Faculty of Electrical Technology and Engineering

DEVELOPMENT OF EXCEL BASED VBA APPLICATION FOR RESIDENTIAL GCPV SYSTEM DESIGN BY ENERGY REQUIREMENT

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Bachelor of Electrical Engineering Technology with Honours

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DEVELOPMENT OF EXCEL BASED VBA APPLICATION FOR RESIDENTIAL GCPV SYSTEM DESIGN BY ENERGY REQUIREMENT

RACHEL ANAK MICHAEL

A project report submitted
in partial fulfillment of the requirements for the degree of
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Tajuk Projek : DEVELOPMENT OF EXCEL BASED VBA APPLICATION FOR RESIDENTIAL GCPV SYSTEM DESIGN BY ENERGY REQUIREMENT

Sesi Pengajian : Semester 1 2023/2024

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I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.

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DEDICATION

To my beloved family, whose unwavering love and support were the bedrock of my journey. You believed in me when I doubted myself, and your sacrifices made this moment possible.

To my dear friends, who navigated this adventure with me. Your presence was a constant source of strength and joy.

To my inspiring supervisor, whose guidance and expertise illuminated the path. Your dedication to knowledge and unwavering faith in my potential shaped this work.

To the countless researchers who came before me, paving the way for me to stand on their shoulders and reach new heights.

To the future generation of renewable energy, who I hope will find answers and inspiration within these pages. May this work contribute to a brighter future filled with innovation and discovery.

ABSTRACT

Solar photovoltaic (PV) industry is not only great for the environment, but also for boosting the economy, as it is a multimillion-dollar industry. For PV system installers, designing a PV system typically requires the use of specialised software or an application that is only understandable by a technical person and can be quite challenging for customers with no technical background. Therefore, to overcome this problem, this project aims to develop an Excel-based Visual Basic for Applications (VBA) application for the design of residential grid-connected photovoltaic (GCPV) systems that is free, user-friendly, and accessible for non-technical person. The project's objectives are achieved through a combination of literature review and software development. To do so, an application is developed using the VBA programming language that is integrated into Microsoft Excel. In this semester, the full development of VBA based application is succesfully executed and the expected result from the application conforms to the actual result from manual calculation. It is envisaged that the successful implementation of this project will expedite and promote more installation of PV systems and hence reduce the dependency on fossil fuel-based electrical energy.

ABSTRAK

Industri fotovoltaik solar (PV) bukan sahaja baik untuk alam sekitar, tetapi juga untuk meningkatkan ekonomi kerana ia merupakan industri berjuta-juta dolar. Bagi pemasang sistem PV, merekabentuk sistem PV biasanya memerlukan penggunaan perisian khusus atau aplikasi yang hanya difahami oleh orang teknikal dan boleh menjadi sangat mencabar bagi pelanggan yang tidak mempunyai latar belakang teknikal. Oleh itu, untuk mengatasi masalah ini, projek ini bertujuan untuk membangunkan aplikasi Visual Basic for Applications (VBA) berasaskan Excel untuk merekabentuk sistem fotovoltaik grid-connected (GCPV) kediaman yang percuma, mudah digunakan, dan boleh diakses oleh orang bukan teknikal. Objektif projek ini dicapai melalui gabungan kajian literatur dan pembangunan perisian. Untuk melakukan ini, satu aplikasi dibangunkan menggunakan bahasa pengaturcaraan VBA yang diintegrasikan ke dalam Microsoft Excel. Pada semester ini, aplikasi berasaskan VBA ini berjaya dilaksanakan dan pengiraan yang diharapkan dari aplikasi ini selaras dengan pengiraan manual. Ia dijangkakan bahawa kejayaan pelaksanaan projek ini akan mempercepat dan mempromosikan lebih banyak pemasangan sistem PV dan dengan itu mengurangkan kebergantungan kepada tenaga elektrik berasaskan bahan api fosil.

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First and foremost, I would like to express my deepest gratitude to my family for their unwavering support and encouragement throughout this journey. Their faith in me fuelled my determination and helped me overcome every hurdle.

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Last but not least, I want to thank me. I want to thank me for believing in me, I want to thank me for doing all this hard work, I want to thank me for having no days off, I want to thank me for never quitting.

This thesis would not have been possible without the invaluable support of these individuals and entities. I am eternally grateful for their contributions and forever indebted to their kindness.

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LIST OF SYMBOLS

V	-	Voltage
A	-	Amphere
W	-	Watts
mm	-	Milimeter
$Pmax$	-	Maximum Power
Voc	-	Open Circuit Voltage
Isc	-	Short Circuit Current
$\%/°C$	-	Percentage of VOC per degree Celcius

LIST OF ABBREVIATIONS

PV	-	Photovoltaic
UI	-	Utility-interactive
WP	-	Water Pumping
DC	-	Direct Current
AC	-	Alternating Current
GCPV	-	Grid-Connected Photovoltaic
VBA	-	Visual Basic Application
VBE	-	Visual Basic Editor
IRENA	-	International Renewable Energy Agency
PIDGCPV	-	Pre-Installation Design for GCPV
WTH	-	Water Thermal Heating
EMF	-	Electromagnetic Fields
NOCT	-	Nominal Operating Cell Temperature
BOS	-	Balance of System
NREL	-	National Renewable Energy Laboratory
SAPV	-	Standalone Photovoltaic
SA	-	Standalone
SaaS	-	Software as a Service
kWh	-	Kilo-watt per hour
kWp	-	Kilo-watt peak
Wdc	-	Watts DC
Wac	-	Watts AC

CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy is energy derived from naturally occurring resources that can replenish themselves over time. These resources include sunlight, wind, rain, tides, and geothermal heat, among others. Renewable energy sources differ from conventional energy sources such as fossil fuels because they utilise naturally replenishing resources, making them a more sustainable and environmentally friendly alternative. Renewable energy has many potential benefits, including environmental, economic, and social benefits. One of the most significant benefits of renewable energy is that it is much better for the environment than fossil fuels which contribute heavily to issues, as it produces significantly lower greenhouse gas emissions, helping to mitigate climate change. Additionally, renewable energy can provide immediate cost savings. According to the International Renewable Energy Agency (IRENA), more than 60% of newly installed renewable power in 2021 had lower costs than the world's cheapest coal-fired option in the G20 [1]. In other words, renewables are already cheaper than fossil fuels on average, and their advantage is growing. Among the various renewable energy sources, Figure 1.1 shows that solar energy has emerged as the most popular and widely adopted [2]. Solar energy is popular because it is abundant, widely available, and has minimal environmental impacts. Solar power has also gained popularity due to its versatility, as it can be used for both electricity generation and water heating.

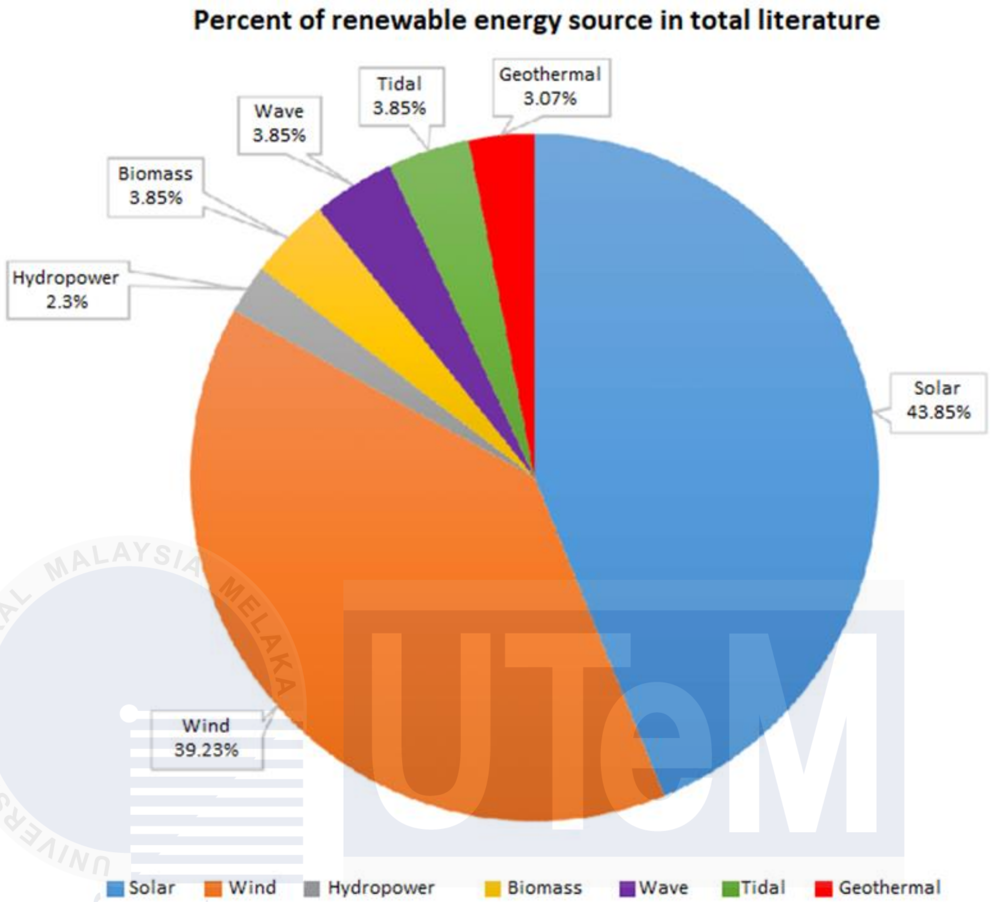


Figure 1.1 The pie chart of seven renewable energy sources [2]

Solar photovoltaic (PV) is a technology that converts sunlight into electricity. It is a renewable energy source that has gained popularity in recent years due to its numerous benefits. Solar PV systems require low maintenance, making them a hassle-free source of energy. Once installed, they require minimal maintenance and can last for up to 25 years. There are two types of solar PV which are Grid-Connected PV (GCPV) and Standalone PV. Standalone PV systems are not connected to the grid and are used in remote areas where there is no access to the grid. GCPV systems are connected to the grid and can supply excess electricity back to the grid.

GCPV systems have the advantage of effective utilization of generated power because there are no storage losses involved. Excess solar energy generated can be sold to the grid, which can help offset the cost of the system. GCPV systems are relatively cheaper and more reliable than standalone systems due to their connection to the utility grid, which provides a backup power source when solar panels are not producing enough energy and they do not require battery banks, which can be unreliable and require frequent replacement. Lastly, the government has implemented FiT, NEM, Selco, and LSS initiative programmes to encourage the use of renewable energy in Malaysia, specifically solar energy.

Most GCPV application systems, such as PVSyst, SMA, and Helioscope, display what is required to prospective customers after simulating or generating how much the GCPV system should use. However, most application systems are too technical for the average person.

1.2 Problem Statement

The problem statement for this project is that the application for most GCPV system designs are more focused on technical people, as only technical people can comprehend the terms, parameters and requirements used in the application. Therefore, it is believed there is a need to develop something easier to operate and more understandable for non-technical people interested in installing a GCPV system in their residences.

1.3 Project Objective

The main aim of this project is to propose a user-friendly application for non-technical people that are interested in installing a GCPV system with reasonable accuracy. Specifically, the objectives are as follows:

a) To develop an Excel-based application capable of accurately calculating the number of solar panels and PV inverters required for a GCPV system based on energy requirement.

b) To test the performance of the VBA application with different energy requirement inputs.

c) To validate the accuracy of manual calculations.

1.4 Scope of Project

The scope of this project are as follows:

a) This application is intended for residential grid connected PV design (GCPV).

b) Using VBA coding for generating calculation.

c) The project will adhere to the Sustainability Energy Development Authority (SEDA) standards and regulations for the design and installation of GCPV systems.

d) Using one specific model of solar panel and PV inverter.

e) Developing an application capable of calculating the number of solar panels and PV inverters for a GCPV system based on the energy requirement of a residence.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes Excel based VBA Application PV design based on energy demand. This chapter contains background study, previous works, and comparison of previous works. This chapter examines the history of PV systems, solar PV system generation, PV system components, web-based PV design software and applications, as well as Microsoft Excel. This section examines the five fundamental principles for meeting the requirements of this research. The second section provides context for the current research by discussing studies that influenced the characteristics, development, methodologies, applications, and user interfaces of these tools. Comparing past works requires an extensive literature search. Prior works are evaluated for their applicability and qualities. This comparison contextualises and highlights the significance and originality of the research. This chapter concludes by identifying Excel-based PV design system limitations and improvement areas, thereby preparing this paper to contribute novel solutions and enhancements to this research.

2.2 Background Study

Background study is a vital component of any paper, providing the necessary foundation for understanding the research topic within its broader context. This section consists of five main elements which are history of photovoltaic (PV) system, concept of Solar PV System Generation, Components of PV System, Web-based PV Design Software and Applications, and Microsoft Excel.

2.2.1 History of Photovoltaic (PV) system

The photovoltaic effect was discovered by French physicist, Alexandre-Edmond Becquerel in the 19th century, which is when PV systems first became popular. This effect refers to a substance's capacity to generate an electric current when exposed to light. In 1954, Daryl Chapin, Calvin Fuller, and Gerald Pearson at Bell Labs in the United States developed the first usable silicon photovoltaic cell which had an efficiency of 6%, capable of converting enough solar energy into electricity to run common electrical appliances. Figure 2.1 shows the silicon P-N photo-EMF cell developed in Bell Labs and Figure 2.2 shows solar energy converting apparatus invented by Daryl Chapin, Calvin Fuller, and Gerald Pearson. Late in the 1950s, the first conventional photovoltaic cells were manufactured, and throughout the 1960s, they were primarily used to power space satellites.

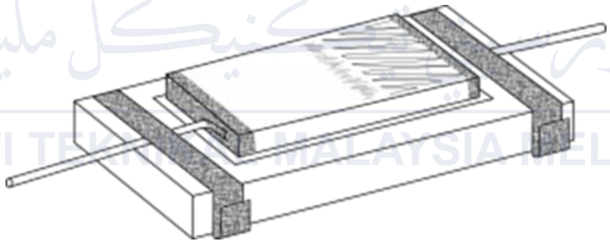


Figure 2.1 Silicon P-N photo-EMF cell [3]

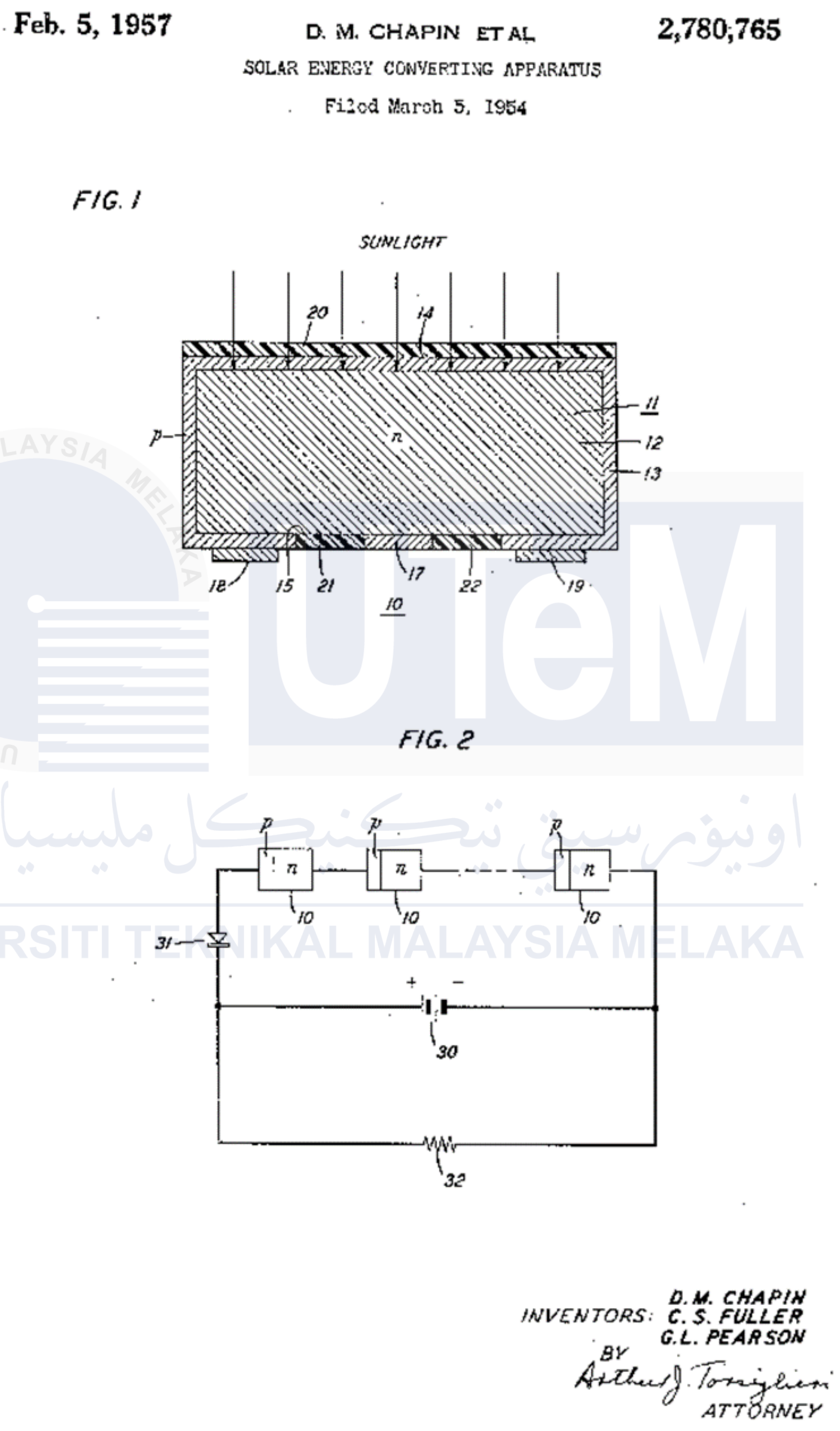


Figure 2.2 Solar Energy Converting Apparatus [4]

Sharp Corporation created the first silicon solar cell photovoltaic module in 1963, as shown in Figure 2.3, which was the largest PV system at the time, producing 242W. Since then, PV cell efficiency has increased substantially. Due to the oil crisis in the 1970s, interest in renewable energy increased, and governments began to invest in PV system research and development.

Figure 2.3 The first mass production of single-crystal solar cells [5]

Since then, PV technology has continued to advance, increasing in efficiency and decreasing in price. The development of thin-film PV technology in the 1990s enabled more flexible and lightweight PV panels. In recent years, there has been an emphasis on integrating PV systems with other technologies such as energy storage and electric vehicles.

PV systems are currently employed for a wide range of applications, including residential and commercial electricity generation, off-grid power, and portable devices. PV installations are possible on rooftops, in fields, and even on bodies of water.

PV technology research is ongoing, with a focus on increasing efficiency, lowering costs, and improving reliability. This includes research into new materials, such as perovskite, and new system designs, such as bifacial PV panels. In the transition to a low-carbon energy system, it is anticipated that PV systems will play an increasingly significant role.

2.2.2 Concept of Solar PV System Generation

Solar photovoltaic (PV) systems are a type of renewable energy system that converts sunlight to electricity. The components of the system are a charge controller, a battery bank, an inverter, and solar panels. The solar panels consist of PV cells that are composed of semiconducting materials that convert sunlight to direct current (DC) electricity. PV cells are composed of semiconducting materials that convert solar energy into direct current. Figure 2.4 shows the working of solar cell whereby, when sunlight strikes a PV cell, it excites the semiconductor material's electrons, causing them to flow and generate an electrical current. The PV cells are typically arranged in panels and connected to an inverter, which converts direct current (DC) into alternating current (AC) current that can power homes and businesses, and other electrical loads. The battery bank stores excess solar energy for use during cloudy days. The charge controller regulates the current between the solar panels and the battery bank.

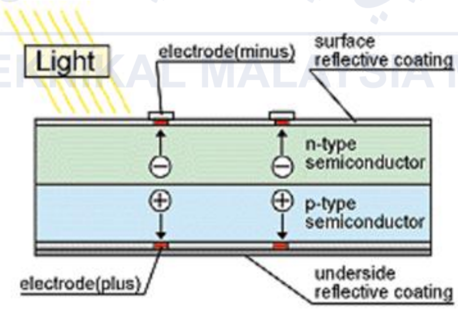


Figure 2.4 Working of Solar Cell [6]

There are two types of PV Systems which are Standalone and Grid-Connected System (GCPV).

The term "standalone" refers to a system that is not connected to a grid facility. Standalone systems are able to generate their own electricity and power their own appliances. Standalone electrification systems are viable for remote areas in countries with limited or no access to electricity due to their distinct living conditions and dispersed population. Solar PV panels produce electrical energy that must be stored or saved in a standalone system because load requirements can differ from solar panel output. Typically, a battery bank is used for this purpose.

A GCPV system is a system for producing electricity that is connected to the utility grid as shown in Figure 2.5. This PV system consists of solar panels, an inverter, and the necessary equipment for grid connection. GCPV systems are viable for various applications, including residential. Typically, GCPV systems do not require battery backup, as excess energy generated by the system is automatically transferred to the utility grid.

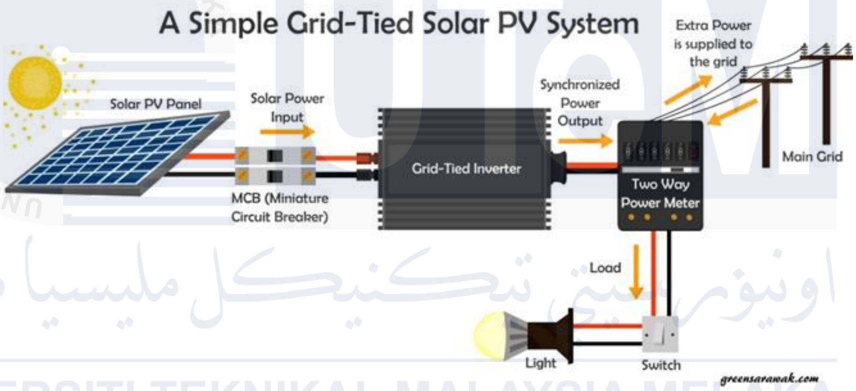


Figure 2.5 Simple Grid-Tied Solar PV System [7]

In residential settings, grid-connected rooftop systems typically have a capacity of 10 kilowatts, which is sufficient to meet the household's energy needs and the excess energy is fed into the grid which will be used by other consumers connected to the grid. The feedback or excess power transfer system monitors the transferred power via a metre. In some instances, the wattage of the PV system may be less than the normal consumption due to several factors, and in these cases, the consumer will utilise grid energy.

Solar PV systems have been incorporated into utility-scale projects, such as wind and solar farms, to supply the grid with clean, renewable energy which lessen reliance on fossil fuels, and mitigate climate change. There are difficulties in integrating solar PV systems into the power grid, such as intermittency and variability. Nevertheless, these obstacles can be overcome by employing energy storage systems and advanced control systems.

2.2.3 Components of PV System

The primary components of a solar PV system are photovoltaic (PV) modules, also known as solar panels. PV modules are comprised of solar cells made of silicon that convert sunlight into electricity. Figure 2.7 shows the cross-section of a solar cell. These cells are chained together to form modules or panels, which are larger units as shown in Figure 2.6. Individual modules can be used, or multiple modules can be connected to form arrays. As part of a comprehensive PV system, one or more arrays are connected to the electrical grid. Due to their modular design, PV systems can be constructed to meet virtually any size or scale of electricity demand. There are numerous types of photovoltaic modules or solar panels in the market. Figure 2.8 shows the most common solar panels, which are monocrystalline, polycrystalline and thin-film. Monocrystalline solar panels are more efficient than polycrystalline solar panels, which are made from multiple silicon crystals. Thin-film solar panels are more flexible and lighter than crystalline silicon panels. Table 2.1 summarises the three most common solar panel types. When selecting the appropriate PV panels for construction project, the desired rating must be considered. To select the appropriate PV modules for your PV system, the installation location, module technology, and datasheet must be considered. In Figure 2.9, datasheet of YLM-J 3.0 PRO 530-555 W is selected. The specifications that need to take account are power output with the range of 530W to 555W. For 530W, the voltage at P_{max} is 41.40V, current at P_{max} is 12.81A, open-circuit voltage is 49.22V, short-circuit current is 13.69A, temperature coefficient of V_{oc} is -0.27%/℃, and lastly temperature coefficient of I_{sc} is 0.05%/℃. Additionally, all the specifications must be examined to ensure the optimal output.

