Hydro-PV-Wind-Battery-Diesel Based Stand-Alone Hybrid Power System

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Abstract: **This paper presents a hydro-PV-wind-battery-diesel based hybrid power system to show the economic viability of an off-grid isolated renewable energy system for remote area. Global warming problem, due to man-made greenhouse gases (GHGs), appear to be a major concern of the world. Current power generation causes 25.9% of global carbon emissions; due to the fast depletion of fossils fuels, direct and indirect GHGs emission from thermal power plants renewable energy (RE) resources are emerging as a realistic means to solve the global warming problem. The main objective of the present study is to determine the optimum size of the hybrid power system able to fulfill the requirements of 166 kWh/day primary load with 21kW peak load for 100 households for a remote area. In this study we have considered a village in the remote area Cox's bazar, Bangladesh. There is a good potential for wind and solar energy and also some potential for hydro energy. Battery and diesel generator is considered to increase the reliability of the system.. The proposed hybrid model is able to fulfill the load demand of the village under investigation with cost of energy (COE) 0.188$/KWh with operating cost 7,761$/yr., which is economical than the diesel and battery only system. The analysis also indicates that about 66% of the total energy is coming from the renewable energy sources, which reduces the CO_2 emissions to 35,743 kg/yr., compared with the diesel and battery only system. The energy modeling software for renewable energy based hybrid energy systems, HOMER, is used to carry out the analysis.**

Keywords: ***HOMER, hybrid, renewable energy, wind power, photovoltaic, hydro***

I. INTRODUCTION

It is evident that the global demand for electricity will be increased significantly over the next decades. Because of the environmental concern with fossil fuel search for clean energy is getting attention. Renewable energy (RE) is one of the best sources of clean energy that have a very low environmental impact compared to the conventional energy sources. RE sources never run out, on the other hand conventional energy sources are finite and one day everything will be depleted. Wind, solar, tidal, wave, geothermal and biofuels are considered as renewable energy sources. When RE resources are used to generate power for a stand-alone power system in remote areas, they are coupled with diesel generators to increase the reliability of the system [1]. Diesel generators can be used as a back-up, when RE sources fail to meet the load and when the battery charge depleted for better reliability and economy [2]. The advantages of hybrid power systems are more reliability and cost effectiveness compared to those that use only one source of energy [4, 5]. The decentralized hybrid system plays an important role to reduce the electricity gap in a hilly or remote area, where the grid connection is far away and not economically feasible [6,7]. Bangladesh is a developing country; the development of this country is very slow. The use and availability of electricity of a country is an important scale to measure the development of the country. The power crisis is a common problem in Bangladesh. This article considers a Bangladesh power system as a test case where conventional fossil fuels to generate power is not adequate [3]. Today only an estimated 49% of the population in Bangladesh is connected to the national electricity grid. The supply of electricity is not reliable though and peak demand cannot be met. In the rural areas, where more than 70% of the population lives, only about 25% have electricity. In Bangladesh total electricity generation capacity is only 8315 MW. Energy generation resources in the country are natural gas (67.11%), furnace oil (21.7%), diesel (6.15%), coal (2.41%) and the remaining 2.65% is coming from hydro energy. The people of this country used natural gas also in cooking purpose, so in near future there will be a huge crisis of natural gas. So they should search for alternative energy sources for electricity generation. In this case renewable energy will be the one of the best solution. A hybrid hydro-wind-battery-diesel based power system is proposed. The available RE resources (wind and solar) data is collected from the NASA surface methodology for Cox's Bazar in the south-eastern part of Bangladesh. In rural household normally uses electricity for lighting, cooling (only electric fan) and entertaining (TV) [2]. The load variation is only in the summer period because of additional coolers.

HOMER is general-purpose hybrid system designing software that is very useful to design a decentralized electric power systems. The software designs an optimal power system to fulfill the requirements of the desired loads. HOMER can perform hundreds or thousands of hourly simulations to ensure the best possible matching between supply and demand in order to design the optimum system. HOMER can also perform sensitivity analysis where the value of certain parameters (e.g. diesel price) can be varied to determine their impact on the cost of energy for the system in question [8].

