A GUI Based Software for Sizing Stand Alone AC Coupled Hybrid PV-Diesel Power System under Malaysia Climate

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Abstract. This paper presents the development of Graphical User Interface (GUI) software for sizing main component in AC coupled photovoltaic (PV) hybrid power system based on Malaysia climate. This software provides guideline for PV system integrator to design effectively the size of components and system configuration to match the system and load requirement with geographical condition. The concept of the proposed software is balancing the annual average renewable energy generation and load demand. In this study, the PV to diesel generator (DG) ratio is introduced by considering the hybrid system energy contribution. The GUI software is able to size the main components in the PV hybrid system to meet with the set target of energy contribution ratio. The rated powers of the components to be defined are PV array, grid-tie inverter, bi-directional inverter, battery storage and DG. GUI is used to perform all the system sizing procedures to make it user friendly interface as a sizing tool for AC coupled PV hybrid system. The GUI will be done by using Visual Studio 2015 based on the real data under Malaysia Climate.

1. Introduction

In Malaysia, most of the rural area lacked of electricity from the grid utility power supply especially in Sabah and Sarawak. They have to rely on decentralized DG as the main source[1] which it does not guarantee 24-hour electricity supply. To overcome this problem the Ministry Education of Malaysia has launched a large electrification program using PV hybrid program for rural schools in Sabah [1]. This program aimed to solve the electricity problem in Sabah using Stand-Alone PV Hybrid System [2]. The Stand-Alone PV hybrid (SPVH) system is system that combine PV with the another power generating source as a backup such as batteries and DG. The main advantage of SPVH is to produce as much as possible energy from renewable energy sources to ensure that it is sufficient energy to meet the load demands [3].

PV hybrid system installed in rural schools in Sabah can be classified in two types Direct Current (DC) and Alternate Current (AC) coupled topology [4]. The DC coupled system is widely accepted to provide power to small load applications. However, AC coupled system offers more advantages for large system [5-7]. Generally, the PV hybrid system involves five components which are PV array, grid-tie inverter, bi-directional inverter, battery storage and backup source. Figure 1 shows the block diagram of hybrid PV system.

However, AC coupled PV hybrid system is a relatively new system in Malaysia. Therefore, the sizing issue becomes a major challenge and there is still no detailed procedures that are based on

Malaysia's climate [8]. Usually, most of AC coupling system in Malaysia was designed by system provider from country origin [9, 10].

Based on study [11] ,the performance of the actual system is presented by using AC coupled PV hybrid power system installed at one of the rural school electrification in Sabah. It shows the low performance ratio of the system and indicates the PV system is oversized and the unbalance PV energy generated with the energy consumption by user.

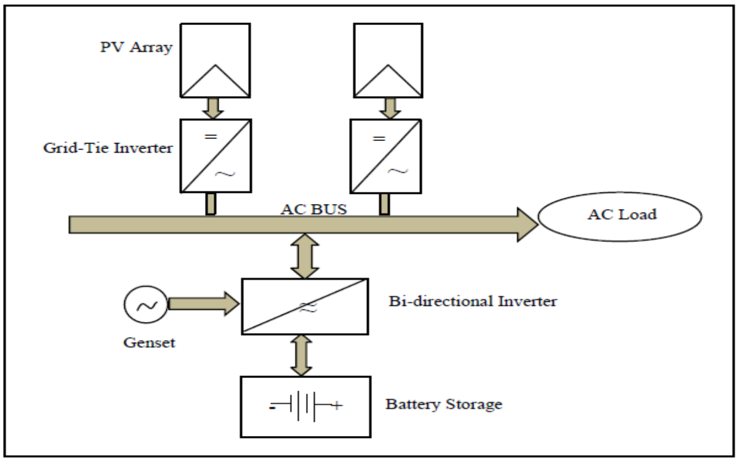

Figure 1: Block Diagram of AC Coupled Hybrid PV Power System.

