Sizing Software of a Solar Farm System

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***Abstract*— This paper presents a sizing software for the design of a solar farm system. A solar farm is basically a large-scale application of grid-connected photovoltaic system installation. The sizing software provides few guidelines to the designer for the planning procedure before the final of optimum array configuration is decided. Some specifications that the designer may consider are the type of PV module, the type of inverter, the available space for installation, the required energy per year and also the sum of money to be allocated for the instalment. The output result of this software will be the suggestion of possible configuration of the total number of modules in series per string with the total number of strings in parallel. This software also does the prediction of the system performances such as final yield, specific yield and performance ratio. The expected income is provided by the software is based on the Feed-in Tariff rates and the energy generated by the system. The software used in the design is Visual Basic where it consists of programming and windows application design.**

Keywords-Photovoltaic; Solar Farm; Visual Basic; sizing; software.

I. INTRODUCTION

Electrical energy is one of the most important needs in human life especially for the world today where the developments of technology have gone forward. The generation of electrical energy can be more relevant to replace the existing energy that relied on coal, oil and natural gas. These conventional energy sources usually will eventually diminish and the process could damage the environment, economic progress and human life. Therefore an alternative way to generate electrical energy that could be developed is by making use of renewable energy (RE).

RE is energy that comes from natural processes and does not have a limited supply. Besides being an energy security and as the conventional energy sources are running out, RE is important nowadays since the technologies have much lower environmental impact than the conventional energy technologies which will cause pollution, emission of hazardous gasses and global warming to the environment [1]. Therefore it is advisable to keep on installing the RE power system.

There are many types of RE sources: Solar photovoltaic (PV) energy, hydropower, wind energy, biomass, etc. The type of source that is going to be discussed in this paper is the solar photovoltaic energy. A PV power system uses solar panels to absorb energy from the thus generate electricity through inverter [2].

Solar photovoltaic system is classified by two types which are the Stand-alone PV (SAPV) power system and the Grid-connected PV (GCPV) power system. The SAPV power system can be used for the generation of energy for the user’s own consumption while the GCPV power system transfer the generated energy directly to the grid line. For this case, the electricity generated by the GCPV power system in Malaysia will be selling to the Tenaga Nasional Berhad (TNB) [3].

A solar farm system is actually an application of a large scale of grid-connected PV system [4] where the design criteria would be the same except for the type of PV module or inverter used where the large scale of PV system require a higher level of voltage level.

Before installing any of the PV power system, the design needs to be determined by the calculations of all the specific criteria to find out and match several issues such as available space, energy requirements, finances, number of modules, inverters, etc. [5],[6]. As the method of calculation consists of many steps and equation especially for a large scale situation such as the solar farm system, the software for the design of the solar farm sizing is proposed.

A sizing software is basically proposed to make the designing process becomes easier. Furthermore the software most probably will provide an idea/suggestions to the designer before the designer can make the final decision.

II. METHODOLOGY

The sizing software of a solar farm system was developed using visual basic software with the aim of finding the optimum array configuration. The designing of the sizing software is presented in flowchart of Fig. 1.

Before designing software, a literature review was done in order to study and understand the fully requirement and application of the software used. In this case, the software used to make the sizing software is visual basic.

Besides that, a study of the sizing method was also done to ensure that the design provided by this sizing software is appropriate. The data and specification needed for the software design was determined after the study thus the design of the sizing software is preceded with the data collected.

The software used is the Microsoft Visual Basic 2010 Express. This software used to the design the windows application which requires a programming language [7] to insert the formulas, equations, design specifications, etc. The completed program is then tested to observe the output results. If the results are not compatible with the expected result thus the software will be edited until the expected results were obtained. The expected results are the output that is calculated manually by using the equation of the sizing. Finally a completed project will be published as software that can be installed by a user.

