Design of a Stand Alone Hybrid Power System for a Remote Locality in Bangladesh

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Abstract—**This paper proposes design for an off grid solar-wind-diesel hybrid power system for a remote locality. At first availability of solar and wind resources for different locations in Bangladesh has been studied. According to the solar irradiance and wind speed data Swandip has been chosen as project site. To save energy, we have designed the load for this locality. Using HOMER, different combinations have been tested to find the optimized solution considering both cost and electricity production.**

***Index Terms*—Hybrid power system, Homer, Weibull function.**

I. Introduction

Development and adoption of reliable sources of renewable energy nowadays has become a major challenge to the most part of the world. Bangladesh, not being exempted, faces many challenges in the era of globalization on it. Sustainable development of the energy sector is a potential factor to maintain economic competitiveness and progress. The world oil crisis in 2000s powerfully illustrated that the concerns over the energy resources which exposed the vulnerability of the energy supply and the over dependence on fossil fuel for energy. These conditions lead to the necessity for the diversification of energy resources.

Renewable sources can be a potential solution of energy crisis in Bangladesh. In this paper, we designed an off grid solar-wind-diesel system for a remote locality, Swandip. The reason for selecting Swandip lies in the absence of grid supplied electricity and availability of solar and wind resource. Swandip has total population of 44,451 with 8231 households, each household comprises of 5.4 persons in average [1]. Only 3.21% people get electricity connection in this island [2]. In our proposed system, about 950 households can be supplied with electricity. Assuming the size of each household to be 5.4, about 5130 people can get electricity connection with only 5% capacity shortage. That means our proposed system can supply power to about 11.54% people which is 3.5 times higher than the percentage of people are now getting electricity.

II. Wind And Solar Resource Assessment

A. Wind Speed Probability

It is a matter of common observation that the wind is not steady and in order to calculate the mean power delivered by a wind turbine from its power curve, it is necessary to know the probability density distribution of the wind speed. So we used Weibull probability distribution to estimate availability of wind resources in different coastal areas of Bangladesh.

In non-dimensional form, Weibull probability distribution function can be written as [3]

$$f(v;k,\lambda) = \left(\frac{k}{\lambda}\right) \times \left(\frac{v}{\lambda}\right)^{(k-1)} \times e^{-\left(\frac{v}{\lambda}\right)^k} \quad (1)$$

Where k > 0, shape parameter
λ > 0, scale parameter
v, wind speed

In this paper cumulative distribution function is used to describe the probability that the real-valued random variable V with a given probability distribution will be found at a value less than or equal to v.

Cumulative distribution function of Weibull function is

$$f(V \leq v) = 1 - e^{-\left(\frac{v}{\lambda}\right)^k} \quad (2)$$

where Justus approximation are used [3];

$$k = \frac{\sigma}{v}^{-1.086} \quad (3)$$

$$\lambda = \frac{\overline{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (4)$$

The gamma function,

$$\Gamma\,(n)=\int_0^\infty x^{n-1}e^{-n}dn \quad (5)$$

Mean wind speed,

$$\overline{v} = \left(\sum_{i=1}^{N} \frac{fivi^n}{\sum_{i=1}^{N} fi}\right)^{1/n} \quad (6)$$

Standard deviation,

$$\sigma = \frac{\sqrt{\left(\sum_{i=1}^{N} fi*(vi-\overline{v}\right)}^2}{\sum_{i=1}^{N} fi} \quad (7)$$

According to the above equations and wind speed for different locations at 25m high above sea level [2], the annual probability of wind speed above 4m/s for different locations has been calculated.In this calculation used Weibull parameters are given in Table I.

TABLE I
WEIBULL PARAMETERS FOR DIFFERENT LOCATIONS [4]

Location	Annual mean value of k	Annual mean value of λ
Kutubdia	1.69	3.69
Kuakata	1.57	3.06
Swandip	1.64	5.11

After that the annual probablity destribution functions calculated with the equations no. (1) and (2) are shown in Fig. 1.

