DECISION-MAKING ON PV MODULES FOR VERY LARGE SCALE PHOTOVOLTAIC SYSTEMS USING IMPROVED ANALYTIC HIERARCHY PROCESS

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The theoretical potential of solar energy is enormous, far beyond what the world could ever require. With Photovoltaic Module (PV) efficiencies, solar energy from desert regions would be more than enough to meet all the electricity demand in both industrialized and developing countries. In this project report, three kinds of silicon-based PV modules namely mono-crystalline silicon (sc-Si), multi-crystalline silicon (mc-Si) and amorphous silicon (a-Si) are being discussed. Analytic hierarchy process (AHP) was performed on decision-making of which PV module is suitable to be installed in a very large scale PV system. Four major criterion are importantly highlighted in this study; the cost, the energy requirement, the CO\textsubscript{2} emissions and the energy pay-back time. The judgments of each criterion is obtained then put in matrix form to implement the iteration process to meet the demands of accuracy, simplicity and consistency. Once the weight of the criterion is obtained, the process in AHP method is furthered done to pairwise between the weight of criterion and the alternatives. From the AHP results, a conclusion that sc-Si is the optimum option for very large scale photovoltaic power generation which to be installed in the desert. From the analysis procedure, the AHP method provided an analyzed tool effectively for the decision-making on PV module.
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CHAPTER 1

INTRODUCTION

1.1 Project Background

In these years, the world economic growth and population increase need more energy, especially in developing countries. If world energy demands continue to increase, in certain countries, the primary energy source will be exhausted. Renewable energies are expected to resolve both the energy and the environmental issue and solar energy is one promising renewable. It is already known that the world’s large deserts present a substantial amount of energy-supplying potential. [1] Therefore there are many researches being conducted about very large-scale photovoltaic power generation (VLS-PV) system on a desert. Despite applying the energy in a bigger scale, nowadays, few houses and building also may take advantage on this renewable energy – solar energy. But, in considering installing the photovoltaic modules, a few matters should be informed first – the factors influence, cost, design and installation checklist.

Heat and light are two main forms energy that come from the sun. There are two main types of solar power systems; the first is solar thermal system that trap heat to warm up water and the second is a number of solar cells electrically connected to each other and mounted in a support structure or frame called Photovoltaic (PV) module that convert sunlight directly into electricity. The PV module can be wired
together to form an array. In general the larger the area of a module or array, the more electricity can be produced.

The PV module can be wired together to form an array. In general the larger the area of a module or array, the more electricity can be produced. When the PV modules are exposed to sunlight, direct current (DC) is generated. An inverter then converts the DC value into alternating current (AC), so that it can be fed into one of building’s AC distribution boards without affecting the quality of power supply.

When installing the PV module for Very Large Scale area, one most good example of study is done by International Energy Agency Photovoltaic Power Systems Programme (IEA/PVPS) Task 8 in order to examine and evaluate the potential of VLS-PV system, which have capacities ranging from several mega-watts to giga-watts, and to develop practical proposals for demonstrative research towards realizing VLS-PV systems in the future [2]. The most important parts of PV systems are the cells which form the basic building blocks of the unit, collecting the sunlight, the modules which bring together large numbers of cells into a unit, and in some situation, the inverters used to convert the electricity generated into a form crystalline silicon, or thin film. PV system nowadays that available in the market is grid-connected, off-grid and hybrid system but among of all these system, the grid-connected is the most widely used.

The analytic hierarchy process (AHP) is a decision method that widely applied in many decision-making fields, which was developed by American operation scientist T.L. Saaty in 1973 [3]. It has particular applications in group decision making and used on complex decision question essences, the influencing factors and the intrinsic relations. AHP is mostly applied in many fields such as government, business, industry, healthcare and education, and in helps decision makers find one that best suits their goal and their understanding of the problem. The word ‘hierarchy’ means an arrangement of items (objects, names, values, categories and so on) in which items are represented as being “above”, “below” or “at the same level as” one another. In relation, AHP is used in decision-making to decide which
technology is suitable and stable enough in applying which PV technology in very large scale photovoltaic manufacturing.

Generally, the importance of applying PV modules is as important as applying renewable energy – solar energy as it is environmentally friendly, minimal maintenance, maximum reliability and the system are easily expanded.

