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Software Design Tool for Sizing PV Stand-Alone System and Hybrid PV-Diesel System with Iraq Climate

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Abstract

This paper displays the improvement of Graphical User Interface programming for sizing principle segment in Stand-Alone PV system and PV- Diesel hybrid power system based on Iraq conditions. The solar system software is a tool depends on the input data by the user to give correct results on the basis of what has been introduced. Therefore, this software tool Includes products (PV modules, charge controller, inverter, battery and diesel generator) which can be obtained from the market with their detail. This software presents a guideline for photovoltaic system integrator to match the load requirement to design the effective size of components and system configuration, in hybrid PV–Diesel system. The ratio of photovoltaic solar energy to diesel generators is introduced by considering the contribution of hybrid system energy.

Keywords: Renewable energy, Standalone PV System, Hybrid PV-Diesel System, Solar Power System, PV Design Program.

أداة تصميم برمجية لتحجيم النظام الفوتوفولتائي المستقل و النظام الهجين الفوتوفولتائي-ديزل عند مناخ العراق

سجى مجيد هاشم، اسامة فاضل عبد اللطيف، فلاح ابراهيم العطار

الخلاصة:

يعرض هذا البحث تحسين برمجة واجهة المستخدم الرسومية لمبدأ تحجيم نظام الطاقة الكهروضوئية المستقلة ونظام الطاقة الهجينة الكهروضوئية-الديزل وفقًا لظروف العراق. برنامج النظام الشمسي هو أداة تعتمد على إدخال البيانات من قبل المستخدم لإعطاء النتائج الصحيحة على أساس ما تم تقديمه. لذلك، تتضمن أداة البرنامج هذه المنتجات (الوحدات الكهروضوئية وحدة التحكم في الشحن والعاكس والبطارية ومولد الديزل) والتي يمكن الحصول عليها من السوق بتفاصيلها. يقدم هذا البرنامج إرشادات لنظام كهروضوئي متكامل ولمطابقة متطلبات الحمل لتصميم الحجم الفعال للمكونات وتكوين النظام، في النظام الهجين الكهروضوئي- ديزل يتم إدخال نسبة الطاقة الشمسية الفولطاضوئية إلى مولدات الديزل من خلال النظر في مساهمة طاقة النظام.

1. Introduction

Iraq is located in the Middle East between latitude (29° 5' and 37° 2' N), and longitude (38° 45' and 48° 45' E) [1]. Iraq receives more than 3000 hours of solar radiance per year in Baghdad [2]. A renewable energy source is one of the most efficient and sustainable clean and sustainable energy solutions in the world. Solar energy is the most prominently among renewable sources, as it's an inexhaustible resource and its exploitation has thus far been ecologically friendly. Solar electricity is electric power generated from sunlight using devices called solar cell modules [3]. Solar energy can be considered one of the most important and reliable energy sources to cover the restricted availability of the traditional energy sources [6]. The conventional stand-alone diesel is not economically viable because of the high cost of diesel, which might have significant effect on the operating and maintenance cost as well as an environment impact because of the high emission of CO_2 from the system [9]. The proportion of pollutants reduction in the system is related to the penetration of renewable energy in the system. Therefore, and due to the lack of electricity, and the importance of available diesel generator as complement source

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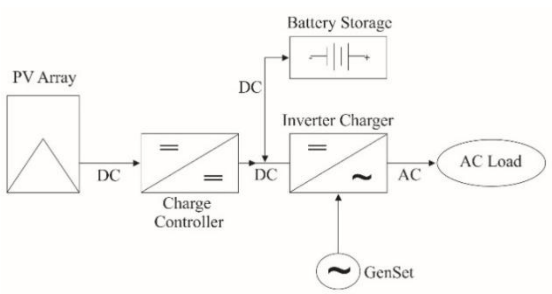
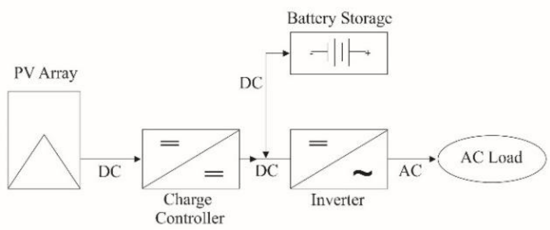
with solar power system for more reliability, the hybrid photovoltaic (PV)-Diesel system is designed to provide the load and charge a battery storage if the solar energy source with a battery storage system is unable to provide the load [5]. The main benefit of the hybrid system is to provide cover in the case of the weakness of one source with another available source [4]. In addition to, the generating system of PV-Diesel hybrid power configuration being more economically viable option [5]. The world needs to minimize the global air pollution to control the environment changes by encourage and support the dependence on renewable energy sources which are considered as an environmentally friendly source of electricity. Some programs included all, or most additional renewable energy sources and others are designed specifically for solar energy source applications simulation features. For simulation, optimization and analysis is an increasing extent in general as a technique for improved or investigated operating performance.

