



Design of Graphical User Interface Development Environment Software for sizing of Grid Connected Photovoltaic (GCPV) system

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Abstract

This work presents a design of graphical user interface development environment (GUIDE) software for sizing of Grid Connected Photovoltaic (GCPV) system. The simulation model of the GCPV system design is developed by using GUIDE in MATLAB. The developed GUI display the performance of the PV system based on the three scenarios. The three scenarios are sizing based on architecture constraint, the energy required and budget constraint. The size of the GCPV system is from 4.6 kW to 60.0 kW. A GUIDE is developed to design and calculate the suitable size of photovoltaic (PV) module, analyses the optimum array configuration, selection of inverter, size of cable, determine the specific yield and performance ratio. The GUI be able to make a user's job easier and beneficial in assisting the GCPV system design process compared to the manual calculation of the GCPV system.

Keywords: Graphical User Interface Development Environment (GUIDE), Graphical User Interface (GUI), Grid Connected Photovoltaic (GCPV)

1. Introduction

To simplify the sizing process of the GCPV system, a graphical interface (GUI) is developed as a pictorial interface to an application. The GUI should behave in a predictable and understandable way so that a consumer knows what to anticipate when he or she an action is conducted. For example, whenever a mouse click takes place on a pushbutton, the GUI should initiate the actions referred to on the label of the key [1]. GUI plays an essential role in computing as the interface is provided by its advantages. Furthermore, it is easier to be used for non-technical people or for the beginners. For instance, the user can work on a particular work and get the work done with ease just with few clicks on buttons. Despite the fact that the resources available are a lot in nature, it is very challenging to create and operate in a feasible manner. In previous studies, Marizan Sulaiman et al [2] proposed a methodology for a GUI Based Teaching and Learning Software for System Sizing of A Stand-Alone Hybrid Solar Electricity System. Ramya A et al [3] recommended the simple optimization algorithm offers been developed and executed in MATLAB for locating the number of wind generators and photovoltaic panels necessary for installation in any program ensuring that the full total cost of the machine is minimized with the specified demand getting met.

This work is focused on designing, implementing and evaluating a Grid Connected PV system based on three scenarios. To get the very best performance of the operational system, the process of designing the system should be carried out perfectly. Firstly, performance ratio (PR) is the most crucial variables for evaluating the efficiency of photovoltaic (PV) system to the utility grid. The performance ratio is the ratio of the actual and theoreti-

cally possible energy outputs. It is largely in addition to the orientation of a PV system and the incident solar irradiation on the PV system. Besides that, the performance ratio can be utilized to compare the photovoltaic (PV) system at different places all over the global world. The closer the value of performance ratio (PR) to 75% or more, the relevant PV system is operating efficiently [4]. Second, its specific yield (SY) also among the important to observe the efficiency of the system [5]. A typical value of SY can range from 1000kWh/kWp to over 2000kWh/kWp but the actual value is driven by many factors which include location, module selection and balance of system efficiency. The aim of this project is to design the simulation model for sizing of Grid Connected PV (GCPV) system by using GUIDE in MATLAB. The second objective is to verify the simulation model with the theoretical mathematical calculation for sizing of GCPV system. Lastly, the aim is to guide the system designer during the initial design stage of the GCPV system.

In overall, this paper has presented the sizing of Grid Connected PV system by using GUIDE/MATLAB and evaluating the formula used in designing a GCPV system. This sizing is focus on three type of constraints which are sizing based on area, energy consumption and budget. Based on this paper, designer required to select the type of PV module and inverter before trying matches with the inverter window characteristics. The costs and owning GCPV system are declining, residential, commercial and utility scale adoption of this technology is on the rise. Although there are many benefits of GCPV such as its long working life (25 – 30 years) [6], low operation and maintenance costs and environmental advantages over fossil fuels power plants. Lastly, we summarize the results of this sizing based on the system performance ratio.



2. Methods and Materials

The concept of Graphical User Interface (GUI) is to guide the designer in sizing a GCPV system. Sizing based on area, the energy required and budget is a must in designing a GCPV system. In order to prove the design is good, the simulation of the system implementation must be done. Fig.1 shows the GCPV system consists of PV modules, where it captures the sunlight and converts the sunlight into electricity. Since the PV modules generate DC signal, a grid inverter or inter-tie inverter is required in order to convert direct current (DC) signal into alternating current (AC) signal to feed electricity to the grid. Then, the inverter converts the DC electricity from the solar power panels into 240V AC electricity which can be utilized by the household (single-phase system). The power-generating capability of a photovoltaic system is certainly denoted in kilowatt peak. The inverter is connected to the grid.

