Design of Hybrid Solar PV Diesel Mini Grids in Iraq

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ABSTRACT:

Hybrid system based on photovoltaic is considered an effective option to electrify remote and isolated areas far from grid. This is true for areas that receive high averages of solar radiation annually. Using diesel generator as a standby source will make utilization of hybrid systems more attractive. An economic feasibility study and a complete design of a hybrid system consisting of photovoltaic (PV) panels, a diesel generator as a backup power source and a battery system supplying a small community in Baghdad were presented in this paper. Specifications of the hybrid system components are then determined according to the optimized values.

A new concept in power generation is a micro-grid. A micro-grid involves connecting several small alternative power sources in addition to the main grid on a particular site. Some examples where it could be used would be an offices, houses , industrial site or shopping centre. Little is known about micro-grid behavior on the whole. Some models exist which describe the components of a micro-grid, although to date a successful model of an entire micro-grid system has not been developed.

Two areas were chosen to do this research . Currently models of a photovoltaic array, a wind turbine and a gas turbine have been developed. These are connected to a load and the mains power supply.

1.INTRODUCTION:

Different types of renewable energy sources are nowadays used to supply different applications in rural and urban areas [1]. Increased reliability and energy security issues are of the most benefits that can be achieved by using hybrid renewable systems [1,2]. Hybrid systems that depend on photovoltaic (PV) are considered the most popular among other types of renewable systems. The main advantages of this technology are their low maintenance costs and low pollutant emissions [3]. In this paper, a hybrid PV–diesel generator–battery system for generation of electric energy for a small Iraqi community is analyzed. The block diagram of this system is shown in Figure 1. The type of the hybrid system and its configuration depend mainly on the availability of the renewable source in the location selected for installing this hybrid system. For this case, the average daily solar radiation intensity on a horizontal surface is about 5.6 kWh/m2 while the total annual sunshine hours amounts to about 3000 hours. These values are relatively considered high and very encouraging for using PV generators. For the optimized tilted surface, it is found that this average is about 6.1 kWh/m2. The highest averages are in summer months (June to August). Optimization of sizes of different components constructing the hybrid system is one of the important issues that shall be considered while designing this system. Maximizing utilization of the renewable source, minimizing the cost of generating energy and minimizing the pollutant emissions are objective functions of this optimization. It has concluded that a PV/diesel generator hybrid system is the more feasible system compared to a diesel generator system or standalone PV system for Iraqi case. It has used software to optimize a suggested PV/diesel hybrid system in Iraq that has a climate that approximately likes climate of Baghdad. He has reached to the conclusion that the most optimal configuration in for the experiment that involves PV and diesel. A similar study done for a village in Iraq, it [6] has suggested many configurations of the desired system using different types and sizes of components to select the optimal one. In this paper, different components making the hybrid system shall be modeled, studied, specified, and chosen appropriately to minimize the system cost. Data analysis of solar radiation measurements are also reviewed and studied in this paper. It is assumed that the optimized configuration shall fulfill the load requirement for each hour in the year (no interruption of power system).[5]

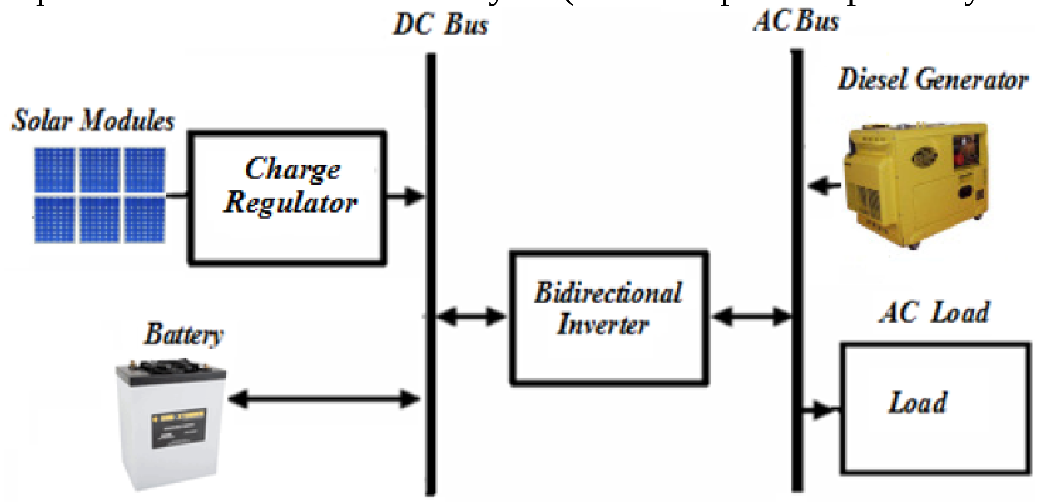

Fig.(1) Blockdiagram of PV Desiel system [6]

In this paper the economic analysis is done based on life cycle costing method where all types of costs for different components (initial costs, maintenance costs, fuel and operation costs, replacement costs, and salvage value) are taken into account. Cost of energy (COE) which is the cost required to produce 1 kWh is the indicator used in the optimization process. It is the ratio between the total annual cost and the total annual energy required by the load. Different economic factors that affect the value of money over the life time of the project are also considered. These rates are: inflation rate and discount rate. The life cycle period of the project is considered 24 years. It is the life cycle of the component that has maximum life time. Figure(2)shows a typical hourly load curve. [7,8]

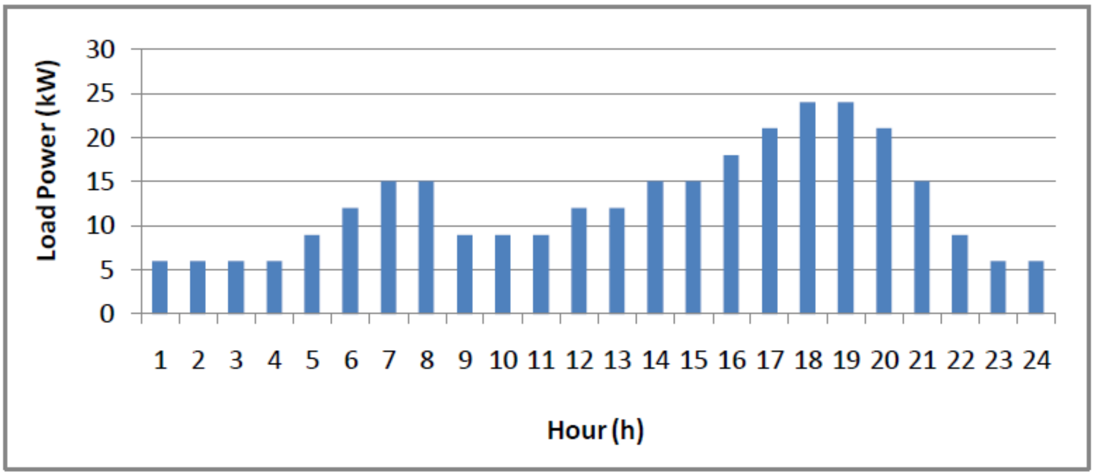

Fig.(2) A typical hourly load curve

Small scale hybrid power systems offer a means to quickly electrify areas that have little chance of being connected to a centralized grid in the foreseeable future. Hybrid power systems combine two or more electricity generation methods, like diesel engines and solar panels, into a single plant to reduce long term generation costs. While it is possible to find governments or organizations to fund the capital cost of an electrification project, recurring costs over the life of the system can be as large as or larger than capital costs. [9]

