Prospect of Stand-Alone PV-Diesel Hybrid Power System for Rural Electrification in UAE

Mutasim Nour *‡, Golbarg Rohani*

* School of Engineering and Physical Sciences

(M.Nour@hw.ac.uk, golbarg.rohani@gmail.com)

‡ Corresponding Author; Mutasim Nour, Heriot - Watt University Dubai Campus P O Box: 294345, Dubai, 00971 44358717, M.Nour@hw.ac.uk

Received: 19.08.2014 Accepted: 07.09.2014

Abstract- The aim of this study is to design and present an optimal stand-alone PV-diesel hybrid renewable power system for a rural village in Al Gharbia located in the western region of Abu Dhabi in UAE. The hybrid power system consists of three 500 kW diesel generators, 1500 kW photovoltaic arrays, 600 kW battery storages, and 1000 kW converter. The power system is capable of providing 1000 kW average load and up to 2300 kW peak load. The total electrical load which can be generated from this system is equal to 9,133,835 kWh in a year. The proposed hybrid system is evaluated using Hybrid Optimization Model for Electric Renewable (HOMER). The obtained results show that the hybrid system with 27% of photovoltaic penetration found to be the optimal system for the village under investigation (Um Azimul) with initial cost of $9,775,000 and total net present cost of $35,059,276 over 25 years. The cost of energy (COE) for PV/diesel/battery power system with 27% solar penetration was found to be 0.313$/kWh for a diesel price of 0.9$/l. The techno-economic analysis for the optimal hybrid system is presented to evaluate the decentralized generation and compare with grid extension for Um Azimul. The achieved results show that the stand-alone PV-Diesel power system is more feasible and economical than grid extension. The optimal hybrid system presented in this paper reduces CO2 emissions by 23% compared to the conventional diesel generator power system.

Keywords- Renewable energy; HOMER; PV-Diesel Hybrid energy system; rural electrifications; techno-economic study

1. Introduction

Continuous burning of fossil fuels for power generation leads to major environmental impacts including global warming, hazardous air pollutions, and acid rain since currently more than 75% of the power system energy is produced from fossil fuels. Rapid depletion of conventional fuels' finite resources is another matter of concern due to increasing energy demand. Development of renewable energy is being encouraged as a green solution in several countries including United Arab Emirates with the purpose of tackling emission problems and fulfilling future energy demands. Presently renewable fulfill 15%-20% of the world's total energy demand. [1] UAE is taking steps towards major initiatives in the country such as ratifying the Kyoto protocol to the UN convention on climate change and having the target of achieving 7% renewable energy power generation by 2020.

One type of prospective renewable power generation in UAE is Hybrid Renewable Energy System (HRES). Hybrid energy system is a system of energy which combines more than one source of energy, either conventional fossil based or renewable based, in order to provide specific load requirement. An energy system that consists of one or more renewable energy source is called Hybrid Renewable Energy System.

The purpose of integration of renewable and conventional energy sources is that weakness of some sources can be complemented by other sources in a natural or controlled way. [2] Renewable energy can't be reliable everywhere due to its variable nature. HRES is designed to increase the reliability of renewable energies. In such systems, the conventional source is mostly diesel generators. By integrating diesel generators and renewable sources, merits of one can compensate disadvantages of the other one. For example stand-alone diesel generator which operates at low load is inefficient and hence costly, even at zero load, diesel generator consumes 30% of full-load fuel consumption. [3] The autonomous diesel generator has high operation cost, demands constant maintenance and the transportation of fuel to remote locations is difficult and costly, mainly during winter. [4]

Other benefits of hybrid system are less fuel consumption and less dependency on fuel supply, flexible supply to load curve, ease of upsizing the system, less operation and maintenance cost compared to diesel generator and less independency of efficiency to load curve. [5] The high growth rate of fuel price over the past recent years makes the HRES more feasible compared to previous years.

HRES is specifically feasible to provide electricity for remote locations like islands and rural area where grid's extension is not feasible due to high cost. [6] Islands, for instance seem to be remarkably suitable due to difficulty of fuel transportation and high cost of under-sea grid extension. [7] Rural electrification is costly in many developing countries because of geographical remoteness and climatic conditions, therefore villages represent a high potential market for hybrid power systems. [8]

The UAE national grid development network determines that there are remote rural areas where the grid is not accessible. The stand-alone HRES is a feasible solution for rural electrification at UAE due to the high cost of grid extension at this country. Despite the fact that there are few studies about HRES at UAE, many reported studies confirm the feasibility of hybrid systems for other countries with hot climate similar to UAE such as Saudi Arabia or Egypt. However the results are different due to divergent of parameters like different solar and wind parameters in different countries, different load demands and fuel prices.