1.2 Problem Statements

There are many things to be considered when installing and applying the PV system such as the technology used, the installation angle, the shading, the solar PV output file, the solar PV yield and the most important factor is the cost for PV solar system.

Solar PV systems can be classified based on the end-use application of the technology. There are two main types of solar PV systems: grid-connected (or grid-tied) and off-grid (or stand alone) solar PV systems. Most solar PV that used grid-connected systems are installed on buildings or mounted on the ground if land is not a constraint. The latter is also is also known as Building Integrated Photovoltaic (BIPV). With BIPV, the PV module usually displaces another building component such as window glass or roof or wall cladding, thereby serving a dual purpose and offsetting some cost. The ratio of solar PV supply to power grid supply varies, depending on the size of solar PV solar system. Whenever the solar PV supply exceeds the building’s demand, excess electricity will be exported into the grid. When there is no sunlight to generate PV electricity at night, the power grid will supply all of the of the building’s demand. A grid-connected system can be effective way to reduce your dependence on utility power, increase renewable energy production, and improve the environment. Off-grid solar PV systems are applicable for areas without power grid. Currently, such solar PV systems are usually installed
at isolated sites where the power grid is far away, such as rural areas or off-shore islands. But they may also be installed within the city in situations where it is inconvenient or too costly to tap electricity from the power grid. An off-grid solar PV system needs deep cycle rechargeable batteries such as lead-acid, nickel-cadmium or lithium-ion batteries to store electricity for use under conditions when there is little or no output from the solar PV system, such as during the night.

A solar PV system is powered by many crystalline or thin film PV modules. Individual PV cells are interconnected to form a PV module. This takes the form of a panel for easy installation. PV cells are made of light-sensitive semiconductor materials that use photons to dislodge electrons to drive an electric current. There are two broad categories of technology used for PV cells, namely crystalline silicon; the majority used thin film, which newer and growing in popularity.

Crystalline cells are made from ultra-pure silicon raw material such as those used in semiconductor chips. They use silicon wafers that are typically 150 to 200 microns (one fifth of a millimetre) thick. Thin film is made by depositing layers of semiconductor material barely 0.3 to 2 micrometres thick onto glass or stainless steel substrates. As the semiconductor layers are so thin, the costs of raw material are much lower than the capital equipment and processing costs. For example, a thin film amorphous silicon PV array will need close to twice the space of a crystalline silicon PV array because its module efficiency is halved, for the same nominal capacity under Standard Test Conditions (STC) rating.
1.3  Project Objectives

Quantitative evaluation in types of PV module system is the main core in this article, so it is important to gather as much as theoretical and practical knowledge regarding solar system. The major objective of this research is to identify the most convenient and effective PV module to be installed in large scale area. The selection is done using improved Analytic Hierarchy Process (AHP) method.

Its measurable objectives are as follows:

1.3.1  To identify the type of PV module
1.3.2  To determine the relation characteristic regarding the selected PV module
1.3.3  To analyze the priority of each selection
1.3.4  To show the efficiency of AHP in solving complex decision-making problem

1.4  Project Scopes

This research is primarily concerned with the selection on which PV module for very large scale photovoltaic system. The method used to evaluate which most suitable PV module is AHP method. The scopes of this project are:

1.4.1  For evaluation using AHP, three alternatives of PV module is tested and four criterion is choose
1.4.2  The iteration is done up to three times
1.4.3  Preliminary classification of most suitable PV module is selected based on result obtained.
1.5 Layout of Thesis

This thesis contains five chapters. Chapter 1, the Introduction represent the overview of the study including the project background, problem statement, project objectives and project scopes of this study. Meanwhile, Chapter 2, describe the Literature Review of the study including the theories and the method of Analytic Hierarchy Process (AHP).

Chapter 3 outlines the Methodology used throughout the study. The explanation in detail regarding the PV module and how these data is interpreted with the AHP method in order to select the best module to be installed in large scale area.

