Feasibility Study of Photovoltaic/Wind/Battery Hybrid System for Oman

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***Abstract*— This paper addresses the need for electricity to supply 880 km road from Nizwa to Salalah in Oman. Feasibility study of a Photovoltaic/Wind/Battery system has been proposed for the highway energy requirements. The investigations found that 26,400,00 OMR required to installing overhead line system, 46,704,487.5 OMR for the cost of electricity for 25 years with total cost of 73,104,488 OMR excluding the cost of diesel generator and the PV system found costing 24,523,211 OMR only for 25 years. It's about one third of the cost if we used diesel generator to generate the required electricity, where it is a noticeable results. The study presents an evaluation of conventional, diesel and PV/Wind/Battery Hybrid system used for highway energy requirements such as lighting, SOS, billboard, etc. According to the result of the optimization, optimum numbers for solar panels, batteries and the number of stations has been decided. Also, the performance parameters of the proposed system are evaluated in term of sensitivity analysis. Moreover, the analysis shows that using PV system instead of diesel generator will prevent green house gases emission 27,325,762 kg/year of CO2, 67,450 kg/year of CO, 601,860 kg/year of NOx, 7,471 kg/year of HC, 54,875 kg/year of SO2, and 5,085 kg/year of Particulate matter 1,129,371 kg/year of suspended particles.**

Keywords-Hybrid system; photovoltaic; wind; feasibility; cost of energy

I. INTRODUCTION

Depleting oil and gas reserves, combined with the growing concerns about global warming, have made it inevitable to seek renewable energy sources. The integration of renewable energies such as solar energy is becoming increasingly attractive and is being used widely, for substitution of oil-produced energy, and eventually to minimize atmospheric degradation [1]-[2]. Many researches, field work and papers have been published and performed to encourage the use of renewable energy depending on the excellent result they have found. Some PV system design and evaluation work done for different applications can be found in [3-8]. In [3], the authors present the requirement of PV solar system to provide power to a health clinic in the rural areas in southern Iraq. They used HOMER software computer model to estimate the best economic system. The proposed system designed with a daily load of 31.6 kWh which is composed of 6-kW PV modules, 80 batteries (225 Ah and 6 V), and a 3-kW inverter. The total initial cost, net present cost, and cost of electricity produced from the system are 50,700 US$, 60,375 US$, and 0.238 US$/kWh, respectively. The results shows that the price of electricity produced from the diesel generator is four times greater than the one produced from the PV system, which considered as the best system to be used in remote areas. The results also shows that using PV system instead of diesel generator can prevent the release of 14,927 kg/year of CO2, 36.8 kg/year of CO, 329 kg/year of NOx, 4.08 kg/year of HC, 30 kg/year of SO2, and 278 kg/year of suspended particles. In [4], the authors climates that if they use an optimization solution of a hybrid system of renewable energy by using the Homer software for remote areas in Tunisia. The Hybrid systems have combination of different energy sources like wind/battery, PV/battery, wind/PV/battery, wind/PV /diesel/battery. The climatic data are for specific area of Hawaria in Tunisia. The optimal configuration of the hybrid system wind/PV/diesel/battery used for reliable load supply and also considered the meteorological data changes is inferred from two optimal configurations chaises: (wind/PV/battery) and (diesel/battery). For the wind/PV/ battery the optimal configuration is composed by 8 kW panel PV, 118 batteries, 2 wind turbine and 12 kW power converters. The initial cost and the operation cost 165.450 US$, 2.102 US$/yr respectively. The total net present cost 189.559 US$ and the cost energy produced 0.540 US$/kWh. For the diesel / battery the optimal configuration is composed by 5 kW diesel generator, 18 batteries and 2 kW power converters. The initial cost and the operation cost 11.934 US$, 10.707 US$/yr, respectively. The total net present cost 134.747 US$, the cost energy produced 0.382 US$/KWh and the diesel 11.269 L. For the wind/PV/diesel generator/battery with the load of 85 kWh/d the optimal configuration is composed by 8 kW panel PV, 2 wind turbine, 118 batteries, 5 kW diesel generators and 12 kW power converters. The authors find that the combination of a diesel generator, as buck-up source, with the hybrid wind/PV/battery system can be considers as the best solution for reliable supply without interruption of the load under the climatic data change. Reference [5], discussed the efficient system of sustainable renewable energy for domestic used and its total cost in Khartoum in Sudan. The method used by the author was to collect of the basic data of solar radiation, wind speed and