Therefore, this software is developed as a tool to design AC Coupled Hybrid PV-Diesel Power System by using Graphical User Interface (GUI). Besides that, each components in AC coupled PV hybrid system can be sized accurately to meet the load demand and prevent the un-utilized power in the system.

2. Software Design Methodology

The concept of this sizing tool acts as a guideline for PV system integrator to design effectively the size of AC coupled PV hybrid system components. This sizing tool is developed by using GUI platform based on Visual Studio 2015.The overall procedures in this sizing tool are summarized in the flow chart in Figure 2 begins with main menu interface and ends with summary of PV hybrid configuration. Main menu is the first interface of the system. For the first windows, the user can analyze the stages involved in sizing a stand-alone solar hybrid system.

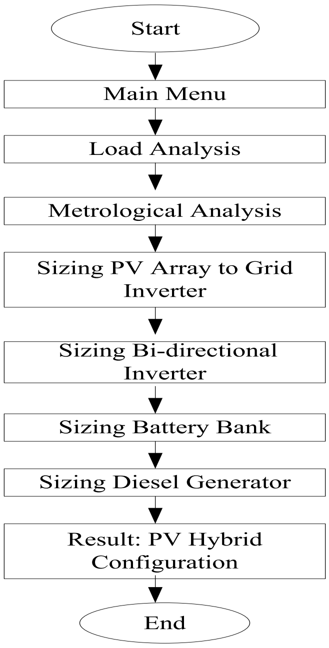

Figure 2. Procedure in sizing an AC Coupled Hybrid PV System.

3. System Sizing

Proper system sizing is essential for sustainability and reliability. The system sizing will be used to decide on size of each components involved in the PV hybrid system.

3.1 Sizing PV Array to Grid Inverter

Using this software, the PV to grid inverter sizing for the hybrid system gives the optimum size of PV array that matched with the grid inverter based on the energy requirement. In this step, the configuration of PV array that matches to the grid inverter is to be defined.

3.1.1 PV Array Power. The PV array as the main source of renewable energy used to supply the consumer with required amount of energy demand based on their load. This amount can be defined by the PV to DG ratio, n of the system. There are several losses affected the output of PV array power. The following formula is proposed to estimate the required PV array power at Standard Test Condition (STC) by using equation (1):

$$P_{STC} = \frac{n \times E_d}{PSH \times f_{tem} \times f_{mm} \times f_{dirt} \times f_{ag} \times \eta_{inv} \times \eta_{cab} \times \eta_{bd} \times \eta_{batt}} \qquad (1)$$

P_{stc} is power of PV array at STC.
n is fraction of energy contributed by PV (PV to DG ratio) .
E_d is energy demand per annum.
PSH is peak sun hour per annum.
f_{dirt} is power de-rating factor due to dirt.
f_{mm} is power de-rating factor due to the module mis-match.
f_{tem} is power de-rating factor of power due to average daily maximum ambient temperature.
f_{ag} is power de-rating factor of aging.

η_{inv} is maximum efficiency of inverter.
η_{cab} is efficiency of DC cable from PV to inverter
η_{bd} is maximum efficiency of bi-directional inverter.
η_{batt} is efficiency of battery.

3.1.2 Total Number of PV Module Required.
By using the value of PV array power, the estimated total number of PV modules required for the system based on the selected module is determined by equation (2)[12].

$$N_{tot} = round\_up\left[\frac{P_{stc}}{P_{mod\_stc}}\right] \quad (2)$$

P_{stc} is power of PV array at STC.
N_{tot} is total number of PV modules required.
P_{mod_stc} is maximum power rating of PV module at STC

3.1.3 Optimum Range Size of Grid Inverter.
The optimum size of grid inverter for the system is calculated based on the PV array capacity. The design factors, f_{d1} and f_{d2} must be selected appropriately based on the types technology of module used and how they are mounted at the site [12]. In this study, the values for f_{d1} and f_{d2} are 0.9 and 1.0 respectively. The technology of the module used is mono-crystalline with free standing structure. The optimum range of size of grid inverter can define by equation (3) as follows:

$$f_{d1} \times (N_{tot} \times P_{mod\_stc}) \leq P_{nom\_inv} \leq f_{d2} \times (N_{tot} \times P_{mod\_stc}) \quad (3)$$

f_{d1}, f_{d2} are design factors.
P_{nom_inv} is nominal AC power output of the selected inverter.

