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Simulations of Hybrid Renewable Energy Systems and Environmental Impact for Qena Al-Gadida City

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***Abstract*— This study presents Cost and Environmental matching of Renewable Energy Systems for the new cites in Egypt by making economic evaluation of photovoltaic systems with different renewable energy systems to choose the best economic system with taking into consideration the environmental impact, The selected city "Qena Al-Gadida" City, New Urban Communities Authority, Egypt.**

***Keywords*— Wind, Turbine, Photovoltaic, Module, Battery, Diesel Generator, Fuel Cell, Simulation, Hybrid, Renewable, Energy, System, Environmental, Impact, Homer.**

I. INTRODUCTION

Since the oil crisis in 1970s the world has been experiencing higher prices of conventional fuel and further it has started producing negative impacts on the environment. It is also reported that the fossil fuel resources has also started depleting in major oil producing countries and this will eventually lead to a greater scarcity of energy resources in the world. The environmental issue is a major concern, particularly emission of carbon dioxide. All the above reasons have led engineers and environments to find a sustainable and friendly environment solution and they came with renewable energy [1→3]. The wind and solar energy are omnipresent, freely available, and environmental friendly. The wind energy systems may not be technically viable at all sites because of low wind speeds and being more unpredictable than solar energy. The combined utilization of these renewable energy sources are therefore becoming increasingly attractive and are being widely used as alternative of oil-produced energy. Economic aspects of these renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. A renewable energy system consists of two or more energy sources, a power conditioning equipment, a controller and an optional energy storage system.

These renewable energy systems are becoming popular in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products [4]. The New Cities of Egypt represent a major effort to redistribute investment and population away from Cairo and the Delta in a brave attempt to use desert land, the biggest challenge is the provision of electricity and water facilities for new cities. The selected city "Qena Al-Gadida" City, New Urban Communities Authority, Egypt.

II. RENEWABLE ENERGY SYSTEM COMPONENTS

The renewable energy system consists of the following components:

1. BWC Excel-R wind turbine.
2. CHSM 6610P-250 photovoltaic panel.
3. Trojan L16P Battery.
4. Converter.
5. Fuel Cell.
6. Diesel generator.

A. Wind Turbine:

In this simulation, Bergey Wind Power's BWC Excel-R model is considered. It has a ratedcapacity of 7.5 kW and provides 48 V dc as output. Its initial cost is $28500 and its replacement at$24500 [5]. Annual operation and maintenance cost is $200. Its life time is estimated at 20 years, a number from 1 unit to 10 is considered.

B. Photovoltaic module:

KD140SX- UFBS photovoltaic panel is considered in the scheme, with initial and replacement cost $ 265 with rated power 250 watt [6]sizes to be considered are (0.25 0.5 1 1.5 2 2.5 3 3.5 4 4.50 5 5.5 6 6.5 10 20 30 40 50 60 100).

C. Battery

Trojan L16P Battery models (6 V, 360Ah, 1.075 kWh), Cost of one battery is $275 and maintenance cost $3 [7], a number of unit considered are (10 20 50 100 150 200 250 300).

D. Converter

For a 1 kW converter the installation and maintenance costs are taken as $1000 and $10, number of units to be considered (1 2 3 4 5 6 10 20 30 50 100 150 200) KW

E. Fuel Cell

A fuel cell is an energy conversion device, which converts the chemical energy of a fuel and oxidant, often hydrogen and oxygen, to electrical energy fuel cells are similar to batteries, however, unlike battery a fuel cell must be continuously provided with fuel, with initial and replacement cost $3000 and $2700 respectively, for 1KW size and operation and annual maintenance cost $0.02[8] sizes to be considered are (1 2 3 4 5 6 7 10 15 20).

F. Diesel generator.

For the diesel generator sizes of diesel generator to consider in simulation vary from 3 to 7 kW. Their initial costs and their replacements are respectively (2990, 2400$), (3978, 3200$), (4984, 4000$), (5981, 4800$) and (6978, 5600$). Their operation and maintenance are of 0.05$/h [9].

