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Photovoltaic Cell Sizing Software Development by Android Studio for Solar Powered Tube-well System

Jeffrey Kiu Yong Jie[1], Mohd Zainizan Sahdan[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussien Onn Malaysia, 86400, Batu Pahat, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Renewable solar energy takes an important role in solving the high power demand from the rapid growth of the human population. The people who live in the rural area did not have a chance to access modern energy, where lots of them suffer from the shortage of clean water and the limited amount of power supply. In this study, a solar powered tube-well system is designed with the evaluation of working hours of the water pump motor in a day and cost for the system by considering of solar irradiation throughout the day. A software application of photovoltaic sizing calculator is designed and developed by Android Studio to simplify the calculation with the implementation of a method derived from graph analysis of daily solar irradiation and electrical performance of photovoltaic modules. The developed app named *Pivee Sizinlator* can calculate the number of photovoltaic modules required and the rating of other components for 2 types of off-grid systems: with and without battery. The finding of this study shows that photovoltaic system without battery requires fewer photovoltaic modules than the system with battery for the same working hours. Hence, system without battery is more cheaper as it uses fewer photovoltaic modules and have no battery. A model of stand-alone solar powered tube-well system without battery is successfully designed as the solution for the water shortage problem of people in rural areas. The final system model design would be consisting of 14 PV modules, a 1HP water pump motor and a 12V 3kW rating of inverter that can be work for 10 hours.

Keywords: Photovoltaic Sizing, Solar Powered System, Stand-alone System, Android Studio

1. Introduction

The power consumption increases rapidly as the population of human increases, same as the advancing of technology also will also demand an extra power. There is a total consumption of 136.90 billion kWh of electric energy every year in Malaysia **Error! Reference source not found.**. According to the WorldData website, the production of electric energy is mainly on fossil fuels, which is 78% of

Corresponding author: zainizan@uthm.edu.my

the total production, 18% on hydro power and 4% from the other renewable energy. However, the high usage of fosil fuels bring to the rising of CO_2 emissions that pollutes the environment and causes global warming [2]. Not only that, fossil fuels, which are non-renewable energy, will be totally exhausted one day in the future. The price of fossil fuel will also keep increasing from day to day because of the high demand from all across the world. Renewable energy is defined as the source of energy that keep existing each and every day within the evolution of nature [3]. This energy can be said as permanently available or unlimited supply as it will replenish naturally over time. There many forms of renewable energy: sunlight/solar power, wind, tides/waves, biomass and geothermal energy.

Solar energy is more popular among all the renewable energy as it is a clean and promising energy source, which is also one of the most abundant energy resource available in most of the place [4],[5]. Solar energy, as from its name, is the energy from the sun that will be converted into electrical or thermal energy depends on users. It does not emit any greenhouse gases or other harmful gases that would pollute the environment. Since solar energy depends on sunlight, the whole system would only generate electricity when day time. Hence, it is best to use solar energy in the country which have the sun shines throughout the year. Solar energy is converted to electrical energy by photovoltaic cell/solar panel. There are a few kinds of photovoltaic cell can be found in the market, they are mono-crystalline silicon, poly crystalline silicon, thin film and amorphous. Those PV cell have different efficiency and cost which trades between each other. In this study, the solar panel will be used to provide electric to a water pump motor, which needs an AC inverter to convert its DC output to AC.

There are still many population living in developing countries which do not have a chance in accessing the modern energy while most of them are the poor who lives in rural areas [6]. With limited power supply, those people in the rural area mostly rely on natural resources to keep on their daily life such as burning timbers for warm and cooking foods. Furthermore, there are also many rural areas with limited supply of clean water. Underground water may seem to be the best choice for long term water supply by constructing a tube-well to extract fresh water from surface or deeper groundwater aquifers. However, a tube-well needs quite amount of electricity to pump the water from underground but the limited power supply has yet become the obstacle for this plan in order to achieve it. Therefore, an alternative power supply is needed for the water pump and this is the time when renewable energy has come to its role. Among all of the renewable energy, solar energy is the most convenient as sunlight is available at anywhere, unlike hydro and wind energy which depends on its location where water or wind are present. Moreover, solar energy only needs photovoltaic cell in order to produce electricity that makes construction of the system to be very simple.