Without a community being able to regularly generate funds to pay for salaries, fuel, and replacement parts, an electricity plant will quickly cease operating. The principle advantage of a hybrid plant is its ability to affordably extend reliable electricity access into remote communities. [10]

2. MODELLING OF THE SOLAR-DIESEL HYBRID POWER SYSTEM:

By modeling, we mean re-producing different system configurations (power system sizes) and the associated costs (investment costs and electricity generation costs), based on different input conditions/ parameters (such as Electric Load, Solar Insolation, Solar penetration, etc). There will be 3 outcomes from this modeling:

1. Power System sizing for different input conditions/ parameters
2. Investment Costs and the Levelized Cost of Electricity generations for different input conditions/ parameters.
3. Savings on the GHG emissions. [12]

The focal point of our study is area 1 for which we will also consider different experiments for sensitivity analysis. We shall also present the modeling for Baghdad. We will present our indicative technical configuration of the proposed Solar-Diesel Hybrid System. For this, we utilized learning from our recent training program at University of Technology.

Also we will present our methodology for developing the excel sheet tool that can model the Solar-Diesel Hybrid Power System, based on different input parameters. For developing this tool, we utilized learning from our university and our experience at Baghdad Iraq. [13]

2.1. Indicative Technical Configuration of the proposed Solar-Diesel Hybrid Power System:

A Hybrid Power system is that power supply system which utilizes two or more power sources. This helps in improving the reliability of the system as there is less reliance on one method of power production. Solar Diesel Hybrid System utilizes solar and Diesel as the power supply and battery as the power backup. A Power converter system is an important component of Hybrid System that controls the power supply and power backup system in the most efficient manner. The Figure1 below shows the indicative configuration of the proposed Solar-Diesel. Hybrid Power system. This is on the lines of a system. [14,15]

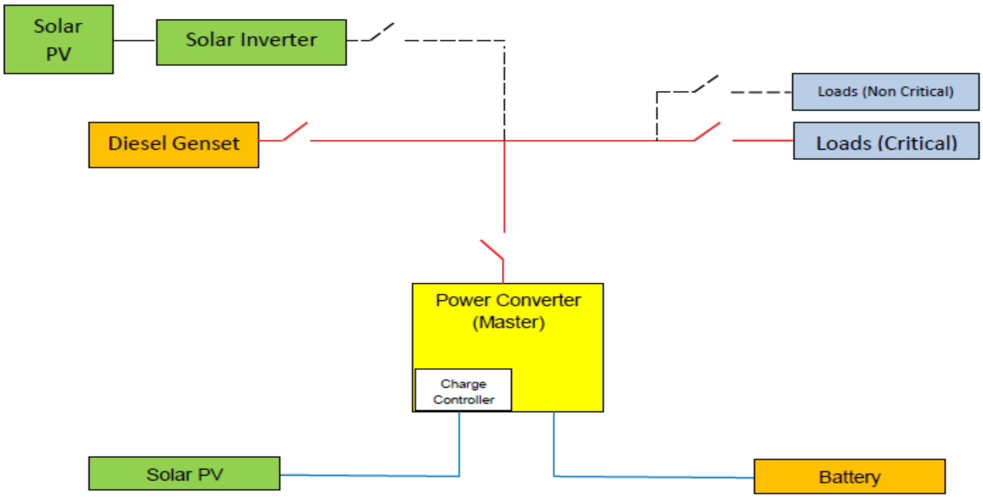

Fig.(3) the inductive configuration of the proposed solar-diesel [16]

2.2 Problems with Diesel Mini Grids and the need for Renewable Energy:

In the earlier paragraphs, we observed that almost entire Off grid sector in Iraq is based on Diesel Genset. However, there are serious problems with Diesel Electrifications:

1. **High Cost of Electricity Generation-** Diesel is already quiet expensive in Iraq and transportation cost of Diesel to Iraq further increases the cost. Figure(4) below indicates the Regional Oil prices which dictates Oil Prices in Iraq. [17]
2. **Carbon Emissions with Diesel Genset**: A Diesel Genset generally emits 750 Grams of CO2 with production of 1 KWh of electricity. This emission rate can go higher in case of Oil based electricity generation. [17]
3. **Problems with Partial Load of operation of Diesel Genset-** Diesel Gensets have an inherent problem that when they operate at partial load , then its fuel efficiency decreases significantly. Generally a Diesel Genset requires around 300 ml of Diesel for generating 1 unit of electricity, however at partial load, this requirement increases. Figure(4) below presents the drop of fuel efficiency at partial load

Generator Size (kW)	1/4 Load (gal/hr)	1/2 Load (gal/hr)	3/4 Load (gal/hr)	Full Load (gal/hr)
20	0.6	0.9	1.3	1.6
30	1.3	1.8	2.4	2.9
40	1.6	2.3	3.2	4.0
60	1.8	2.9	3.8	4.8
75	2.4	3.4	4.6	6.1
100	2.6	4.1	5.8	7.4
125	3.1	5.0	7.1	9.1
135	3.3	5.4	7.6	9.8
150	3.6	5.9	8.4	10.9
175	4.1	6.8	9.7	12.7
200	4.7	7.7	11.0	14.4
230	5.3	8.8	12.5	16.6
250	5.7	9.5	13.6	18.0
300	6.8	11.3	16.1	21.5
350	7.9	13.1	18.7	25.1
400	8.9	14.9	21.3	28.6
500	11.0	18.5	26.4	35.7
600	13.2	22.0	31.5	42.8
750	16.3	27.4	39.3	53.4
1000	21.6	36.4	52.1	71.1

Fig.(4) the fuel efficiency with load [18]

This figure(4) shows that how the fuel efficiency drops at partial load operation.