3.1.4 Sizing of PV Array to Grid-Inverter selected.
The range of estimated total number of PV modules that matches with a selected inverter calculated according to the nominal output power of grid tie inverter selected and also the design factor for the system. To determine the range of number of PV modules that matched a specific inverter[12] can define by equation (4) as follows:

$$N_{pv\_inv} = N_{min} \ldots\ldots N_{max} \quad (4)$$

N_{pv_inv} is range of number of PV modules matched to the selected inverter
N_{min} is minimum number of PV modules.
N_{max} is maximum number of PV modules.

$$N_{min} = round\_up\left[\frac{P_{nom\_inv}}{P_{stc\_mod} \times f_{d1}}\right] \quad (5)$$

$$N_{max} = round\_down\left[\frac{P_{nom\_inv}}{P_{stc\_mod} \times f_{d2}}\right] \quad (6)$$

P_{nom_inv} is nominal AC output power of the inverter.

3.1.5 Number of Modules in Series.

The range number of PV modules connected in series in a string.

$$N_s = N_{s\_min} \ldots N_{s\_max} \tag{7}$$

N_s is number of PV modules in series.
N_{s_min} is minimum number of PV modules in series.
N_{s_max} is maximum number of PV modules in series.

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$$N_{s\_min} = {}_{round\_up}\left[\frac{V_{min\_inv\_mppt} \times f_{s2}}{V_{mp\_min} \times \eta_{cab}}\right] \tag{8}$$

$$N_{s\_max} = {}_{round\_down}\left[\frac{V_{max\_inv\_input} \times f_{s1}}{V_{oc\_max}}\right] \tag{9}$$

$V_{min\_inv\_mppt}$ is minimum MPPT input of voltage of inverter.
f_{s1}, f_{s2} are safety margins .

The safety margin f_{s1} and f_{s2} are valued 0.95 and 1.1. These values are introduced for a safety purpose. The values of safety margin are depending on 5% less and 10% over from the window voltage of grid-inverter selected.

3.1.6 Number of Modules in Parallel.

The maximum possible number of string in parallel is calculated according to the input DC current of grid-inverter selected, the current short circuit at STC of module and the safety margin. In general, grid-inverter of PV system categorized base on power rating have single MPPT and multiple MPPT which is take into account during calculate the number of PV string connected in parallel. It is determined by equation (10) as [12]:

$$N_p = {}_{round\_down}\left[\frac{I_{dc\_inv} \times No\_of\_MPPT}{I_{sc\_stc} \times f_{s3}}\right] \tag{10}$$

N_p is maximum number of string in parallel.
I_{dc_inv} is maximum input current of the inverter.
I_{sc_stc} is short circuit current of PV module.
f_{s3} is safety margin.(varies from 1.1 to 1.25).

3.1.7 Array Configuration.

The array configuration is the optimum numbers of PV module which are connected in series and parallel for the system. The total number of PV module is determined by equation (11) as[12]:

$$N_t = N_s \times N_p \tag{11}$$

N_t is the total number of PV modules in the array.

3.2 Number of Grid-Tie Inverter.

The total number of grid inverter can calculated according to the actual power array and nominal power of inverter selected in equation (3). The total number of grid inverter can define using equation (12) as [12] :

$$N_{grid\_inv} = roud\_up\left[\frac{N_t \times P_{mod\_stc} \times f_{de-rate}}{P_{nom\_inv}}\right] \tag{12}$$

N_{grid_inv} is the number of grid inverter.

3.3 Bi-directional inverter Sizing.
To select the power rating of bi-directional inverter suitable for the system, the power peak demand need to considered. The total number of bi-directional selected can defined by equation (13) :

$$N_{bd\_inv} = round\_up\left[\frac{PPD}{P_{ac\_bd}}\right] \tag{13}$$

N_{bd_inv} is the number of bi-directional inverter.
PPD is power peak demand.
P_{ac_bd} is nominal output power of the selected bi-directional inverter.

