Selection of Optimized Mix of Generation Technologies for Hybrid Renewable Energy Power Plant in Sri Lanka

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ABSTARCT:

A renewable energy source based hybrid power plant has been proposed as an economical option for Eluvaithivu, an isolated Islet located close to the Jaffna peninsula in Sri Lanka. Eluvaithivu is a small islet with 130 houses[1]. Seventy houses are supplied electricity by a 28 kVA diesel generator owned by the Ceylon Electricity Board (CEB) and supply is given approximately 6½hours per day. The average monthly consumption of the islet is 3,100 kWh. Cost of electricity generation is about 50 Rs/kWh while the average tariff charged by CEB is about 5 Rs/kWh. Due to this reason there is considerable amount of financial loss. This financial loss prevents the complete electrification and round the clock supply to this islet.

This paper presents a scenario for supplying electricity demand to Eluvaithivu Islet by using mini-grid hybrid power system consisting of renewable sources, battery and diesel generators. Some topologies of hybrid power system are considered, simulations are performed and the results are presented in order to find out the most efficient and economic way for providing the power supply to this Islet.

The research study proposes a wind-diesel hybrid power system as the most cost effective generation technology for this Islet. This will enable supplying electricity round the clock to this Islet and minimize the financial loss by about 60%. Renewable energy contribution will be approximately 70% of the total energy demand.

1. INTRODUCTION

Eluvaithivu is a small islet located on the western side of the Jaffna peninsula in Sri Lanka. The Islet is oriented in a north-south direction and covers an area of 1.7 km^2. Population in the Islet is 685 individuals belonging to 185 families living in 130 houses. Majority of them are fishermen. Large part of the islet is covered by dense vegetation comprising Palmyra and Coconut palm trees. Islet's western side is covered with coral and limestone whereas the eastern side is sandy. Almost the entire Islet is underlain with limestone.

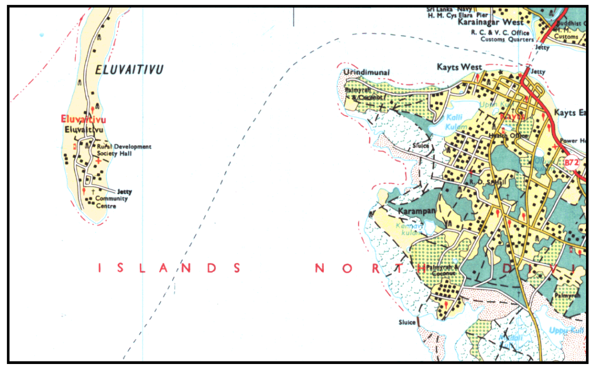

Figure 1: Geographical location of Eluvaithivu Islet

At present 70 houses are electrified by a 28 kVA diesel generator owned by the Ceylon Electricity Board (CEB) and operated from 4.30am to 6.30am and 6.00pm to 10.30pm, approximately 6½hours per day. The average monthly consumption of the Islet is 3,100 kWh. Cost of electricity generation is about 50 Rs/kWh while the average tariff charged by CEB is about 5 Rs./kWh. There is a huge financial loss in its operation. This financial loss prevents the complete electrification and round the clock supply to the Islet. This paper presents a scenario for supplying electricity demand in Eluvaithivu Islet by using mini-grid hybrid power system consisting of renewable energy sources, battery and diesel generators.

2. HYBRID POWER SYSTEM

Eluvaithivu has huge potential for utilizing renewable energy sources, such as solar energy, wind energy to provide a quality power supply to this Islet. The abundant energy available in this Islet can be harnessed and converted into electricity in a sustainable way to supply the necessary power to improve the living standards of the people, who do not have a chance to get national grid power supply in near future.