There are twelve main types of software programs for simulating solar photovoltaic system these are RETScreen, INSEL, PV F-Chart, Solar Design Tool, NREL Solar Advisor Model, TRNSYS, SolarPro, PV DesignPro-G, ESP-r 11.5, PV*SOL Expert, PVSYST 4.33 and HOMER with many others available such as Polysun, DDS-CAD PV, APOS photovoltaic StatLab, SolarNexus, PV Designer, Valentin Software, NREL's, PV Cost Simulation Tool, BlueSol 3.0 [7]. The programs of renewable energy have been used extensively throughout the world in terms of analysis, simulation, optimization, economical evaluation, monitoring and control [8]. Most of these programs are complicated and need time to learn it. In Iraq most data are different from what has been used in these programs such as the average solar irradiation, products of solar system components, and their prices. Therefore, a new program is designed which is easy to use and does not require much time or many steps to learn. By using Graphical User Interface (GUI) based on Visual Studio (VS) 2008 as instrument for the program design. Also, this program is compatible with Iraq conditions and contains the Iraq solar irradiation, products that available in Iraqi markets with their details and prices, or the user can use the manual input for adding a new product as another option.



(a)



(b)

Figure (1): The block diagrams of mode description for **(a)** Hybrid PV- Diesel Power System **(b)** Stand-Alone PV Power System.

Hussein et al. [8] used electrical calculation to design off-grid PV system program tool using Visual Basic (VB) to proportional with Iraq conditions. The program was tested by installing PV solar system in the Ministry of science and technology. The analyzed results of the program were compared with actual measured data over the year and the design results are very similar to the actual state of Iraq. Mohamed et al. [10] developed the Graphical User Interface software by using Visual Studio 2015 for sizing main component in AC coupled PV hybrid power system based on the real data under Malaysia climate. The software was able to size the main components in the photovoltaic hybrid system to meet with the set purpose of energy contribution ratio. Also, the program defined the rated powers of the components to the PV array, battery storage, bi-directional inverter, grid-tie inverter and diesel generator as a backup energy system to supply electricity in rural area. Kassem et al. [11] analyzed the PV- Battery system for an off-grid power station in Sohag city. And used hybrid PV-Battery system for supplying a combined pumping and residential load to determine the cost effective PV configuration and to meet the estimated load at minimum cost. The sizing of the hybrid system components are investigated by using RETScreen and HOMER programs, the PV-battery hybrid system was found to be suitable economically.

2. Software Design Methodology

This software program acts as a guideline for photovoltaic power system integrator to sizing the solar system components. The software program is developed by employing GUI platform based on VS 2008 (C Sharp language) and for create database by using SQL Server Management Studio Express 2005 to design standalone PV power system and hybrid PV-Diesel power system. The overall process of input and output data for this software design tool are summarized in the block diagram in Fig.2 to explain the input and output information in this software program under the name of University of Baghdad (UOB) Solar System Design Tool.

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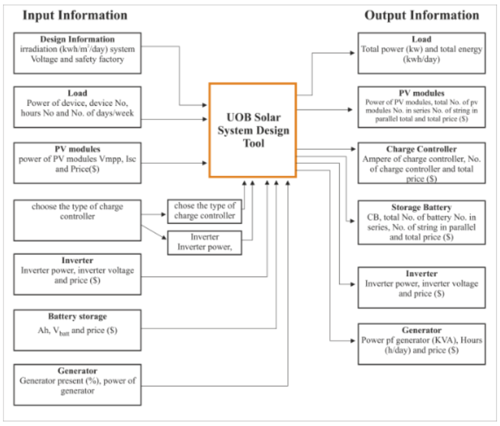

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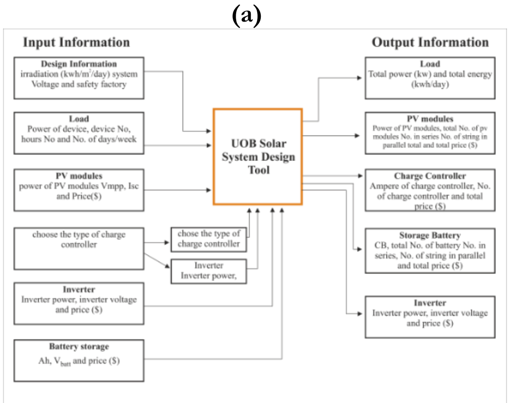

(b)

Figure (2): The block diagrams for description UOB Solar System Design Tool **(a)** Proposed Methodology for the Implementation of Sizing Hybrid PV-Diesel Power System **(b)** Stand-Alone PV Power System.