III. SIMULATIONS OF RENEWABLE ENERGY SYSTEM

HOMER software simulates the operation of the proposed system along the year by making an energy balance between the generation and the load to determine the feasible system architecture which meet the load demand under the site condition beside specifying the cost-effective combination based on the total net present cost [TNPC] which is the summation of all the costs and revenue all over the project life time which is assumed 25 years.The system cost is defined as sum of system components, for example Photovoltaic cost $\mathbf{C}_{PV}$, wind turbine cost $\mathbf{C}_{WT}$, battery cost $\mathbf{C}_{BAT}$, converter cost $\mathbf{C}_{CONV}$, fuel cell cost $\mathbf{C}_{FC}$.

$\mathbf{C}_{system} = \mathbf{C}_{PV} + \mathbf{C}_{WT} + \mathbf{C}_{CONV} + \mathbf{C}_{BAT} + \mathbf{C}_{FC}$, Where the cost of each element is given by: Ci= Ni * [CCosti + RCosti * Ki + OMCosti], i= PV, Wind Turbine, Diesel Generator, Fuel Cell, Battery and Converter.Where Ni is the number/size of the system component, CCosti is the capital cost, RCosti is the replacement cost, Ki is the number of replacement, and OMCosti is operation and maintenance cost through the system operation [11].

A number of seven combinations are to be considered as follows:

1. Wind turbine and Diesel generation.
2. PV panel and Diesel generation.
3. Wind turbine and PV panels.
4. Wind turbine, PV panels and Diesel generation.
5. Wind turbineand Fuel cell.
6. PV panels and Fuel cell.
7. Wind turbine, PV panels and Fuel cell.

These combinations simulated using HOMER software[12] to determine the most optimum combination for Qena AL-Gadida City.

IV. QENA AL-GADIDA CALCULATIONS

A. Load Data:

The annual peak load is 11 KW with energy consumption of 85 KWh/day and the daily profile of the load is shown in Fig. (1)

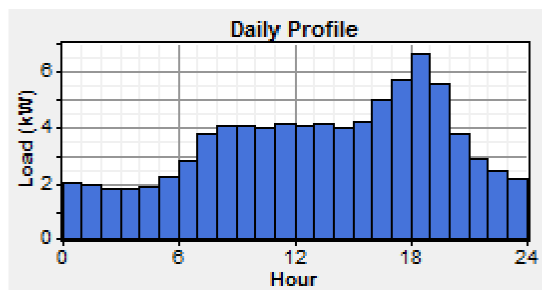

Fig.1: Qena Al-Gadida load profile

B. Wind And Solar Resources

The annual average wind speed and the annual average insolation level at Qena Al-Gadida is 4.91 m/s and 5.89 kWh/m2/day respectively, the monthly wind speed variation, the monthly clearness index and the daily radiation are shown in Fig. (2) and Fig. (3) [10].

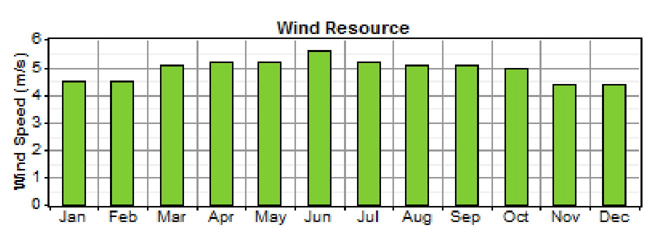

Fig.2: Qena Al-Gadida wind speed

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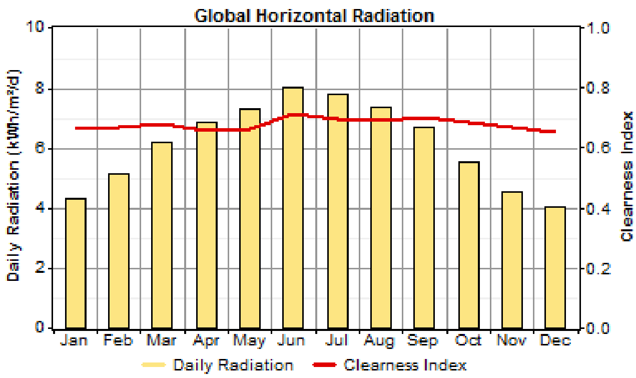

