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Design of hybrid Photovoltaic-Diesel system for Al-Sadder City in Baghdad-Iraq

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Abstract— **The country of Iraq has been struggling for the past couple of decades with electricity problems like inability to supply the demand which leads to continuous power outages. This problem could be dangerous on many levels and especially in critical applications where uninterruptable power supply is necessary like hospitals and military bases. The only solution presented is the use of electrical generators. Even though electrical generators are a reliable sources of energy, they seem to have many disadvantages like their reliability on fossil fuel (diesel in particular) and the Green House Gas (GHG) emissions which causes many health issues especially in populated areas where there are to designated areas to place these electrical generators. This health and safety hazard that costs a lot of money and gives little amount of electricity is not a cost-effective solution on the long term; where more maintenance and replacement is required. This paper presents a cost-effective solution by using a hybrid photovoltaic-diesel generator system, which can be used by the civilians and the government to lower the electricity demand and reduce GHG emissions. A hybrid system is proposed for Al-Sadder city to meet the electrical demands with initial costs, net present costs and energy costs are 39 M$, 1.11 M$ and 0.526 $/kWh, respectively. These costs show great promise in this research area and perhaps more developed microsystems in the future could be the real solution to Iraq's electricity problems.**

***Index Terms*— Power outage, photovoltaic, electrical generators, hybrid PV-diesel system, Green House Gas**

I. INTRODUCTION

Iraq is a country that is famous for its diverse biomes and many resources like rivers, mountains, beaches and deserts as it covers around 437,367 km2 of land and 950 km2 of water. With such outstanding resources Iraq should be the farthest from need especially when it comes to electricity, however due to political issues and the many wars Iraq went through during the last three decades a number of problems continued to last and no correct solution have been made to fix these problems [1]. One resource that Iraq has not taken advantage of is the sun. Lying between latitudes 29° and 38° N, and longitudes 39° and 49° E is a great advantage to the country, as this location seems to be vibrant with solar radiation [2].

Al Sadder city is the chosen area for this study due it having many power outages and a large population, considered one of the highest in population density, making it a perfect place to propose a new solution. Many factors are taken into consideration for this study including the environmental effect which could harm the people of the city as well [3]. Figure 1.1 shows a 2D image of al-Sadder city via Google Maps.

Fig. 1: 2D Map of Al-Sadr City, Baghdad-Iraq via Google Maps [1]

The reason photovoltaic (PV) are chosen as a solution to accompany the electrical generators is that PV relies on solar radiation and as discussed above Iraq seems to have high amounts of it [5]. The PV technology have many advantages as it is mobile, light in weight, free of maintenance, do not produce emissions or noise and above all it is relatively cheap to acquire by citizens as oppose to other renewable energy technologies, especially that its prices are on a downward trend and its efficiency is getting better as research continues, as well as more demand is in the market place [6]. The principle of operation of PV is very simple it is a semiconductor device that turns the lights photons into direct current. This is done a sub-atomic level where the photons energize the electrons on the valence band promoting them to conduction band, thus leaving a positively charges hole. This electron-hole pair is utilized with a barrier (a P-N junction) that creates a potential difference, which is then capitalized on through an external circuit with a load, leading to the flow of a Direct Current (DC) [7]. Different types of PV exist depending on the material used in the building process such as amorphous silicon, mono-crystalline and poly-crystalline. Choosing the right configuration and location for these devices require research and design, like this study [8].