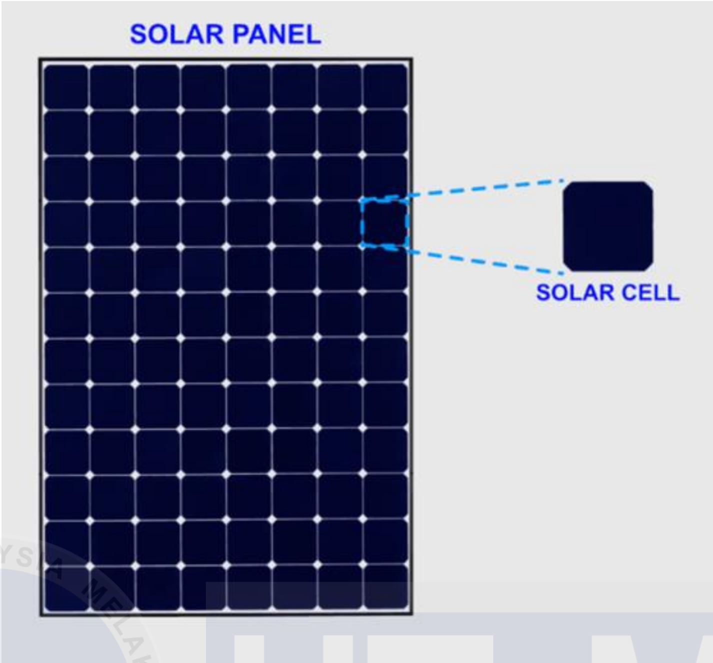


Figure 2.6 Solar Panel [8]

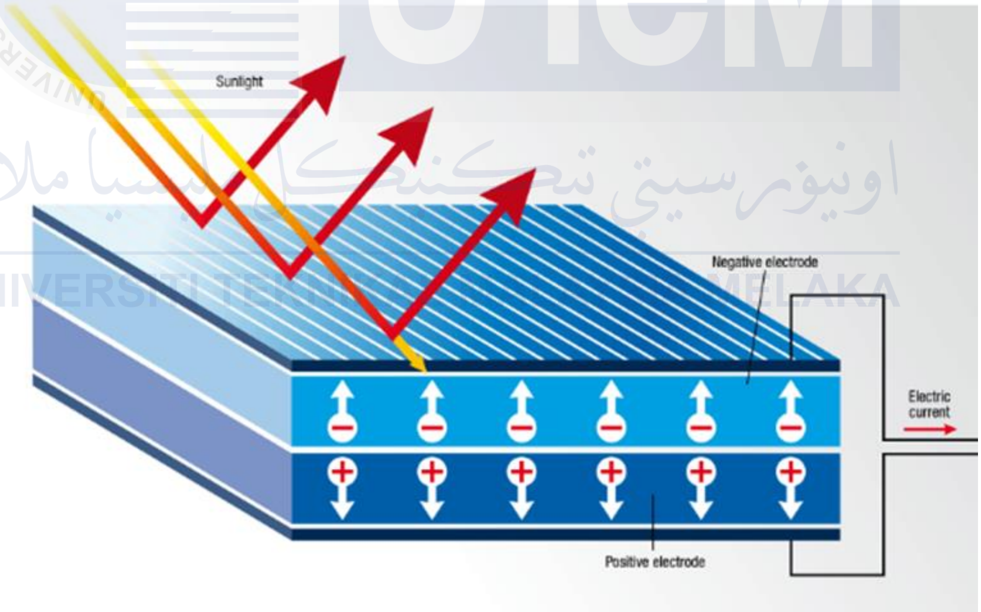


Figure 2.7 Cross-section of a solar cell [9]

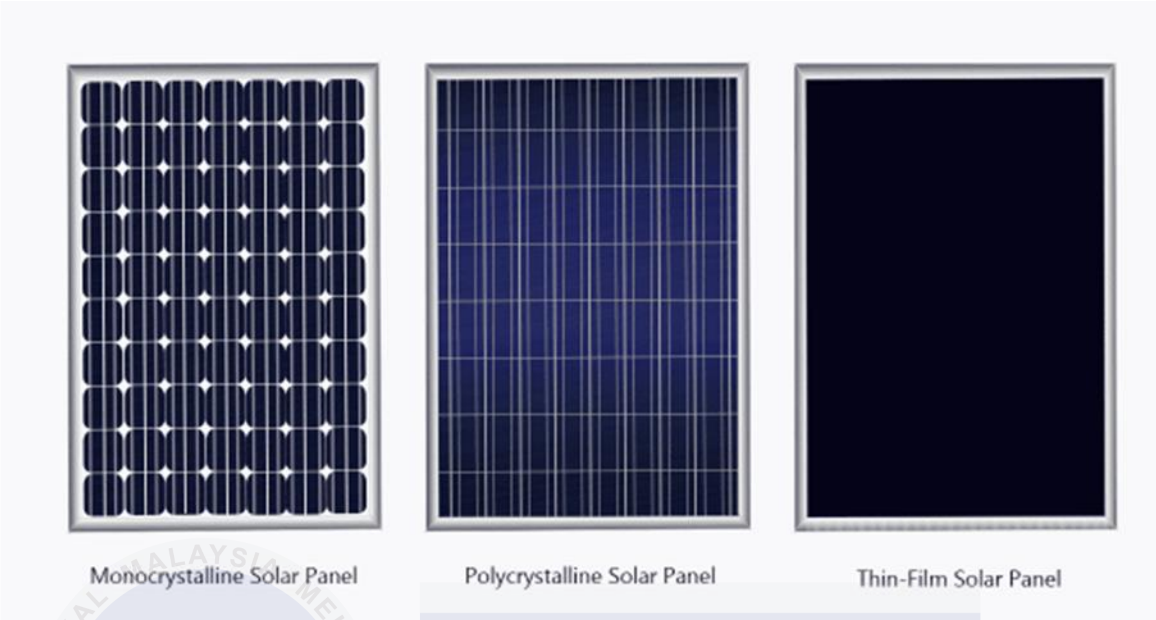
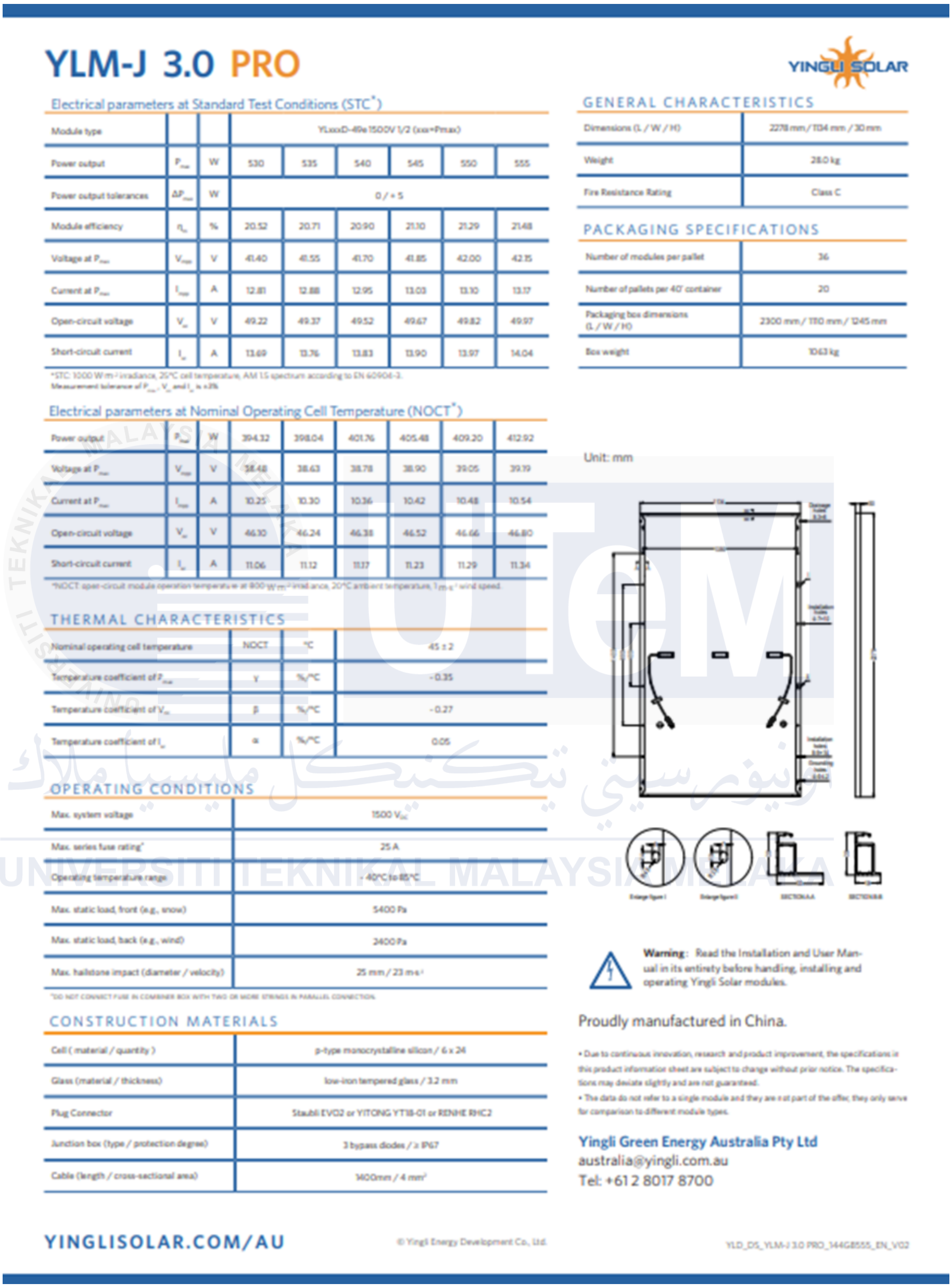


Figure 2.8 Most common solar panels [9]

Table 2.1 Summary table of the three most common solar panel types [9]

Solar Panel Type	Material	Efficiency	Cost	Appearance
Monocrystalline	Pure, single silicon crystal	High (18% or slightly higher)	Highest	Black or blue cells with rounded corners
Polycrystalline	Silicon fragments	Medium (15-17%)	High	Blue rectangular cells
Thin-Film	Various	Low (11%, but may attain 15%)	Lowest	Black or blue uniform surface



YLM-J 3.0 PRO

YINGLI SOLAR

Electrical parameters at Standard Test Conditions (STC*)

Module type			YLxxxD-49e 1500V 1/2 (xxx=Pmax)					
Power output	P_{max}	W	530	535	540	545	550	555
Power output tolerances	ΔP_{max}	W	0 / + 5					
Module efficiency	η_m	%	20.52	20.71	20.90	21.10	21.29	21.48
Voltage at P_{max}	V_{mpp}	V	41.40	41.55	41.70	41.85	42.00	42.15
Current at P_{max}	I_{mpp}	A	12.81	12.88	12.95	13.03	13.10	13.17
Open-circuit voltage	V_{oc}	V	49.22	49.37	49.52	49.67	49.82	49.97
Short-circuit current	I_{sc}	A	13.69	13.76	13.83	13.90	13.97	14.04

*STC: 1000 W m⁻² irradiance, 25°C cell temperature, AM 1.5 spectrum according to EN 60904-3.
Measurement tolerance of P_{max}, V_{oc} and I_{sc} is ±3%

Electrical parameters at Nominal Operating Cell Temperature (NOCT*)

Power output	P_{max}	W	394.32	398.04	401.76	405.48	409.20	412.92
Voltage at P_{max}	V_{mpp}	V	38.48	38.63	38.78	38.90	39.05	39.19
Current at P_{max}	I_{mpp}	A	10.25	10.30	10.36	10.42	10.48	10.54
Open-circuit voltage	V_{oc}	V	46.10	46.24	46.38	46.52	46.66	46.80
Short-circuit current	I_{sc}	A	11.06	11.12	11.17	11.23	11.29	11.34

*NOCT: open-circuit module operation temperature at 800 W m⁻² irradiance, 20°C ambient temperature, 1 m s⁻¹ wind speed.

THERMAL CHARACTERISTICS

Nominal operating cell temperature	NOCT	°C	45 ± 2
Temperature coefficient of P_{max}	γ	%/°C	- 0.35
Temperature coefficient of V_{oc}	β	%/°C	- 0.27
Temperature coefficient of I_{sc}	α	%/°C	0.05

OPERATING CONDITIONS

Max. system voltage	1500 V_{DC}
Max. series fuse rating*	25 A
Operating temperature range	- 40°C to 85°C
Max. static load, front (e.g., snow)	5400 Pa
Max. static load, back (e.g., wind)	2400 Pa
Max. hailstone impact (diameter / velocity)	25 mm / 23 m s⁻¹

*DO NOT CONNECT FUSE IN COMBINER BOX WITH TWO OR MORE STRINGS IN PARALLEL CONNECTION.

CONSTRUCTION MATERIALS

Cell (material / quantity)	p-type monocrystalline silicon / 6 x 24
Glass (material / thickness)	low-iron tempered glass / 3.2 mm
Plug Connector	Staubli EVO2 or YITONG YT18-01 or RENHE RHC2
Junction box (type / protection degree)	3 bypass diodes / ≥ IP67
Cable (length / cross-sectional area)	1400mm / 4 mm²

GENERAL CHARACTERISTICS

Dimensions (L / W / H)	2278 mm / 1134 mm / 30 mm
Weight	28.0 kg
Fire Resistance Rating	Class C

PACKAGING SPECIFICATIONS

Number of modules per pallet	36
Number of pallets per 40' container	20
Packaging box dimensions (L / W / H)	2300 mm / 1110 mm / 1245 mm
Box weight	1063 kg

Warning: Read the Installation and User Manual in its entirety before handling, installing and operating Yingli Solar modules.

Proudly manufactured in China.

• Due to continuous innovation, research and product improvement, the specifications in this product information sheet are subject to change without prior notice. The specifications may deviate slightly and are not guaranteed.
• The data do not refer to a single module and they are not part of the offer, they only serve for comparison to different module types.

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YLD_DS_YLM-J 3.0 PRO_144GB555_EN_V02

Figure 2.9 Datasheet of YLM-J 3.0 PRO 530-555 W [10]

In a PV system, the inverter is a vital component that converts the DC produced by solar panels into AC which can be used by the electrical grid or by local off-grid electrical systems. Figure 2.10 shows the block diagram of solar panel inverter. It ensures that the PV modules operate at their maximum power point at all times, monitors the energy yield of the entire PV system, and alerts the user to any issues. The inverter also monitors the power grid to which it is connected and, for safety reasons, disconnects the PV system from the grid if a problem is detected. In PV systems, there are various types of inverters, including string inverters, microinverters, power optimizers, and central inverters. The most prevalent type of inverter used in PV systems, string inverters connect multiple panels to a single inverter. Figure 2.11 shows a string inverter manufactured by SMA, with AC power output of 700W. Microinverters are smaller inverters that are installed on each panel. They are renowned for their simplicity in system design, lower amperage wires, streamlined stock management, and increased safety. Figure 2.12 shows a microinverter which is manufactured by Enphase. Large-scale PV systems utilise central inverters, which are designed to manage a large number of panels. In off-grid systems, where the inverter draws its DC energy from batteries charged by photovoltaic arrays, standalone inverters are utilised.

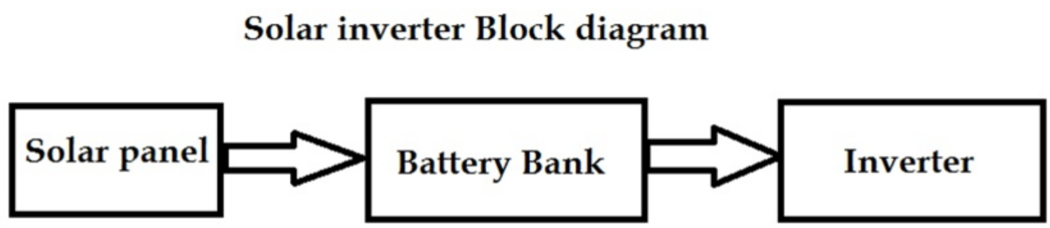


Figure 2.10 Block diagram of Solar Panel Inverter [11]

Figure 2.11 SMA Sunny Boy 700-US 700 String Inverter [12]

Figure 2.12 Enphase IQ7 Microinverter (MC4) Microinverter [13]

Wiring is an essential component of PV design. The wiring for solar panels must be rated for outdoor use and able to handle the system's amperage. There are three types of wiring configurations for PV modules: series, parallel, and series-parallel. In solar panel wiring, the "solar panel string" is the most fundamental and important concept. Several PV modules are connected in series or parallel. Solar panels feature positive and negative terminals for series connection. In Figure 2.13, it is demonstrated how to wire solar panels in series by connecting the positive terminal of one module to the negative terminal of the next. This type of wiring increases the output voltage, which is measurable at the terminals. When solar panels are wired in parallel, the output current increases while the voltage remains constant. The output current is equal to the sum of all currents generated by the string's modules. Series-Parallel Connection refers to a type of solar panel wiring that combines series and parallel connections as depicted in Figure 2.14. This connection wires solar panels in parallel and series by connecting positive to negative terminals to increase voltage. All parallel-connected solar panel strings must have the same voltage. In order for modules to provide optimal system performance, they must all be of the identical model.

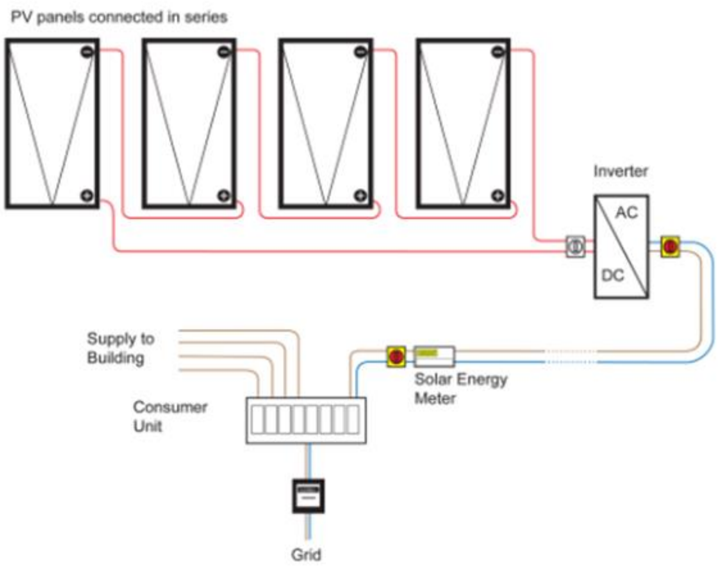


Figure 2.13 PV panels connected in series for grid-tied installation [14]

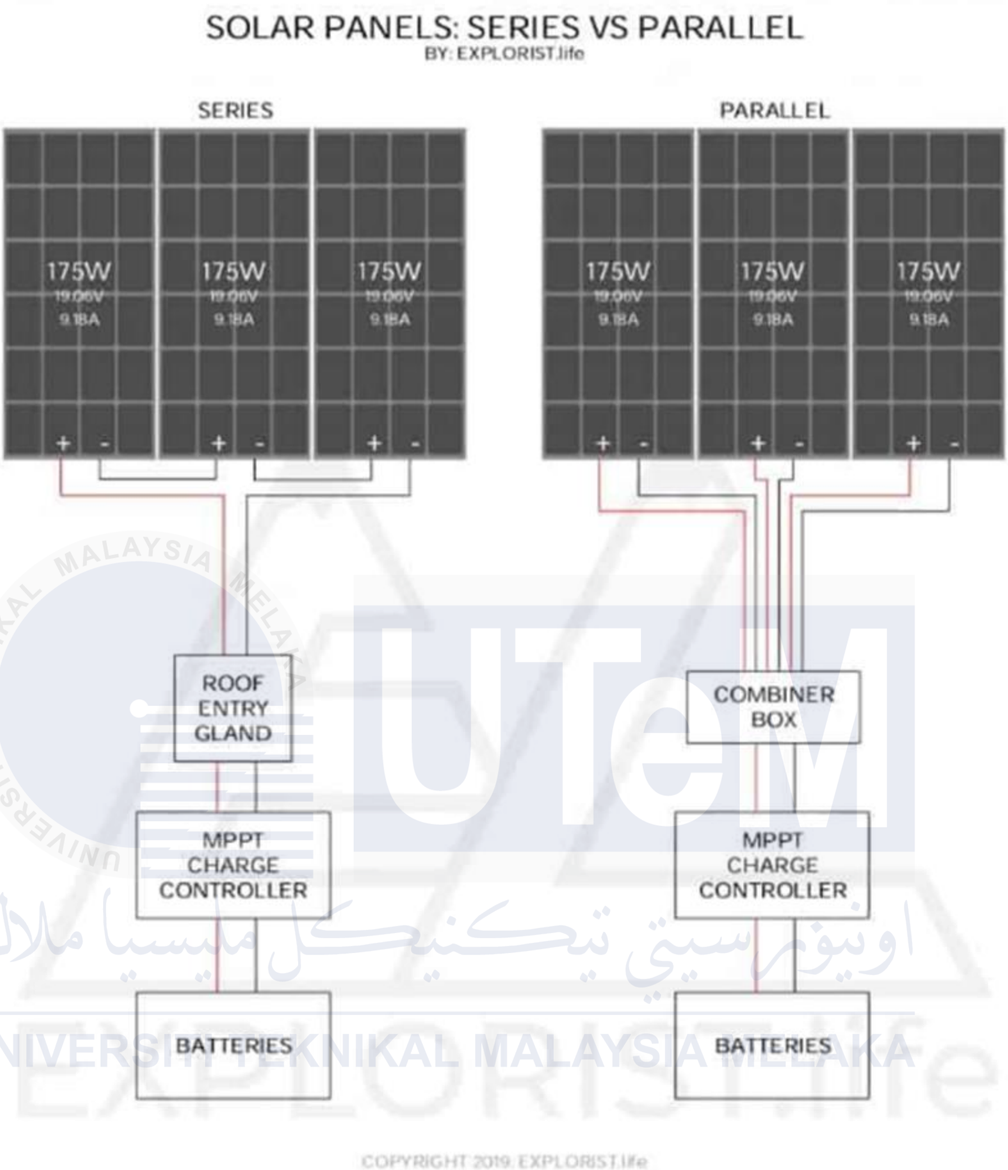


Figure 2.14 Series and parallel solar panel wiring [15]

Mounting is an integral part of the design of PV systems. PV arrays must be mounted on a stable, long-lasting structure that can withstand decades of wind, rain, hail, and corrosion. For PV systems, a variety of mounting structures are available. Building applied photovoltaics (BAPV), ground-mounted racks, pole-mounted racks, building integrated photovoltaics (BIPV), and tracking systems are the five basic types of mounting structures. Mounting surfaces for PV components must be adequate and sturdy. The most common type of mounting structure, building applied photovoltaics (BAPV) are installed with a few inches of space and parallel to the roof surface. Building applied photovoltaics (BAPV) are typically large, utility-scale PV power stations held in place by ground-based mounting supports and racks or frames. When space is limited, pole-mounted racks with panels mounted on a single pole are used. Building integrated photovoltaic (BIPV) systems are directly integrated into building materials such as roofing, windows, and facades. Tracking systems are utilised to track the sun's movement and optimise energy production by adjusting the angle of the PV array. Figure 2.15 shows the comparison of BIPV and BAPV.

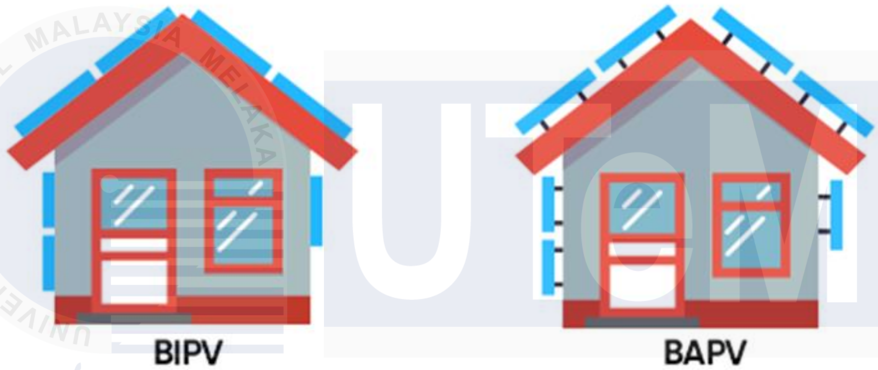


Figure 2.15 Classification of BIPV and BAPV [16]

Cabling is a crucial component of PV design. Solar cables are designed to transfer DC solar energy across a PV system and are used to connect solar panels and PV arrays in a solar power grid. In addition, they come with the appropriate connectors and are pre-installed in the panels. Generally, a PV system employs three types of solar cables: DC solar cables, Solar DC main cables, and solar AC connection cables. Solar main DC cable is typically preferred by experts for outdoor installation. Typical sizes include 2mm^2, 4mm^2, and 6mm^2 In order to complete a solar power project, various types of cables are required. Figure 2.16 shows a DC 6mm^2 cable for solar panel systems. DC cable connects PV panels and inverters, including junction boxes, whilst the inverter and substations are linked via AC cable. To avoid grounding and short circuit issues, lay cables with opposite polarities apart from one another.

Figure 2.16 DC 6mm^2 Solar Photovoltaic Cable for Solar Panel Systems [17]

A battery bank is an essential component of a solar PV system that stores excess energy generated during the day for use at night or on cloudy days. Lead-acid batteries are the most prevalent battery type utilised in PV systems. Table 2.2 shows the comparison of battery bank available in the market. During power outages, battery storage can also be used as a backup power source. To choose the appropriate battery bank for a solar PV system, it is required to determine the system's watt-hour consumption. Additionally, it is essential to purchase high-quality batteries to maintain the chain's integrity and reduce the risk of system performance degradation.

Table 2.2 Comparison of battery bank [18]

Battery Type	Capacity & Power	Life	Maintenance	Cost	Safety
Lead-Acid	Small	Short	Requires frequent maintenance	The cheapest	Can emit harmful gases if not handled correctly
Lithium-Ion	Largest	Longest	Little/no maintenance	The most expensive	Low chance of fire
Saltwater	Large	Long	Little/no maintenance	In between Lead-Acid and Lithium-Ion	No major concerns

2.2.4 Web-based PV Design Software and Applications

In the context of designing PV systems, various software applications and tools play a crucial role in optimising system performance, cost, and efficiency. These applications allow researchers and engineers to model, simulate, and analyse various PV system aspects. There are applications for the design, modeling, and simulation of PV systems, such as PVsyst, SAM, Helioscope, and Solar Labs.