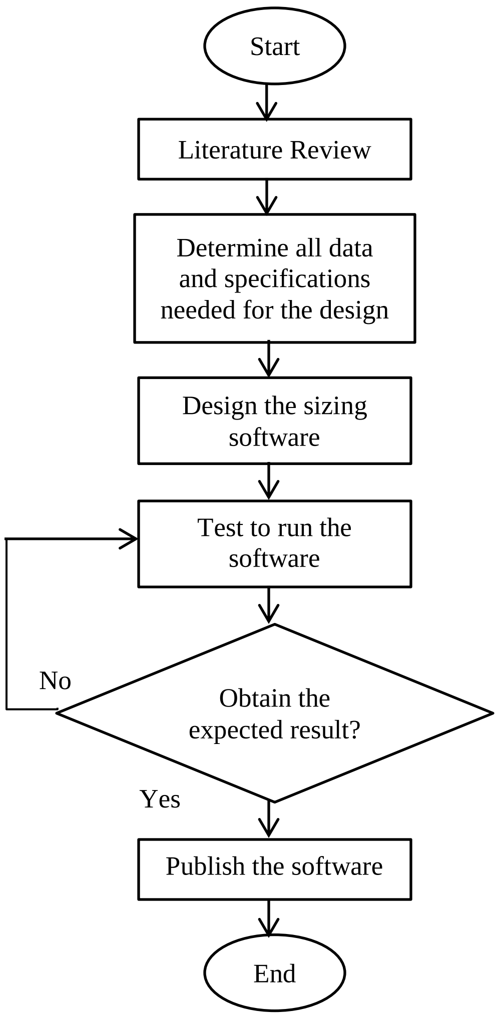


Figure 1: Flowchart of the Sizing Software of a Solar Farm System project

III. GCPV SIZING METHOD

In order to install a GCPV, there are few basic steps that can be used as a guideline to a proper design of the GCPV. There are two parts of designing procedure where the first part is the design based on the designer's specification requirement and another part is to determine the optimum array configuration. Since a solar farm system can be considered as a large scale of GCPV system, therefore the method for the sizing of GCPV can be used in this case. The method which is based on the designer's specification requirement can be divided by three categories: sizing based on area, sizing based on energy requirement and sizing based on budget.

A. *Sizing Based on Area*

For this category, it is chosen for the user who wanted to decide the number of PV modules that can be installed based on the available area. For this category also, there are two possible arrangements of the modules. Therefore from the calculation, the designer can find out the most suitable arrangement from the total possible number of modules in both arrangements. Since the GCPV is usually not a large scale installation, thus the calculation method is basically referred to its application on the rooftop of a house.

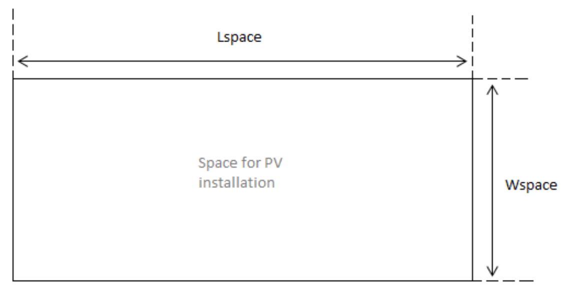


Figure 2: Available space for installation example

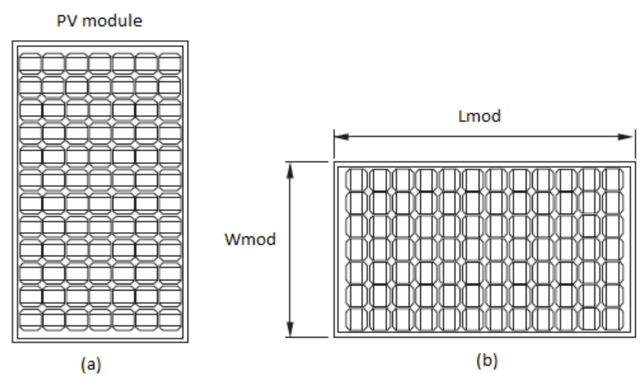


Figure 3: Possible arrangement of modules (a) Length-wise across; (b) Length-wise up [8]

Figure 2 above show the example of the available space area. The parameters needed for the calculation are the length of space area, Lspace, the width of the space area, Wspace, the length of module, Lmod and width of module, Wmod. The possible arrangement of the modules are as in Fig. 3(a) and Fig. 3(b). Therefore the designer can determine whether to arrange the modules in length-wise across or in length-wise up.

