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Sizing of a Hybrid Energy System for Al Mazyouna Area

Abdulmajeed Al Wahaibi[1], Abdullah Al Badi[2]

[1] Department of Petroleum and Natural Gas Engineering
Sultan Qaboos University
Department of Electrical & Computer Engineering, Collage of Engineering, Sultan Qaboos University P.O. 33, Al-Khod, Muscat-123, Sultanate of Oman.
Phone: +00968 92104194, e-mail: Majeed.al.Wahaibi20@alumni.colostate.edu

[2] Department of Electrical & Computer Engineering
Sultan Qaboos University
Department of Electrical & Computer Engineering, Collage of Engineering, Sultan Qaboos University P.O. 33, Al-Khod, Muscat-123, Sultanate of Oman.
Tel: +968 24141324, Fax: +968 24413454, e-mail: albadi@squ.edu.om

Abstract.

Natural gas and diesel currently are the main fuel for electrical power generation in Oman. Decreasing the dependence on national gas and diesel is one of the main goals for Oman's vision of 2040. This paper discusses the optimum design of a hybrid stand-alone power generation system for the power station of Al-Mazyouna located west of Dhofar governorate using HOMER Pro Software. Real load data and solar radiation of Al-Mazyouna were utilized in the modelling approach. Different scenarios of power systems were investigated, using mainly, diesel generators, PV solar panels, and storage batteries to reach an optimal solution. The main factors that were considered to decide the wining setup of a power system are the net present cost, cost of energy and the amount of emissions. The optimum scenario resulted in a net present cost of $84.8 M and a cost of energy of $0.161/kWh compared to a net present cost of $99.4M and a cost of energy of $0.188/kWh for the current system. Additionally, the optimum scenario system limits toxic emissions significantly compared to the base system. The results of the winning scenario showed that the emitted quantities of harmful gases are all reduced by about 28% compared to the base system.

Keywords. Hybrid energy system; PV; Cost of Energy; Net present cost

1. Introduction

Given the vast unused land and available solar energy resources, Oman has excellent potential for solar energy deployment. The strategic geographical location of Oman makes it viable to harness renewable energy technologies on both, smaller and larger scales to cater to the growing need for energy diversification, helps create a cleaner and sustainable environment, and supports economic diversification. The global average daily sunshine duration and solar radiation values for 25 locations in Oman are tremendous, with Marmul having the highest solar radiation followed by Fahud, Sohar and Qairoon Hairiti. The highest insolation of solar energy is observed is in the desert areas as compared to the coastal areas where it is least [1]. Many papers about Oman's wind and solar energy resource utilization were published [2-9]. Currently, there are several large-scale projects utilizing solar and wind energy planned to be constructed in order to help Oman reach its goal of 20% renewable energy on the grid by 2030 [10].

In recent years, due to the fast population growth and rapid increase of industrialization, the world energy consumptions have raising drastically [11]. To meet this high demand for energy, traditional energy resources are no longer up to demand with notice to their challenges, e.g, high cost and greenhouse gas emissions. In the electricity sector, renewable energy has proven to be a reliable and sufficient alternative to traditional resources to meet this rapid increase in energy demand. Hybrid Renewable Energy Systems (HRESs) are defined as an integration of traditional fossil-based resources with renewable energy resources. The optimum size of HRES's components and equipment should be determined in order to assess minimum operation costs and investment and to meet the technical and emission constraints. One of the most critical points in HRES is the optimal planning of the equipment and components that make up the hybrid system, eg., the number of Photo-Voltaic (PV) arrays, number of wind turbines, and capacity of converters and generators so that all of the constraints are satisfied and the objective functions are minimized/ maximized. Many optimization techniques and softwares are proposed and tested in literature [12].