Chapter 4 represents how this studies conducting AHP, step by step in modeling AHP in PV module selection. Chapter 5 discusses the analysis on result obtain from Chapter 4 and the final decision is revealed in this section. The last chapter is Chapter 6 functioning to conclude the study and suggests future works that should be done.
CHAPTER 2

LITERATURE REVIEW

2.1 Theories

Around the world, electricity remains the vital component of national and international development. The implementation of renewable energy resources can provide solutions to these challenges by stimulating the early implementation of economically viable sustainable energy technologies. The energy demand is growing on the different continents unequally. The demand for energy in the world has experienced a sudden increase in the developing regions, particularly in Asia, and predictions are that in 2030, demand will increase by 66% compared to 2000.

Figure 2.1: World primary energy supply by region, 1971-2030
The sun is one of the prerequisites of life on Earth, providing light and maintaining the essential energy cycles. As a ubiquitous source of energy, sunlight can be used in electricity production as well. Solar cells or photovoltaic’s (PVs) are semiconductor devices that convert sunlight into electricity. Most photovoltaic cells available today are made from silicon. As the research on solar cells has progressed, several alternative cell solutions have been discovered. Photovoltaic technology uses sunlight to generate electricity. The basic energy producing unit is the photovoltaic cell.

Figure 2.2 shows the basic operation of a photovoltaic cell. Typically most of the cell has a slight positive electrical charge. A thin layer at the top has a slight negative charge. The cell is attached to a base called a “backplane”. This is usually a layer of metal used to physically reinforce the cell and to provide an electrical contact at the bottom. Since the top of the cell must be open to sunlight, a thin grid of metal is applied to top instead of a continuous layer. The grid must be thin enough to admit adequate amounts electrical energy.

![Figure 2.2: Operation of a Photovoltaic Cell](image)
2.2 PV Module

Photovoltaic module is made up of semiconductor material which is sensitive to sunlight and usually has an area of 1 - 100 cm\(^2\). Individual cells are usually connected together to a module with typical areas of 0.5-2 m\(^2\), and modules are combined in an array to create a PV system which produces the needed output voltage and current. Additionally, the power density of sunlight is low (1 kW/m\(^2\) in clear conditions), so large-scale PV electricity production requires either a large scale area covered with PV modules or mirrors for concentrating sunlight on a smaller area. The power generated by a PV module depends on the module technology and on the intensity of sunlight. The power a module produces at a given moment is proportional to the perpendicular sunlight intensity on the module surface. Power is therefore reduced if conditions are cloudy or if the angle of incidence of sunlight is large. In general, the average power production of a PV system can be reliably estimated on a monthly basis from previously measured meteorological data. Shorter time intervals introduce uncertainty, but weather forecasts can well be used to predict power production one day in advance. As a semiconductor device the PV module is quiet, static, and solid-state. It requires little maintenance in order to operate the conversion of sunlight into electricity is a very reliable process that does not produce any emissions. In addition, the module does not include any moving parts that could wear out or break down. However, the encapsulation of the PV module is critical to ensure that the electrically active parts of the module are not harm by the surrounding environment. In normal operation the system feeding the PV electricity to the network is more susceptible to damage than the module itself.
PV arrays can be built ranging from a few milliwatts up to several megawatts due to their modular design. Existing arrays can always be expanded to meet growing electricity demand, although the electronics in the system may need updating. Easily adaptable and lightweight, the PV panels can be installed virtually anywhere on Earth without concerns for fuel transportation logistics. Furthermore, PV modules can produce electricity at the point of consumption, which reduces transmission losses and can improve service reliability. PV technology also offers an option for energy diversification. It can be used to complement other energy sources, both traditional and renewable. In particular, photovoltaic electricity is well suited for providing additional electricity during peak demand, which in some regions coincides with the sunniest hours of the day due to air conditioning. At present, the major drawback of photovoltaic electricity is its high price. When a lot of power is needed, photovoltaic is seldom cost-effective. However, in small-scale consumption such as in residential buildings, the competitiveness of PV electricity is improving.
While the initial investment into a PV system demands capital, operation and maintenance require next to nothing.

