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A GUI Based Teaching and Learning Software for System Sizing of A Stand Alone Hybrid Solar Electricity System

Marizan Sulaiman, Ahmad Fateh Mohamad Nor and Rosli Omar

Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia

Abstract

This research focuses on the development of Graphical User Interface (GUI) based software that can be used to size a stand-alone hybrid solar system for teaching and learning application. The software is able to calculate the load requirements and then determine the suitable size of the stand-alone solar system's components such as inverter, PV array, solar charge controller, and battery-bank so that the system is able to produce sufficient energy to meet the load requirements. Sizing is very important because if the solar system is not being sized carefully, it might result in producing more energy or less energy than is needed. Diesel generator is chosen to be combined with the solar system to form a hybrid solar system. GUI is used to present all of the procedures system sizing procedures to make it much easier to understand by the users. The GUI will be done by using Visual Basic 2010. The software is targeted for engineering students and practicing engineers.

Keywords: Solar Electricity, GUI, System Sizing, Teaching and Learning Software.

1. Introduction

Electricity has always been one of the most important basic needs for humans. It is almost impossible to imagine how the world would be if there is no electricity. At home, electricity is used to run home appliances such as lights, fans, refrigerator and television. In the industrial sector, electricity is used to operate machines etc. In short, humans are not able to do almost anything without electricity.

The demand for energy especially electricity in Malaysia is increasing rapidly as Malaysia moves towards into becoming a fully developed nation by the year 2020 [1]. However, the current method used for generating electricity in Malaysia consumes fossil fuel such as natural gas and coal as the main energy sources. Other than this fossil fuel will run out completely eventually, this fossil fuel also releases carbon dioxide that can cause climate change and global warming [2]. Besides that, there are some areas especially in the rural and remote areas in Malaysia that have no access to the utility grid. Hence, in 2001 under the Eighth Malaysian Plan, the government introduced the Five Fuel Policy where renewable energy was recognized as the fifth fuel [3].

Renewable energy can be defined as the energy produced from natural processes that can replenish continuously and quickly [4]. There are five sources of renewable energy which are from wind, palm oil industry, biomass, solar radiation, and hydro power [5]. In Malaysia, the renewable energy from solar radiation is very promising because Malaysia receives high solar radiation and has mild ambient temperatures [6].

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However, one of the main problems that limits the utilization of solar energy is the lack of knowledge among the people [7]. The people do not know how to choose the suitable size of the solar system to supply their needs. Besides that, every component in the solar system must be sized carefully in order to adequately meet the load requirements and hence avoid producing more energy or less energy than is needed. Any mistake in sizing the solar system can cause insufficient electrical energy to supply the load requirements [8,9]. Hence, a good and accurate software to design and analysis solar system is needed.

In this paper, a software that can be used for system sizing of a stand-alone hybrid solar system is developed. The sizing procedure for components of a stand-alone hybrid solar system in Malaysia is presented by using GUI and can be used for teaching and learning purposes especially for institution of higher education and training center for utility industries.

2. Software Design Methodology

The concept of this software is to show the procedures and calculations of sizing a stand-alone hybrid solar system. The steps involved are shown using GUI. Visual basic 2010 is used for building the GUI.

The procedure in sizing a stand-alone hybrid solar electricity system starts from load analysis, inverter sizing, PV array sizing, solar charge controller sizing, battery-bank sizing, hybrid components sizing and ends with the study of return on investment of stand-alone hybrid solar system compare to grid utility bills as shown in Figure 1. The first interface is the main menu as shown in Figure 2 that will allow for easy navigation of the system. Here, the user can see the list of the steps involved in sizing a stand-alone solar hybrid system.

Besides that, additional features such as information symbol, next button and displaying calculation equation were added in order to make this software easier to comprehend by the users.

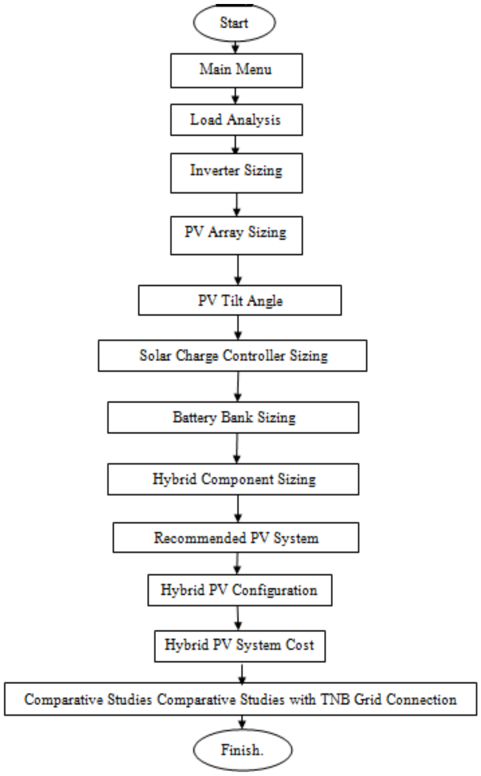

Figure 1: Procedure in sizing a stand-alone hybrid solar electricity system.

Figure 3 shows the load analysis interface. In this section, the amount of energy consumption is calculated. Three important values will be obtained from this step. The first value is the total daily energy consumption. This value is the amount of electrical power need to be produced by the solar system. This value is important to determine the size of the solar array and batteries later on [7,10]. The total daily energy consumption is obtained by the following equation.

$$\sum E_{AC} = \frac{\sum (Q \times PR \times t)}{nINV} \qquad (1)$$

where,

$\sum E_{AC}$ = total daily energy consumption

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(Wh/day)
Q = quantity of electrical appliances
PR = power rating of electrical appliances in watt
t = operating time of electrical appliances in hour per day
$nINV$ = percentage of inverter's efficiency

The second value is the total AC power demand. This value is very important when it comes to choosing the suitable inverter for the system. The following equation can be used to calculate the total AC power demand.

$$P_{AC} = \sum (Q \times PR) \qquad (2)$$

where,

P_{AC} = total AC power demand in watt
Q = quantity of electrical appliances
PR = power rating of electrical appliances in watt

The third value that can be obtained from the load analysis is the weighted operating time. This value will be used in the battery sizing section. The weighted operating time is obtained by the following equation.

$$t_{op} = \frac{(E_1 \times t_1) + (E_2 \times t_2) + \cdots + (E_n \times t_n)}{E_1 + E_2 + \cdots + E_n} \qquad (3)$$

where,

t_{op} = weighted average operating time (hr/day)
E_1 = DC energy required for load 1 (Wh/day)
t_1 = Operating time for load 1 (hr/day)
E_2 = DC energy required for load 2 (Wh/day)
t_2 = Operating time for load 2 (hr/day)
E_n = DC energy required for load n^{th} (Wh/day)
t_n = Operating time for load n^{th} (hr/day)

The second step in sizing a stand-alone solar system is to select the suitable size of the inverter as shown in Figure 4. The power rating of the inverter can be calculated by using the following equation [11].

$$P_{inv} = P_{AC} \times 1.25 \qquad (4)$$

where,

P_{inv} = power rating of the inverter
P_{AC} = AC power demand (obtained from load analysis) in watt