4. Fuel Shortage also cause power interruption and anger amongst people:

Thus, in this research, we saw that Off-grid Electrification in Iraq is majorly based on Diesel and this Diesel based electrification is highly subsidized. High cost of Diesel makes the electricity cost very high and a huge financial burden. This brings in a strong case of Renewable Energy based Off-grid electrification. [19]

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The heart of the system is the Power Converter which will form the Grid and will be the Master of the system. On DC power supply side, it will have connection to the battery and the Solar PV (through a charge controller). DC side is depicted by blue line. On AC Power supply side, it is connected to Diesel Genset and it can also be connected to an external solar inverter. Diesel Genset is connected through a switch which can be made ON and OFF as per the system requirement. AC side is depicted by red line. [21]

3.2: Methodology for Modelling the Hybrid Power System:

Load Profile (area one):

The first step is to gather the hourly load profile. Presented below is the typical load profile for area 1 and area 2. This data is from the scoping mission.

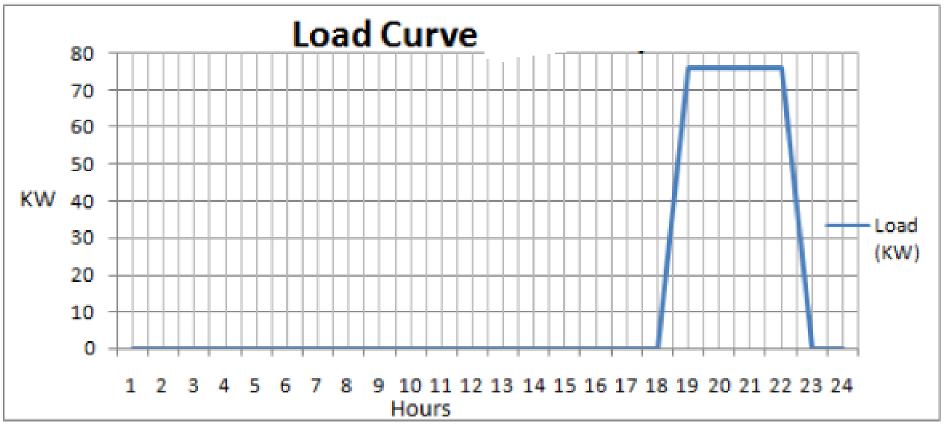

Fig.(5) The load curve of area one

Figure(5) presents the load curve for area 1, which shows a load of 76 KW between 6 pm and 10 pm. This load is same throughout the year. [22]

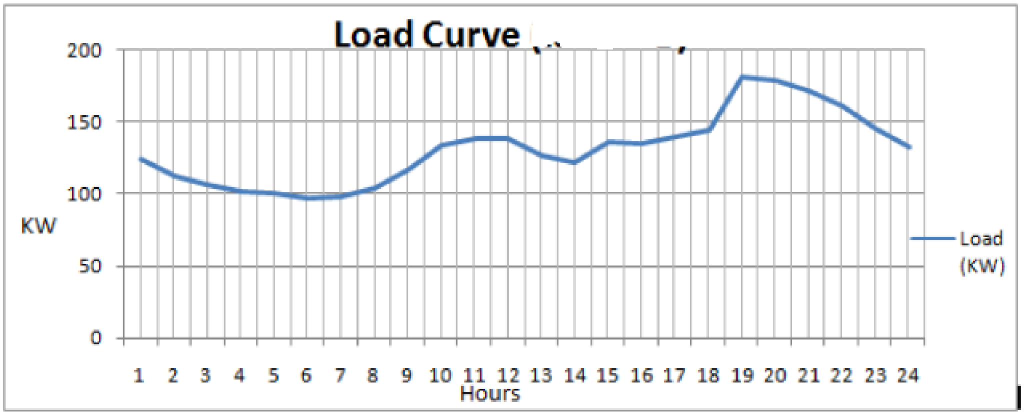

Fig.(6) The load curve of area two

Figure (6) presents the typical load curve for area 2. It shows the maximum load of 180KW between 7 pm to 8 pm and minimum load is around 100 KW between 6 pm to 7 pm.

Solar Isolation:

The second step is to consolidate the Solar Isolation data. I got the Average Monthly Solar Isolation data for Iraq from the report "Assessment of Solar Resources in Iraq" under the project "Iraq Renewable Energy Project" submitted by NREL. Figure(7) below presents the data in the form of graph. This data is based on NREL's Climatological Solar Radiation (CSR) model. [23]

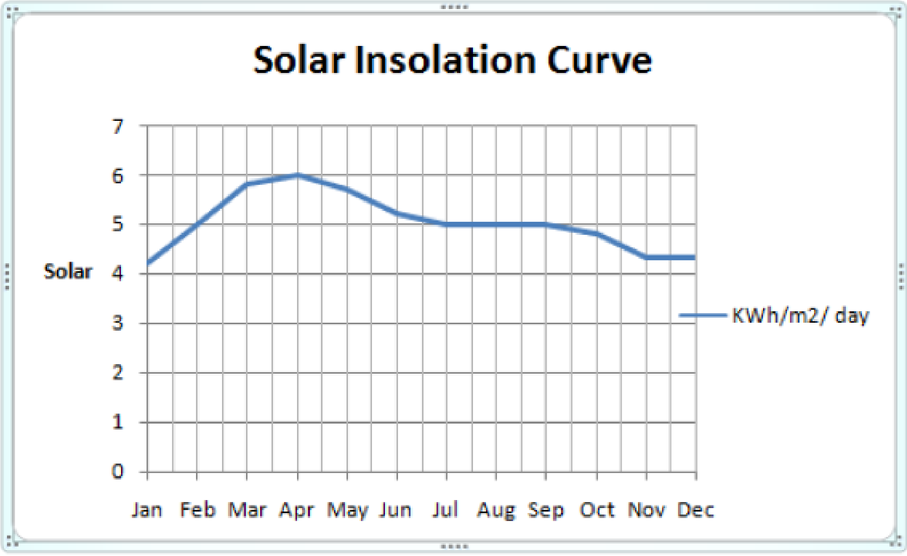

Fig.(7) solar isolation curve

This graph shows that April is the month of maximum solar isolation where isolation can reach 6KWh/m2/day. December-January is the period of minimum solar isolation. The average yearly Solar Isolation was around 5.03 KWh/ m2/day. [24]

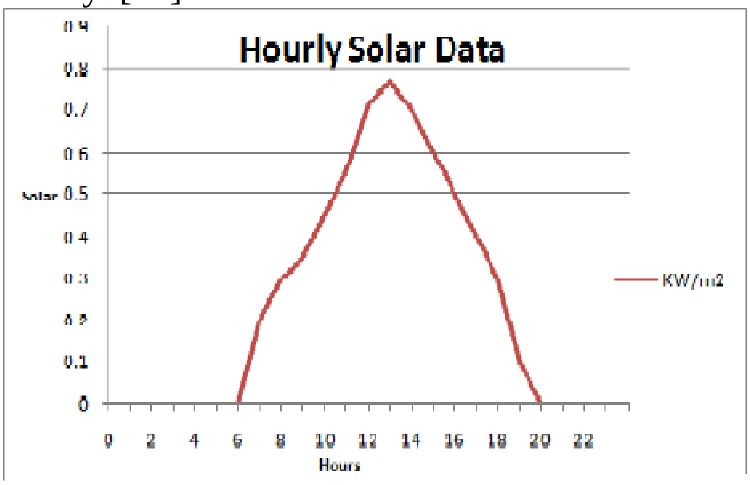

Fig.(8) The hourly solar data

As depicted in the graph, in figure(8) the maximum solar irradiance was between 12pm and 1 pm and it was around 0.75KW/m2.