A stand-alone solar powered system is designed in order to solve the water supply problem in rural area. The sizing of the photovoltaic cell is important in order to support the water pump motor at any time during the day. In order to simplify the sizing of photovoltaic cell, a software application will be developed using Android Studio. To have a longer working period of water pump motor, all the calculation of photovoltaic sizing is in consideration of the solar irradiation throughout the day. The installation of battery to the system is yet to be determined by analyzing the results obtained from software as the cost of the system has to be economical as possible for the rural area.

2. Materials and Methods

2.1 Methods

This project is done by going through 6 phases. The first phase is research phase where the information on photovoltaic system sizing were being studied. The type of photovoltaic cell used is the SPM050-P Polycrystalline Solar Panel because it is cheaper than mono-crystalline. A graph of intensity of solar irradiation throughout the day is taken at latitude of 2-degree North, which the location is Malaysia in this study case. In next phase, graph function for the solar irradiation and electrical performance of PV module were analyzed, followed by the phase where formation of PV system sizing method is done by obtaining the function of graph from the previous phase. Then, the method has been implemented in the software application in the software development phase. The software application is designed using Android Studio, with 2 available modes: system with battery and system without battery that are separated using different calculation method. In the results analysis phase, each mode is tested with 15 different input and the results are compared with each other to determine whether to install battery. For the last phase, a model of of stand-alone solar powered tube-well system is designed with consider of analysis in the previous phase.

2.2 Graph function analysis

The graph of solar irradiation as shown in **Figure 1** is analyzed to obtained the function of the graph. 3 points are obtained from the graph, which are [6, 0], [12, 1050] and [18, 0]. The graph function obtained is shown in *Eq.* ***Error! Reference source not found.***.

$$y = -\frac{175}{6}(x - 12)^2 + 1050 \quad \textit{Eq. 1}$$

This analysis requires the electrical performance graph of the PV modules as shown in **Figure *2*** to perform. The information obtained from the graph are the output power of PV module (W) and the amount of radiation received (W/m^2). The 3 points taken from the graph are [600, 153], [800, 210] and [1000, 245] respectively.

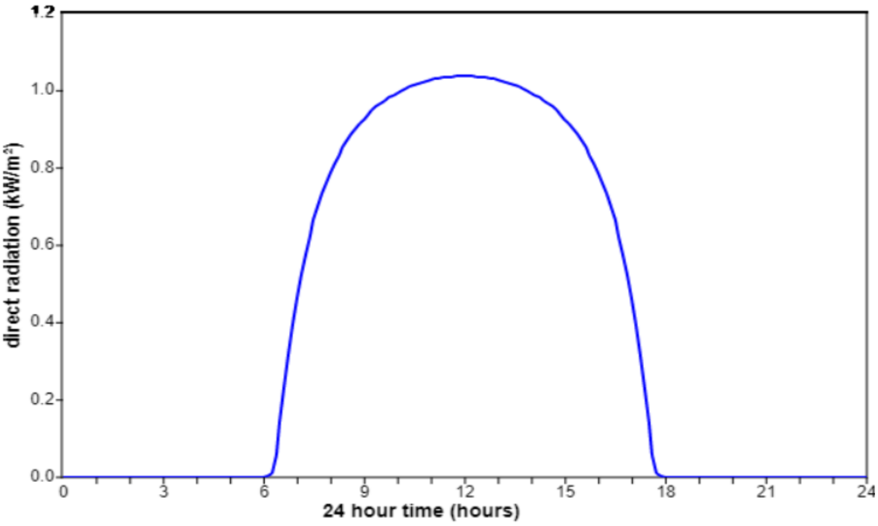

Figure 1: Graph of intensity of solar irradiation throughout the day [7]