The study of hybrid system for three different cities in Iraq indicates that power output from PV is highest in Basrah, then in Mosul and Baghdad while wind power output is completely different and do not follow the same order. [9] Himri et al. [10] conducted a study to evaluate economic feasibility of integrated grid-connected diesel generator and wind turbine to electrify a village in Algeria, found that the contribution of 68% wind and 32% diesel is the best application for a small area with wind speed remains at 3.5 m/s and below for about 31% of the time during the year. Among Persian Gulf countries, Saudi Arabia has large potential for hybrid renewable systems. Most of remote villages in Saudi Arabia get power by means of stand-alone diesel generator. Studies indicate that commercial and residential buildings in Saudi Arabia consume almost 10-45% of the total electricity. The total electricity generation capacity increased from 1141 MW in 1975 to 27000 MW in 2002. Rehman and Al-hadhrami [11] studied a hybrid system including Diesel-PV with battery backup for a village near Rafha with maximum 4.37 MW load in July and August. The results showed that 21% solar penetration with 79% diesel is the best optimum configuration with 19,874,500$ capital cost and 42,776,660$ total net present cost. Other research for the same location in Saudi Arabia with annual peak load of 4231 kW has been studied for Wind-Diesel hybrid system. Wind speed data shows that the wind speed remains 4m/s and lower for 32% of the entire year. The optimization result for a wind speed of 4.95 m/s and fuel price of 0.1$/L shows that a diesel power system is the most feasible economically. This result is because of low cost of fuel in Saudi Arabia and no carbon tax, but for wind speed more than 6m/s and fuel price more than 0.1 $/L, hybrid system is more feasible with 25% penetration of wind. [12]

Eltamaly et al. [13] assessed hybrid renewable energy system for ten different remote sites in Saudi Arabia. They compared the result obtained from computer program with the result from HOMER software and concluded the validation of both the program and the software. The results showed that the hybrid renewable system cost is less than the cost that Saudi Authority pays for private companies to supply remote area with electric energy from diesel generators.

The components sizes and types in a hybrid system are affected significantly by the scale of primary load, type of application and environmental specifications in different studies. Hakimi et al. [14] reported a feasibility study for a hybrid system with 1 kW primary load scale and selected battery bank and fuel cell instead of diesel generator. However, for the larger primary loads, the hybrid system without diesel generator required large battery banks and the cost is not economical.

The present study is conducted to explore the possibility of stand-alone hybrid renewable energy system at the village Um Azimul in UAE and design the optimal hybrid system for this location in order to provide future electrical demand and finally to compare economically HRES with grid extension. Although similar studies were conducted for different countries, this study is the first of its kind to which is conducted in UAE. The hybrid system consists of stand-alone PV-Diesel hybrid power system in order to serve rural electrification. Moreover, the techno-economic analysis for optimal hybrid system is implemented to evaluate the decentralized generation and compare with grid extension for this village. Hybrid Optimization Model for Electric Renewable (HOMER) is the simulation software used in this research to design the proper optimal hybrid systems.

2. Background

UAE energy demand is increasing significantly due to fast economy growth, urbanization and large amount of immigration. Since its independence in 1971, the United Arab Emirates is committed toward achieving a high economic growth. UAE population was 7.2 million at the end of 2011, and is expected to grow to 7.6 million by the end of 2012. It grew more than 9 times from 1975 to 2010. [15] Consequently, primary energy consumptions have quadrupled in the past two decades.

The highest consumption portion of primary energy at UAE is allocated to intensive cooling and desalinated water due to the hot and arid location. The maximum temperature in summer is above 48°C in August and minimum temperature is 10°C in February. UAE is one of the biggest consumers of water in the world with a daily average consumption rate of 90 gallons per capita. It produces 12.5% of the world's total desalinated water. [16]

A conducted study about UAE energy indicates that this country would fail to meet its share in oil market demand by

2015 and its natural gas by 2042. The gap between production and demand will reach to 35x109 GJ/yr for oil and 27x109 GJ/yr for natural gas. [17] High level of energy consumption and hydrocarbon fuels burning escalates carbon emissions. UAE's carbon emission per capita is at least twice and 10 times higher than the developed countries and the world's annual average emission, respectively. As mentioned earlier UAE aims to achieve 7% renewable energy power generation by 2020. United Arab Emirates is endowed with high potentials of wind energy at islands and coastal area along with high intensities of solar radiation, both of which make the country a suitable candidate for using renewable energy. UAE has also several remote villages which are far from grid and have low electrical demands. Decentralized Generation (DG) is a method of generating electricity close to the end user. DG is one of the best solutions for rural electrification with low demand. The type of decentralized power generation that consists of both renewable and conventional energy is known as stand-alone hybrid system.

3. Site Description

This study investigates the stand-alone PV-diesel hybrid power system for one village which is located at Al-Gharbia in the western region of Abu Dhabi Emirate. This region has high potential for stand-alone power system due to low population density, low electrical demand and having several remote villages far from grid. Al Ghrabia has a subtropical and arid climate. It has a Sunny blue sky and high temperature most of the year. Rain falls only 25 days per year, mainly in winter, from December to March. Temperature varies from 10°C in winter to 48°C in summer. The mean daily maximum temperature is 24°C in January and 41°C in August. Humidity changes between 50% and 65%. [18] Um Azimul (Altitude: 130 m, Latitude: 22° 42' N, Longitude: 55° 08' E) is the village with population less than 1000 in south of Al-Ghrabia, close to Saudi Arabian border. Um Azimul is located at Rub al Khali or Empty Quarter which is the largest sand desert in the world.

3.1. Solar Data

Solar resource data point out the amount of global solar radiation in a typical year. This amount includes beam radiation, which comes directly from the sun, plus diffusion radiation coming from all parts of the sky. This quantity is presented as monthly average global solar radiation on the horizontal surface (kWh/m^2.day).

The clearness index is the parameter demonstrating the clearness of the atmosphere. It is the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere. The radiation loss reaching the Earth is due to the presence of moisture, dust, clouds, aerosols or even temperature differences in the lower atmosphere. [19] Solar data including daily radiation and clearness index for Um Azimul are shown in Fig. 1. The solar radiation information is obtained from National Aeronautics and Space Administration (NASA) webpage for each location. As can be seen the highest daily radiation is during May and June and the lowest is during December. The solar data show high potential of solar energy exploit for the village.