PVsyst is a software package used for the investigation, sizing, and data analysis of PV systems in their entirety. As shown in Figure 2.17, PVsyst enables users to model system components, evaluate system performance, and optimise designs based on a variety of parameters. PVsyst is widely employed in solar design and simulation and is regarded as one of the most well-known and comprehensive solar design tools. It is used by engineers worldwide and is the standard for utility-scale and large-scale solar power plants. PVsyst is also utilised for optimal solar power plant design and performance analysis of existing systems.

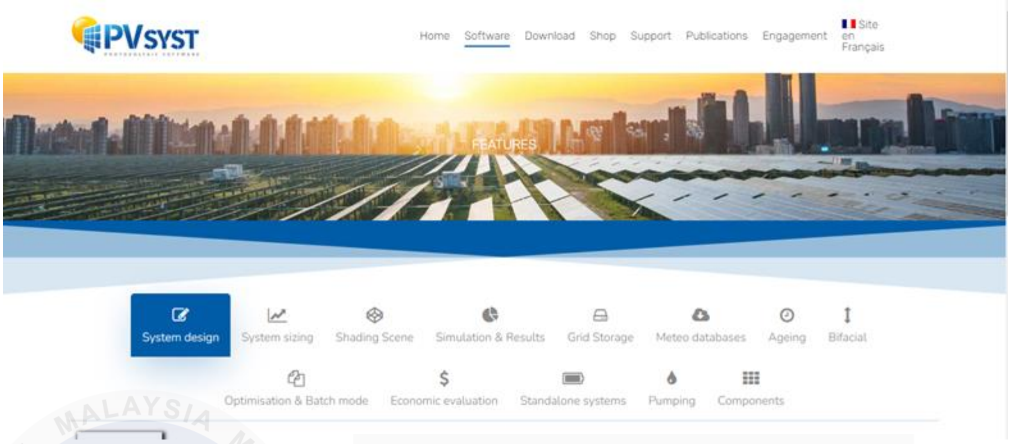


Figure 2.17 PVSyst Software Features Page [19]

SAM is a performance and financial model designed to estimate the cost of energy for grid-connected power projects based on technical and financial inputs. SAM was initially developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories under the name "Solar Advisor Model". SAM is a tool that assists decision-makers in analysing the cost, performance, and financing of any size grid-connected energy project. SAM can be downloaded for free from the NREL website and is widely utilised in the renewable energy industry. Figure 2.18 displays the page of SAM Photovoltaic section.

Figure 2.18 SAM Photovoltaic section [20]

HelioScope is a platform for solar design software created by Folsom Labs. Figure 2.19 shows the homepage of HelioScope. In the solar industry, it is used to design and sell high-performance solar arrays. HelioScope optimises designs and can rapidly run multiple iterations of a project's design, thereby reducing design time by a factor of ten. The design-integrated approach of HelioScope models an array based on its physical design. The software is accessible via a web application, and solar professionals use it to design and analyse solar projects. It is an all-inclusive instrument that includes 3D modelling, shading analysis, and financial analysis. HelioScope is widely employed in the solar industry and is regarded as one of the most prominent solar design software platforms.

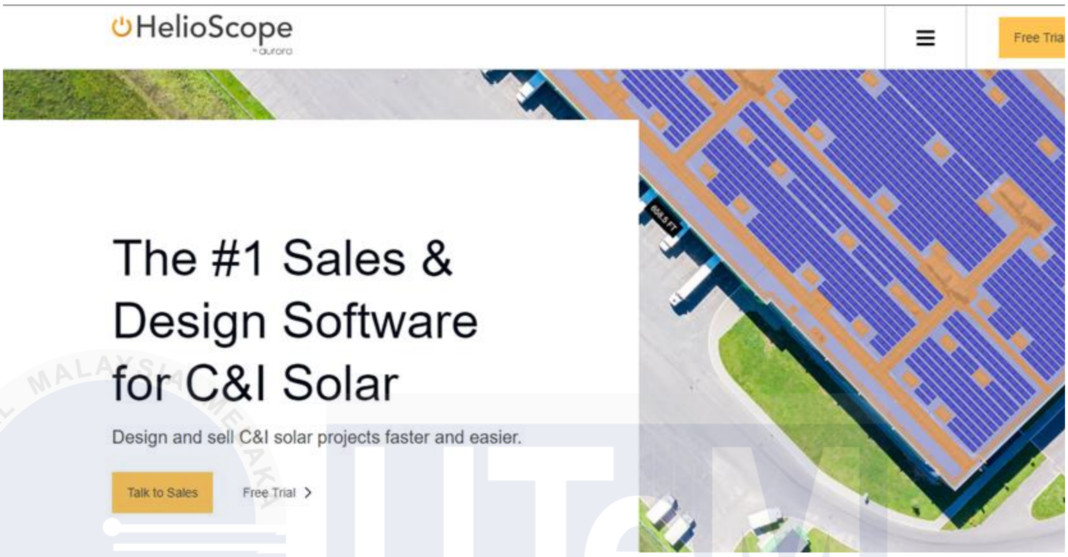


Figure 2.19 HelioScope Homepage [21]

Solar Labs Design Studio is a cloud-based solar design and sales growth application. The company specialises in generating preliminary sales estimates and optimising system designs for solar installers and government agencies. Solar Labs was founded in 2017 with headquarters in New Delhi. It is an easy-to-use tool for optimising the design of PV systems. The software from Solar Labs enables users to simulate both the installation and operation of a future solar system. This expedites and simplifies the sales and engineering processes. Solar Labs is offered as Software as a Service (SaaS) and is accessible via any modern web browser on desktop computers, laptops, and even mobile devices. Figure 2.20 shows the website of Solar Labs.

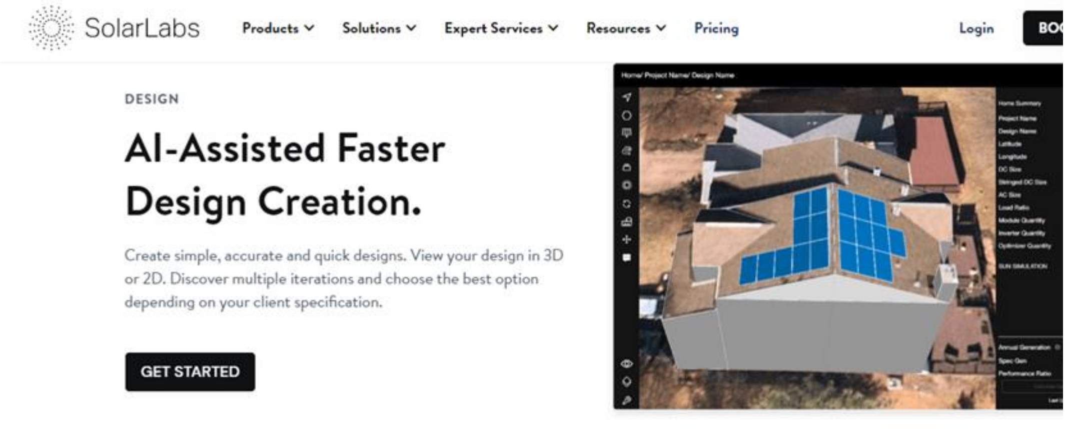
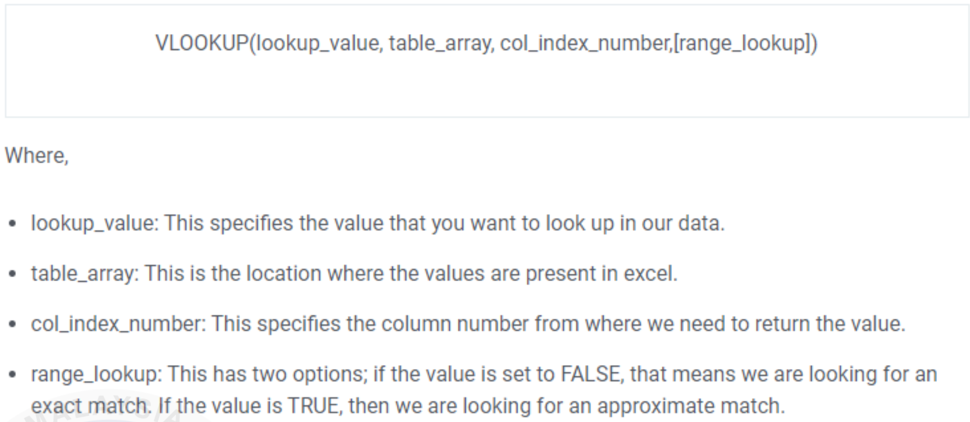


Figure 2.20 Solar Labs Website [22]

2.2.5 Microsoft Excel

Microsoft Excel is a powerful tool widely employed for data analysis, financial modelling, and project management. VLOOKUP and HLOOKUP are among the functions used in Microsoft Excel. Figure 2.21 depicts a simple VLOOKUP function used find a value in spreadsheet. Excel's ability to automate repetitive tasks using Visual Basic for Applications (VBA) is one of its most useful features. VBA is a programming language that enables Excel macro customization and task automation. Excel contains numerous examples of VBA code that can be used to automate tasks. Figure 2.22 shows the basic example of VBA code. Creating a macro to clear the contents of a range of cells, adding serial numbers to a list, and formatting cells according to specific criteria are a few examples. A user-defined function is created to perform a specific calculation, a custom dialogue box to prompt the user for input, and a pivot table from a data set are additional examples. Excel VBA code examples are available from a variety of online resources, including FreeCodeCamp, Automate Excel, The Spreadsheet Guru, Excel Off The Grid, and Excel Champs. These resources provide a variety of VBA code examples, ranging from elementary to advanced, that can be used to automate tasks and increase Excel productivity.



VLOOKUP(lookup_value, table_array, col_index_number,[range_lookup])

Where,

- lookup_value: This specifies the value that you want to look up in our data.
- table_array: This is the location where the values are present in excel.
- col_index_number: This specifies the column number from where we need to return the value.
- range_lookup: This has two options; if the value is set to FALSE, that means we are looking for an exact match. If the value is TRUE, then we are looking for an approximate match.

Figure 2.21 VLOOKUP Function with the help of a simple syntax [23]

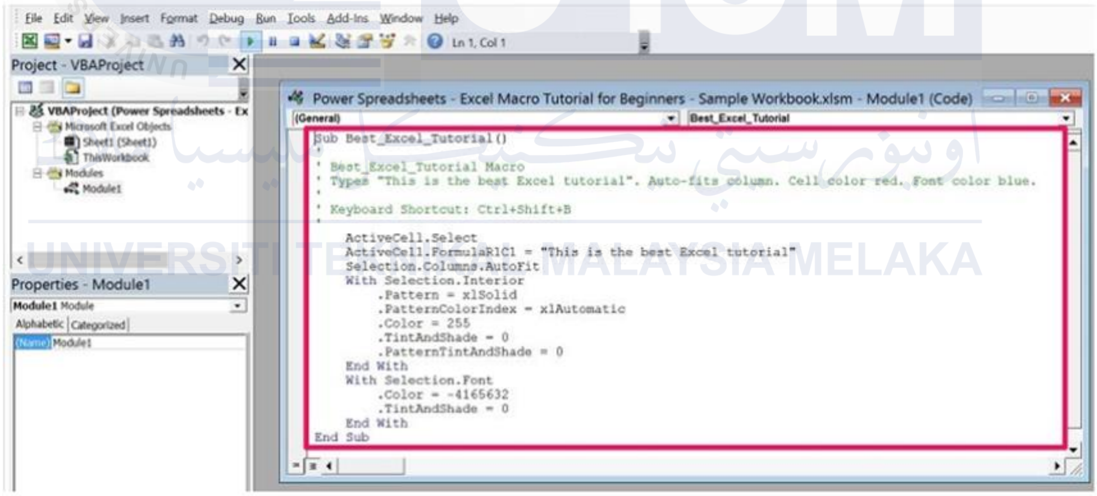


Figure 2.22 Basic example of VBA code [24]

2.3 Previous Works by Others

In this section, this paper will explore the vast amount of knowledge contributed by earlier works by other researchers in the field. These studies provide crucial insights, methodologies, and findings that will shape the current understanding of the topic and serve as the basis for this paper. By analysing these prior contributions, this paper hopes to contextualise the research within the broader academic landscape and to identify potential research gaps or unexplored areas.

2.3.1 Pre-installation Design Simulation Tool for Grid-connected Photovoltaic System Using Iterative Method

Photovoltaic (PV) technology is one of the most promising technologies and if properly utilized, it able to fulfil world demand. [25] There are two main applications for PV system, which are grid-connected PV system and stand-alone PV system (SAPV). GCPV system integrate PV technology with main grid, while SAPV is an off-grid system. GCPV system is a modularity system that uses PV modules to generate DC power and inverters to convert DC to AC power output. One of the most important issues in the implementation of GCPV is accurate system sizing, as improper sizing can lead to either over sizing or under sizing the system and later give significant impact to the investment. An accurate pre-sizing tool for PV system installation is vital for PV system component manufacturers, research and development teams, systems integrators, and end customers. Simulation tools are one of the most common methods to understand PV generation potential at a given location within expected operation constraint. There are seven main categories of computer simulation tools available in the current market, such as performance simulation tools, economic evaluation tools, photovoltaic industry related tools, analysis and planning tools, monitor and control tools, site analysis tools and solar radiation maps.

This previous work presents a user-friendly simulation tool named Pre-Installation Design for GCPV (PIDGCPV) which was developed to assist energy consumers or PV installer in preliminary evaluation on PV system sizing to determine the optimum configuration of GCPV system. It uses an iterative method embedded in Macro Excel integrated with Microsoft Visual Basic application. The simulation tool covers three constraints, which are space, energy requirement and budget. A database for PV modules, inverters, and meteorological data for each state in Malaysia is also embedded in the software.

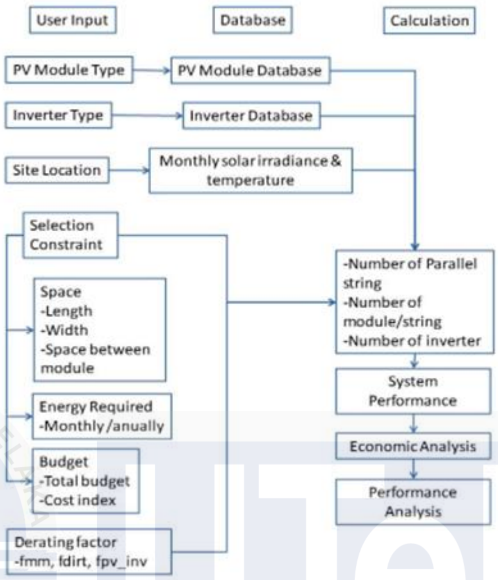


Figure 2.23 Block diagram of simulation steps. [25]

The analysis shows that the capability of the developed simulation tool is giving higher accuracy and can be used as pre installation design tool. The software is suitable for pre-installation design and will be an optimization tool for a pre-selected PV module type, inverter type, and pre-defined constraint by the user. The analysis gives straightforward comparison between the simulated result and the actual installed data based on the constraint selection, and also provides economic and performance analysis for the system installed. The databases are also equipped with technical data needed during sizing calculation.

This section presents an overview of GCPV system sizing, economic analysis and performance analysis simulation methods. It consists of three main parts: user input, database section, and calculation section. The user, energy installer or consumer has to select the types of PV module, inverter, site location and system constraint based on selection menu generated from database embedded in the simulation tool.

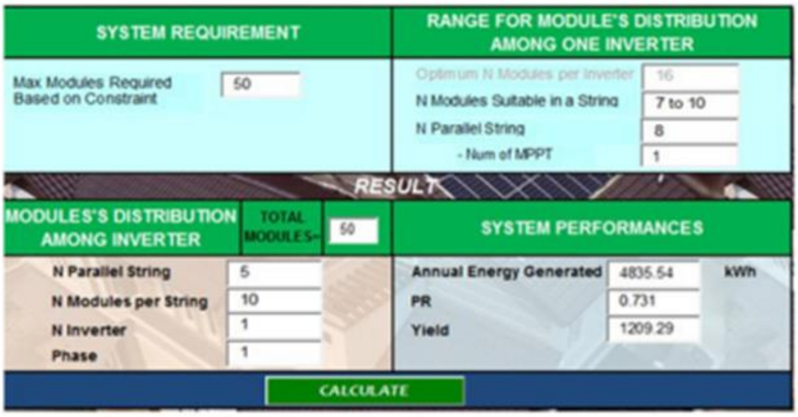


Figure 2.24 PIDGCPV analysis results based on selected constrain. [25]

2.3.2 Tlahuilli-ce: a novel solar energy program for the design of photovoltaic systems

This previous work presents Tlahuilli- ce, a novel software programme for the design of photovoltaic systems (Tlahuilli=Light, ce=1 in Nahuatl). It facilitates access to well-known algorithms for Photovoltaic System Design while providing sufficient detail for the feasibility and design dimensioning stages. It is a Microsoft Excel and Microsoft Visual Basic application that allows non-experts in the solar energy industry to create effective designs. This previous work focuses on Solar Energy systems, and the most important details in this text are the active systems, such as Water Thermal Heating (WTH) and Photovoltaic (PV) systems, which require pumps to circulate water heated by a flat solar collector for storage in a tank and distribution, or a Solar Cell Array Panel that converts sunlight to electricity via the action of a solar semiconductor junction.

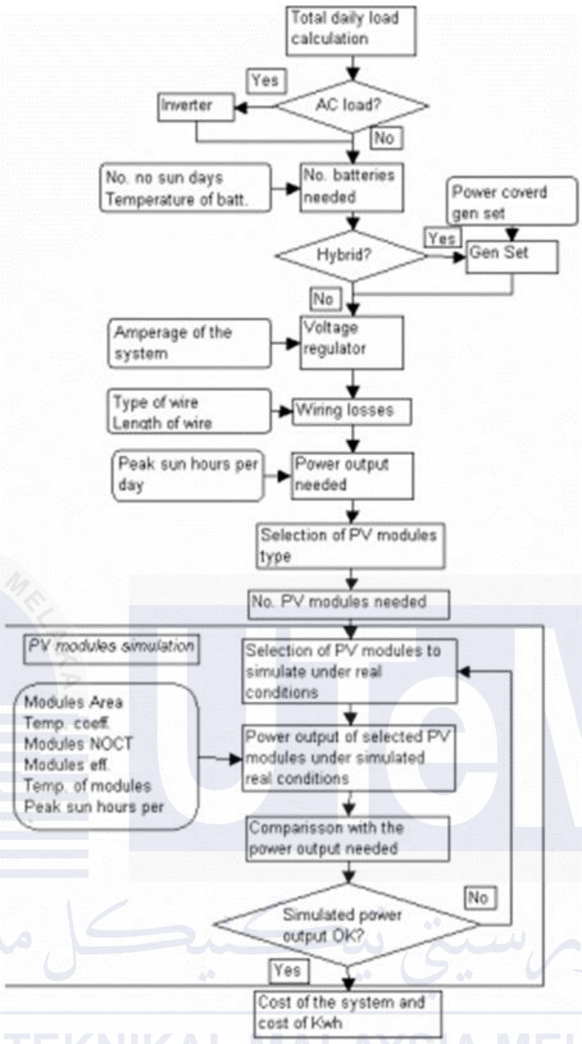


Figure 2.25 Flowchart of Tlahuilli-ce. [26]

Tlahuilli-ce's discussion and management of the types of PV systems discussed in this paper are the most important details which include the stand-alone system (SA), the utility-interactive system (UI), and the water pumping system (WP). The SA system can be hybrid if it has a genset (power generator) as a backup source, or it can be autonomous if it relies solely on the output of the PV array. The UI system interacts with the power grid via an inverter, and when the PV array cannot meet the energy demand, the system draws power from the utility. The WP system, which is one of the most widely used systems in the world, does not consider batteries as a storage medium.

The most crucial aspects of this paper are the characteristics of cells made of Silicon Silicon (Single Crystal, Polycrystalline, or Amorphous) and the PV Solar Array's auxiliary devices, such as batteries, regulators, and inverters. BOS (balance of system) is frequently abbreviated to BOS. In addition to other specifications such as cloudy days and peak sun hours, meteorological factors such as ambient temperature and the temperature at which certain devices are stored, as well as the average monthly meteorological conditions, are considered.

Tlahuilli-ce is a software designed to size the PV system, i.e., it provides the number of Modules selected from a Solar Cell Array Manufacturer Database, the type and number of batteries to be used, the charge controller, and the connection configuration necessary to produce the desired voltage and current specifications. Tlahuilli-ce is a solar system design programme that has been validated against other dimensioning programs, including RetScreen and WatSun. The standalone design is chosen as the base system because the PV system's components can be applied to the two other designs. The only difference lies in the calculation of load for the Water Pump design.

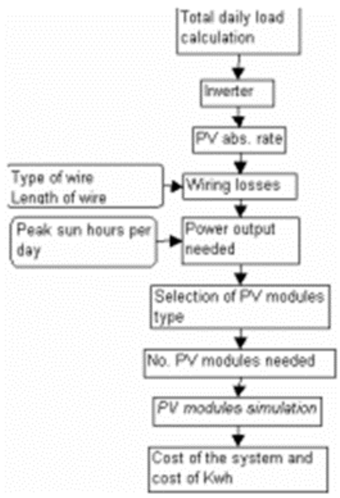


Figure 2.26 Utility interactive design flowchart. [26]

The software computes the required number of solar modules, the comparison between the PV array's simulated power and the peak power demand, as well as the prices of the PV system devices and any additional costs. The selection of an inverter must account for the losses caused by its efficiency factor. [26] The required number of modules is calculated and compared to the output of the simulated PV modules. If the simulated PV array power falls short of the load's requirements, system operation will not be affected because the grid will compensate. The software calculates the parameters of the water pump, and the user selects the pump based on the calculated values. If the water pump operates with an AC inverter, system losses are incurred. The losses of the voltage regulator are added if the pump requires a voltage regulator. As described in previous designs, the selection of PV modules and the comparison of the simulated and required powers are carried out in the same manner.

To create a simulation of a PV array, the characteristics of the chosen modules must be entered. These characteristics include nominal module efficiency, nominal operating cell temperature (NOCT), the temperature coefficient of the module, and meteorological factors such as the monthly mean temperature, the insolation clearness index, and the peak hours per day. The formulas section discusses the calculations, and the user can compare the output to the system's power demand. If the output of the module is less than what is required due to temperature losses, it may be suggested to increase the number of modules.

2.3.3 An integrated multi-objective optimization model for determining the optimal solution in implementing the rooftop photovoltaic system.

This previous study has developed an integrated multi-objective optimization (iMOO) model has been developed for determining the optimal solution in implementing the rooftop PV system hence solving the trade-off problems.. This study was conducted in six steps: establishment of database, generation of installation scenarios, energy simulation, economic and environmental assessment, establishment of iMOO process using a genetic algorithm, and systemization of the iMOO model using a Microsoft-Excel-based VBA. Two criteria were used to assess the robustness and reliability of the developed model. To determine the economic feasibility of the PV system before its implementation, the research team conducted a series of studies to analyse the complex relationships among the several objectives [27].

It used the software program ′RETScreen to establish a reference model for energy simulation using the actual electricity generation data of the target building. The impact factors of the rooftop PV system should be considered to determine the optimal solution, such as regional climates, geographical factors, monthly average daily solar radiation (MADSR), monthly meridian altitude, monthly average temperature, on-site installation factors, rooftop area limit, and budget limit. The study focused on the analysis period of a rooftop PV system, which was set to 25 years, and considered the initial construction cost, initial benefit, operation and maintenance cost, and operation and maintenance benefit. CO2 emission reduction was converted into economic value by using the profit from the sale of carbon credits.

