Hybrid Photovoltaic Systems Design Program (HPVSD) Compatible with Iraq Conditions

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Abstract

This paper presents a visual basic program (HPVSD) for designing and calculating hybrid photovoltaic systems which is compatible with the Iraqi conditions (meteorological, specified design requirements and availability of components in local market) as an improvement to the recently designed Off-Grid Photovoltaic System Design Software (PVSD). This program (HPVSD) contains the options of designing hybrid systems using photovoltaic modules and other sources of energy like wind or grid energy as percentage sharing to generate the required energy per day for the load. This design program includes all the electrical calculations which are needed to design and select the components of system with the specified conditions, the program contains all available components in the local market and it is easy to use, with the ability to print out a full design document including all system components with its specifications. (HPVSD) has been tested and verified through a real project designed and evaluated at the Ministry of Science and Technology.

Key Words: Design, Program, Off-grid Photovoltaic System, Wind Energy and Hybrid System.

برنامج تصميم المنظومات الفوتوفولتائية الهجينة وفق الظروف العراقية (HPVSD)

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الخلاصة

في هذا البحث تم استحداث برنامج تصميمي حاسوبي باستخدام برنامج فجوال بيسك لتصميم المنظومات الفوتوفولتائية الهجينة **(HPVSD)** وفق الظروف العراقية(المناخية، متطلبات تصميمية خاصة ، حسب مامتوفر من المواد في السوق المحلية) والذي يعتبر تطوير لبرنامج تصاميم المنظومات الفوتوفولتائية الغير مرتبطة بالشبكة الكهربائية الذي تم استحداثه سابقا. يحتوي البرنامج الحالي على بدائل لتصميم منظومات هجينة مختلفة تستخدم الالواح الفوتوفولتائية ومصادر اخرى للطاقة مثل طاقة الرياح او الشبكة الوطنية تساهم بنسب مشاركة مختلفة يتم اختيارها من قبل المصمم . ان البرنامج المقترح يحتوي على جميع الحسابات الكهربائية المطلوبة لتصميم واختيار مكونات المنظومة المطلوبة وفق مواصفات معينة، ان هذا البرنامج يتضمن بيانات جميع الاجهزه المتوفرة حاليا في الأسواق المحلية ويمتاز بسهولة الاستخدام مع امكانية طبع تقرير تصميمي كامل عن كل مواصفات ومكونات المنظومة. لقد تم اختبار وتقييم هذا البرنامج عمليا من خلال مشروع صمم ونفذ وقيم داخل وزارة العلوم والتكنولوجيا.

الكلمات المفتاحية: تصميم، برنامج، المنظومات الفوتوفولتائية غير مرتبطة بالشبكة، طاقة الرياح و المنظومات الهجينة.

Introduction

Hybrid systems using different types of energy sources like Photovoltaic (PV) , wind turbines and other available source of energy at site that can generate electrical power by converting solar radiation into direct current electricity solar modules composed of a number of solar cells containing a photovoltaic material, the others uses wind energy as it is available day and night, these energy can be stored during the day and supply the load as it needed.

A new Off-Grid Photovoltaic System Design Software (PVSD had been designed using Visual Basic (VB)(Matsukawa,(2003), Zhang,. and Liu(2010)) (Hussein and Iessa , 2013) with all Iraq conditions and all parameters can be changed manually depending on the place, also this program contains products that can be found in Iraqi local market with their details and prices.

Many Renewable energy design software's had been established like Homer Energy modeling software (Homer Energy,2012)and others, with the limitations that put the designer in a lot of constraints , and these limitations involving the design parameters and the availability of system components, make some difficulty to try different options to design the required system with all assumptions that related to specific or special cases as in Iraq, where most of the real time readings are different from what has been used in these programs such as average irradiation, products and prices. Therefore, a new design program has been introduced to improve the recent design program (PVSD), in order to include the hybrid off-grid systems using different energy sources like (PV, Wind and grid) as energy percentage sharing to generate the required energy for the load.