Sizing of the Solar PV:

Once we have Load data and Solar Isolation data, next step is to size the required Solar PV. For sizing Solar PV, I used the very simple formula as mentioned below:

Solar PV Capacity required (PV) = (Daily Electricity Requirement (Ed)*Solar Fraction)/ (Maximum Energy Yield of PV *Efficiency of solar electricity production)

Sizing of the Power Converter (Master):

Power Converter is the central unit which controls the power generation, energy storage and interacts with the load. The size of the Master should be equal to the maximum power requirement of load at any point of time. Therefore Wattage of Power Converter should be equivalent to P_{max} (with a flexibility of 5% over capacity). However, if the Solar Fraction is zero, we will only utilize Diesel Genset and therefore Power Converter will not be used.

Sizing of the Battery Bank :

Battery Bank absorbs the electricity from Solar in day time and provides to load during night time. The size of the battery bank can be calculated .

Sizing of Diesel requirement :

Step 3 gave us the size of PV. Step 2 gave us the Sd (average daily solar isolation in each month). Daily Solar Electricity Yield can be calculated as: Size of Solar PV *Sd. This was further matched with the daily load requirement. [25]

Sizing of the CO2 emissions :

CO2 emission for hybrid system:

Step 7 gave us the daily electricity production from Solar and Diesel. As a rule of thumb, 750 grams of CO2 is produced while generating 1KWh of Diesel electricity and 36 grams of CO2 is produced while generating 1KWh of solar electricity. In this way, we calculated the CO2 emissions for generating a particular number of electricity units.

Financial Modeling :

In the above eight steps, we were able to size the Power Supply System. Now, in this step,we will explain my strategy to model the Levelized Cost of electricity generation. [25]

4.RESULTS OF THE MODELING OF SOLAR-DIESEL HYBRID SYSTEM FOR area 1 and area 2:

PV data analysis results analysis of the available hourly PV data for a one year shows that yearly average daily solar radiation on a horizontal surface amounts to 5.6 kWh/m2. Figure (9) shows yearly energy generated by a 1 kW PV array for different tilted angles in the location considered where hourly data for solar radiation and ambient temperatures are available. It is obvious that the optimum tilted angle is at 30 º. The yearly average daily solar radiation is 6.1 kWh/m2 at this optimum tilted angle.[26]

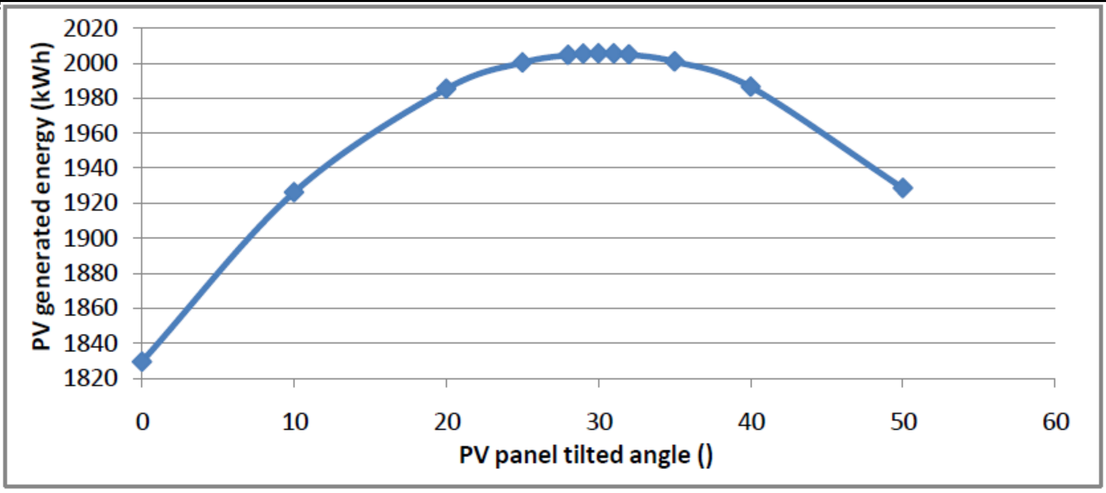

Fig.(9) Effect of tilted angle variation on PV generated energy

Figure (10) shows the contribution of the PV modules and the diesel generator in supplying the load in each month in the year. It is obvious that the diesel generator is off in months May to September where the solar radiation in these months is high.

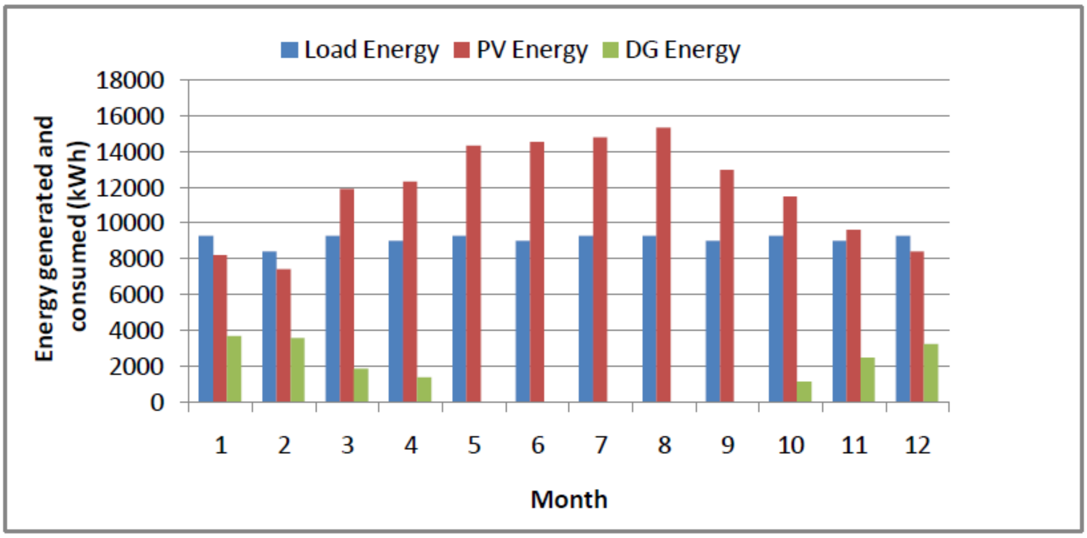

Fig.(10) Energy contribution of PV and diesel generator in each month

Hybrid system design The recommended voltage for the DC bus for this hybrid system is 220 V. Other specifications and design issues of main components making his hybrid system are shown in Table(1).