3.4 Battery Sizing.
The suggested sizing process of battery bank is valid for different types of batteries available. The several steps involved to identify the size of battery bank are as follows:

3.4.1 Total Capacity Required Daily.
The total capacity required to satisfy the total energy required daily. It can be calculated by equation (14) as [12]:

$$C_{req} = \frac{E_{d\_daily}}{SV} \tag{14}$$

C_{req} is total battery capacity required daily.
E_{d_daily} is daily energy demand.
SV is system voltage.

3.4.2 Battery Bank Capacity Required.
Battery bank capacity required is determined as a function of several parameters such as autonomy day, maximum of DOD, temperature correction factor of battery and efficiency of the bi-directional inverter. The autonomy days is defined as the number of days that the battery able to fully support the load demands without recharging by PV or the DG. The autonomy days can be set smaller if the system has DG. The value of temperature correction factor can be identified by defining the lowest daily temperature for the site and correlate with the value given by the manufacture. The amount of battery bank capacity is determine by equation (15) as [12]:

$$C_{bat\_req} = C_{req} \times \frac{T_{aut}}{DOD_{max}} \times \frac{1}{f_{bat\_tem} \times \eta_{bd}} \tag{15}$$

C_{bat_req} is actual amount of battery capacity required.
T_{aut} is the days of autonomy (day/s).
DOD_{max} is the maximum depth of discharge of battery.

f_{bat_tem} is temperature correction factor of battery.

3.4.3 Total Bank Discharge Current.

The total battery bank discharge current is the maximum amount of current needed to satisfy the load demand. The total bank discharge current from the battery is equal to the total load current. This is calculated by equation (16) as[12]:

$$I_{bat\_dis} = I_{tot} = \frac{1}{SV} \times \left[\sum_{i=1}^{n} P_{dc} + \sum_{i=1}^{n} \left(\frac{\frac{P_{ac}}{pf}}{\eta_{bd}} \right) \right] \tag{16}$$

I_{bat_dis} is discharge current from the battery bank
P_{dc} is total power of DC load.
P_{ac} is total power of AC load.
pf is power factor of the AC load.

3.4.4 Number of Batteries in Series String.

The total number of batteries in series can be calculated according to the system voltage and by the chosen nominal voltage of battery. The number of batteries in string can be determined using equation in (17) as [12]:

$$N_{s\_bat} = round\_up\left(\frac{SV}{V_{nom\_bat}} \right) \tag{17}$$

N_{s_bat} is number of batteries/cells in series.
V_{nom_bat} is nominal voltage of battery/cell.

3.4.5 Number of Batteries String in Parallel.

The total number of battery strings can be calculated according to the capacity of battery bank required and the capacity of each battery selected. Selection of the next large standard size of battery is recommended The number of batteries in parallel can be calculated by equation (18) as[12]:

$$N_{p\_bat} = round\_up\left(\frac{C_{bat\_req}}{C_{bat\_selected}} \right) \tag{18}$$

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

3.5 Diesel Generator Sizing

The DG rating is based on the maximum load demand during battery charging. The power from DG is used to charge the battery and provide AC power to the load. When selecting the size of DG, need to be making sure that the DG can meet all the power requirement of the load. The oversize factor of DG is also considered in this study. To ensure a long service life and also good diesel utilization, the DG need to be operated at optimum load [18].The DG rating is calculated by equation (19) as follows [12]:

$$S_{dg} = \frac{S_{max\_dem} \times f_{over}}{f_{dg\_derate}} \tag{19}$$

S_{dg} is the size of a DG required.

S_{max_dem} is the maximum load demand during battery charging.
f_{over} is oversize factor .
f_{dg} is the total de-rating factor of DG (eg:temperature,humidity,altitude).