3.2. Village Electrical Load Data

This study is implemented based on 1 MW average load to be able to fulfill the primary load for 500 households. The primary load data of Al Gharbia is collected from Abu Dhabi Water and Electricity Company (ADWEC). It is assumed that Um Azimul load data follow the load model of other locations at Al Gharbia where the grid is available. The data include minimum and maximum hourly load for each month which is equal to 24 load values (Two load values for 2 hours in each month). The other load values for every month obtained by means of extrapolation to have set of 288 load values (24 load value for 24 hours in each month). All 288 hourly loads are synthesized by helps of simulator to calculate the loads for all 8760 hours of a year. Eventually all 8760 load values are multiply by a proportional factor to provide annual 1000 kW average load for electrical serving of 500 households.

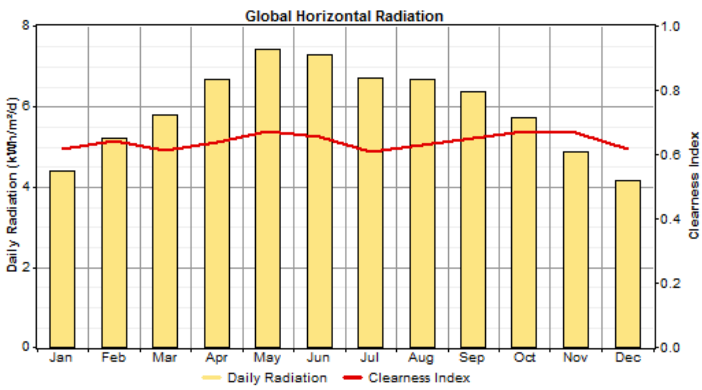

Figure 1. Um Azimul horizontal radiation

Figures 3 and 4 illustrate the load frequency and the hourly profile per month, respectively. Load frequency data show that the highest frequency of load is 1000 kW with 11% frequency in a year. It means that the electrical demand in 11% (40 days) of the year is equal to 1000 kW. As can be seen in Fig. 4, hourly profile conform similar pattern for each month, but the load values change.