Component	Specification	Number	
PV Modules	Each PV module has 200 Wp,26.3 V as Vmp, and 32.9 V as Voc	Number of series PV modules in each string	11
		Number of parallel strings	32
Battery system	Each battery has 2 V DC and 400 Ah	Number of series batteries in each string	110
		Number of parallel strings	4
Diesel Generator	30 kW, 3ph, 400 V, 50Hz		1
Charge Controller	30 kW, 360 V input, 220 V output		1
Bidirectional Inverter	30 kW, 400 V, 3-ph ac ouput, 220 V DC input		1

Table(1) Specifications of different components constructing the hybrid system

4.1: Different Load Experiments for area one:

Based on the household survey, we got the electric load pattern in the area 1 . we utilized this load pattern to size the solar-Diesel hybrid mini grid. Further, we felt that there can be some changes in the load pattern in the near future and we made two extra experiments.

Experiment1: System is sized as per the existing load requirement (as per the load curve generated from the household survey) [27]

Timings	Load	Assumption
s 6 pm to 10 pm	76KW	Load as per the survey results

Experiment 1

Experiment2: In my load survey, I had found that there were around 50% households which did not have TV. However, these households showed a great aspiration of having TVs in the near future. Further, a few percentage of households also showed the aspiration of having refrigerators in the near future.

Timings	Load	Assumption
6 pm to 10 pm	170KW	Load as per the survey results + TVs in all the remaining households+ Refrigerators in 20% households
10pm to 12 am	145 KW	Loads of Lights + TVs + Refrigerators

Experiment 2

4.2: Modelling results for Area 1-Experiment 1:

The figure(5) below gives the actual load profile of area 1. It shows a load of 76KW between 6 pm to 10 pm.

Effect of different Solar PV costs on the Levelized Cost of Electricity:

The graph below in figure(11) shows the impact of different PV costs on the Levelized Cost of Electricity. The discount rate is kept constant at 10%.

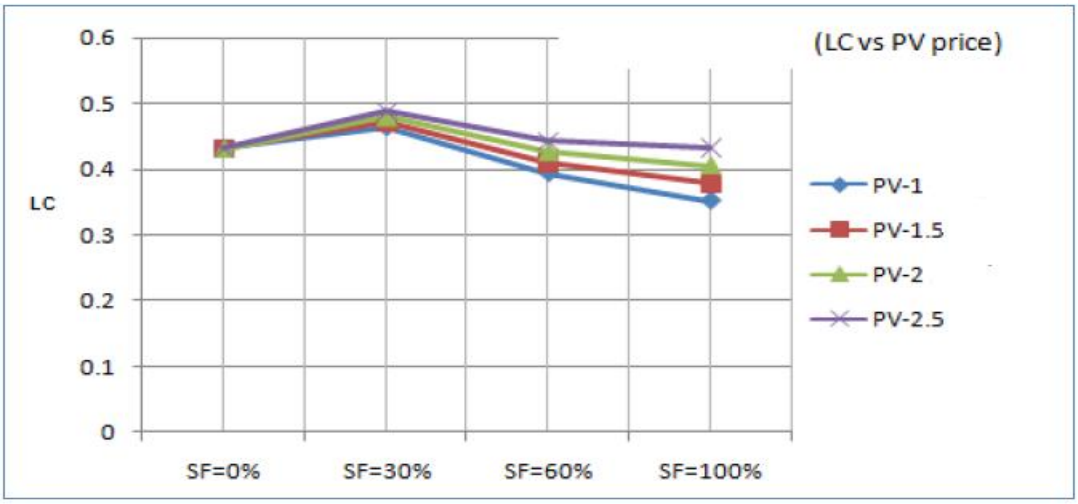

Fig.(11)Different PV costs of Electricity

4.3: Modelling results for area 1-Experiment 2:

Figure(12) Shown below is the load curve of area 1 -Experiment 2 . It shows the load of 170KW between 6 pm to 10pm and load of 145KW between 10 pm and 12 am.

Now applying the Experiment 2-Load profile to the excel application, we got the below mentioned results. [27]

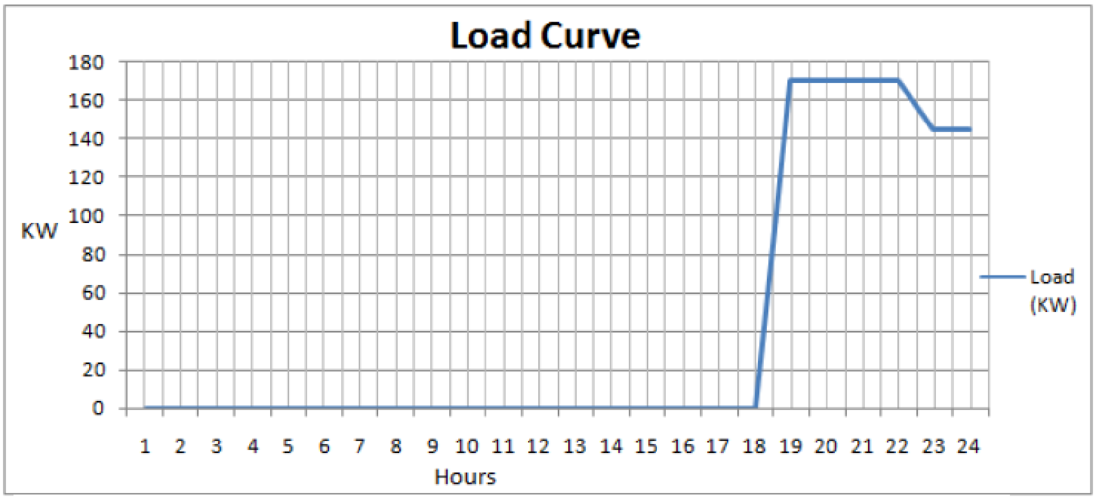

Fig.(12) The load curve for Experiment 2

Effect of different Discount Rates on the Levelized Cost of Electricity (LC) as shown in figure (13) below.