3. System Sizing

The properly photovoltaic system sizing is essential to achieve sustainable and reliable system design. Besides that, each component in the system can be designed accurately to match the required load and prevent the unused power in the system. The system sizing will be determined the size of each components existed in the photovoltaic system.

3.1 Load Profile

Generally load power refers to the electrical or thermal energy demand, Serving load is the primary purpose of any power system [10]. In the state of load analysis, system designer should also discuss all the potential energy resources that can meet the capacity needs by the consumer, and also educate the customers about energy efficiency. The steps for load estimation are:

1. List all the alternative current (AC) electrical appliances to be supplied by the designed power system.
2. Enter the items number of appliances.
3. Enter the operating wattage for one appliance.
4. Enter the number of hours per day for each item will be used.
5. Specify the number of days per week.
6. Multiply steps 2, 3, and 4 to calculate the daily energy requirement for 7 days a week.
7. Multiply steps 2, 3, 4, and 5 divided by 7 days a week to calculate the average daily energy requirement per day [12].

3.2 PV Array Sizing

The photovoltaic modules as the main source of renewable energy converts light energy directly to electrical energy to supply the customer with required amount of energy demand based on the required load. In this software due to several losses affecting on the output power from photovoltaic array, collect it in safety factor (SF). To estimate the actual power of photovoltaic array by equation (1) [10]:

$$P_{PV} = \frac{E_L}{\text{PSH} \times \eta_c \times \eta_{Inv} \times \eta_{Batt}} \times \text{SF} \qquad \ldots(1)$$

where:
P_{PV}: power of photovoltaic array.
EL : the average daily energy demand.
PSH: peak sun hour.
ηBatt : efficiency of battery storage.
ηc : efficiency of charge controller.
ηInv : efficiency of inverter.

The $\eta_c, \eta_{Inv}, \eta_{Batt}$ used (0.9, 0.9, and 0.85) respectively in the software program design. The η_{Batt} used in this equation due to the losses in power produced from PV modules through charging the battery and consequently use to cover the load. In hybrid PV–Diesel system the energy demand will be multiplied by fraction (n), this fraction can be defined by the PV to DG ratio [10]. The final equation will be:

$$P_{PV} = \frac{n \times E_L}{\text{PSH} \times \eta_c \times \eta_{Inv} \times \eta_{Batt}} \times \text{SF} \qquad \ldots(2)$$

n: fraction of energy contributed by photovoltaic (PV to DG proportion).

To estimate the required total number of photovoltaic modules used in the system design depends on the selected module by formula [10] [13].

$$N_{tot} = round\_up \left[\frac{P_{pv}}{P_{mod\_stc}}\right] \qquad \ldots(3)$$

N_{tot}: total number of PV modules.
P_{mod_stc}: nominal power of PV module at standard test condition (STC).

The number of PV modules connects in series per string affect by the type of charge controller either pulse width modulation (PWM) type, or maximum power point tracking (MPPT) type. For PWM type the number of modules in series can be found by equation (4):

$$N_S = \frac{SV}{V_{mpp}} \qquad \ldots(4)$$

Ns: number of PV modules in series for PWM type.
SV: system voltage.
Vmpp: maximum power point voltage.

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For the MPPT type, the number of modules in series can be found by formula [14]:

$$N_{S\_max} = \frac{V_{max\_inv\_input}}{V_{oc\_max}} \quad \ldots(5)$$

Ns_max: maximum number of PV modules in series for MPPT type.
Vmax_inv: the maximum MPPT voltage input.
Voc max: open circuit voltage of PV module.

The number of modules in parallel could be found by depending on the total number of PV modules and number of modules in series per string[14]:

$$N_p = \frac{N_{tot}}{N_s} \quad \ldots(6)$$

where: Np: number of PV strings in parallel.

3.3 Charge Controller Sizing

The charge regulator is an important to protect the battery storage against deep discharge and over charging. It is mainly used as well in charging the batteries by PV arrays [10]. The solar charge controller rating (SCCR) estimation depends on the output from PV array and battery voltage by equation (7):

$$SCCR = Isc \times N_p \times SF \quad \ldots(7)$$

Isc: short circuit current for PV panel.

3.4 Battery Sizing

The batteries are used for energy storage and subsequent utilization. The total battery capacity in Ampere hour (Ah) required meeting the daily energy consumption. It can be calculated by equation (8) [10]:

$$C_{req} = \frac{E_{d\_daily}}{SV} \quad \ldots(8)$$

C_{req}: total battery capacity required daily.
Ed_daily: the daily energy demand.