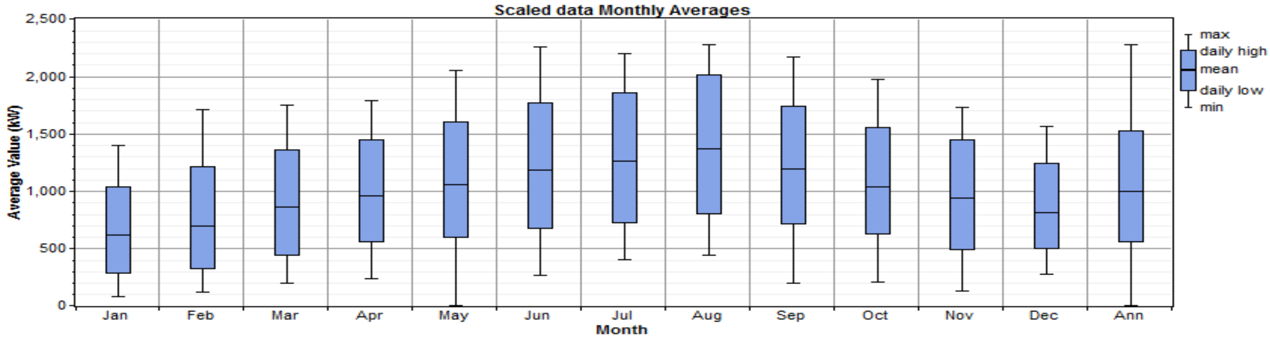

Figure 2. Monthly average load

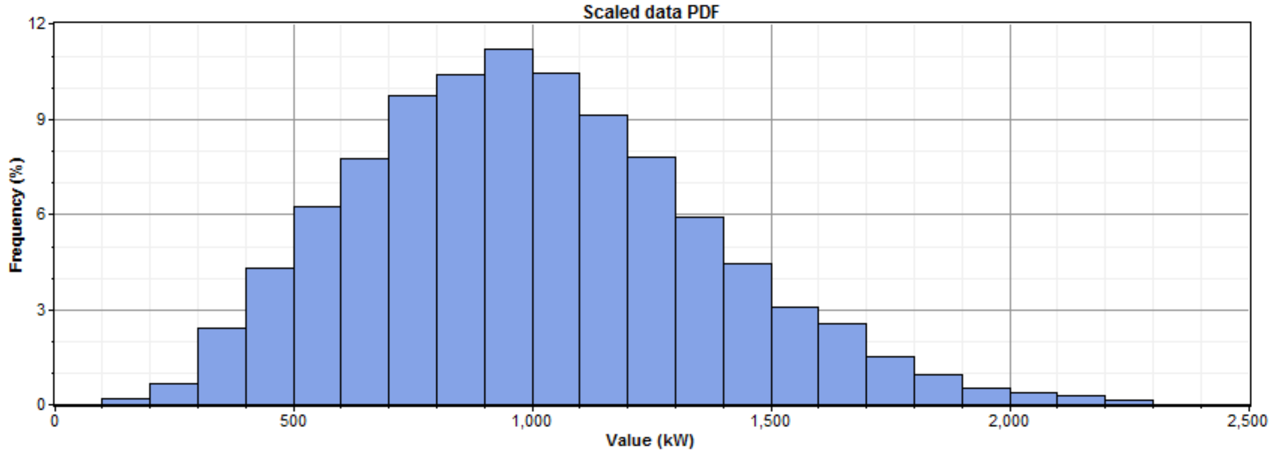

Figure 3. Load frequency

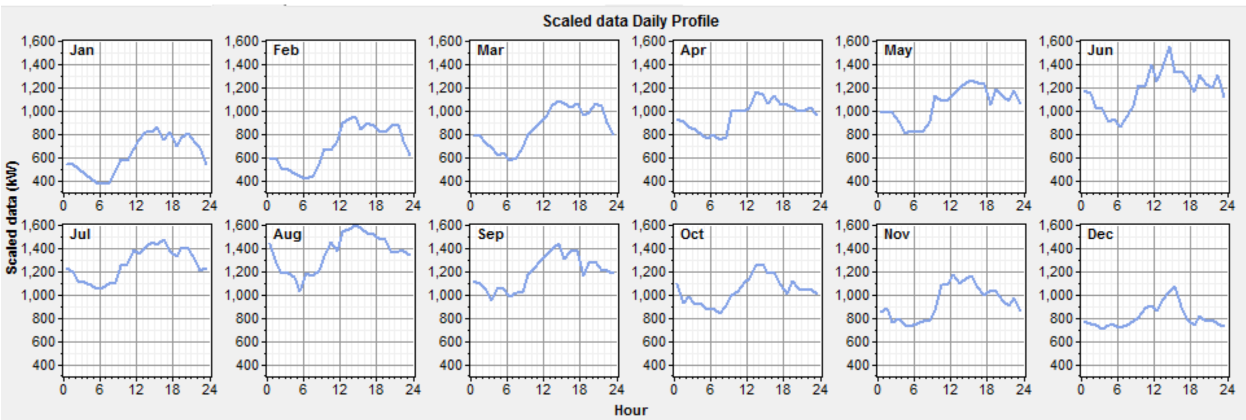

Figure 4. Hourly profile per month.

4. HOMER Input Data

Hybrid Optimization Model for Electric Renewable (HOMER) is the simulation software used in this study to design and evaluate the feasible hybrid systems for the village. HOMER simulates hybrid system's behaviour and evaluates different integrated components for both off-grid and grid-connected systems. Inputs data for this software includes electrical loads, renewable components data like PV specification, wind turbine models, types of batteries and converters, capital costs of components, replacement cost, maintenance and operation costs, fuels cost, renewable resources data like solar radiations, and monthly average wind speeds. After inputting data, HOMER simulates thousands of feasible system configurations and generates optimization result for them. It omits all infeasible integration and ranks feasible arrangements from the lower net present cost.

4.1. *Hybrid System Components*

Renewable source for generating electricity for hybrid system at Um Azimul is Photovoltaic (PV) arrays. Diesel generator is dispatchable energy source which can compensate for renewable sources in a system. The other common components in hybrid systems are batteries. They are used in order to increase the reliability of the system. Whenever renewable sources can feed the demands, the excess energy can be stored in the batteries. Subsequently whenever renewable sources are not available, the batteries feed electricity into the system. Another component used in hybrid systems at this study is an inverter which converters the dc power to ac power. The software selects components based on energy balance calculation for 8760 hours in a year. HOMER considers all possible components configurations and calculates energy balance to find whether this configuration is feasible or not, whether it can meet the electric demand or not. If the systems have batteries or generators, the simulator decides whether to charge or discharge batteries and how to operate generators. For each hour, the electrical demand is compared with the energy that the system can supply at the same hour and then calculates the flow of energy to and from each component. The details of components are given below:

4.1.1PV Panel

Table 1 indicates the specification of SHARP PV-Panels which is used in the proposed hybrid system.

Table 1. PV Panel specification

SHARP 240 WATT	
PV Electrical Characteristics	
Maximum power	240 W
Type of cell	Polycrystalline silicon
Cell configuration	60 in series
Open circuit voltage (Voc)	37.5 V
Maximum power voltage (Vpm)	29.3 V
Short circuit current (Isc)	8.75 A
Maximum power current (Ipm)	8.19 A
Module efficiency	14.7 %
NOCT	47.5 °C
Temperature coefficient (Pmax)	- 0.485 % / °C
PV Mechanical Characteristics	
Dimensions	994 X 1640 X 46 mm
Weight	19 kg
Operating temperature	-40 to 90 °C

4.1.2Diesel Generator

The selected diesel generator is Cummins series. The specification is shown in Table 2 below.

Table 2. Diesel generator specification

Cummins KTA50-G3	
Prime power (50 Hz)	1100kW/1250kVA
Standby power (50 Hz)	1100kW/1375kVA
Speed	1500 rpm
Voltage	230V/400V

Figure 5 shows diesel generator efficiency curve.

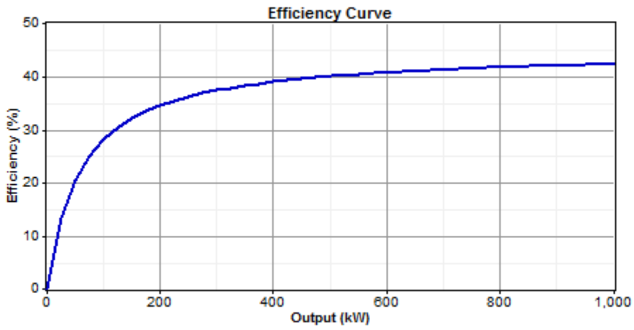

Figure 5. Diesel generator efficiency.