Materials and Methods

The equations that had been used in the Off-Grid system design program are equation (1, 2, 3, and 4) and other related design calculations of photovoltaic system and sizing (Hussein and Iessa, 2013, Sandia National laboratories, 1991).

$$\boldsymbol{E_{pv}} = \frac{\boldsymbol{P_{pv} * E_{sr} * E_{ff(inv)} * E_{ff(PV)}}}{\boldsymbol{SF}} \quad \textbf{....... (1)}$$

Where $\boldsymbol{E_{pv}}$ is the energy that must be generated from the PV modules, $\boldsymbol{E_{ff(inv)}}$ is the efficiency of inverter, $\boldsymbol{E_{ff(PV)}}$ is the efficiency of solar module, $\boldsymbol{E_{sr}}$ is the solar radiation of Iraq, $\boldsymbol{P_{pv}}$ is the peak power of PV, and $\boldsymbol{SF}$ is the safety factor for losses.

$$\boldsymbol{CB} = \frac{\boldsymbol{E_{LD}}}{\boldsymbol{E_{ff(Bat)} * DOD * V_B}} \quad \textbf{....... (2)}$$

Where $\boldsymbol{CB}$ is the capacity of the battery is needed for one day autonomy, $E_{ff(Bat)}$ is the efficiency of battery, DOD is the depth of discharge and V_B is the voltage of battery.

$$\boldsymbol{SCCR = I_{sc} * number\ of\ string * SF} \quad \textbf{... (3)}$$

Where $\boldsymbol{SCCR}$ is the solar charge controller rating and I_{sc} is the short circuit current.

$$\boldsymbol{IS = Total\ power * SF} \quad \textbf{...... (4)}$$

Where $\boldsymbol{IS}$ is the inverter sizing

The Hybrid Off-Grid system design calculations have been designed to interact with the designer as a first step for the User name and Password as shown in Figure (1).

Figure (1) Login Window

Then after the Login, another window will show the new program (**HPVSD**), will ask the designer to choose the specific PV system if it is On-grid PV system or Hybrid Off-Grid PV System as in our case, as illustrated in Figure (2).

Figure (2) HPVSD Window

The first windows for the Hybrid Off-Grid is designed to ask for the (**Design Information)** such as Project Name, Project Number, Current type of the system(AC or DC),Design type (Fixed or Tracking), Losses factors (Dust, High temperature, and Wiring losses),(Tolerance of Solar Panel, and Efficiency of Inverter ..etc.),then you have to choose the Hybrid System Type (PV and Grid, PV and Wind turbine) and the Hybrid System Percentage, as shown in Figure (3). This window will chose the type of hybrid and the first input information that will be used for calculations of the output energy of the hybrid system.

Figure (3) Design Information

The second windows for the Hybrid Off-Grid is designed to ask for the (**Load Calculations**) such as, Power, Hours, Time per Day and per Week as illustrated in Figure (4) ,which related to summer and winter season, then the designer choose either winter or summer total energy for the calculations and sizing the system.

Figure (4) Load Calculations

The third windows for the Hybrid Off-Grid program is designed to ask for the (**PV Design and Calculations**), type of solar charger (PWM, MPPT), the Average Solar Irradiation, type of Solar Modules, Battery Capacity…etc., as precented in Figure (5).