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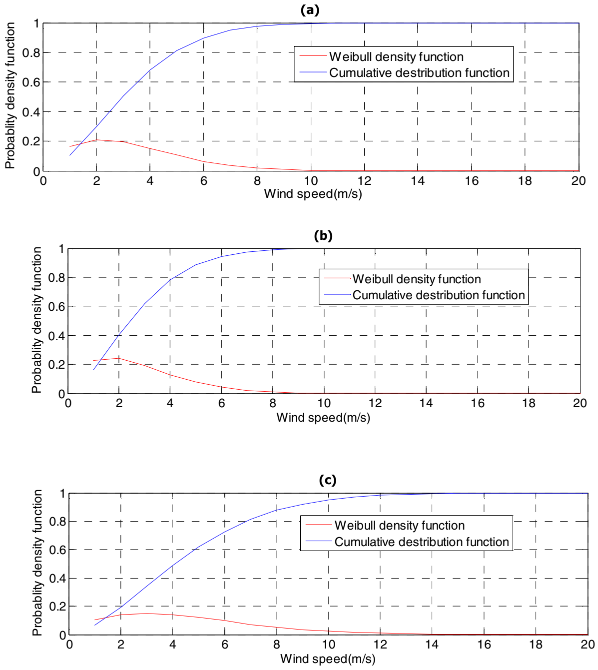

Fig. 1 Weibull Density Function vs. Wind velocity for (a) Kutubdia (b) Kuakata (c) Swandip

The results obtained from the above curves are summarized in Table II. So from the frequency distribution Swandip is the best location for wind power plant in Bangladesh

TABLE II
ANNUAL PROBABILITY OF WIND SPEED ABOVE 4m/s IN COASTAL AREAS

Location	**Annual probability(%)**
Kutubdia	31.79
Kuakata	39.89
Swandip	51.21

B. Solar Availability

Global Horizontal Irradiance (GHI) describes the solar resource available to a flat-plate oriented horizontal to the earth's surface. The required and available GHI are summarised in Table III.

TABLE III
AVERAGE SUNLIGHT IN SWANDIP [5]

	Average GHI (kWh/m^2)	**Average daily sunlight(Hour)**
Required	3	6
In Swandip	4.26	6.6

The average daily sunlight hours in Swandip that can be harnessed is ~6.6 hrs. That means it is within the approximated 6-8 hr. range. The average GHI in Swandip is $4.2kWh/m^2$, fairly above the $3kWh/m^2$ threshold [6]. Hence Swandip is apparently suitable for implementation of a solar power generation scheme.

III. Load Design

We have modeled our loads for every household with 6 persons. Our loads are designed for DC operation as we wanted to save inverter cost and energy with low power rating appliances.

Following loads are considered for different households:
L1: A 7W LED lamp
L2: A 5W LED lamp
L3: A 3W LED lamp
F1, F2: Two 18W 36 inch DC ceiling fans
M1: A 5W mobile charger
Total load for a household: 56W.

We considered LED lamp for energy saving purposes [7].We used weighted average method to approximate peak load of the system at May. We choose 30 houses randomly to calculate demand factor. A total of 11 combinations of active loads have been considered and are shown in Table IV.

TABLE IV
DIFFERENT COMBINATIONS OF LOADS

Combinations	**On-Off state of different Loads**						**Total load (W)**
	L1	**L2**	**L3**	**F1**	**F2**	**M1**	
C1	√	√	×	√	√	×	48
C2	√	×	√	√	√	×	46
C3	√	√	√	√	√	×	51
C4	√	√	√	√	√	√	56
C5	√	√	√	√	×	×	33
C6	×	√	×	√	×	×	23
C7	√	×	×	√	×	×	25
C8	×	√	√	√	×	√	31
C9	×	√	√	√	√	×	44
C10	×	√	√	√	√	√	49
C11	×	×	√	√	×	×	21