Figure 6 shows Fuel consumption diagram for 1MW diesel generator.

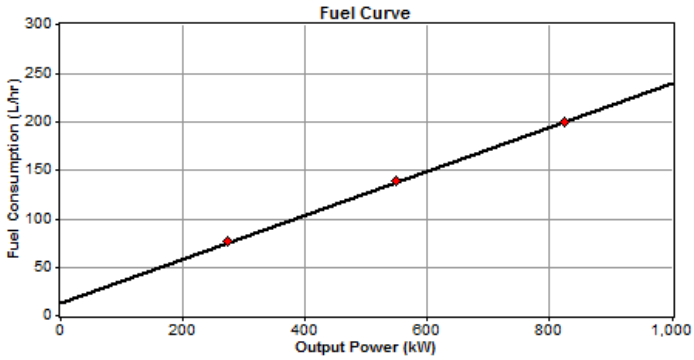

Figure 6. Diesel generator fuel curve.

The Generator Fuel Curve Intercept Coefficient and Slope can be found from engine performance data and fuel consumption diagram in Fig. 6 as below:

Generator Fuel Curve Intercept Coefficient: 0.01356 L/hr/kW rated

Generator Fuel Curve Intercept Slope: 0.2265 L/hr/kW output

4.1.3Battery

*Rolls Sur*rette 4KS 25P is the selected battery in this study which is produced by North American manufacturer, Rolls Surrette.

4.2 Components Costs

*T*able 3 illustrates the components costs. The costs obtained by quotations of different suppliers and companies in the UAE and other overseas companies.

Table 3. Components cost

Component	Size	Capital ($)	Replacement ($)	O&M ($/yr)	Life time
PV	1 (kW)	2800	2800	20	20 years
Cummins KTA50-G3	1000 (kW)	250000	250000	5	15000 hours
Converter	1 (kW)	1000	1000	0	15 years
Surrette 4KS 25P	1	7000	7000	100	Determined by lifetime curve

In addition to components price, the other required costs include:

Diesel: 0.9 $/kWh

Grid extension capital cost for 132 kV transmission line DEWA: 275,000 $/km (According to DEWA data)

5. Results and Discussion

This section presents the simulation and analysis of thousands of possible integrated components. The infeasible configurations were discarded while all feasible systems in order based on total net present cost. The analysis of results is presented in terms of optimizations results, economic analysis, emission analysis and grid extension comparison result.

5.1 *Optimization Result*

The optimization result determines the best possible system configuration for a particular location. The best system or optimum system is the one with the lowest total net present cost that can meet user requirements. The optimizations lists show comparable results of all systems. These results include the size and number of components, capital and operating cost, NPC and COE, renewable fraction, and fuel consumption of all feasible system. [20] Fig. 7 shows different optimum results simulated for average load of 1000 kW at Um Azimul. The optimal systems are ranked from the lowest NPC.

As shown in Fig. 7, the simulation is run to achieve optimal system with initial cost of $ 9,775,000 and total net present cost of $35,059,276 over 25 years. The optimal hybrid system consists of PV-diesel-battery with PV penetration of 27%. Fig. 8 depicts the schematic diagram of the designed HRES model. The model consists of three 500 kW diesel generators, 1500 kW photovoltaic arrays, 600 kW battery storages, and 1000 kW converter. The model is capable to provide 1000 kW average load and up to 2300 kW peak load. The total electrical load which can be generated from this system is equal to 9,133,835 kWh in a year