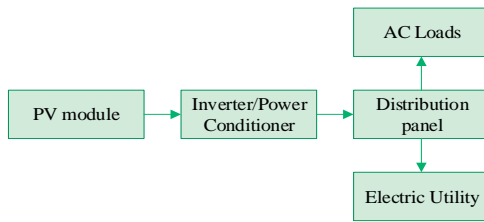


Fig.1: Block Diagram of Grid Connected Photovoltaic system

In Fig.2, the procedure in sizing a GCPV system starts from selection of a capacity of PV system, types of PV module, constraint, inverter sizing and ends with the value of performance ratio and specific yield. The main menu of proposed GUI is shown in Fig.3 with the brief instruction of the graphical user interface (GUI). On the main menu, the designer can view the flow of the steps involved in sizing a GCPV system. However, the additional features such as for information symbol, next button and displaying calculation equation is added to make this GUI much accessible to end up being comprehended by the designer. Fig.4 shows the capacity of the GCPV system which is from 4.6 kW to 60.0 kW. Next, the designer selects the type of photovoltaic module required. The datasheet of each PV module is provided for the user to compare the characteristics of the PV module.

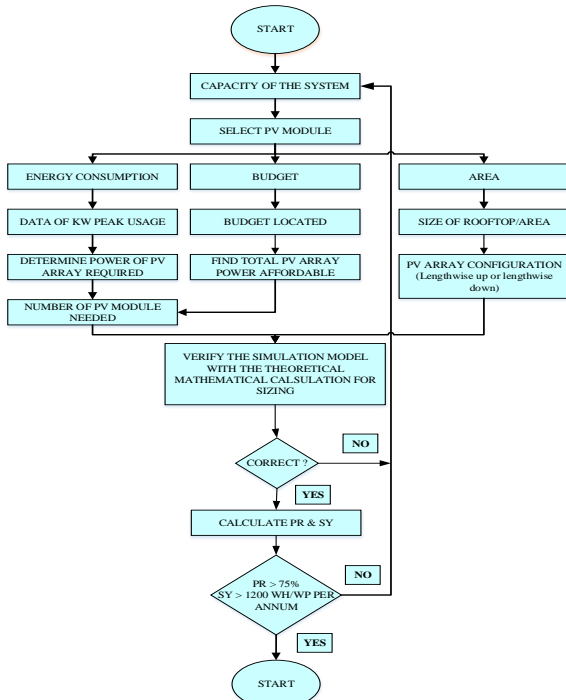


Fig.2: Flowchart of sizing process in a GCPV system

3. Results and Discussion

Three methods of sizing are developed in GUIDE as an interactive application for sizing GCPV system are; based on area, the energy required and budget.

3.1. Sizing Based on Area

In architecture constraint, the designer is able to know the total amount of photovoltaic (PV) module that can be installed predicted on the available area [7]. As a result, the designer can get the best option arrangement for the total possible number of PV modules in both types of arrangements; lengthwise up or lengthwise across. Fig.6 shows the possible location of the photovoltaic (PV) array can be installed. Refer to Fig.7, the GUI portal shows the result when the designer inserts the length and width of the roof and gap between the PV modules. Two important values are obtained from this step which is the number of modules in lengthwise across or lengthwise up. The lengthwise up is obtained by using (4) while lengthwise across is calculated using (1).

$$N_{\text{max module across}} = N_{\text{across up}} \times N_{\text{across across}} \quad (1)$$

$$N_{\text{across up}} = \text{round down} \left[\frac{W_{\text{roof}}}{W_{\text{mod}} + \Delta} \right] \quad (2)$$

Where: Δ is the allowed inter-module gap (m)

$$N_{\text{across across}} = \text{round down} \left[\frac{L_{\text{roof}}}{L_{\text{mod}} + \Delta} \right] \quad (3)$$