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II. Literature Review

Due to the global control of the fossil fuel industry alongside politics renewable energy is still not considered as a primary source of energy to satisfy industries [9]. Other reasons might be due to insufficient research in the field as well as problems of cost effectiveness [10]. However, in order for renewable energy application to expand and become more predominant, research must be made and focused on solving global issues like climate change through green energy, and energy inequality [11]. Since solar power is still not in a stage where it can totally replace fossil fuels, this paper was written to join the PV technology to the electrical generators which are fuel dependent [12]. This is considered a powerful combination due to the fact that it has improved reliability, reduced carbon emissions and energy supply for 24 hours over the course of the year. Sopian et al. (2005) [13], proposed the use of a PV-Diesel hybrid system which was installed and tested for operation (successfully) in the middle and top stations of the Langkawi Cable Car resort facilities. The system has the diesel generator as a secondary source of energy as it operates only when the battery is out of charge or excess loaded is needed to be satisfied. The researchers used 60 kVA for the diesel generator and an 8 kW PV-Array and concluded that this combination actually is better for the environment than a sole diesel system, as well as its ability to serve the load all of the time, and lower maintenance cost of diesel generator due to less hours of operation.

Fischmann(2008) [14] provided an example of a mining site in South Africa with 2×800 kVA Perkins Gensets and a 500 kVA grid connection which is upgraded with 1 MWp PV. This is a clear example of a hybrid PV-Genset system and it shows that it saves about 450,000 liters of diesel. This is another successful system that is implemented in a crucial application in mining.

Alwaeli et al. (2016) [15] presented a study to design a PV system configuration with best cost technology. The numerical analysis was conducted using HOMER software and REPS.OM. HOMER configuration indicated an energy cost of 0.315 USD/kWh. The study showed the great promising future for photovoltaic technology and its implementation in the Sultanate of Oman.

Kazem & Chaichan (2016) [16] outlined a design of a system that can supply electrical power in the desert areas of Oman. The study examined different parameters affected the PV system as solar radiation intensity, temperature, and system costs. These parameters were taken into consideration utilizing HOMER programming to explore the ideal and solar PV frameworks.

Chaichan et al. (2016) [17] analyzed the design of a hybrid system of PV/ diesel engine used to supply 10kW Telecommunication Tower in Al-Buraimi, Oman. The optimized solution was studied using the Homer software. The results were indicated as the proficient energy system for the required load. The results showed that the best PV system must be of 50kW with a starting cost of 143.402$, the net present expense of the system was 324.569$, and the energy cost is 0.29 $/kWh. When the diesel generator power cost was evaluated it revealed that the system energy cost 0.584$ while the standalone PV system energy cost was 0.344$. The study concluded that the use of a hybrid PV/diesel system to power telecommunication tower in Al-Buraimi, Oman can be considered as the best choice based on the resulted energy cost.

Kazem et al (2016) [18] investigated the electrical energy requirements to supply an isolated island of Masirah in Oman. The possibility of using renewable energy with the current diesel generators to meet the electrical power demand was studied. The study evaluated the use of two renewables, solar and wind energies. HOMER software was used in the study, and the results proposed different technologies contained solar photovoltaic, wind turbine, and diesel generators in addition to storage batteries for electrical generation. The results revealed that the cost of energy can be reduced by 75 % when the proposed PV/wind/diesel hybrid power system is utilized. In the same time, the greenhouse emissions would be reduced about 25 % compared to the diesel generators system emitted gases

From this survey; The PV-Diesel hybrid system is cost-effective and more reliable than its conventional counterpart with the advantage of being more environmental friendly. Some researchers prefer using the intuitive method, however more details and accuracy is achieved via the numerical method using various tools like HOMER software which seems to be the leading software in this field. HOMER offers its user complete energy analysis as well as cost [19-45].

The aim of this article is to introduce a practical and efficient solution for Al-Sadder city, which is facing the electricity shortage problems (as all Iraqi cities). This particular set-up shows more potential to solve problems of reliability and pollution from energy sources. Also hybrid PV/Diesel systems seemed to produce more and considered more reliable for the load.

III. Design aspects

Based on literature survey it appears that the HOMER software is an effective tool to design and simulate micro-grid systems. It is important to provide the software with real-date input such as average monthly solar radiation data, required application/load demand; technologies intended to provide power, etc.

HOMER software will then simulate the data proposed and will present the best configurations on a list and display the optimal system configuration on top of that list.