other required input data, and then the authors used HOMER software to develop the hybrid optimization simulation. The proposed load is 54 kWh/d, and 5.3 kW as a peak. The cost of the PV module including installation has been considerate as 220 SP/W for Sudan. The cost of turbine with tower and installation has been considered as 96000 SP/turbine. For load higher than 1 kW, turbine from southwest wind power (model: W175, capacity, 3 kW) has been considered at the cost of 200000 SP/turbine with tower and installation. The operation and maintenance cost has been taken as 500 SP/year. In addition 800 kW converter and 3500 batteries were considered and the total net present cost 19.1 US$. He it is found that better to use wind/PV combination system for 50 homes instead of single home system. Furthermore, if the turbine cost decreases in Khartoum the overall cost of energy would be low. Results of the simulation display that utilizing renewable generators, such as wind generator and PV reduces the operating costs using a third class of housing at Khartoum state. In [6], the author used HOMER software for optimization to find the best cost benefit of hybrid -solar power generation relative to use cost in Nigeria. The benefit of the analysis of cost for a wind/solar hybrid system was done using HOMER software and comparison was also made with utility supply. Central grid power has the least expensive option but may not be available to most rural households far from the grid. Hence it is necessary to supply these areas from isolated power sources. The proposed system used (0.05 – 0.4 kW) PV panel with (0.4 kW DC) FD series wind turbine, (0.1 – 1.5 kW) converter, and (200 Ah / 12 V, bank size: 1-8 batteries, vision 6 FM200D) battery. He result obtained from the optimization gave the initial capital cost as 3,455 US$ while operating cost is 69 US$/year. Total net present cost (NPC) is 4251 US$ and the cost of energy (CoE) is 1.74 US$/kWh. Also he found that the hybrid system have a pay-back period of about 33 years and at current costs. In reference [7], design of a hybrid power generation system suitable for remote area application by using HOMER software have been proposed, having a primary load of 3 kWh/d and a 307 peak, it is being supplied by a Micro-hydro model, wind turbine models, PV array models, a diesel generator and batteries. The Micro-hydro model is designed to produce a 100 kW of capacity, with capital cost of 300,000 US$ and a price of replacement 300,000 US$, the operating and maintenance (O&M) cost is 2% of capital costs of 6,000 US$. There are 18 WES wind turbine, having a capital cost of 11,000 US$, a replacement cost of 10,000 US$, and O&M of 110 US$ per year. There are 200 PV model in the system, with a capacity of 200 kW (1 kW for each array). The capital cost and the replacement cost are 5,600 US$ and 5,000 US$, respectively. The O&M cost is 10 US$/year. There is one battery of 6 V, and a capacity of 6.94 kWh. The capital cost of the battery is 700 US$, the replacement cost is 600 US$, the O&M cost is 0.1 US$/year. There is only one diesel generator with a capacity of 70 kW, a capital cost of 18,000 US$, a replacement cost of 18,000 US$, an O&M cost of 0.15 US$/year. Also, a converter (inverter/rectifier) that has a capacity of 1 kW, a capital cost of 140 US$, a replacement cost of 126 US$, an O&M cost of 0.15 US$/year. The author illustrates the importance of equalizing between environment and energy, economy, through determining the optimum hybrid configuration. Also, the cost of energy for this purposed scheme is comparably higher than the conventional energy sources, but with less environmental side effects and more efficiency. As its clear from these papers, the use of hybrid power generation system by using combination of PV, wind turbine and diesel generators, which have less cost and environmental friendly with less pollution emission than using only diesel generators. Reference [8] presented a method for optimal sizing of a standalone PV system for remote areas in Sohar, Oman. Also, PV array tilt angle as well as the size of the system's energy sources are designed optimally for better performance and lower energy cost. In this study a numerical methods for optimization of the PV module tilt angle, PV array size and storage battery capacity has been implemented using MATLAB rather than HOMER based on hourly meteorological data and load demand. The authors claimed that for Sohar zone the tilt angle of a PV array must be adjusted twice a year where the PV array must be slanted at 49 degrees in the period of 21/09-21/03 (n=255-81), while it must be horizontal (tilt angle is zero) in the period of 21/03-21/09 (n=81-255). This adjustment practice gain the energy collected by a PV array by 24.6%. As for the PV system size, the results show that the sizing ration of the PV array for Oman is 1.33 while the sizing ratio for battery is 1.6. However, the cost of energy generated by the proposed system is 0.196 $/kWh.

