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Design of a Cost Effective Off-Grid Wind-Diesel Hybrid Power System in an Island of Bangladesh

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Abstract**—**Bangladesh is a developing country with large population. Demand of electrical energy is increasing day by day because of increasing population and industrialization. But due to limited resources, people here are suffering from power crisis problem which is considered as a major obstacle to the economic development. In most of the cases, it is extremely difficult to extend high tension transmission lines to some of the places that are separated from the mainland. Renewable energy is considered to be the right choice for providing clean energy to these remote settlements. This paper proposes a cost effective design of off-grid wind-diesel hybrid power system using combined heat and power (CHP) technology in a grid isolated island, Sandwip, Bangladesh. Design and simulation of the wind-diesel hybrid power system is performed considering different factors for the island Sandwip. Detailed economic analysis and comparison with solar PV system clearly reveals that wind-diesel hybrid power system can be a cost effective solution for the isolated island like Sandwip.

Keywords**—**renewable energy, off-grid, wind-diesel hybrid system, CHP technology, economic analysis

I. Introduction

Energy crisis is considered as one of the major problems all over the world in recent times. In this critical stage, renewable energy is considered as the most important alternative energy source. For the last few years Bangladesh is facing acute power crisis problem. Bangladesh is situated between 20°34' and 26°38' north latitudes and 88°01' and 92°41' east longitudes with nearly 162 million people living on 144,000 km2 land area. The coastal area in the southern part of Bangladesh has a huge potential of wind power generation. On the other hand islands like Sandwip, Kutubdia, Maheshkhali, St. Martin are not suitable for grid-connected system. This paper presents a cost effective design of off-grid wind-diesel hybrid power system in the island Sandwip of Bangladesh. CHP technology has been incorporated in design for optimal operation of the system.

Wind-diesel hybrid power systems considerably reduce the need for storage of fuel, fuel consumption cost, and greenhouse gas emission [1]-[3]. Studies have shown that the integration of wind power into traditionally diesel-only remote area power supply (RAPS) systems can significantly reduce the harmful emissions and life-cycle costs. Design of a wind-diesel hybrid remote area power supply (RAPS) system nullifying many common constraints is depicted in [4]. Utilization of Renewable Energy (RE) sources is growing in grid-connected mode as well as in remote isolated communities. Remote communities need to use RE to reduce their diesel consumption. Hybrid power systems with some long-term energy storage can optimally use RE resource [5]. A suitable mathematical model of wind-diesel hybrid power system is developed in [6] to study its response following a frequency disturbance on an island electric system. An algorithm for optimal sizing of all the components of a stand-alone hybrid wind-diesel electrical power generation system, in the sense of minimum energy cost is reported in [7]. DC link stability analysis of hybrid wind-diesel power system considering load disturbances is presented in [8]. Improved sizing method of storage units and robust control of hybrid wind-diesel power system is reported in [9]-[10].

CHP is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat. With the recent trend towards the decentralization of power supply, CHP systems have become important [11]. A new algorithm for economic dispatch of CHP is reported in [12]. CHP technology is utilized for the design purpose of off-grid wind-diesel hybrid system in Sandwip island of Bangladesh. Detailed economic analysis of the proposed system is also carried out to validate the design.

II. Analysis of Wind Data in Sandwip

Bangladesh has a 724 km long coastal line along the Bay of Bengal. There are also many islands in the Bay where wind speed is high enough to produce electricity commercially. The strong south/south-western monsoon wind come from the Indian Ocean traveling a long distance over the Bay of Bengal, through the coastal area of Bangladesh. This wind blows over Bangladesh from March to September with a monthly average speed of 3 m/s to 9 m/s at different heights. According to the studies of Bangladesh Meteorological Department (BMD), wind speed is high in Bangladesh during the Monsoon (7 months, March–September). In rest of the months (October –February) wind speed remains either calm or too low. The peak wind speed occurs during the month of June and July. Fig.1 shows the average wind speed in March– September at the island Sandwip.

A. Wind Velocity Calculation

Wind velocity changes with height. The rate of increase of velocity with height depends upon the roughness of the

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terrain. The variation of average wind speed can be determined from the following power law expression,

$$\frac{V_z}{V_{ref}} = \left(\frac{h}{h_{ref}}\right)^{\alpha} \quad (1)$$

Where,

V_z = average wind velocity at height h meter (m/s)

V_{ref} = average wind velocity at reference height (m/s)

h = the height where the velocity of wind is to be calculated (m)

h_{ref} = reference height (m)

α = dimensional constant that varies from 0.1 to 0.4 depending on the nature of the terrain