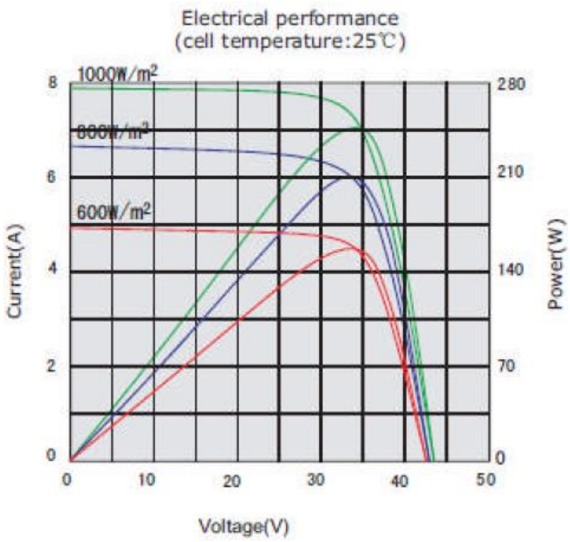

Figure 2: Electrical performance for SPM050-P polycrystalline solar panel

The equation derived and the respective graph is shown in **Figure 3**. It can be seen that that the graph is discontinued at $x = 553$. By assuming the minimum solar irradiation can be received by the module to 100, the last point of the original graph is replaced with point [100, 0]. The function obtained from the modified graph is shown in $y = \sqrt{872.1(x + 1985.142)} - 1348.5$ *Eq. 2*.

$$y = \sqrt{872.1(x + 1985.142)} - 1348.5 \qquad \textit{Eq. 2}$$

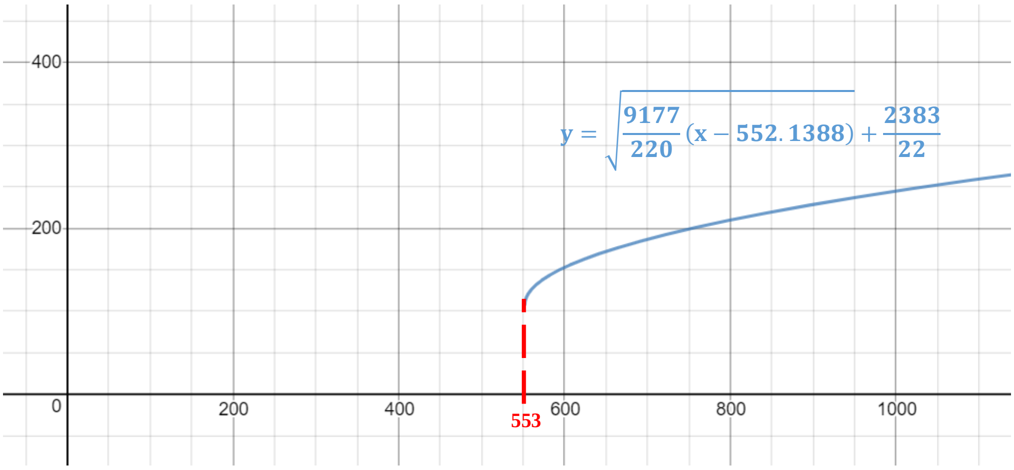

Figure 3: Graph of $y = \sqrt{\frac{9177}{220}(x - 552.1388)} + \frac{2383}{22}$

2.2 Equations of system with battery mode

In this mode, the calculation of PV sizing is done for the system with battery. First, total power used by the AC and DC loads per day is calculated by summing all the multiplication of the input power and their working time per day as shown in $Power\ Req_{total} = Power_{AC} \times Working\ Time_{AC} + Power_{DC} \times Working\ Time_{DC}$ Eq. 3. Then, the total Watt-peak rating needed for PV modules is obtained by multiplying the total power used per day with loss of 30% [8] and divided with sun peak hour for the region, which is 4 hours for Malaysia as shown in $\text{Watt} - \text{peak Rating Req} = \frac{\text{Power Req}_{\text{total}} \times \text{System Loss}}{\text{Sun Peak Hour}}$ *Eq. 4*. Next, the number of PV modules required by the system can be calculated by dividing the total Watt-peak rating needed with the rated output Watt-peak of the PV modules as shown in $\text{No. of PV modules} = \frac{\text{Watt−peak Rating Req}}{\text{Rated Output Watt−peak}}$ *Eq. 5*.