And the required storage batteries capacity is defined as a function for many parameters like the maximum depth of discharge (DOD), autonomy days (AD) and the efficiency of an inverter and battery. The AD is characterized by the quantity of days that the batteries can supply the required load without recharging by photovoltaic modules or diesel generator. The battery capacity can be determined by using equation [16] [14] [[6] [5]:

$$C_{Bat\_nom} = \frac{E_{d\_daily} \times AD}{DOD \times SV \times \eta_{Batt} \times \eta_{Inv}} \quad \ldots(9)$$

$C_{Batt\text{-}nom}$: actual amount of battery capacity required.

The number of batteries in series per string can be found by the nominal voltage of selection battery and according to the system voltage. The total number of batteries in series per string can be calculated by equation (10) [10] [15]:

$$N_{s\_bat} = round\_up\left[\frac{SV}{Vnom\_bat}\right] \quad \ldots(10)$$

Ns_bat : number of batteries/cells in series.
Vnom_bat : nominal voltage of battery/cell.

The number of batteries strings in parallel calculate relies on the selected battery capacity at STC and the total capacity of required batteries. By using equation the total number of batteries strings in parallel can be found as follows (11)[10][15]:

$$N_{p\_bat} = round\_up\left[\frac{C_{bat\_nom}}{C_{bat\_selected}}\right] \quad \ldots(11)$$

N_{p_bat} : number of battery string in parallel.
$C_{bat\_selected}$: capacity of each battery selected.

3.5 Inverter Sizing

The inverter must be set to 10-25% at least from the maximum AC power of the load. Also, it must cover the starting current of AC loads through power surge to protect electric motors such as washing machines and refrigerators [6]. The size of inverter in system design is calculated depending on the power of loads, the inverter size (IS) is calculated by equation (12) [8].

$$IS = Total\ Power \times SF \quad \ldots(12)$$

3.6 Diesel Generator Sizing

The sizing of rated diesel generator is dependent on the peak power requirement during batteries' charging. The generator power is used to provide AC power to the load and charge the battery. When the size of diesel generator is selected, make sure that the diesel generator is equivalent to the power demand by the load. To obtain a good diesel utilization and a long service life, the generator must be operated at optimum load. The estimating of DG size can be found by [10] [15]:

$$S_{dg} = \frac{S_{max\_dem} \times f_{over}}{f_{dg\_derate}} \quad \ldots(13)$$

S_{dg}: size of a DG required.
S_{max_dem}: maximum required power during Battery charging.
F_{dg_derate}: the complete de-rating factors of DG (eg: temperature, humidity…etc).
f_{over}: oversize factor.

The number of hours required to cover the load and charge the battery is based on PV to DG ratio (n) is [10][15]:

$$h = \frac{(1-n) \times E_L}{S\_(max\ \_dem)} \quad \ldots(14)$$

h: number of hours required for cover the load and charges the battery.

In this software program, the number of hours is calculated in h/day. The output voltage of the AC diesel generator is usually equal to the AC bus voltage, so the DG can be connected in parallel to match the system current requirement [9].

Fig.3 shows the main interface of the photovoltaic system design tool. It contains the access information, such as project name, designer or username, and the date. It contains, as well, the type of system presented by stand-alone PV system and hybrid PV-Diesel system.

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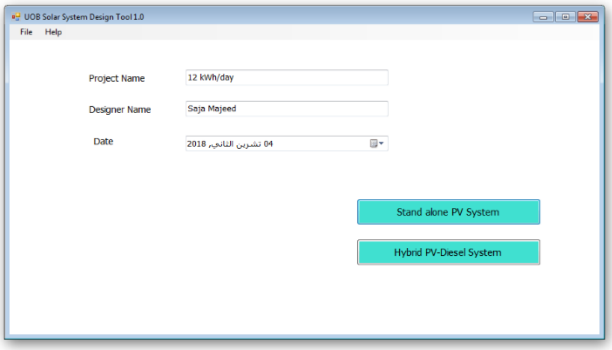


Figure (3): The main interface in the software sizing system.

