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A Thorough Analysis of PV Solar based Microgrid System for Rural Electrification using HOMER-Pro

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Abstract

The usage of fossil fuel is still in high demand despite having low carbon emissions and operating costs of renewable energy sources. Bangladesh has a tropical monsoon climate, thus it experiences warm temperatures throughout the year. Therefore, solar energy could become an encouraging prospect as one of the solutions for the future energy crisis. Durgapur is a remote village of Bangladesh where no electricity supply system exists and it has been taken for the analysis purpose. HOMER-Pro (Hybrid Optimization Model for Electric Renewables) software is used to evaluate the production. PV solar panel has been taken as the major contributor to fulfill the demand of 33.3 kWh/days for fifty houses. The diesel generator is used to supply the baseload to the user even if there is no sunlight available. The main objective of this report is to study the feasibility and economic aspect of the project. With 4.8 kW-hr/m^2/day average solar radiation, solar panels provided 12.8 MW-h annually which is 86% of the total production. The capital cost has been found approx. 3.6 million BDT. Per unit cost of energy (CoE) has been reduced by half with the integration of solar energy along with diesel generator. The carbon emission has also been found significantly low (approx. 2600kg/year) compare to other fossil fuels' production. The estimated Cost of Energy is of this project is found to be $0.494 or 39 BDT per unit.

Keywords: *Renewable Energy, HOMER- Pro, PV Solar, Microgrid*.

I. Introduction

The usage of Renewable energy resources is increasing day by day. Especially in developing countries like Bangladesh, it is a good practice region to research electricity generation and supply at a minimum cost by renewable resources. In this paper, it has been tried to generate and supply the electricity in a remote village of Bangladesh named Durgapur by the solar cell as there is no electricity available yet. HOMER-Pro is used for simulating and optimizing the minimum project cost.

Today, the load demand has tremendously increased in the rural areas of developing countries like Bangladesh because of economic growth. Transporting and distributing energy to the rural, hilly, or island areas are always a big challenge to any government/company. Especially in the island areas where the whole region is isolated by water, the transportation of high voltage AC power is very difficult. Therefore, the Microgrid system can answer this problem. A microgrid is a power grid with less capacity than a conventional power station. Usually, renewable sources are used for the microgrid. But fuel-based generation can also be used for instant or emergency power supply. If there is any permanent or temporary grid for a community or residential area with its generation, distribution, and storage system then it'll be considered as a microgrid. The advancement of renewable technologies like solar PV, solar thermal, wind, biomass, geothermal, micro-hydro, and tidal energy, etc. can meet the demand in an environmentally friendly way. Microgrid systems can play an important role to provide reliable, secure, and low carbon emission energy to the communities (Panhwar *et al*., 2017). The installation of a DC Microgrid system is easy and more convenient to provide the minimum energy demand to the people. Whereas AC supply requires more complex energy systems and involves much more investment in terms of money.

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Hybrid renewable energy systems are more sustainable than single-sourced electricity in off-grid rural areas because of the intermittency of these renewable energy resources (Kamran *et al*., 2018). But sometimes the capital cost for these green technologies may cost huge money. Besides that during off-peak season or night, the production of minimum demand can become tough if the storage capacity is not that great. Thus integration of renewable energy and conventional energy can be an effective way to fulfill the demand. In this proposed design, PV Solar and diesel generator has been used. The diesel generator is used to supply the baseload to the user even if there is no sunlight available. Our proposed project area is located at Durgapur village (23º 64` 33.72``N and 89 º91`67.20``E) near to the Padma river. The area is located about 20 km east of Faridpur Shador thana. It is effectively a rural area and an isolated island. The main objective of this report is to study the feasibility and the economic aspect of the proposed microgrid project that will cover the energy demand for 50 families.

II. Literature Review

Most appliances use DC power internally in their life work but use AC power as input. It needs conversion from AC to DC for the DC voltage what is used to switch on the appliances (Garbesi et. al., 2011). It is observed that 33% of energy can be saved if standard technology is replaced by DC power. Further14% could be saved if DC appliance is directly operated by DC. Internals DC components are operated by AC input, but there need AC- DC conversion as they can't operate in AC directly. In this process there produce heat both in working and standby mode. But if these appliances are directly powered by PV power then the problem of heat production can be easily avoided from the circuit. (Makarabbi *et al*., 2014) that saves a considerable amount of energy (Matayoshi *et al*., 2015)

It is preferable to use a standby diesel generator with Hybrid Renewable Energy System (HRES). Many distribution generators like PV solar, wind, biomass, small hydro, microturbine, and fuel cell can be integrated to entertain off-grid and grid-connected loads (Parag et al., 2019). Components of HRES are technically modeled in the first section and then HOMER-Pro has been used in the 2nd section to simulate and optimize HRES on a specified given off-grid location (Kamran *et. al*., 2015).