4. Result

The results of this research consist of the rated powers and configuration of main components in AC coupled PV hybrid power system depends on the load demand. In this research, an AC coupled PV hybrid power system installed at one of the rural school in Sabah is chosen as a case study case to validate the feasibility of developed software. The system size is 15kWp. The AC coupled PV hybrid system is designed to supply electricity to the whole school building included office computer lab, teacher's quarter, and guard house. The actual load demand for 7 months used and analyze to calculate the size of algorithm for the system components.

Figure 3 shows the main interface of the PV system design tool for AC Coupled PV hybrid system. The main interface shows the list of the steps involved in sizing AC Coupled PV hybrid system. It allow for easy navigation of the system. It includes the load analysis, and sizing for each of the parameter such as PV Array, Grid – Tie Inverter, Bi-Directional Inverter, Battery Bank, and DG.

Figure 3. The main menu of the sizing software.

In this research, the weather profile was studied under Malaysia's climate. It is very important to understand the geographical distribution of the solar irradiance and the operating temperature condition at the site before the PV system installation. The daily solar irradiance is graphically represented in Figure 4. From that, the amount of PSH will be obtained. This value is important to determine the amount of PV array power of the system. The system is designed to supply electricity to the whole school building included office computer lab, teacher's quarter, and guard house. The types of connected loads are ceiling fans, computers, projectors, photocopy machine, water pump and etc. The entire appliances are operating using AC power. This system supply power continuously to the respective building with backup by DG. Figure 4 also shows the load analysis interface. In this section the user can view the actual load graph plotted for daily by selecting the month and day buttons. In addition, from this part the user can also know the values of power peak demand and the amount of energy demand. These values are important to determine the size of bi-directional inverter [8, 10] and also the size of PV array respectively later on [8].

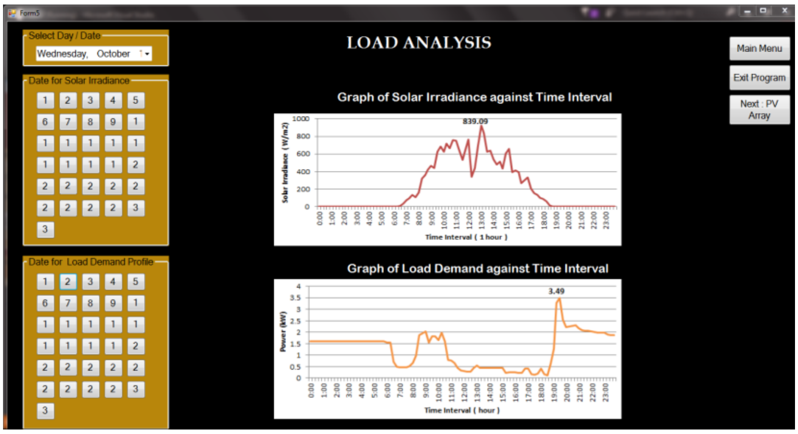

Figure 4. Metrological and Load Analysis Interface.

The first step in sizing an AC coupled PV hybrid system is sizing the Photovoltaic Array to Grid Inverter. The PV to grid inverter sizing gives the optimum size of PV array that matched with the grid inverter based on the energy requirement.

From that, the optimum size of grid inverter for the system is calculated based on the actual final number of PV array capacity and the optimum range size of inverter is determined. There are 6 types of grid inverter available in database and the new data specification can be added manually. From the optimum range of grid inverter above, the actual size, the total number and the type of grid inverter available as in data base can be selected shown in Figure 5.

The second step in sizing an AC coupled PV hybrid system is to determine the PV array configuration. The array configuration is the optimum numbers of PV module which are connected in series and parallel for the system. Figure 6 shows an example of a PV array which consists of 12 PV modules connected in series and 2 PV modules connected in parallel.

In the same interface shows in Figure 6, the third step in sizing an AC coupled PV hybrid system which is calculated the total number of grid inverter according to the actual power array and nominal power of Grid inverter selected.