The second window has been designed as home interface. It allows for easy navigation of the system components in this software design tool. It has the design information (Irradiation, System voltage and Safety factor). The peak sun hour (PSH) in a software program used 5.5 kWh/m^2/day as default value. The safety factor for compensation of PV-Cell temperature losses, cable losses, dust and mismatch losses [13]. Also, it contains a diagram that explains the type of power and includes components of the selected system such as the load analysis, PV Array, Inverter, Battery Bank, and DG for hybrid PV-Diesel system as shown in Fig.4. Figure (5) shows the table of solar irradiation for Baghdad and other governorates. To receive the maximum radiation levels over the year, the PV array needs to be correctly oriented [6]. The solar irradiation data was obtained from Photovoltaic Geographical Information System (PVGIS) website. In Baghdad city, the suitable tilt angle for orientation PV array in winter season is (45° – 48°), and for the summer season is 18°, the optimal tilt angle through the year is 33° for fixed photovoltaic modules and according to the latitude of Baghdad. In this program the user can input the average (daily, monthly and yearly) solar irradiation for the system design.

The graphs of solar irradiation will appear as shown in Fig.6. for Baghdad city in term of average radiation (KWh/m^2/day) in Iraq. Fig.7 shows the load profile window. In this window the user can input the Loads power used daily or weekly within a year or several months based on design system through input type of device, power of the device, quantity and the number of days in week to view the actual load. From power and energy screen in load window, the user can know the values of the amount of energy demand and the power peak demand. These values are important in any sizing system.

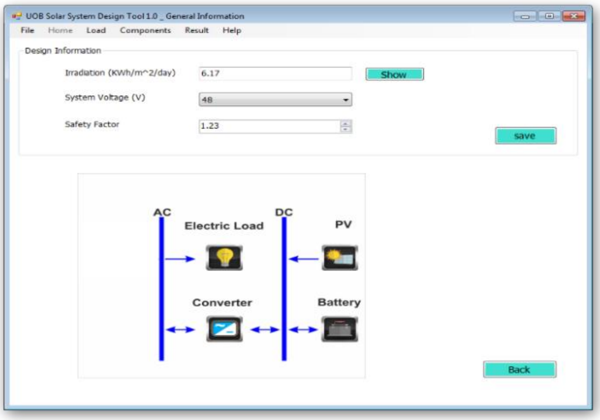
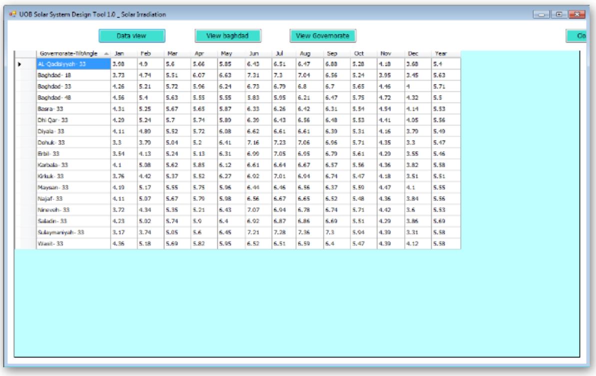


Figure (4): The home interface.

The second step is sizing the solar PV modules. This step has two important parameters, firstly is the average solar radiation along the year and the secondly is the safety factor of photovoltaic modules due to losses which has been calculated from design information screen in second window [8]. In software program there are types of photovoltaic modules available in Iraq stores and Iraq companies can choose it from a combo box. For new data specifications and new types of module, the check box can be used as manual input for adding it manually as shown in the Fig.8.



Governorate-TiltAngle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AL-Qadisiyyah - 33	3.98	4.9	5.6	5.66	5.85	6.43	6.51	6.47	6.88	5.28	4.18	3.68	5.4
Baghdad - 18	3.73	4.74	5.51	6.07	6.63	7.31	7.3	7.04	6.56	5.24	3.95	3.45	5.63
Baghdad - 33	4.26	5.21	5.72	5.96	6.24	6.73	6.79	6.8	6.7	5.65	4.46	4	5.71
Baghdad - 48	4.56	5.4	5.63	5.55	5.55	5.83	5.95	6.21	6.47	5.75	4.72	4.32	5.5
Basra - 33	4.31	5.25	5.67	5.65	5.87	6.33	6.26	6.42	6.31	5.54	4.54	4.14	5.53
Dhi Qar - 33	4.29	5.24	5.7	5.74	5.89	6.39	6.43	6.56	6.48	5.53	4.41	4.05	5.56
Diyala - 33	4.11	4.89	5.52	5.72	6.08	6.62	6.61	6.61	6.39	5.31	4.16	3.79	5.49
Dohuk - 33	3.3	3.79	5.04	5.2	6.41	7.16	7.23	7.06	6.96	5.71	4.35	3.3	5.47
Erbil - 33	3.54	4.13	5.24	5.13	6.31	6.99	7.05	6.95	6.79	5.61	4.29	3.55	5.46
Karbala - 33	4.1	5.08	5.62	5.85	6.12	6.61	6.64	6.67	6.57	5.56	4.36	3.82	5.58
Kirkuk - 33	3.76	4.42	5.37	5.52	6.27	6.92	7.01	6.94	6.74	5.47	4.18	3.51	5.51
Maysan - 33	4.19	5.17	5.55	5.75	5.96	6.44	6.46	6.56	6.37	5.59	4.47	4.1	5.55
Najaf - 33	4.11	5.07	5.67	5.79	5.98	6.56	6.67	6.65	6.52	5.48	4.36	3.84	5.56
Nineveh - 33	3.72	4.34	5.35	5.21	6.43	7.07	6.94	6.78	6.74	5.71	4.42	3.6	5.53
Saladin - 33	4.23	5.02	5.74	5.9	6.4	6.92	6.87	6.86	6.69	5.51	4.29	3.86	5.69
Sulaymaniyah - 33	3.17	3.74	5.05	5.6	6.45	7.21	7.28	7.36	7.3	5.94	4.39	3.31	5.58
Wasit - 33	4.36	5.18	5.69	5.82	5.95	6.52	6.51	6.59	6.4	5.47	4.39	4.12	5.58