Farid Barrozo Budes and his team in 2018 gave a brief analysis of HOMER-Pro software that works to simulate and optimize the different energy supply systems purposed. The systems have been simulated in HOMER Pro software which can estimate, simulate, and optimize the operational costs and the emissions on energy systems using renewable energies. Their simulation is integrated by a diesel generator with an output power of 15 kW, a fuel cell generator with an output of 3 kW, 3 kW output of a biogas generator, energy storage with a nominal capacity of 1.02 kWh, an inverter with a max. The output power of two photovoltaic systems with a maximum output power of 0.29 kW to supply the scaled annual average of 165.44 kWh/day (Lal *et al*., 2011). The data values obtained reveal that the total operational cost difference between the optimal system and the worst system is around 75%, the annual operation cost difference is around 64% and the kWh cost for the users takes a difference of 76%; and the reduction of CO_2 emissions take a value of 57% between the optimal system and the worst system (Budes, 2018).

III. Methodology

In this research, the goal is to implement an electric generation system by solar cells and supply it at a lower cost. For this HOMER-PRO has been used for project simulation and cost analysis. In this project, first of all, a remote village has been selected where no electricity available yet and no grid system beside the area. Then the total load demand of the selected area has been calculated by physical assessment. Renewable resources like solar irradiance and other data which are needed for completing the also have been collected. After that simulation and cost analysis has been done by HOMER-Pro. Energy engineers and researchers use various tools and software like HOMER, Hybrid2, TRNSYS, PVsyst, Energy Plus, etc. to model the energy systems and implement the energy management technique. These tools optimally size the components and perform optimization and sensitivity analysis based on load demand, availability of resources, and their cost. HOMER is the latest simulation model that chooses the viable hybrid energy system among various energy resources. HOMER performs optimization analysis on all possible combinations of the equipment used and sorts out the feasible one based on the optimization variable. It provides thousands of combinations and after comparing understands the variability of the system with the change in variables that are beyond the control such as wind speed, solar irradiance, hydro flow, and fuel cost (Muhammad *et al*., 2018).

The proposed microgrid system combines the Genset module and PV solar. Below is the schematic diagram of the proposed project.

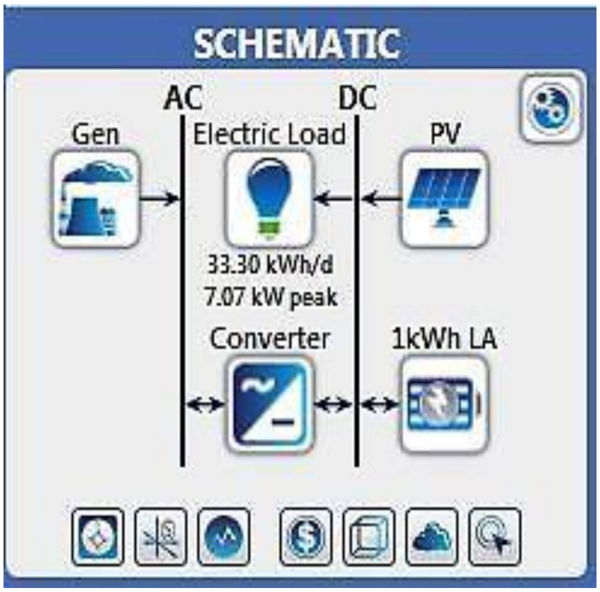

Figure 1: Schematic diagram of a microgrid system

Bangladesh has a tropical monsoon climate. thus it gets enough sunlight throughout the year. The average solar irradiation is found in Bangladesh approximately 4.42 kW/m^2/day.

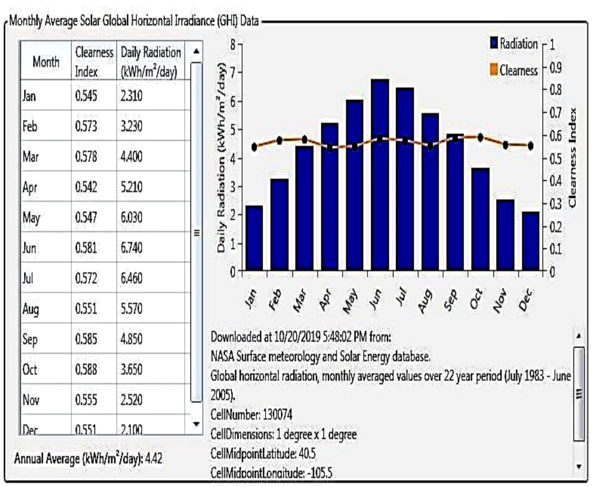

Figure 2: Solar radiation profile

The required demand has been divided into two different cases. Table 1 shows the total demand that needs to be fulfilled in the proposed system. In the first case, both Genset and solar PV combined will deliver the required energy.