Figure 2: The main menu of the sizing software

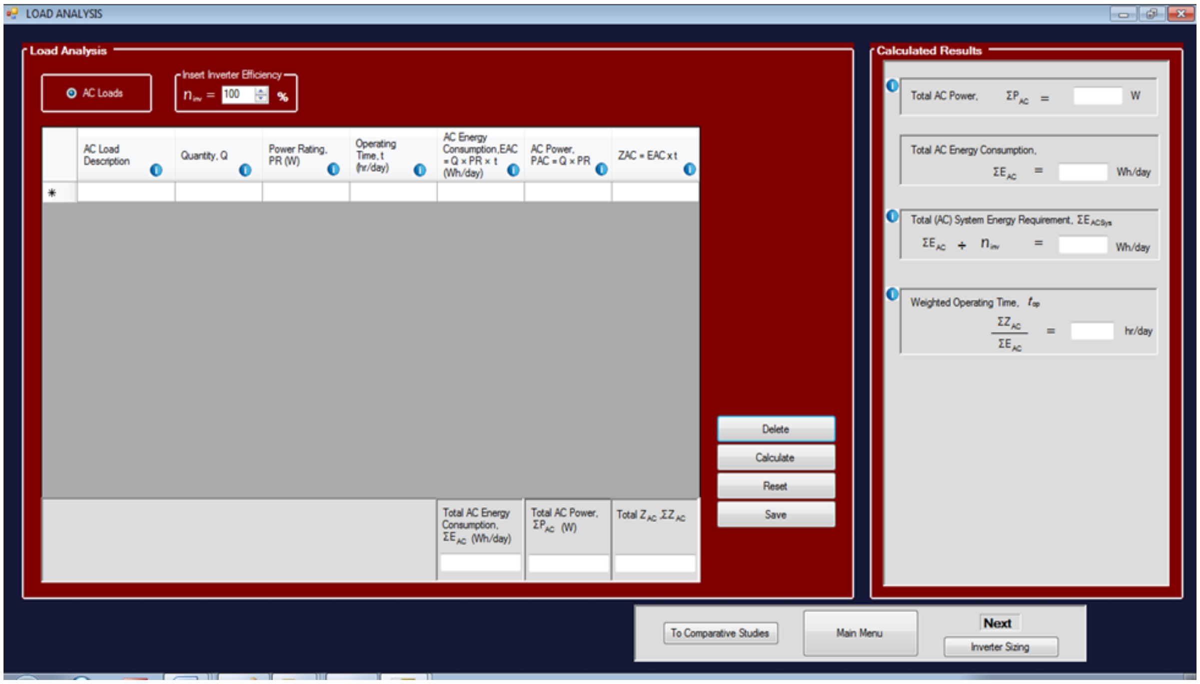
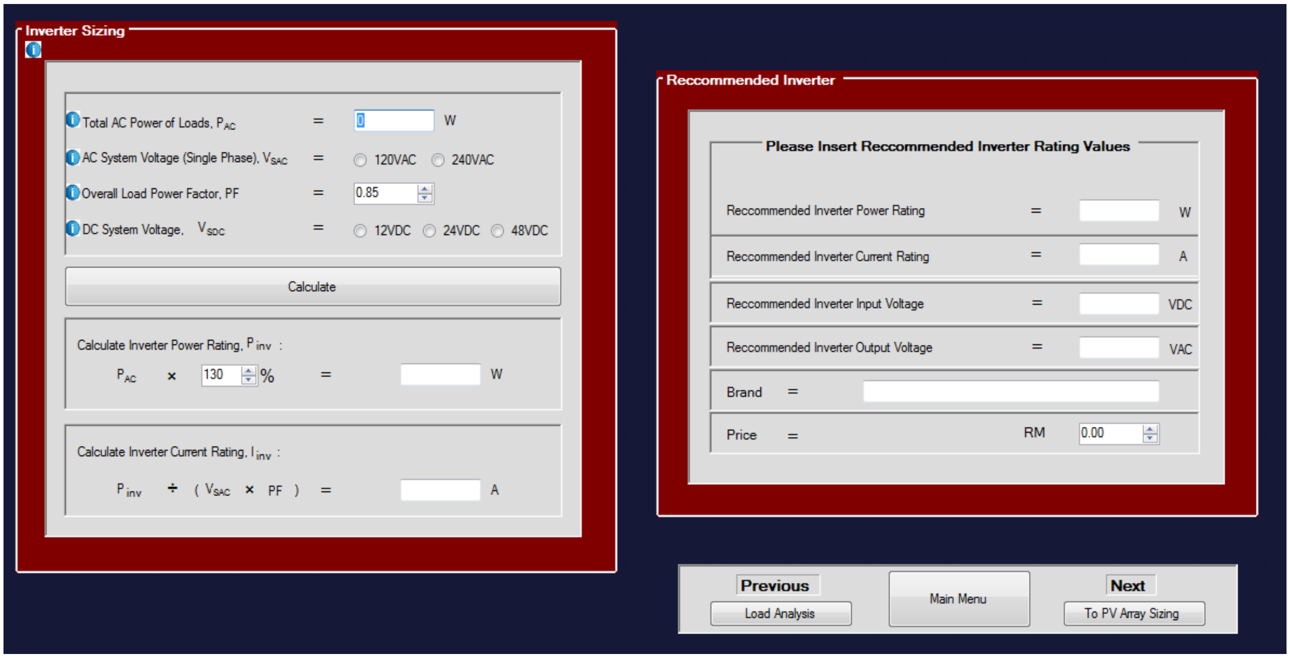


Figure 3: Load analysis interface



Total AC Power of Loads, P_{AC} = 0 W

AC System Voltage (Single Phase), V_{SAC} = ○ 120VAC ○ 240VAC

Overall Load Power Factor, PF = 0.85

DC System Voltage, V_{SDC} = ○ 12VDC ○ 24VDC ○ 48VDC

Calculate Inverter Power Rating, P_{inv} :

P_{AC} × 130 % = W

Calculate Inverter Current Rating, I_{inv} :

P_{inv} ÷ (V_{SAC} × PF) = A

Please Insert Reccommended Inverter Rating Values

Reccommended Inverter Power Rating = W

Reccommended Inverter Current Rating = A

Reccommended Inverter Input Voltage = VDC

Reccommended Inverter Output Voltage = VAC

Brand =

Price = RM 0.00

Figure 4: Interface for inverter sizing

The third step is solar array sizing. At this step, the required current and voltage that must be produced by the solar array are determined. The required array current can be calculated by using Equation (5) [7].

$$I_{array} = \frac{\sum E_{AC}}{\eta_{batt} \times V_{SDC} \times t_{PSH} \times C_s} \qquad (5)$$

where,

I_{array} = required solar array current (A)

$\sum E_{AC}$ = total daily energy consumption (Wh/day)

η_{batt} = battery system charging efficiency

V_{SDC} = system voltage of the battery

t_{PSH} = peak sun hours (hr/day)

C_s = soiling derating factor

Then the required solar array voltage can be calculated by using the equation below [7].

$$V_{array} = \frac{1.2 \times \{V_{SDC} + [V_{SDC} \times C_{\%V} \times (T_{max} - T_{ref})]\}}{\eta_{batt} \times C_s} \qquad (6)$$

where,

V_{array} = maximum expected module temperature in degree Celsius

V_{SDC} = system voltage of the battery

$C_{\%V}$ = temperature coefficient for voltage (usually $-0.004/^{0}C$)