VILLAGE LOAD DATA:

To perform the present study, we have used the load data for 8760 hours for the village under investigation. Here the peak load is 21 Kw. The monthly average load is shown in fig.1and the daily load variation is shown in the fig.2

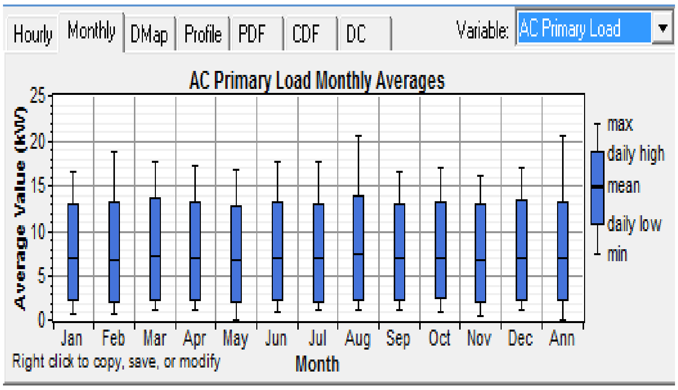

Fig. 1: Monthly average load for the 100 households.

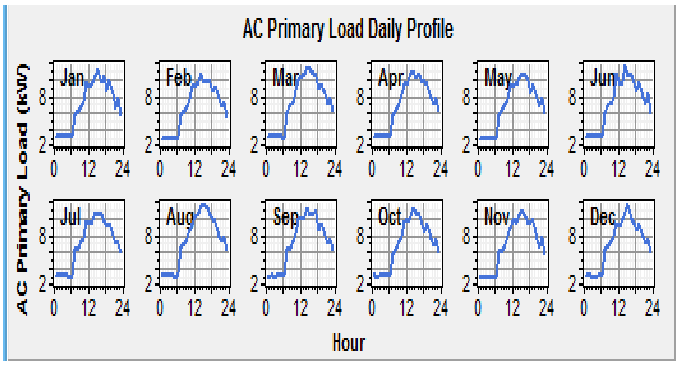

Fig.2: Daily change of load during every month s of the year

WIND-PV-DIESEL HYBRID SYSTEM:

In hybrid power systems there may be huge number of combination of wind, PV, diesel, hydro and batteries. This flexibility is a very big advantage to design an optimized hybrid model. In this study a hydro-PV-wind-battery-diesel hybrid power system and a power converter is used to design and meet the load requirements. The schematic diagram of the hybrid model is shown in fig.3.