Table 1: Average load demand evaluation of the proposed location

Load	Quantity	Watt	Hour	Watthour
LED	3	7	6	126
Fan	2	22	10	440
TV	1	20	2	40
Mobile	2	15	2	60
Demand (per house)				**666**
Total Wh/day (50 Households)				**33300**

Table 2: Average energy demand during no sunlight

Load	Quantity	Watt	Hour	Watthour
LED	1	7	6	42
Mobile	1	15	2	30
Demand (per house)				**72**
Total Wh/day (50 Households)				**3600**

Table 3 shows the parameters of selected solar panels which are rated 250 Wp. No digital or auto tracking has been installed. 1 kWh lead-acid battery is selected for storage purposes.

Table 3: Design parameters (PV Solar)

Parameters	Value	Remark
Average solar Radiation	4.8 kWhr/m^2/day	Manual Tracker
PV module size	250 Wp	
Battery Voltage	12V	
Battery DOD	80%	
Battery efficiency	90%	
Average panel lifetime	20-25 years	flat PV module
Min battery life time	5-7 years	Maintenance free
Distribution pole span	30m	
Nominal distribution voltage	220-230VDC	
Area required per kW panel	10m^2	
Inflation rate	6%	On total project cost
Interest rate on bank loan	3%	Per year (flat rate)

IV. Result analysis

By using solar irradiance, load profile, and details of the components, HOMERuses hourly time series data, simulates a hybrid energy system, and generates a list of optimization cases. It is found that the Cost of energy 0.494 $/kWh. The details and individual components' generation cost result has been given below. Table 4 shows the individual component's generation cost& make a reasonable comparison among the structural units. The cost of PV generation is 0.154 $/kWh with a capacity factor of 17.4%.

Table 4: System Structure for Optimum Case

1. Photovoltaic		
Quantity	**Value**	**Unit**
Rated Capacity	8.67	kW
Total Production	12739	kWh/year
PV Penetration	95	%
Operating Hours	4386	Hrs./year
Capacity Factor	17.4	%
CoE	0.154	$/kWh
2. Diesel		
Quantity	**Value**	**Unit**
Rated Capacity	2.07	kW
Total Production	2072	kWh/year
Fuel Consumption	951	L/year
Operating Hours	1009	Hrs./year
Capacity Factor	2.88	%
Marginal CoE	0.236	$/kWh
3. Battery		
Quantity	**Value**	**Unit**
Nominal Capacity	48	kWh
Wear Cost	0.335	$/kWh
Storage Depletion	8.1	kWh/year
Losses	140	kWh/year
4. System converter		
Quantity	**Value**	**Unit**
Capacity	1.96	kW
Operating hours	1009	hrs./year
Capacity Factor	11.4	%
Losses	104	kWh/year

The rated capacity of PV is 8.67 kW and the PV penetration is 95%. For the diesel generator, the marginal generation cost is 0.236 $/kWh.The wearing cost for battery 0.335 $/kWh with 140 kWh losses per year. The system converter has a capacity factor of 11.4% with losses of 104 kWh/year.

Table 5: Daily Generation vs. Demand

Source	Generation	Demand
PV	34.9 kWh/day	33.3 kWh/day
DG	5.6 kWh/day	2.6 Kwh/day

Table 5 makes a comparison between generations Vs demand load. The average daily demand is found to be 33.3 kWh. It is already obtained by only the PV generation of 34.9 kWh/day. But considering some losses it's required some generation from the diesel generator. The minimum scaled demand of 2.6 kWh/day. It's for a day when there is no proper sunlight, on rainy days especially. It is considered that there is no generation from PV. The generation from diesel generator is 5.6 kWh/day which will be enough to supply the minimum demand.

Total emissions of fuel burning for electricity generation Emissions from diesel generators have been described in Table 6.

Table 6: Emissions of various gases (from HOMER-Pro)

Quality	Value	Units
Carbon Dioxide	2,490	kg/yr.
Carbon Monoxide	15.7	kg/yr.
Unburned Hydrocarbons	0.685	kg/yr.
Particulate matter	0.0951	kg/yr.
Sulfur Dioxide	6.1	kg/yr.
Nitrogen Oxides	14.7	kg/yr.