$$Power\ Req_{total} = Power_{AC} \times Working\ Time_{AC} + Power_{DC} \times Working\ Time_{DC} \qquad \textit{Eq. 3}$$

$$\text{Watt} - \text{peak Rating Req} = \frac{\text{Power Req}_{\text{total}} \times \text{System Loss}}{\text{Sun Peak Hour}} \qquad \textit{Eq. 4}$$

$$\text{No. of PV modules} = \frac{\text{Watt−peak Rating Req}}{\text{Rated Output Watt−peak}} \qquad \textit{Eq. 5}$$

For any AC load used in the system, an inverter is needed. The size of inverter will be calculated by multiplying the total power required by AC loads per day with 25% of the capacity [8] as shown in $\text{Inverter Size} = \text{Power Req}_{\text{AC}} \times 1.25$ *Eq. 6*.

$$\text{Inverter Size} = \text{Power Req}_{\text{AC}} \times 1.25 \qquad \textit{Eq. 6}$$

The battery capacity can be calculated by taking the total power required by the system divided with 0.85 battery loss, 0.6 depth of discharge and nominal battery voltage, then multiply with the intended battery life in days [8] as shown in $\text{Battery Capacity} = \frac{\text{Power Req}_{\text{total}}}{\text{Batt.Loss}\times\text{Depth of Discharge}\times\text{Nominal Batt.Voltage}} \times \text{Batt. Life}$ *Eq. 7*.

$$\text{Battery Capacity} = \frac{\text{Power Req}_{\text{total}}}{\text{Batt.Loss}\times\text{Depth of Discharge}\times\text{Nominal Batt.Voltage}} \times \text{Batt. Life} \quad \textit{Eq. 7}$$

The rating of solar charge controller will be determined by the product of number of PV modules and short-circuit current, I_{sc} of module, then multiply by 30% of the capacity [8] as shown in $\text{Solar Charge Controller} = (\text{No. of PV modules} \times I_{sc}) \times 1.3$ *Eq. 8*.

$$\text{Solar Charge Controller} = (\text{No. of PV modules} \times I_{sc}) \times 1.3 \quad \textit{Eq. 8}$$

2.3 Equations of system without battery mode

In system without battery mode, solar irradiation became an important factor in order to let the system work under low sunlight condition such as in the morning and evening. Hence, the calculation will be more specific by taking the graph function of solar irradiation throughout the day and also the electrical performance of the PV module. The first step of the calculation is to obtain minimum solar irradiation of the working period. The time of the day where solar irradiation is minimum within the working period is obtained by subtracting half of the working hour from the number 12 as shown in $\text{Time} = 12 - \frac{\text{Working Hour}}{2}$ *Eq. 9*. The time is inserted into equation of solar irradiation graph from $y = -\frac{175}{6}(x-12)^2 + 1050$ Eq. 1 to obtain minimum solar irradiation of the working period as shown in $\text{Solar Irradiation}_{\text{min}} = -\frac{175}{6}(\text{Time} - 12)^2 + 1050$ *Eq. 10*.

$$\text{Time} = 12 - \frac{\text{Working Hour}}{2} \quad \textit{Eq. 9}$$

$$\text{Solar Irradiation}_{\text{min}} = -\frac{175}{6}(\text{Time} - 12)^2 + 1050 \quad \textit{Eq. 10}$$