The maximum number of modules that can be installed lengthwise up is calculated as:

$$N_{\text{max module up}} = N_{\text{up up}} \times N_{\text{up across}} \quad (4)$$

$$N_{\text{up up}} = \text{round down} \left[\frac{W_{\text{roof}}}{L_{\text{mod}} + \Delta} \right] \quad (5)$$

$$N_{\text{up across}} = \text{round down} \left[\frac{L_{\text{roof}}}{W_{\text{mod}} + \Delta} \right] \quad (6)$$



Fig.3: Main menu of GUI portal



Fig.4: GUI portal of the maximum power of GCPV system



Fig.5: Brand of the photovoltaic module



Fig.6: Possible location of PV array



Fig.7: GUI portal of Architecture constraint

3.2. Sizing Based on Energy Requirement

The user also able to design the GCPV system based on energy consumption. The user can predict energy requirement based on the previous usage of the electricity for each month from the electric bill within a year or less. Nevertheless, the designer may apply this sizing method by inserting the total assumption of the energy in a year. Next step is to determine the power output of photovoltaic (PV) array at the standard testing condition (STC). It could be calculated by dividing the energy required with multiplication of peak sunlight hours (PSH) and other factors. Finally, the possible amount of photovoltaic (PV) array at STC with the maximum power rating of the PV module at STC is calculated automatically in GUI [5]. Besides that, the number of modules that are needed to be installed depends on the energy that is required to be supplied by the PV system. The amount of energy to be supplied by PV can be calculated as in (7).

$$E_{req} = \frac{\epsilon}{100\%} \times \frac{12}{n} \times \sum_{m=1}^{12} E_m \quad (7)$$

Where:

E_{req} : the energy required per annum (kWh)

ϵ : Percentage of energy to be supplied using PV (%)

E_m : energy consumption for month m (kWh)

m: a month with available data

n: number of months with available data

The required minimum power of PV array can be calculated as (8):

$$P_{array\ stc} = \frac{E_{req}}{PSH(poa) \times K(deration) \times \eta(sub\ system)} \quad (8)$$

$$K_{deration} = k_{mm} \times k_{tem\ p\ ave} \times k_{dirt} \quad (9)$$

$$k_{tem\ p\ ave} = 1 + \left[\left(\frac{\alpha(power)}{100\%} \right) \times (T_{cell\ ave\ max} - T_{stc}) \right] \quad (10)$$

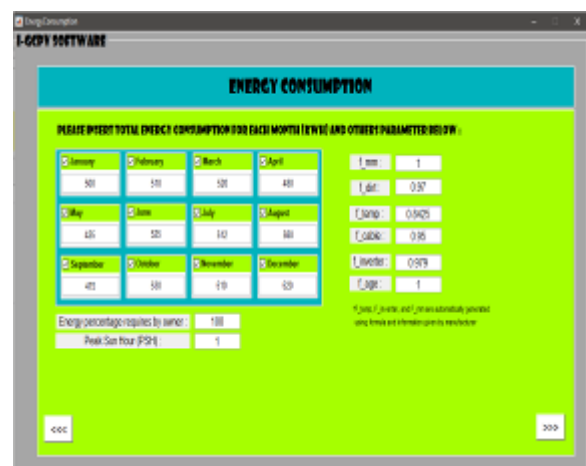


Fig.8: GUI portal of Energy required

$$T_{cell\ ave\ max} = T_{amb\ ave\ max} + T_{elevated} \quad (11)$$

$$n_{sub\ system} = n_{cable} \times n_{inv}$$

$$\eta_{sub\ system} = \eta_{cable} + \eta_{inv} \quad (12)$$

Where:

$P_{array\ stc}$: the power of the PV array at STC (Wp)

PSH_{poa} : peak sun hour received on the plane of array (poa) per annum (h)

$k_{tem\ p\ ave}$: de-rating factor of power due to average maximum cell temperature (decimal)

$T_{cell\ ave\ max}$: average maximum cell temperature (deg C)

$T_{amb\ ave\ max}$: average maximum ambient temperature (deg C)

$\eta_{sub\ system}$: sub-efficiency of the system (decimal)

η_{cable} : efficiency of DC cable from PV to the inverter

η_{inv} : is the efficiency of the inverter (decimal)

The minimum number of PV modules in the system can be calculated as in (13):

$$N_{min\ module} = \text{round up} \left[\frac{P(array\ stc)}{P(module\ stc)} \right] \quad (13)$$

Where:

$N_{min\ module}$: minimum number of PV modules required

$P_{module\ STC}$: power rating of PV module at STC (Wp)

Fig.8 displays the GUI portal of energy required. In this case study, the energy consumption sizing is calculated. Three important values are obtained out of this step. The first value is the total month energy intake. This value is important to determine the total estimated number of PV module. The minimal number of PV modules needed is obtained by (13).