Hybrid Optimization Model for Electric Renewables (HOMER) software is one of the most powerful tools for this purpose. HOMER has been deployed worldwide by many researchers to assess different hybrid systems [13]. To choose the site for a hybrid power source, many elements are viewed as to which are reliant upon a mix of load demand, cost of energy storage, occasional accessibility of fuel sources, site geography and delivery, and occasional energy requirements [14]. Rohit Sen et al. [15] demonstrated that a hybrid combination of renewable energy generators in an off-grid location can be a cost-effective alternative to grid expansion, as well as being sustainable, techno-economically viable, and environmentally friendly. Leong Kit Gan et al. [16] provided some insight into the factors to consider when determining the storage system capacity for hybrid PV–Wind–diesel systems, both for short and long-term operation. Lanre Olatomiwa et al. [17] investigated the economic feasibility of hybrid power generation systems in six sites chosen from each of Nigeria's six geopolitical zones. The author analyzed seven different systems implemented in HOMER's software to acquire the most cost-effective viable solution. The load demand, site topography, seasonal availability of energy sources, and cost of energy storage are all considerations that go into account as to which hybrid power sources to use at a specific location.

The objective of this paper is to study the feasibility of upgrading the power generation at Al-Mazyouna to a hybrid system using an optimum mix of diesel, and renewables to ensure cost, and environmental effect reduction. HOMER Pro was used to conduct an economic analysis of the Hybrid Power System for Al Mazyouna. HOMER seeks to decrease the total net present cost (NPC) both in determining the best system configuration and in operating the system, and economics plays a key role in the simulation. The best-suited configuration is chosen based on the simulation findings.

2. Existing System

A. Diesel Generators

Four diesel generators are used to meet the load demand in Al Mazyouna, with a total installed capacity of 10,000 kW [18].

B. Load Profile

The real load data for Al Mazyouna, which was obtained from Tanweer Company [18], is presented in Figure 1. The maximum average load reached 7 MW in June and drop to an average value of 2 MW in January. The maximum peak load reached 9.4 MW in September. The total amount of Diesel consumed in 2019 was 11,061,000 Liter [18].

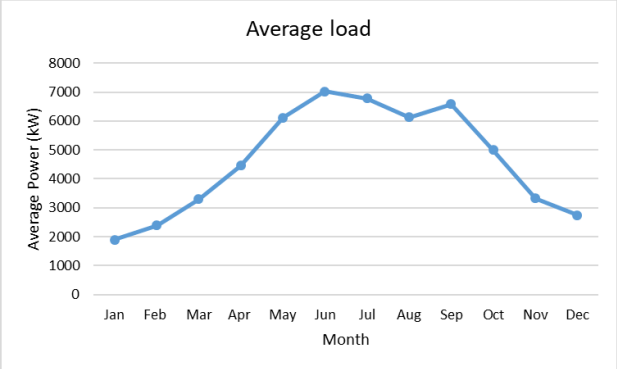

Figure 1: Average Load Per Month for 2019

C. Solar Irradiance

The monthly average measured daily solar radiation for a site near Al Mazyouna is presented in Figure 2. The yearly average daily value of solar radiation is 6.8 kWh/m^2.

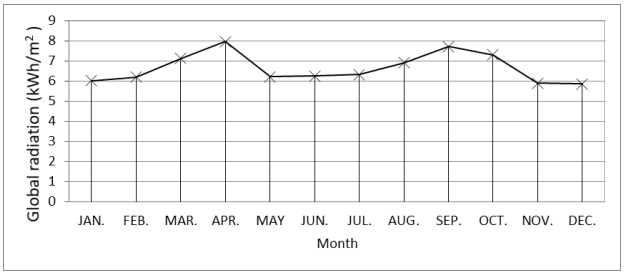

Figure 2: Measured Monthly Average Daily Global Radiation At a Site Near Al Mazyouna

3. Modeling Of The Proposed System Using HOMER

The proposed hybrid system considered for Al Mazyouna is shown in Figure 3. The proposed system consists of existing four diesel generators, PV panels, a converter, and battery storage. In normal operation, PV panels and the diesel generators feed the load demand and the excess energy is stored in the battery until full capacity of the battery is reached. The energy from the battery will be taken to eliminate the need to bring another diesel generator on-line to meet a short term increase in the load that exceeds the diesel capacity already on-line. As a result, the integration of PV with a diesel system, supplemented with short-term battery storage, can meet the required load distribution on a 24-hour basis.