Total 2490 kg/year carbon dioxide emits from fuel burning, 15.7 kg of carbon monoxide produces per year Hydrocarbons remains unburned 0.685 kg/year. Particle matter production is 0.0951 kg/year. 6.10 kg of sulfur dioxide emits from fuel-burning per year. Nitrogen oxides emission is 14.7 kg/year. Heavy metals are used for PV panel generation and disposal of this material is another great environmental concern.

System Converter Emissions
Cost Summary Cash Flow Compare Economics Electrical Fuel Summary Autosize Genset Renewable Penetration Generic 1kWh Lead Acid Generic flat plate PV

Production	kWh/yr	%
Generic flat plate PV	12,739	86.0
Autosize Genset	2,072	14.0
Total	14,811	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	12,078	100
Deferrable Load	0	0
Total	12,078	100

Quantity	kWh/yr	%
Excess Electricity	1,256	8.48
Unmet Electric Load	76.6	0.630
Capacity Shortage	112	0.925

Quantity	Value	Units
Renewable Fraction	82.8	%
Max. Renew. Penetration	1,436	%

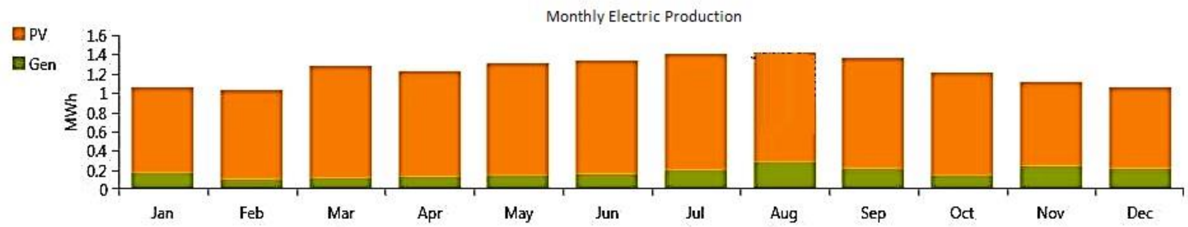

Figure 3: Summary of Electrical Power Output

PV (kW)	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
8.36	8.20	48	1.96	LF	$76,262	$0.494	$2,512	$44,155	82.8
17.0		47	$145,962	CC	$84,294	$0.563	$1,501	$65,100	100
	8.20	27	5.96	CC	$104,931	$0.675	$7,114	$13,988	0
	8.20		2.98	CC	$145,659	$0.970	$11,004	$4,994	0
0.0885	8.20		3.01	CC	$145,962	$0.971	$11,001	$5,268	0

System	Gen					PV		1kWh LA			
Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($/yr)	Fuel Cost ($/yr)	Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Operating (hours	Nominal Capa (kWh)
951	1,009	2,072	951	24.8	951	25,067	12,739	20.8	6,282	0	48.0
0						51,000	25,919	20.3	6,534	0	47.0
4,596	2,596	14,436	4,596	63.9	4,596			11.7	7,022	0	27.0
8,494	8,760	18,980	8,494	215	8,494						
8,491	8,760	18,968	8,491	215	8,491	251	135				

Figure 4: Categorized generation and cost summary

Figure 3 shows the total electrical generation both by PV and diesel generator and also yearly consumption. It is obtained from the simulation from PV the generated electricity is 12,739 kWh/year which means 34.9 kWh/day which meets the required energy of 33.3 kWh/day. The generator generates 2072 kWh/year that means 5.6 kWh/day as a baseload. The DC primary load 12078 kWh/year. Some excess energy is produced of 1.256 kWh/year which can be sold for the utility sector, such as EVs recharging. Almost 86% of electricity generates from PV Solar.

Figure 4 shows the different combinations of generation costs. From the above data for PV & generator combined generation with storage, the total NPC is $76,262 where for only PV with storage the NPC is $84,294 for the only generator with storage the NPC is $104,931 for the only generator without storage the NPC is $145,659 for PV and generator without storage the NPC is $145,902. So, the best way to generate the required demand in PV & generator combined generation with storage. By using solar irradiance, load profile, and details of the components, HOMER uses hourly time series data, simulates the energy system, and generates a list of optimization cases. The simulation was done with and without the consideration of sensitivity variables like load profile and diesel price. The simulation results are shown in figure 4. The cash flow summary for 25 years of the projects shown in figure 5.

The operating cost almost remains constant throughout the lifespan of the project, which is from for each year as shown in figure 5. Replacement cost will be spending whenever a component is needed to replace till the end of the project. The fuel cost of the batteries has been counted 4 times throughout the project. All these costs discussed above are cash outflows while there is a salvage value at the end of this project and that is called cash inflow.