The report issued by the Ministry of Oil and Gas that the current production level is the highest since about nine years. And according to current production rates, the reserve is drained in just 16.5 years instead of 22 years (and according to higher production rates achieved by the Sultanate in the recent period, the oil reserves run out even before 16.5 years old). According, Oman contain a relatively small stockpile of oil compared to the rest of the Gulf, and this clearly means that it would have on the Omani government to plan for innovation and development of other sources of income as well as the development of exploration and the search for oil by renewable means [9]. Regarding this situation, it will be useful for the Omani government to save both money and energy and apply hybrid photovoltaic/wind/battery system to supply electricity and lightning for 880 km for a cost of about 20,405,000 OMR (53,697,368 $) only instead of 73,104,488 OMR (192,380,231 $) excluding the cost of diesel generator (1$ ≈ 0.38 OMR).

II. INSTALLING CONVENTIONAL STREET LIGHTING

In this section the cost of installing conventional street lighting only for the targeted area (880 km) from Nizwa to Salalah have been done using the following information provided by Majan Electricity Company [10]:

- 29 poles needed per 1 km,
- Required cost of civil work for a foundation of (60 cm × 60 cm × 120 cm), which cost 200 OMR,
- The dimension of the cable for light is (4 c × 16 mm^2 and for MFP 4 c × 70 mm^2),

- The used light is galvanize light of 250 W,
- The distance between the poles is 35 - 40 meter,
- The height of the pole is 6 - 8 meter,
- Cost in total for 1 km is 22,000 - 30,000 OMR.

For each 1 km 29 pole needed, since there is 880 km → (880 × 29) = 25,250 pole needed. To find the capital cost of the system then 30,000 OMR/km × 880 km is equal to 26,400,000 OMR. To find the cost of the electricity to supply these lights for 12hr/day (in average) and 1 kWh cost 0.01 OMR then 12hr/day × 365 day/year × 25 year × 0.01 OMR/kWh × 0.25 kW × 25,250 pole = 6,912,188 OMR. The cost of electricity for 25 years = 34,122 KWh/d x 365 d/yr x 25 yr x 0.15 OMR/KWh = 46,704,487.5 OMR. Finally, the total cost of using electricity provided from diesel generator for 25 years with the installation = 46,704,487.5 + 26,400,000 = 73,104,488 OMR. It is important to mention that the cost of buying and installing of electricity generation station was not taken in consideration. Also, the substations, transformers, etc costs are not taken in this calculations. We calculated the best condition with lowest cost ignoring the losses of each light, maintenances of all equipments like transformers, wires and lights and other important maintenance occur due to accidents. As its obvious here in Oman the percentage of accident is high and cause losses for many areas.

III. Install Hybrid PV/Wind/Battery for Street Lighting

The system will be supplying lightning for street of 880 km from Nizwa to Salalah with billboards, traffic lights, lightning for resting and telephones. The LED lights will light up the road for 12 hours from 6 PM to 6 AM with 112 W for each light with separation distance of 35 km along 880 km. Numbers of needed lights is 25,520 light with total rated power of 2,858,240 W. Traffic lights will be apply for each 50 km with a load of 7 W each and needed number is 18 pieces, total load will be 126 W and it will work for 24 hours. Telephones will be available each 10 km with 3 W each, 88 telephones needed with total load of 264 W for 24 hours. Billboard will be applied for each 25 km with 2 LED light of 36 W each and they will work for 12 hours from 6 PM to 6 AM, total required number is 36 pieces. Two lights will be used for each billboard with total load will be 2592 W. Suggested resting chairs for each 25 km with 2 LED light for each with 36 W each, total load is 2592 W and they will work for 12 hours from 6 PM to 6 AM. The total load for all mentioned components above at night for 12 hours from 6 PM to 6 AM will be about 2,863,814 W and 390 W at day time for 24 hours as base load to supply traffic lights and telephones as shown in Table I [11]-[15].

A. System Components

The proposed system consists of PV modules, Wind turbines, charge controller, batteries, inverter and the rest of the balance-of-systems, which includes wiring, fuses, modules structure and other system safety devices. The system configuration is shown below.