The socio-economic condition of Swandip has been considered to give different probability of occurrence for different combinations. To save electricity bill consumers will try to use more L3 (3W LED lamp) than L2 (5W LED lamp) and L1 (7W LED lamp).In May consumers are compelled to use fan (F1) due to excessive heat .So all combinations contains F1 and bigger household will switch the second one (F2). So F2 has only 6 combinations. It is most probable that the number of houses using L3 lamp and avoiding F2 fan will be high. So C_8 and C_9 have highest weightage during peak hours for a household with 6 persons. For Swandip we assume peak hours 7P.M to 9 P.M.

Peak household demand = $(2\times C_1 + 3\times C_2 + C_3 + 2\times C_4 + C_5\times 2 + C_6\times 1 + C_7\times 1 + C_8\times 7 + C_9\times 5 + C_{10}\times 4 + C_{11}\times 2) \div 30$ =39.53W

So Demand factor=39.53/56
=70.59%

Diversity factor has been considered as1 in this design as very few loads are connected. We have assumed piecewise linear load model for our design and simulation. To calculate demand factor we considered middle class and lower middle class families in Swandip. In this paper it has been considered to supply electricity to 950 houses. As the peak household demand is 38.67W, the plant capacity is 39.53×950=37.55 kW≅ 37kW

IV. Overall System

The overall system is depicted in Fig. 2. In this paper, we proposed 7 wind turbines which will drive 7 permanent magnet synchronous generators. The output of generator is rectified to 120V dc and supplied to the DC bus. Similarly, diesel generator output is fed into the DC bus after being rectified to 120V dc. The outputs of PV panel and battery banks are also 120V dc. The reason for choosing 120V as bus voltage is to avoid huge amount of current resulting damage to the bus. Our estimated peak load is 37kW. So for 120V bus voltage bus current will be 37kW/120V ≅ 300A which is tolerable to the bus.This 300A current is divided into six parallel cables and each cable contains 50A current at 120V. Now this 50A current is fed to a feeder. There are about 150 household under each feeder. We have used 6 feeders each supplying 6kW power. A buck converter which has a variable duty cycle such as 10% is connected before each load. So output of converter becomes 12V. This conversion is necessary because our proposed load works at 12V. This type of connection is not too costly because converters are relatively cheap and small in size.

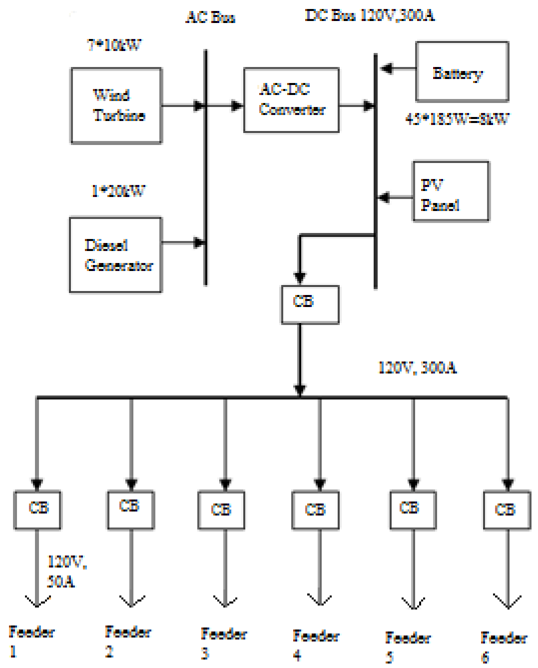

Fig. 2 Block diagram of system components

V. Simulation With HOMER

HOMER is used to simulate the system and selects the optimized combination of components [8-9]. According to the model of the system in Fig. 2, the system configuration in HOMER is shown in Fig. 3.