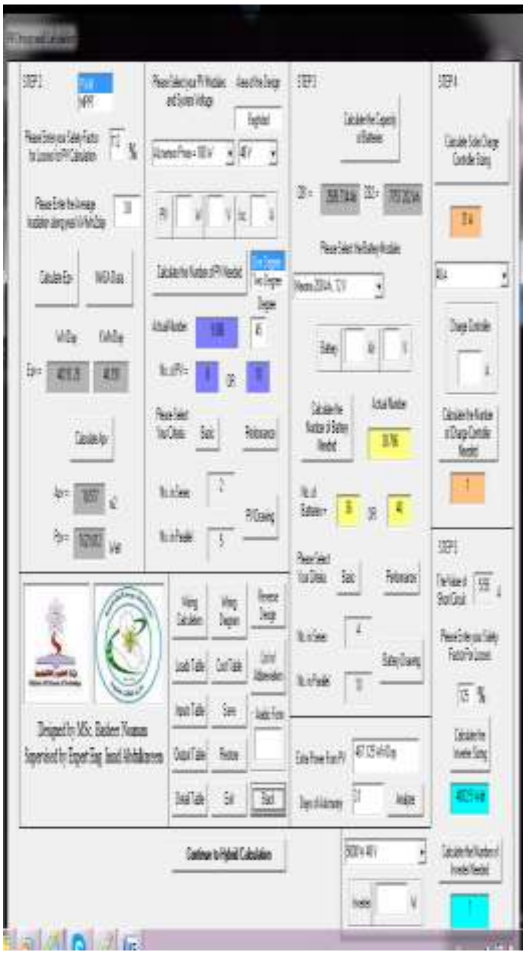


Figure (5) PV Design and Calculations

This window will give the results directly to the designer, Who can chose the best choice for the PV system, after the designer finish this stage should go on the window to another icon (**Continue to Hybrid Calculation**) which move to continue designing the other hybrid sources (Grid Design, wind turbine calculations) depending on the chosen system from windows of Figure (3).

Figure (6) shows the (**Grid Design Calculations)** window, it will ask for Grid Hours per Day and the Grid Availability Days per Week, then the calculated Energy per hours will appear.

Then the final design output of hybrid system can be shown after pressing on (Next) icon that shown in windows of Figure (11).

Figure (6) Grid Design Calculation

Grid are designed to ask for the other type of hybrid system related to (**Wind Design Calculation**), that deals with Wind turbines selection as listed in the program (power of wind turbine), can be followed when the designer choose the option of (PV and Wind turbine) as in Figure (3), windows of Wind Design calculation is shown in Figure (7).

The power output of wind turbine is calculated from equation (5) (Siraj, 2010, Wind Resource Assessment Handbook, 1997, CanWEA, 2010, Bhadra, and Banerjee, 2010 and, Blanco, 2009).

$$\boldsymbol{Wp} = [\boldsymbol{Cp} * \boldsymbol{A} * \boldsymbol{PD} * \boldsymbol{G}] \quad \text{........ (5)}$$

Where $\boldsymbol{Wp}$ is the power generated from wind turbine?

$\boldsymbol{Cp}$ Is the coefficient of performance of the wind turbine (17%-35%) depending on wind speed and manufacturer specifications?

$\boldsymbol{A}$ Is swept area of the wind turbine blade in m².

$\boldsymbol{PD}$ is the power density of the wind equation (6) (Wind Resource Assessment Handbook,1997).

$$\boldsymbol{PD} = \mathbf{0.5} * \boldsymbol{S}^{\mathbf{3}} * \dot{\rho} \qquad \text{......... (6)}$$

Where **S** is the annual average wind speed in m/s.

$\dot{\rho}$ is the air density in kg/m³.

G Is the (generator efficiency (range 50%-80%) multiplied by gear box bearing efficiency (range 90% - 95%)) of the wind turbine.

After the input information's filled by designer according to required design parameters, the results will appear on the same page as in Figure (7).

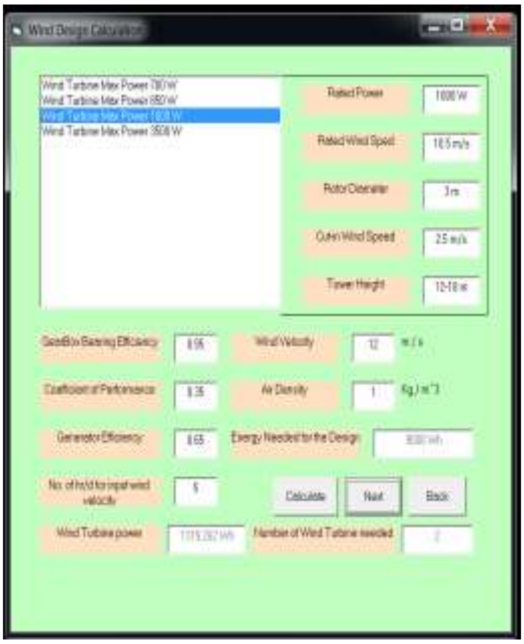


Figure (7) Wind Design Calculation

The final needed wind turbines that appear as a result should be divided by the number of hours assumed for the selected wind speed per day, the final calculated number of wind turbine will appear after you press (Calculate) icon, as shown in Figure (7).