Al-Sadder city is located 33.3899° N, 44.4607° E it has an estimated population of around 3,500,000 people living in a round 1 million residents. This truly shows the level of population density and need for electricity, especially during summertime where air conditioners are necessary for a healthy and comfortable living. Before starting the HOMER design and analysis, 5 important topics must be discussed.

A) Photovoltaic specifications

For consistency reasons, one type of PV is chosen for this study, the PV panel chosen is a 200 Wp module, a maximum voltage of 17.7 V, a maximum current of 11.30 A, an Open Circuit (OC) Voltage of 22.1 V and a Short Circuit (SC) current of 12.68 A. The efficiency of this module is 13.9%. As for the temperature coefficients; the temperature coefficient of

Voc = 0.36%/K and the temperature coefficient of Isc = 0.06 %/K.

B) Electrical Generators in Al-Sadder city and chosen specifications for research

The number of electrical generators in Al-Sadder city is about 661 generator distributed across the city which contains about 82 sectors. Majority of sectors carry about 10 generators. Al-Waeely et al. [3] provided percentages of people whom own generators with different ratings (in kVA) from a sample of 60 owners. The majority, whom represent about 36.8%, use generators with 350 kVA and above, this produce electricity to people whom subscribe to them. The rest of generators owned with following ratings; 150 kVA (represent 18.3%), 200 kVA (represent 18.3%) and 250 kVA (represent 26,6%). Based on these percentages total rating of all generators combined is about 171400 kVA, and with a power factor of 0.9 the power of these generators is around 154.3 MW.

C) Set up locations

The location in which the hybrid system is setup is very important and it must be noted that the PV and the generator do not have to be in the same exact location as wires and cables can connect them as a single unit. Photovoltaics can be placed on roofs where they are subjected to solar radiation and no shadow and because they do not produce noise. Electrical generators however need to be placed at a safe distance from actual place of living, a suggestion can be made is to place the generators in basements with ventilation system. Being placed in the basement is good to protect them from theft, high ambient temperatures which may cause explosion, and noise that may disrupt neighbors.

D) Tilt Angle

The tilt angle is the angle choosing for fixed solar cells in order to get the most solar radiation on average annually. Many researchers and companies use tilt angle same to the latitude of the installation place. Consumer should then add 15 degrees to tilt angle in winter and subtracts 15 degrees in summer. Tilt angle chosen for Al-Sadder city is 33.4° ± 15°.

F) The technical design aspect

The Stand-alone PV system requires a number of devices/equipment to complete the system; like batteries, charge controllers, inverters and connected wires. The batteries will store the produced DC current during daytime, while change controller will regulate the voltage and protect both the battery and the PV module. The inverter will turn the DC current into Alternating Current (AC) so it can be used by home applications, majority of which are AC powered application.
The stand-alone technique is a smart method; however for such fluctuating grid, support of a grid-tie PV panel on a large scale can save the grid from electrical outages and perhaps improve the grids stability. However, this is not the point of the research.

Furthermore, in order to design a hybrid system with a primary source like a generator and a secondary source like a PV module a number of notes must be taken into consideration.
1) The solar cells sole job is to back-up the generators or to reduce the load.
2) Users will have to compromise between illumination applications and air conditioning, however with solar cells in-place; users can use the generator power for air conditioning and the PV power for illumination and other small home applications.
3) The solar cell does not require maintenance and has a longer lifetime than the generator; this means that the hybrid system will have more than a generator during its lifetime.

IV. Proposed System Configuration

A) Inputs to HOMER Software

A 33.4° tilt angle is chosen as explained above, and to suit the Iraqi solar radiation for HOMER the following data downloaded from NASA website is used as solar resources input, the data is shown in Table 1. Table 1 shows Monthly Averaged Insolation Incident on a Horizontal Surface (kWh/m^2/day) for Baghdad (Latitude 33.39, Longitude 44.461).