T_{max} = maximum expected module temperature in degree Celsius

T_{ref} = reference temperature (usually $25^{0}C$)

η_{batt} = battery system charging efficiency

C_s = soiling derating factor

The number of solar modules that has to be connected in parallel or series can be calculated using the following equations [7]:

$$\text{Number of solar modules in parallel} = \frac{I_{array}}{\text{maximum power current}, I_{mp}} \qquad (7)$$

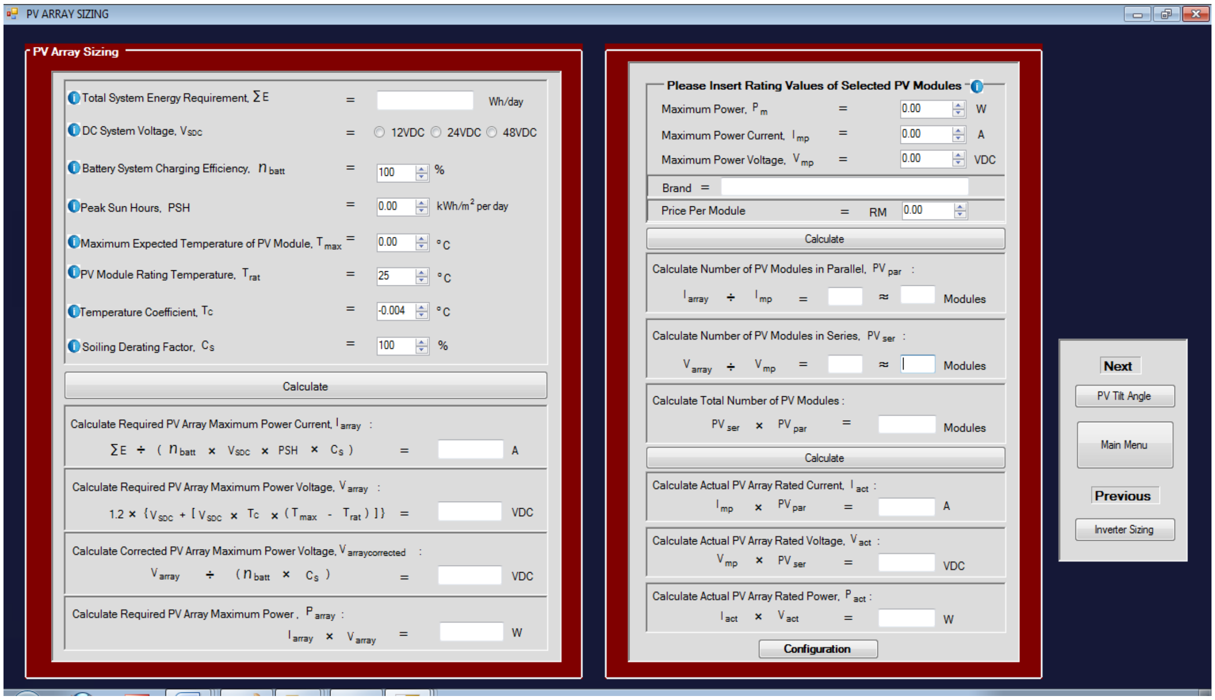
$$\text{Number of solar modules in series} = \frac{V_{array}}{\text{maximum power voltage}, V_{mp}} \qquad (8)$$

The configuration of the PV modules can also be displayed by clicking the configuration button in Figure 5. Figure 6 shows an example of a PV array which consists of 5 PV modules connected in series and 2 PV modules connected in parallel. Then, the PV tilt angle is determined. The interface for this purpose is depicted in Figure 7. For sites that are located at higher latitude than 300 (for example the sites in countries such as Russia and Australia), the solar module should be mounted at a tilt angle of 150 plus the latitude angle, but for sites that are located between latitude of 150S and 150N (for example Malaysia), the tilt angle of 150 is used [7].

Figure 8 shows the interface of the fourth step in sizing a stand-alone solar system which is selecting the suitable size of the charge controller. The current rating of the charge controller can be calculated by using Equation (9) [7].

I_{CC} = maximum power current of solar array × 1.25 (9)

Where I_{CC} is the current rating of the charge controller



Total System Energy Requirement, ΣE = Wh/day

DC System Voltage, V_{SDC} = ○ 12VDC ○ 24VDC ○ 48VDC

Battery System Charging Efficiency, n_{batt} = 100 %

Peak Sun Hours, PSH = 0.00 kWh/m² per day

Maximum Expected Temperature of PV Module, T_{max} = 0.00 °C

PV Module Rating Temperature, T_{rat} = 25 °C

Temperature Coefficient, T_C = -0.004 °C

Soiling Derating Factor, C_S = 100 %

Calculate Required PV Array Maximum Power Current, I_{array} :
$\Sigma E \div (n_{batt} \times V_{SDC} \times PSH \times C_S)$ = A

Calculate Required PV Array Maximum Power Voltage, V_{array} :
$1.2 \times \{V_{SDC} + [V_{SDC} \times T_C \times (T_{max} - T_{rat})]\}$ = VDC

Calculate Corrected PV Array Maximum Power Voltage, $V_{arraycorrected}$:
$V_{array} \div (n_{batt} \times C_S)$ = VDC

Calculate Required PV Array Maximum Power , P_{array} :
$I_{array} \times V_{array}$ = W

Please Insert Rating Values of Selected PV Modules

Maximum Power, P_m = 0.00 W

Maximum Power Current, I_{mp} = 0.00 A

Maximum Power Voltage, V_{mp} = 0.00 VDC

Brand =

Price Per Module = RM 0.00

Calculate Number of PV Modules in Parallel, PV_{par} :
$I_{array} \div I_{mp}$ = ≈ Modules

Calculate Number of PV Modules in Series, PV_{ser} :
$V_{array} \div V_{mp}$ = ≈ Modules

Calculate Total Number of PV Modules :
$PV_{ser} \times PV_{par}$ = Modules

Calculate Actual PV Array Rated Current, I_{act} :
$I_{mp} \times PV_{par}$ = A

Calculate Actual PV Array Rated Voltage, V_{act} :
$V_{mp} \times PV_{ser}$ = VDC

Calculate Actual PV Array Rated Power, P_{act} :
$I_{act} \times V_{act}$ = W

Figure 5: Interface for PV array sizing

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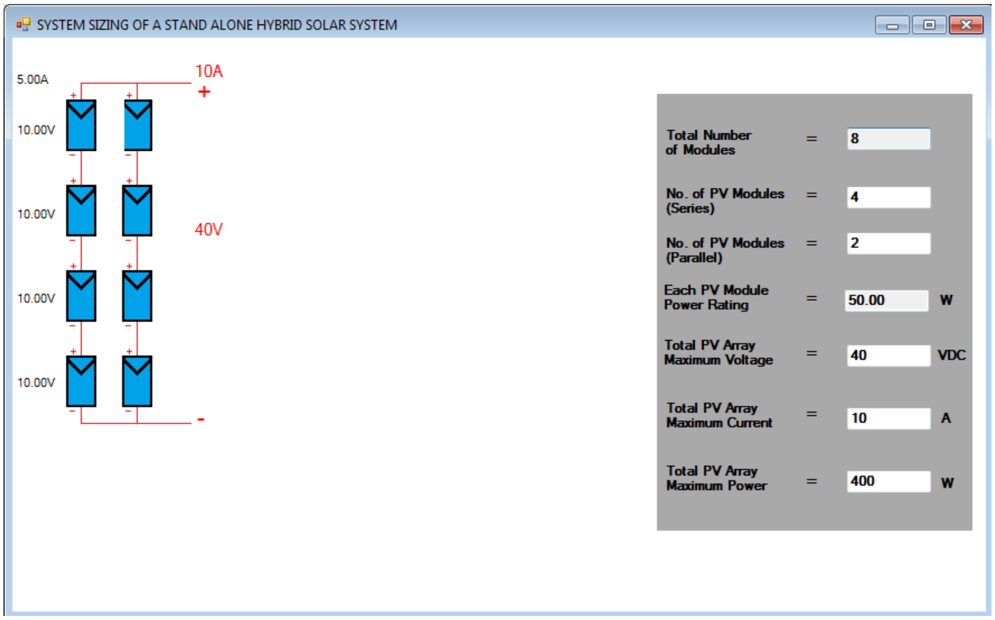