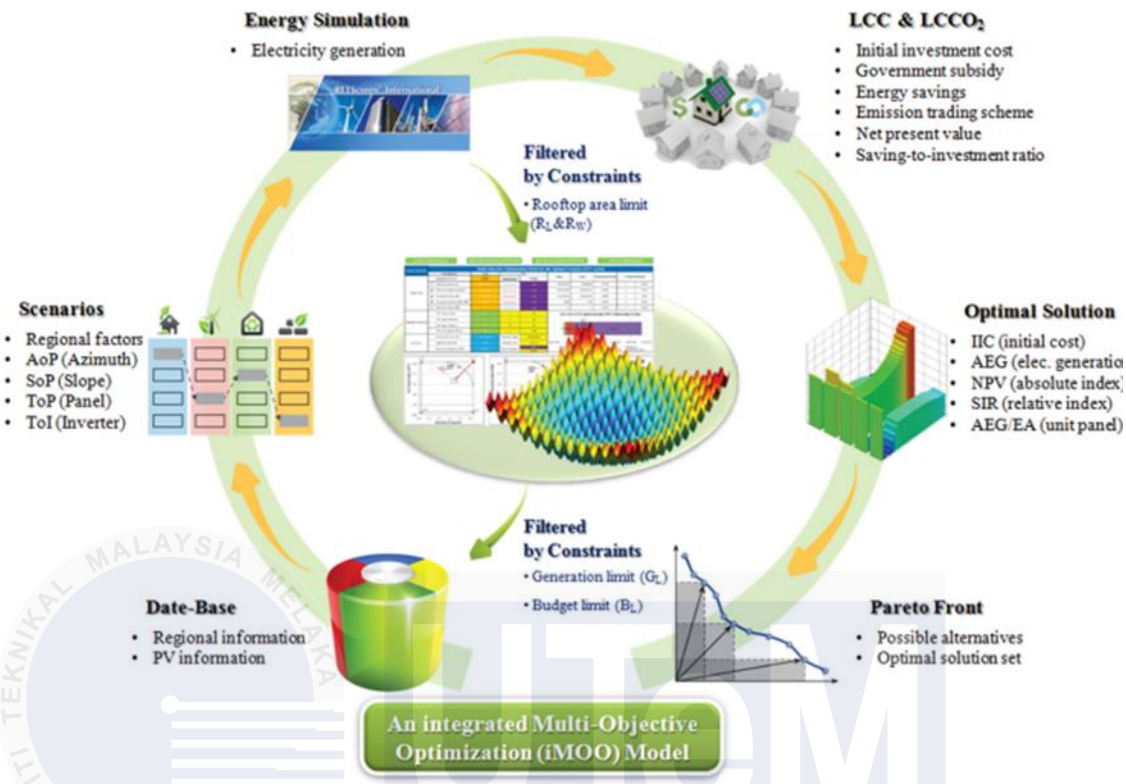


Figure 2.27 Research framework [27]

2.3.4 Developing industrial strength simulation models using Visual Basic for Applications (VBA).

This previous study has developed an advanced tutorial demonstrates the basic concepts developed by the author to transfer data between Excel and Arena using VBA. VBA can be used to communicate simulation data with a wide range of VBA supported tools, such as Access, AutoCAD, and Visio. The author has used embedded VBA code to generate the entire Arena experiment frame and animation displays for many very complex simulation models. The Debug Compile feature checks that all variables have been defined prior to execution, and many VBA errors can be interactively debugged and corrected without restarting the model.

The Simulation Workbook format has proven to be a benefit when designing the initial model structure, as all model variables, attributes, expressions, resources, queues, and stations are specified in the workbook [28]. The information read from the Simulation Workbook is reported in a text-based file, Workbook.TXT. If input data errors are detected, a special report file, Message.TXT, is generated to provide a record of how the simulation run was structured. The VBA code and associated data are independent of the internal data structures of either Arena or Excel, and the model developer must take the necessary steps to pass the required data between VBA and Arena. Arena does not control the order of its symbols unless the model developer specifically numbers each symbol.

The text-based report format was difficult to use for analysis purposes, so the Arena 4.0 database has been an initial step in eliminating this shortcoming. VBA can be used to print the average and maximum values of the fifth Arena Discrete Statistic, as well as to assure the location of a particular piece of Arena information. It is also important to incorporate error checking for smooth model execution.

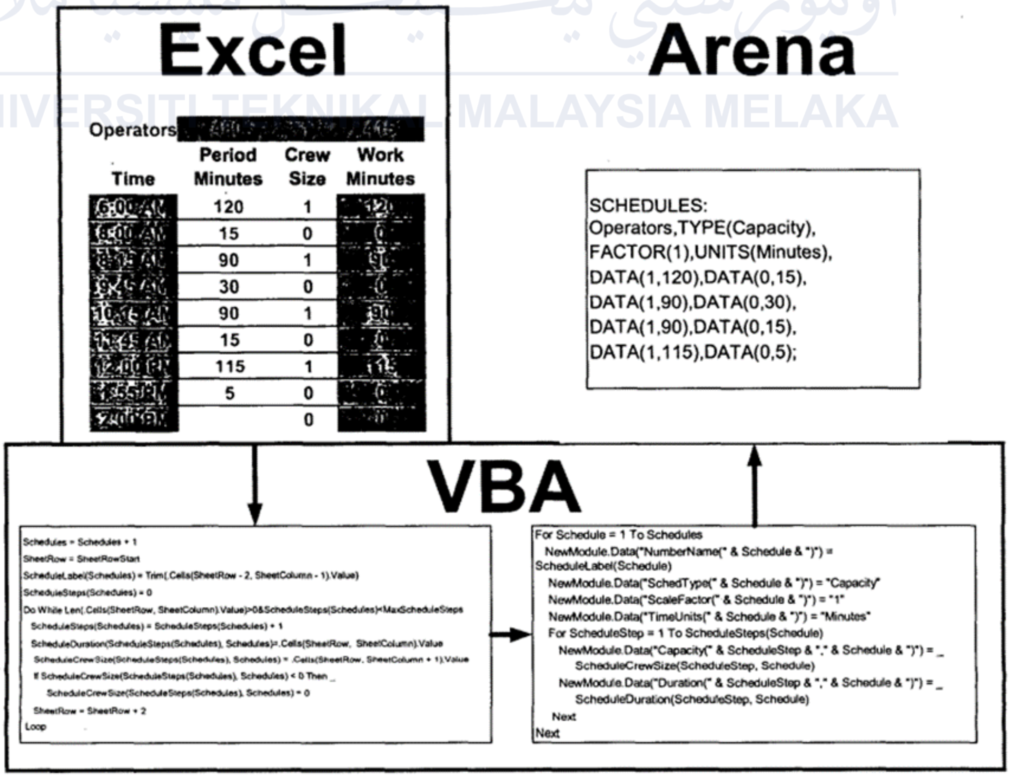


Figure 2.28 VBA Data Exchange, Excel to Arena [28]

2.3.5 Applying Excel VBA to Implement Comparison among Physical Experiment Data

This previous work has conducted research using Excel VBA to implement comparison among physical experiment data. It works out an Excel tool which has both function of one-factor analysis of variance and multiple-comparison at the same time, enabling us to compare the different groups of data. The comparison method is often used in sports teaching experiment and analysis, and the variance analysis method is convenient for testing whether there are differences between average grades. Statistical computing is often encountered in statistics, and calculation precision is one of the common faults in the statistical work [29].

Microsoft's Excel built-in data analysis has the function of single factor analysis of variance and is easy to use. Excel realization of automation is compared between sample groups and are used to input raw data and use tools in Excel to make data analysis. The most important details in this paper are the methods used to compare Excel samples between groups of various teaching methods.

Group	Observation value	sum	average	
Row 1	17	3.3	0.19412	0.0268
row 2	17	5.3	0.31177	0.0261
Row 3	17	2.7	0.15882	0.0463
Row 4	17	1.5	0.08824	0.0224

Source of difference	quadratic sum	freedom of motion	Average variance	F	critical value	F(.05)
Groups	0.445	3	0.14824	4.8755	0.00408	2.74819
Group	1.946	64	0.0304			
sum	2.391	67	p<.05 significance of difference			

Figure 2.29 Analysis of variance [29]

2.3.6 Distance-based and stochastic uncertainty analysis for multi-criteria decision analysis in Excel

These authors have developed a program in Excel and written in Visual Basic for Applications to examine the robustness of a solution obtained when using multi-criteria decision analysis (MCDA). Distance-based and stochastic uncertainty analysis approaches allow a decision to be made with confidence that the alternative chosen is the best performing alternative under the range of probable circumstances. The program is illustrated by applying it to a sustainable water resource development problem in the Northern Adelaide Plains, South Australia. This paper presents and describes a program that incorporates the ability to undertake deterministic MCDA, the distance-based uncertainty and the stochastic volatility analysis approach. The program is restricted to assessing decision problems with a maximum number of 30 alternatives and 24 criteria and supports two existing MCDA techniques: the value focused Weighted Sum Method (WSM) and the PROMETHEE outranking method. It is designed to support two proposed uncertainty analysis methods: a distance-based uncertainty analysis approach and a stochastic uncertainty analysis approach. Flexibility has been incorporated into the program, allowing individual input parameters to be varied.

The objective function minimises a distance metric, which provides a numerical value of the amount of dissimilarity between the original input parameters of the two alternatives under consideration and their optimised values [30]. This case study demonstrates how all the available information, including uncertainty, can be incorporated in the analysis concurrently, providing additional information on the robustness of the alternatives to variation in the input parameters and allowing confidence to be placed in the outcome of the analysis. This paper applies the program to a water resource allocation case study, but it can be applied to any kind of usage conflicts between natural resources and economic development.

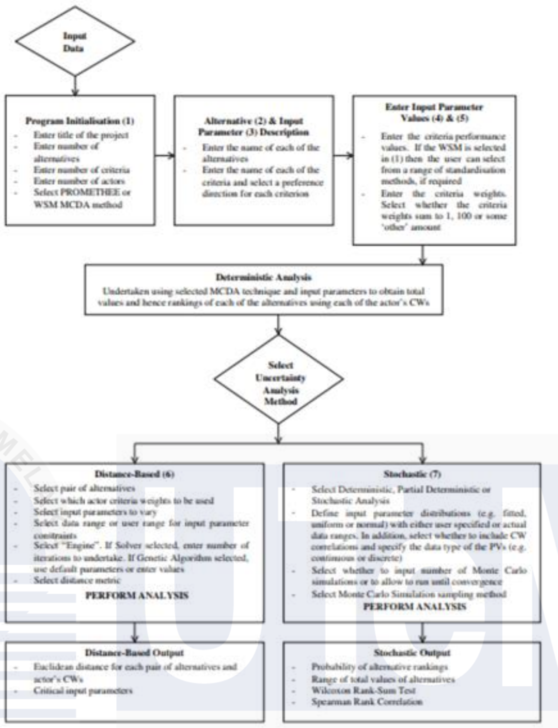


Figure 2.30 Program structure. [30]

2.3.7 Applications of Excel VBA in Data Calculation and Charts Creation of Mineral Resource Economics

This previous study discusses the applications of Excel VBA in data calculation and charts creation of Mineral Resource Economics. It is an implementation of Microsoft's event-driven programming language Visual Basic 6 and its associated integrated development environment (IDE). VBA enables building user defined functions, automating processes, accessing Windows API, and other low-level functionality through dynamic-link libraries (DLLs). Visual Basic for Applications (VBA) is a macro programming language used by resource economists to store data and perform calculations. VBA code interacts with the spreadsheet through the Excel Object Model, and user-created subroutines execute these actions and operate like macros generated using the macro recorder. VBA procedures can be developed, tested, and modified in the Excel Visual Basic Editor (VBE). VBA procedures become part of the workbook in which they are developed and when the workbook is saved. The most important details in this paper are the use of Macro Recorder and Excel VBA to calculate the annual increment of mineral resources.

Excel VBA is able to automate tasks that users normally do manually and provides batch processing functions to help users do relative things by loop programs [31]. The main parts of creating batch charts from the data of mineral resources are the use of the For-Next loop to create charts and select their chart types.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
2	Coal(Gt)	0.00%	-0.52%	-1.43%	0.00%	-1.97%	0.00%	-1.14%	-0.48%	-0.61%	-0.27%	-0.69%	6.31%	-0.52%	-0.79%	-3.17%
3	Iron ore(Gt)	0.00%	-0.76%	-2.29%	0.00%	-1.25%	-0.47%	-0.79%	-0.96%	-0.65%	-0.81%	-0.99%	10.78%	0.00%	-1.35%	-0.61%
4	Magnitite(10 Kt)	0.00%	-0.94%	-1.96%	-0.34%	-0.60%	-0.89%	-4.40%	-8.83%	-0.33%	-0.08%	-0.34%	27.84%	-1.51%	0.08%	-2.09%
5	Phosphorite(10 Kt)	0.00%	-0.01%	-14.80%	0.00%	-0.01%	0.00%	0.00%	-0.08%	-0.11%	-0.12%	-0.16%	43.77%	-0.03%	-0.09%	-0.11%
6	Potassium shale(Kt)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
7	Magnesite(10 Kt)	0.00%	-0.41%	-0.28%	-0.42%	-0.49%	-0.77%	0.00%	0.00%	-0.02%	-0.18%	-0.35%	131.45%	-0.17%	-0.16%	-4.60%
8	Oulopholite(10 Kt)	0.00%	0.00%	0.00%	0.00%	-0.06%	-0.12%	-0.11%	-0.15%	-0.19%	-0.40%	-0.23%	-0.24%	-0.32%	-2.49%	-0.52%
9	Bentonite(Kt)	0.00%	-0.03%	0.00%	-1.70%	-0.07%	-0.90%	-1.60%	-0.40%	-0.18%	-0.21%	-0.27%	4.77%	-0.19%	-0.37%	-0.31%
10	Zeolite(10 Kt)	0.00%	-0.10%	-0.07%	-0.25%	-0.12%	-0.31%	-0.07%	-0.01%	-0.02%	-0.03%	-0.02%	357.36%	0.00%	0.00%	-1.26%
11	Copper(t)	0.00%	-3.45%	-2.91%	-3.24%	-1.97%	-0.70%	-0.51%	-2.36%	12.97%	3.18%	-2.05%	-0.50%	-1.98%	-1.86%	-0.70%
12	Lead(t)	0.00%	20.34%	-0.05%	42.79%	-2.12%	0.38%	-0.46%	-1.10%	4.53%	6.69%	8.82%	-9.70%	2.53%	7.79%	5.02%
13	Zinc(t)	0.00%	1.45%	-0.01%	4.34%	2.84%	2.10%	-0.06%	-0.48%	3.49%	3.06%	0.10%	-0.57%	-0.34%	1.77%	2.43%
14	Limestone(10 Kt)	0.00%	3.00%	5.23%	-4.55%	6.14%	1.32%	-0.24%	6.06%	5.41%	3.41%	6.28%	-5.14%	3.30%	20.13%	0.28%
15	Gold(Kg)	0.00%	-5.29%	87.63%	13.26%	12.80%	-18.75%	-9.82%	-1.01%	15.57%	5.99%	12.55%	-20.90%	-4.87%	-14.14%	-6.61%
16	Glass sandstone(10 Kt)	0.00%	-0.57%	-0.53%	-0.51%	-0.60%	-1.69%	-0.78%	-0.59%	0.51%	19.60%	17.47%	6.73%	-0.44%	1.37%	-1.22%
17	Kaolin (Kt)	0.00%	0.00%	99.68%	0.00%	-5.98%	0.00%	-0.42%	-0.21%	0.00%	-0.64%	-0.21%	-0.56%	0.00%	-0.56%	0.00%

Figure 2.31 Result of calculation for annual increment of mineral resources [31]

2.3.8 Applications of Excel VBA in Data Processing of Magnetic Survey

This previous study discusses the applications of Excel VBA in data processing of Magnetic Survey where Visual Basic for Application (VBA) is an event-driven programming language implemented by Microsoft's Visual Basic 6 and its associated integrated development environment (IDE). VBA enables building user defined functions, automating processes and accessing Windows API (Application Programming Interface) and other low-level functions through dynamic-link libraries (DLLs) [32]. It supersedes and expands on the abilities of earlier application-specific macro programming languages such as Word's WordBasic.

VBA procedures are used to map geologic structure, geology and mineralization in grassroots mineral exploration. To assemble the filed measuring data, magnetometers and portable GPS receivers should be assembled and stored into workbooks of Excel files. Geophysicists often find magnetic anomalies and use them to determine geologic structures and locations of iron mines.

Ordinary Kriging method is a widely used method of interpolation for calculating these missed data. Magnetic anomalies can be analysed by relatively bigger difference in magnetic data of adjacent measuring points, and using VBA in Excel to highlight display the impossible magnetic anomalies is helpful for geophysicists to find mines. To find the missing points and insert their information of line numbers and point numbers in Excel files, green background color is used to highlight them. The most important details in this are the color index, variable "Ptemp" and variable "PNumber" used to record the point numbers of two adjacent measuring points, and the method used to calculate the information of missing points. Magnetic measuring data is often transferred to computers in the form of text files and Excel files, and Geophysicists can use Visual Basic for Applications (VBA) programs in Excel files to highlight anomalous measuring points.

2.3.9 Methodology of Laboratory Workshops on Computer Modeling with Programming in Microsoft Excel Visual Basic for Applications

This previous study discusses the methodology of Laboratory Workshops on Computer Modeling with Programming in Microsoft Excel Visual Basic for Applications (VBA). It presents the main stages and consequences for numerical simulation of classic math models in ecology via MS VBA Excel (for continual and discrete systems). The methodical of printout of results of numerical simulation and automation of Excel charts creation are also presented. It explains the advantages of MS Excel VBA over other systems such as MATLAB, Maple and Mathematica for students in the laboratory works on CM. These advantages include the programming language being suitable to modern software, the syntactical structure and some main elements of VBA being equal to similar properties of such software as Pascal, the software having a natural connection with OS Windows and MS Office Applications, and the software having applications not only for economic-oriented usage in university education, but also in some advanced universities of the USA. It is also known that most MS Office users are uninformed about VBA programming, and that Excel VBA is taught in engineering specialties as high-tech-oriented programming.

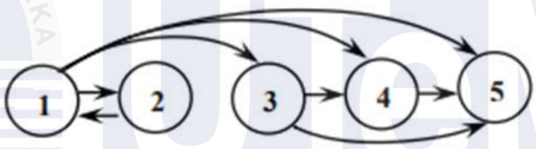


Figure 2.32 Graph of Stages of VBA Excel Programming in computer modelling. [33]

Excel VBA programming is a powerful tool for solving difficult scientific, technical, or economic problems [33]. It can be used to transfer results of simulation (calculations and diagrams) to other Office programs with high productivity. The four stages of VBA Excel programming in computer modeling are results of computations, automated Excel charts building due to stage 3, preparing scientific reports based on 3-rd and 4-th stages in Office applications, and using MS VBA Excel to simulate CM problems described as ordinary differential equations (ODEs). This article describes the implementation of a numerical simulation in Excel VBA with important stages, such as inserting numerical values of the simulated problem to range cells in Excel worksheet, ensuring that the VBA program is working properly, adding fragment of VBA code lines to program order, organizing output of computed results to defined range cells, printing of results of computation, and creating standalone Excel charts according to numerical values obtained in the stage 4-th (stage of diagrams building). The restrictions of the computer simulation apply, and the technic of programming via MS VBA Excel facilitates conditions of computer simulation and contributes to organizing of very easy and convenient output for the obtained results of computations.

```
Set curcell=Worksheets("Out").Cells(r, 1)
           curcell.Value=t
Set curcell Worksheets("Out").Cells(r, 2)
           curcell.Value=y(1, r)
Set curcell=Worksheets("Out").Cells(r, 3)
           curcell.Value=y(2, r)
```

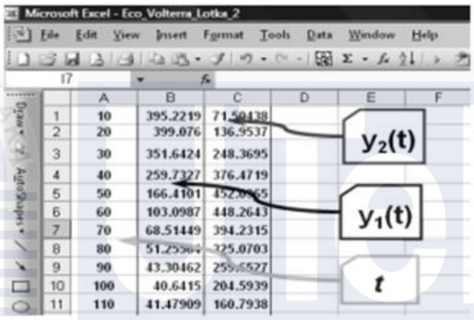


Figure 2.33 Printout results of numerical simulation in defined Excel worksheet in preliminary defined cells range. [33]

2.3.10 Product metrics for spreadsheets—A systematic review

This previous work reviews five major digital libraries for scientific papers that define or use spreadsheet product metrics and creates a novel catalogue of product metrics. It outlines the basic terminology behind spreadsheets, defines research questions, and provides details about the systematic literature review process. The metric is a function that maps software (or spreadsheet) data to a numerical value. Errors in spreadsheet calculations can have tremendous effects, and there is a strong need for applying quality assurance methods, techniques, and tools during the development of spreadsheets [34]. The use of product metrics has been advocated for the spreadsheet domain for several years, but the metrics proposed in the literature sometimes suffer from several shortcomings. This paper aims to aggregate and synthesize the existing knowledge about product metrics for spreadsheets through a systematic literature review.

The research questions and research method used to search for spreadsheet metric related publications were as follows: which spreadsheet product metrics are defined and used in the literature and for which purposes? Are the definitions of the metrics used consistent? How do researchers evaluate their metrics?

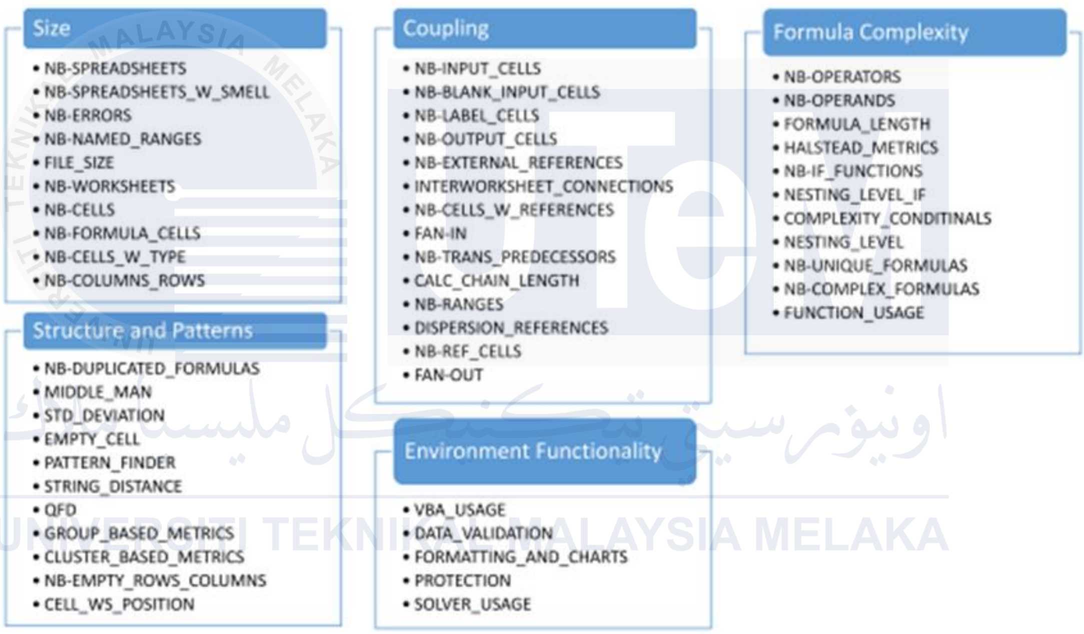


Figure 2.34 Overview of 57 metrics organized in five categories. [34]

	A	B	C	D	E	F
1	Coffee Consumption: Department 1					
2		Employee				
3	Quarter	Anderson	Bourne	Connor	Dredd	Total
4	1	35	1745	80	98	=SUM(B4:E4)
5	2	47	21	51	66	=SUM(B5:E5)
6	3	46	12	46	39	=SUM(B6:E6)
7	4	74	15	57	43	=SUM(B7:E7)
8	Total	=SUM(B4:B7)	=SUM(C4:C7)	=SUM(D4:D7)	=SUM(E4:E7)	=SUM(F4:F7)

(a) Department1

	A	B	C	D	E
2		Department			
3	Quarter	Departement 1	Department 2	Depratment 3	Total
4	1	=Department1!F4	=Department2!F4	=Department3!F4	=SUM(B4:D4)
5	2	=Department1!F5	=Department2!F5	=Department3!F5	=SUM(B5:D5)
6	3	=Department1!F6	=Department2!F6	=Department3!F6	=SUM(B6:D6)
7	4	=Department1!F7	=Department2!F7	=Department3!F7	=SUM(B7:D7)
8	Total	=Department1!F8	=Department2!F8	=Department3!F8	=SUM(B8:D8)

(b) Total

	A	B	C	D	E
1	Investment Options				
2	Input				
3	Coffee / year	=Total!E8			
4	Service years	3			
5	Coffee total	=B3*B4			
6					
7	Comparison				
8	Type	Investment	Coffee price	Yearly service	Total
9	Capsule	100	0,3	100	=B9+C9*B5+D9*B4
10	Drip	250	0,15	100	=B10+C10*B5+D10*B4
11	Automatic	800	0,1	200	=B11+C11*B5+D11*B4

(c) Investment

Figure 2.35 Formula views of different worksheets used to explain concepts and metrics. [34]

The returned papers were manually analysed and filtered in a two-step process, and the two authors decided on the inclusion of the remaining papers based on the following inclusion criteria: Does a paper describe an approach based on some measurable characteristic of spreadsheets? All papers that assess quality of spreadsheets using only non-measurable characteristics were discarded.

The number of worksheets (NB-WORKSHEETS) and number of cells (NB-CELLS) metrics are used to estimate the size of spreadsheets and corpora. There are three variants of this metric: (i) the number of named ranges, (ii) spreadsheets that contain multiple references, (iii) input cells with errors, (iv) input cells that are referenced by other cells and contain an error value, and (v) output cells with errors. The worksheets metric is easy to measure, but can be problematic because some spreadsheet programs automatically add three worksheets when a new workbook is created.

Calculation chain length and number of transitive predecessors can also be computed. The number of references (NB-CELLS_W_REFERENCES and FAN-IN) was found to be more difficult to read and comprehend by spreadsheet users. Other metrics in this context are reachability, number of paths, and number of references. Dispersion of references (DISPERSION_REFERENCES) measure the physical distance of a cell to its referenced cells, and faults are assumed to occur more frequently when the referenced cells are in different rows, columns or worksheets. Size Metrics, Coupling Metrics, and Formula Complexity Metrics are the most frequently used metric categories in the literature, and NB-FORMULA_CELLS and NB-WORKSHEETS and NB-CELLS are often used Size Metrics.