- Option 1: Length-wise across
  The method of calculation below show how to find the total number of PV modules that can be installed if the modules are arranged in length-wise across to the available space area. Nt_{acr} is total

possible number of PV modules in lengthwise across.

$$N_{acr\_up} = round\ down\ \left[\frac{W_{space}}{W_{mod}}\right] \quad (1)$$

$$N_{acr\_acr} = round\ down\ \left[\frac{L_{space}}{L_{mod}}\right] \quad (2)$$

$$Nt_{acr} = N_{acr\_up} \times N_{acr\_acr} \quad (3)$$

- Option 2: Length-wise up
  The method of calculation below show how to find the total number of PV modules that can be installed if the modules are arranged in length-wise up to the available space area. Nt_{up} is total possible number of PV modules in lengthwise up.

$$N_{up\_up} = round\ down\ \left[\frac{W_{space}}{L_{mod}}\right] \quad (4)$$

$$N_{up\_acr} = round\ down\ \left[\frac{L_{space}}{W_{mod}}\right] \quad (5)$$

$$Nt_{up} = N_{up\_up} \times N_{up\_acr} \quad (6)$$

From the calculation of the two methods, the designer can decide to choose the total number of modules between the results above.

B. Sizing Based on Energy Requirement

In order to install a GCPV, a designer can decide on the energy requirement based on the previous usage of energy for each month within a year or below. The energy required, Ereq per annum can be calculated as in the Eq. 7 below where ∂ is the fraction of energy to be supplied using PV, Ei is the energy consumption for month i and n is the number of months with the available data.

However for the solar farm sizing, the designer can also calculate using this method by inserting the total assumption of the energy required. Next step is to find the power output of PV array at STC. It can be calculated by dividing the required energy with the multiplication of PSH, the factor due to mismatch of power (f_{p_mm}), factor due to dirt (f_{dir}), factor due to daily maximum ambient temperature (f_{tem_ave}), the inverter maximum efficiency (η_{Inv}) and the efficiency of DC cable from PV array to inverter (η_{pv_inv}).

Finally the possible number of PV modules can be determined by dividing the power output of PV array at STC with the maximum power rating of PV module at STC (P_{mod_stc}).

$$E_{req} = \partial \times \frac{12}{n} \times \sum_{i=1}^{i=n} E_i \quad (7)$$

$$P_{arr\_stc} = \frac{E_{req}}{PSH \times f_{tem\_ave} \times f_{p\_mm} \times f_{dir} \times \eta_{inv} \times \eta_{pv\_inv}} \quad (8)$$

$$N_t = round\ up\ \left[\frac{P_{arr\_stc}}{P_{mod\_stc}}\right] \quad (9)$$

C. Sizing Based on Budget

Besides determining the total number of PV modules based on area and energy requirement, the last method can be determined by using the sum of money allocated for the investment, Budget. This sum of money will be divided by the cost index of the PV system, kcos. After that this amount then will be divided by the maximum power rating of PV module at STC. The calculation is as shown in the equation below:

$$P_{arr\_stc} = \frac{Budget}{k_{cos}} \quad (10)$$

$$N_t = round\ down\ \left[\frac{P_{arr\_stc}}{P_{mod\_stc}}\right] \quad (11)$$

According to all of the method of sizing as stated before, the final value of the total PV module to be installed would be on the designer's choice. The calculation of the methods above will just be an indication to the designer so that the final value will not exceeded the possible value.

Another part of the calculation method is to determine the optimum array configuration. For this part, it can be done through these steps:

- Step 1: Determine the optimum number of PV module to be installed that matches a specific inverter.
- Step 2: Determine the extreme limit of voltage produced by the PV module.
- Step 3: Determine the number of modules in series per string.
- Step 4: Determine the number of string in parallel.
- Step 5: Determine the optimum array configuration.

In addition, the system performance prediction were also included in this sizing software in order to observe the condition to see whether the PV module and inverter are match to each other and will results in a steady output. One of the items that can observe the system performance is the final yield, Yf. Final yield is the energy generated by the complete GCPV system after the inverter [1]. The final yield can be calculated as Eq. 12.

$$Y_f = P_{arr\_stc} \times PSH \times f_{tem\_ave} \times f_{p\_mm} \times f_{dir} \times f_{age} \times \eta_{inv} \times \eta_{pv\_inv} \quad (12)$$

Next the specific yield, SY should be defined. The system would be a good system if the specific yield is more than 1200 kWh over a year. The calculation of the specific yield is in Eq. 13 below:

$$SY = \frac{Y_f}{P_{arr\_stc}} \quad (13)$$

Other than that, the performance ratio, PR should be greater than 70% for performances over a year [5]. This is the condition for a reasonably good system in Malaysia.