Table 1: NASA monthly averaged insolation data of Al-Sadr city [22]

Month	Monthly Averaged Insolation (kWh/m^2/day)
1	2.96
2	4.03
3	4.98
4	5.39
5	6.48
6	7.56
7	7.00
8	6.71
9	5.55
10	3.98
11	2.98
12	2.62

The annual interest rates of Iraq for the year of 2016 are about 6%. The prices of diesel per liter are 0.86 USD/L which is the global price of diesel for 22nd of August 2016 [23].

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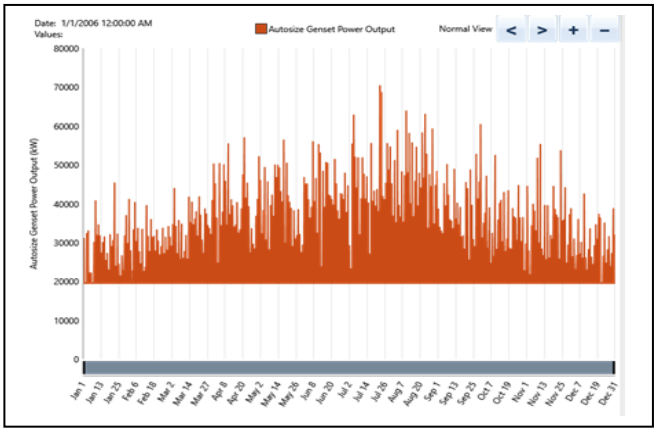
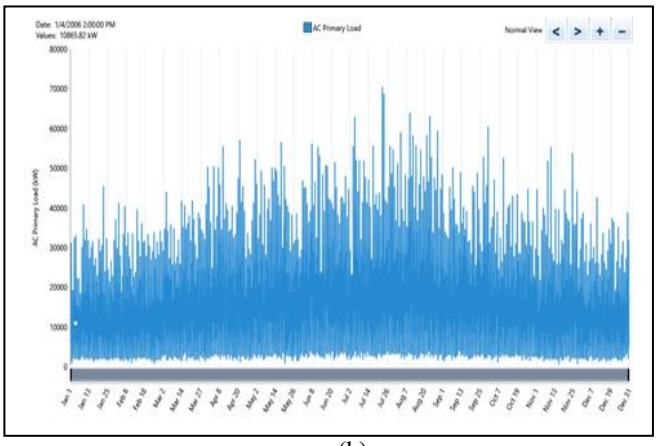
B) HOMER configuration for diesel generators

Currently, diesel generator is used to supply the load in Al-Sadder city. The schematic of the system with different component has been modeled in HOMER. Figure 2 shows the load in Al-Sadder city and power generated by the diesel generator. The primary load is 120,861,720 kWh/yr with excess electricity 34.4% and 27% capacity factor. The total fuel consumed per day is 143,123. It is found that the diesel generator fulfill the required demand. The cost assumption for the system are: capital cost $39,000,00, O&M cost $356,941,666 , and fuel cost $454,779,997. The simulation results found that NPC is $1.22B and the CoE is $0.582.



(a)

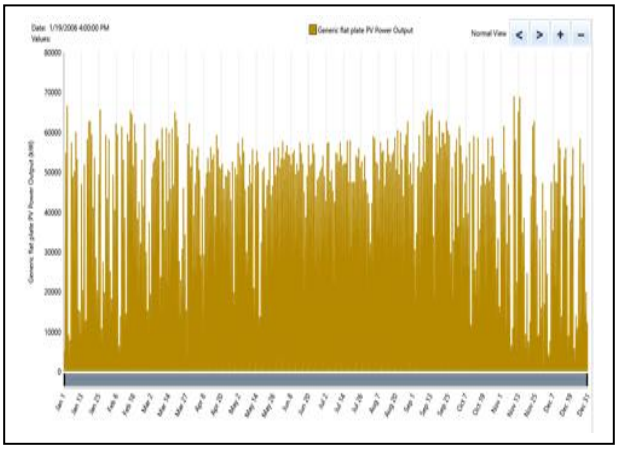


(b)