Total Number of Modules = 8

No. of PV Modules (Series) = 4

No. of PV Modules (Parallel) = 2

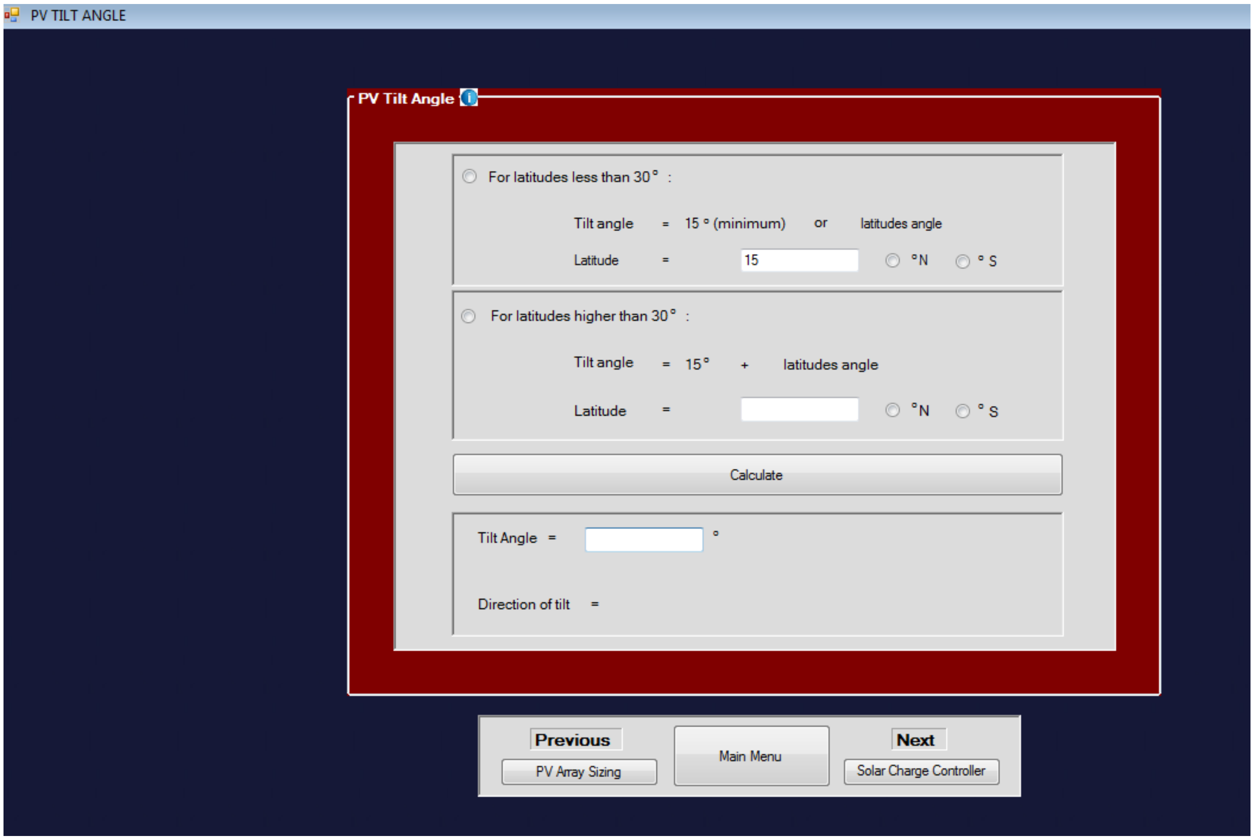
Each PV Module Power Rating = 50.00 W

Total PV Array Maximum Voltage = 40 VDC

Total PV Array Maximum Current = 10 A

Total PV Array Maximum Power = 400 W

Figure 6: Example of PV array configuration.



○ For latitudes less than 30° :

Tilt angle = 15° (minimum) or latitudes angle

Latitude = 15 ○ °N ○ ° S

○ For latitudes higher than 30° :

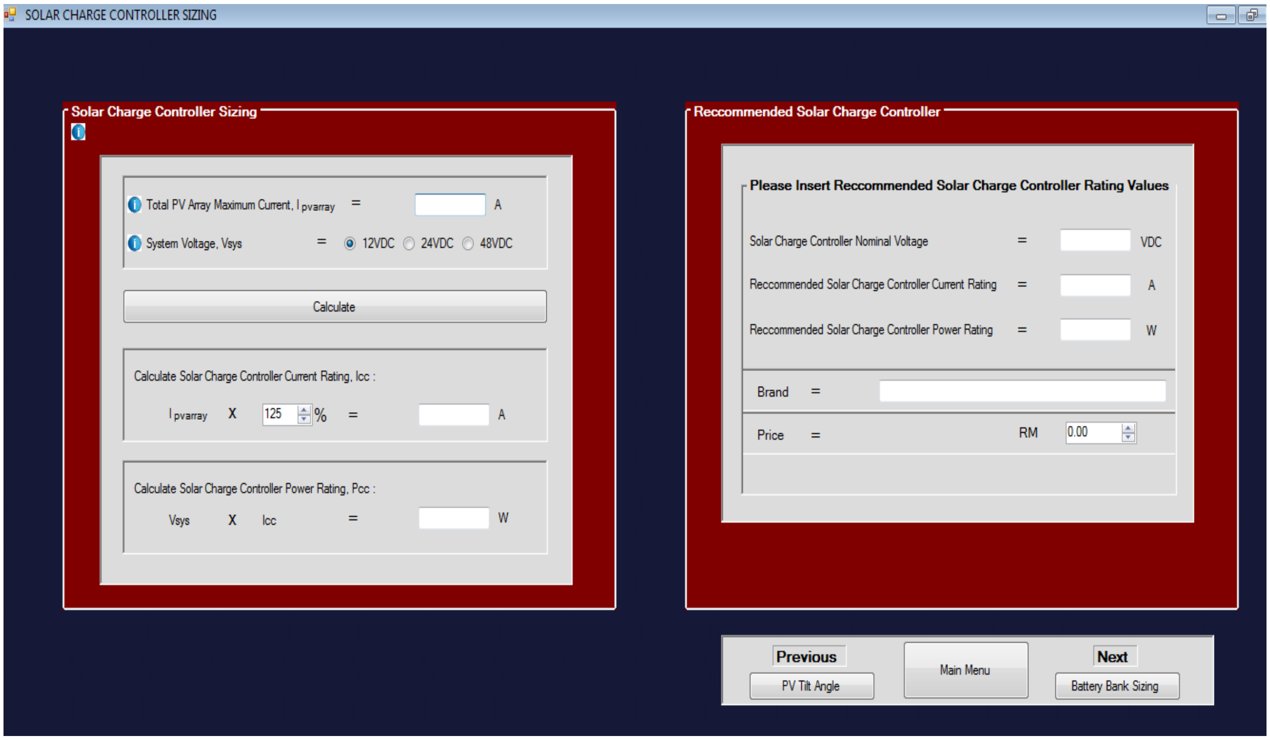
Tilt angle = 15° + latitudes angle

Latitude = ○ °N ○ ° S

Tilt Angle = °

Direction of tilt =

Figure 7: Interface for PV tilt angle



Total PV Array Maximum Current, $I_{pvarray}$ = A

System Voltage, Vsys = ● 12VDC ○ 24VDC ○ 48VDC

Calculate Solar Charge Controller Current Rating, Icc :