To relate the photovoltaic modules or system to environmental aspects, there are a lot to be discussed. Photovoltaic technology provides clean energy: sunlight acts as the fuel and there are no harmful emissions or polluting gases released during operation. In particular, PV systems do not produce any CO2 emissions when operating, so they can be used to cut greenhouse gas emissions. Apart from operation, PV systems nevertheless carry the environmental weight of other stages in their life cycle. The life cycle of photovoltaic systems consists of the manufacturing, operating, decommissioning and recycling of the system. The life cycle of the module can extend at its best over 40 years whereas the other components of the system last substantially less and thus require replacement. Presently the components do not have a large impact on the energy requirements of a grid-connected PV system compared to the energy-intensive module production. Most of PV’s ecological footprint originates from the manufacturing process, which can be traced in detail.

Manufacturing consumes a relatively large amount of energy and bulk materials as well as some scarce or toxic substances. The energy used in PV production is taken from the grid, so the overall emissions of photovoltaic electricity are mostly inherited from the grid electricity generated by fossil fuels. One of the main environmental concerns with photovoltaic modules is the hazardous substances involved in the production of the modules, including large volumes of acid and alkaline etchants as well as smaller amounts of toxic lead. In addition, certain PV technology has specific needs: for example, the hazardous substances used in PV technology are deposited in a very stable and fixed way in the solar cell and therefore pose hardly any threat to the environment. The risks concerning the toxic materials used in photovoltaic should not be exaggerated as long as their disposal is properly attended to.
Photovoltaic can also be evaluated in terms of energy pay-back time. Energy payback time illustrate the time taken for power generation to compensate for the energy used in production. For photovoltaic modules it is typically 2 to 4 years, which amounts to approximately 10% of their expected lifetime. The payback times decrease when the cells become more efficient, so considerable reductions up to less than one year or 3% as anticipated in the future. In improving the cost-effectiveness of photovoltaic’s, most of their environmental impacts are bound to go down as well: the impacts are mainly associated with material use or process that will have to be eliminated or optimized. Since new advances are constantly reported, the performance and cost limits have evidently not been met, and there are still plenty of improvements to be performed before optimal production is reached. As the environmental impact of the module production decreases, the role of the other components will become more important in terms of the energy efficiency of the whole PV system.

The cost of a solar system depends on many factors: system configuration, equipment options, labor cost and financing cost. Prices also depending on factors such as the house itself, how the module is integrated into the roof or mounted on the roof. The cost also depends on the system size or rating, and the amount of electricity it produces, generally, solar PV system entail high capital costs. With solar power, you can save on the purchase of electricity from the grid. But, even with these savings, it will take a long time to recover the capital cost of the solar PV installation. The operating costs for solar PV installation are negligible, but the annual maintenance cost beyond the warranty period may amount to 0.5% to 1% of the capital cost of the installation. Therefore on an overall basis, solar PV derived electricity is still much more expensive than that from the power grid. However, the cost of solar historically been falling by about 4% a year, and if this continues, solar PV may be competitive within the next 10 years. Basically costs for all kinds of PV systems are composed of many parts such as PV module, inverter, cable, array support, foundation and so on. They also depend on a variety of factors, including system size, location, customer type, grid connections and technical specifications.
2.3 Analytic Hierarchy Process (AHP) Method

The analytic hierarchy (AHP) is a decision method that widely applied in many decision making fields, which was proposed by American operation scientist T.L.Saaty in 1973 [3]. The unique characteristic of analytic hierarchy process is that drastically analyzing on the complex decision question essences, the influencing factors and the intrinsic relations, it makes decision-making process mathematical quantified using less quantitative information, thus provide a simple decision method for the multi-selection problems. AHP method also has been used by many authors to resolve decision-making issues in project selection (Dey and Gupta, [4]; Mian and Christine, [5]). Project selection issues have been discussed in various management functions like in research and development (Loch and Kavadias, [6]), environmental management (Eugene and Dey, [7]), and quality management (Hariharan et al., [8]).

