ISSN 2278-3091
Volume 9, No.1.2, 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse2691.22020.pdf
https://doi.org/10.30534/ijatcse/2020/2691.22020

Development of User Interface Design Tool and Training Kit for Standalone Photovoltaic System

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ABSTRACT

Photovoltaic (PV) is one of the renewable energy sources (RES) that widely used in Malaysia that harvest energy from the sunlight to generate electricity. Designing the proper sizing of standalone PV system (SPVs) is challenging due to the lack of technical knowledge especially for non-technical users. Therefore, one of the potential contributions to the development of SPVs is to simplify the design stage for both technical and non-technical people. The designing of PV system including the size of PV panel, battery, charge controller and inverter has been drafted through Microsoft Excel and Visual Basic softwares. The proposed attractive Standalone Photovoltaic Excel Visual Basic for Application (SPEVBA) design tool can automatically calculate the PV system sizing; provides the estimated cost of the PV system and the potential carbon dioxide (CO_2) emission reduction. Moreover, development of PV training kit helps the user to understand the concept and the connection of equipment in the SPVs. The PV design tool and PV training kit are user-friendly, free of charge (PV design tool), interesting, easy to use and understand for both technical and non-technical users.

Key words: Renewable Energy, Standalone Photovoltaic system (SPVs), User Interface, Standalone PV Training Kit.

1. INTRODUCTION

Electricity is vital in human living because a human cannot do many things without electricity. The need for electricity is essential in all aspects of production including residential, commercial and industrial sectors. Currently, the demand for electricity is increasing and the limitation of fossil fuels are a global challenge to cover up the demanded energy generation gap. The utilization of fossil fuel for electricity generation also causes of the environmental threat i.e. acid rain, increased air pollution, global warming etc [1]. The carbon dioxide (CO_2) emissions in the Asia Pacific from 2000-2016 is shown in Figure 1 [2]. It is undeniable that electricity is significant to humans. To address this issue, the Malaysian government (MyG) had emphasized on implemented RES. Among RES, Solar energy is one of the most important and potential source used to replace the fossil fuels in Malaysia [3] The MyG had encouraged the people to focus on RES by introducing renewable energy as the 5th fuel strategy in the energy-mix under the National Energy Policy in 2001 [4]. The government aims to achieve the target whereby in 2020, the power generation from RES needs to reach 2080 MW [5].

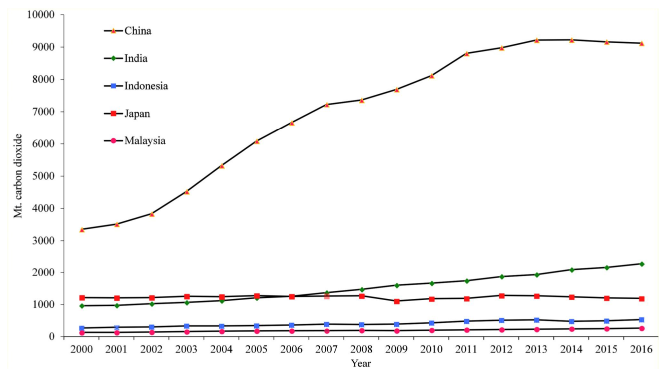

Figure 1: Carbon Dioxide Emission in Asia Pacific (2000-2016)

A general SPVs consists of solar PV panels, solar charge controller, batteries, inverter, distribution board, and AC load as shown in Figure 2.

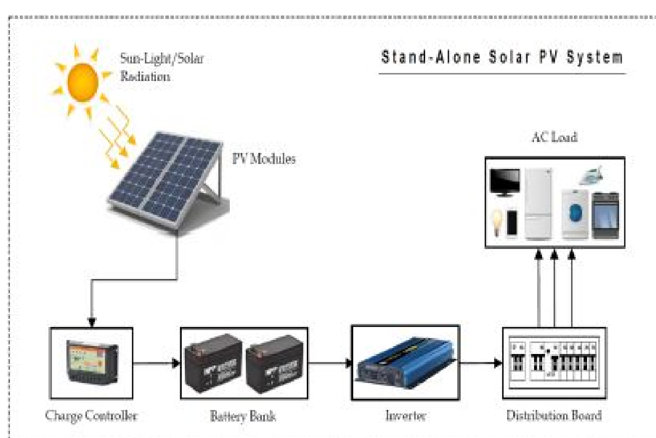

Figure 2: Configuration of stand-alone PV system

In order to design and install the SPVs some steps as the assessment of location and examination of the radiations, demand estimation, voltage and elements selection, inverter capacity determination, battery storage capacity calculation, the requirement of the charge controller, and the sizing of cable should be included [6]. Besides these steps, few criteria need to be considered before designing the PV system i.e. energy losses in the system, sun peak hours, and the battery characteristic [7].