Fig.3: Qena Al-Gadida solar irradiance

C. Simulation Results

1. Wind and Diesel generation:

Fig.4 shows Design of Wind and Diesel System

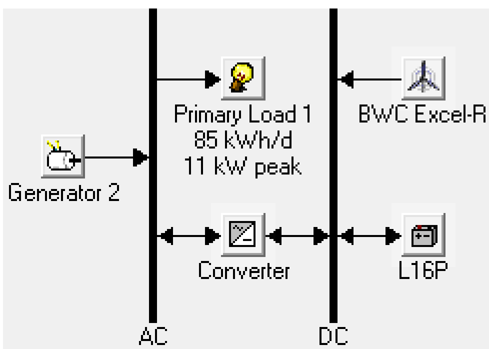

Fig.4: Wind and Diesel System.

The simulation results present the optimum combination: 1 wind turbine, 4KW generator, 10 battery and 4KW converter as shown in Table. (1), with initial cost: 39,228$, operating cost: 7,917$/year and cost of energy: 0.359 $/KWh, Fig. (5) Shows the energy yield of the optimum solution.

Table.1
Wind and Diesel Simulation Results.

				XLR	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
				1	4	10	4	$ 39,228	7,917	$ 140,438	0.359	0.40	0.02	7,398	6,605
					5	10	2	$ 9,734	10,560	$ 144,723	0.369	0.00	0.02	11,271	8,323
					7			$ 6,978	11,979	$ 160,111	0.408	0.00	0.02	12,787	8,760
				1	7		3	$ 38,478	11,280	$ 182,676	0.463	0.35	0.01	11,102	8,397

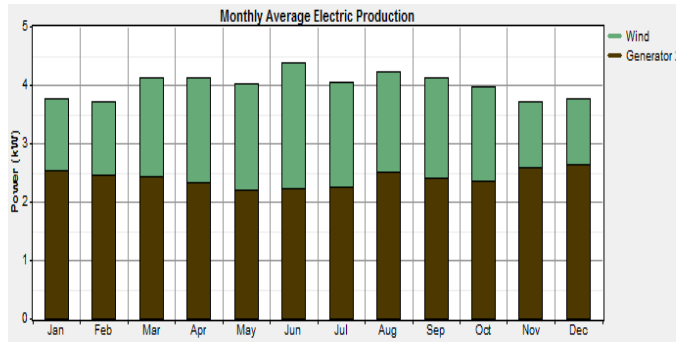

Fig.5: Wind and Diesel Electric Production

2. PV and Diesel generation:

Fig.6 shows Design of PV and Diesel System

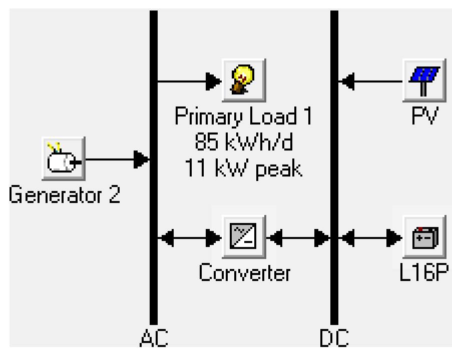

Fig.6: PV and Diesel System

The simulation results present the optimum combination: 15 KW PV, 3KW generator, 50 battery unit and 6KW converter as shown in Table. (2) and Fig. (7) Shows the energy yield of the optimum solution.

Table.2
PV and Diesel Simulation Results.

				PV (kW)	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
				15	3	50	6	$ 37,740	5,438	$ 107,255	0.271	0.68	0.00	4,486	4,646
				21		100	10	$ 58,500	4,498	$ 115,997	0.296	1.00	0.02		
				21	7		6	$ 33,978	8,088	$ 137,368	0.349	0.69	0.02	7,962	6,108

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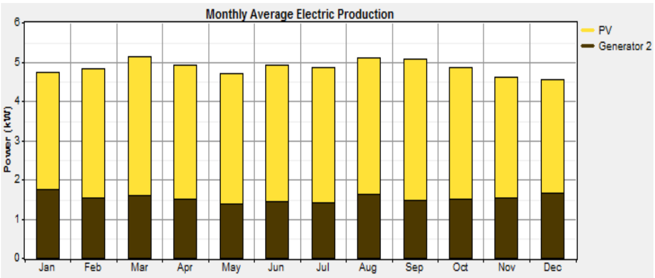