$I_{pvarray}$ X 125 % = A

Calculate Solar Charge Controller Power Rating, Pcc :

Vsys X Icc = W

Solar Charge Controller Nominal Voltage = VDC

Reccommended Solar Charge Controller Current Rating = A

Reccommended Solar Charge Controller Power Rating = W

Brand =

Price = RM 0.00

Figure 8: Interface for charge controller sizing

The fifth step in sizing a stand-alone solar system is sizing the capacity of the battery bank. The first step of sizing the battery bank is to determine the required capacity of the battery bank by using Equation 10 [7].

$$B_{out} = \frac{\sum E_{AC} \times t_a}{V_{SDC}} \tag{10}$$

where,

B_{out} = required battery bank capacity (Ah)

$\sum E_{AC}$ = total daily energy consumption

t_a = reserved days (number of days that the battery will not be charged by the solar array)

V_{SDC} = system voltage

The second step is to determine the average discharge rate of the battery bank. It can be calculated by using Equation (11) [7].

$$r_d = \frac{t_{op} \times t_a}{DOD_a} \tag{11}$$

where,

r_d = average discharge rate of the battery bank (hr)

t_{op} = weighted average operating time (hr/day)

t_a = reserved days (number of days that the battery will not be charged by the solar array)

DOD_a = allowable depth of discharge

Finally, the rated capacity of the battery bank is calculated using Equation (12) [7].

$$B_{rated} = \frac{B_{out}}{DOD_a \times C_{T,rd}} \tag{12}$$

where,

B_{rated} = rated battery bank capacity (Ah)

B_{out} = required battery bank capacity (Ah)

DOD_a = allowable depth of discharge

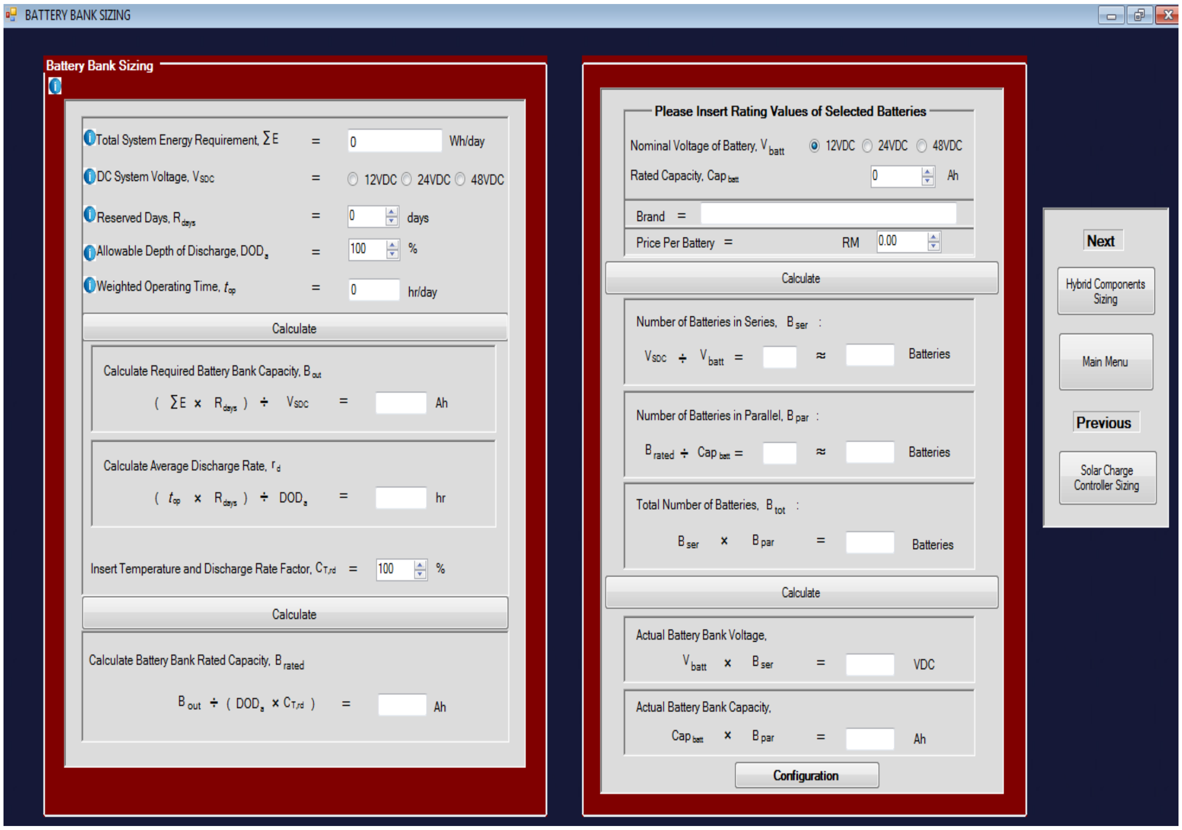
$C_{T,rd}$ = the temperature and discharge rate derating factor of the battery bank

The number of batteries that has to be connected in parallel or series can be calculated using the following equations [7].

$$\text{Number of batteries in parallel} = \frac{B_{rated}}{\text{capacity of the selected battery}} \quad (13)$$

$$\text{Number of batteries in series} = \frac{V_{SDC}}{\text{nominal voltage of the selected battery}} \quad (14)$$

The configuration of the battery-bank can also be displayed by clicking the configuration button in Figure 9. Figure 10 shows an example of a battery which consists of 3 batteries connected in series and 2 batteries connected in parallel.