The main advantages of using renewable energy sources for generating power in remote Islets are obvious, such as the high cost of transportation of fossil fuel and there is increasing concern over the issues of climatic changes and global warming. The disadvantage of standalone renewable energy power system is the availability of renewable energy sources will have varying daily and seasonal patterns, which results in difficulties in regulating the output power to cope with the load demand. Thus, combining the renewable energy power generation with conventional diesel power generation will enable the power supply to be more reliable and affordable. This kind of power generation system, which consists of renewable energy and fossil fuel generators together with an energy storage system and power conditioning system, is known as a hybrid power generation system.

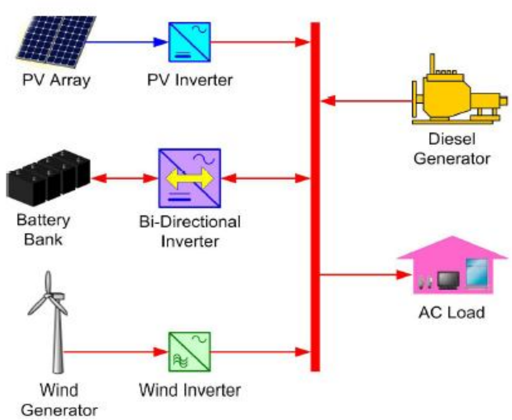

Figure 2: Schematic diagram of a typical hybrid power generation system

A hybrid power system has an ability to provide 24-hour grid quality electricity to the load. This system offers a better efficiency, flexibility of planning and environmentally benefitted system compared to stand-alone diesel generator. The operational and maintenance costs of the diesel generator can be reduced as a consequence of improving the efficiency of operation and reducing the operational time, which also means less fuel usage. The system also gives the opportunity for expanding its capacity in order to cope with the increasing demand in the future. This might be done by increasing either the rated power of diesel generator, renewable generator or both of them.

3. LOAD PROFILE

In order to design a power system which is ideal and dedicated to Eluvaithivu Islet, its electricity demand should be estimated correctly considering current load and future expansions.

3.1 Load profile of the existing power system

With support of CEB daily load pattern has been recorded and populated in tabular form for analysis. Following graph shows the load profile of the existing power system

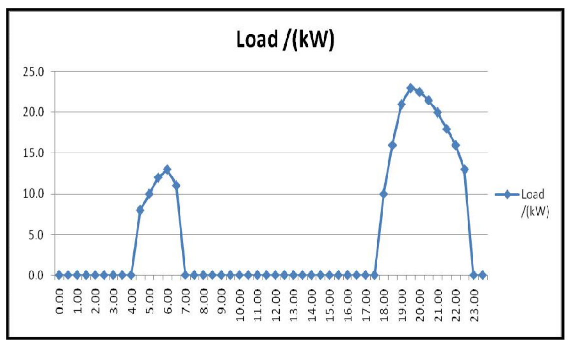

Figure 3: Average load pattern of the Islet[2]

3.2 Load profile of the proposed power system

In order to design a mini-grid hybrid power system, load profile of the future system has been predicted carefully with the help of survey, which has been conducted among the residents of islet. The existing load profile was used together with the data collection to predict the actual load profile of the proposed system.

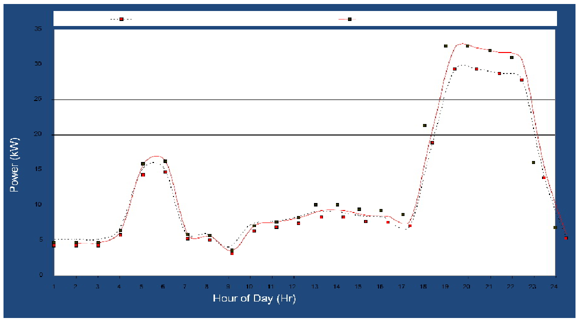

Figure 4: Predicted load pattern of future[1]

Energy efficient lighting system was also considered in the design of load profile. However, final power system was selected such a way that it operates even without the energy efficient lighting system. Further the total power system is designed to withstand for any varying loads. Primary load has annual average of 319kWh/day with annual peak of 44 kW. If proposed Ice-plant and other industries are materialized then load will hit the annual average of 500kWh/day.