After the minimum solar irradiation is obtained, the minimum power required by the PV module is calculated. There is 2 equation used because from **Figure *2***, which is the original graph has an undefined output for solar irradiation less than 553W/m^2. This result is avoided by using an assumption (see section 2.2) to derive a new equation. Hence, the equation from **Figure *2*** is used to calculate minimum PV module power output for minimum solar irradiation more than or equal to 600W/m^2 while $y = \sqrt{872.1(x + 1985.142)} - 1348.5$ *Eq. 2* is used for minimum solar irradiation less than 600W/m^2 as shown in $\text{Power Output}_{\text{min}} = \sqrt{\frac{9177}{220}(\text{Irradiation} - 552.1388) + \frac{2383}{22}}$ *Eq. 11* $\text{Power Output}_{\text{min}} = \sqrt{872.1(\text{Irradiation} + 1985.142)} - 1348.5$ *Eq. 12* respectively.

$$\text{Power Output}_{\text{min}} = \sqrt{\frac{9177}{220}(\text{Irradiation} - 552.1388) + \frac{2383}{22}} \quad \textit{Eq. 11}$$

$$\text{Power Output}_{\text{min}} = \sqrt{872.1(\text{Irradiation} + 1985.142)} - 1348.5 \quad \textit{Eq. 12}$$

Since the minimum PV module power output is obtained, the amount of PV module needed to supply the whole system can be calculated. The number of PV module required by the system is calculated by dividing the minimum PV module power output from the total power required by the system with additional 30% of system loss as shown in $\text{No. of PV module required} = \frac{\text{Power Req}_{\text{total}}\times\text{System Loss}}{\text{Power Output}_{\text{min}}}$ *Eq. 13*.

$$\text{No. of PV module required} = \frac{\text{Power Req}_{\text{total}}\times\text{System Loss}}{\text{Power Output}_{\text{min}}} \quad \textit{Eq. 13}$$

Similar to system with battery, an inverter is also needed if any AC load is used in the system. The sizing of the inverter of system without battery is the same with the system with battery. The size of inverter will be calculated by multiplying the total power required by AC loads per day with 25%

of the capacity, as shown in $\text{Inverter Size} = \text{Power Req}_{AC} \times 1.25$ *Eq. 6*.

3. Results and Discussion

The PV sizing calculator that is designed and developed with Android Studio is named as '*Pivee Sizinlator*'. *Pivee Sizinlator* has a total of 7 of pages or 'activities': 1 activity of splash screen (also known as welcome screen), 1 activity of menu activity for choosing the different mode of 'System with Battery' and 'System without Battery', 2 activities for each mode and 3 activities of help page which can be triggered by clicking the help button on top right of the menu activity, with battery activity and without battery activity. Figure 4 shows the menu activity where the user can choose between with battery mode or without battery mode. Figure 5 and 6 shows the system with battery mode and system without battery mode respectively.

Both of the modes are tested with 11 trial input of different load working hour to obtained the number of PV modules required. For the calculation, the water pump motor used will be fixed to 0.75kWh and the type of PV module used in this project will be the SPM050-P Polycrystalline Solar Panel with rated output power peak, P_m of 50W and short circuit current, I_{sc} of 2.84A. Besides, the sun peak hours that is needed in system with battery mode is fixed to 4 hours. All the results are tabulated and shown in **Table 1** and

Table *2* respectively.