The diesel generators are sized to meet the peak demand of the load and are operated at times when the PV power and the battery energy fails to satisfy the load demand.

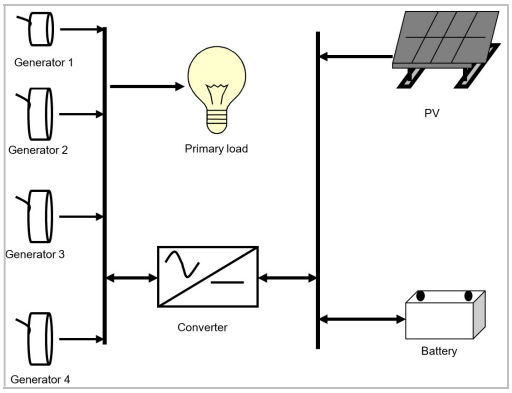

Figure 3: The Proposed Hybrid System for Al Mazyouna

4. Input Data

A. Load

Figure 4 shows the 2019 load data for Al Mazyouna in Homer software. Daily and monthly profiles are presented. The higher monthly load happening during the period from May to October. The percentage of annual capacity shortage of the system is zero.

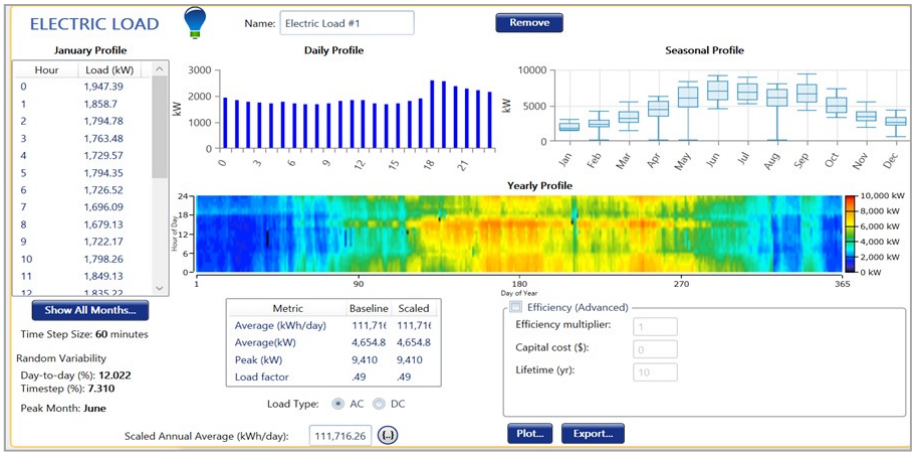

Figure 4: Al Mazyouna Electrical Load in Homer Pro Software

B. Photovoltic

The current local cost for PV, in Oman, is around 900 US$/kW, the operation and maintenance (O&M) cost is around $10/year/kW. The derating factor to compensate for efficiency reduction due to temperature, dust and wiring loses was taken as 0.9. Maximum power point tracking was taken as a standard installation.

C. Batteries and Converter

The battery capacity was chosen from batteries specified in HOMER. The cost for the inverter is around $500/kW and O&M of $ 0/kW, with a lifetime of 15 years and efficiency of 98 %. The technical information for the battery [13] is presented in Table 1.

Table 1: Technical Data and Study Assumptions of PV, Diesel Unit, Inverter and Batteries

Description	Data
PV	
Capital cost	900 US $/kW
Life time	25 years
Operation and maintenance cost	10 US $/year
Batteries	
Type of batteries	Generic 1MWh Li-Ion
Nominal voltage (V)	600 V
Nominal capacity (kWh)	1.67E+03
Nominal capacity (Ah)	1E+03
Operation and maintenance cost	10 $/year
Cost	203,000 $
Lifetime	15 years
Inverter	
Capital	500 US $/kW
Life time	15 years
Operation and maintenance cost	0 US $/year
Diesel unit	
Each unit	250 US $/kW
Diesel	0.71 US $/Liter
Interest rate	
Discount rate	8%
Inflation rate	2%

5. Studied Senarios

A. The Base Power System Consisting of Diesel Generators Only

The base system that is currently utilized in Al Mazyouna power station facility consists of four diesel generators to meet a peak demand of 9410 (kW). The electric needs of Al Mazyouna are met with 11,180 kW of generator capacity. The operating and maintenance costs for the current system is $7.69M per year. Figure 5 presents the distribution of power generation among the four diesel generators throughout the year.

