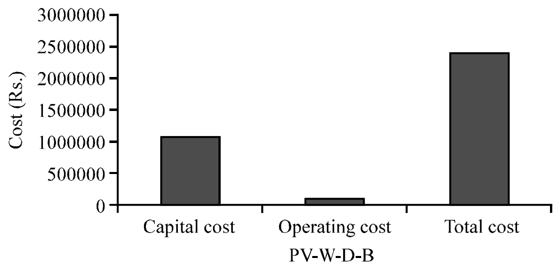

Fig. 6: Cost for PV-wind-diesel-battery

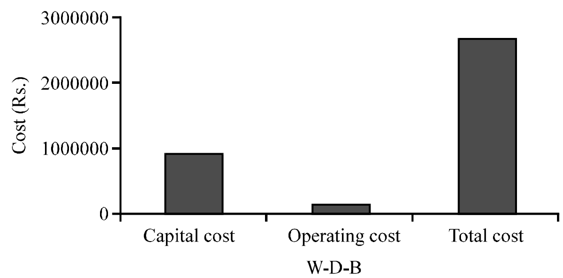

Fig. 7: Cost for wind-diesel-battery

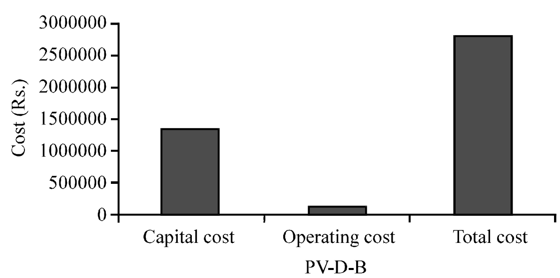

Fig. 8: Cost for PV-diesel-battery

and the NPC is Rs. 28,06,488. The RE fraction represents 58% of the energy production. The generator will be running 5,472 h and will consume 1621 L year^{-1} of diesel fuel. The least cost system is wind turbine with diesel generator consisting of 1 kW of wind turbine, 1 kW diesel generator, 5 batteries and 1 kW inverter capacity for an initial capital cost of Rs. 13,33800 and a NPC of Rs. 28,06,488 and COE of Rs. 19 kWh^{-1}.

PV-wind-battery only: Figure 5 details the optimization of PV-Wind-Battery System. As can be seen, this is the most expensive system of all the hybrid system considered. This is due to the fact that this system being totally renewable energy sources require large number of battery banks.

Figure 9 gives the cost structure of PV-Wind-Battery System. As can be seen from Fig. 9, the operating cost is almost negligible but capital cost and total cost are very high.

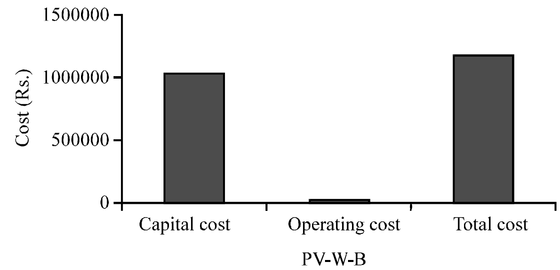

Fig. 9: Cost for PV-wind-battery

Table 4: Effect of interest rate and diesel price on electricity cost

Types of hybrid systems	Effect of interest rate in COE (Rs. kWh^{-1}) 0%	6%	Effect of diesel price in COE (Rs. kWh^{-1}) Rs. 50	Rs. 55
PV-Wind-Diesel-Battery	5	17	5	7
Wind-Diesel-Battery	7	19	7	9
PV-Diesel-Battery	7	19	7	9
PV-Wind-Battery	10	43	10	15

Table 5: Comparison of COE

Types of hybrid systems	COE (Rs. kWh^{-1})	RF (%)	Consumption of fuel (L)
PV-Wind-Diesel-Battery	5	70	1221
Wind-Diesel-Battery	7	55	1863
PV-Diesel-Battery	7	60	1621
PV-Wind-Battery	10	100	Nil

Effect of interest and diesel on electricity cost: These type of projects in developing countries are usually undertaken by the government and hence, the assumption of 0% interest rate when analyzing the system. The effect of different interest rates on the cost of electricity produced for all types of system are shown in Table 4. Figure 4 showed that at 6% interest rate, the cost of the electricity produced is almost 75% of actual cost of energy. Similarly, the effect of price of fuel has a large impact on the cost of electricity produced (Fig. 4). The simulation showed that varying the price from Rs. 50-55 L^{-1} increases the cost of electricity produced from Rs. 5-7 kWh^{-1} for the PV-Wind-Diesel-Battery System. The effect of fuel price and interest rate on the COE for other system can be seen in Table 4.