Designing a PV power system is very complicated, which involves system calculations, designing processes, and testing processes. To make the design process easier, the PV design software has developed. The PV design software technology is evolving as fast as PV hardware. A few types of PV design softwares as PV Syst, PV*SOL, System Advisor Model (SAM), and HOMER are discussed in Table 1.

Table 1: Comparison of PV design software [8] [9]

Factors	**PV Syst**	**PV*SOL**	**System Advisor Model (SAM)**	**HOME R**
User-friendly	No	No	Yes	Yes
Cost	$1050 USD	$1543 USD	Free if pay taxes in the US.	$1543 USD
Complexity	Complex	Complex	Moderate	Moderate
Accuracy	High	Moderate	Moderate , accurate only in the US	Moderate

Previously the designing and the sizing for SPVs is calculated by the designer to determine the criteria of the PV design system [10]. The price rate and specifications of the equipment needed are not provided regarding the equipment and connection of the PVs which is user-friendly, free and easy to use by any technical and non-technical users [11]. No design tool is. Therefore, to solve the problem that faces by the engineers, a user interfaces standalone PV design is proposed in this research. The PV training kit can also introduce the standalone PV system to the people that have a lack of knowledge on the PVs installation.

2. METHODOLOGY

In general, this project contains two parts, which are the development part of the software and the development part of the hardware. For the development part of the software, the software Microsoft Excel Visual Basic for Application used. This tool introduces the easy process to obtain the number of a solar cell, size of the battery bank, criteria of batteries, charge controller, inverter, the prices of the equipment and the potential emission of CO_2 to be reduced. For the development part of the hardware, the hardware of the standalone PV training kit is developed.

2.1 User Interface Design Tool

The development of the SPEVBA design tool will be divided into five parts. The first part is the load calculation followed by the second part is the PV modules sizing, then the third part is the inverter sizing next will be the fourth part that is the battery sizing and finally is the last part, which is the solar charge controller sizing.

2.1.1 Load Calculation

The load needs to be calculated first before the PV Sizing be to carry out. It can be calculated through the daily energy consumption, E. It is defined by the following equation [10].

$$E = P \times n \times \square \quad (1)$$

where P is the power rating of the item appliances, n is the quantity of the item appliances and $\square$ is the usage hour per day of the item appliances.

The total daily consumption needs to multiply k factor, k_1 to consider the losses in the system where 30% is considered.

$$E(total) = \sum E \times k_1 \quad (2)$$

where k_1 is 1.3 and 30% losses are considered for total daily consumption [7].

2.1.2 PV Modules Sizing

The PV Modules Sizing has been calculated. Different sizes of PV modules will produce different amounts of power. To find out the sizing of the PV module, the total peak watt produced needs. The peak watt (Wp) produced depends on the size of the PV module and climate of site location. Panel generation factor or peak sun hour which is different in each site location. In Malaysia, the panel generation factor is 3.5. Equation (3) shows the equation to calculate the total watt needed for PV modules, *Ppv* [7] [10].

$$Ppv = \frac{E(total)}{PSHmin} \quad (3)$$

where *PSHmin* is Minimum peak sun hours per day

After that, the number of PV panels for the system is calculated. Equation (4) shows the equation for calculating the number of PV panels for the system, *Npv*.

$$Npv = roundup\left(\frac{Ppv}{Pmax\ (panel)}\right) \quad (4)$$

where *Pmax* (panel) = Maximum power of the panel.

2.1.3 Inverter Sizing

The inverter sizing is calculated as well. The input rating of the inverter should never be lower than the total watt of appliances. For stand-alone systems, the inverter must be large enough to handle the total amount of Watts that will be used at one time. Equation (5) shows the equation of calculating the inverter size with consideration of 30% energy lost [7].

$$P(inv) = P\ (total) \times k_2 \quad (5)$$

where $P(inv)$ is inverter sizing, $P\ (total)$ is a total watt of all appliances and k_2 is the 1.3 k factor where 30% losses are considered for the inverter.