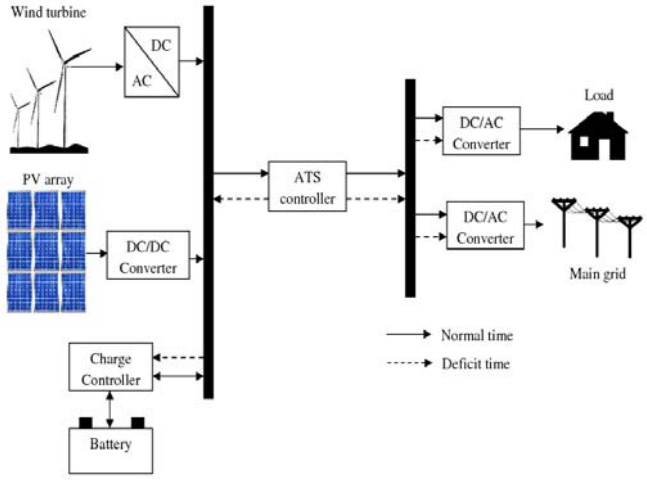

Figure 1. PV/Wind/Battery Hybrid System Configuration.

B. PV Array

The PV array is a combination of PV modules that produces direct-current (DC) electricity directly proportional to the incident solar radiation upon it, ignoring its temperature and voltage to which it is exposed. The suggested PV panels to be used in the system simulation are 200 W (at 1000 W/m^2 and 25 ^{o}C) and 12 V and have estimated capital cost of US$ 2.00/W and replacement cost of US$ 1.07/W. This cost includes shipping, tariffs, and mounting hardware, installation, and control system, wiring and dealer markups. The lifetime is assumed to be 25 years. A derating factor of 93% was applied to the electric production from each panel. In this analysis we considered the panels modeled at an angle of equal to 27°. The solar radiation data is as shown below.

C. Inverter

An inverter converts electric power from DC to AC. It has been assumed that 94% efficiency for all sizes of invertors to be considered. The estimated price of an inverter is US$ 0.40/W, and its lifetime is up to 25 years with 94.5% efficiency.

TABLE II. LOAD PROFILE

Load	Type	Power (W)	Qt	Duration (h)	Separation distance	Total power (W)
1	light	112	25,520	12	35m	2,858,240
2	billboard	36	72	12	25 km	2592
3	traffic light	7	18	24	50 km	126
4	lightning for rest	36	72	12	25 km	259
5	Telephones	3	88	24	10 km	264
						2,863,814

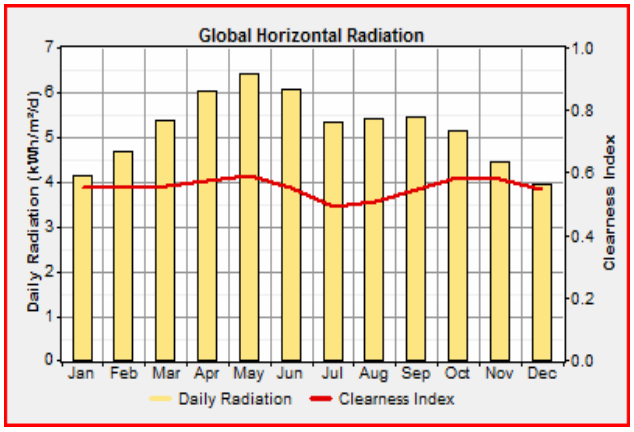

Figure 2. Solar radiation of Oman.

D. *Battery*

To store a certain amount of DC electricity at fixed round-trip energy batteries are used. It efficiency depend on the limits of how quickly it can be charged or discharged without causing damage, and how much energy can cycle through it before it desires to be replaced. HOMER assumes that the batteries remain constant throughout its lifetime and are not affected by exterior factors such as temperature. The chosen battery has a 2-V, 1,500-Ah capacity. Its lifetime is considered to be 5136 kWh of throughput per battery.

E. *Wind System*

Wind power system is used to produce electricity by using small generator at each turbine. Where the wind energy makes the blades to turn and this mechanical motion operates a turbine to work and produce electricity. The estimated price of the generator is US$ 1.50/W. We considered size of 250 kW in the analysis. The wind speed (m/s) data of Thumrait for 10 m height is given Figure 3.

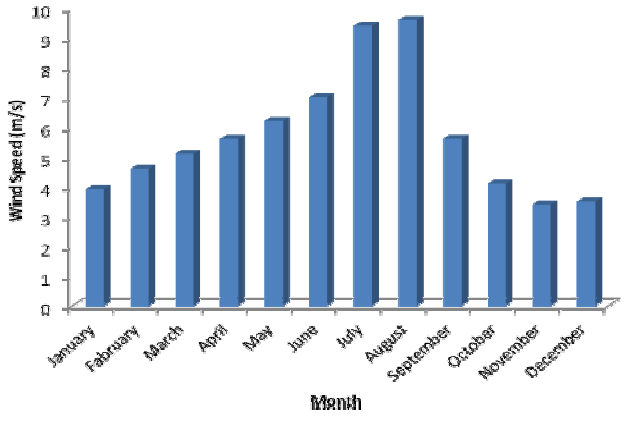

Figure 3. Monthly average of wind speed in Thumrait [13].