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PV (kW)	Label (kW)	Label (kW)	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Label (hrs)	Label (hrs)
1500	500	500	500	600	1000	$ 9,775,000	1,977,906	$ 35,059,276	0.313	0.27	1,635,358	8,299	6,291	2,363
1500	500	500	500	600	1200	$ 9,975,000	1,977,848	$ 35,258,532	0.315	0.27	1,631,032	8,218	6,249	2,351
2000	500	500	500	600	1200	$ 11,375,000	1,883,908	$ 35,457,668	0.317	0.34	1,511,893	7,796	5,766	2,191
2000	500	500	500	600	1000	$ 11,175,000	1,904,786	$ 35,524,556	0.318	0.34	1,535,502	8,057	5,916	2,227
1500	500	500	500	600	1500	$ 10,275,000	1,985,524	$ 35,656,664	0.319	0.27	1,630,792	8,212	6,248	2,351
2000	500	500	500	600	1500	$ 11,675,000	1,881,800	$ 35,730,720	0.319	0.34	1,503,465	7,638	5,708	2,179
2500	500	500	500	600	1200	$ 12,775,000	1,835,184	$ 36,234,804	0.324	0.41	1,437,559	7,544	5,497	2,091
2500	500	500	500	600	1500	$ 13,075,000	1,816,458	$ 36,295,428	0.324	0.41	1,413,779	7,210	5,380	2,068
1500	500	500	500	600	2000	$ 10,775,000	1,998,807	$ 36,326,464	0.325	0.27	1,630,792	8,212	6,248	2,351
2000	500	500	500	600	2000	$ 12,175,000	1,894,497	$ 36,393,032	0.325	0.34	1,502,972	7,626	5,707	2,179
2500	500	500	500	600	1000	$ 12,575,000	1,872,631	$ 36,513,512	0.326	0.40	1,476,980	7,929	5,721	2,140
2500	500	500	500	600	2000	$ 13,575,000	1,824,162	$ 36,893,916	0.330	0.41	1,409,033	7,109	5,361	2,068
3500	500	500	500	500	1500	$ 15,175,000	1,723,585	$ 37,208,204	0.333	0.51	1,310,434	6,711	5,005	1,958
3000	500	500	500	600	1500	$ 14,475,000	1,780,801	$ 37,239,620	0.333	0.47	1,353,472	6,927	5,147	2,000
3000	500	500	500	600	1200	$ 14,175,000	1,811,540	$ 37,332,568	0.334	0.46	1,388,446	7,385	5,312	2,033
3500	500	500	500	500	1200	$ 14,875,000	1,763,268	$ 37,415,488	0.335	0.50	1,353,906	7,260	5,194	1,991
1500	500	500	500	800	1000	$ 11,175,000	2,056,649	$ 37,465,872	0.335	0.26	1,636,252	8,298	6,290	2,351
1500	500	500	500	800	750	$ 10,925,000	2,084,652	$ 37,573,852	0.336	0.26	1,667,490	8,514	6,554	2,464
3500	500	500	500	500	2000	$ 15,675,000	1,717,053	$ 37,624,708	0.336	0.52	1,292,952	6,407	4,940	1,958
1500	500	500	500	800	1200	$ 11,375,000	2,056,787	$ 37,667,640	0.337	0.27	1,632,133	8,218	6,248	2,339
3000	500	500	500	600	2000	$ 14,975,000	1,780,640	$ 37,737,560	0.337	0.47	1,341,745	6,711	5,102	2,001
3000	500	500	500	600	1000	$ 13,975,000	1,859,893	$ 37,750,676	0.337	0.45	1,438,678	7,837	5,575	2,083
2000	500	500	500	800	1200	$ 12,775,000	1,962,490	$ 37,862,204	0.338	0.34	1,512,601	7,793	5,765	2,182
3500	500	500	500	500	1000	$ 14,675,000	1,818,501	$ 37,921,548	0.339	0.49	1,410,705	7,770	5,481	2,048
2000	500	500	500	800	1000	$ 12,575,000	1,983,335	$ 37,928,676	0.339	0.34	1,536,161	8,056	5,915	2,217
1500	500	500	500	800	1500	$ 11,675,000	2,064,427	$ 38,065,300	0.340	0.27	1,631,865	8,211	6,246	2,340
2000	500	500	500	800	1500	$ 13,075,000	1,960,436	$ 38,135,956	0.341	0.34	1,504,209	7,636	5,708	2,170
3500	500	500	500	600	1500	$ 15,875,000	1,762,702	$ 38,408,252	0.343	0.51	1,310,656	6,709	5,004	1,950
2000	500	500	500	800	750	$ 12,325,000	2,048,192	$ 38,507,764	0.344	0.33	1,604,207	8,425	6,335	2,363

Figure 7. Optimization result list.

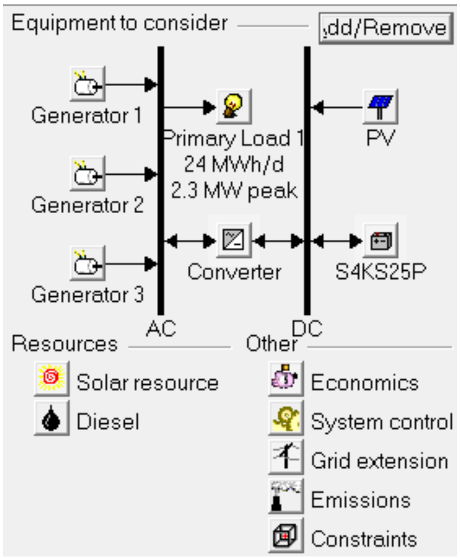

Figure 8. PV-diesel hybrid model.

The comparison of different optimal systems shows that higher fractions of renewable energy in hybrid systems increase the capital costs. However, the net present cost mostly depends on the total fuel price. The levelized cost of energy is 0.313 $/kWh which is triple higher than UAE's tariff. It emphasizes that stand-alone hybrid system is an expensive electrification system. Multiple generators are used instead of one generator with higher capacity to reduce the amount of excess electricity. In addition, the presence of battery storage increases the initial capital cost of a system sharply. However, battery storage reduces the operating hours of diesel generator in a system and consequently has high affect in emission reduction and fuel consumption. The penetration of renewable and diesel generator for the hybrid system with the lowest NPC is shown in Fig. 9.

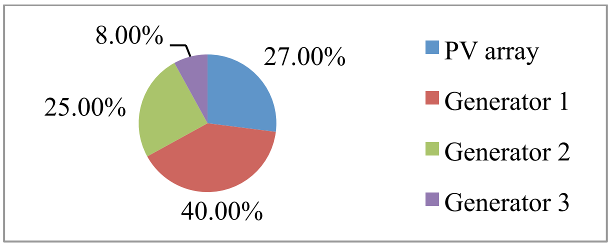

Figure 9. Hybrid system components penetration.

The monthly average power production is shown in Fig. 10. PV panels generate 2,420,852 kWh per year and three generators totally generate 6,712,973 kWh per year. The hybrid system produces 9,133,835 kWh in a year while the primary load of the villages is 8,749,122 kWh in one year. The excess electricity is equal to 121,769 kWh/year or 1.33%. The unmet electric load and capacity shortage are close to zero. If the system cannot supply the required amount of operating reserve plus load, the software shows the shortfall as "capacity shortage" and the unmet load is the shortfall that occurs when the electrical demand exceeds the supply.

