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Hybrid Renewable Energy Systems: A Comparison Using Optimization Technique for Energy Security

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ABSTRACT

The initial cost of a stand-alone renewable energy (RE) option is higher than a conventional fuel-driven engine, but has less or negligible operating cost. Advantages of RE for technology reliability and cost front, system designers are looking for ways to combine both generators - renewable and fossil fuel based into one system known as hybrid power system. This paper deals with the sizing, generator running hours, sensitivity analysis, optimization, and green house gas (GHG) emission. For this purpose locations have been selected where feasibility of hybrid renewable energy systems (HRES) is analyzed for the same load demand using suitable RES. One site is a small remote community of Amine in Lakshadweep Islands, located in southern India in the Arabian Sea, where solar, wind energy is always available throughout the year to provide Energy Security. For optimizing, simulating the system HOMER software is used of National Renewable Energy laboratory, USA.

KEYWORDS Optimization technique, Emission, hybrid energy, renewable energy integration, sensitivity analysis.

1. Introduction

Energy is the ultimate factor which is responsible for industrial, agricultural, and living-standard growth. The use of RE technology has been rapidly increasing to meet growing energy demand. However, the main disadvantage associated with standalone RES are their inability to provide energy security due to unpredictable, seasonal and time dependant nature. The standalone solar photovoltaic (SPV) system cannot provide reliable power during non-sunny days whereas standalone wind system cannot deliver power to a constant load due to significant fluctuation in wind speed magnitude for high cut-in speed range from 3.5 to 4.5 m/s . Therefore, over sizing of system becomes necessary to achieve reliability which causes the design expensive. As far as initial cost is concerned, solar or wind energy system (WES) is costlier than diesel generator (DG) set for the same capacity but operation and maintenance (O&M) costs are always lower than DG set .

For analytical studies, a remote location namely Amini Island is chosen, which is one of the clusters of 36 Lakshadweep Islands, located in southern India in Arabian Sea at latitude 11.1 °N and longitude 72.7 °E at 1 m above sea level.

2. Selection of Software

Modeling of HRES is the process of developing mathematical model of its components and factors affecting its function. By means of mathematical model and its simulation through computer, performance of a system is analyzed under different situations. Methodologies are generally adopted for modeling system component of HRES with special reference to solar and wind energy . Some specialized softwares are available for simulation and optimization hybrid systems, e.g., HOMER (Optimization Model for Electric Renewables), RETSreen (Renewable Energy Technology Software), LEAP (Long-range Energy Alternatives Planning), Hybrid2, energyPRO3 (Energy Projects), RAPSIM (Remote Area Power Supply Simulator) etc. HOMER is a micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications .

3. Methodology

HOMER software is used as tool for analyses purpose. Optimization technique is applied to HRES according to different criterions based on each component of the system, total integrated system, and optional energy control. The parameters of investment, cost of energy, consumption of energy/fuel, and system sustainability are also considered as parameters Cost of energy (COE) is the average cost per kWh of useful electrical energy produced by the system, given by:

$$COE = (C_{ann,tot} - C_{boiler} E_{thermal}) / (E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}) \quad (1)$$

where, $C_{ann,tot}$ = total annualized cost of the system [$/yr]

C_{boiler} = boiler marginal cost [$/kWh] = 0

$E_{thermal}$ = total thermal load served [kWh/yr] = 0

$E_{prim,AC}$ = AC primary load served [kWh/yr]

$E_{prim,DC}$ = DC primary load served [kWh/yr] = 0

E_{def} = deferrable load served [kWh/yr] = 0

$E_{grid,sales}$ = total grid sales [kWh/yr] = 0

The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. In systems that do not serve a thermal load ($E_{thermal}$=0), this term will be equal to zero.

To get optimal configuration and control of HRES, an analysis of multifactor function is conducted:

COE is to be kept minimum, which is given by

$$\text{Min } (COE = f(L, CU_i, n_i, COF_i, QF_i, RE, T_i, P_i \ldots)) \quad (2)$$

L – Energy consumption,

CU_i – Overall cost of each unit,

n_i – Number of the units of the same type,

COF_i – Cost of fuel,

QF_i – Fuel consumption of the unit,

RE – Available Renewable Energy,

T_i – Life time of the unit,

P_i – Rated power of the unit.

- System sustainability is the maximum stability or minimum number of supply interruption, is given by

min (E_{rr} = f (L_i, RE, P_i, SF_{min}, SF_{max} …)) (3)

Where E_{rr} – Number of supply interruptions, L_i – Load with its own priority, SF_{min},

SF_{max} – Minimum/Maximum stored energy.