2.1.4 Battery Sizing

The battery sizing also needs to be calculated. It recommended for using in a solar PV system is a deep cycle battery. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. The specifications of the battery are the nominal battery voltage (*Vdc*), days of autonomy (*DOA*), battery efficiency (η), depth of discharge (*DOD*) and total energy required (*E*). The battery size can be calculated as follows Equation (6) [7].

$$C = \frac{E \times DOA}{\eta \times DOD \times Vdc} \quad (6)$$

where *C* is the battery capacity (AH).

2.1.5 Solar Charge Controller Sizing

The Solar Charge Controller Sizing will be calculated. Moreover, have to make sure that the solar charge controller has enough capacity to handle the current from the PV array. Equation (7) shows the equation of calculating the Solar Charge Controller Sizing with the consideration of the 30% factor of safety [7] [10].

$$Ireg = Isc \times k_3 \quad (7)$$

where *Ireg* is the rated current of the charge controller, *Isc* is the short circuit current and k_3 is the 1.3 k factor. In addition, 30% of the factor of safety is considered.

2.2 PV Training Kit

The Standalone PV training kit is a kit that combined all the components of the photovoltaic system. The purpose of this Standalone PV training kit is to introduce the PV system to the public and let the user know the connection of the system. With the help of the PV training kit, the explanation of the standalone PV system will be more easily. It starts from the generation part of the electricity, which is the solar panel that generated direct current (DC), then it will be connected to the DC watt meter to obtain the voltage, current, power, and energy of the solar panel produced DC electricity. Then from the DC watt meter, it will connect to the solar charge controller for the solar panel side. After that, the battery will also connect to the solar charge controller for the battery side. Basically, the solar charge controller functions as the device that controls the voltage and cuts off the charging when the battery is full to avoid overcharging, limit the ampere of charging current flow to the battery and prevent reverse current flow [12]. Next, the load side of the solar charge controller will be connected to the inverter for the conversion of DC to AC. Moreover, there will be an AC power meter connected between the inverter and the AC load. The AC power meter will read the reading of the load, which includes the current, voltage, and power. Figure 3 illustrates the connection of the overall system for the standalone PV training kit.

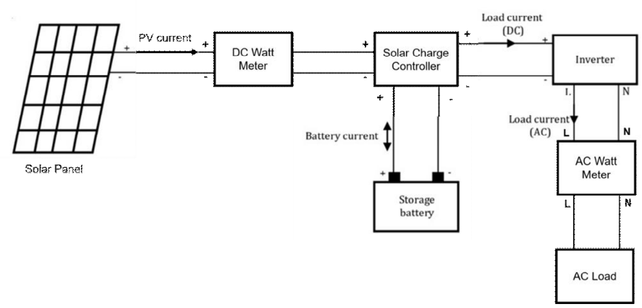

Figure 3: Connection of the overall system for the standalone PV training kit

3. CASE STUDY

Two case studies have been conducted to analyze the performance of the tool. Two locations have been chosen to do the case study. Each case study has its specific load and based on real situation application. The first case study will be the single house in a rural area in Kuching, Sarawak. The second case study will be the small size chili fertigation project in Parit Raja, Johor. Analysis of the peak sun hour for both locations has been conducted. Besides, CO_2 Emission Avoidance has been analyzed for both locations.

3.1 Case Study 1: Single House at Rural Area in Kuching, Sarawak

Case study 1 considered a single house in a rural area in Kuching, Sarawak. This study examined the household appliances load, such as fan, light, television, and washing machine. In order to obtain the exact value of the peak sun hour, the average daily irradiance data is collected from the PVGIS-SARAH database from January to December, and analysis had been made for case study 1 [13]. Table 2 shows the daily average irradiation values (Wh/m^2) for one year. The total value of daily average irradiation is 50618 Wh/m^2.

To obtain the average peak sun hour, the total daily average irradiation value will need to be divided by twelve months. After that divide again with one thousand (W/m^2) due to the Standard Test Condition (STC) for solar panel irradiance is 1000 (W/m^2) and module temperature 25°C from the Florida Solar Energy Center (FSEC) Standard [14].