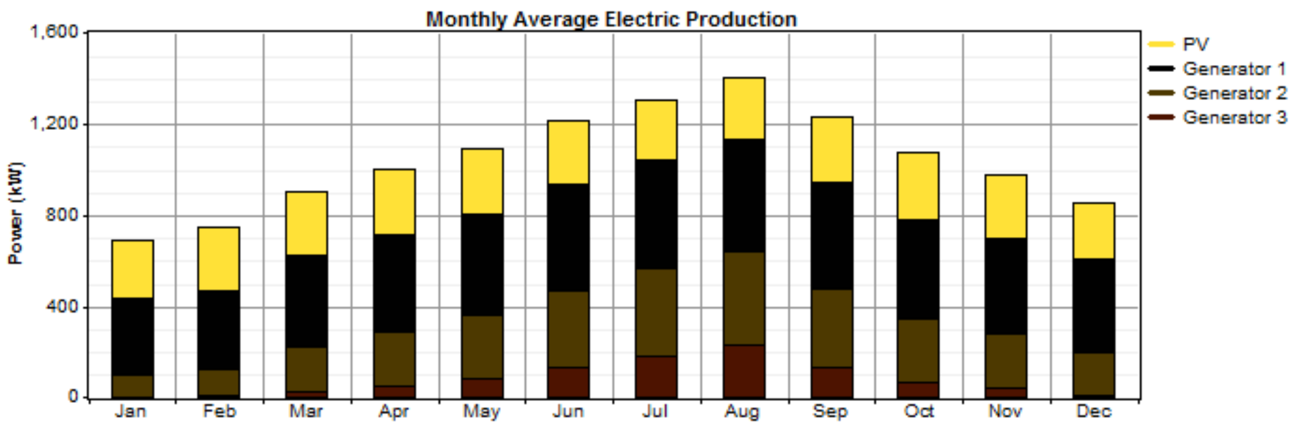

Figure 10. Monthly average power production.

5.2 Economical Analysis

The optimized system configuration is the hybrid system with the minimum total net present cost (NPC). The NPC includes different costs such as the price of initial construction, operation and maintenance, replacement, fuel, salvage, penalties due to emissions, etc. during the whole project lifetime which is 25 years in this.

The NPC is calculated by equation (1) [11]:

$$C_{NPC} = C_{ann,tot}/CRF(i,R_{proj}) \quad (1)$$

$CRF(i,R_{proj})$: Capital recovery factor is a ratio used to calculate the present value of an annuity. It can be calculated using equation (2) [11]:

$$CRF(i,N)=[i(1+i)^n]/[(1+i)^N-1] \quad (2)$$

i : Annual real interest rate, 6% at present study. It is the discount rate used to convert between one-time costs and annualized costs. Drop of interest rate causes reduction of capital recovery factor and leads to bigger NPC.

N: The number of years, 25 years at present study

The calculated Capital recovery factor is equal to 0.0782.

$C_{ann,tot}$: Total annualized cost, is the sum of the annualized costs of each system component.

The annualized cost includes annual operating cost plus the capital and replacement costs annualized over the project lifetime.

5.3 Emission

The result of electricity generation by the diesel generatorand the grid is pollutants production. The annual emission of pollutants is calculated by multiplying the emission factors by the total annual fuel consumption. The fuel properties are required in order to calculate emission factor. Fuel properties of diesel are shown in Table 4:

Table 4. Diesel properties

Lower heating value	43.2 MJ/kg
Density	820 kg/m^3
Carbon content	88 %
Sulfur content	0.33 %

The greatest amount of emissions in hybrid systems is CO_2 emission. The CO_2 emission factor at this study is 2.633 kg/liter of diesel. To calculate the amount of emission saved by the hybrid system, the new conventional system is simulated which consists of three diesel generators and doesn't include renewable source. The achieved pollutant results are shown in Tables 5 and 6 for hybrid system and conventional system, respectively. As can be seen in the tables, the amount of emission is 4,306,436 kg/yr using the HRES while it increases to 5,642,797 kg/yr using conventional system. Comparing two tables shows that having renewable energy components lead to a 23% reduction in total emission.

Table 5. Hybrid system emissions

Hybrid system	
Pollutant	**Emissions (kg/yr)**
Carbon dioxide	4,306,436
Carbon monoxide	10,630
Unburned hydrocarbons	1,177
Particulate matter	801
Sulfur dioxide	8,648
Nitrogen oxides	94,851
Total	4,422,543

Table 6. Conventional system emissions

Conventional with diesel generator	
Pollutant	**Emissions (kg/yr)**
Carbon dioxide	5,642,797
Carbon monoxide	13,928
Unburned hydrocarbons	1,543
Particulate matter	1,050
Sulfur dioxide	11,332
Nitrogen oxides	124,285
Total	5,794,935

5.4 Grid Extension

This part of simulation result compares the cost of a stand-alone hybrid system with the extension of the grid. The comparison result for the selected hybrid system is shown in Fig. 11. The diagram demonstrates that the cost of grid extension is higher than hybrid system, if the distance between the system and the grid is more than 83 km. This distance is known as breakeven grid extension distance. The breakeven grid extension distance occurs when the net present cost of extending the grid is equal to the net present cost of the stand-alone system. The distance between Um Azimul and the available grid at Liwa is 143 km. Consequently, a stand-alone system is more cost effective and hence more feasible than a grid extension for this village.