4. RENEWBLE POTENTIALS

In order to design a mini-grid hybrid power system, the potential renewable resources has to be measured and validated using field measurements.

The general climate prevailing in the Islet is very much similar to the overall climatic condition of the northern part of Sri Lanka.

4.1 Solar Potential in the Islet

There is no meteorological station available in the northern region to record solar radiation data. Thus, data sourced from NASA (www.eosweb.larc.nasa.gov) website, which indicates that the solar radiation levels are fairly uniform over this region and varies from 4.4 kWh/m2/day to 6 kWh/m2/day.

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.552	4.926
February	0.592	5.681
March	0.585	5.994
April	0.554	5.823
May	0.521	5.415
June	0.466	4.774
July	0.465	4.785
August	0.456	4.741
September	0.493	5.063
October	0.484	4.716
November	0.491	4.442
December	0.510	4.424

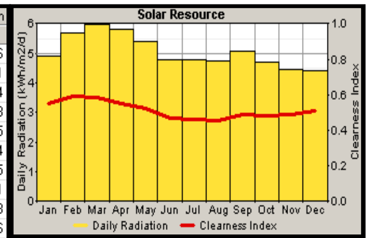

Figure 5: Solar Radiation throughout a year

4.2 Wind Potential in the Islet

Several coastal areas in Sri Lanka, including the northern region, experience strong winds during the period of the south-west monsoon (May to October), and moderate winds during the north-east monsoon (December to February). Satellite data obtained regarding wind potential in this Islet is given below

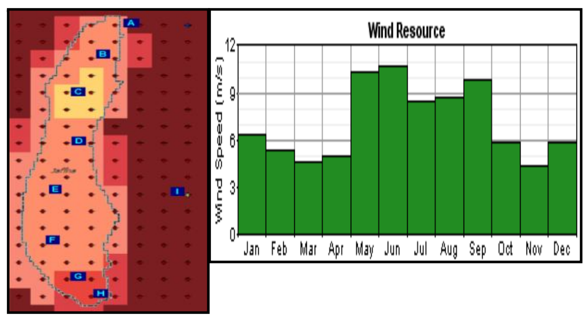

Figure 6: Average Wind potential in the islet

Table 1: Wind potential over the segmented areas of the Islet

Location	Annual Average Wind Speed (m/s)	Annual Average Wind Power Density (W/m3)
A	6.77	268
B	6.61	249
C	6.50	237
D	6.57	246
E	6.73	265
F	6.87	282
G	7.05	307
H	7.33	345

Eluvaithivu is well exposed to both monsoons and its mean annual average wind speed is 6.75 m/s at 20m height.

4.3 Other Renewable potentials in the Islet

Out of many options available, some technology options such as biomass, wave energy, and tidal energy are not considered due to the absence of adequate data and immaturity of technology.

5. SYSTEM COMPONENTS

Electricity can be generated from various sources such as Diesel Generators, Solar Panels, Wind Turbines, Biomass Gasifiers and Tidal Wave Generators. Out of many options, only the following technological options and their combinations were studied in detail to identify the most suitable power system for Eluvaithivu[3]-[6].

- Solar Photo Voltaic (Solar PV)
- Wind Turbine Generators (WTG)
- Diesel Generator Sets (DG Sets)
- Batteries
- Converters
- Hybrid Controllers

To obtain the best hybrid power system configuration, HOMER software which is a hybrid power optimization software developed by the National Renewable Energy Laboratory (NREL, USA) has been used.

6. POWER SYSTEM CONFIGURATION

The power system configuration used in the HOMER software is given below.