Total System Energy Requirement, ΣE = 0 Wh/day

DC System Voltage, V_{SDC} = ○ 12VDC ○ 24VDC ○ 48VDC

Reserved Days, R_{days} = 0 days

Allowable Depth of Discharge, DOD_a = 100 %

Weighted Operating Time, t_{op} = 0 hr/day

Insert Temperature and Discharge Rate Factor, $C_{T,rd}$ = 100 %

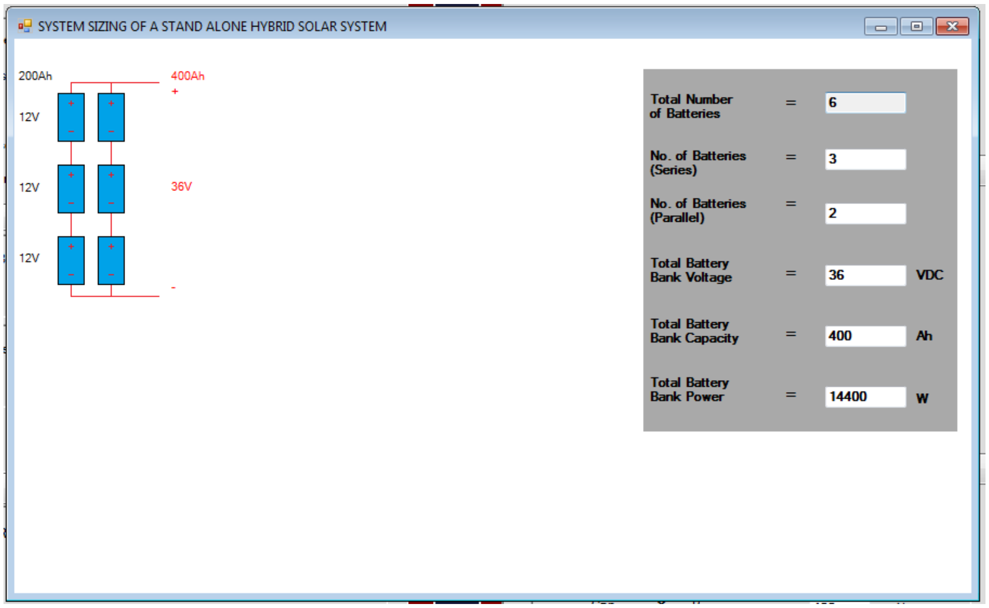
Nominal Voltage of Battery, V_{batt} ● 12VDC ○ 24VDC ○ 48VDC

Rated Capacity, Cap_{batt} 0 Ah

Brand =

Price Per Battery = RM 0.00

Figure 9: Interface for battery bank sizing



Total Number of Batteries = 6
No. of Batteries (Series) = 3
No. of Batteries (Parallel) = 2
Total Battery Bank Voltage = 36 VDC
Total Battery Bank Capacity = 400 Ah
Total Battery Bank Power = 14400 W

Figure 10: Battery-bank configuration

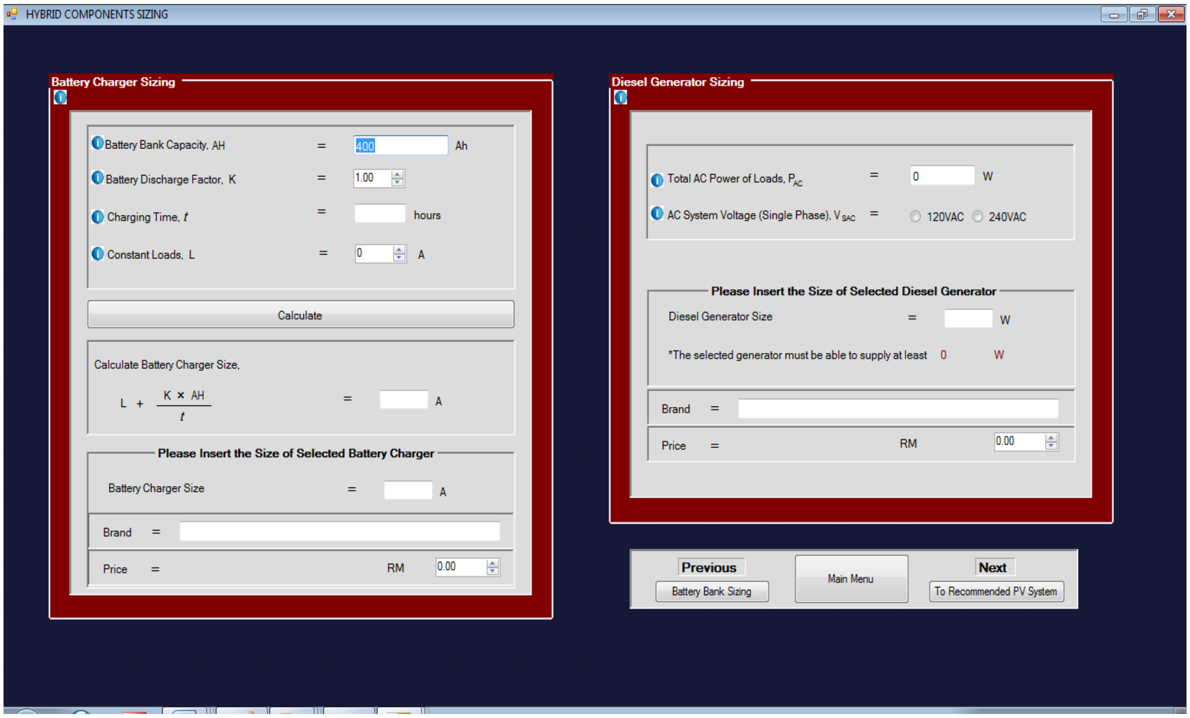
This paper will combine the stand-alone solar system with a diesel generator to form the hybrid system. Besides that, a battery charger will be used to charge the battery bank when the solar array cannot produce electricity due to no sunlight. The diesel generator will be used for supplying electrical power to the battery charger and to the loads. Hence, there are two extra components that need to be sized in a stand-alone hybrid solar system which are the size of diesel generator and the size of the battery charger. Figure 10 shows the interface for hybrid components sizing. The sizing of diesel generator is similar to sizing the inverter. The diesel generator must be able to supply at least the same amount of power as the total AC power demand obtained in load analysis and it must have the same output voltage with the AC system voltage [12]. Meanwhile the size of the battery charger can be determined by using the following equation [13].

$$BC = L + \frac{K \times AH}{T} \qquad (15)$$

where,

BC = size of the battery charger in ampere
L = other controls load (A)
K = battery discharge factor (usually 1.1 for lead acid and 1.4 for Ni-Cad)
AH = battery capacity in ampere hour
T = charging time in hours

After that the user can see the summary details of the PV system as shown in Figure 11. Figure 12 shows the graphical diagram of the system that will help the user to have a better view at the system. After that, the software can help in calculating the estimated cost for the solar system. The interface of the cost estimation is shown in Figure 13. Finally, the study of return on investment of stand-alone hybrid solar system compare to grid utility bills can be calculated and presented. The interface for that purpose is shown in Figure 14.