Fig.7: PV and Diesel Electric Production

3. *Wind and PV:*

Fig.8 shows Design of PV and Wind System

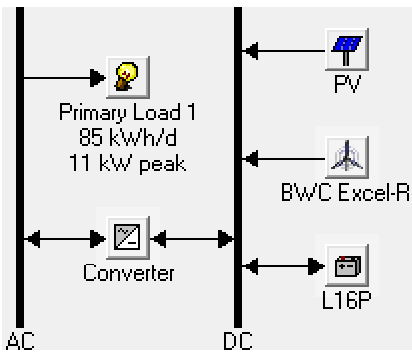

Fig.8: PV and Wind System

The simulation results present the optimum combination: 21KW PV, 0 wind turbine, 100 battery unit and 10 KW converter as shown in Table. (3), and Fig. (9) Shows the energy yield of the optimum solution.

Table.3
Wind and PV Simulation Results.

	PV (kW)	XLR	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	21		100	10	$ 58,500	4,498	$ 115,997	0.296	1.00	0.02
	20	1	50	10	$ 72,250	3,508	$ 117,096	0.299	1.00	0.02

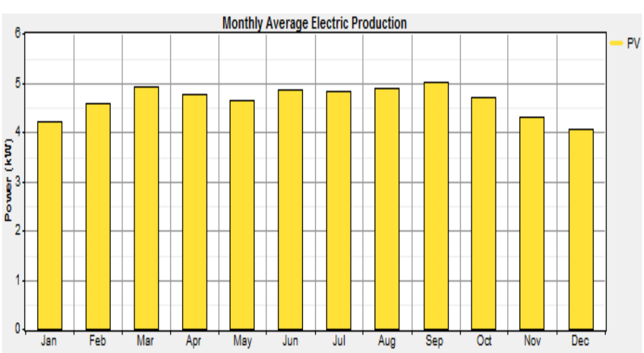

Fig.9: PV and Wind Electric Production

4. *Wind, PV and Diesel:*

Fig.10 shows Design of PV, Wind and Diesel System

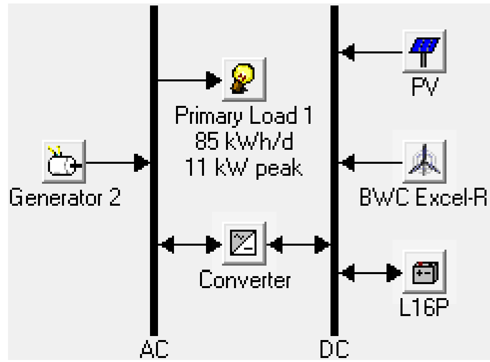

Fig.10: PV, Wind and Diesel System

The simulation results present the optimum combination: 15 KW PV, 0 wind turbine, 3KW generator, 50 battery unit and 6 KW converter as shown in Table. (4) and Fig. (11) Shows the energy yield of the optimum solution.

Table.4
Wind, PV and Diesel Simulation Results.

	PV (kW)	XLR	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
	15		3	50	6	$ 37,740	5,438	$ 107,255	0.271	0.68	0.00	4,486	4,646
	11	1	3	20	6	$ 53,990	4,449	$ 110,859	0.280	0.79	0.00	3,101	3,396
	20	1		50	10	$ 72,250	3,508	$ 117,096	0.299	1.00	0.02		
	20			150	10	$ 71,250	4,112	$ 123,818	0.315	1.00	0.01		
	20		7		6	$ 32,978	8,167	$ 137,376	0.349	0.68	0.02	8,049	6,181
	17	1	7		6	$ 58,478	7,826	$ 158,521	0.401	0.75	0.01	7,117	5,821

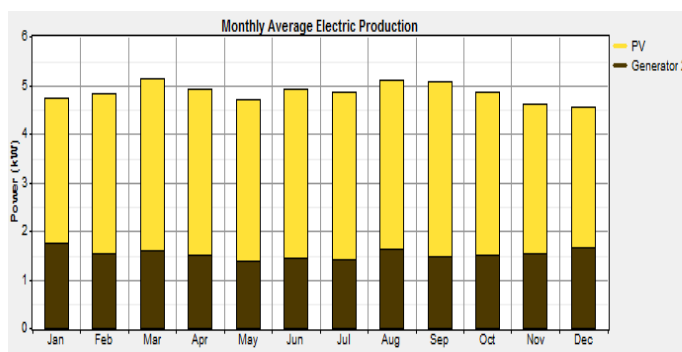

Fig.11: PV, Wind and Diesel Electric Production

5. *Wind Turbine and Fuel Cell:*

Fig.12 shows Design of Wind and Fuel Cell System.