2.3.11 The analysis of several commonly used Excel function in accounting practice

This previous study presented an analysis of several commonly used Excel function in accounting practice, such as the IF function and VLOOKUP function. These functions are used to find the target data and references in Excel data list. The IF () function returns two parameters: logical_test and value_if_true. The VLOOKup function is used to search the information in the designated area of the form [35]. It is used to locate the target data in a form area, lock the target cell's column, the bank and the intersection of the column is the target cell, and access the number from the target cell. The VLOOKUP function is used to calculate the product number of the number of products, and the results of the tables are excluded from the tables due to restrictions.

	A	B
1		
2	产品编号	数量
3	725C4066K-AP-8	=VLOOKUP(A3,productivity,2,FALSE)
4	990Y4145K-AP-4	=VLOOKUP(A4,productivity,2,FALSE)
5	999E-200S	=VLOOKUP(A5,productivity,2,FALSE)
6	A200X@2-3	=VLOOKUP(A6,productivity,2,FALSE)
7	A318-D6001-0.15L	=VLOOKUP(A7,productivity,2,FALSE)
8	A7005M@2-4	=VLOOKUP(A8,productivity,2,FALSE)
9	DEX808-15	=VLOOKUP(A9,productivity,2,FALSE)
10	DN81601-20	=VLOOKUP(A10,productivity,2,FALSE)
11	DP63007-4	=VLOOKUP(A11,productivity,2,FALSE)
12	DP65005-20	=VLOOKUP(A12,productivity,2,FALSE)
13	DP66005-4	=VLOOKUP(A13,productivity,2,FALSE)
14	DPZ001-3.5	=VLOOKUP(A14,productivity,2,FALSE)
15	GAD04-20	=VLOOKUP(A15,productivity,2,FALSE)
16	KBZ01-3	=VLOOKUP(A16,productivity,2,FALSE)

Figure 2.36 VLOOKUP functions used [35]

2.3.12 Detecting Problematic Lookup Functions In Spreadsheets

This previous study investigates the use of lookup functions in spreadsheets, which are used to search for a value in a range and return a corresponding row or column. It finds that a minority of 43% of lookup formulas use the default setting where an approximate match may be returned, 77% of approximate matches are used unnecessary and 23% of approximate lookups are problematic. Lookup functions are used in many different business domains, from finance and logistics to planning and operations, with an estimated 23 million professional users in America. LOOKUP and VLOOKUP are two different functions that can be used to find an approximate match. It is important to note that approximate matching only works when the search range is sorted, as it relies on binary search when searching [36].

Approximate match is not the most common setting in lookup functions, as only 43% of lookup formulas uses this setting. The authors searched for cases in which the approximate match was used, but where it was not 'needed'. The authors found that in a staggering 4,792 (77.6%) of all approximate matches, the approximate setting was not needed. This is problematic, as binary search is used instead of linear search, and it is doubtful whether spreadsheets users are aware of such intricacies in the spreadsheet's execution engine. The current research gives rise to several avenues for future work, such as implementing detection of lookup smells into existing code bases, performing a user study, implementing refactoring for smelly LOOKUP functions, and creating more involved refactoring.

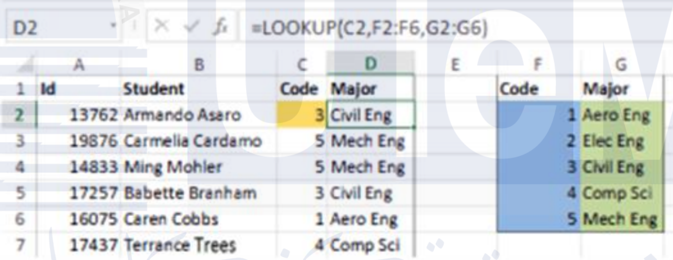


Figure 2.37 A LOOKUP function, used in this example to couple two tables. [36]

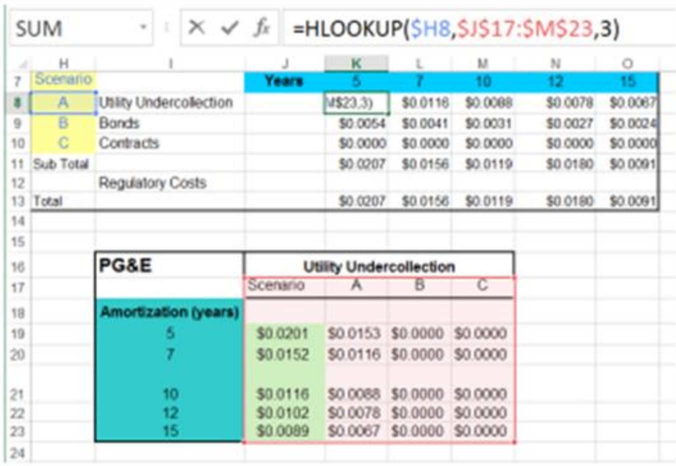


Figure 2.38 A V LOOKUP function including the header row. [36]

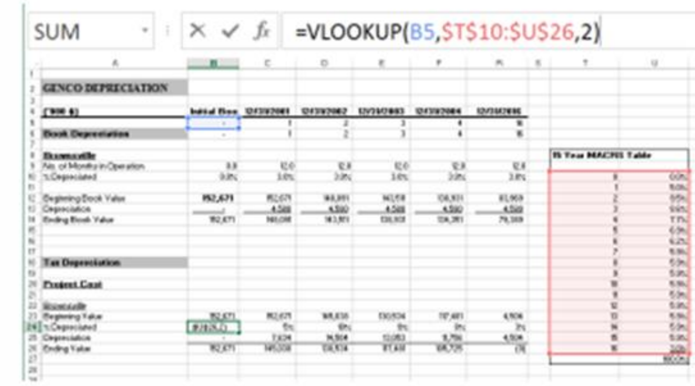


Figure 2.39 A V LOOKUP function using the approximate setting, but only searching for values occurring in the search range. [36]

2.4 Comparison of Previous Works

Table 2.3 The details of the project from different authors

No.	Authors	Title	Application	Remark (Features)
1.	Nur Dalilah Nordin, Hasimah Abd Rahman	Pre-installation design simulation tool for grid-connected photovoltaic system using iterative methods	The Pre-Installation Design for GCPV (PIDGCPV) simulation tool provides greater accuracy and can be used for pre-installation design to aid energy installers in determining the optimal configuration of a GCPV system. A software that enables users to select the type of PV module and inverter model, the type of constraints, the values for system derating factors and site system location, and the optimal inverter-to-PV array ratio.	• Utilizes an iterative method built into Macro Excel and Microsoft Visual Basic • The simulation tool addresses three constraints, which are space, energy requirement and budget. • The software contains a database of PV modules, inverters, and meteorological data for each Malaysian state. • It is comprised of three primary sections: user input, database, and calculation. • The analysis provides a direct comparison between the simulated result and the actual installed data based on the constraint selection, as well as the economic and performance analysis for the installed system.
2.	Eduardo Díaz-Escobar, Dr. Liliana Díaz Olavarrieta	Tlahuilli-ce: a novel solar energy program for the design of photovoltaic systems.	A novel software programme for the design of photovoltaic systems. It facilitates access to well-known algorithms for Photovoltaic System	• It is a Microsoft Excel and Microsoft Visual Basic application that allows non-experts in the solar energy industry to create effective designs

			Design while providing sufficient detail for the feasibility and design dimensioning stages. Software designed to size the PV system, i.e., it provides the number of Modules selected from a Solar Cell Array Manufacturer Database, the type and number of batteries to be used, the charge controller, and the connection configuration necessary to produce the desired voltage and current specifications	• Water Thermal Heating (WTH) and Photovoltaic (PV) systems, which require pumps to circulate water heated by a flat solar collector for storage in a tank and distribution, or a Solar Cell Array Panel that converts sunlight to electricity via the action of a solar semiconductor junction. • The SA system can be hybrid if it has a genset (power generator) as a backup source, or it can be autonomous if it relies solely on the output of the PV array. • The UI system interacts with the power grid via an inverter, and when the PV array cannot meet the energy demand, the system draws power from the utility. • The WP system, which is one of the most widely used systems in the world, does not consider batteries as a storage medium. • The software calculates the parameters of the water pump, and the user selects the pump based on the calculated values.
3.	Choongwan Koo, Taehoon Hong, Minhyun Lee, Jimin Kim	An integrated multi-objective optimization model for determining the optimal solution in implementing the	Aimed to develop an integrated multi-objective optimization (iMOO) model for solving the trade-off problems.	• The study was conducted in six steps: establishment of database, generation of installation scenarios, energy simulation, economic and environmental assessment,

		rooftop photovoltaic system.		establishment of iMOO process using a genetic algorithm, and systemization of the iMOO model using a Microsoft-Excel-based VBA. • It used the software program 'RETScreen to establish a reference model for energy simulation using the actual electricity generation data of the target building.
4.	Marvin S. Seppanen	Developing industrial strength simulation models using Visual Basic for Applications (VBA).	This advanced tutorial demonstrates the basic concepts developed by the author to transfer data between Excel and Arena using VBA designing the initial model structure, as all model variables, attributes, expressions, resources, queues, and stations	• Embedded VBA code to generate the entire Arena experiment frame and animation displays for many very complex simulation models. • The Debug Compile feature checks that all variables have been defined prior to execution, and many VBA errors can be interactively debugged and corrected without restarting the model. • VBA can be used to print the average and maximum values of the fifth Arena Discrete Statistic, as well as to assure the location of a particular piece of Arena information. • The Arena 4.0 database has been an initial step in eliminating the difficult usage of text-based report format for analysis purposes.
5.	Shi hai-bo	Applying Excel VBA to Implement Comparison among	Works out an Excel tool which has both function of one-factor analysis of variance and multiple-comparison	• The comparison method is often used in sports teaching experiment and analysis, and the variance analysis

		Physical Experiment Data	at the same time, enabling us to compare the different groups of data.	method is convenient for testing whether there are differences between average grades. • Statistical computing is often encountered in statistics, and calculation precision is one of the common faults in the statistical work. • The comparison method is often used in sports teaching experiment and analysis, and the variance analysis method is convenient for testing whether there are differences between average grades.
6.	K.M. Hyde, H.R. Maier	Distance-based and stochastic uncertainty analysis for multi-criteria decision analysis in Excel using Visual Basic for Applications	A program that incorporates the ability to undertake deterministic MCDA, the distance-based uncertainty and the stochastic volatility analysis approach. allow a decision to be made with confidence that the alternative chosen is the best performing alternative under the range of probable circumstances program to extend the analysis of existing software for MCDA based on WSM and PROMETHEE	• A program in Excel and written in Visual Basic for Applications to examine the robustness of a solution obtained when using multi-criteria decision analysis (MCDA). • Demonstrates how all the available information, including uncertainty, can be incorporated in the analysis concurrently, providing additional information on the robustness of the alternatives to variation in the input parameters and allowing confidence to be placed in the outcome of the analysis • It can be applied to any kind of usage conflicts between natural resources and economic development.

7.	Liu Pengpeng, Du Ruiqing	Applications of Excel VBA in Data Calculation and Charts Creation of Mineral Resource Economics	The use of Macro Recorder and Excel VBA to calculate the annual increment of mineral resources.	• An implementation of Microsoft's event-driven programming language Visual Basic 6 and its associated integrated development environment (IDE). • VBA enables building user defined functions, automating processes, accessing Windows API, and other low-level functionality through dynamic-link libraries (DLLs). It is also built into Office for Mac applications and other Microsoft applications. • VBA code interacts with the spreadsheet through the Excel Object Model, and user-created subroutines execute these actions and operate like macros generated using the macro recorder. VBA procedures can be developed, tested and modified in the Excel Visual Basic Editor (VBE). • Excel VBA is able to automate tasks that users normally do manually and provides batch processing functions to help users do relative things by loop programs.
8.	Du Ruiqing, Sun Sanjian, Ouyang Longbin	Applications of Excel VBA in Data Processing of Magnetic Survey	Applications of Excel VBA in data processing of Magnetic Survey. Visual Basic for Application (VBA) is an event-driven programming language implemented by Microsoft's	• VBA enables building user defined functions, automating processes and accessing Windows API (Application Programming Interface) and other low-level functions through dynamic-link

			Visual Basic 6 and its associated integrated development environment (IDE).	libraries (DLLs). It supersedes and expands on the abilities of earlier application-specific macro programming languages such as Word's WordBasic.
9.	S.T.Huseynov	Methodology of Laboratory Workshops on Computer Modeling with Programming in Microsoft Excel Visual Basic for Applications	Presents the main stages and consequences for numerical simulation of classic math models in ecology via MS VBA Excel (for continual and discrete systems). The methodic of printout of results of numerical simulation and automation of Excel charts creation are also presented. The implementation of a numerical simulation in Excel VBA with important stages, such as inserting numerical values of the simulated problem to range cells in Excel worksheet, ensuring that the VBA program is working properly, adding fragment of VBA code lines to program order, organizing output of computed results to defined range cells, printing of results of computation, and creating standalone Excel charts according to numerical values obtained in the stage 4th (stage of diagrams building).	• These advantages include the programming language being suitable to modern software, the syntactical structure and some main elements of VBA being equal to similar properties of such software as Pascal, the software having a natural connection with OS Windows and MS Office Applications, and the software having applications not only for economic-oriented usage in university education. • It is also known that most MS Office users are uninformed about VBA programming, and that Excel VBA is taught in engineering specialties as high-tech-oriented programming. • The four stages of VBA Excel programming in computer modeling are results of computations, automated Excel charts building due to stage 3, preparing scientific reports based on 3rd and 4th stages in Office applications, and using MS VBA Excel to simulate CM problems described as ordinary differential equations (ODEs).

				• The use of MS Excel VBA code to create suitable VBA code for more complicated computer simulation problems.
10.	Birgit Hofer, Dietmar Jannach, Patrick Koch, Konstantin Schekotihin, Franz Wotawa	Product metrics for spreadsheets—A systematic review	Reviews five major digital libraries for scientific papers that define or use spreadsheet product metrics and creates a novel catalog of product metrics Aims to aggregate and synthesize the existing knowledge about product metrics for spreadsheets	• Outlines the basic terminology behind spreadsheets, defines research questions, and provides details about the systematic literature review process. • The number of worksheets (NB-WORKSHEETS) and number of cells (NB-CELLS) metrics are used to estimate the size of spreadsheets and corpora. • Degree of evaluation is determined by the amount of spreadsheet complexity, corpus size, fault prediction, code smells and refactoring, risk assessment and auditing, and sum. • Two types of empirical or experimental studies: (i) studies where user-perceived quality levels were compared with metric values or by manual annotations from human evaluators, and (ii) studies where the effectiveness of the metrics was judged indirectly, e.g., by the resulting fault prediction performance.
11.	Qingmin Yu	The analysis of several commonly used Excel	Presents an analysis of several commonly used Excel function in	• These functions are used to find the target data and references in Excel data list. The IF () function returns two

		function in accounting practice	accounting practice, such as the IF function and VLOOKUP function	parameters: logical_test and value_if_true. • The VLOOKup function is used to search the information in the designated area of the form • Used to locate the target data in a form area, lock the target cell's column, the bank and the intersection of the column is the target cell, and access the number from the target cell. • LOOKUP function is used to calculate the product number of the number of products, and the results of the tables are excluded from the tables due to restrictions
12.	Felienne Hermans, Efthimia Aivaloglou, Bas Jansen	Detecting Problematic Lookup Functions In Spreadsheets	Investigates the use of lookup functions in spreadsheets, which are used to search for a value in a range and return a corresponding row or column Implementing detection of lookup smells into existing code bases, performing a user study, implementing refactoring for smelly LOOKUP functions, and creating more involved refactoring.	• Lookup functions are used in many different business domains, from finance and logistics to planning and operations • LOOKUP and VLOOKUP are two different functions that can be used to find an approximate match

2.5 Summary

This chapter covers in depth Excel-based photovoltaic (PV) design applications by energy requirements. It has three main sections: background study, previous works by others, and comparison of previous works. Photovoltaic (PV) system history, solar PV system generation, PV system components, web-based PV design software and applications, and Microsoft Excel are covered in background study section. The first section explores the fundamental objectives of this study. The second section examines influential studies that influenced the development of these tools. Features, development processes, methodologies, applications, and user interfaces are highlighted to contextualise the research. The comparison section examines the applications and characteristics of previous literature. This comparison contextualises and emphasises the significance and originality of the current research. In conclusion, this chapter identifies potential flaws and improvement areas in current Excel-based PV design systems, allowing this paper to propose novel solutions and enhancements.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the "Excel Based PV Design Application by Energy Requirements" system that will be implemented and how the project's goals will be achieved. In this chapter, a general overview of the system building's approach to this project will be presented. Throughout this chapter, the development of this project is detailed and illustrated. This chapter also describes the optimal strategy for achieving the desired result.

3.2 Methodology

This section presents an Excel and VBA-generated system for PV design based on energy requirements. Figure 3.1 illustrates this overall project flow. Simple system processes are designed and documented utilising flowcharts. Using a flowchart facilitates understanding of the steps and execution of a process. Figure 3.1 depicts the subsequent phases of product design and fabrication. Using a flowchart, Figure 3.1 illustrates the process used to construct this project. This strategy was used to describe the execution procedure for the project. In addition, it assists in determining which tasks must be prioritised and completed in order of importance.

Using the developed flowchart as a guide, the project methodology begins with the formulation of a problem statement and objectives. Next, a literature review on a topic relevant to the PV system design and application used for PV design is conducted. Included in the research sources were articles, journals, and websites. Most academic articles originated from the IEEE and ScienceDirect websites. Conduct additional research on PV Design and Excel following this phase. Next, the required formula and procedure are examined and evaluated. The majority of methods and formulas are available online. There are numerous instructional videos for this method available online. After gathering this information online, the construction of the project begins with the development of an Excel template. After the design has been completed, the Excel template is implemented. Afterwards, the template is evaluated by inserting the necessary values. If a problem arises, the template will go through a troubleshooting stage and then resume testing until success is attained. If no errors are encountered, the application will be created, and the template will be implemented simultaneously. The application and template will go through a validation process after they are created. Following the validation of the application, the project will be tested. If the project runs smoothly, it will be deemed a success and move on to the analysis of results and data. However, if an error prevents the project from running, it will undergo a troubleshooting procedure. After resolving any issues with the project, it will be retested. Upon project completion, the data will be analysed and collected to gather results and continue report writing. After completing and finalising the report, it will be submitted to the supervisor and grading panels. BDP 1 comes to an end upon completion of the report and presentation.

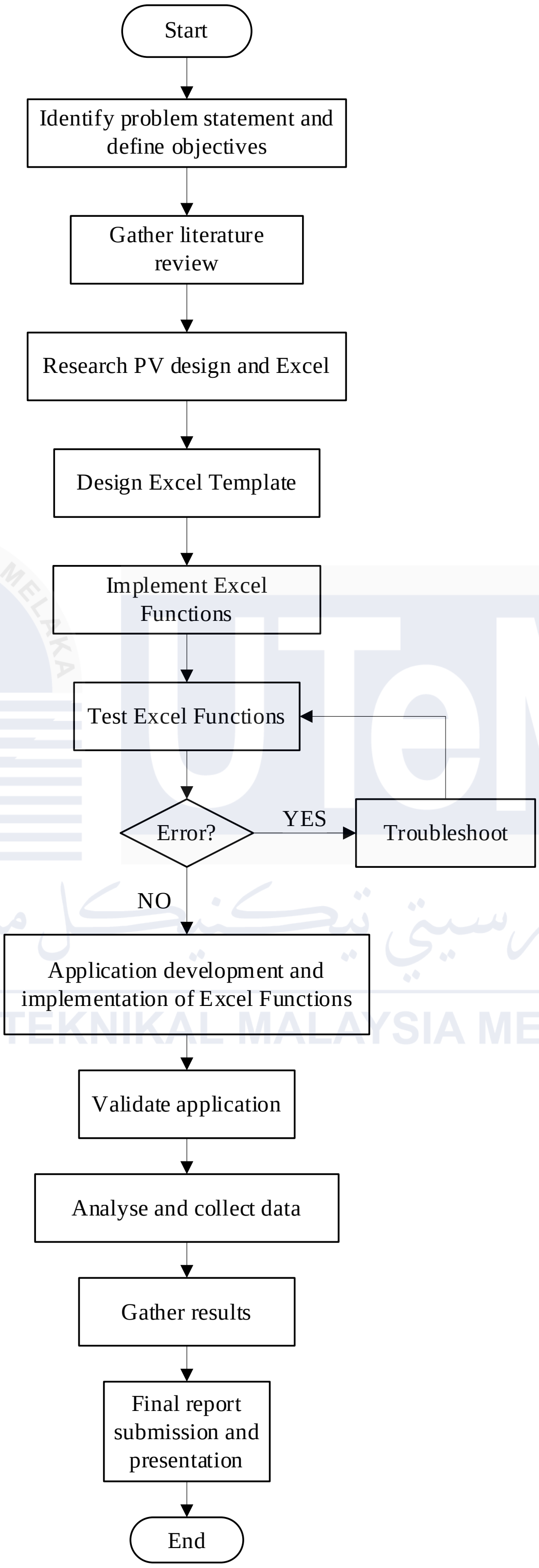


Figure 3.1 Flowchart for the whole project

3.3 Project Architecture

This is a block diagram depicting the operation of the project. According to the Figure 3.2, the application will require the user to input their desired energy consumption in order to design a PV system. The user will then enter the energy requirement's value into the application, at which point the application will perform a calculation to determine the quantity of solar panels and inverter necessary to meet the energy requirement. After the calculation has been performed, the number of solar panels and inverters will be generated and displayed.

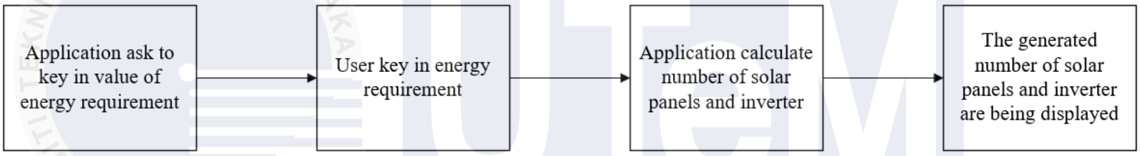


Figure 3.2 Block diagram of the project

3.4 Software of the Project

HLOOKUP is a built-in function in Microsoft Excel that performs horizontal lookups by searching for a value in the top row of a table and returning the value in the same column based on the index number. HLOOKUP is a function in Microsoft Excel that allows users to perform horizontal lookups. [37] [38] It searches for a value in the top row of a table and returns the value in the same column based on the index number. [37] [38] HLOOKUP is used when comparison values are located in a row across the top of a table of data, and you want to look down a specified number. [37] [38] The syntax for the HLOOKUP function in Microsoft Excel is: `*HLOOKUP(value, table, index_number, [approximate_match])* ` [37] [38]

The HLOOKUP function is available in all versions of Microsoft Excel 2016, Excel 2013, Excel 2010, Excel 2007 and lower. [37] The function can be used as a worksheet function (WS) in Excel and can also be incorporated into VBA programs. [37] [39] To use HLOOKUP in VBA, you need to use the `*Application.WorksheetFunction*` method [39]. HLOOKUP is used when you need to search for a value in the top row of a table or array of values and return the value in the same column from a row you specify [39]. It is useful when you have data arranged horizontally and you want to find specific information based on certain criteria [37] [38]. HLOOKUP can be used when you have data arranged vertically, but it requires transposing the data first [40]. HLOOKUP is useful for finding specific information based on certain criteria [37] [38]. It saves time by allowing users to quickly search for information without having to manually scan through large amounts of data [37] [39]. It can be used to create more complex formulas that incorporate multiple functions [37]. HLOOKUP can be used in various industries such as finance, engineering, and science where data analysis is required [37] [39]. It can be used for various purposes such as calculating grades, analyzing sales data, and tracking inventory levels [37] [39]. HLOOKUP is related to GCPV design in the sense that it can be used to retrieve information from a table by searching a row for the matching data and outputting from the corresponding column [41]

know, like their phone number.

VLOOKUP stands for "Vertical Lookup" and is a built-in Excel function that helps you look for a specified value by searching for it vertically across the sheet [42]. It is a search tool that allows you to look up data in a table, where each row is an entry and each column holds different types of data [43] The VLOOKUP function consists of four arguments: lookup_value, table_array, col_index_num, and [range_lookup] [42]. The lookup_value is the value for which you want to find matching data and must appear in the first column of the lookup table; it can be a value, a text string, or a cell reference [44]. The table_array is the name or address of the lookup table. The col_index_num is the number of columns Excel must count over to find the matching value [44]. The range_lookup argument is optional and can be either TRUE or FALSE. If the range_lookup argument is FALSE, VLOOKUP will find only exact matches. If the range_lookup argument is TRUE, or if a range lookup argument is not entered, VLOOKUP can find approximate matches [44]. VLOOKUP is a useful tool for data analysis and can bring back corresponding values from a big data set on the fly for multiple values [45]. It can save time and effort when working with large datasets by automating the process of finding specific information [42].

VBA stands for Visual Basic for Applications, which is a programming language used to automate tasks in Microsoft Office applications, including Excel [46]. It allows users to create custom functions, automate repetitive tasks, and build user interfaces [46]. VBA works by users write VBA code directly in the Visual Basic Editor (VBE) within Excel [47]. The VBE provides a development environment where users can write, test, and debug their code [47]. Users can also create custom user forms and interfaces using VBA code [48]. VBA be used to create an automated data entry form in Excel by creating a user form with input fields for each data point they want to collect [48]. They can then write VBA code to validate the data entered into each field and transfer it to the appropriate location in the spreadsheet [48]. This can save time and reduce errors when entering large amounts of data into a spreadsheet. VBA can be used to develop an Excel-based application for energy requirement in residential GCPV system design by giving developer to write VBA code to automate calculations related to energy requirements for residential GCPV system design [49]. They can also create user forms that allow users to input data and view results in a more user-friendly way [50] [51]. This can help streamline the design process and make it easier for users to understand the results of their calculations.