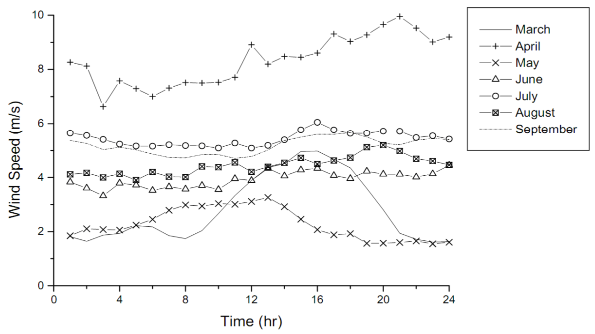

Fig. 1 Average wind speed at Sandwip in March–September

The wind speed data at Sandwip is recorded at 20 m height. The wind velocity at the height of 20 m is not sufficient to generate electricity commercially. Using (1) and assuming α = 0.4, wind speed at 45 m height is calculated at Sandwip. This height is chosen to avoid the extra cost of tower construction. Table I shows the wind speed at 45 m height in different months.

TABLE I
WIND SPEED AT 45 METER HEIGHT

Month	Wind speed (m/s)
Jan	4.83
Feb	3.79
Mar	8.59
Apr	11.5
May	3.14
Jun	5.42
Jul	7.5
Aug	6.12
Sep	7.14
Oct	5.71
Nov	5.2
Dec	4.87

It is observed from Table I that the average wind speed is 6.15 m/s at Sandwip which is sufficient to generate electricity commercially.

B. Power Generation by Wind Turbine

Power generated by a wind turbine at particular height can be calculated by following equation,

$$P = \frac{1}{2}\rho a V^3 C_p \quad (2)$$

Where,

ρ = wind power density (w/m^2)

a = area swept by the rotor (m^2)

V = velocity of wind (m/s)

C_p = rotor efficiency

III. DESIGN OF WIND-DIESEL HYBRID POWER SYSTEM

To design the hybrid power system in Sandwip, diesel generator has been combined with wind power generation. Diesel generator has been chosen for its operating feasibility, low cost, quick start and small size. It has good thermal and electrical efficiency. Moreover it has low fuel consumption and good load support. But only diesel generator is not cost effective to meet the current electrical demand in Sandwip. In that case a wind-diesel hybrid system can be a cost effective solution. Fig.2 shows the block diagram of the hybrid system.

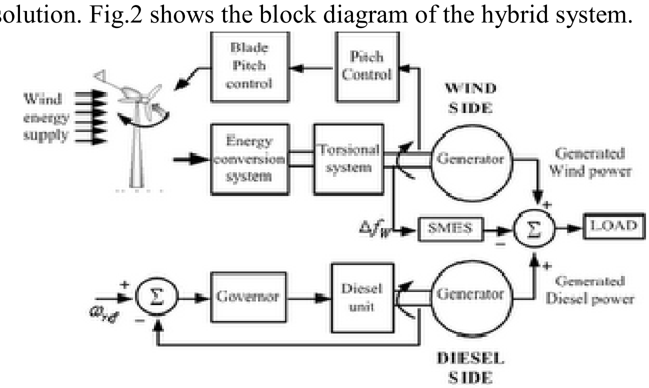

Fig. 2 Block diagram of wind-diesel hybrid power system

A. Analysis of Electrical Demand in Sandwip

Through necessary survey, an electrical system for a single home, shown in Table II, has been considered for analyzing the electrical demand in Sandwip.

TABLE II
A TYPICAL ELECTRICAL LOADING FOR A SINGLE HOME

Appliance	Number (s)	Unit capacity (W)
Florescence Light	2	20
Fan	1	80
TV	1	100
	Total	220 W

There are 45389 units of households in the entire island. Total electrical demand is calculated by considering the same average electrical load for all the houses in the island. For random variability of the load profile, day to day factor of 17% and time-step to time-step of 19% is considered in the design. Including all the factors and assumptions, energy demand per day is 168 MWhr and the peak demand is 24 MW in Sandwip.

B. Thermal Load in Sandwip

Sandwip has a few industries. So, most of the thermal load is in agricultural sector. In the harvesting season, huge amount of electricity and thermal load is required for boiling and breaking paddy to rice. Processing of agricultural crops also require huge amount of thermal load. Moreover dehumidification equipment and drying process need huge amount of heat. Water pump, rice mill, granary etc can also run by low pressure steam created from the CHP plant.

C. Wind Turbine

Average wind velocity at 45m height is 6.15 m/s in Sandwip. But at winter, wind velocity goes below the average wind velocity. Cut-in speed of high capacity wind turbines is more than 4 m/s. Enercon E33 wind turbine is a suitable choice for low wind speed. The irregularity of wind speed can be fixed by gear system. It has a rated capacity of 335 kW and cut-in speed of 2.5m/s .The installation cost for Enercon E33 (50 m height tower) is $ 500000. Considering the above factors, Enercon E33 turbine has been chosen for the hybrid system.