Figure 4: Menu activity

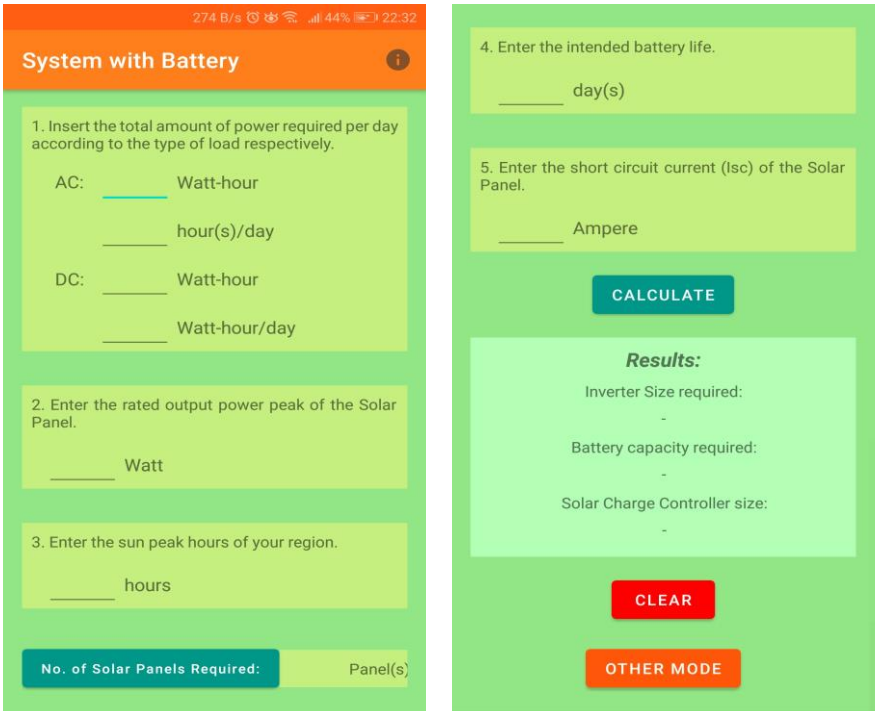

Figure 5: System with battery activity (top half& bottom half

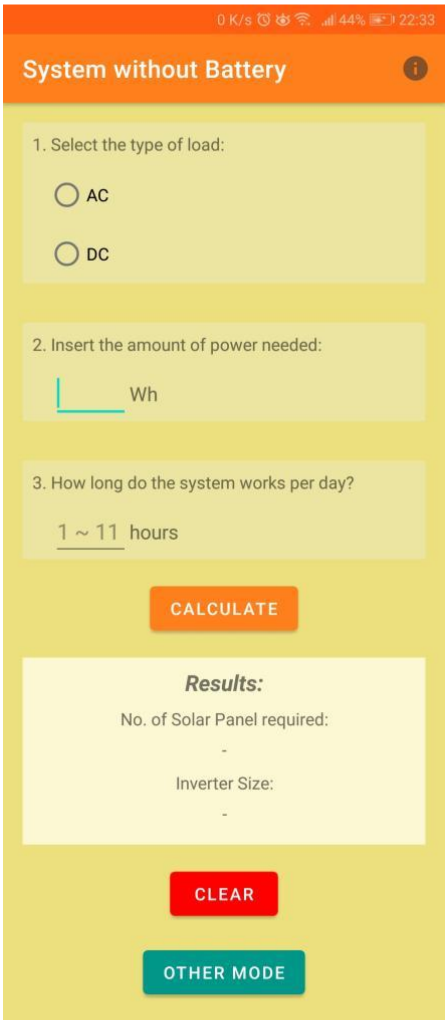

Figure 6: System without battery activity

Table 1: Trial results of system with battery by varying the working hours

Trial Variables	Working hours (hr/day)	No. of PV module required	Inverter Rating (W)	Battery capacity (Ah)	Solar Charge Controller Sizing (A)
1	1	4	937	367	14
2	2	9	937	735	33
3	3	14	937	1102	51
4	4	19	937	1470	70
5	5	24	937	1838	88
6	6	29	937	2205	107
7	7	34	937	2573	125
8	8	39	937	2941	143
9	9	43	937	3308	158
10	10	48	937	3676	177
11	11	53	937	4044	195

Table 2: Trial results of the system without battery by varying the working hours

Trial Variables	Working hours (hr/day)	No. of PV module required	Inverter Rating (W)
1	1.0	3	937
2	2.0	3	937
3	3.0	4	937
4	4.0	4	937
5	5.0	4	937
6	6.0	4	937
7	7.0	5	937
8	8.0	6	937
9	9.0	8	937
10	10.0	14	937
11	11.0	44	937

The relationship between system with and without battery is investigated to determine the need of battery installation. System with battery shows a linear relationship while system without battery shows an exponential relationship between the number of modules and working hour of loads as shown in **Error! Reference source not found.**. In the line graph of system without battery, there is a huge increase between working hour of 10 and 11, where the solar irradiation by the time is getting smaller. By comparing the number of modules required for each system, the system with battery will required more modules than system without battery for the same working hour.