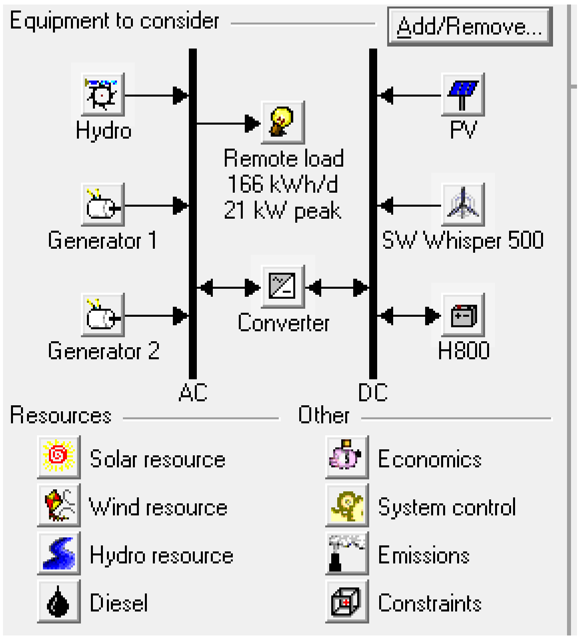

Fig. 3: The proposed hybrid system for 100 households

II. INPUT DATA

To design a technically viable hybrid system, we need to consider per hour energy requirements, the resources availability and energy production. Therefore, HOMER (Hybrid Optimization Model for Electric Renewables), the renewable energy-based hybrid system optimization software designed by the United States National Renewable Energy Laboratory (NREL), is used for all sites. HOMER is general-purpose hybrid system designing software that is very useful to design a decentralized electric power systems. In HOMER the main input data include the hourly solar radiation, wind speed, water flow rate, diesel price; technical feature and cost data of wind turbine, PV module, power converters; system controls; system constraints and economic parameters. The software designs an optimal power system to fulfill the requirements of the desired loads. HOMER can perform hundreds or thousands of hourly simulations to ensure the best possible matching between supply and demand in order to design the optimum system. HOMER can also perform sensitivity analysis where the value of certain parameters (e.g. diesel price) can be varied to determine their impact on the cost of energy for the system in question [2]. Before installing a renewable energy system for power generation, economic analysis is very important and should be made. HOMER makes economic analysis and ranks the systems according to their net present costs, COE and operating cost.

CONTROL PARAMETERS:

The control parameters we have used for this study are:

Yearly real interest rate = 6%
Working life span of the plant = 25years
Price considered for diesel (US$/l) = 0.5, 0.76 and 1.0

Operating reserve:

In this study we have considered operating reserve for load 10%. As the solar and wind energy is intermittent, so we have also considered operating reserve solar power output and the wind power output.
The percent of load, load for every hour = 10%
The percent of renewable energy output, solar power output = 10%
The percent of renewable energy output, wind power output = 25%

Wind turbines:

The parameters, I have used for wind turbines are-
Size of the wind turbine considered (kW) = 0, 3x1, 3 × 2, 3 × 3, 3×5
Wind turbine cost (US$/turbine) = 6940
Replacement cost of wind turbine (US$/turbine) = 5551
The O&M cost (US$/turbine/year) = 12 Operation life of the Working life span of wind turbines (Years) = 15

Photovoltaic modules:

Considered Photovoltaic sizes (kW) = 0, 24x6, 24x12, 24x16, 24x24 and 24x30
Photovoltaic array cost (US$/kW) = 2650.58
Photovoltaic array replacement cost (US$/kW) = 2120.42
Operation and maintenance cost of PV array (US$/kW/year) = 15
Working life of photovoltaic panels (years) = 25

Hydro turbine:

Nominal power of hydro turbines (KW) = 5.15
Available head (m) = 1.75
Hydro turbine capital cost ($) =3600
Hydro turbine replacement cost ($) =3600
O&M cost ($/yr.)= 18
Working life of the hydro turbines (Years) = 25

Power converter:

The sizes considered for power converter (kW) = 5, 10, 15, and 20
Power converter cost (US$/kW) = 180
Power converter replacement cost (US$/kW) = 120.5
O&M cost of power converter (US$/kW/year) = 0
Working life span of power converter (years) = 15
Inverter efficiency (%) = 90

Battery:

Nominal capacity = 800Ah (1.6 KWh)

Battery quantities considered = 2, 4, 5 and 10
Cost of battery per single unit (US$) = 135
Replacement cost of battery per single unit (US$/kW) = 115
O&M cost of power converter (US$/kW/year) = 0.96
Working life span of power converter (years) = 4
Diesel generators:
Sizes of Generator 1 considered (kW) = 0 and 10
Sizes Generator 2 considered (kW) = 0 and 10
Total operating hours (hours) = 20,000
Capital cost (US$/kW) = 1205
Replacement cost (US$/kW) = 965
O&M cost (US$/hour) = 0.240

III. SOLAR RADIATION, WIND SPEEDS AND WATER FLOW AT THE STUDY

The monthly average wind speed is shown in fig.4 and the fig.5 shows diurnal variation of hourly mean wind speed. The monthly solar radiation profile and the daily variation of hourly mean solar radiation is shown in fig.6 and fig.7 respectively. Fig.8 and fig.9 shows the monthly average water flow rate and daily variation of water flow respectively.