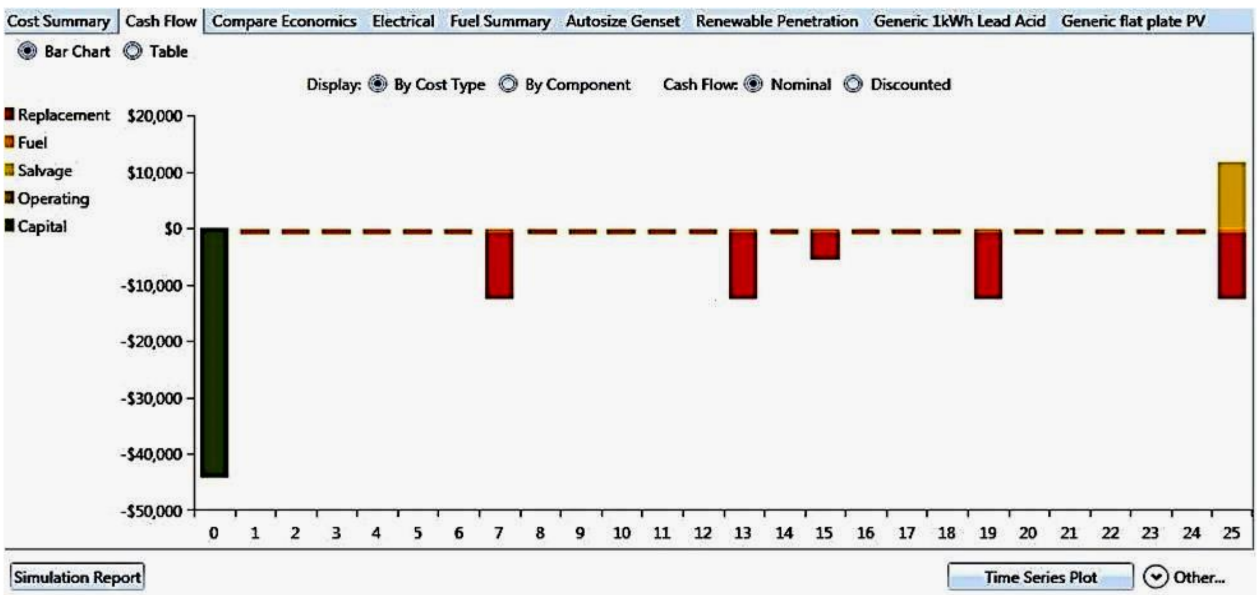

Figure 5: Project's cash flow

Table 7: Cost summary

Components	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	$4,100.00	$1,724.18	$317.30	$12,161.3	-$304.10	$17,998.76
DG	$14,400.00	$20,446.93	$1.84	$0.00	-$2,443.06	$32,405.71
1kWh LA	$25,066.64	$0.00	$2.14	$0.00	$0.00	$25,068.78
Converter	$588.82	$245.69	$0.00	$0.00	-$45.73	$788.78
System	$44,155.46	$22,416.9	$321.28	$12,161.2	-$2,792.89	$76,262.04

Different sources of energy (solar and Diesel generator) are integrated into a form of a microgrid. Cost summary of the optimum system in Table 7 depicts that the fuel and O&M cost of the DG increases the cost of the system exponentially. On the other hand, the cost of the system is directly vulnerable to the replacement of storage battery after each period of 6 years during the lifetime of the project it is found that the Cost of energy 0.494 $/kWh. However, it is found that diesel generator is a cost-effective source of energy in terms of fuel cost that is much high in a country that depends upon imported oil. In the future study, many distributed sources like microturbine, steam turbine, fuel cell, micro-hydro, and biogas generators can be integrated into the system that put a positive economic impact on the whole system and can have indigenously. It is required $44,155 or 3532400 BDT initial costs to start the power plant. Running cost $2512 or 200960 BDT and the Cost of Energy is $ 0.494 or 39 BDT.

V. Conclusion

In this paper, a solution to the lack of electricity and energy conversion technologies is proposed. Distributed sources of energy (solar and Diesel generator) are integrated forming a microgrid. Components of a hybrid energy system are modeled and using HOMER Pro an optimum system is configured. It is found that the energy cost is 0.49 $/kWh. However, it is found that diesel generator is a cost-effective source of energy in terms of fuel cost that is much high in a country that depends upon imported oil. In the future study, many distributed sources like microturbine, steam turbine, fuel cell, micro-hydro, and biogas generators can be integrated into the system that put a positive economic impact on the whole system and can have indigenously.

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