Jogunuri et al. [9] demonstrated an off-grid photovoltaic system sizing where the calculation is in consideration of tilt angle of module at sun peak hour and the temperature coefficient. The calculation would give a higher module efficiency as tilt angle will increase the maximum solar irradiation received from the sun. However, the calculation method is not suitable for a system without battery. Hence, this study case investigate on off-grid photovoltaic system sizing where the calculation is in consideration of the daily solar irradiation and compare with the electrical performance of the photovoltaic module. A new method is formed and is implemented into the software application. With this new calculation method, the system can be built without battery and the working hours can be ranged between 1 - 11 hours.

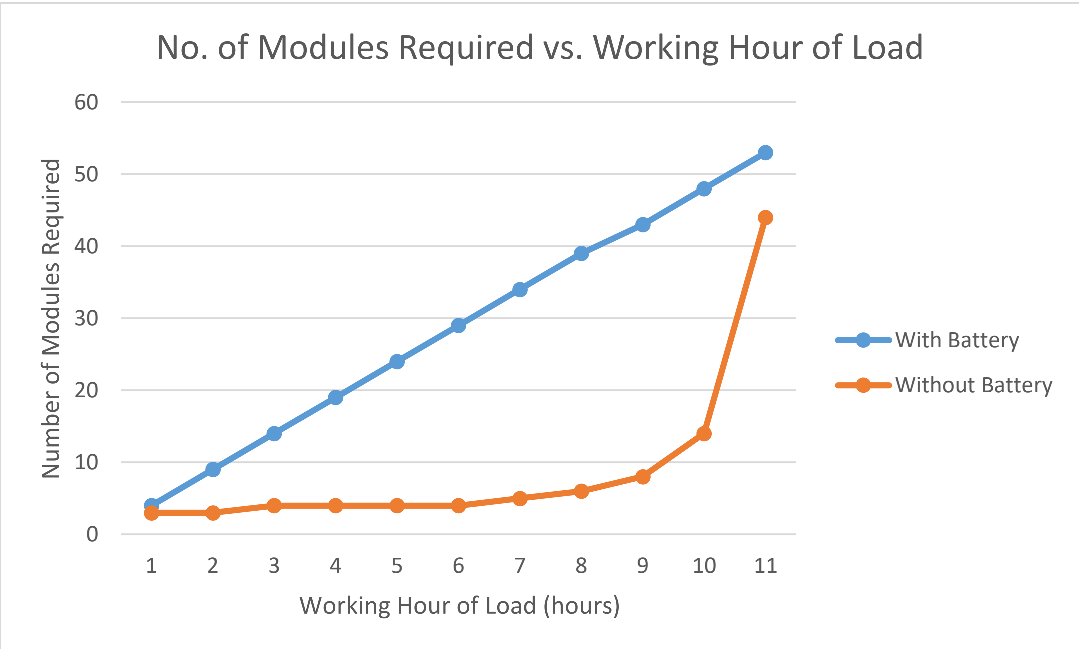

Figure 7: Graph of relationship between 2 modes

By summarizing all analysis of the results, a stand-alone solar powered tube-well system without battery is designed for solving the water shortage in the rural area. This system is more economical and can be affordable by the people with limited budget. The full model design is shown in **Figure *8***8.