Besides the performance of the system, there is another calculating part that can be called as clean energy cash-back where total energy produced by the PV system will be paid. The estimated income can be predicted by referring to the Feed-in Tariff (FiT) rates [9] with according to the total energy produced by the installed PV system.

IV. RESULT AND DISCUSSIONS

The initial process of the sizing software requires the designer to select the types of PV module and the types of inverter for the system. There are over sixty types of PV module and over forty types of inverter provided by the software. The inverters provided by this software are particularly designed for the solar farm system as it requires a high level of maximum voltage. The selection of PV module and inverter are as in Fig. 4 and Fig. 5.

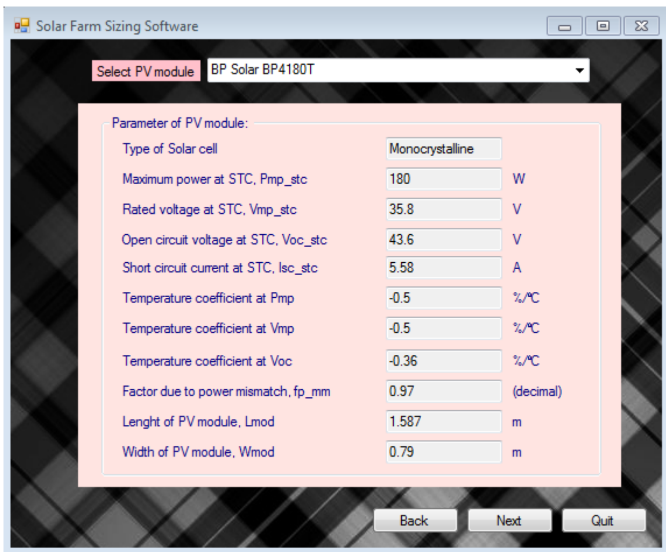


Figure 4: Types of PV module selection

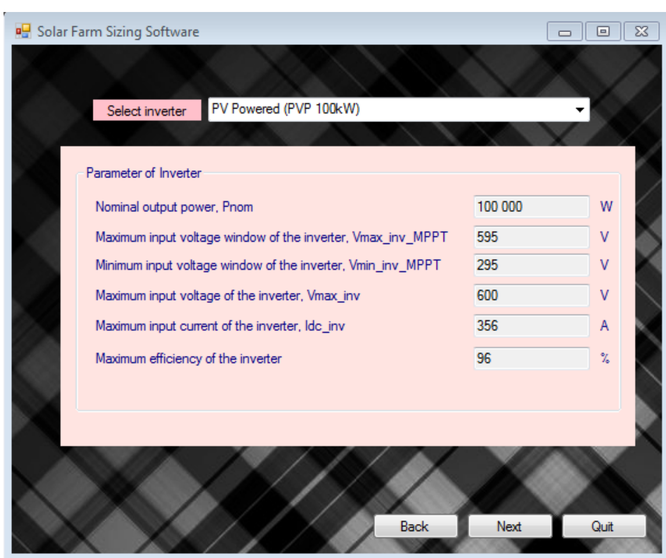


Figure 5: Types of inverter selection

After the selection of PV module and inverter types, the designer needs to select the location to install the system. The given location provided will allow the software to collect the irradiation data of the chosen location by the designer from the monthly irradiation database. This option is shown in Fig. 6 where the designer will also need to choose the azimuth and tilt angle for the solar panel. The table of irradiation data [10] also will be display for the designer's observation.

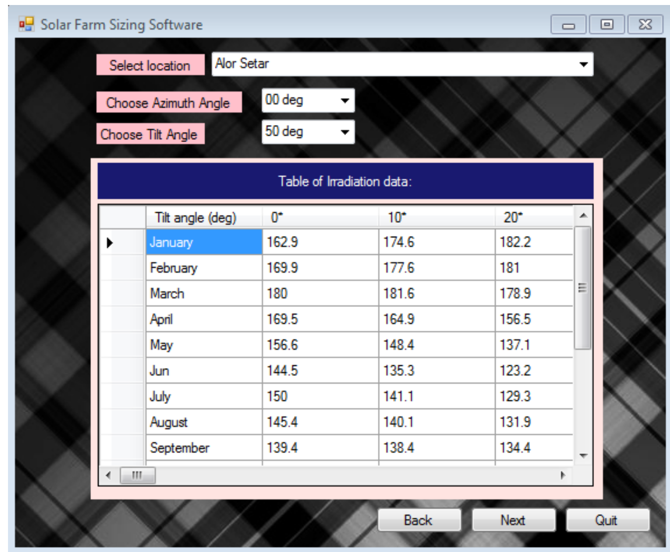


Figure 6: Selection of location, azimuth angle and tilt angle.