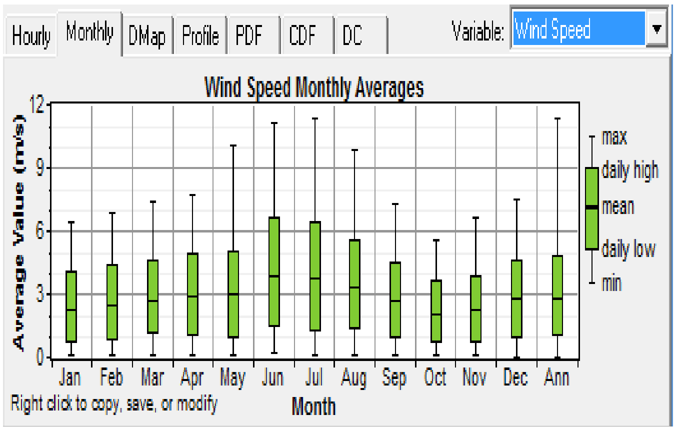

Fig. 4: Monthly average wind speed for the site

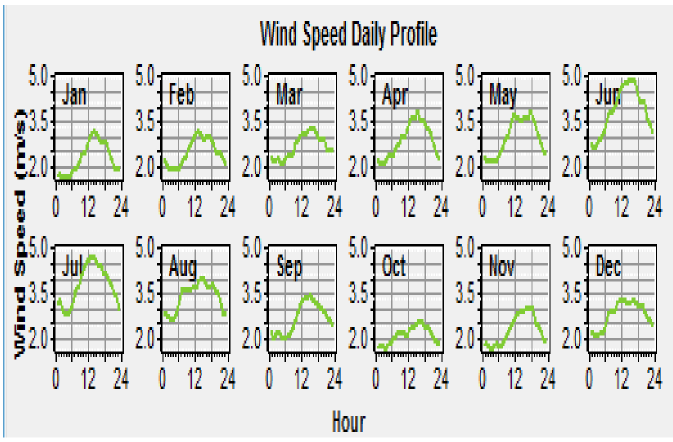

Fig.5: Daily variation of hourly mean wind speed

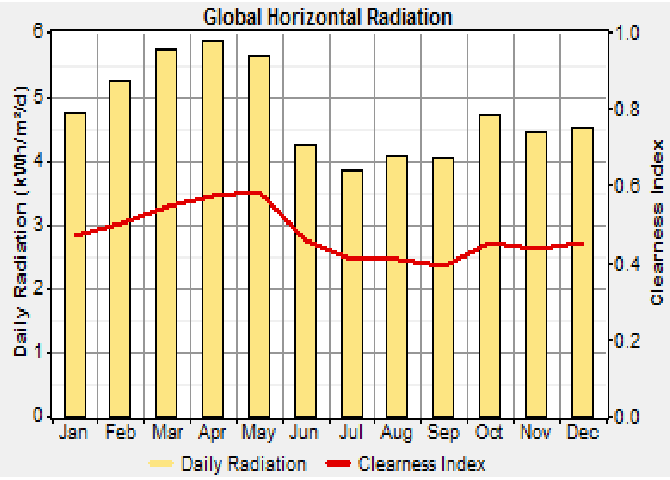

Fig. 6: Monthly mean and extreme solar radiation

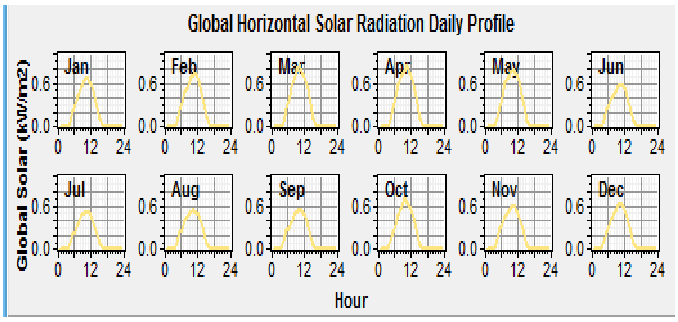

Fig.7: Daily variation of hourly mean solar radiation

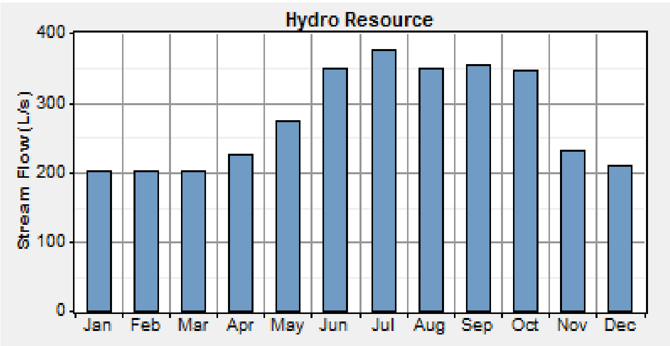

Fig.8: Monthly average water flow rate

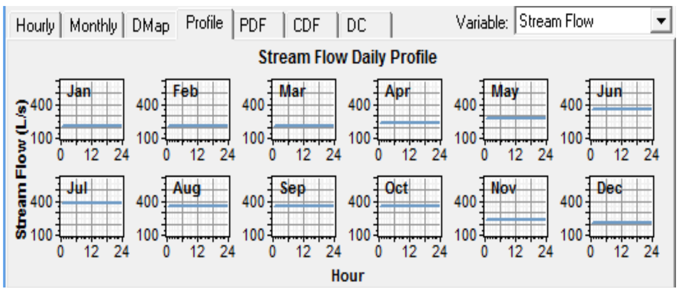

Fig.9: Daily variation of hourly mean water flow

III. RESULTS AND DISCUSSION

With respect to the above input, total runs is 25,920, which consists of 3 sensitivities for diesel price and 8,640 simulation runs for each diesel price. A high speed computer hp ENVY dv4 with core i5 is used to run the simulations. According to the results HOMER suggest that the optimal Hydro-PV-wind-battery-diesel based hybrid system for the village consists of Hydro turbine of 5.15Kw, 1(one) wind turbines of 3kW, 12kW PV panels, battery banks and a diesel generator of 10kW). According to the results initial investment cost is $46,702 with operating cost $7,761 per year, the total net present cost (NPC) is $145,917 and the cost of energy (COE) is $0.188 per KWh. The results also show that the renewable energy integration to the proposed model is 66%. According to the results if the diesel price is $0.76 per liter, the diesel only system is not economical than the proposed model. The output energy, the cost analysis and the GHG emissions for the proposed hybrid model is shown in the forthcoming paragraphs.