Table 2: Daily average irradiation value (Wh/m2) from January to December for case study 1

Month	Daily average irradiation value (Wh/m^2)
January	4299
February	4487
March	4623
April	4296
May	3761
June	3519
July	3785
August	4052
September	4332
October	4327
November	4689
December	4448
Total	50618

Therefore, the peak sun hour determination for this location reaches to 4.2 hours. Figure 4 represents the daily average irradiation values. It is clear to see that the month of March and November have the highest irradiation, but on the other hand, it has the least irradiation from May to July.

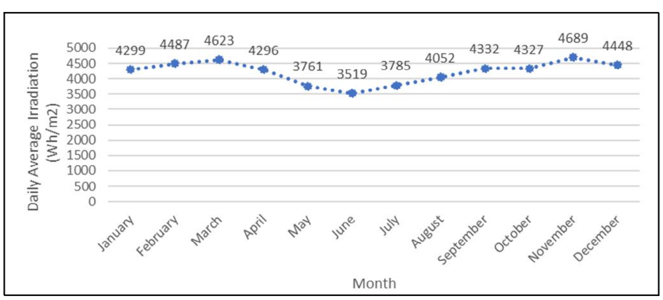

Figure 4: Daily average irradiation values for case study 1

According to the Sustainable Energy Development Authority (SEDA), a study by Malaysian Green Technology Corporation (MGTC) regarding the overall average emission produced by grid-connected electricity. The production of CO_2 emission for peninsular is 0.694 tCO2/MWh, and Sabah & Sarawak is 0.536 tCO_2/MWh [15]. Based on case study 1, the total daily energy consumption is 3302 Wh. If the system runs for a year which will consume 1.21 MWh. If the household load is supply by the fossil fuel or gas by Tenaga Nasional Berhad (TNB) generation plant, there will be a 0.65 tCO_2 been produced per year just for one house in Kuching, Sarawak. Therefore, by using the SPVs for case study 1, the total CO_2 emission that can be avoided will be 0.65 tCO_2, and it is equal to 650 kg CO_2 per year.

3.2 Case Study 2: Small Size Chili Fertigation Project in Parit Raja, Johor

Case study 2 considered a small size chili fertigation project in Parit Raja, Johor. This study examined the load that been used in chili farms such as lighting for the chili farm and a 1kW motor pump. The motor pump needs to run five minutes with a total number of eight times per day. Thus, it has to run forty minutes daily. In order to obtain the exact value of the peak sun hour, the average daily irradiance data is collected from the PVGIS-SARAH database for one year from January to December, and analysis had been made for this case study 2 [13]. Table 3 illustrates the daily average irradiation values (Wh/m^2) for this location. The total value of daily average irradiation for one year is 53902.77 Wh/m^2.

Table 3: Daily average irradiation value (Wh/m^2) from January to December for case study 2

Month	Daily average irradiation value (Wh/m^2)
January	5263.99
February	5513.78
March	5017.94
April	4459.7
May	3800.15
June	3592.82
July	3681.89
August	4037.67
September	4441.69
October	4663.53
November	4792.42
December	4637.19
Total	53902.77

Therefore, the peak sun hour determination for case 2 is 4.5 hours. Figure 5 represents the daily average irradiation values for this location. It can be noticed that the highest irradiation was in the month of January to March. Differently, from May to July have the least irradiation.

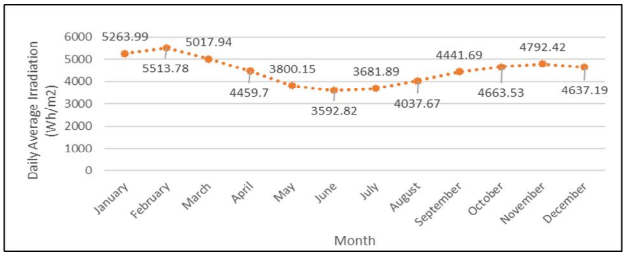

Figure 5: Average daily irradiation values for case study 2

Based on case study 2, the total daily energy consumption is 881 Wh. If the system runs for a year which will consume 0.32 MWh. There will be 0.21 tCO_2 been produced per year for one chili fertigation project in Parit Raja, Johor. Therefore, by using the SPVs for case study 2, the total CO_2 emission that can be avoided will be 0.21 tCO_2, and it is equal to 210 kgCO2 per year.Based on the two case studies, the specification and price of the components for both systems can be summarized in Table 4.