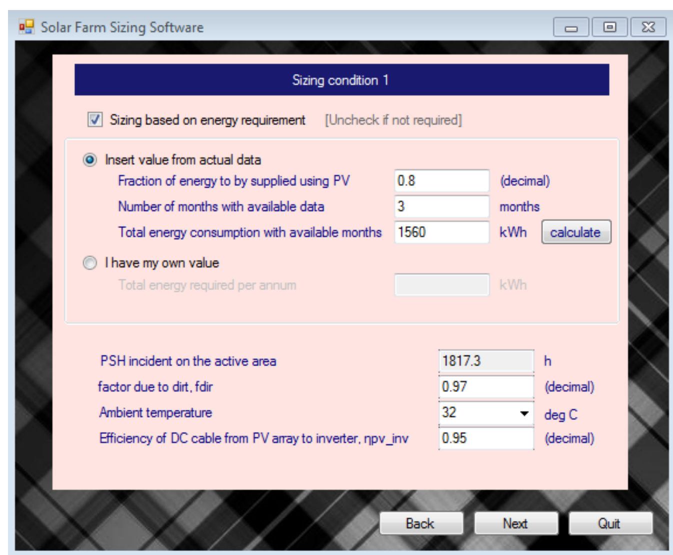
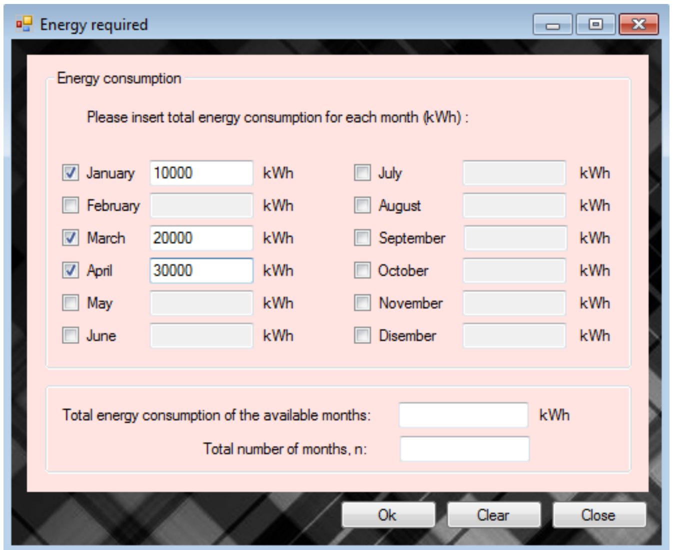


Figure 7: The second sizing condition and some additional required data

The irradiation database provided by the software was collected for the panel which facing south since it is the best for Malaysia's condition. Next, the software will provide the sizing method based on the designer's specific requirement. The designer can choose whether to select from the three conditions given: sizing based on area, sizing based on energy requirement and sizing based on budget. However the designer can skip and deselect these options. The first condition is available on the forth panel as shown in Fig.7.

Figure 7 shows the first sizing condition. For this part, the designer is required to select whether to insert the total energy consumption from the actual available data or just stating the total energy required by the designer for a year. If the designer chooses to insert the total energy based on available data, he/she can click on the “calculate” button to calculate the value of the data where a new window will open as in Fig. 8 and the designer can only insert the available data.



`Figure 8: New window to calculate the total energy consumption based on available data