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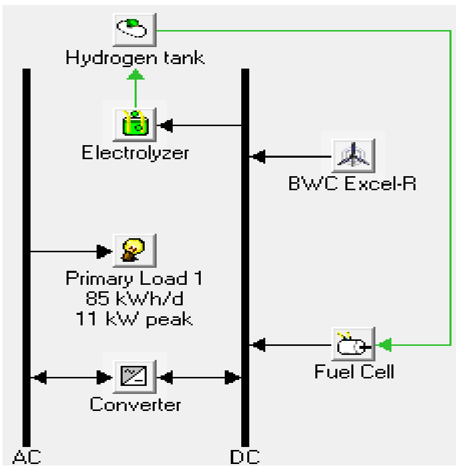

Fig.12: Wind and Fuel Cell System

The simulation results present the optimum combination: 7 BWC wind turbine, 7 KW Fuel Cell, 10 KW converter, 20 KW Electrolyzer and 25 kg hydrogen tank as shown in table (5) and Fig. (13) Shows the energy yield of the optimum solution.

Table.5
Wind and Fuel Cell Simulation Results.

	XLR	FC (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
	7	7	10	20	25	$ 303,000	11,334	$ 447,892	1.140	1.00	0.02	4,741

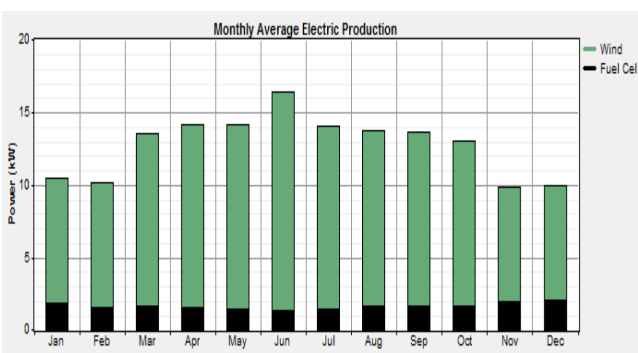

Fig.13: Wind and Fuel Cell Electric Production

6. PV and Fuel cell:

Fig.14 shows Design of PV and Fuel Cell System

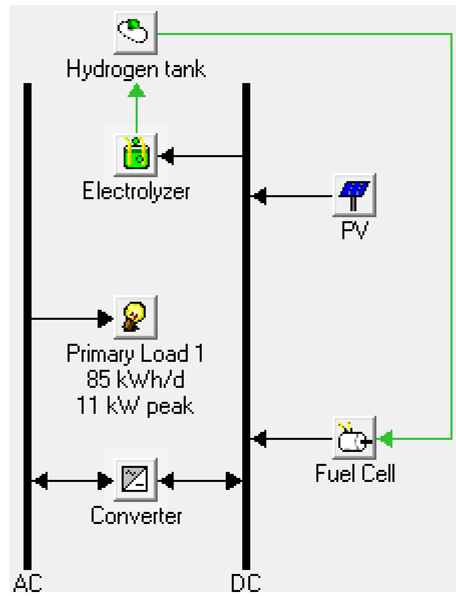

Fig.14: PV and Fuel Cell System

The Simulation Results don't present any optimum solution, no solution found.