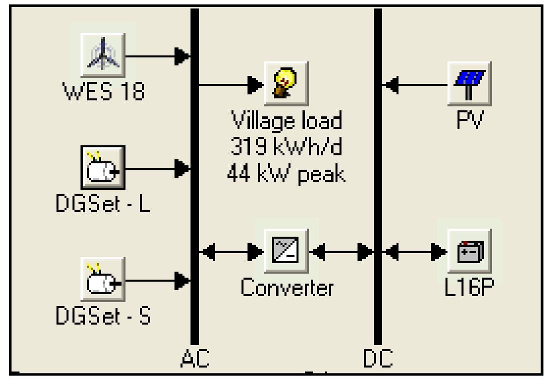

Figure 5: Schematic diagram of the power system used for HOMER analysis

7. ANALYSIS TO FIND THE OPTIMAL OPTION

Technology options ranked according to the Net Present Cost (NPC). A screen view of the homer software optimization output is given as follows;

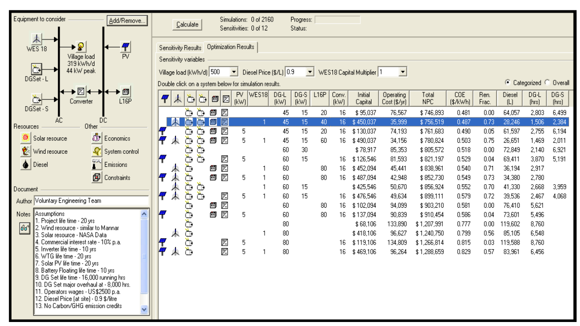

Figure 6: Optimized result from the HOMER analysis

The output shows that two diesel Generator systems with battery backup and a hybrid controller is the winning configuration. It is followed closely by a configuration having one Wind Turbine Generator (WTG) with two diesel Generators and battery backup with a hybrid controller. The wind-diesel hybrid system ranks second in the list. NPC of the wind-diesel system is only 1.3% higher than that of the winning configuration. This means, even a modest deviation of the fuel price and/or the wind turbine price from those assumed in the analysis could alter the ranking. Also it should be noted that wind-diesel hybrid system will give 73% of the total annual energy demand from the wind energy, thereby approximately 70% fuel will be saved. This leads towards an energy consumption based to 100% on renewable energy sources.

Twelve different cases (mixture of generation technologies) were studied with operational and economical analysis. It shows few mixtures of generation technologies are suitable for this Islet electrification project. Following table illustrate above scenario.

Table 3 displays some good options, which can be considered. Here, Option-1 is diesel only system and Option-9 is the best if enough initial capital is available, and given that the excess energy is used in a productive manner. Option-5 deserves as next high priority option with reasonable investment.

When considering existing market with more reliable operating wind turbines, It goes to a mixture of one wind turbine (80 kW) and two diesel generators (45 kW + 15 kW) together with battery energy storage and converter (16kW) as a reliable and economical solution to electrify this Islet.

8. PROJECT COST

The cost of the proposed system (option 9) is about 50 million Sri Lankan Rupees. The payback from the fuel saving alone is about 6 to 9 years when compared with the existing diesel based generation technology while providing electricity round the clock to the Islet. The indicative cost breakdown is as follows;