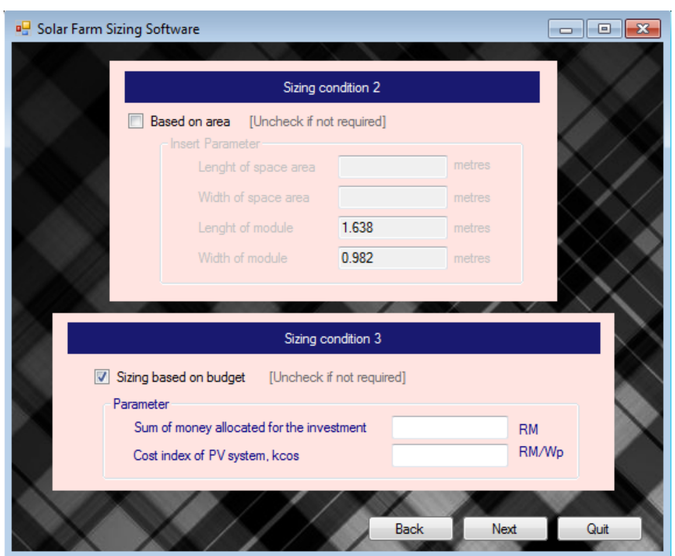


Figure 9: The second and third sizing condition

Next, the software need to collect some additional information from the designer such as the dirt factor, the ambient temperature and the efficiency of DC cable from PV array to inverter.

The second and third sizing conditions are as in Fig. 9 below. The designer need to insert the size of the available space for the sizing based on area. If the designer wishes to calculate based on budget, both sum of money allocated for the investment and the cost index of PV system should be inserted. The cost index of PV system usually will change according to time.

The software is now will display the results of the three sizing condition as in Fig. 10 where it shows the total possible number of PV module to be installed based on the conditions stated.

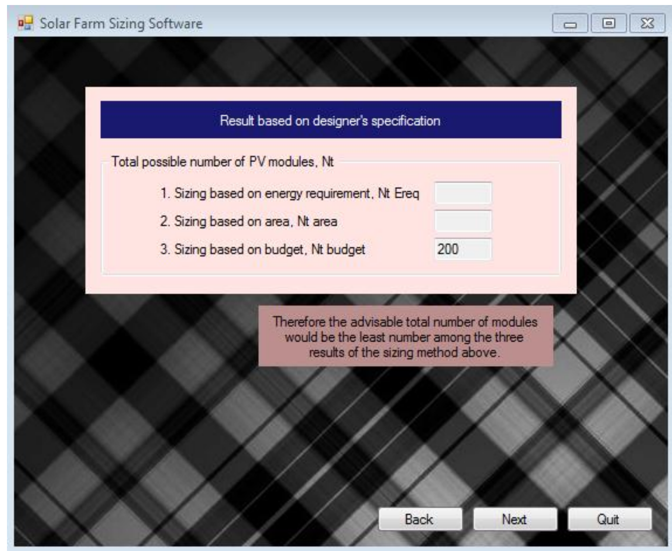


Figure 10: The result of total possible number of PV module based on the three conditions

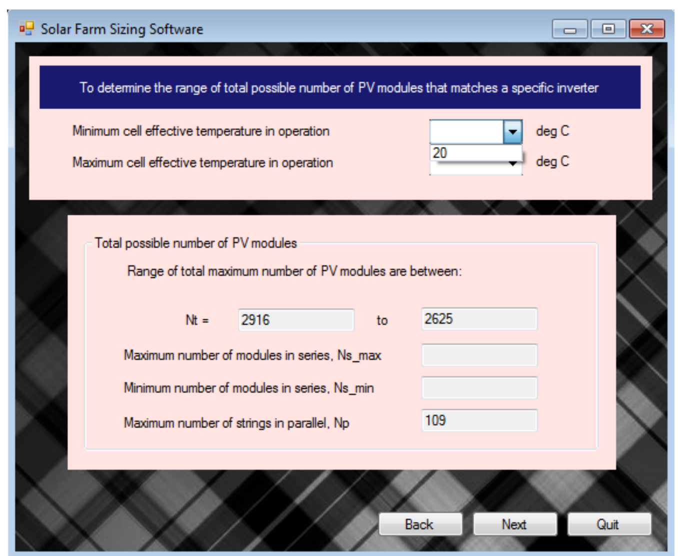


Figure 11: The result of total possible number of PV module

The designer then can proceed to the next sizing method which to determine the range of total possible number of PV modules that matches a specific inverter. The next requirements needed by the software are the minimum and maximum cell effective temperature in operation as in Fig 11. After that the software will display the total possible number of PV module.

With the total possible number of PV modules calculated by the software, the software is then will provide the suggestions of possible array configuration. Therefore the designer can decide the most suitable matches of the total number of modules in series, Ns with the maximum number of strings in parallel.

The result of the suggested combination can be seen in Fig. 12. From the result, the designer then should select one of the possible configurations to observe the system performance prediction as in Fig. 13.