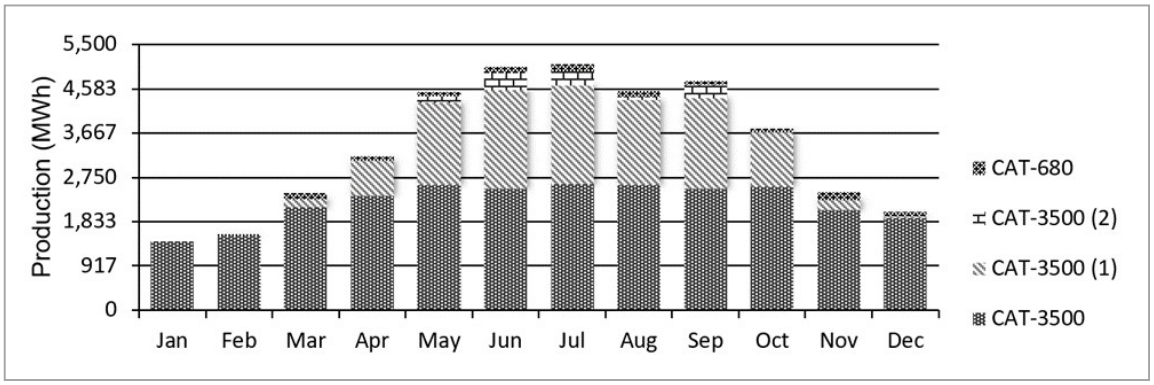

Figure 5: The Base Case Scenario

The fuel consumption of the whole system reached a usage of 10,825,419 Liter of diesel. The emissions of the system which comes from the four different diesel generators is shown in Table 2.

Table 2: Emissions of The Base System

Quantity	Value	Units
Carbon Dioxide	28,601,650	kg/yr
Carbon Monoxide	15,661	kg/yr
Unburned Hydrocarbons	5,068	kg/yr
Particulate Matter	1,176	kg/yr
Sulfur Dioxide	70,974	kg/yr
Nitrogen Oxides	155,714	kg/yr

B. The Second Scenario, Diesel Generators, PVs and Storage Battery

To reduce the system net present cost, save the fuel for other purposes, and reduce the emission of gases, a renewable energy source (PV) with battery storage were added to the system. The simulation results that present the different possible combination of the hybrid system is illustrated in Table 3.

There are more than 341,324 solutions were simulated by the software. The results are ranked based on the least cost of energy and the least net present cost. The best proposed system consists of 5360 kW PV, batteries with nominal capacity of 21,082 kWh, and three diesel generators with each having a capacity of 2800 kW. Furthermore, there will be significant reduction in diesel consumption compared to the base system. The emitted quantities of Carbon Dioxide, Carbon Monoxide, Unburned Hydrocarbons, Sulfur Dioxide, and Nitrogen Oxides are all reduced by about 28% compared to the base system. The monthly electrical energy production form the hybrid system is shown in Figure 6, the percentage of renewable energy penetration (PV) reached around 23% as illustrated in Table 4.

Table 4: Percentage of Production of different Components in The Hybrid System

Production	kWh/yr	%
Generic flat plate PV	8,843,868	20.7
Schneider ConextCoreXC 680kW with Generic PV	1,354,655	3.16
Schneider ConextCoreXC 680kW with Generic PV (1)	1,354,655	3.16
CAT-3500kVA-50Hz-PP	17,846,586	41.7
CAT-3500kVA-50Hz-PP (1)	10,597,202	24.7
CAT-3500kVA-50Hz-PP (2)	2,820,062	6.59
Total	42,817,028	100