The AHP method is a comprehensive framework, which is designed to cope with the intuitive, the rational, and the irrational when it comes to a multi-objective, multi-criterion and multifactor decision with and without certainty for any number of alternatives. It also has been applied to many complex problems with various decision analyses, which enable decision-makers to derive ratio scale priorities or weights as opposed to arbitrarily assigning them. Many others recognize a very important feature that AHP supports decision-makers by allowing them to structure complexity, to exercise judgment, and to incorporate both objective and subjective considerations in the decision process. The AHP is also a novel decision analyzing approach that structures a problem using a hierarchy. It enables us to make effective decision on complex issues by simplifying and expediting human natural decision-making processes. Some other sees the AHP is the theory of measurement for dealing with quantifiable or tangible criteria that has found rich applications in decision theory, conflict resolution and in models of the brain. To illustrate this process in an easy way, Bagchi and Rao define that this hierarchy starts with a top level containing the ultimate objective of the problem. The sub-objectives, if any, constitute the next level, followed by the criterion variable affecting the higher-level objectives. The bottom level of the hierarchy contains the options or alternatives.
Therefore, each hierarchical level can be seen as being made up of elements (or criterion variables) that in turn, are decomposed into sub-elements that make up the next level of the hierarchy.

Over the years, AHP has become one of the most widely used multiple criteria decision-making tools for researchers and decision makers. Many outstanding works have been published based on AHP in different fields such as planning, selecting best alternative, resource allocations, resolving conflict, optimization, etc., and numerical extensions of AHP.

The AHP is an operational research model which can be adapted for any analysis involving pair-wise comparison. This tool was first developed by Saaty in 1980, and later improved upon in subsequent years (Saaty, 1980, 1994, 2000, and 2001). The process requires the decision maker to provide judgments about the relative importance of each criterion and then specify a preference for each decision alternative to 3 each criterion. The output of the Analytic Hierarchy Process is a prioritized ranking indicating the overall preference for each of the decision alternatives (Saaty, 1980, 1994, 2000, and 2001). One advantage of the Analytic Hierarchy Process is that it is designed to handle situations in which the subjective judgments of individuals constitute an important part of the decision process. It is designed for situations in which ideas, feelings, and emotions affecting the decision process are quantified to provide a numerical scale for prioritizing the alternatives (Taha, 2006). This tool can enable the marketers in the companies in the Nigerian food and beverage industry, which is the main focus of this study, determine the relative importance of the relationship marketing variables and use this knowledge to develop their strategic relationship marketing mix.

The Analytic Hierarchy Process (AHP) by Saaty is a multicriteria decision-making (MCDM) technique that has been widely used to solve complex decision problems, in which both qualitative and quantitative aspects are considered. Although AHP has been widely applied in engineering, government, industry,
management, manufacturing, personal, political, social, and sports [9], it is also considerably criticized for its possible rank reversal phenomenon, which means changes of the relative rankings of the other alternatives after an alternative is added or deleted.

AHP, created by Professor T.L. Saaty in Pittsburgh University in United States, is a decision analysis method of bringing quantify and qualitative analysis together [3]. It is a simple and convenient decision-making method that can provide an approach to the complex decision-making problems with multiple targets, multiple criteria and no architectural characteristic. AHP can make the complex decision-making process by using less quantify information on the bases of analysis inner, affecting factors and inherent relations of the problems.

There are three steps common to all decision-making technique involving numerical analysis of alternatives.

1) determine the relevant criteria and alternatives.
2) attach numerical measures indicating relative importance of the criteria,
3) assign a ranking or preference to each alternative, possibly by processing the numerical values.

2.4 Description of Previous Method

Generally, PV cells are made of light-sensitive semiconductor materials that use photons to dislodge electrons to drive an electric current. There are many kinds of PV Modules, for example, mono crystalline silicon, multi-crystalline silicon, a-Si, CdTe, hybrid, ribbon, EFG, HIT, CIS and so on [10]. Two major types are crystalline silicon and thin film. Crystalline cells are made from ultra-pure silicon raw material such as those used in semiconductor chips. They use silicon wafers that
are typically 150-200 microns (one fifth of a millimetre) thick. While, thin film is made by depositing layers of semiconductor material barely 0.3 to 2 micrometres thick onto glass or stainless steel substrates. As the semiconductor layers are so thin, the costs of raw material are much lower than the capital equipment and processing costs. For crystalline silicon the available product are made up of poly-crystalline and mono-crystalline. For thin film, it may come in amorphous silicon (a-Si), Tandem a-Si, Cadmium Telluride and many more. The listed technology is suitable used for very large scale photovoltaic system.