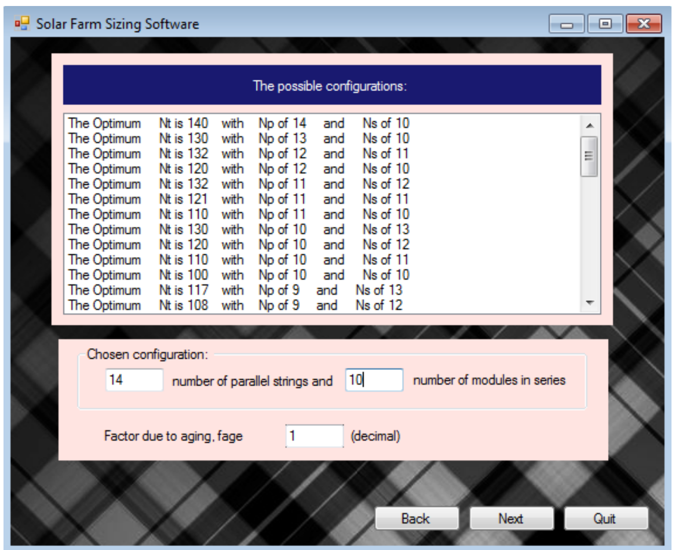


Figure 12: The suggestion possible configuration by the software

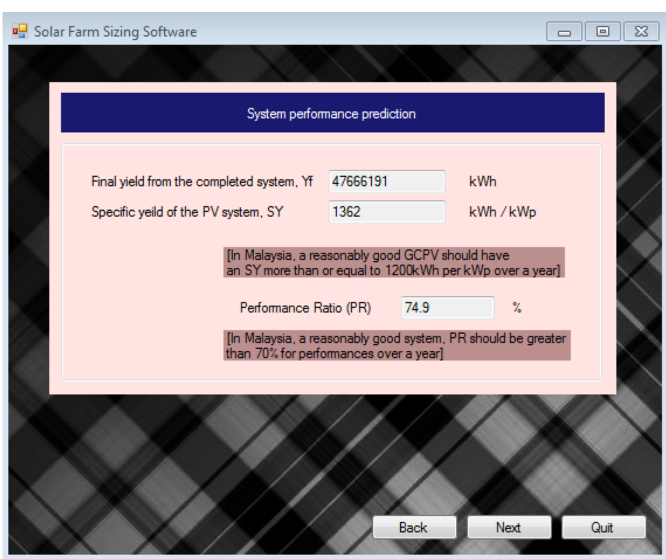


Figure 13: The system performance prediction

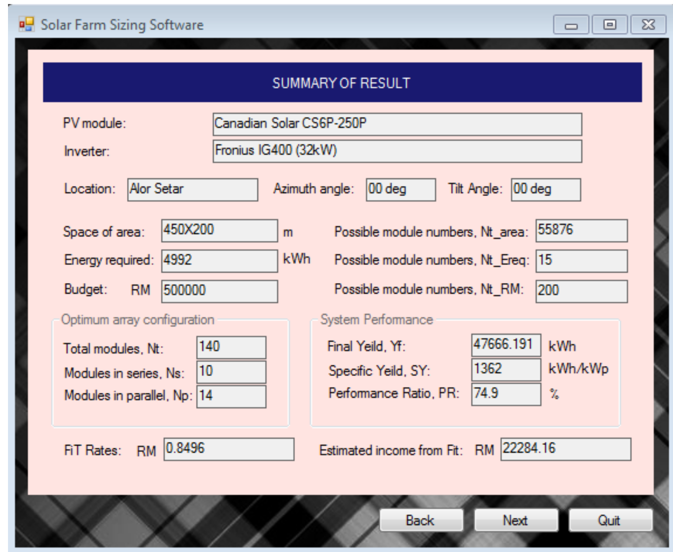


Figure 14: The summary of overall result

The performance prediction consists of field yield from the completed system, the specific yield of the PV system and the performance ratio.

The final panel will display the summary of the overall result where the whole design of the system can be observe from the initial criteria that the designer selected. Fig. 14 shows the details of the summary. The final result also indicates the expected income based on the FiT rates and the total energy generated by the system [11].

V. CONCLUSION

Sizing software of a solar farm system is presented in this project. The results concluded that the user/designer will be given choices on determining the final optimum number of array configuration suggested by the software. The designer may observe the suitability of the PV module and inverter match in order to get the best performance. The most important thing is that this software is able to make the design easier compared to the manual calculation of sizing method.

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