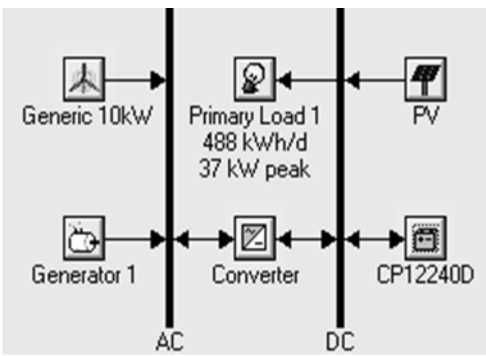

Fig. 3 System configuration in HOMER

To achieve the appropriate solution, different types of cost for various components are given in Table V according to the recent data for Bangladesh as input parameters [4].

TABLE V
INPUT PARAMETERS FOR HOMER SIMULATION

Parameter	Capital cost($/kW)	Replacement cost($/kW)	O&M ($/yr.)
PV module	4060	3692	8
Wind turbine	1725	1540	8
Diesel generator	328	300	0.01/hr.
Converter	420	350	1
Battery	30	28	1

Assuming the lifetime of the project to be 25 years, three optimum solutions are obtained as presented in Table VI.

TABLE VI
SIMULATION RESULTS

Combination	PV (units)	Wind Turbine (units)	Diesel generator (kW)	Battery (units)	Conv. (kW)
1	8	7	20	350	28
2	4	7	0	30	28
3	4	0	30	50	28

Battery is rated in nominal voltage 12V, nominal capacity 100 Ah (0.288 kWh).

The turbines have three-bladed rotors, between 20m – 25m in diameter, on top of a tower, typically between 20m – 30m high and rated power 10kW.

The PV panel compromises 45 cells with 185 W per cell.

Using the above mentioned data, HOMER simulation has been done to get the optimized results. From the simulations we get three results. These results are presented in Table VII.

TABLE VII
COST ANALYSIS OF SIMULATED RESULTS

Combination	Initial Capital	Op Cost $/yr.	Total NPC	COE $/kWh
1	79580	36949	551918	0.251
2	53820	46473	647897	0.290
3	41320	54490	743635	0.331

From the three optimized results, second one has no diesel generator backup which results in less reliability as cant supply sufficient electricity during bad weather. Third one has no generation from wind turbine which results in more dependency on non-renewable source diesel. So we have omitted these two combinations. First result has contributions from all of the energy sources. Moreover it costs least for per kWh energy. So we have selected the first one as the most optimum result.

For this solution we get almost half (44%) of the generation from renewable sources as shown in Table VIII.

TABLE VIII
ANALYSIS OF THE OPTIMIZED RESULT

Production	kWh/yr.	%
PV Array	9,573	4
Wind Turbines	94,347	40
Generator 1	133,285	56
Total	237,205	100

VI. Cost Analysis

In Table VIII cash flow for 25 operating years has been shown. We can see that although renewable sources have high capital cost, they have low replacement and operation and maintenance (O&M) cost and no fuel cost [10]. But high fuel and replacement cost make diesel generator as the most expensive component of the system. It comprises 56% of total cost.

TABLE VIII
OPTIMIZED COST ANALYSIS

Component	Capital ($)	Replacing Cost ($)	O&M ($)	Fuel ($)	Total ($)
PV	36920	0	818	0	37738
Wind turbine	14000	0	716	0	14716
Diesel Generator	6400	33697	17902	369972	427510
Battery	10500	45221	4474	0	59837
Converter	11760	0	358	0	12118
system	79580	78918	24268	369972	551919

VII. Conclusion

The proposed system is suitable where grid connection is not available. Moreover it includes DC load modeling and omits costly inverter reducing transmission loss. This is an isolated energy efficient system very preferable for a developing country like Bangladesh. In this proposed system cost of energy is .251$/kWh or 17.57tk/kWh. Diesel based power plant generally costs more than 20tk/kWh in Bangladesh. So the proposed system is more cost efficient. A further improvement of the total scheme can be done by replacing diesel with biogas. This plant scheme can be used in Charfassion, Hatiya etc. to give off grid electrification.

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