3.3. Sizing Based on Budget

This sizing method dependent on the amount of cash allocated for installing the GCPV system. This amount of cash will be divided by the price index of the PV system. According to any technique of sizing, the ultimate amount of the PV module to end up being installed will be on the designer's choice. The calculation of the methods is to ensure that the final worth does not exceed the possible worth. Furthermore, the number of modules which can be installed is depends on how much cash the stakeholder is ready to spend on the PV system.

$$B = P_{array\ stc} \times k_{index} \quad (14)$$

Where:

B: the sum of money allocated for the system (monetary unit)

k_{index} : cost index of the complete PV system (monetary unit per Wp)

Thus, the maximum number of PV modules affordable can be calculated as in equation (15):

$$N_{max\ module} = \text{round down} \left[\frac{P(array\ stc)}{P(module\ stc)} \right] \quad (15)$$

For this part, the designer must insert the budget and GCPV cost index into the GUI. By referring to Fig.9, the budget is RM40,000 and the GCPV cost index is RM8/kWp. From the input, the GUI will automatically calculate the total affordable number of PV modules ($N_{total_estimate}$). $N_{total_estimate}$ is calculated based on (14) and (15). Mathematically, $N_{total_estimate}$ are 18 modules. In addition, specific yield (SY) and performance ratio (PR) is calculated based on (16) and (17).



Fig.9: GUI portal of budget constraint

$$SY = \frac{E(sys)}{P(array\ stc)} \quad (16)$$

$$PR = \frac{E(sys)}{P(array\ stc) \times H(tilt)} \quad (17)$$

Since the number of PV modules is calculated in previous portal, the next step is to match the PV array specifications with a suitable inverter. The range of suitable inverter with the PV array can be determined as in (18).

$$P_{array} \times 0.9 \leq P_{nom_inv} \leq P_{array} \times 1.0 \quad (18)$$

Where: 0.9 & 1.0 are derating factors of PV array (decimal)

In addition, the value of the derating factor depends on many parameters such as the type of PV cell material, module and array assembly, mounting style and ventilation rate. Other than that, the ranges of numbers of modules that matches with the power capacity of an inverter also need to be calculated. The numbers of modules is calculated using (19) and (20).

$$N_{min} = \text{round up} \left[\frac{P(inv\ nom)}{k1 \times P(module\ stc)} \right] \quad (19)$$

Where:

$$N_{max} = \text{round down} \left[\frac{P(inv\ nom)}{k1 \times P(module\ stc)} \right] \quad (20)$$

N_{range_module} : range of numbers of modules, $N_{min} \dots N_{max}$

N_{min} : minimum numbers of modules

N_{max} : maximum number of modules

N_{inv_nom} : nominal AC output power of is inverter (W)