Figure (5): The solar irradiation interface for Baghdad and other governorates in Iraq.

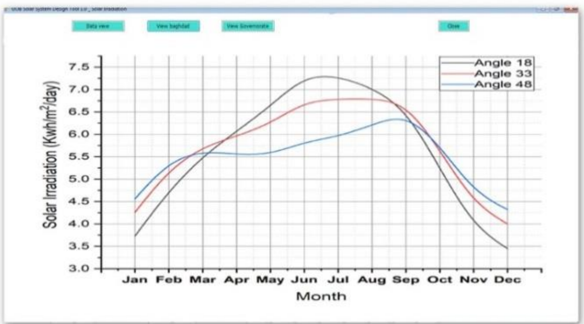


Figure (6): Metrological of solar irradiation in Baghdad.

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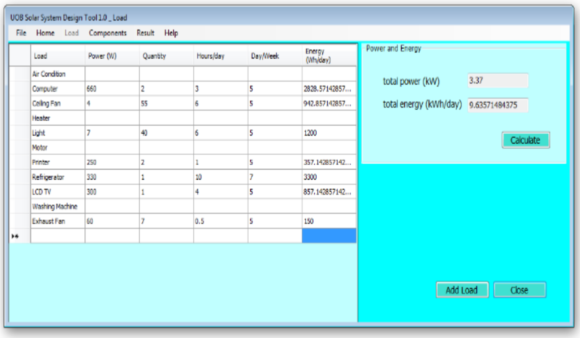

Figure (7): The load interface.

The third step is the size of battery storage capacity. The battery storage sizing depends on the total daily required energy consumption and battery capacity. Also, there is a list of batteries types available in Iraq stores and Iraq companies can choose it from a combo box or through entering the battery capacity at STC, battery voltage and its price manually as shown in Fig.9.

The fourth step is sizing solar charge controller, it is consistent of two types of charge controllers, which are PWM and MPPT, to calculate the current size. Also, it contains the combo box and the manually input property as shown in Fig.10.

The fifth step is sizing the inverter. The inverter sizing includes three important parameters. First, the short circuit current (I_{sc}) of module which will be imported automatically when selecting the PV module. The second is the safety factor for inverter. And the third is the value of peak power required from the load power profile window. Then, they will be employed to determine the size and number of the inverter. Also, the property of combo box and manually input exist in the interface as shown in Fig.11.

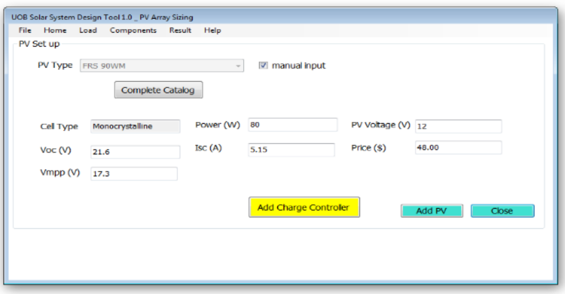

Figure (8): Photovoltaic module interface.

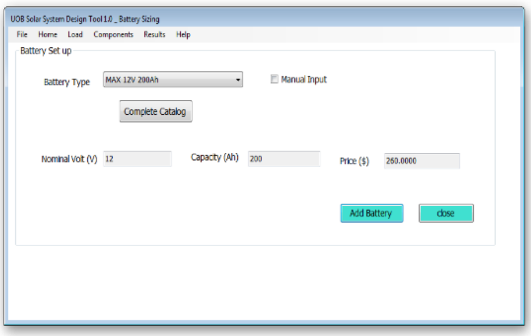

Figure (9): Battery Sizing Interface.