Table 3: Some of the hybrid options which are suitable for consideration

Op.	WES18 (kW)	Gaia 11 (kW)	Solar PV (kW)	DG-L (kW)	DG-S (kW)	Converter (kW)	Battery (Trojan L16P) (Nos)	COE ($/kWh)	Renew. Fraction (%)	Excess Energy (kWh/Yr)	Capital RE Equipment Cost ($)
1	-	-	-	45kW	15 kW	16 kW	40	0.48	0%	0	61,000
2		1 (11kW)		45kW	15 kW	16 kW	40	0.45	25%	315	151,000
3		2 (22kW)		45kW	15 kW	16 kW	40	0.43	46%	16,350	231,000
4		3 (33kW)		45kW	15 kW	16 kW	40	0.44	61%	43,700	311,000
5		2 (22kW)	10kW	45kW	15 kW	16 kW	40	0.44	53%	23,300	281,000
6		2 (22kW)	15kW	45kW	15 kW	16 kW	40	0.45	55%	27,900	311,000
7		3 (33kW)	10kW	45kW	15 kW	16 kW	40	0.46	66%	52,700	371,000
8	1 (80kW)			45kW	15 kW	-	-	0.57	67%	121,900	395,000
9	1 (80kW)			45kW	15 kW	16 kW	40	0.50	71%	103,600	421,000
10	1 (80kW)		10kW	45kW	15 kW	16 kW	40	0.52	74%	112,300	471,000
11			20kW	45kW	15 kW	16 kW	40	0.50	18%	1,100	171,000
12			30kW	45kW	15 kW	16 kW	40	0.52	25%	5,650	221,000

Table 04: Cost break down of the components

No	Description	Nos./Capacity	Unit Cost (US$)	Total Cost (US$)
1	Wind Turbine Generator (80kW @13m/s from Reputed Make)	1 Nos. (80kW)	350,000	350,000
2	Diesel Generator 1	45kW	-	15,000
3	Diesel Generator 2	15kW	-	10,000
4	Converter (Inverter + Rectifier)	20kW	-	20,000
5	Battery Bank	80 Nos. (170kWh)	250	20,000
6	Hybrid Controller	1 Nos.	-	20,000
7	Protection & Metering	Sum	-	5,000
8	Cable termination including cables	Sum	-	5,000
9	Capacitor Bank and Power Quality Filter (Harmonic Filter)	Sum	-	10,000
10	Building for Power House	Sum	-	10,000
11	Project Development Cost	Sum	-	9,000
12	Contingencies (%)	-	-	26,000
	Total Project Cost			**500,000**

9. ECONOMIC VIABILITY

The cost of electricity generated by the selected wind-diesel plant configuration (Option 9) works out to US$ 0.50/kWh, while the operational cost amounts to US$ 0.20/kWh. Based on the CEB tariff charged from presently electrified customers in the Islet, households pay on average US$ 0.05/kWh. If this power plant proposed as community owned wind-diesel system then the consumers will have to pay almost 4 times the present expenditure on electricity just to meet the operational cost of the proposed wind-diesel plant. Though the wind-diesel system would maintain 24-hour supply of electricity as compared with the limited supply from exiting CEB's diesel generator, it seems most unlikely that the Islet population would be willing to incur such a high expenditure on electricity. Thus, the economic viability of the project, in the form of a community owned wind-diesel system operated on cost-recovery basis, would be not viable.

According to the calculation, the average operational cost of supplying electricity by the CEB's existing diesel generator amounts to Rs.50/kWh (US$0.50). Charging a tariff of only US$0.05/kWh, CEB incurs a financial loss of about US$ 17,500 per year in operating the existing diesel generator system in the Islet. And the loss will further increase with diesel price escalations and increased electrification of the Islet. In this context, the wind-diesel option with an estimated operational cost of US$ 0.20/kWh has the potential to reduce the financial loss to CEB by about 60%. Therefore, electrification of the Eluvaithivu Islet using a wind-diesel system would be an economically attractive option for CEB.

10. CONCLUSION

The overall study proposes the wind-diesel hybrid power system as the most economical system to electrify the Eluvaithivu. The choice of one wind turbine (80 kW) and two diesel generators (45 kW + 15 kW) together with battery energy storage and converter (16kW) is the most reliable and economical hybrid system to electrify the Islet. The study also confirmed that this project will not an attractive solution if it is owned by the community itself. But the study strongly recommends that, if the CEB implement this project on its own, it would be an ideal win-win situation for both CEB and Islet community as it brings partial green power concept while reducing financial loss by 60% to the CEB and electrifying the islet round the clock.

Further this will be a new pilot project on the hybrid generation technology, where the research and development can be boosted for more new directions in the country.

11. REFERENCES

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