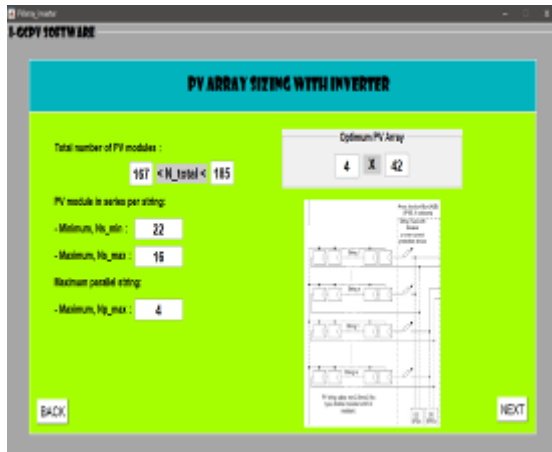


Fig.10: GUI portal total number of PV modules

An optimum number of PV array will be calculated based on the value of its minimum and a maximum number of PV modules in series per string as shown in (13) and also the maximum number of parallel string. In Fig.10, a total number of PV modules obtained is between 16 to 16. The GUI portal has the function of retrieving the values of optimum number of PV array. In this case, since the number of PV modules has been established, the designer has the provision to choose the type of inverter to be used based on the nominal power of inverter that matches with PV array. If the designer selects the type of inverter which is beyond the nominal power range, a message will be displayed. This allowed the designer to selects the suitable inverter. If the user select un suitable inverter, it is essential for the designer to be informed. Therefore, the designer can reselect another type of inverter to ensure the sizing is accurate. Fig.11 shows that the type of inverter based on a range of nominal power inverter. In this case, the size of the inverter requires matches with the PV array is between 4.293 to 4.77 kW. Predicated on the type of inverter provided, the designer can choose the inverter with a nominal power output value of 4.6 kW because 4.6 kW. The selected model is SMA Sunny Boy inverter due to the nominal power within the range. This nominal power output is important for designing an installation in order to correctly dimension its cabling.

After the designer chose the suitable inverter for their sizing, next the designer needs to insert the length of string and array cables in the balance of system (BOS) GUI portal. This part is very important because all the values are needed to be known either the sizing data is valid or not. In this GUI, the inverter is single MPPT. Therefore, only one value of length of the string is needed. Besides that, the designer also needs to insert the percentage of voltage drop for the cable. Normally, the range of voltage drop is between 1% to 5%. Type of cable material also needs to be considered in this balance of system (BOS) as it will give the effect on the budget and losses in sizing. Then, the designer needs to choose the type of the conductor to be used. In this case, there are two types of conductor; which is copper and aluminum. In addition, the aluminum conductor is considerably less expensive while the copper conductor is more much expensive but has greater conductivity. Fig.12 presents the GUI portal of the balance of system (BOS). In this GUI, the designer inserts the length of string and array parameter as 20.5m and 5m, respectively. Then, the percentage of voltage drop for the string cable is 1% and 2% for array cable. GUI automatically calculates the DC cable parameter based on the type of cable; aluminum or copper. From the GUI, the string cable size is 2.8945 sq.mm. Therefore, the suitable size of cable is 4.0 sq.mm.

The final panel displays the performance prediction as in Fig.13. The software summarizes the overall result where the whole design is valid to be designed or not based on the options selected by the designer. If the system is good, the specific yield (SY) should be greater than 1200 Wh/Wp per annum. The specific yield is calculated in (16). The result of the performance ratio (PR) is higher than 75%, therefore the system sizing is good. The final

result also indicates the expected income predicted by the FIT rates and the total energy produced by the system.



Fig.11: Types of the inverter based on a range of nominal power inverter



Fig.12: GUI portal of the balance of system (BOS)

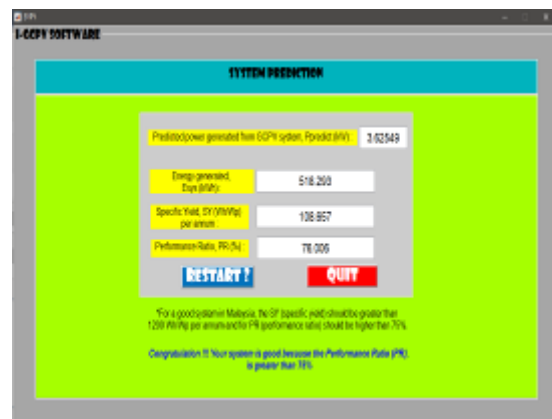


Fig.13: System prediction of sizing GCPV

The three types of sizing for a Grid Connected PV system have been obtained based on all the formula given. The performance ratio must be more than 75% for a good system [8]. Moreover, PV modules with better temperature coefficient and efficiency can improve the yield of the PV system by two to four percent.

4. Conclusion

The development of Graphical User Interface Development Environment (GUIDE) for sizing of Grid-Connected Photovoltaic System by using MATLAB was successfully designed. The GUI interface shall improve the user's understanding in sizing. Hence, the GUI able to determine the optimum amount of array configuration recommended for the GCPV system. The most crucial aspect is that the GUI provides relieve to the developer in term of its function when compared to the manual calculation for sizing

GCPV system. For the future recommendation, it is suggested to add features for calculating the alternating current (AC) cable size. Besides that, the proposed GUI is utilized direct connection to the grid. The improvement of this GUI is recommended to add an indirect connection. This type of connection is utilized if the energy generated by the GCPV system is for the owner own utilization and only surplus energy will be transferred to the grid.

Acknowledgement

We gratefully thanks faculty of electrical engineering, Universiti Teknologi Mara (UiTM) for financial support.

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