Battery Bank Capacity, AH = 400 Ah

Battery Discharge Factor, K = 1.00

Charging Time, t = hours

Constant Loads, L = 0 A

Calculate Battery Charger Size,

$$L + \frac{K \times AH}{t} = \quad A$$

Please Insert the Size of Selected Battery Charger

Battery Charger Size = A

Brand =

Price = RM 0.00

Total AC Power of Loads, P_{AC} = 0 W

AC System Voltage (Single Phase), V_{SAC} = ○ 120VAC ○ 240VAC

Please Insert the Size of Selected Diesel Generator

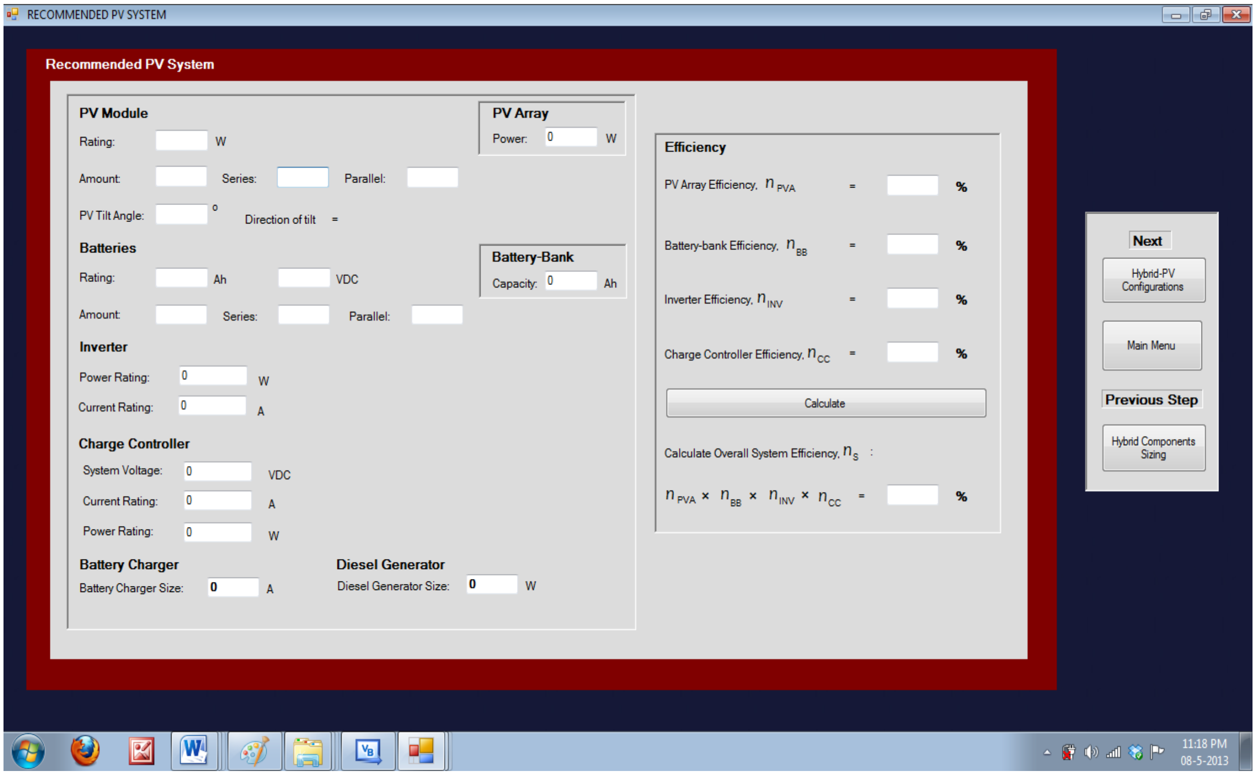
Diesel Generator Size = W

*The selected generator must be able to supply at least 0 W

Brand =

Price = RM 0.00

Figure 10: Interface for hybrid components sizing



PV Module

Rating: W

Amount: Series: Parallel:

PV Tilt Angle: ° Direction of tilt =

PV Array

Power: 0 W

Batteries

Rating: Ah VDC

Amount: Series: Parallel:

Battery-Bank

Capacity: 0 Ah

Inverter

Power Rating: 0 W

Current Rating: 0 A

Charge Controller

System Voltage: 0 VDC

Current Rating: 0 A

Power Rating: 0 W

Battery Charger

Battery Charger Size: 0 A

Diesel Generator

Diesel Generator Size: 0 W

Efficiency

PV Array Efficiency, η_{PVA} = %

Battery-bank Efficiency, η_{BB} = %

Inverter Efficiency, η_{INV} = %

Charge Controller Efficiency, η_{CC} = %

Calculate Overall System Efficiency, η_S :

$\eta_{PVA} \times \eta_{BB} \times \eta_{INV} \times \eta_{CC}$ = %

Figure 11: Interface for recommended PV system

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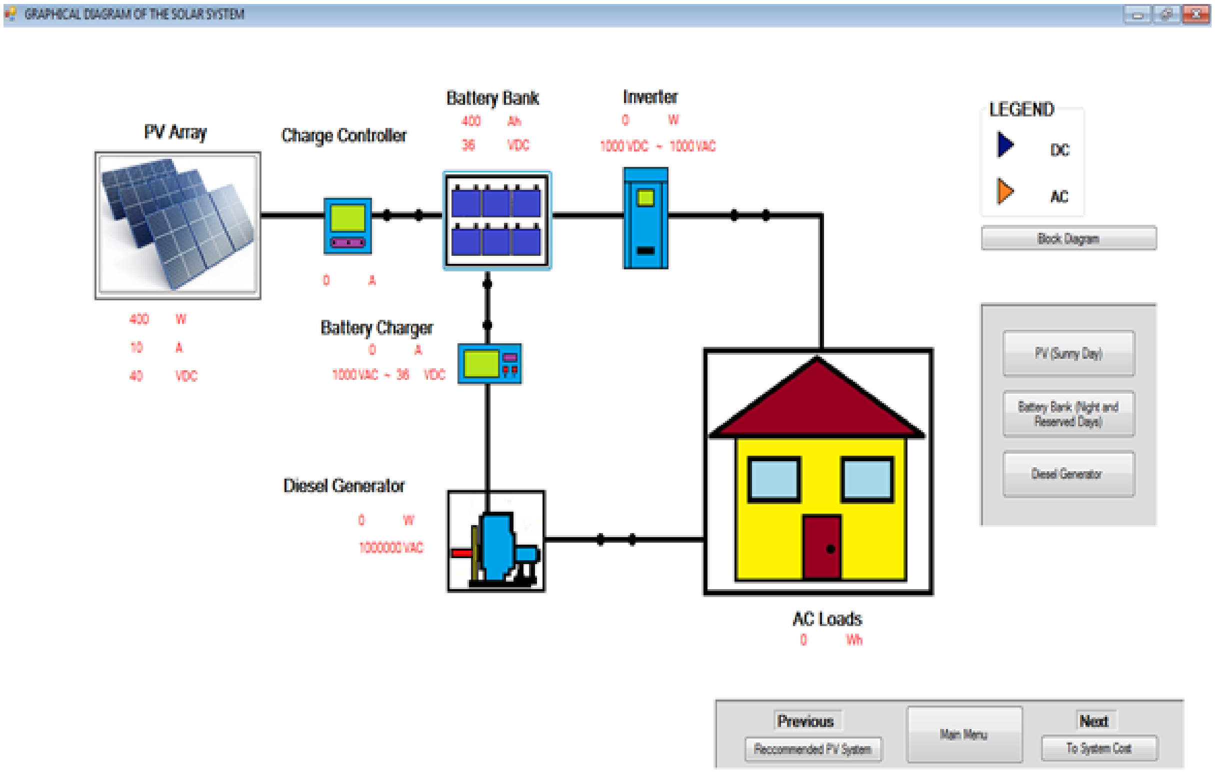
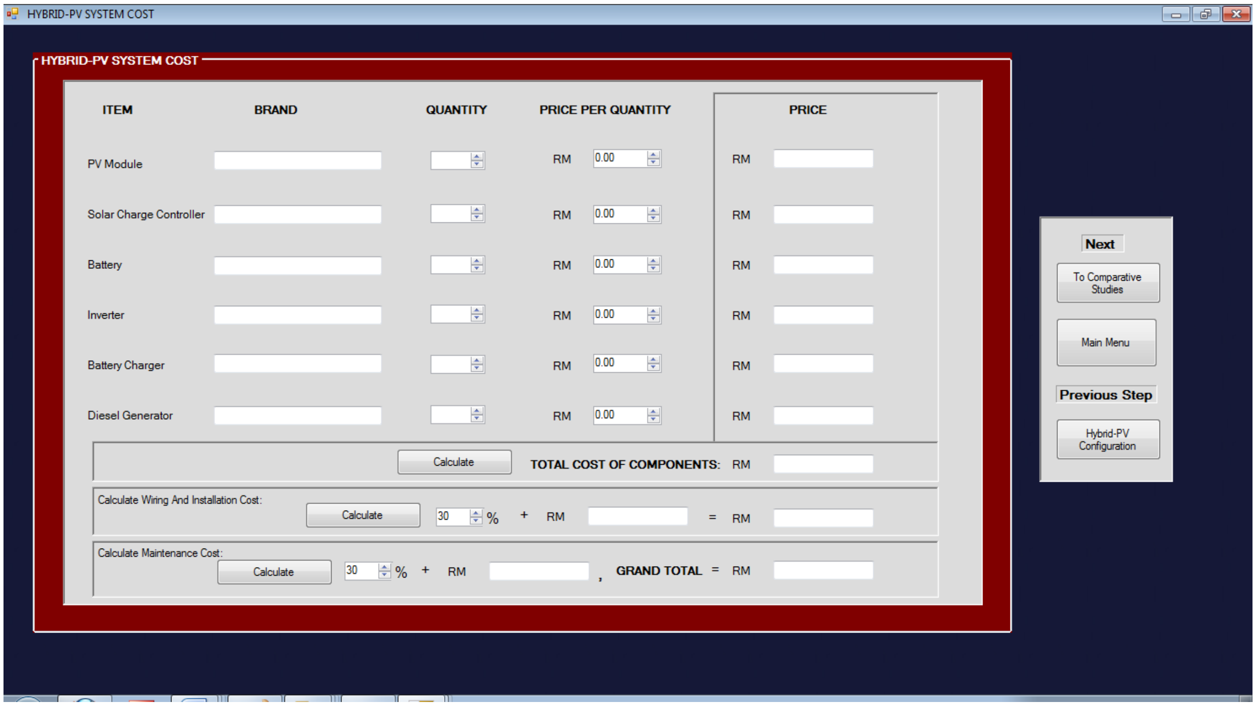