Results and Discussion

The results of the program Hybrid Off-Grid design shows, the designer and project components details. The results of the Hybrid Off-Grid Design have been divided into several tables as shown in Figures (8, 9, 10, 11, 12, 13 and 14).

Figure (8) shows all the designer Inputs of the design parameters that used from windows of Figures (3,4 and 5) (Average Irradiation, Tilt Angle of the solar panels, Type of panel Fixation (Fixed, Tracking),Solar Cell Module, PV side system Voltage, Battery Capacity ,Cables Lengths).

Also the calculated Total Power of the hybrid system, Total Energy wanted from the system.

Figure(8) PV Calculation Inputs

Figure (9) shows the details information of the load and energy calculations of the system, all other design parameters for the hybrid system.

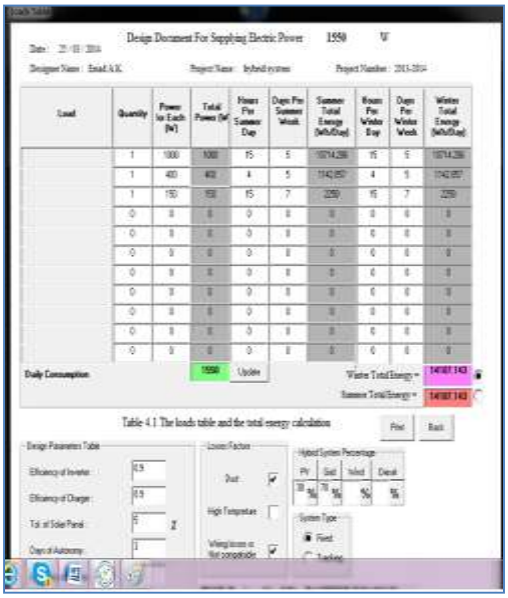


Figure (9) PV Calculation Outputs

Figure (10) shows the other Output results of the PV system Sizing (Number

Of Solar Modules and Number of Series and Strings), (Number of Batteries and Number of Series and Strings), Solar Charger Controller and Inverter Sizing, and the cables sizing of the whole PV system.

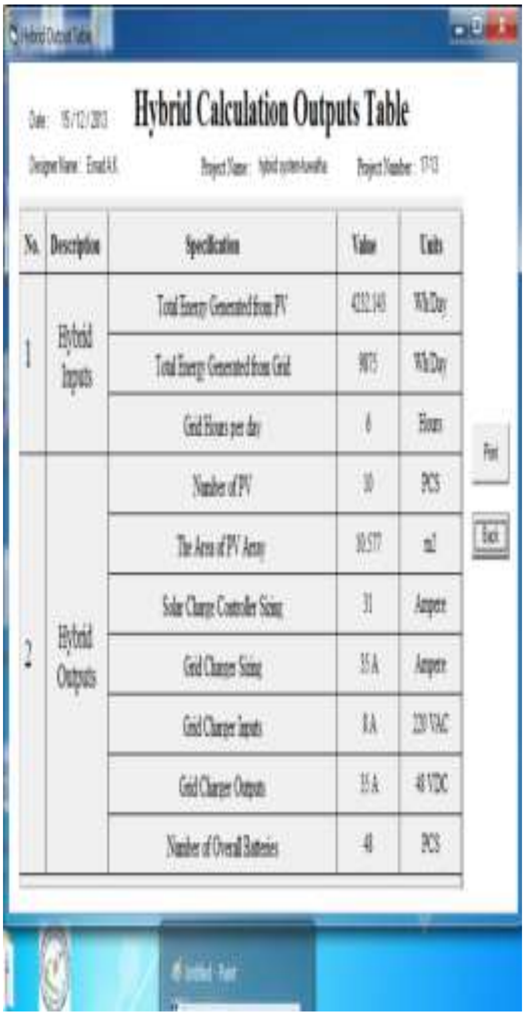
Date: 25/3/2014 — **Electrical Calculation Outputs Table**