D. Diesel Generator

In the proposed hybrid system, design diesel generators operate in parallel with the wind turbine to increase the maintenance flexibility, efficiency and distribute the electric load more optimally. Cost of per MW of diesel generator is considered to be around $ 200000.

E. Cost of Other Equipments

The cost of other equipments like battery, converter, micro-turbine etc is presented in Table III.

TABLE III
COST OF ACCESSORIES

Equipment	Cost ($)
Battery	900/ String
Converete	1350/ MW
Micro-turbine	1000000/MW

IV. SIMULATION RESULTS AND ANALYSIS

A. Economic Analysis

Simulation software HOMER is used to design and simulate the wind-diesel hybrid power system. HOMER analyses the system according to the COE (cost of electricity) of the system. Other factors which influence the analysis are capital cost, operating cost, renewable energy factor, total NPC (Net present cost) and diesel consumption rate. There are some sensitive operative factors like diesel price factor, surface roughness length, minimum load ratio etc.

After introducing CHP technology to the system, total efficiency increases. Because of increased efficiency of generator, the fuel cost decrease by 5%-25 % depending on the generator output per month. The simulation results depict that the production cost of electricity per kW may vary from $ 0.12 to 0.23 depending on wind velocity. Monthly electric production and cash flow summary of the proposed system is shown in Fig.3 and 4, respectively.

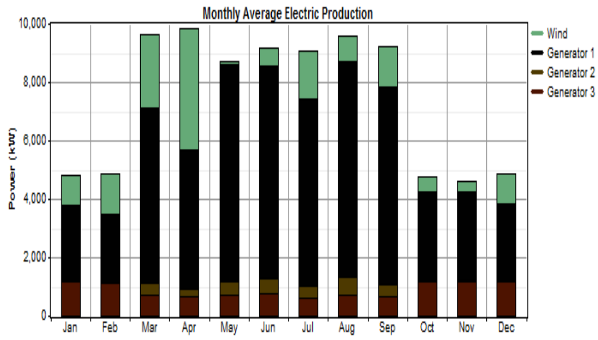

Fig. 3 Monthly average electric production

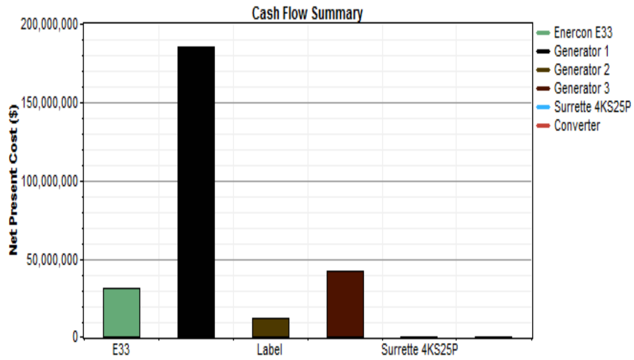

Fig. 4 Cash flow summery of total system

A cost comparison between wind and solar PV system is shown in Table IV.

TABLE IV
COST COMPARISON OF WIND AND SOLAR PV SYSTEM

Energy System	Fuel Cost ($/kwhr)	Initial investment cost ($/kwhr)	Transmission and distribution cost ($/kwhr)	Total cost ($/kwhr)
Wind	0	0.08	0.023	0.103
Solar PV	0	1.05	0.02	1.07

The simulation results clearly reveal that wind-diesel hybrid system using CHP technology is the most cost effective off-grid power system for Sandwip.

B. Environmental Effect

Wind-diesel hybrid system with CHP technology reduces gas emission by a significant amount due to reduced fuel consumption. This reduction in gas emission is determined using HOMER software. The annual amount of reduction of gas emission is presented in Table V.

TABLE V
REDUCTION OF GAS EMISSION

Gas (Pollutant)	Reduction of emission (kg/ year)
Carbon dioxide	33,053,228
Carbon monoxide	81,587
Unburned hydrocarbons	9,037
Particulate matter	6,150
Sulfur dioxide	66,377
Nitrogen oxides	728,009

V. CONCLUSION

In the 21st century human life is directly depending on electricity. The energy crisis is severe in Bangladesh which is a threat to the economical development. Still only 39% of the populations have access to electricity. In the coastal areas and the isolated islands where grid connection is not feasible, alternate electric sources like wind and solar PV can be the potential solutions. But the solar PV system is at least 4 to 5 times more expensive than wind power system. On the other hand only the wind power system cannot satisfy the whole demand of electricity. In this situation, a wind-diesel hybrid systems incorporating CHP technology can be a cost effective solution for the isolated islands. Moreover CHP technology reduces the emission of gases and help to trim down the environmental pollution.

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