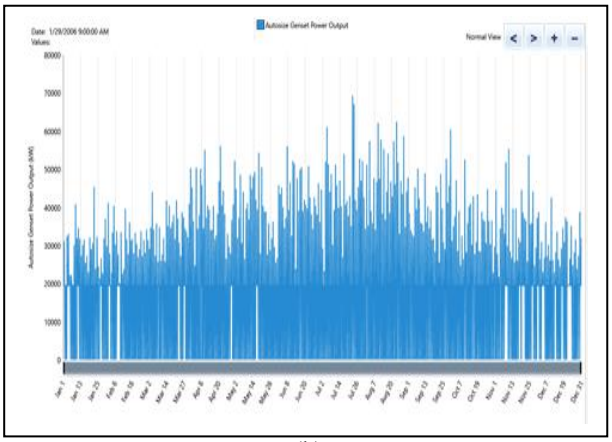
Fig. 2: (a) Power generated by diesel generator, (b) Electrical load in Al-Sadder city

C) HOMER configuration for hybrid

The hybrid system of PV/Diesel generators has been modeled and simulated by HOMER to evaluate the feasibility of the system. The cost assumption for the system is: PV capital cost 201,781,125, O&M cost $11,712,148 and fuel cost is $0, diesel generator capital cost $39,000,000, O&M cost $356,941,666, and fuel cost $454,779,997. The simulation results found that NPC is $1.11B and the CoE is $0.526. Figure 3 shows the power generated by PV and diesel generators. It is clear seen that there is a good sharing between the two technologies is providing power to the load. The total fuel consumed per day is 104,417.



(a)



(b)

Fig. 3: Power generated by (a) PV, (b) diesel generator

V. ENVIRONMENTAL RESULTS

Table 2 shows greenhouse gases for the two systems (diesel generators system hybrid PV/diesel generators system).
The emission of Carbone dioxide, Carbone monoxide, unburned hydrocarbons, particular matter, sulfur dioxide and Nitrogen oxides by using only diesel generators are the largest comparing with the hybrid system. The emission of unburned hydrocarbons is the minimum by using hybrid power system that has diesel generators and PV panel system comparing with only diesel system.

VI. CONCLUSION

This paper presented the effective way of using renewable resources in Baghdad to support supplying electricity with installed old diesel generator in Al-Sadder city. The PV is used supporting diesel generators. HOMER is used to calculate and evaluate, design, and analyze performance of the system based on supplied by NASA and hybrid system PV/diesel life time

for 25 years. As well, installed system diesel generators have been investigated, and it found Net Present Cost (NPC) is $1.22M with Operation Cost of 68.1M $/year and the Cost Of Energy (COE) equals to 0.582 $/kWh. Whereas by using supporting Hybrid system of renewable energy of PV/diesel with old system found The total net present cost (NPC) is $1.11M with Operation Cost of 49.7M $/year and the Cost Of Energy (CoE) equals to 0.526 $/kWh. Moreover, using old installed Diesel generators have badly impact to our environment. The study has shown that there is a good reduction in the greenhouse gases emission in the case of hybrid system. In conclusion it is feasible to use hybrid system PV/Diesel for Al-Sadder city in term of economic and environmental side views.

Table 2: Greenhouse gases for the diesel and proposed systems

Pollutant	Emission (Diesel generators system) (kg/yr)	Emission (Diesel generators and PV system) (kg/yr)
Carbone dioxide	137,549,564.29	100,350,198.43
Carbone monoxide	339,521.61	247,700.25
Unburned hydrocarbons	37,608.55	27,437.57
Particular matter	25,594.71	18,672.79
Sulfur dioxide	276,223.50	201,520.69
Nitrogen oxides	3,029,577.46	2,210,248.36
Total	141,258,090.12	103,055,778.09

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