Table 4: Specification and estimated price of the components for both case studies system

	Component	*Specification*	*Price (RM)*
Case Study 1	*PV modules*	*840W*	*1500*
	Solar Charge Controller	*30A*	*119*
	Battery	*1000Ah*	*6800*
	Inverter	*2000W*	*207*
		Total Cost	*8626*
Case Study 2	*PV modules*	*280W*	*500*
	Solar Charge Controller	*10A*	*15.5*
	Battery	*200Ah*	*1360*
	Inverter	*1000W*	*88.7*
		Total	*1964.2*

4. RESULTS AND DISCUSSION

This section discussed the application of the proposed SPEVBA and developed PV training kit as follows:

4.1 User Interface Design Tool

The user interface design tool is called SPEVBA and the development of the SPEVBA design tool consists of two parts. The main part is the load calculation, where all the load and demand estimation are design. Figure 5 shows the load calculation of the SPEVBA design tool which consists of the Appliances column, power rating of the appliance column, the quantity of the appliance column, usage hour per day column, daily energy consumption column and the bar for the total daily consumption with 30% energy losses consideration. Furthermore, the second part of the calculator is the result part. After the load has been calculated, the result part can be shown by pressing the next button. The result consists of PV module sizing, inverter sizing, battery sizing, solar charge controller sizing, cost of each component, total system cost, and the potential emissions to be reduced. Figure 6 represents the result of the overall SPEVBA Design Tool.