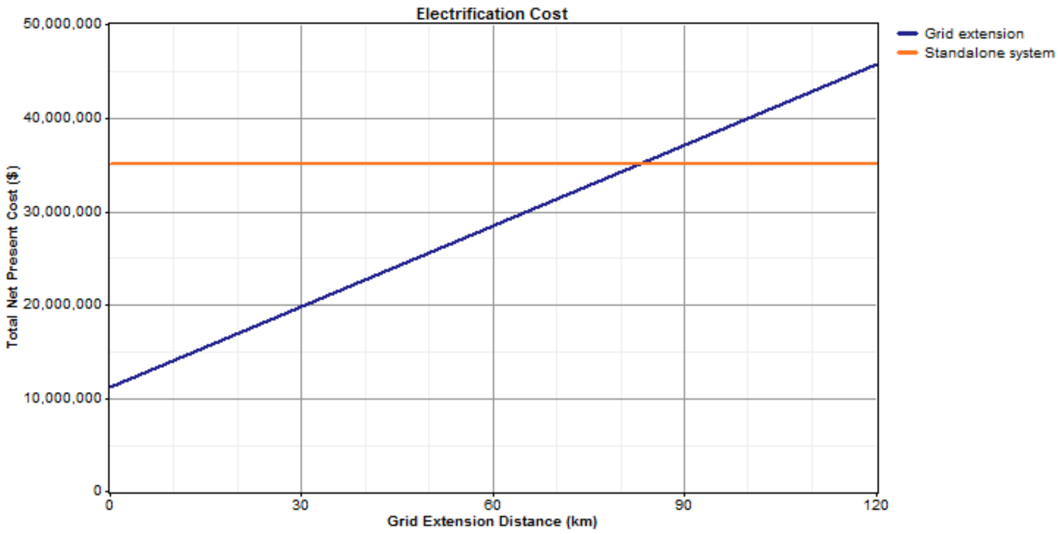

Figure 11. Breakeven grid extension diagram.

5.5 Results Validations

Although the reliability of the results obtained in this paper cannot be evaluated experimentally since there is no actual HRES and this study is the first of its kind to be conducted in UAE, comparison with other studies in the same capacity could benchmark and validate the reliability of the results in terms of renewable fraction and cost. Several studies reported the economic analysis of similar HRES in different countries during recent years. Ghasemi et al. [21] analyzed the economic feasibility of PV-Diesel system in eastern part of Iran to provide electricity for a village with 200 kWh/d average load and 18 kW peak load demand. The loads are almost 120 times less than electrical demand at Um Azimul. The solar radiation average of Iranian village is 5.1 kWh/m^2/d while Um Azimul's is equal to 5.94 kWh/m^2/d. Comparison of the result between the two villages reveals approximately similar range of renewable fraction (RF) and levelized cost of energy (COE) for both locations. COE of Iranian village is 0.304 $/kWh and the RF is 0.22-0.3 and Um Azimul's COE and RF is 0.313 $/kWh and 0.27, respectively.

Rehman and Al-hadhrami [11] analysed a Diesel-PV hybrid system with battery backup for a village near Rafha in Saudi Arabia with maximum 4.37 MW load in July and August. The results show renewable penetration of 21% with COE of 0.219 $/kWh when the diesel price is 0.2 $/l. The sensitivity result of the research at Saudi Arabia explains that the hybrid system become more economical than conventional diesel system when the fuel price become more than 0.6$/l. This confirms the validity of the result obtained in this study when the diesel price is 0.9$/l and could be the conclusion of diesel price increase.

Other conducted studies at different locations with similar environmental specifications like KSA, Jordan, and South Africa show close range of RF and COE to this study as well. The higher diesel price in all these reports lead to higher COE, but still the RFs are close to each other since the high price of PV limits the penetration of solar energy. Analysis of HRES in Jordan with average solar radiation of 5.9 kWh/m2/d and diesel price of 0.238 $/l shows 23% RF and 0.297 $/kWh COE.[22] The study at six locations in South Africa with radiation range of 3-6 kWh/m^2/d and diesel price of 0.7 $/l reached the result of 0.2-0.7 RF. [23] Another economical research in KSA, Dhahran with 5.84 kWh/m2/d radiation and 0.1 $/l diesel price leaded to 0.179 $/kWh COE and 22% RF. [24]

6. Conclusion

United Arab Emirates has high potentials of solar and wind energy. The broad investigation of different locations at present study defines that the islands and north-west coastal area of the country have wind energy potentials. Stand-alone hybrid systems are suitable for the remote areas of Al Gharbia due to the low electrical demand and long distance from the grid. The Distance between grid and Um Azimul village is 143 km. For this village stand-alone PV-Diesel power system is more feasible than grid extension. The hybrid system with 27% of photovoltaic penetration found to be the optimal system at Um Azimul with initial cost of $9,775,000 and Total net present cost of $35,059,276 over 25 years. The optimal hybrid system presented in this paper reduces 23% fuel consumption and CO2 emissions compared with the conventional diesel generator power system. The levelized cost of energy for the designed stand-alone hybrid systems is 0.313 $/kWh, while the current tariff is 0.1 $/kWh and the diesel price is 0.9 $/lit. Therefore, it is necessary that the government amends the current policies and regulations to encourage private sectors to invest on the renewable energy. Also, financial incentives in green energy can be structured, such as income tax expense deductions, capital cost allowance deductions, research and development credits, special fund and grants, and tradable emission credits.

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