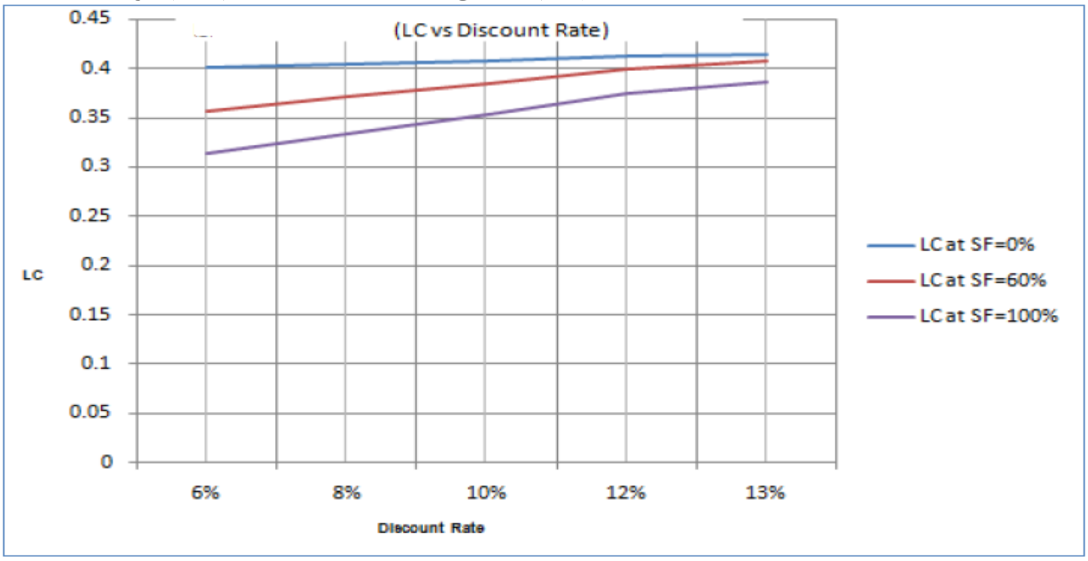

Fig.(13) Cost of Electricity vs discount rate

4.4: Modelling results for Area 2:

Area 2 has a bigger Electric Load, with a significant Load in the day time. System modeling for area 2 will also help us in understanding the impact of solar penetration in the above mentioned experiment.

The graph in figure(14) below presents a typical daily load profile of area 2.

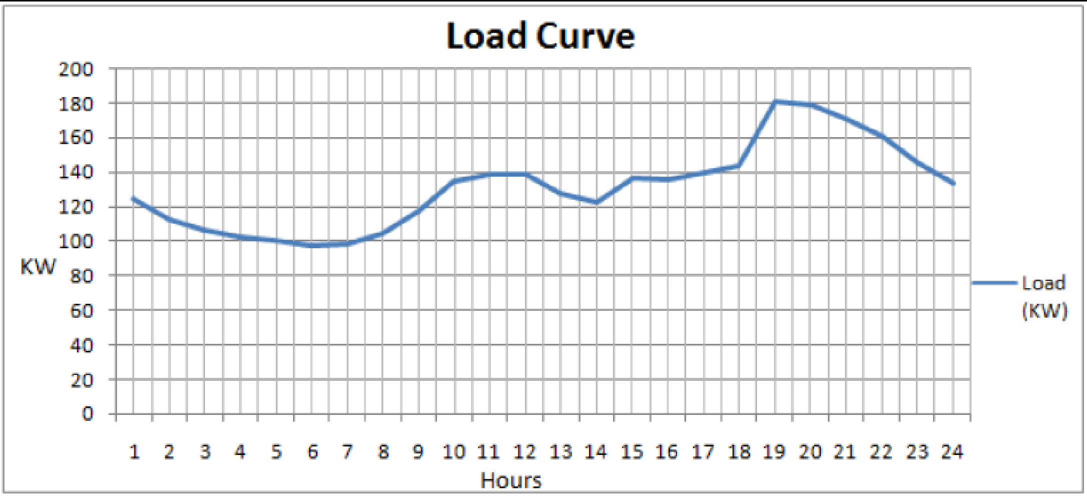

Fig.(14) The load curve for area 2

Effect of different Solar Fractions (SF) on the Levelized Cost of Electricity (LC) and the comparison with area 1- Experiment 2:

It is clearly visible from the graph below that in area 2, there is further reduction of cost in all solar penetrations.

Although, there is no relation between Load of area 2-Experiment 2 and Load of area 2, however, this sensitivity shows that with the growth of load in the day time, there will be significant reduction of LC. [26,27]