![Image](image.png)

Figure 2.4: Different types of photovoltaic module system

Typically the different type of common PV module performs different conversion efficiencies. Mono-crystalline silicon takes 12.5 up to 15% Poly-crystalline silicon takes 11-14%, Amorphous Silicon (a-Si) takes up 5 to 7% and Cadmium Telluride (CdTe) takes from 9 up to 12% of conversion efficiency. For crystalline silicon PV modules, the module efficiency is lower compared to the sum of the component cell efficiency due to presence of gaps between the cells and the border around the circuit such as wasted space that does not generate any power hence lower total efficiency.

Another important differentiator in solar PV performance, especially in hot climates, is the temperature coefficient of power. PV cell performance declines as cell temperature rises. For example, in bright sunlight, cell temperature in certain place can reach over 70°C, whereas PV modules are rated at a cell temperature of 25°C. The loss in power output at 70°C is therefore measured as \((70 - 25)\) multiply temperature coefficient. Most thin film technologies have a lower negative temperature coefficient compared to crystalline technologies. In other words, they tend to lose less of their rated capacity as temperature rises. Hence, under certain place’s climatic condition, thin film technologies will generate 5-10% more
electricity per year. When applied the suitable PV module in large scale area such as in desert, which the climate is hot throughout the year, more and more energy for electricity will accommodate the need of countries.

Mono-crystalline is the original PV technology invented in 1955, and never known to wear out. Poly-crystalline entered the market in 1981. It is similar in performance and reliability. Mono-crystalline modules are composed of cells cut from a continuous crystal. The material forms a cylinder which is sliced into thin circular wafers. To minimize waste, the cells may be fully round or they may be trimmed into other shapes, retaining more or less of the original circle. Because each cell is cut from a single crystal, it has a uniform color which is dark blue.

Poly-crystalline cells are made from similar silicon material except that instead of being grown into a single crystal, it is melted and poured into a mold. This forms a square block that can be cut into square wafers with less waste of space or material than round single-crystal or mono-crystalline wafers. As the material cools it crystallizes in an imperfect manner, forming random crystal boundaries. The efficiency of energy conversion is slightly greater per watt than most Mono-crystalline modules. The cells look different from mono-crystalline cells. The poly-crystalline surface has a jumbled look with many variations of blue color. In fact, there are quite beautiful like sheets of gemstone. In addition to the above processes, some companies have developed alternative such as ribbon growth of crystalline film on glass. Most crystalline silicon technologies yield similar results, with high durability. Twenty-year warranties are common for crystalline silicon modules. Mono-crystalline tends to be slightly smaller in size per watt of power output, and slightly more expensive than poly-crystalline. The construction of finished modules from crystalline silicon cells is generally the same, regardless of the technique of crystal growth. The most common construction is by laminating the cells between a tempered glass front and a plastic backing, using a clear adhesive similar to that used in automotive safety glass. It is then framed with aluminum.
The silicon used to produce crystalline solar modules is derived from sand. Even it is the second most common element on Earth, but it is still costly. This is because to produce photovoltaic effect, it must be purified to an extremely high degree. It is also in high demand in the electronics industry because it is the base material for computer chips and other devices. Crystalline solar cells are about the thickness of a human fingernail. They use a relatively large amount of silicon.
CHAPTER 3

METHODOLOGY

3.1 Project Methodology

In order to choose the most suitable PV module, this research is performing method in decision-making by using a very compatible method known as Analytic Hierarchy process (AHP). Thomas Saaty developed this method with a purpose to be an effective means of dealing with complex decision-making. AHP helps capture both subjective and objective evaluation measures, providing a useful mechanism for checking their consistency relative to consider alternatives, thus reducing bias in decision-making. AHP concepts can be applied to problems of size estimating in support of cost modeling. Since many cost models use some measure of size as a cost driver and since accurate size measurement is often elusive, AHP type sizing can be invaluable in overcoming challenges of credible estimating. Using the AHP involved the mathematical synthesis of numerous judgements about the decision problem at hand. It is not uncommon for these judgements to number in the dozens or even the hundreds.

This chapter will discuss on how the research is done literally in order to obtain useful information about the PV module and AHP method. The research is conducting in phase’s basis as follows:
Phase 1: Literature reviews on previous works regarding PV module selection.

Before implementing the AHP method, one major research done is about understanding the basic concept of PV, types of PV module and its important characteristic applied which will influence the purpose of installation and also any other related issues.