Table 3: HOMER Pro Optimiztion Results

Architecture									Cost				System	
									NPC ($)	COE ($)	Operating cost ($/yr)	Initial c. ($)	Ren Frac (%)	Total Fuel (L/yr)
									$84.8M	$0.161	$5.79M	$9.94M	23.3	7,934,016
									$85.7M	$0.163	$5.94M	$8.92M	21.2	8,163,348
									$85.7M	$0.163	$5.94M	$8.92M	21.2	8,163,348
									$87.0M	$0.165	$6.09M	$8.31M	19.0	8,380,473
									$86.9M	$0.165	$5.74M	$12.7M	23.3	7,934,254
									$87.8M	$0.167	$5.89M	$11.7M	21.2	8,163,369
									$87.8M	$0.167	$5.89M	$11.7M	21.2	8,163,369

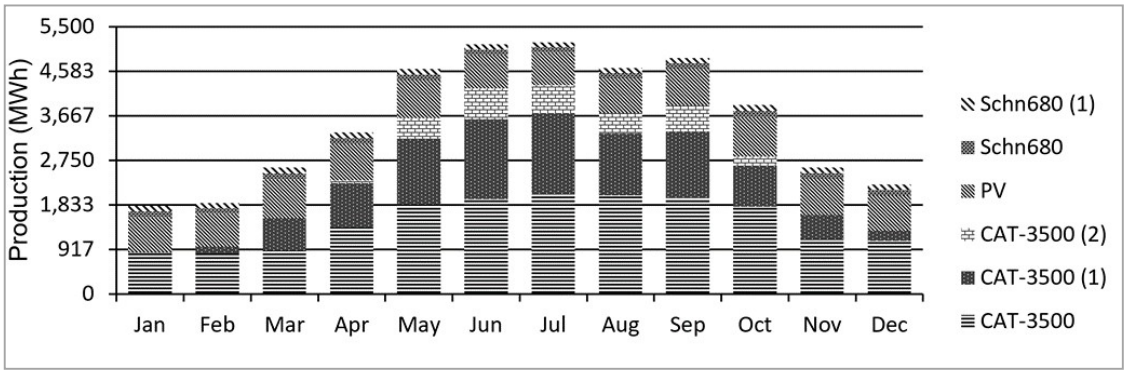

Figure 6: Second Scenario Electric Production

6. Economic Analysis

For the base system the net present cost was estimated to be $99.4M and the operation and maintenance costs were about 7.69M/year and lastly cost of energy is about $0.188/kWh. A comparison between the base system and the optimized scenario in term of net present cost, cost of energy, and operation and maintenance is displayed in the Table 5.

Table 5: Comparison Between The Base System and The Recommended One

Scenario	Components	NPC ($M)	O&M ($M/yr)	CoE ($/kWh)
1 (Base)	4 Diesel generators Only	99.4	7.69	0.188
2	3 Diesel Generators + 3 PV + Battery + Converter	84.8	5.79	0.161

The net present cost for the recommended hybrid system is $84.8 M and the cost of energy is $0.161/kWh. In addition, the winning scenario limits the emission significantly compared to the base system. The results showed that the emitted quantities of Carbon Dioxide, Carbon Monoxide, Unburned Hydrocarbons, Sulfur Dioxide, and Nitrogen Oxides are all reduced by about 28 % compared to the base system. We can generalize that implementing renewable energy components does not only limit the emissions but also can decrease both the net present value and the cost of energy.

7. Conclusion

Hybrid Renewable Energy Systems are a suitable substitute for existing traditional energy systems in order to fulfill the rising energy demand, particularly in the electrical sector. As Oman looks to direct its energy transition and put capital into its sector reorganization, renewable energy is a key topic in the vision of Oman's utility sector. Hybrid systems are a vital and strategic solution for the provision of electric power in the Sultanate of Oman. Decreasing the dependence on national gas and diesel is one of the main goals for Oman's vision of 2040.

Homer Pro software was used to conduct an economic analysis for a hybrid power system in Al Mazyounah rural area in Oman. For the site location different Scenarios with different components were analyzed and proposed for Al Mazyounah power station. It was found that using a system that consists of diesel generators, PV solar panels and storage batteries is the best option for this area. The optimum scenario for this site resulted in 23% PV energy penetration, net present cost of $84.8 M and the cost of energy of $0.161/kWh

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