Designer Name: Emad A.K. — Project Name: hybrid system — Project Number: 2013-2014

No.	Description	Specification		Value	Units
2	Outputs	Number of PV		16	PCS
		Number of Series		2	
		Number of String		5	
		Number of Batteries		40	PCS
		Number of Series		4	
		Number of String		10	
		Inverter Sizing		4012.5	Watt
		Solar Charge Controller Sizing		31	Ampere
		The Area of PV Array		10.577	m2
		Wire Area Section Between	Fuse Rated Current	Value	Units
		Panels	___	1.00 ~1.5	mm2
		Panels and Combiner Box	8.571 A	7.64 ~4	mm2
		Combiner Box and Charger	41.379 A	20.45 ~25	mm2
		Charger and Battery	41.379 A	5.29 ~6	mm2
		Battery and Inverter	44.15 A	63.4 ~70	mm2
		Inverter and Main Board	11.761 A	0.18 ~1	mm2

Figure (10) PV Calculation Outputs

Figure (11) shows the final hybrid calculation outputs for (PV + Grid), which give the Total Energy Generation from PV system and Grid according to the percentage share that fixed in the design input as in window of Figure (3), and the Grid Hours per day, Number and Area of PV Array, Solar Charge Controller Sizing, Grid Charge Controller Sizing, Number of Overall Batteries.



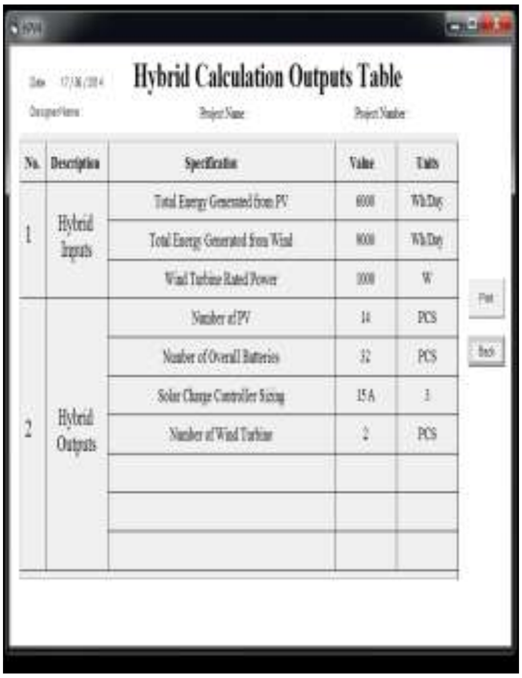
Date: 15/12/2013 — **Hybrid Calculation Outputs Table**

Designer Name: Emad A.K. — Project Name: hybrid system-kuwaitha — Project Number: 17/13

No.	Description	Specification	Value	Units
1	Hybrid Inputs	Total Energy Generated from PV	4232.143	Wh/Day
		Total Energy Generated from Grid	9075	Wh/Day
		Grid Hours per day	6	Hours
2	Hybrid Outputs	Number of PV	10	PCS
		The Area of PV Array	10.577	m2
		Solar Charge Controller Sizing	31	Ampere
		Grid Charger Sizing	35 A	Ampere
		Grid Charger Inputs	8 A	220 VAC
		Grid Charger Outputs	35 A	48 VDC
		Number of Overall Batteries	48	PCS

Figure (11) Hybrid Calculation Outputs (PV + Grid)

Figure (12) shows the final hybrid calculation outputs for (PV + Wind Turbine) option that continue what has been done in hybrid system related to (Wind Design Calculation) as in Figure (7) , which give the Total Energy Generation from PV system and Wind Turbine according to the percentage share that had been fixed in the design input as in window of Figure (3),and the final Number of PV Panels and Solar Charge Controller sizing, Power and Number of Wind Turbines, Number of Overall Batteries .