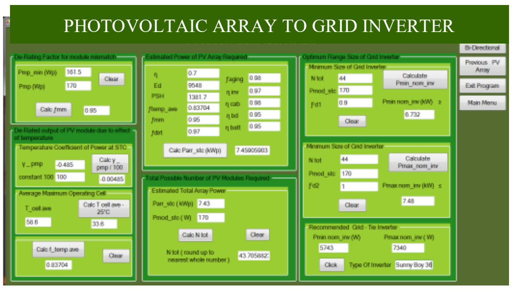

Figure 5. Photovoltaic Array to Grid Inverter Interface.

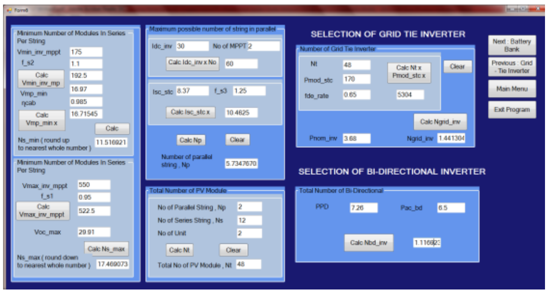

Figure 6. PV Array Configuration, Grid Inverter and Bi-directional Interface.

The fourth step in sizing AC coupled PV hybrid system is sizing bi-directional inverter. As mentioned, the value of power peak demand from the load analysis interface will be used to calculate the size and number of bi-directional as shown in Figure 6. The fifth step is sizing the capacity of the battery bank. The first step of sizing the battery bank is on energy requirement and capacity required daily. The tool will display the possible configuration in series and parallel of batteries that can match the required capacity as shown in Figure 7.

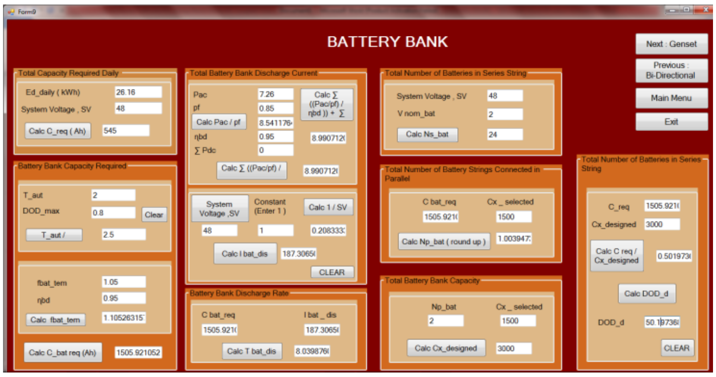

Figure 7. Battery Sizing Interface.

The DG will be used for supplying electrical power to the loads when the PV array cannot produce electricity due to no sunlight. The DG 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. Then, the user can directly key in the value of de-rating factor involved base on site of case study in the sizing window in Figure 8. After that, the actual size of DG will appear on the tools. After complete all the steps, the user can review the detail recommended configuration of the PV hybrid system as shown in Figure 9.

Figure 8. DG Interface.

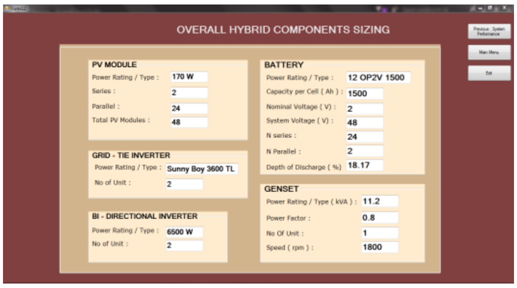

Figure 9. Interface for recommended AC coupled PV hybrid system

5. Conclusion

The development of software tool by using GUI interface has been developed in this study. This software tool is used to find an algorithm for sizing of AC coupling PV hybrid system components. The developed algorithm consists of PV array, grid-tie inverter, bi-directional inverter, battery storage and DG as a backup system for the electrification in rural area. In addition, this software is important to assist the user with minimal knowledge and enhance the user's understanding on design the AC coupled PV hybrid system; conveniently they can use this tool to develop their own PV hybrid system.

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