3.5 Setup of Project

This section will explain the steps taken to create the project's application. The first step of the project setup is to open the Microsoft Excel software. Figure 3.3 shows the layout of Microsoft Excel spreadsheet.

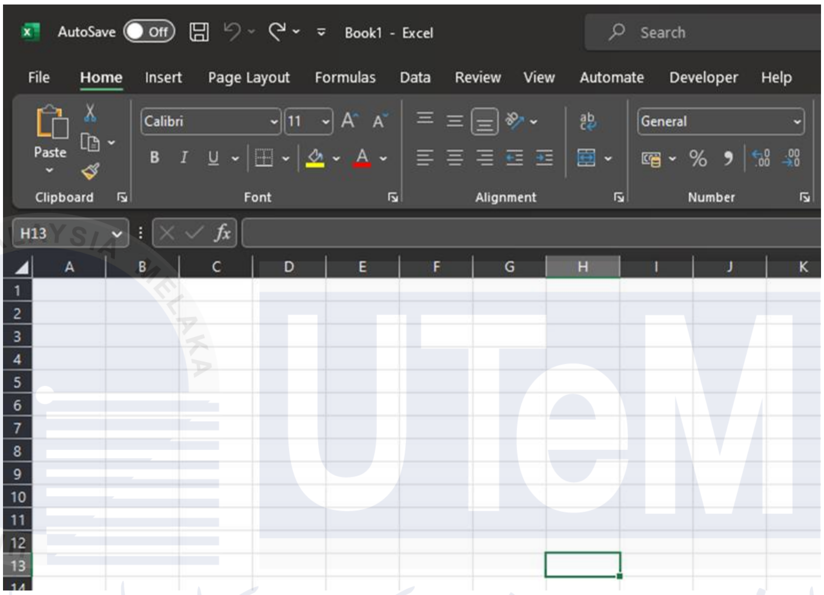


Figure 3.3 Step 1

Next, insert all the details required on the spreadsheet as shown in Figure 3.4. As per mentioned, details are based on datasheet of one specific model of solar panel and PV inverter.

1					
2	**Solar panel datasheet**			**Inverter datsheet**	
3					
4	Power output STC (Pnom)	400Wp		Rated output power	2000W
5	Efficiency	22.60%		Max. Efficiency	97.20%
6	Voltage at Pmax	65.8V		Recommended max PV power	4000Wp
7	Current at Pmax	6.08A		Max input Voltage	600V
8	Open circuit Voltage (Voc)	75.6V		Rated input Voltage	360V
9	Short circuit Current (Isc)	6.58A		Max input current per MPPT	10A
10				Max short circuit current	18A
11					
12					

Figure 3.4 Step 2

Next, click on the “Developer” tab on the Visual Basic extension on top right of the Microsoft Excel. Visual Basic is important to create the dashboard of the project.

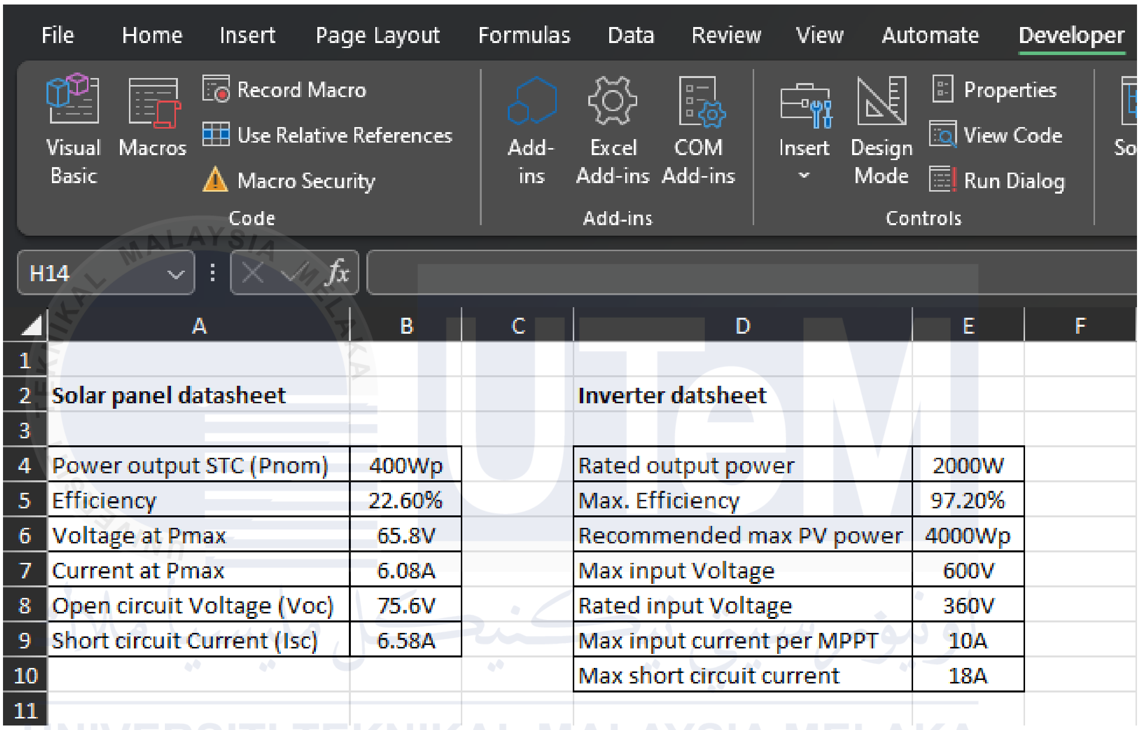


Figure 3.5 Step 3

Next, Figure 3.6 shows the layout of Microsoft Visual Basic for Applications when the “Visual Basic” option is selected that can be found in the “Development” taskbar. It will show the “canvas” to create the dashboard.

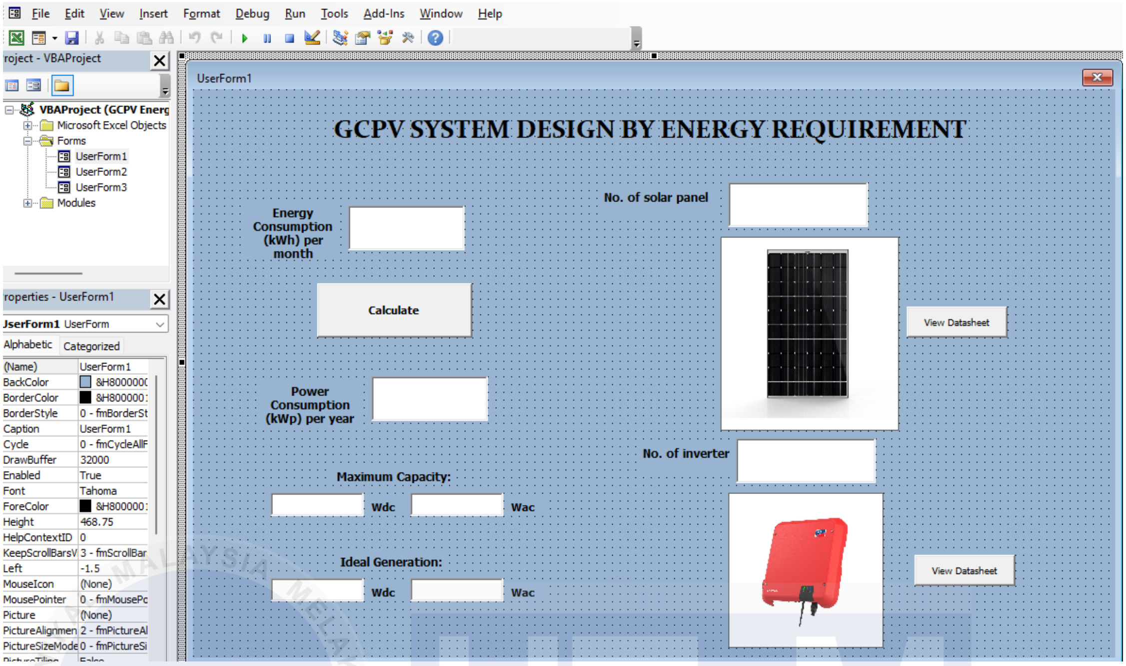


Figure 3.6 Step 4

Next, Figure 3.7 shows that when the Visual Basic Software have been launched and created a project, the "Userform" icon is clicked which can be found on the second row of the software.

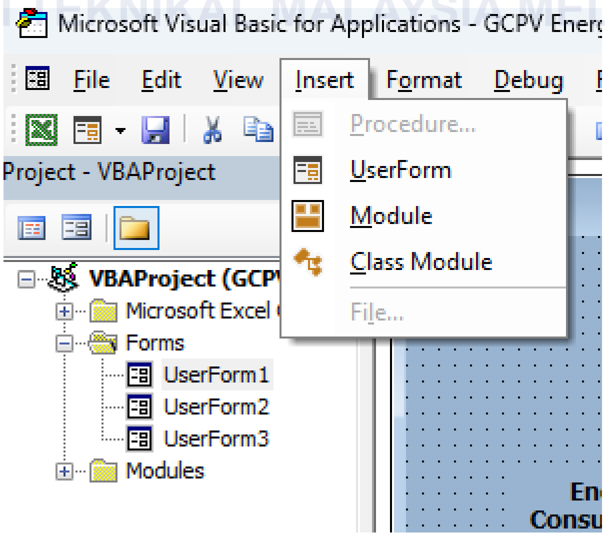


Figure 3.7 Step 5

Next, Figure 3.8 Userform is displayed as shown. Userform is a blank canvas for the creation of dashboard.

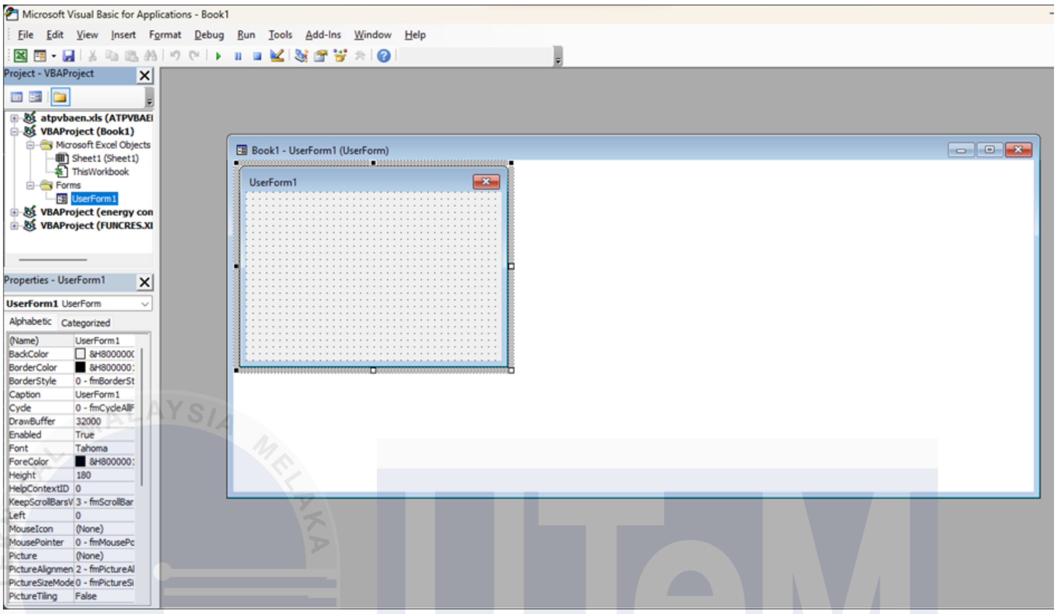


Figure 3.8 Step 6

Next, shows that a toolbox pop-up appeared to edit the Userform in Figure 3.9. This toolbox consists of many options to edit the dashboard on Userform.

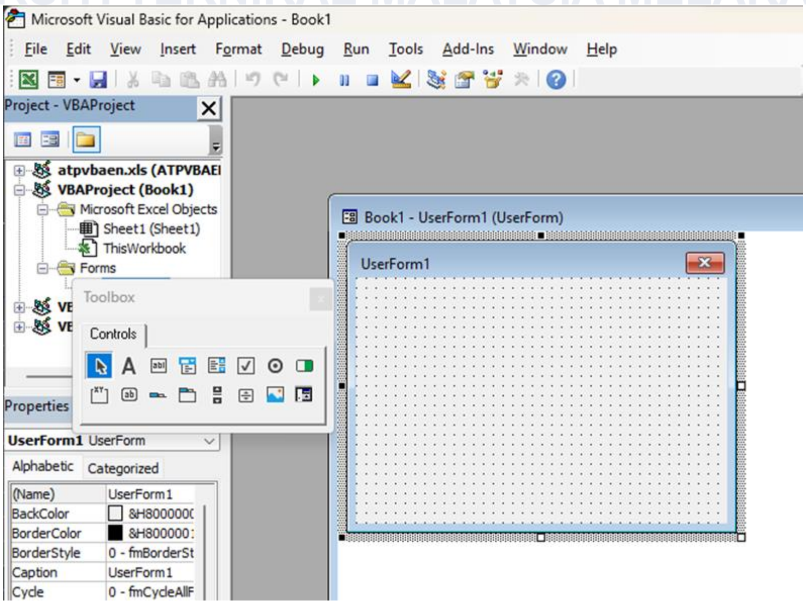


Figure 3.9 Step 7

Next, a “Label” option is selected to put in the Userform as seen in Figure 3.10. “Label” is a text for the type of data needed to enter and display.

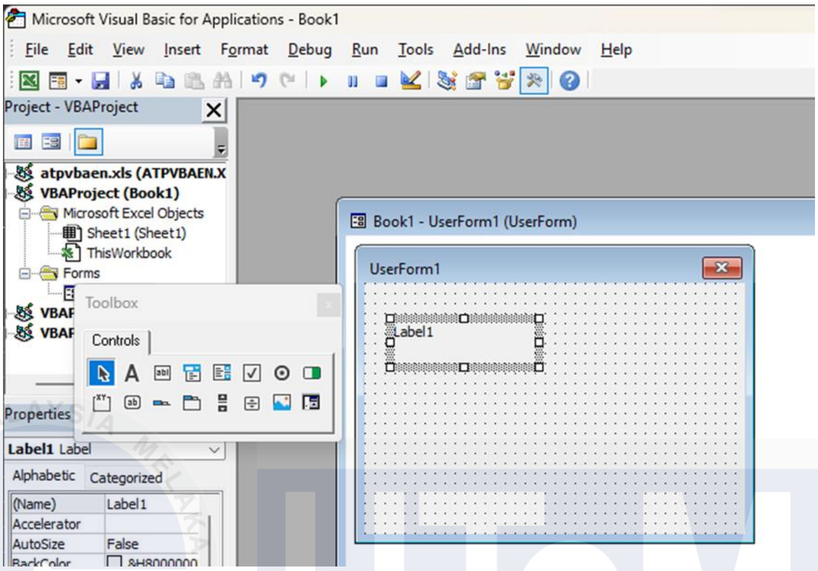


Figure 3.10 Step 8

Next, “Textbox” is added next to “Label” and add another set of “Label” and “Textbox” under the first set as shown in Figure 3.11. “Textbox” is to display the answers generated after calculations.

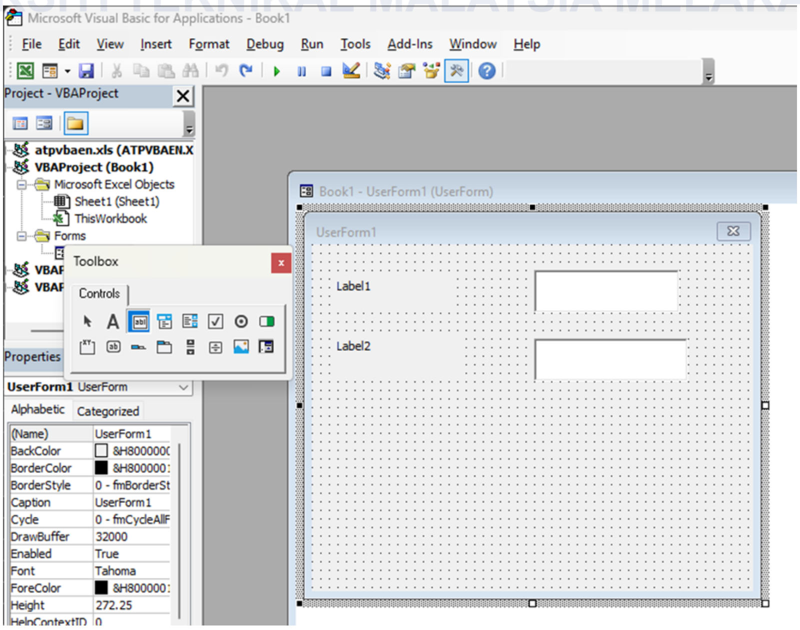


Figure 3.11 Step 9

Next, in Figure 3.12 "CommandButton" is added to give indication to start calculating the values that will be added in the two "Textbox". In this "CommandButton", coding will be inserted to run the calculation.

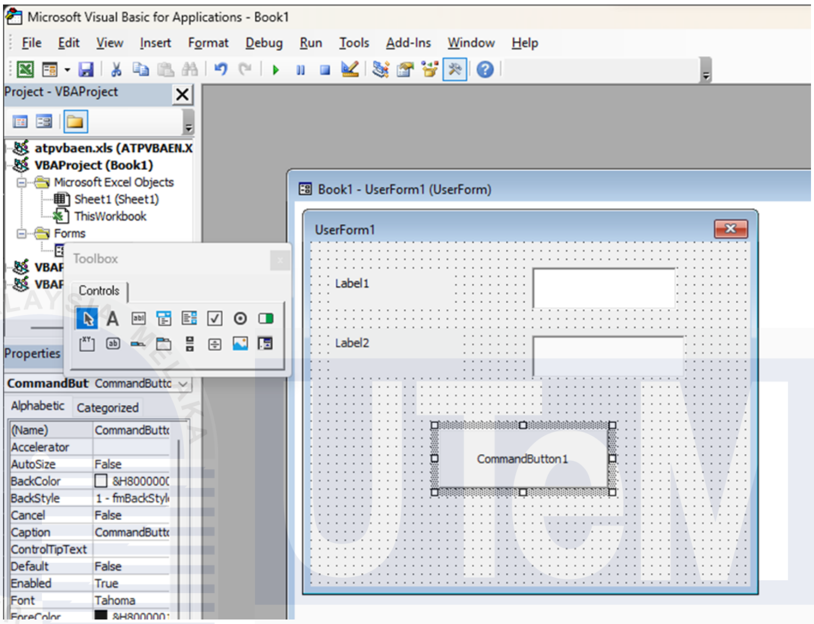


Figure 3.12 Step 10

Next, in Figure 3.13, the last "Label" is added which will display the final result. The result displayed will take account of all the data entered by user and also calculations of quantity of solar panels and PV inverters needed.

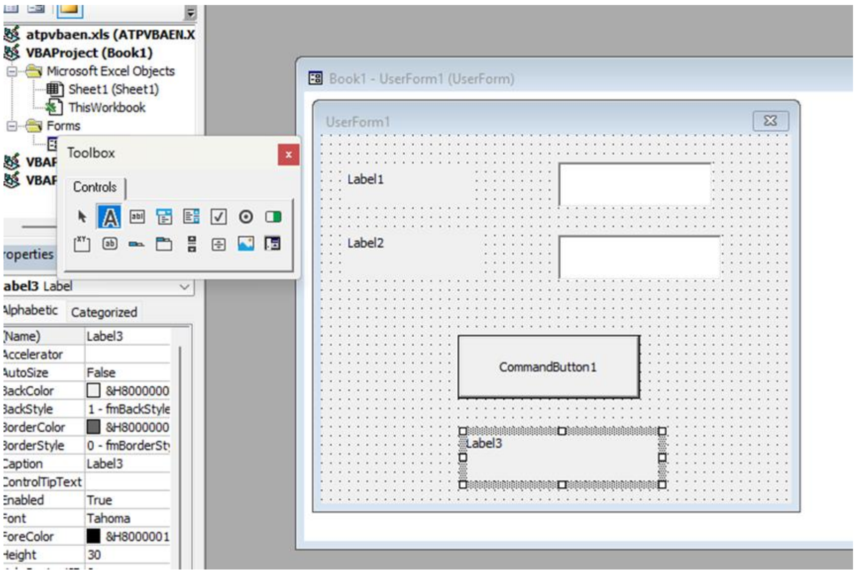


Figure 3.13 Step 11

In Figure 3.14, the “CommandButton” is double clicked for the VBA coding. This is to check that the coding has no error to perform calculation. The calculations generated will be compared to manual calculations.

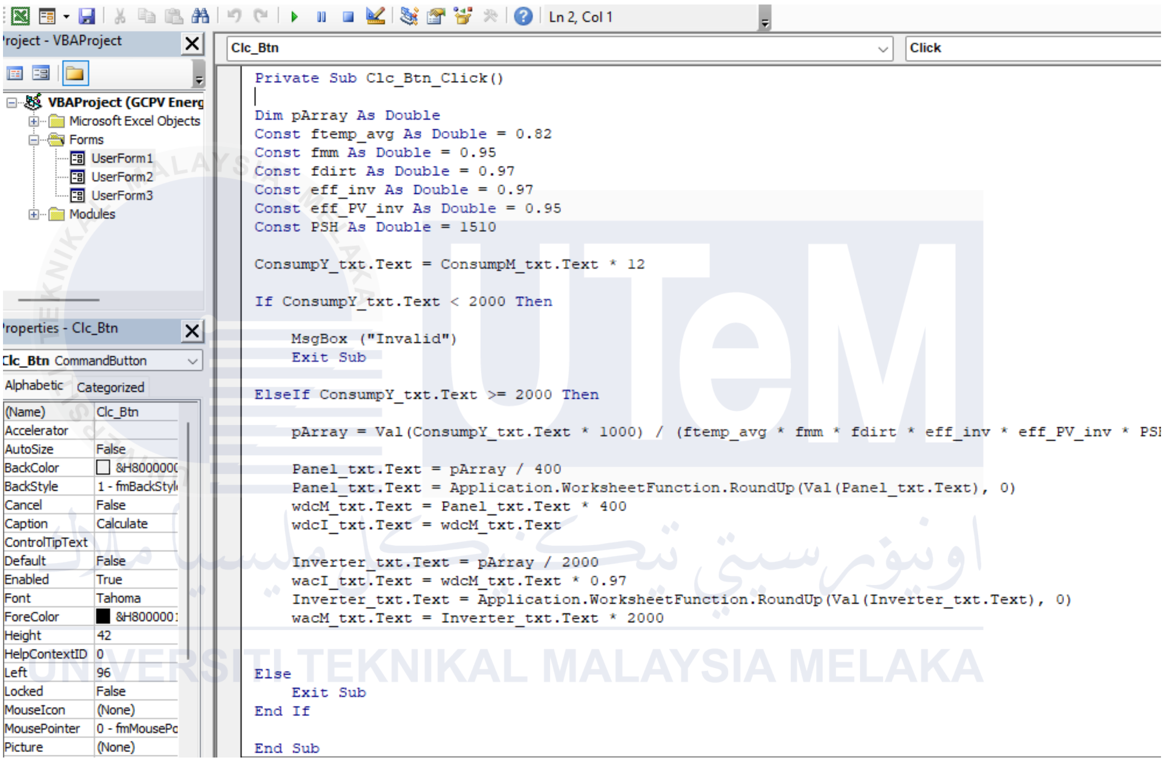


Figure 3.14 Step 12

Next, in Figure 3.15, all the “Label”, “Textbox” and “CommandButton” are renamed accordingly. This is to make sure that the texts are clear and easy to read.

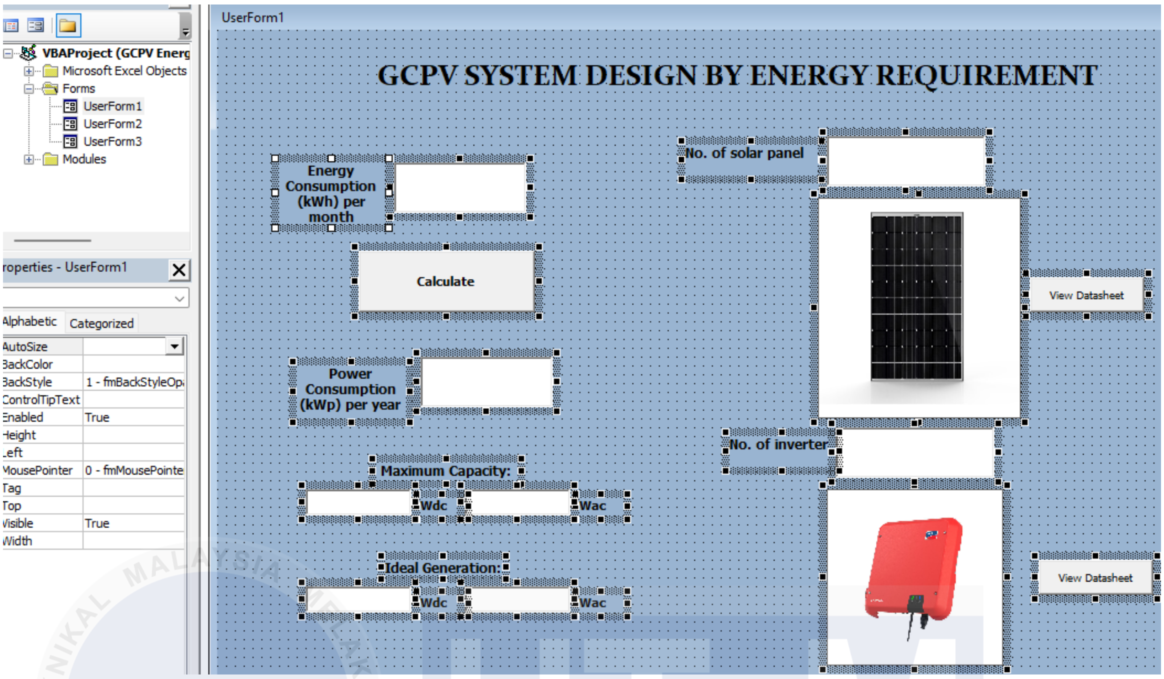


Figure 3.15 Step 13

Next, in Figure 3.16, another userform is created to insert the datasheet of solar panel. To insert the datasheet image, click on "Picture" and upload the datasheet image. Datasheet is important to be displayed to make sure that the details entered in Excel spreadsheet are the same.