7. Wind turbine, PV panels and Fuel cell:

Fig.15 shows Design of PV, Wind and Fuel Cell System

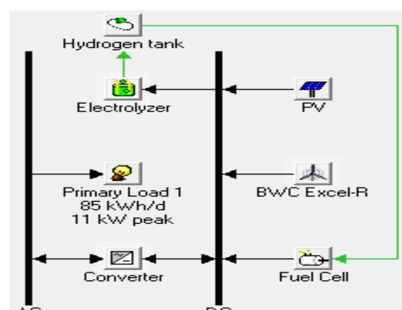

Fig.15: PV, Wind and Fuel Cell System

The simulation results present the optimum combination: 40 KW PV, 1 BWC wind turbine, 7 KW Fuel cell, 10 Kw Converter (Inverter & Rectifier), 17 KW Electrolyzer and 5 Kg hydrogen tank as shown in table (6) and Fig. (16) Shows the energy yield of the optimum solution.

Table.6
PV, Wind and Fuel Cell Simulation Results.

	PV (kW)	XLR	FC (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
	40	1	7	10	17	5	$ 140,000	8,506	$ 248,741	0.633	1.00	0.02	4,707

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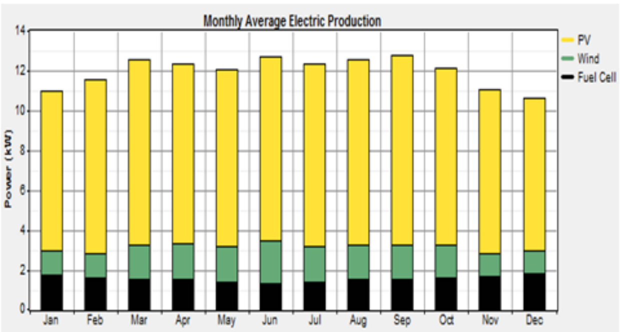

Fig.16: PV, Wind and Fuel Cell Electric Production

V. Load Shedding

Load Shedding is a preferred method of saving energy of the system. During certain times of the day, or during emergencies, large consumers of electricity will reduce their electricity usage, thus reducing the load on the system. This can save the cost of having extra components and reduce the cost of electricity for consumers. For Qena Al-Gadida loads a percentage of 20% of the peak load is reduced for the peak months (April, August) on the peak hour (18:00:19:00) as shown in **Eqn (1&2)**.

April load shedding= 7.053 kw - 20% ×7.053 kw = 5.6424 kw. **Eqn.1**

August load shedding= 7.437 kw - 20% ×7.437 kw =5.9496 kw. **Eqn.2**

Calculation of the optimum system (PV & diesel) after load shedding:

The simulation results present the optimum combination of (PV & diesel) system after load shedding For Qena Al-Gadida as shown in table (7).

Table.7
PV and Diesel Simulation Results after load shedding.

	PV (kW)	XLR	Label (kW)	L16P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
	18		3	20	6	LF	$ 32,490	5,283	$ 100,027	0.258	0.76	0.02	3,914	4,853

VI. Simulation Of Non-Renewable Energy System

Fig.17 shows Design of Non-Renewable Energy System for the selected site Qena Al-Gadida.

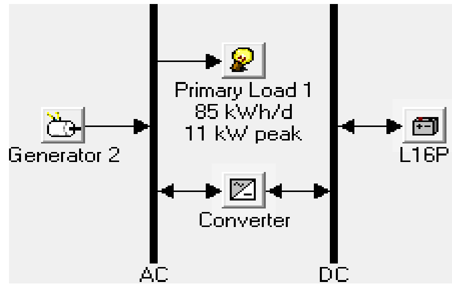

Fig.17: Non-Renewable Energy System

The simulation results present the optimum combination: 5 KW generator, 10 battery unit and 2 KW converter as shown in Table. (8) and Fig. (18) Shows the energy yield of the optimum solution.

Table.8
Non Renewable Energy System Simulation Results.

	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
	5	10	2	$ 9,734	10,560	$ 144,723	0.369	0.00	0.02	11,271	8,323
	7			$ 6,978	11,979	$ 160,111	0.408	0.00	0.02	12,787	8,760

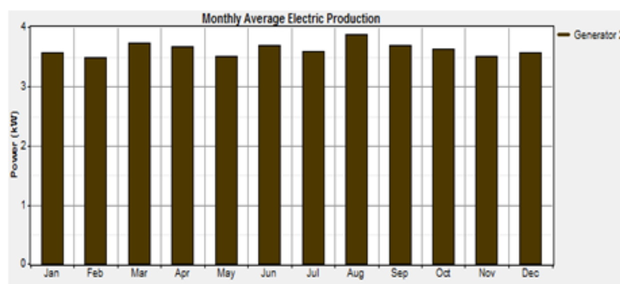

Fig.18: Non Renewable Energy System Electric Production

VII. Conclusion And Summary Of Results

The seven simulation results are summarized in table (9) showing the system architecture and economic value.