Figure 12: Graphical diagram of the solar electrical system



ITEM	BRAND	QUANTITY	PRICE PER QUANTITY	PRICE
PV Module			RM 0.00	RM
Solar Charge Controller			RM 0.00	RM
Battery			RM 0.00	RM
Inverter			RM 0.00	RM
Battery Charger			RM 0.00	RM
Diesel Generator			RM 0.00	RM

Calculate TOTAL COST OF COMPONENTS: RM

Calculate Wiring And Installation Cost: Calculate 30 % + RM = RM

Calculate Maintenance Cost: Calculate 30 % + RM , GRAND TOTAL = RM

Figure 13: Interface for cost estimation

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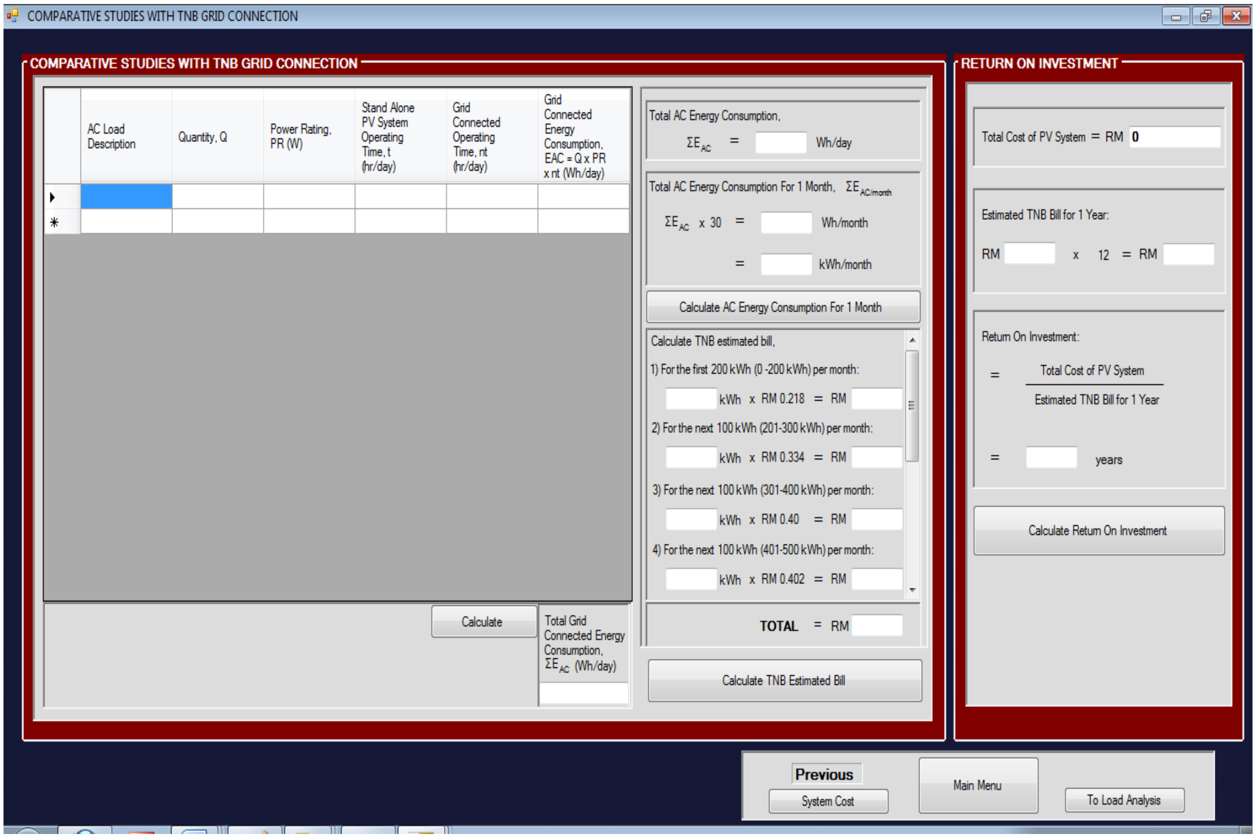

Total Cost of PV System = RM 0

Figure 14: Interface for study of return on investment of stand-alone hybrid solar system compare to grid utility bills

3. Significant of Results.

It is expected that this software will be able to calculate the optimum size of every components in the stand-alone hybrid solar system to meet the load requirements. Any mistakes in sizing those components will affect not only the amount of energy produced, but also can cause the increasing of the system's cost. Hence, the cost estimation and the study of return on investment of the stand-alone hybrid solar system compare to grid utility bills can be very helpful.

4. Conclusion

The GUI interface will help to enhance the user's understanding. Hence, this software can be used for teaching and learning applications especially for institute of higher education and training centers of utility industries. In this research work, a software package that can be used for system sizing of a stand-alone hybrid solar system has been developed. The development of the software is based on calculations of sizing procedure for components of a stand-alone hybrid solar system. The software makes use of GUI that can help the users to understand even though they have little knowledge about sizing PV systems.

Acknowledgement

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