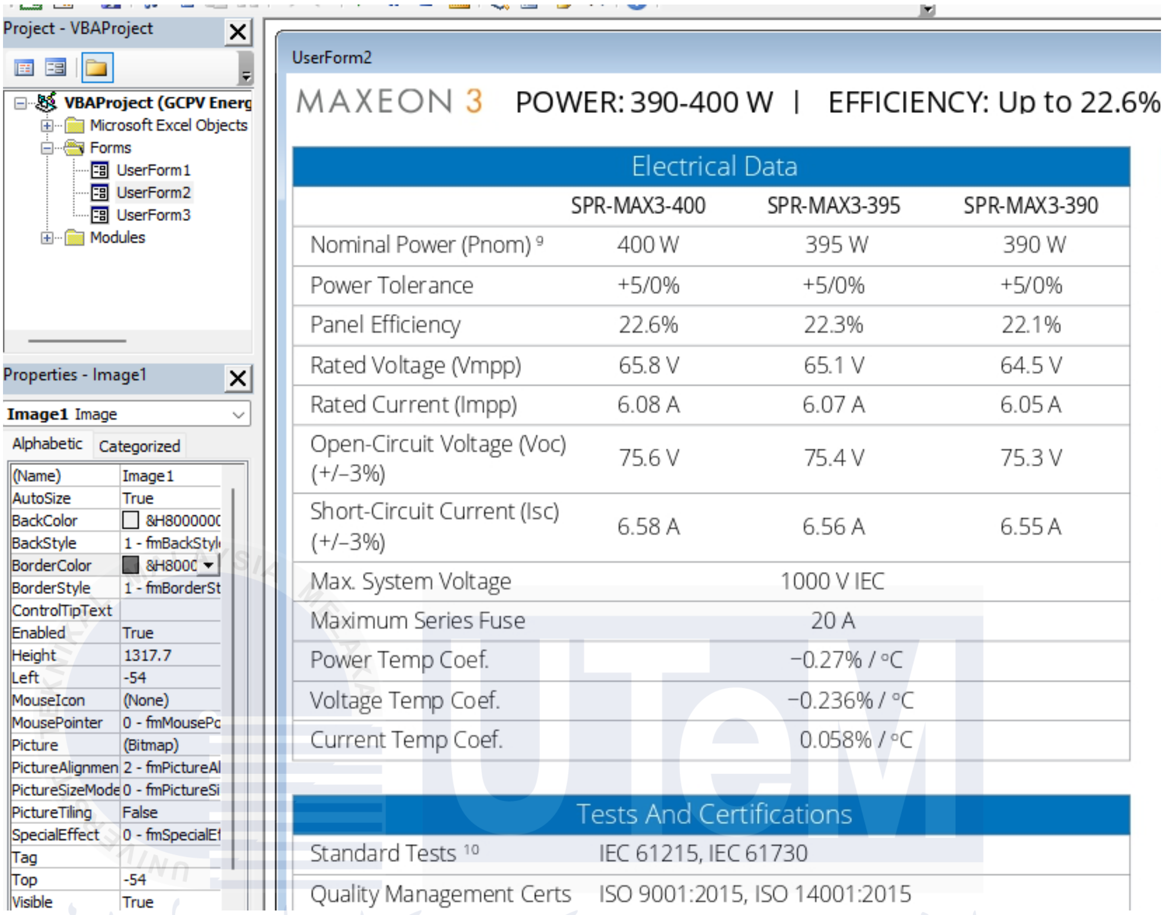


Figure 3.16 Step 14

Next, in Figure 3.17, a coding is made under the button of “View Datasheet” next to the solar panel image. This is to make sure that the datasheet can only be viewed when clicking on the button and will display in another userform.

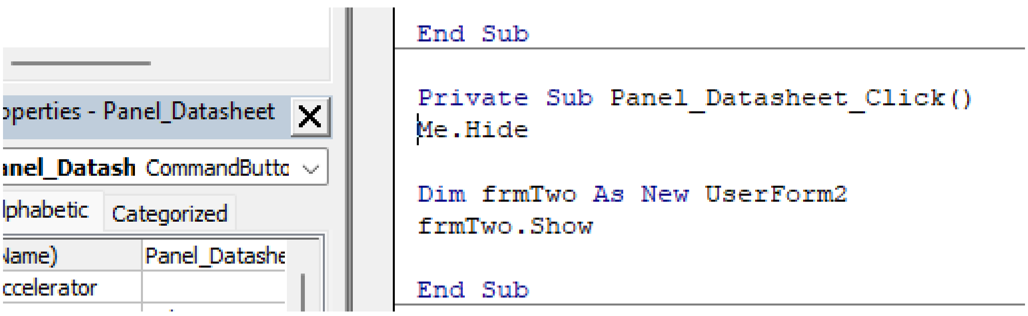


Figure 3.17 Step 15

Figure 3.18 shows the taskbar of the project and the "play" button on the top of the Visual Basic Software is pressed. This is to make sure that the dashboard is able to be displayed on Excel Spreasheet.

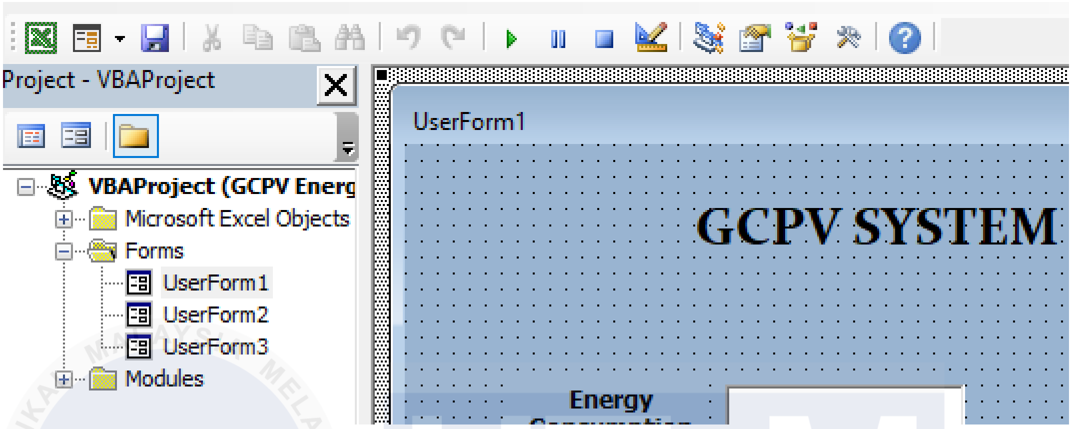


Figure 3.18 Step 16

Next, in Figure 3.19, the dashboard of the application automatically bring us to the Excel Spreadsheet and a pop-up of userform is displayed. When the dashboard can be displayed, it is a successful execution.

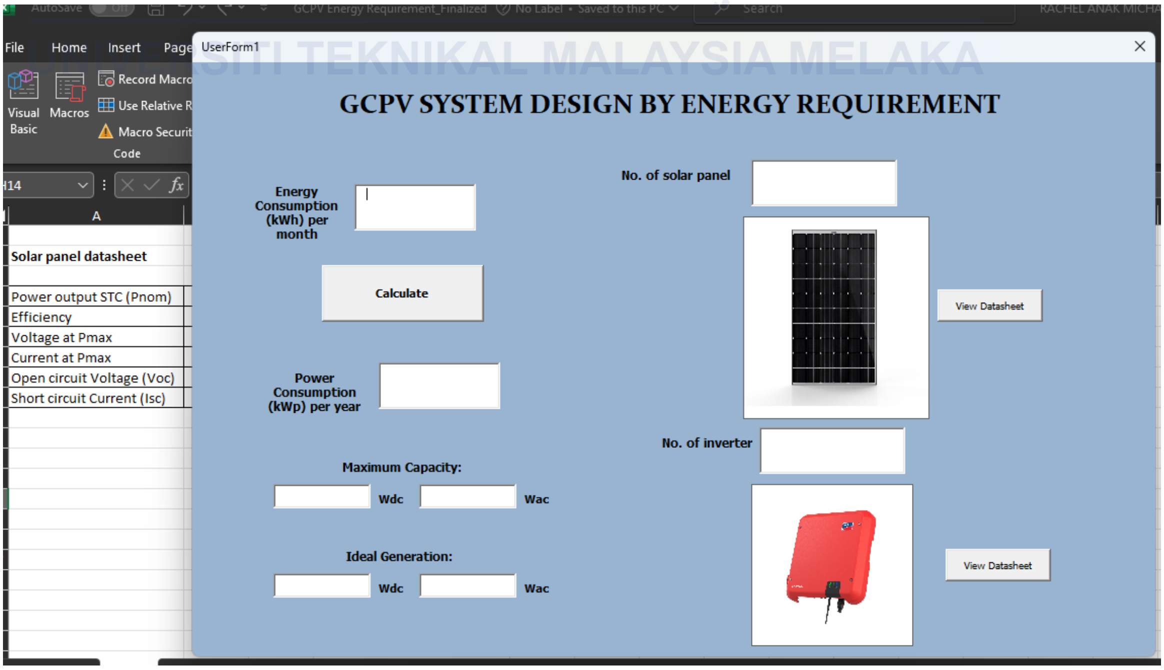


Figure 3.19 Step 17

In order to extract Visual Basic Dashboard into Microsoft Excel, click on the Form Control button besides the Visual Basic icon and place the button on the Excel sheet.above step, the application is ready to be tested. Lastly, the dashboard is generated on the Excel spreadsheet. To test it out, the values are entered according to the spreadsheet to make sure the result generated is the same as the ones in the spreadsheet as shown in Figure 3.20.

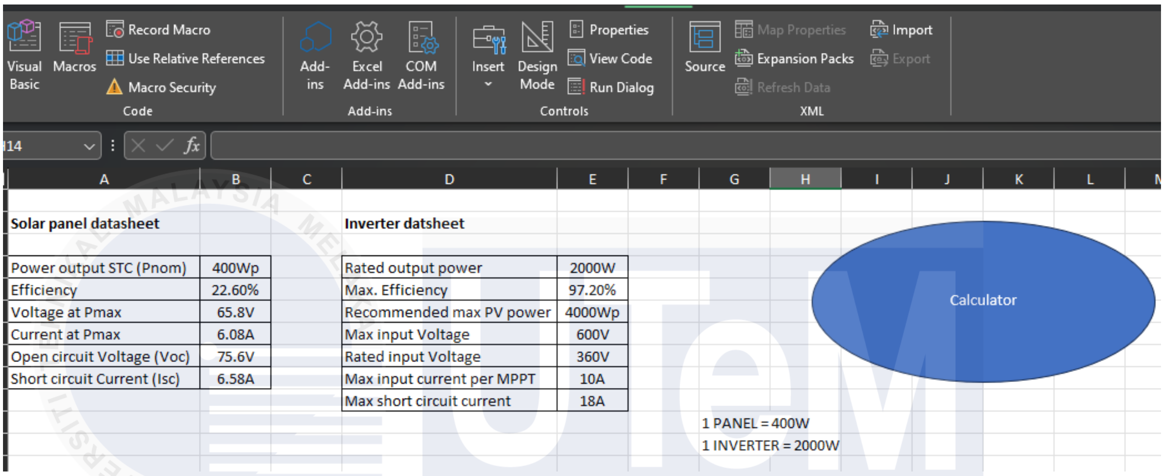


Figure 3.20 Step 18

Lastly, the dashboard is generated on the Excel Spreadsheet. To test it out, the values are entered and the result is generated as shown in Figure 3.21. The values are based on coding in VBA and manual calculations.

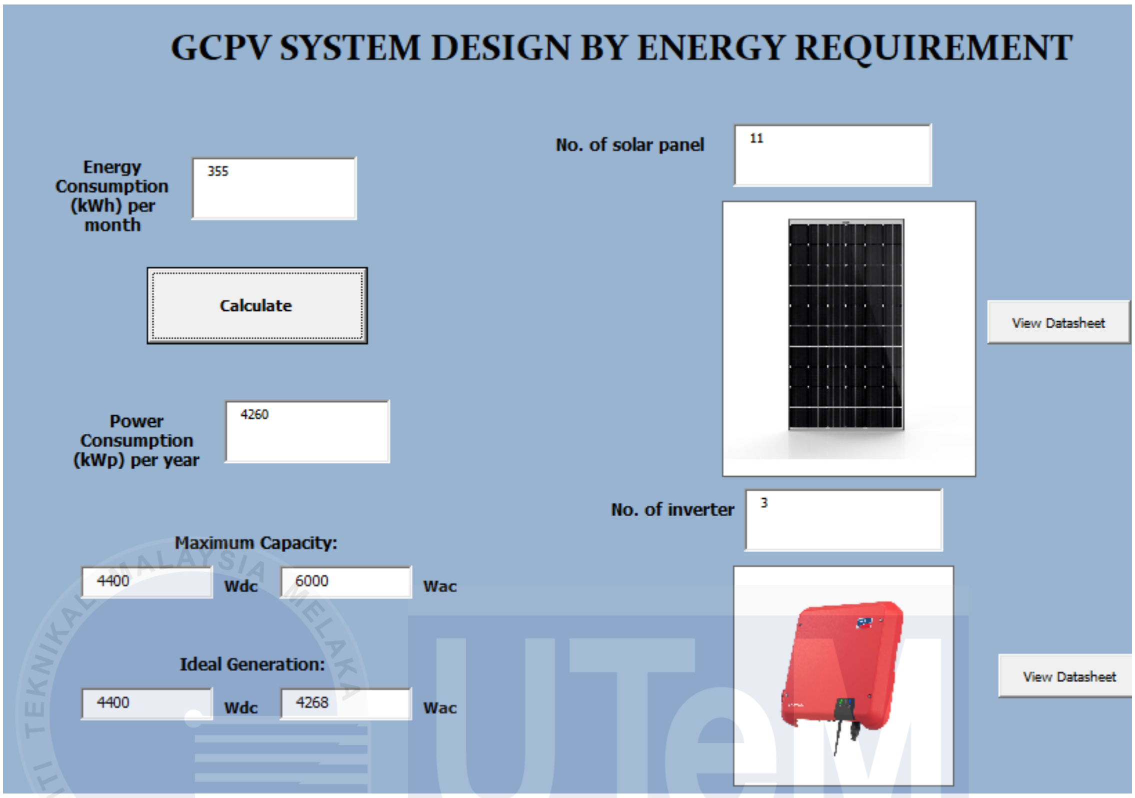


Figure 3.21 Step 19

3.6 Gantt Chart

The Gantt Chart illustrated the progression of the project schedule in terms of date and task, thereby ensuring that the project stays on track. Time management is more effective and conducive when it is planned from the outset.

No	Task / Week	PSM1														PSM2													
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Briefing for PSM 1 by JK PSM, FTKEE	■																											
2	Project Tiltle Confirmative and Registration		■	■	■	■																							
3	Briefing with Supervisor		■																										
4	Study the Project Background		■																										
5	Drafting Chapter 1: Introduction			■																									
6	Task progress evaluation 1			■	■																								
7	Drafting Chapter 2: Literature Review				■	■																							
8	Table of summary literature review					■																							
9	Drafting Chapter 3: Methodology						■	■	■	■	■																		
10	Work on the Software/Hardware							■	■	■	■																		
11	First draft submission to Supervisor											■																	
12	Task progress evaluation 2												■																
13	Submission report to the panel													■															
14	Presentatiom pf BDP1														■														
15	Drafting Chapter 4: Analysis Data and Result															■	■	■											
16	Data Analysis and Results																	■	■	■									
17	Record the result																			■	■	■	■						
18	Drafting Chapter 5: Conclusion and Recommendation																							■	■				
19	Compiling Chapter 4 and Chapter 5																								■	■			
20	Submit the report to Supervisor																										■		
21	Finalise the report																											■	
22	Presentatiom pf BDP2																												■

3.7 Summary

This chapter details the methodology necessary to implement the user-friendly "Excel-Based PV Design Application by Energy Requirements." The main purpose of the methodology is to describe the VLOOKUP and HLOOKUP functions in Microsoft Excel, as well as VBA. This function allows users to easily search for products. This chapter describes the proposed procedure for initiating a new system development project. To achieve all of the project's objectives, each improvement outlined in this chapter must be successfully implemented. In addition, a flowchart and a block diagram are used to explain the step-by-step process and demonstrate how the project system operates.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will explain the project's progress while highlighting the results. This chapter will describe the whole sysrtem, including the yearly power consumption, quantities of solar panels and PV inverters, maximum capacity, and ideal generation. This chapter will also explain the expected outcomes and limitations. This chapter demonstrates application testing and analysis, including the output result and the application's influence using the variation in input parameters.

4.2 Results and Analysis

The developed program facilitates the calculation of yearly power consumption, solar panels, PV inverters, maximum capacity, and ideal generation. After inputting a monthly energy consumption, the user selects the "calculate" option. The dashboard will display the yearly power consumption in kWp, quantities of solar panels and PV inverters, maximum capacity and ideal generation, both in Wdc and Wac. If a user wishes to manually compute the entire system, he or she must follow the correct procedures in order to obtain accurate results. The formula was also applied to the undertaking. Using this program as opposed to manual methods saves time. However, the yearly power consumption must be greater than or equal to 2000kWp. All of the calculations shown below are the considerations that must be made when manually calculating the steps. These parameters are essential, but all of these stages can be skipped when using the developed application.

4.2.1 Condition 1

There are several conditions in which the values entered are unable to be calculated and a pop-up of run-time error'13' will be displayed. Figure 4.1 and Figure 4.2 show the result for when invalid values are entered, such as alphabets or any other symbols that are not in numbers.

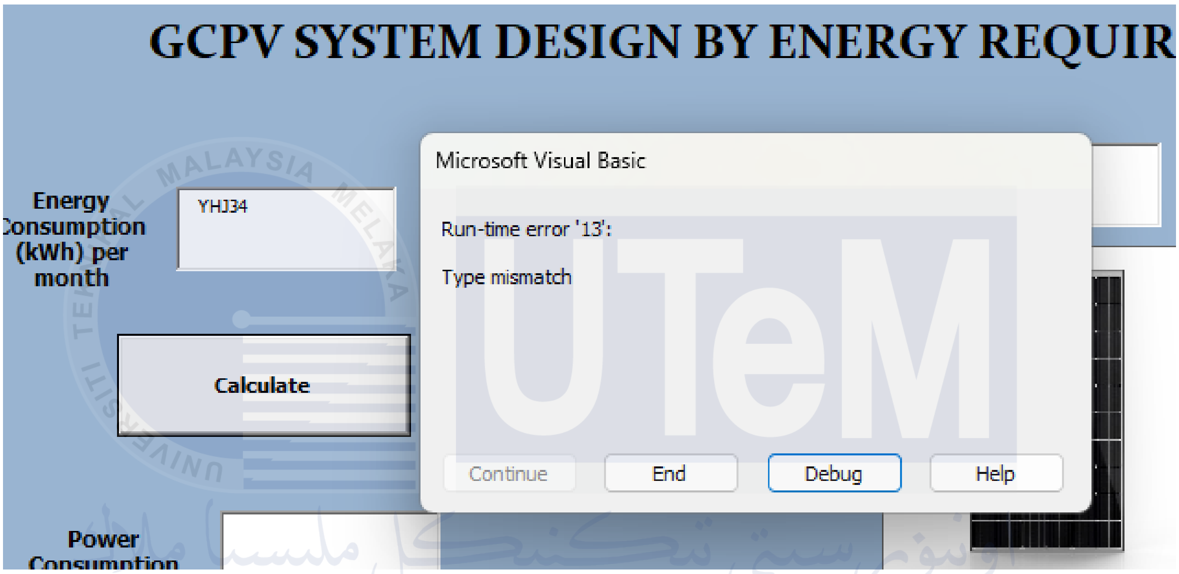


Figure 4.1 shows the example of run-time error message 1

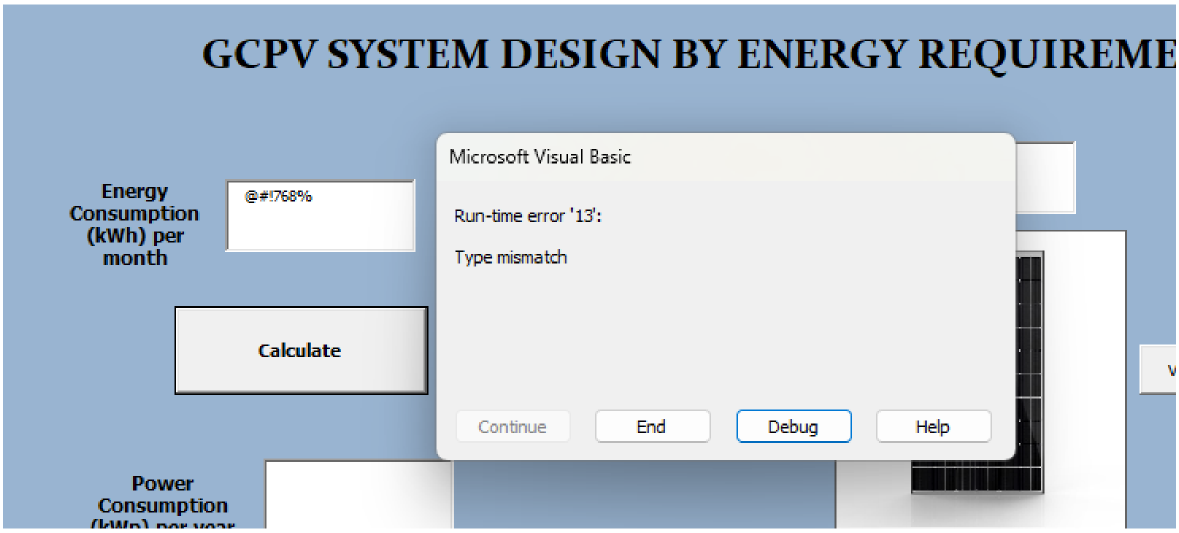


Figure 4.2 shows the example of run-time error message 2

4.2.2 Condition 2

In this subsection, numerical values are entered. However, the value for power consumption (kWp) per year is below 2000kWp and can only calculate yearly power consumption. Hence, it will display a pop-up stating “Invalid”. Figures 4.3 and 4.4 show the results for when the numbers are entered.

$$Power\ consumption\ per\ year = Energy\ consumption\ per\ month\ \times 12$$

From Figure 4.3, the user inserts 166kWh as their monthly energy consumption. Therefore, it will display 1992kWp as the power consumption (kWp) per year.

$$166kWh \times 12 = 1992kWp$$

From Figure 4.4, the user inserts 57kWh as their monthly energy consumption. Therefore, it will display 664kWp as the power consumption (kWp) per year.