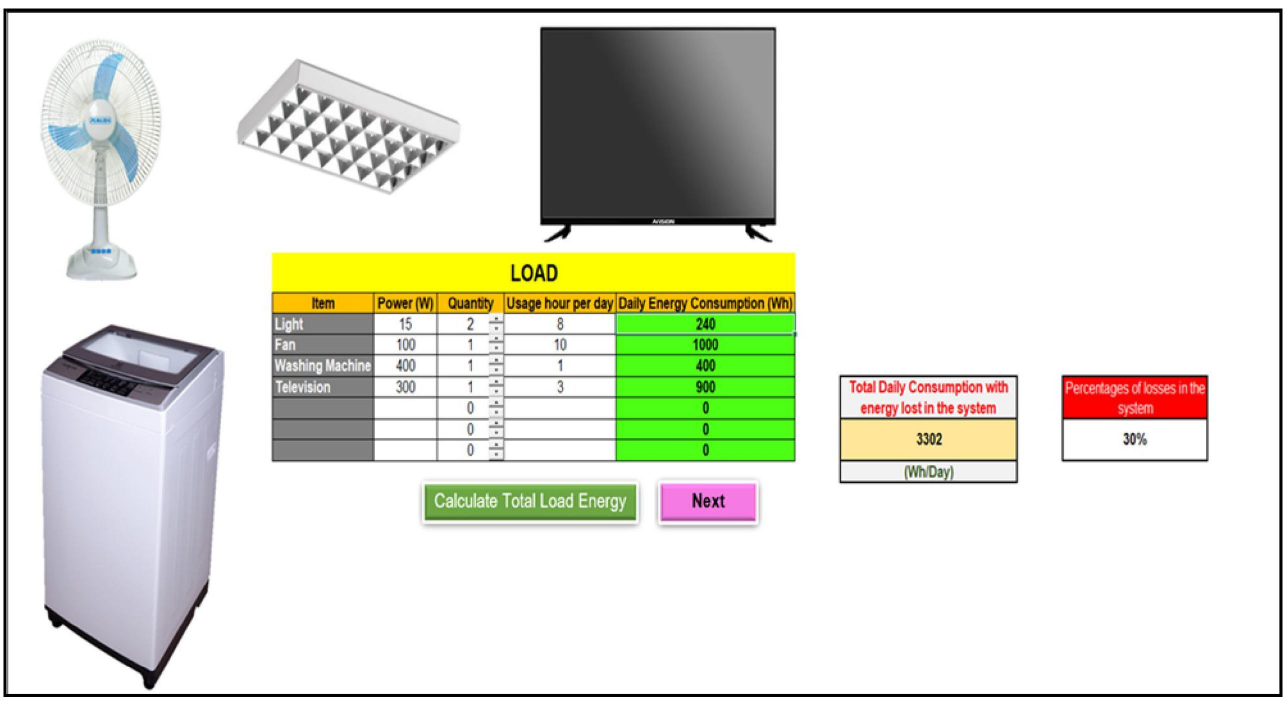

Figure 5: Load Calculation part of the SPEVBA Design Tool

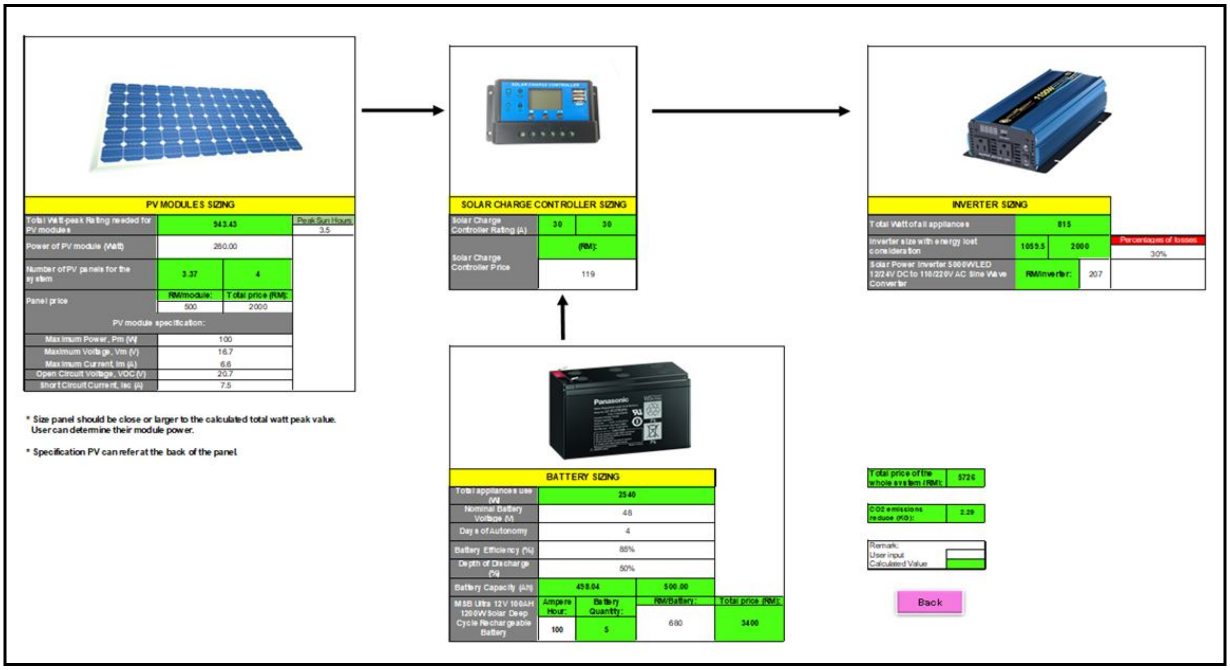

Figure 6: Result of the overall SPEVBA Design Tool

4.2 PV Training Kit

A portable PV training kit is developed to make the introduction of a standalone PV system easily understood by any people. The PV training kit is developed by using a 10W solar panel, pulse width modulation (PWM) solar charge controller, 12V lead-acid battery, inverter, DC wattmeter, AC wattmeter, and load. Figure 7 shows the PV training kit that been developed.

Figure 7: Developed PV training kit

5. CONCLUSION

In this paper, a standalone photovoltaic user interface design tool and PV training kit is developed. The development of the SPEVBA design tool using Microsoft Excel and Visual Basic Application. This research helps the technical or non-technical user to design the SPVs easy and shortly. The SPEVBA design tool is also very user-friendly, free of charge and portable with access at any place. Moreover, the hardware of this standalone PV training kit has successfully utilized among public with testing and demonstration. This PV training kit can promote the concept and operation of SPVs to the public and advantages of RES such especially solar energy.

ACKNOWLEDGEMENT

This research was supported by Ministry of Education of Malaysia through Fundamental Research Grant Scheme (FRGS/1/2018/TK04/UTHM/02/17) and partially sponsored by Universiti Tun Hussein Onn Malaysia.

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