The results shows that the most optimum combination is PV and Diesel with Net Present Cost of 107,255 $ and cost of energy 0.271 $/kWh. Fig.19 shows Cash flow summary for PV and Diesel system of Qena Al-Gadida. Table (10) shows the optimum system (PV & diesel) before and after load shedding.

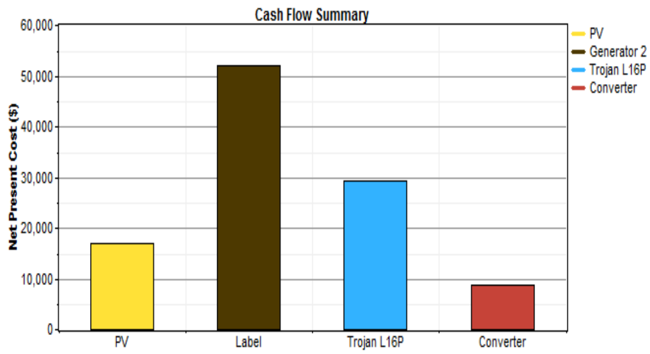

Fig.19: Cash flow summary of PV and Diesel system

Table.9
Comparison between the seven Simulation Results.

System	Architecture	Net Present Cost($)	Cost of energy ($/kwh)
Wind and Diesel	1 BWC WT 4 KW generator 10 L16P battery 4 KW converter	140,438	0.359
PV and Diesel	15 KW PV 3 KW generator 50 L16P battery 6 KW converter	107,255	0.271
PV and Wind	21 KW PV 0 BWC WT 100 L16P battery 10 KW converter	115,997	0.296
PV, Wind and Diesel	15 KW PV 3 KW generator 50 L16P battery 6 KW converter	107,255	0.271
Wind and Fuel Cell	7 BWC WT 7 KW FC 10 KW Converter 20 KW Electrolyzer 25 Kg Hydrogen Tank	447,892	1.140
PV and Fuel Cell	No Solution	No Solution	No Solution
Wind, PV and Fuel Cell	1 BWC WT 40 KW PV 7 KW FC 10 KW Converter 17 KW Electrolyzer 5 Kg Hydrogen Tank	248,741	0.633

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Table.10
the optimum system (PV & diesel) before and after load shedding.

City	Before Load shedding	After load shedding
Qena Al-Gadida	Net present cost: 107,255 $ Energy cost: 0.271 $/kwh System architecture: 15 KW PV 3KW generator 50 L16P battery 6 KW converter	Net present cost: 100,027 $ Energy cost: 0.258 $/kwh System architecture: 18 KW PV 3KW generator 20 L16P battery 6 KW converter

VIII. Qena Al-Gadida Gas Emissions Calculations

Table (11,12) present the reduction of pollutant emissions achieved by choosing to supply the load by the chosen hybrid system (PV and diesel) rather than by the non-renewable energy system (diesel generator) [13,14]. As tables show, the total amount of green house emission due to use of hybrid system is 14,746 kg/yr which is around 51.6 % less than use diesel system by 30,480 kg/yr. if we choose the combinations of (fuel cell), the percentage of reduction of gas emissions will increase in the three study cases but in our study we don't make only optimization of environmental matching but optimization of site matching and cost matching.

Table.11
Qena Al-Gadida Non-Renewable Energy System Gas Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	29,680
Carbon monoxide	73.3
Unburned hydrocarbons	8.12
Particulate matter	5.52
Sulfur dioxide	59.6
Nitrogen oxides	654

Table.12
Qena Al-Gadida Renewable Energy System Gas Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	14,359
Carbon monoxide	35.4
Unburned hydrocarbons	3.93
Particulate matter	2.67
Sulfur dioxide	28.8
Nitrogen oxides	316

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