- If use of RE (*REU*) is maximum, the fuel consumption (*FC*) is minimum. The objective is represented by

max (REU = f (L, RE, Pi, SF_{min}, S_{max} …)) (4)

min (*FC* = *f* (*L, RE*, P_i, SF_{min}, SF_{max} …)) (5)

From equations (2) and (3), optimization criterion is combined to get a target function is:

Opt (min (*COE*), min (*Err*)) (6)

4. HRES Simulation

The proposed HRES is to be installed for light and power loads in different schools located at Amini Island .The objective of HRES is to achieve energy security with optimized values of system components. For the sake of optimization, the software chooses equipment/s and sizes of different systems such as SPV, wind turbine, DG set, battery bank and converter.

5. Simulation Results

Simulation result provides important detail of optimal hybrid system, like size of the system component, total net present cost, COE, and GHG emission.

In the case, hybrid SPV-WES-DG system is proposed for an actual primary load demand of 880 kWh/day, 149 kW peak along with batteries (Vision 6FM200D, 12 V, 200 Ah, 2.4 kWh) and converter for Amini Island. DG set and battery bank are opted to maintain electric supply if solar and/or wind energy is not able to supply the load sufficiently.

There are two choices of optimization results:

- Overall system ranking shows top-ranked system configurations according to net present cost.
- **Categorized ranking shows least cost system of each type**.

Sensitivity results provide huge amount of output data for several sensitive cases of each component and variable. A sensitivity case is a specific combination of sensitivity variable values. Eight values are specified for the wind speed (average value 4.61, 5, 6, 10, 15, 20, 25, and 30 m/s) and three values for diesel price (0.6, 0.8, and 1 $/L). The software performs a separate optimization for each sensitivity case.

These results are indicated either in tabular or in graphic form. In the tabular form, sensitivity results consist of a list showing the least cost system for each sensitivity case.

The optimization result obtained from the simulation of the hybrid SPV-WES-DG system suggested for the Amini Island is shown in Table 2 and 3. Besides other detail, it is also found that electrical energy production by WES is 1,130,671 kWh/yr (93%) whereas 87,552 kWh (7%) by DG, for wind speed 4.61 m/s.

Sensitivity case: Wind speed: 4.61 m/s, Diesel Price: 0.6 $/L, Hub Height: 25 m, SoC: 25%

Table 1: Simulation Results of different sensitivity values of wind speed

Wind Speed m/s	Optimal System Configurations					Optimal Cost of Energy $/kWh	Initial Capital $	DG Running Hours	GHG Emission Kg/year
	SPV kW	Wind Generator WES-18	DG kW	Battery Nos.	Converter kW				
4.61	-	10	100	168	100	0.125	159,600	903	76,661
5	-	10	100	180	100	0.106	162,000	643	55,207
6	-	10	100	156	100	0.076	157,200	310	26,838
10	-	6	100	96	100	0.038	113,200	99	8,050
15	-	4	50	96	50	0.024	74,200	85	3000
20	-	5	-	96	50	0.022	74,200	0	0
25	-	4	-	96	50	0.020	66,200	0	0
30	-	4	-	96	50	0.020	66,200	0	0

Sample calculation of COE for wind speed 4.61 m/s:

Primary load = 880 kWh/day

= 321,200 kWh/yr

The total annualized cost of the system obtained= 40,083 $/yr

From Equation (1), $COE = C_{ann,tot}/E_{prim,AC} = 40{,}803/321{,}200$

= 0.12479 $/kWh

0.125 $/kWh

Table 2: Cost breakdown

Component	Initial Capital	Annualized Capital	Annualized Replacement	Annual O&M	Annual Fuel	Total Annualized
	($)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
WES	80,000	6,258	0	500	0	6,758
DG	16,000	1,252	276	1,806	17,467	20,801
Battery	33,600	2,628	6,877	672	0	10,177
Converter	30,000	2,347	0	0	0	2,347
Total	159,600	12,485	7,153	2,978	17,467	40,083

6. Results and Discussions:

In the first case of Amini Island WES, SPV, DG set, battery, and converter are selected for simulation purpose but equipments configured after simulation are WES, DG set, battery, and converter. SPV is not found in the configuration in this simulation result as shown in Table 2.The result in Table 1 is found for the eight different sensitivity variables of wind speed, diesel price of 0.6 $/L, hub height 25 m, and set point SoC 25%. The simulation shows that COE (i) decreases as wind speed increases, (ii) increases with the increase in diesel price, (iii) decreases as hub height increases, and (iv) increases with set point SoC.As wind speed increases, the running hours of DG set decreases and hence GHG emission decreases. The emission is zero for wind speed more than 15 m/s as DG set is not configured. Hence carbon credits are saved.

7. Conclusions:

Energy security is important for an island; therefore hybrid system is preferred over one particular RES, so that strong points of conventional and RES are availed. If biomass is available, it is always beneficial to use biomass energy so that GHG emission is avoided. RE equipments are being selected by the software itself to provide a particular optimal configuration. Therefore, sometime a compromise is made at the cost of COE, making simulation ineffective. Sometime optimal configurations simulated by the software are not practically possible to install, hence compromise has to be made in favour of second or third most economical configuration.

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