F. *System Analysis*

The process of our simulation serves two purposes. First, it decides whether the system is feasible or not by using HOMER software, where it describes the system's feasibility if it can sufficiently serve the electric load and satisfy any other constraints imposed by the user. Second, it determines the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. Life-cycle cost analysis includes all costs that occur within the life duration of the system. HOMER uses the total net present cost (NPC) to represent the life-cycle cost of a system. The total NPC condenses all the costs and revenues that occur within the project lifetime in today's dollars, with future cash flows discounted back to the present using the discount rate. In the optimizing process, HOMER simulates every system configuration. Table II presents the HOMER simulation results for PV/Wind/Battery Hybrid System. Optimal result is achieved when the system is composed of 4500 kW PV modules, 20,000 batteries, 5000 kW inverter and 100 wind turbine. The initial capital, operating and total NPC cost are 53,000,000 $, 836,764$ and 63,696,652 $ respectively. The most noticeable result is cost of energy (CoE) where it was found to be 0.400 ($/KWh) as shown in table below.

TABLE II. CATOGRIZED OPTIMIZATION RESULTS

PV (kW)	FL250	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
4500	100	20000	5000	$ 53,000,000	836,764	$ 63,696,652	0.400	1.00	0.00

As it's clear that the total net cost is 63,696,652 $ for PV/Wind/Battery Hybrid system and from our calculation is 207,835,520.8 $ which it is about one third less if we use Hybrid system. Noticing that our PV/Wind/Battery Hybrid system emit zero pollution where diesel generator emit lots of greenhouse gases as mention in next point.

IV. INSTAIING CONVENTIONAL STREET LIGHTING WITH DIESEL ENGIN

Fuel is used to produce electricity by using generator. A huge range of generators are available (diesel, propane, gasoline and bio-fuel). In this analysis, we used diesel fuel to produce electricity from the generator, because it is more efficient, its lifetime is longer than the others and because it is the used fuel in Oman as it considered as one of the suppliers of fuel. The price of the generator is 200,000 $ and we considered generator size of 2000 kW in the analysis.

To compare the hybrid system results with the diesel generator to choose the best and costless system, the analysis shows that a size of 7000 kW generator have been estimated with capital, operating and total net cost are 700 $, 39345652 ($/yr) and 503669504 $ respectively as shown in Table III. The CoE is found to be 3.164 ($/kWh), which is considered to be high as a compared with CoE of proposed Hybrid system (0.400 ($/kWh)).

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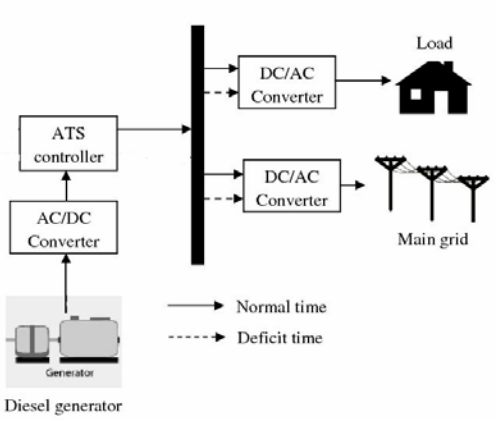

Figure 5. Diesel generator system

TABLE III. DIESEL SYSTEM RESULTS

Label (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
7000	$ 700,000	39,345,652	$ 503,669,504	3.164	0.00	10,376,888	8,759

V. ENVIRONMENT BENEFITS

Using conventional fuel (petrol, diesel, etc) to generate electricity will produce pollution which affects the environment by emitting large amounts of greenhouse gases. According to the analysis of using a hybrid system instead of a diesel generator the amount of pollution shown in Table IV. By using renewable-energy technologies, the emission of all these harmful gases can be radically reduced to zero.

TABLE IV. POLLUTANT EMISSION OF DIFFERENT GASES

Pollutant	**Emission (Kg/yr)**
Carbon dioxide	27,325,762
Carbon monoxide	67,450
Unburned hydrocarbons	7,471
Particulate matter	5,085
Sulfur dioxide	54,875
Nitrogen oxides	601,860

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