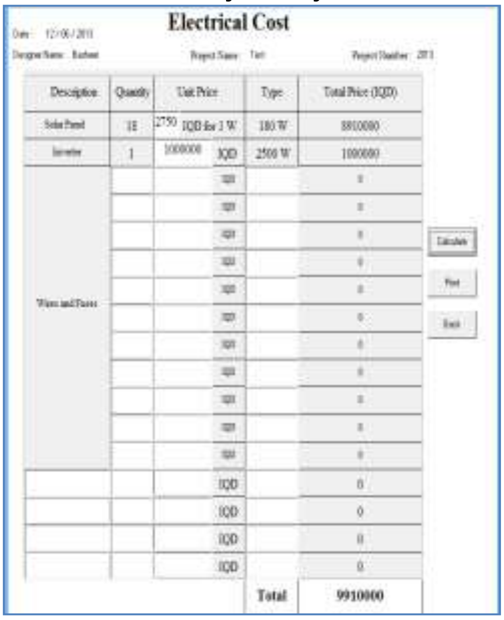


Hybrid Calculation Outputs Table

No.	Description	Specification	Value	Units
1	Hybrid Inputs	Total Energy Generated from PV	6000	Wh/Day
		Total Energy Generated from Wind	9000	Wh/Day
		Wind Turbine Rated Power	1000	W
2	Hybrid Outputs	Number of PV	14	PCS
		Number of Overall Batteries	32	PCS
		Solar Charge Controller Sizing	15 A	1
		Number of Wind Turbine	2	PCS

Figure (12) Hybrid Calculation Outputs (PV + Wind Turbine)

Figure (13) shows the Cost Table of the system components that had been came out from the design calculations in the program, which can be filled by the designer according to the prices of the available market, and can end with the final cost of the hybrid system.



Electrical Cost

Description	Quantity	Unit Price	Type	Total Price (IQD)
Solar Panel	18	2750 IQD for 1 W	180 W	8810000
Inverter	1	1000000 IQD	2500 W	1000000
Wires and Fuses		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
		IQD		0
			Total	9910000

Figure (13) Cost Table of Components

Figure (14) shows the overall wiring diagram of the PV system design, which shows the cables sizing on each section.

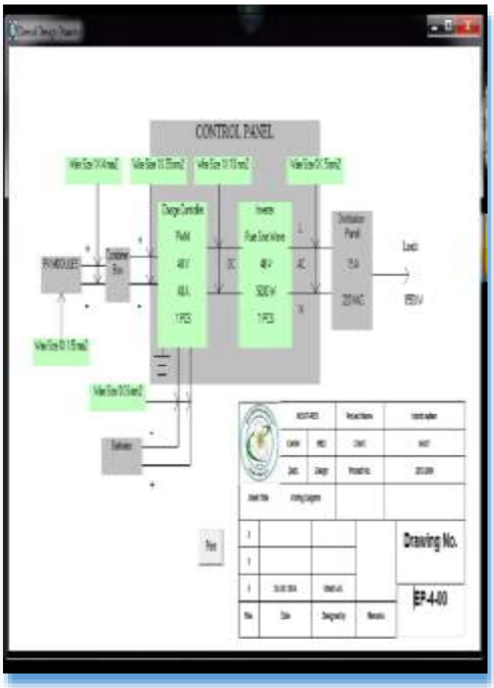


Figure (14) Overall Wiring Diagram for the Design of PV System

The Figures (8, 10 , and 14) printed out as A4 size, present the Design Document's Report as an example of Hybrid Off-Grid (PV + Grid)with capacity of(14 kWh/day) to the load which had been designed for (Tuwaitha-site conditions close to Baghdad city). The results of this program had been verified with the designed and installed Hybrid Off-Grid solar power system in Iraq.

Conclusions

This paper has completed the last version for Off-Grid PV system design with new software using features not available in other software to complete the set of options for designer. The program has been designed based on photovoltaic design equations and other energy sources in order to create the hybrid system. Also this software save a lot of time in designing and evaluating any Hybrid Off-Grid PV system and it deliver a full design document in short time by one designer.

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