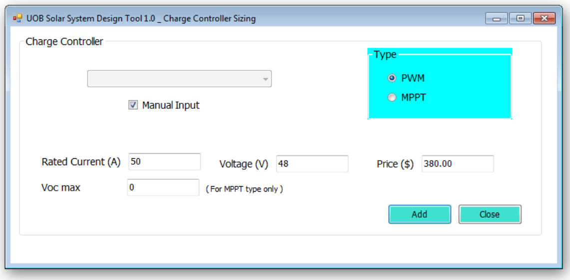

Figure (10): The charge controller interface.

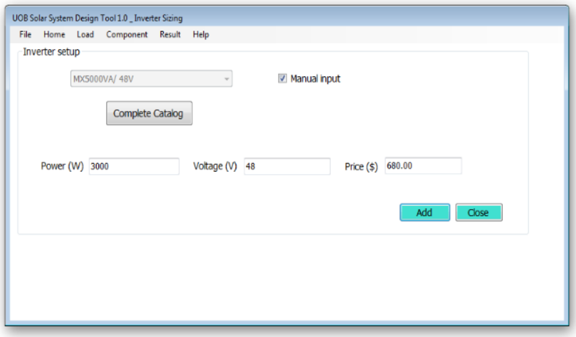

Figure (11): Inverter Sizing Interface.

When the selected system is hybrid PV-Diesel system the home interface will be as shown in Fig.12. The fraction of energy contributed by photovoltaic (PV to DG ratio) and the power of diesel generator are presented in generator interface as shown in Fig.13.

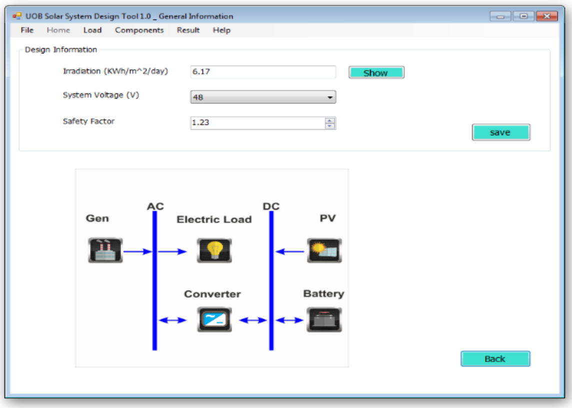

Figure (12): Window after adding DG for Home interface.

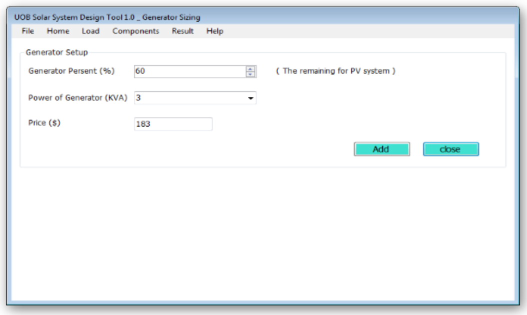

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Figure (13): The DG Interface in hybrid system.

4. Result and Discussion

Fig.14. shows the result interface for stand-alone PV system in software program. The result presented by the energy of loads, power of PV modules, total number of modules and the number series and parallels based on the system voltage. Also, the program will calculate the charge controller current and the number o it. also, it will calculate the power of inverter and the number of it. The program will calculate the total capacity of batteries in ampere-hour, total number of batteries and how many in series and how many in parallel based on the system voltage. In addition, it contains the total cost of each component and initial capital cost as approximate value. By press on button Calculate all of the above results will be calculated.

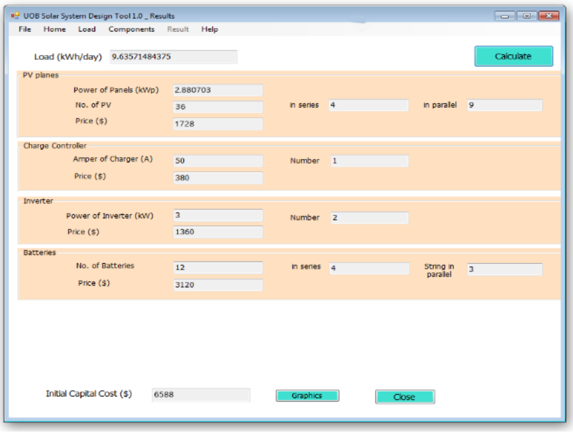

Figure (14): The result Interface in stand-alone PV system.