TABLE I. The optimal hydro-pv-wind-battery-diesel hybrid system

Sensitivity variables

Diesel Price ($/L) 0.76

Double click on a system below for simulation results.

Categorized

PV (kW)	W500	Hydro (kW)	Label (kW)	Label (kW)	H800	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Label (hrs)
12		5.15	10		10	10	$ 39,762	7,844	$ 140,040	0.181	0.65	8,690	3,167	
12		5.15		10	10	10	$ 39,762	7,844	$ 140,040	0.181	0.65	8,690		3,167
12		5.15	10	10	10	10	$ 40,967	7,862	$ 141,469	0.183	0.65	8,723	3,154	48
12	1	5.15	10		10	10	$ 46,702	7,761	$ 145,917	0.188	0.66	8,400	3,115	
12	1	5.15		10	10	10	$ 46,702	7,761	$ 145,917	0.188	0.66	8,400		3,115
12	1	5.15	10	10	10	15	$ 48,807	7,698	$ 147,213	0.190	0.67	8,332	3,008	50
		5.15	10	10	10	5	$ 8,260	11,685	$ 157,632	0.204	0.42	13,164	4,741	84
	1	5.15	10	10	10	5	$ 15,200	11,534	$ 162,645	0.210	0.44	12,787	4,705	77
		5.15	15		10	5	$ 7,658	13,724	$ 183,100	0.236	0.42	14,964	4,706	
		5.15		15	10	5	$ 7,658	13,724	$ 183,100	0.236	0.42	14,964		4,706
	5	5.15	10		10	10	$ 42,655	11,077	$ 184,256	0.238	0.50	11,450	4,162	
	5	5.15		10	10	10	$ 42,655	11,077	$ 184,256	0.238	0.50	11,450		4,162
16			15	10	10	15	$ 49,472	13,542	$ 222,585	0.287	0.37	15,275	408	4,754
16	1		10	15	10	15	$ 56,412	13,399	$ 227,699	0.294	0.38	14,916	4,761	350
16			15		10	15	$ 48,267	15,509	$ 246,520	0.318	0.37	16,999	4,997	
16				15	10	15	$ 48,267	15,509	$ 246,520	0.318	0.37	16,999		4,997