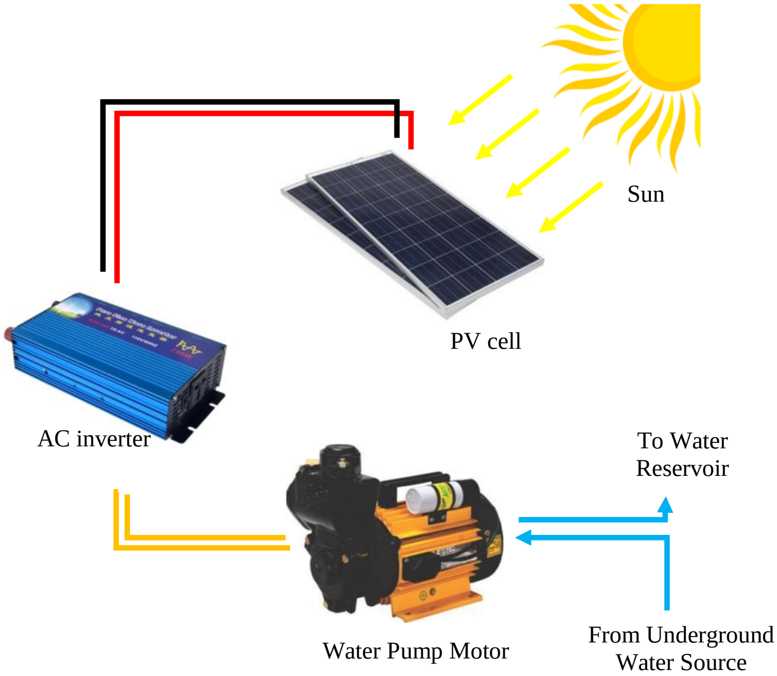

Figure 8: Model of a stand-alone solar-powered tube-well system without battery

Since system with battery needs more modules to power the system, system without battery will be more suitable as it is easier to install and cost much cheaper. In spite of the weakness where the system will be unable to power the motor in cloudy and rainy day, it can be solved using the alternative storage which is the water storage. The water tank can be filled by the tube-well system while sunny day and the water can be used during cloudy day or even at night time. Figure 8 shows the model of stand-alonesolar powered tube-well system without a battery.

From the trial results of system without battery obtained in **Table 1** and

Table *2*, 10 working hours of load would be ideal as it provides a considerable amount of working period with an acceptable amount of PV modules used. Hence, the final system model design would be consisting 14 PV modules, a 1HP (or 0.75kWh) power of water pump motor and a 12V 3kW rating of inverter. The inverter size needs to be at least 3 times greater than the capacity of water pump motor to handle the surge current during the starting of the motor [8][9].

4. Conclusion

As conclusion, the PV sizing calculator software application which is called *Pivee Sizinlator* is successfully designed and developed using Android Studio. The mode of system without battery is also implemented with the method derived from graph analysis of solar irradiation and electrical performance of PV modules. The cost and effectiveness of both modes are evaluated and a solution to solve the water shortage problem of the rural area is proposed. System without battery is chosen as it is easier to install and cost much cheaper. A model of stand-alone solar powered tube-well system without battery is successfully designed as the solution for the problem. The full system model design would be consisting 14 PV modules, a 1HP (or 0.75kWh) power of water pump motor and a 12V 3kW rating of inverter.

Acknowledgment

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

Appendix A

Table A: Specification of polycrystalline module SPM050-P

Model	SPM050-P
Cells	Polycrystalline silicon solar cell
Max Power Pm (W)	50
Max Power Voltage Vm (V)	18.8
Max Power Current Im (A)	2.65
Open-circuit Voltage Voc (V)	21.3
Short-circuit Current Isc (A)	2.84
Module Efficiency (%)	10.0
Maximum System Voltage (V)	DC715V
Series Fuse Rating (A)	10

Table B: Specification of Kirloskar water pump motor

Model	MINI 40S Single Phase
Capacity	200 to 3000 LPH
Power Rating	0.75kW / 1 HP
Voltage Range	180 - 240 Volts (1 phase)
Rated Voltage	230V
Full Load Current	4.5 amps

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