Comparison of COE: A summary of the COE and RF of the different types of hybrid system are listed in Table 5. It is interesting to note, that the PV-Wind-Diesel-Battery Hybrid System shows the lowest COE and high amount of RF (the portion of power generated by the renewable energy source compared to that of the total power drawn from the system). The 2nd lowest COE of Rs. 7 kWh^{-1} is for Wind-Diesel-Battery Hybrid System. The reason for the increase in COE for the other system is that contribution of RF is reduced and automatically increasing the consumption of fuel. The highest COE and also high amount of RF (100%) belongs to PV-wind-battery. The conclusion from the study of Table 5 is that any 1 renewable energy sources with diesel to produce the power for isolated clinic, leads to decrease in COE.

EXPERIMENTAL RESULTS

The simulation results are verified by experimentally using as different types of hybrid PV/Wind System model for power generation to isolated clinic shown in Fig. 1 which is located at Ramanathapuram (district) Tamil Nadu (state) in India. The earlier mentioned system is tested by PV module, wind turbine, battery bank and converter and also the system specification is discussed earlier. The simulation result of effect of interest and diesel on electricity cost and also comparison of COE for different types hybrid system is tested by experimental set up, as shown in Fig. 10. The experimental results show that the leastcost of energy at Rs. 5 kWh^{-1} is obtained from PV-wind-diesel-battery and also experiment result shows that the COE decreases with 0% of interest.

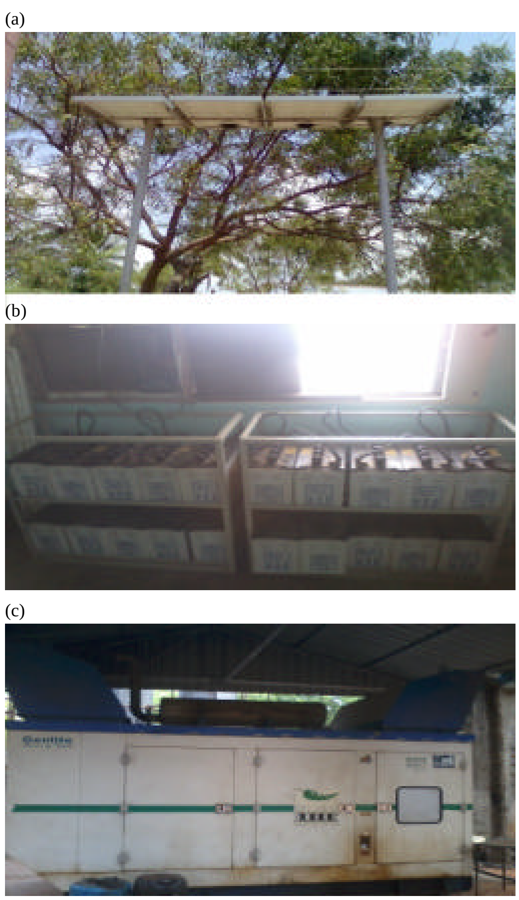

Fig. 10: The photograph of the experimental setup for: a) Solar panel; b) Battery bank; c) Generator

CONCLUSION

From the analysis and the experimental verification the following conclusion are drawn:

- The health clinic at remote coastal areas of Tamil Nadu in India can render satisfactory service to the community around if they are given Hybrid-Standalone Power System
- The optimized and least expensive model of such Standalone Hybrid System is fund to be PV-Diesel-Wind-Power-Battery-Converter System
- As the capital cost is high, the government should provide such system, through a subsidized project

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