All the readings obtained then will be analysed in AHP method to choose the most compatible PV module to be installed in large-scale area with minimum cost estimation.

Phase 2: Understanding the basic concept of AHP Method

The precepts of AHP are reflected in observation of workings of the human mind. When confronted with a complex problem, humans tend to group elements of the problem by certain. The procedure for using the AHP can be summarized as follows:

- Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives.
- Establish priorities among the elements of the hierarchy by making a series of judgements based on pair-wise comparisons of the elements.
- Synthesize these judgements to yield a set of overall priorities for the hierarchy
- Check the consistency of the judgements
- Come to a final decision based on the results of this process
The above mentioned procedure of AHP eliminates the difficulty in comparing a large number of factors at the same time. The weight can be assigned individually by experts in a team, and processed statistically to reflect overall tendencies and to identify controversial issues. Therefore it can gain relative weight and provide a measure of coherence. But the weight achieved by this method still have certain subjectivity because arbitrariness is still contained in relative importance matrix, and the opinions given by the experts teams may conflict with each other. If it fails the consistency check in fourth point, and second till fourth point will be carried out repeatedly and the experts have to reappraise. Moreover, the index system of AHP is usually regarded as static process. Once the weights of the factors are determined, the selection criterion of different kinds of PV module is evaluated with some weights. But actual concentrations of factors are changing along with market situation. Hence, it is necessary to change the weights of factors for different kinds of PV module.

**Phase 3: AHP Model of PV Module Selection**

When the previous phase is settled, the next phase to be conducted is modelling the AHP method to obtain the objective in selecting the PV module. There are a few steps in this phase.

- Establishing analytic hierarchy structure
- Weights calculation of fixed criterion
- Weights calculation of alternative criterion
Figure 3.1: Project flow chart

1. Start
2. Data Collecting (Experimental Work)
3. Develop Hierarchy Tree (Identify Type of PV module as alternatives and Criterion)
4. Judgments on each item
5. Run the iteration through the AHP for each of criterion
6. Evaluate the eigenvector
7. Pairwise each eigenvector
8. Result Analysis
9. End
CHAPTER 4

AHP MODELLING OF PV MODULE SELECTION

Decision-making involves the use of intelligence, wisdom and creativity in order for humans to satisfy basic needs or to survive. Evaluating a decision requires several considerations such as the benefits derived from making the right decision, the costs, the risk, and losses resulting from the action taken if the wrong decision is made. Modern day decision-making has been inherently complex when many factors have to be weighed against competing priorities. One of modern tools developed in the last 30 years used to assess, prioritize, rank and evaluate decision choices is the Analytic Hierarchy Process (AHP). Thomas Saaty developed AHP method in the 1970s as a way dealing with weapons tradeoffs, resource and asset allocation, and decision making when he was a professor. AHP uses the judgement of decision makers to form a decomposition of problems into hierarchies.

4.1 Establishing Analytical Hierarchy Structure

 Basically, an important part of this process is to accomplish these three steps:

- To state the objective of the study
- To define the criteria
- To pick up the alternatives

The objective of this study is to determine which PV module is the most suitable and compatible to be installed in large-scale area and may fulfill the need to supply much
electrical energy. In conjunction of PV module selection, many important criteria of PV module is define. By the time the criterion is identified, the final process is to pick up alternatives which are available in the market. As illustrate in the following diagram, the steps then arranged in a hierarchical tree.

![Diagram](https://via.placeholder.com/150)

Figure 4.1: A general hierarchy tree

Four major important criteria that to be consider in PV module selection are the cost and the environmental issue which is the energy requirement, CO₂ emission rate and Energy Payback Time (EPT) [10]. The cost is a major consideration as it is important to achieve the early objective of the project to supply electrical energy. Energy requirement obtained by dividing total primary energy requirement of the PV system throughout its life-cycle with annual power generation. CO₂ emission rate is a useful index to know how much PV module is effective for the global warming while the EPT means years to recover primary energy consumption throughout its life-cycle by its own energy production.

The following figure shows the hierarchy tree for the project with labeling the criterion and the alternatives. Iteration will be done maximum to three time for each criterion and also for the alternatives to meet the criterion. Then, the pair wise of the
REFERENCES