The details related to energy like energy generated by hydro, wind, PV, battery and diesel generators; excess energy, the unmet load, capacity shortage and renewable fraction for the proposed model is shown in fig.6.

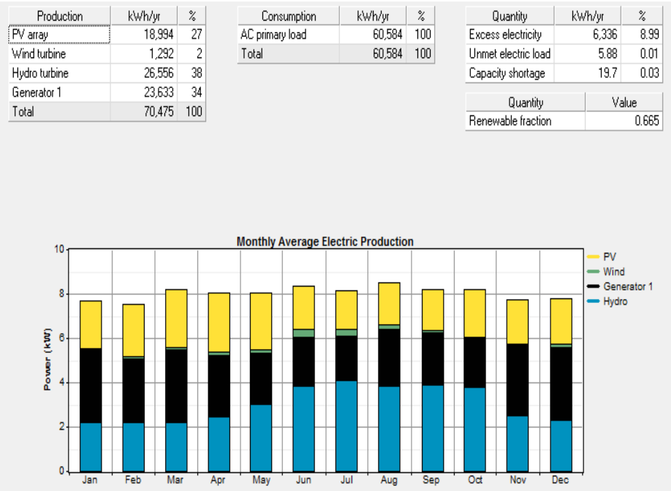

Fig.9: Energy yield for the proposed hybrid system.

The results show that most of the energy is produced by hydro turbines (38%). Energy produced by PV array is 27% and wind turbine is only 2% of the total energy, the remaining percentage of energy is coming from diesel generator.

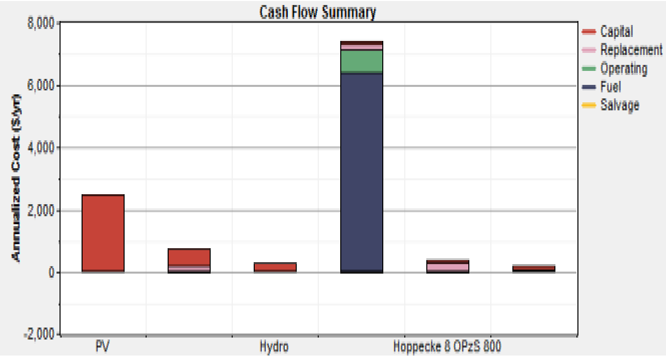

Fig. 10: Cash flow summary of various components of the hybrid system

TABLE II. Yearly cost details of the hybrid power system

Component	Capital ($)	Replace-ment($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	31,807	0	96	0	0	31,903
SW Whisper 500	6,940	2,316	153	0	-431	8,979
Hydro	3,600	0	230	0	0	3,830
Generator1	1,205	2,247	9,557	81,612	-182	94,439
Hoppecke 80PzS 800	1,350	3,292	123	0	-207	4,558
Converter	1,800	503	0	0	-94	2,209
System	46,702	8,358	10,159	81,612	-913	145,917

TABLE III. Annual GHG emissions from the hybrid system

Pollutant	Emissions (kg/yr)
Carbon dioxide	22,121
Carbon monoxide	54.6
Unburned hydrocarbons	6.05
Particulate matter	4.12
Sulfur dioxide	44.4
Nitrogen oxides	487

The table above shows the annual GHG emissions for the proposed hybrid system. The hybrid system consists of 12 KW PV, 1 SW Whisper 500, 5,15 KW Hydro, 10 KW Generator, 10 Hoppecke 80PzS 800 cycle charging, 10KW Rectifier and 10 KW Inverter. The total NPC is $145,917. The Levelized COE and operating cost is $0.188/KWh and $7,761/yr respectively.