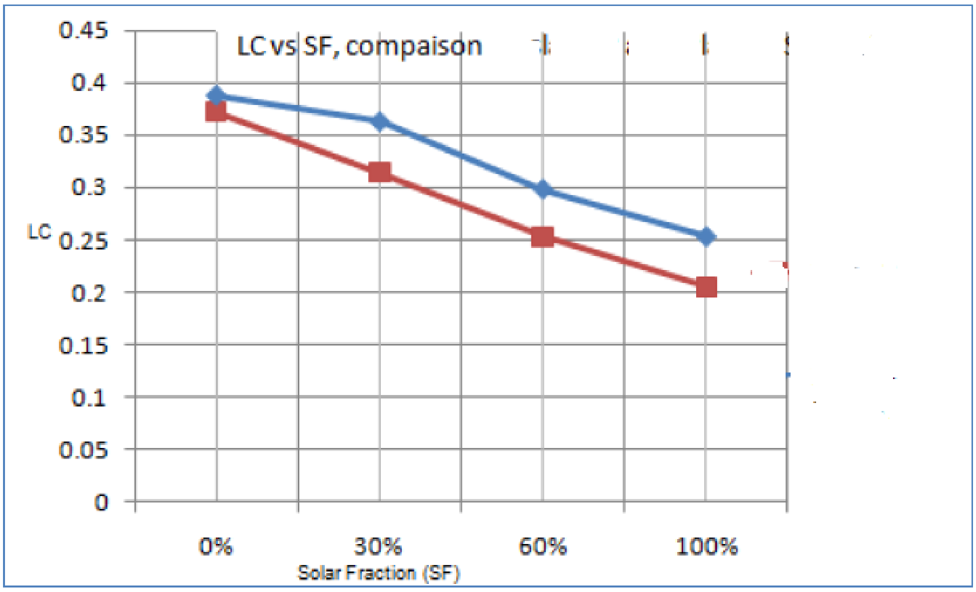

Fig.(15) LC vs SF for area 2

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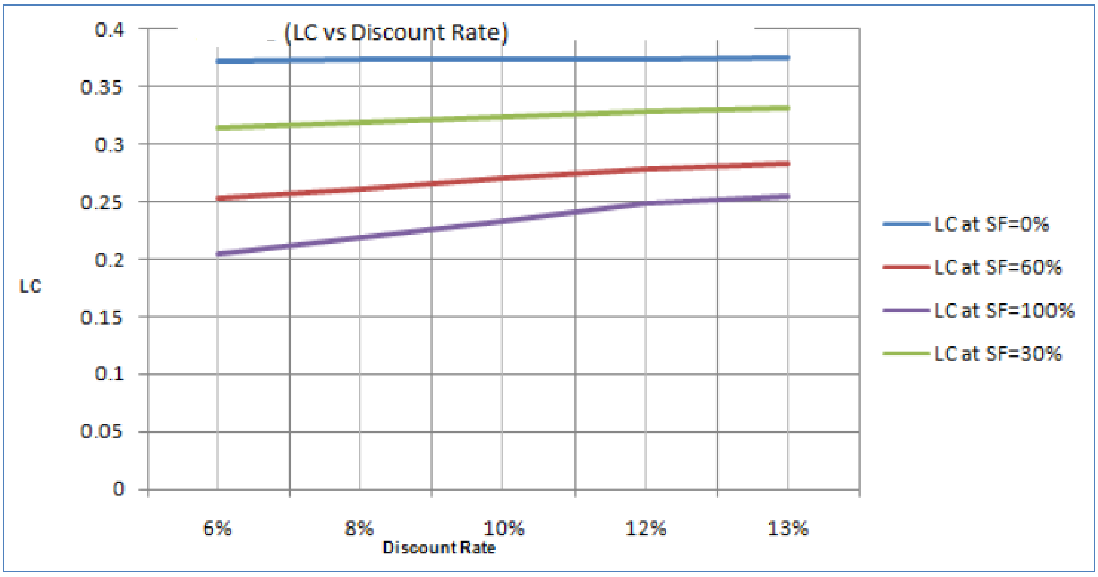

Fig.(16) The LC vs Discount Rate for area 2

Effect of different Solar PV costs on the Levelized Cost of Electricity as shown in figure (17) .

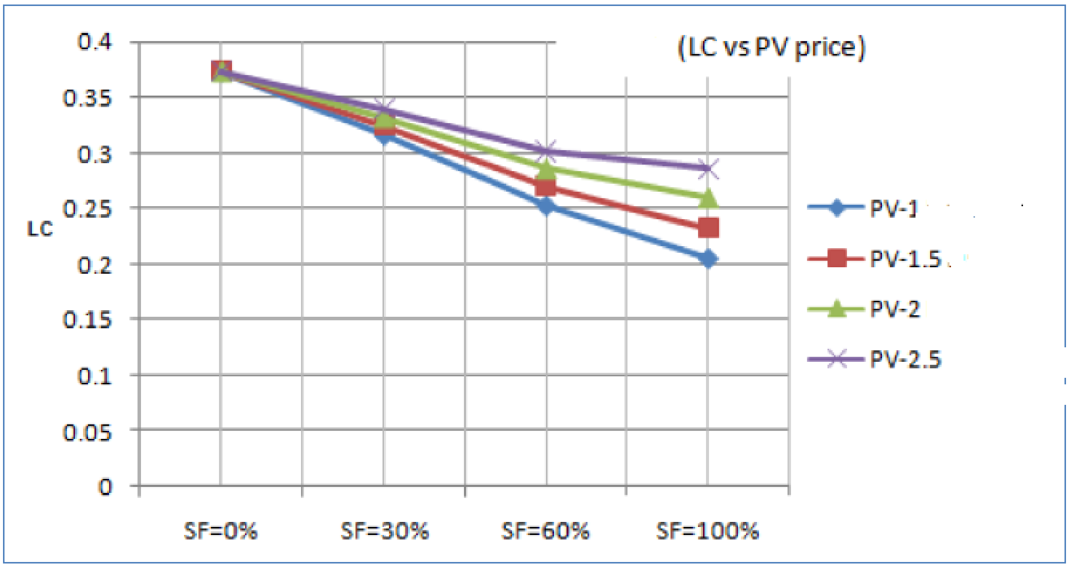

Fig.(17) The LC vs PV price

The graph above indicates that solar penetration will be viable even at much higher prices of Solar PV. [27]

5.CONCLUSIONS:

Solar radiation data analysis for the location of the study shows that the yearly average is 5.6 kWh/m2 .day while tilting the PV modules at the optimized angle results in yearly average equals to 6.1 kWh/m2 .day. This angle is found to be 30 º. Two experiments are analyzed in this paper. The most economic experiment is the one that includes in addition to the PV panels, the battery system and the diesel generator. The COE for this experiment is found to be 5000 I.D./kWh and happens at 100% PV contribution and 0.7 AD. Other experiment dependent on standalone PV and diesel only give results of COE greater than this value. For the diesel only experiment, both the COE and amount of produced CO2 are greater. The amount of produced CO2 is about 7 times greater compared to the hybrid one. This is in fact a very important environmental issue that shall be focused on. Considering remote areas which are far away from the grid, this solution is the most feasible one even compared with electrifying these remote areas from the grid.

Designing a hybrid power system is a complicated systems engineering problem.

A hybrid system is comprised of multiple technologies each mature in their own right, but it is their combination that allows for significant reduction in the cost of electricity to communities currently far from the grid. In most cases, hybrid power systems are flexible platforms that can provide cheaper electricity than systems using only one energy source.

While there are many papers describing new optimization techniques and optimized hybrid power system designs, none couple optimization with experimental validation. This paper fills that literary gap by generating an optimized hybrid system design for two areas performance with that predicted results.

Specific to area 1:

* In the existing experiment, where several small Diesel Gensets are serving to several small clusters of households, people are paying a very high cost of electricity (~5000 I.D./ KWh); Also the cost of electricity generation is very high to individual Genset owner (~2000 I.D. / KWh)

I had then proposed a Solar-Diesel Hybrid Mini Grid where a Central Power Converter (Master Inverter on the lines of areas 1 and 2) plays the role of Master with power inputs from Solar, Diesel and Battery BackUp. Following were the main findings:

* In Experiment 1 [Existing load pattern of 76 KW between 6 pm to 10 pm], Levelized electricity cost (LC) was observed to be lower at higher solar fraction / penetration (SF). It was observed that LC decreases with increasing SF, however, high cost of Master (Power Converter) makes lower SF expensive and this resulted in a peak of LC at SF=30%. LC at SF =0% was observed to be better then SF=30%, because Master is no more required and the cost is omitted.
* In Experiment 1, as the Discount rate increases from 6% to 13%, viability of higher solar penetrations (SF) was observed to be decreasing. At

higher discount rates (>13%), SF=0% (Diesel only option) was found to be more viable.