Fig.15. shows the graphics which explain the connection of stand-alone PV system for 48 system voltage that explains the connection way, each PV module and storage battery is 12V. In addition to that, it contains the cost chart to explain the ratio for each component with respect to the initial capital cost.

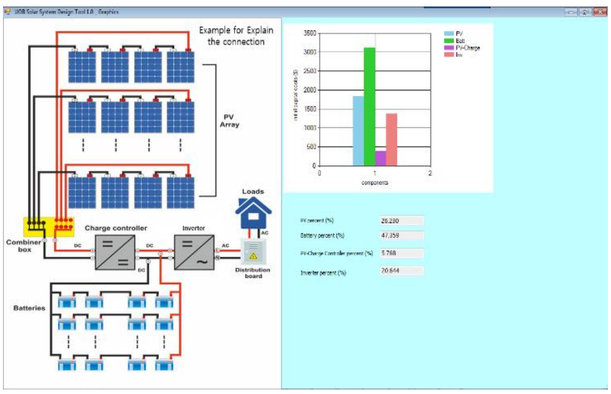

Figure (15): The connection and cost chart for stand-alone PV system

Fig.16. show the result of choosing hybrid PV-Diesel system with adding the ratio of contribution by diesel generator is 60% (the percent of renewable energy is 40%).

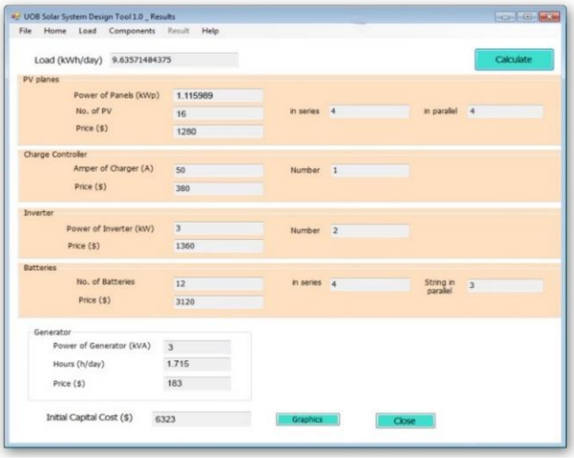

Figure (16): The result interface with adding DG.

A practical case study was measured with a system installed at the Ministry of Science and Technology in Baghdad city to determine the compatibility between the theoretical design results by software program and the actual energy required to cover the required load and to validate the feasibility of the developed software. The stand-alone photovoltaic system is designed to work with one day in cloudy and dusty days as autonomy day and the data is taken and recorded from the system for one year. With the tilt angle 33° changeable to 45° and 18° angles (for winter and summer seasons respectively) to supply electricity on the fourth floor of the Department of Renewable Energies building included these types of connected loads: office computer lab, LCD lights, fan, printer, TV and refrigerator. To supply the required power with 3.37KW and 12KWh the energy of loads for 6 hours/day and for 5 days/week.

Table (1) shows the case study for stand-alone PV power system installed in the Ministry of Science and Technology to verify the program analyzed result with compare to the actual measured data over the year 2012 as mentioned in the research [8]. The theoretical results obtained from UOB solar system design tool program is compared with experimental results for generated energy by PV array, taking into account the effect of solar irradiation and other loses.

Table (1): The generated energy in (KWh) according to UOB Solar System Design Tool compared to experimental generated energy from research and the relative error percentage between them [8].

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Month	Generated Energy (Theoretical) kWh	Generated Energy (Experimental) kWh	Error (%)
Jan	8.145	7.820	4%
Feb	9.945	8.460	14.9%
Mar	11.390	9.460	16.9%
Apr	11.788	10.180	13.6%
May	12.918	11.640	9.9%
June	14.489	12.450	14%
July	13.882	12.580	9.4%
Aug	13.882	12.460	10%
Sep	13.170	10.470	20.5%
Oct	10.134	9.330	7.9%
Nov	7.538	7.490	0.6%
Dec	7.203	7.210	0.09%

5. Conclusion

The software program tool was used to find algorithms for the sizing of standalone photovoltaic power system and hybrid PV-Diesel power system components. The designed algorithms consist of PV array, charge controller, battery storage, inverter and generator as a backup system. This software is important to support the user with minimal acquaintance in solar system designing. Also, it reinforces the user's understanding power in system design. In addition, it saves a lot of time in design and evaluates the power system. From the case study in software tool, we conclude that the design results are more suitable for all year long in comparison with the energy load demand (9.6357 kWh/day). The design result is very identical to the actual condition in Iraq. And the reason of the rise and drop in the generated energy for two months, September and December respectively, in the same year is related to the solar irradiation in these months, change in loads consumption, and the effects of weather conditions as illustrated in relative percentage of error.

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