$$57kWh \times 12 = 664kWp$$

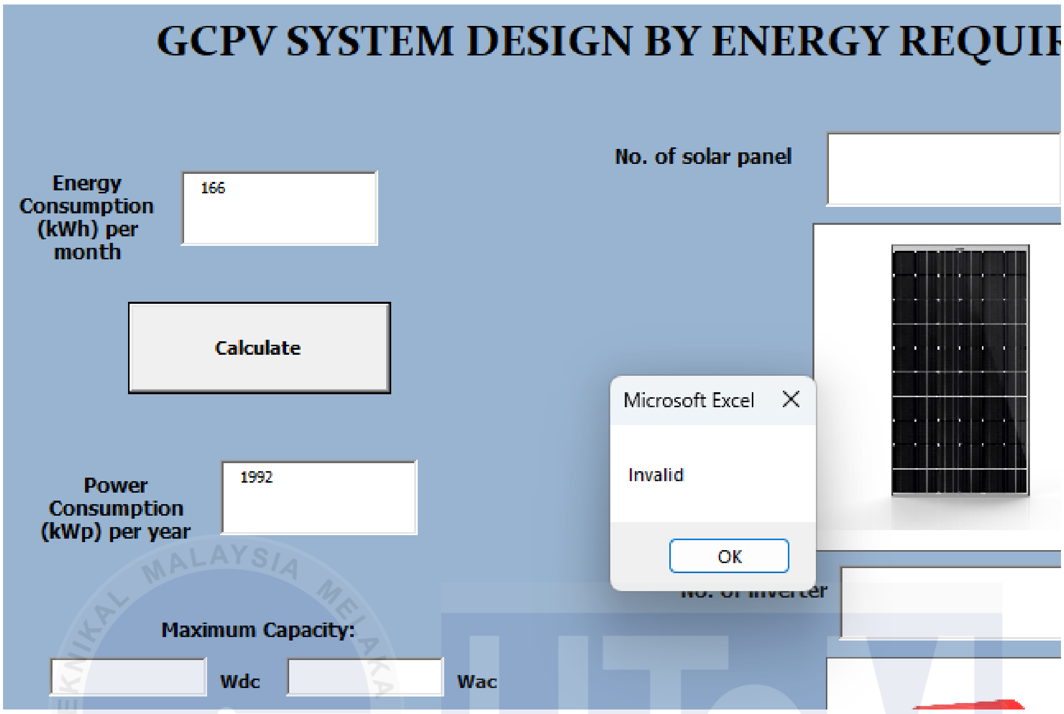


Figure 4.3 shows the example of invalid message 1

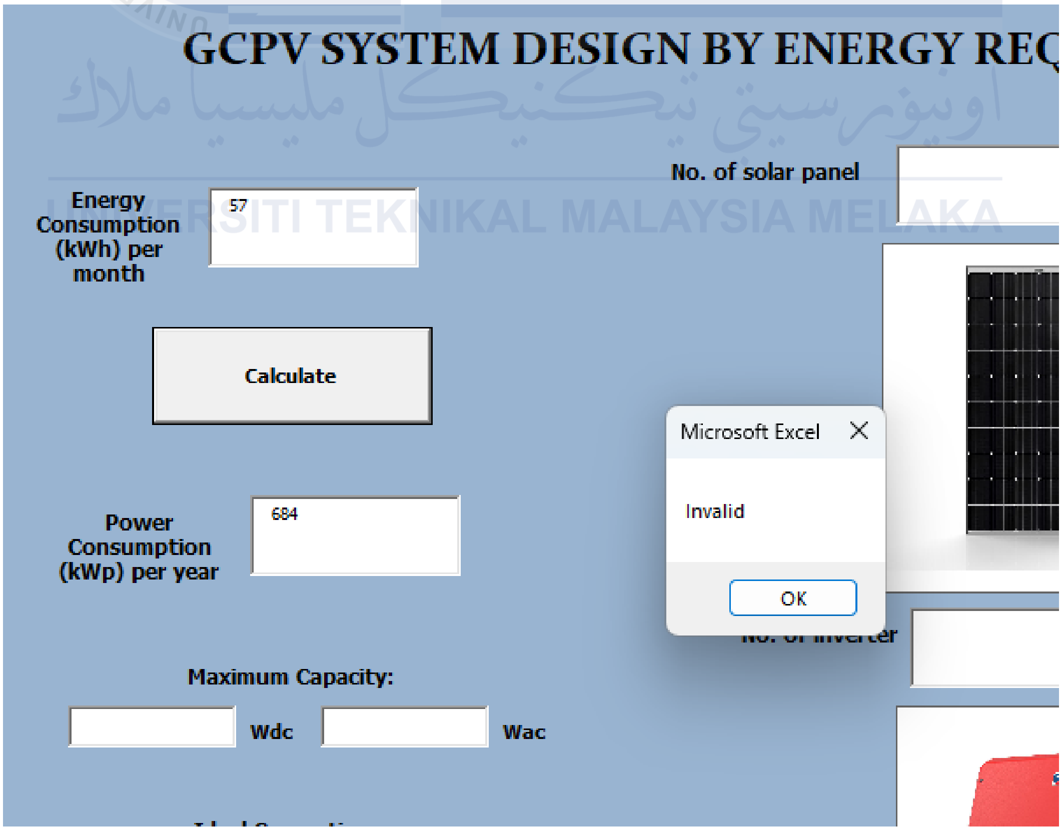


Figure 4.4 shows the example of invalid message 2

4.2.3 Condition 3

In this subsection, values are entered and calculated. It will display the value of the ideal generation that is able to cover the whole system. Figures 4.5 and 4.6 show the result for when these values are entered.

$$Power\ consumption\ per\ year = Energy\ consumption\ per\ month\ \times 12$$

$$Parray = \frac{Power\ Consumption\ per\ year}{ftemp\_avg\ \times\ fmm\ \times\ fdirt\ \times\ eff\_inv\ \times\ eff\_PV\_inv\ \times\ PSH}$$

$$Number\ of\ solar\ panel = \frac{Parray}{400W}$$

$$Number\ of\ PV\ inverter = \frac{Parray}{2000W}$$

$$Maximum\ capacity\ for\ solar\ panel, Wdc = no.of\ solar\ panel\ \times 400W$$

$$Maximum\ capacity\ for\ PV\ inverter, Wac = no.of\ PV\ inverter \times 2000W$$

$$Ideal\ generation\ for\ solar\ panel, Wdc = no.of\ solar\ panel\ \times 400W$$

$$Ideal\ generation\ for\ PV\ inverter, Wac = (no.of\ solar\ panel \times 4000W)\ \times 0.97$$

From Figure 4.5, the user inserts 355kWh as their monthly energy consumption. Therefore, it will display 4260kWp as the power consumption (kWp) per year. From the yearly power consumption, the application generates a calculation of 11 solar panels, 3 inverters, maximum capacity of 4400Wdc and 6000Wac, and ideal generation of 4400Wdc and 4268Wac.

$$355kWh \times 12 = 4260kWp$$

$$Parray = \frac{4260kWp}{0.82 \times 0.95 \times 0.97 \times 0.97 \times 0.95 \times 1510}$$

$$= 4.0516kW$$

$$\approx 4.052kW$$

Number of solar panels needed:

$$\frac{4.052kW}{400W} = 10.13$$

$$\underline{\approx 11\ modules}$$

Number of PV inverters needed:

$$\frac{4.052kW}{2000W} = 2.026$$

$$\underline{\approx 3\ inverters}$$

Maximum capacity for solar panels:

$$\underline{11 \times 400W = 4400Wdc}$$

Maximum capacity for PV inverters:

$$\underline{3 \times 2000W = 6000Wac}$$

Ideal generation for solar panels:

$$\underline{11 \times 400W = 4400Wdc}$$

Ideal generation for PV inverters:

$$\underline{(11 \times 400W) \times 0.97 = 4268Wac}$$

From Figure 4.6, the user inserts 256kWh as their monthly energy consumption. Therefore, it will display 3072kWp as the power consumption (kWp) per year. From the yearly power consumption, the application generates a calculation of 8 solar panels, 2 inverters, maximum capacity of 3200Wdc and 4000Wac, and ideal generation of 3200Wdc and 3104Wac.

$$256kWh \times 12 = 3072kWp$$

$$Parray = \frac{3072kWp}{0.82 \times 0.95 \times 0.97 \times 0.97 \times 0.95 \times 1510}$$

$$= 2.9217kW$$

$$\approx 2.922kW$$

Number of solar panels needed:

$$\frac{2.922kW}{400W} = 7.305$$

$$\underline{\approx 8\ modules}$$

Number of PV inverters needed:

$$\frac{2.922kW}{2000W} = 1.461$$

$$\underline{\approx 2\ inverters}$$

Maximum capacity for solar panels:

$$\underline{8 \times 400W = 3200Wdc}$$

Maximum capacity for PV inverters:

$$\underline{2 \times 2000W = 4000Wac}$$

Ideal generation for solar panels:

$$\underline{8 \times 400W = 3200Wdc}$$

Ideal generation for PV inverters:

$$\underline{(8 \times 400W) \times 0.97 = 3104Wac}$$

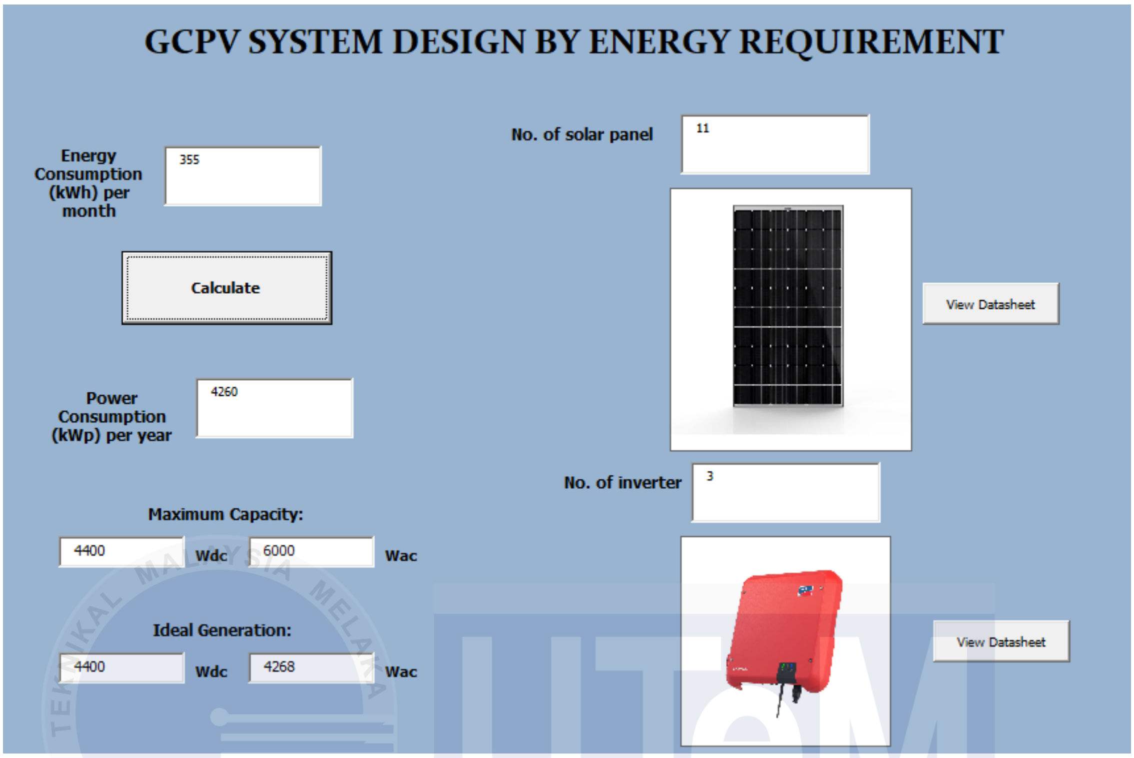


Figure 4.5 shows the result of ideal generation value higher than yearly power consumption.

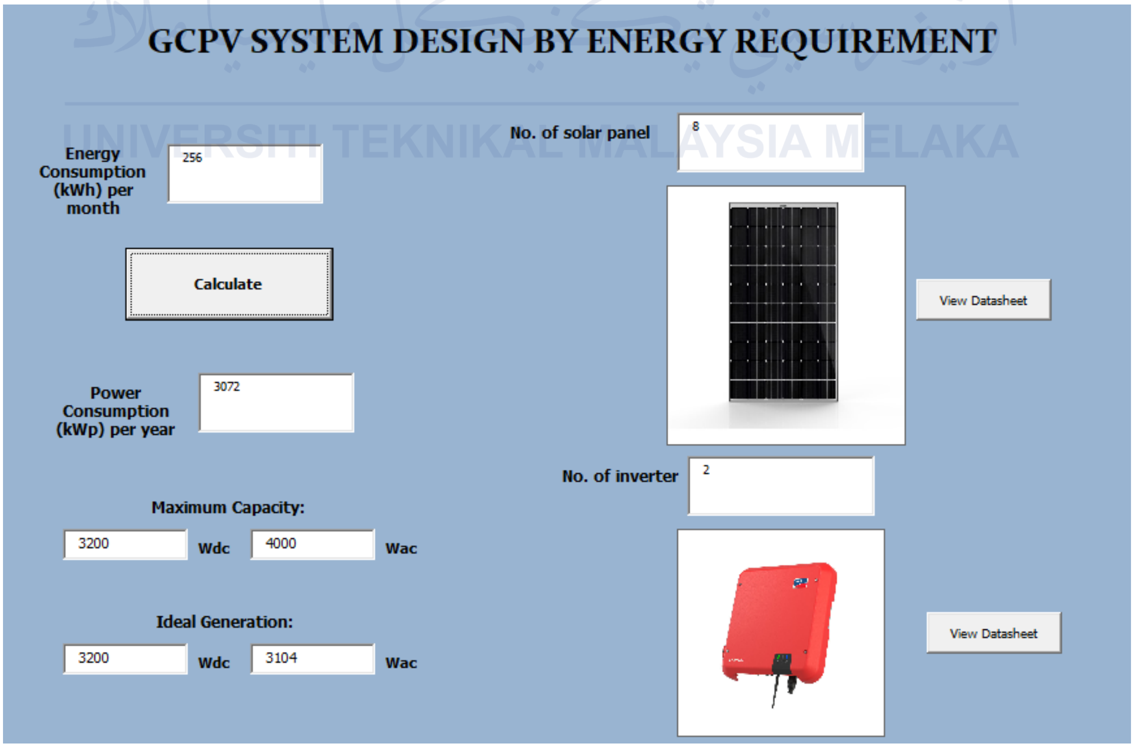


Figure 4.6 shows the result of ideal generation value higher than yearly power consumption

4.2.4 Condition 4

In this subsection, values are entered and calculated. It will display the value of the ideal generation that is unable to cover the whole system. As an engineering student, the limitation occurs at the coding where it is possible to limit the range of yearly power consumption as it is not a constant. Another limitation is when the value of ideal generation for PV inverter is less than the yearly power consumption due to the losses in PV inverter and assumption of the monthly energy consumption. Hence, to overcome this limitation and achieve the ideal PV system is to insert value of the highest monthly energy consumption.

4.2.4.1 Yearly Power Consumption of 5724KWp

From Figure 4.7, the monthly energy consumption is 477kWh which is assumed for every month. In some months, it might be lower than 477kWh. The yearly power consumption is 5724kWp and the ideal generation for PV inverter is 5432Wac. Therefore, 5432Wac is sufficient and can cover the whole system. The acceptable range for error is less than or equal to 10%. For this case, the error percentage is 5.1%.

$$Power\ consumption\ per\ year - ideal\ generation\ for\ PV\ inverter = Difference$$

$$= 5724 - 5432$$

$$= 292$$

$$\frac{Difference}{Power\ consumption\ per\ year} \times 100 = \frac{292}{5724} \times 100$$

$$\underline{= 5.1\%}$$

From Figure 4.7, the user inserts 477kWh as their monthly energy consumption. Therefore, it will display 5724kWp as the power consumption (kWp) per year. From the yearly power consumption, the application generates a calculation of 14 solar panels, 3 inverters, maximum capacity of 5600Wdc and 6000Wac, and ideal generation of 5600Wdc and 5432Wac.

$$477kWh \times 12 = 5724kWp$$

$$Parray = \frac{5724kWp}{0.82 \times 0.95 \times 0.97 \times 0.97 \times 0.95 \times 1510}$$

$$= 5.444kW$$

Number of solar panels needed:

$$\frac{5.444kW}{400W} = 13.61$$

$$\underline{\approx 14\ modules}$$

Number of PV inverters needed:

$$\frac{5.444kW}{2000W} = 2.722$$

$$\underline{\approx 3\ inverters}$$

Maximum capacity for solar panels:

$$\underline{14 \times 400W = 5600Wdc}$$

Maximum capacity for PV inverters:

$$\underline{3 \times 2000W = 6000Wac}$$

Ideal generation for solar panels:

$$\underline{14 \times 400W = 5600Wdc}$$

Ideal generation for PV inverters:

$$\underline{(14 \times 400W) \times 0.97 = 5432Wac}$$

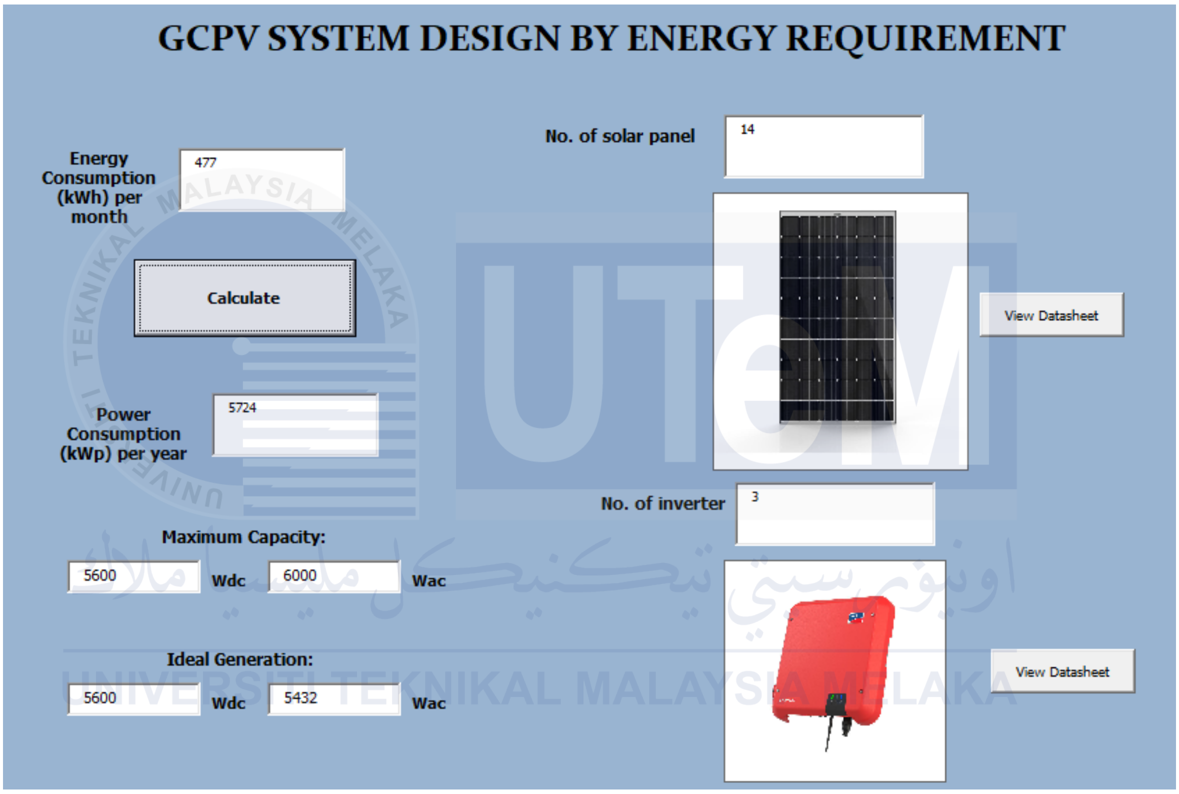


Figure 4.7 shows the result of ideal generation lower than yearly power consumption

4.2.4.2 Yearly Power Consumption of 3600KWp

From Figure 4.8, the user inserts 300kWh as their highest monthly energy consumption. Therefore, it will display 3600kWp as the power consumption (kWp) per year. From the yearly power consumption, the application generates a calculation of 9 solar panels, 2 inverters, maximum capacity of 3600Wdc and 4000Wac, and ideal generation of 3600Wdc and 3492Wac. The error percentage shown is 3% which is within the acceptable range for error.

$$Power\ consumption\ per\ year - ideal\ generation\ for\ PV\ inverter = Difference$$

$$= 3600 - 3492$$

$$= 108$$

$$\frac{Difference}{Power\ consumption\ per\ year} \times 100 \ = \frac{108}{3600} \times 100$$

$$\underline{= 3\%}$$

$$Power\ consumption\ per\ year = Energy\ consumption\ per\ month\ \times 12$$

$$300kWh\ \times 12\ = 3600kWp$$

$$Parray = \frac{3600kWp}{0.82\ \times\ 0.95\ \times\ 0.97\ \times\ 0.97\ \times\ 0.95\ \times\ 1510}$$

$$= 3.4238kW$$

$$\approx 3.424kW$$

Number of solar panels needed:

$$\frac{3.424kW}{400W} = 8.56$$

$$\approx 9\ modules$$

Number of PV inverters needed:

$$\frac{3.424kW}{2000W} = 1.712$$

$$\approx 2\ inverters$$

Maximum capacity for solar panels:

$$9 \times 400W = 3600Wdc$$

Maximum capacity for PV inverters:

$$2 \times 2000W = 4000Wac$$

Ideal generation for solar panels:

$$9 \times 400W = 3600Wdc$$

Ideal generation for PV inverters:

$$(9 \times 400W) \times 0.97 = 3492Wac$$

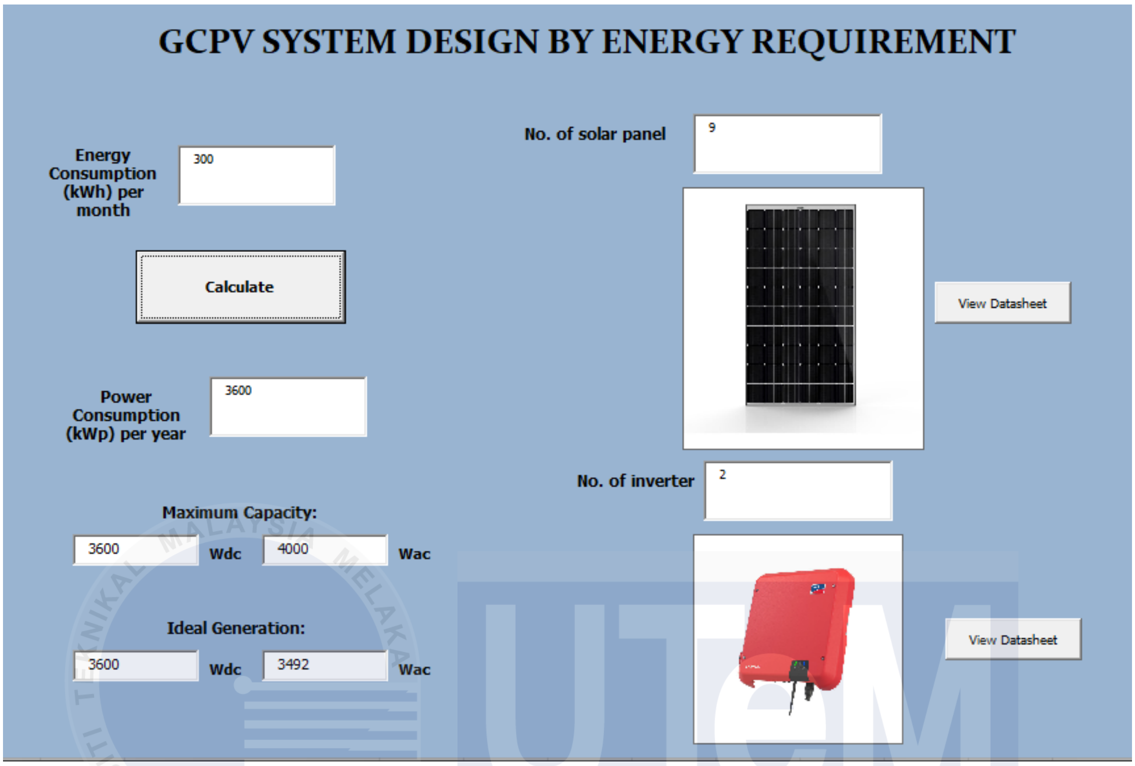


Figure 4.8 shows the result of ideal generation lower than yearly power consumption

4.3 Summary

The outcome of the project explained in this chapter is the simple application of generating the quantities of solar panels and PV inverters needed based on energy requirement. In this chapter, application ability and analysis are demonstrated. The desired result for this project is the user will key in their monthly energy consumption for GCPV system. This project succesfully calculated the ideal number of solar panels and PV inverters needed for the whole system. The project will be using VBA coding and interface for the dashboard.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter will provide a summary of the project, including the project's history, research on previous journal articles, methodology used to create the project, and results of the project. In addition, this chapter describes the future work that can be implemented and the potential of the project.

5.2 Conclusion

In chapter 1, the project's context is described. This chapter also discusses the background of the project and applications of grid-connected photovoltaic systems. This chapter also describes the problem statement, the objectives that this project aims to achieve, and the project's scope.

The research of the preceding paper and article is then discussed in chapter 2. This project's software and parameters are described in the research report. This chapter also describes the grid-connected photovoltaic system's components.

Next, chapter 3 discusses the methodology required to implement the Excel with VBA GCPV System Design Apps that are user-friendly. The methodology's primary objective is to describe the role of VBA in Excel functions. This capability allows users to simply know their product and output power of PV system by energy requirement.

In chapter 4, the project results, and the steps necessary to utilise the project are discussed. It also included the steps of manual calculation for the whole PV system. The dashboard layout of the project is also included. In this project, few limitations were discovered which occurs at the coding where it is possible to limit the range of yearly power consumption as it is not a constant. Another limitation is when the value of ideal generation for PV inverter is less than the yearly power consumption due to the losses in PV inverter and assumption of the monthly energy consumption. Hence, the highest monthly energy consumption is chosen so it can cater the whole system. This is to make sure that the PV system is able to cover the yearly energy consumption.

5.3 Future Work

For future work, the dashboard can be enhanced with a new layout capable of displaying multiple options for solar panel and solar inverter varieties. This project can also be utilised for determining output based on surface area.

5.4 Project Potential

This is a simple application that solar PV installers can use to upgrade the customer's comprehension of how large a system they need to install according to their yearly energy requirement. This application may also be sold to companies that are registered with the Sustainable Energy Development Authority (SEDA).

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