Specific to area2:

* Applying the same model to area 2, it was observed that LC will decrease with increasing Solar Fraction and any solar penetration will give better LC as compared to Diesel ONLY option.
* Although there is no direct relation between area 1 and area 2, however area 2 has a significant load in the day time compared to area 1-Experiment 2. While comparing the two, area 2 shows more drop in LC compared to Area 1-Experiment 2. This means that as the load will grow in day time, LC will decrease significantly.
* It was also observed that there is a strong case of putting Solar PV on the rooftops of areas Resorts. An estimated 173 KWp of Polycrytalline Solar PV can be put on the roof tops of the selected area Resorts. Open grounds in area 2 provides further opportunity of Solar PV installation in the island.

6.REFERENCES:

[1] International Energy Agency, 2012 (www.iea.org)
[2] Hybrid Mini grids for rural Electrification , Alliance for Rural Electrification, 2010 (www.ruralelec.org)
[3]Missionary Electrification Development Plan, 2012, Department of Energy Iraq.
[4] Geographic, Technological and Economic Analysis of isolated Diesel grids by Paul Bertheau, year 2012
[5] University of Baghdad, 2010,Solar Energy in Iraq.
[6] Diesel Service and Supply Inc, USA (www.dieselserviceandsupply.com)
[7] Analysis of Renewable Energy Retrofit Options to Existing Diesel Mini grids , Asia Pacific Economic Cooperations
[8] Hybrid System by Center for Engineering Research, Saudi Arabia
[9] G.Watt, R. Helstroom, and T. Vassallo, "CSIRO Energy Technology: CHP
and Cooling using Micro Turbines in Australia," CSIRO Energy Technology, Tech. Rep., 2003.
[10] R. Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle, and R. Guttromson, "The CERTS MicroGrid Concept," Assistant Secretary of Energy Efficiency
and Renewable Energy, Office of Power Technologies of the U.S. Department of Energy, California, Tech. Rep., 2002.

[11] A. Klinger. (2003, Aug) Northern power systems microgrid power network to address risk of power outages. [Online]. Available: www.northernpower.com

[12] O. Wasynczuk, “Modeling and dynamic performance of a self-commutated photovoltaic inverter system,” *IEEE Transactions on Energy Conversion*, vol. 4, no. 3, pp. 322–328, Sep 1989.

[13] K. Ro and S. Rahaman, “Two loop controller for maximizing performance of a grid-connected photovoltaic-fuel cell hybrid power plant,” *IEEE Transactions on Energy Conversion*, vol. 13, no. 3, Sep 1989.

[14]Bhandari, R. and I. Stadler (2011) “ Electrification using solar photovoltaic systems in Nepal” Applied Energy Vol. 88, No.2,pp. 458-465.

[15]Kamalapur, G.D. and R.Y. Udaykumar (2011) “ Rural electrification in India and feasibility of Photovoltaic Solar Home Systems” International Journal of Electrical Power & Energy Systems Vol. 33, No.3,pp. 594-599.

[16]Daud, A-K. and M.S. Ismail (2012) “ Design of isolated hybrid systems minimizing costs and pollutant emissions” Renewable Energy Vol. 44, No. ,pp. 215-224.

[17][Twaha, S., M.H. Idris, M. Anwari and A. Khairuddin (2012) “ Applying grid-connected photovoltaic system as alternative source of electricity to supplement hydro power instead of using diesel in Uganda” Energy Vol. 37, No. 1,pp. 185-194.

[18] R. Ruther, D.C. Martins and E. Bazzo. Hybrid Diesel/Photovoltaic Systems Without Storage for Isolated Mini-grids in Northern Brazil. in Photovoltaic Specialists Conference, 2000. 2000. Anchorage, AK.

[19] R.L.G. E.L. Maxwell, A Climatological Solar Radiation Model, in The 1998 American Solar Energy Society Annual Conference, T.C. R. Campbell-Howe, B. Wilkins-Crowder, Editor. 1998, American Solar Energy Society: Albuquerque, NW. pp. 505-510.

[20] S.A. Incorporated, Sunny Island 5048U Installation and Instruction Manual. 2007: Grass City, CA.

[21] C.D. Barley and C.B. Winn, Optimal dispatch strategy in remote hybrid power systems, Solar Energy 58 (1996) 165-179.

[22] O. Skarstein and K. Uhlen, Design Considerations with Respect to Long-Term Diesel Saving in Wind/Diesel Plants, Wind Engineering 13 (1989) 16.

[23] Lister-PetterALPHA Series LLD Water-Cooled Genset Technical Data Sheet. 2008. p 4.

[24] DSKAB Datasheet, C.P.G. Inc., Editor. 2007: Minneapolis.
[25] J.F. Manwell and J.G. McGowan, A Lead Acid Battery Storage Model for Hybrid Energy Systems, Solar Energy 53 (1993) 10.
[26] J.F. Manwell, J.G. McGowan, E.I. Baring-Gould and W.M. Stein. Recent Progress in Battery Models for Hybrid Wind Power Systems. in Proc 1995 AWEA Annual Conference. 1995.
[27] E. Hyman, Modeling and Computerized Characterization of Lead-Acid Battery Discharges. 1986, BEST Facility.

الخلاصة:

يعتبر النظام الهجينى باستخدام الخلايا الشمسية خيارا فعالا لتزويد المنـــاطق النائيـــة والمعزولة بعيدا عن الشبكة بالطاقة الكهربائية. وهذا صحيح بالنسبة للمناطق التي تتلقى كميات عالية من الإشعاع الشمسي سنويا . وان استخدام مولدات الديزل كمصـــدر احتيـــاطي جعـــل الاستفادة من النظم المختلطة أكثر جاذبية. وقد استخدمت مولدات الـــديزل كمصـــدر احتيـــاطى للطاقة ونظام البطاريات لتزويد منطقتين منطقة 1 ومنطقة 2 من بغـــداد لدراســـة الجـــدوى الاقتصادية والتصميم الكامل لنظام هجينى يتكون من الالواح الشمسية (PV) ومولدات الـــديزل فى هذا البحث. ثم تم تحديد مواصفات مكونات النظام الهجينى وفقا لقيم التصميم الأمثل.

فى المنظومات الحديثة تم تطويرالانظمة المكونة من الالواح الكهروضوئية ومولدات الرياح ومولدات الديزل والتوربينات الغازية والتى يتم ربطها الى الاحمال المختلفة.