TABLE IV. Annual GHG emissions from the diesel only system

Pollutant	Emissions (kg/yr)
Carbon dioxide	57,864
Carbon monoxide	143
Unburned hydrocarbons	15.8
Particulate matter	10.8
Sulfur dioxide	116
Nitrogen oxides	1,274

The table above shows the annual GHG emissions for the diesel only system. The hybrid system consists of 15KW Generator1, 15 KW Generator2, 10 Hoppecke 80PzS 800 cycle charging, 5 KW Rectifier and 5 KW Inverter. The total NPC is $250,598. The Levelized COE and operating cost is $0.324/KWh and $19,192/yr respectively.

Table-III and Table-IV Shows the annual GHG emissions from diesel only system and hybrid system respectively. The proposed hybrid system would be able to avoid 35,743 kg of CO_2 annually that will reduce the CO_2 emissions by 61.77% in every year. As a result the emissions penalty will be reduced significantly and the air pollutions of the area will be less.

SENSITIVITY ANALYSIS:

If the diesel price changes, the COE and the operating cost of the hydro -PV-wind-battery-diesel hybrid system also changes. Table V shows the change in diesel price has direct impact on the COE and the operating cost for both the proposed hybrid system and diesel only system.

TABLE V. Effect of diesel price on COE and operating cost

Diesel price ($/L)	*Hyro-wind-pv-battery-diesel hybrid system*		*Diesel only system*	
	COE ($/KWh)	Opera-ting cost ($/yr.)	COE ($/KWh)	Operating cost ($/yr.)
0.50	0.148	6,583	0.229	13,477
0.76	0.188	7,761	0.324	19,192
1.00	0.221	9,693	0.411	24,466

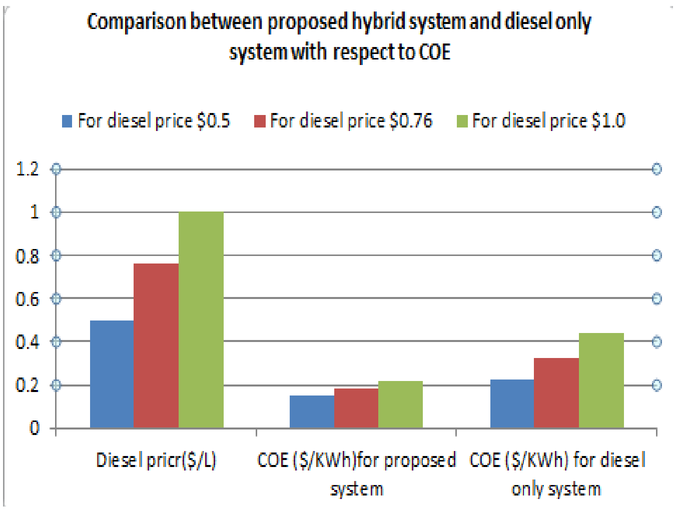

Fig.11: Effect of diesel price on COE of hybrid power system and diesel only system

The table-V clearly shows that the COE and the operating cost of the proposed hybrid system charging low prices than the diesel only system for all the diesel prices considered for the present analysis. Fig.11 compares the COE between proposed hybrid system and the diesel only system and it shows clearly that the hybrid system is economical with respect to all diesel prices that we have considered.

IV. CONCLUSIONS

A hydro-wind-PV-battery-diesel based hybrid stand-alone power system is proposed for the remote area. For diesel price 0.76$/L, the COE for the proposed hybrid model is 0.188$/KWh, that is 0.324$/KWh for diesel only system. The operating cost for the hybrid system is 7,761$/yr, for diesel only system it is 19,192$/yr. The proposed hybrid system is able to integrate 66% of renewable energy for electricity generation, which reduces huge amount of CO2 emissions annually that is necessary for safer world and better life for all the living beings of the world.

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