OPTIMAL POWER DISPATCH OF HYBRID PV/DIESEL SYSTEMS USING HEURISTIC BIO-INSPIRED ALGORITHMS

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ABSTRACT

Generally due to the strategic equatorial region, Malaysia is advancing into solar energy as a replacement of alternative source for an electrical energy production to meet the escalation load demand. Thus, the integrated hybrid system like *PV-Genset* set system are developed to generate power to meet load demand where it can be fitted into its local geography and others according to specification. However, this does not guarantee the hybrid system to generate power optimally as weather conditions (solar insolation, temperature and others) changes periodically and influence the power generation and the power dispatch to the load. Therefore, the hybrid system does not operate at the optimal state and without a proper dispatching controller it may lead to over stress one or the other hybrid system component causes frequent wear and tear with higher maintenance cost to the system. In order to curb this situation, the hybrid system requires a specific approach along with a controller to search and to dispatch the hybrid *PV-Genset* system generated power at the best potential optimal state. A Bio-Heuristic approach can be applied to determine the optimal power generation while a dispatch controller dispatches the electric hybrid power system to the load demand. The aim of this research is to implement the selected bio-heuristic approach such as Particle Swarm Optimisation (PSO) while Fuzzy Logic is used as a dispatch controller for a small scale hybrid *PV-Genset* system. The simulation of the hybrid *PV-Genset* system modelling is simulated using two types of tropical weather conditions (sunny and rainy). From this research, simulation results are obtained and series of analysis is conducted using MATLAB/SIMULINK. Through the analysis, results have shown the contribution of each hybrid system component operates at the optimum level while power is dispatch to the load based on the hybrid system capability.

CONTENTS

CHAPTER 1

INTRODUCTION

Photovoltaic-Generator set hybrid system is one of the most common integrated power generation system used widely in most countries. Furthermore, it is also environmental friendly towards nature. This chapter provide the general information of this research with brief explanation in each section. The respective sections are divided as project background, problem statement as well as the objective and scope of this research.

1.1 Project background

Concerns on conserving and minimising the impact on the environment are consciously growing. Interests on environmental issues are increasing and ideas on developing green technology for power generation application purposes have attracted the attentions of many countries. Solar photovoltaic (*PV*) system generates pollution-free electricity and its solar energy is available at no cost, unlike conventional generation system that using fossil fuel. The advantages of renewable energy such as solar, wind and tidal energies are sustainable and eco-friendly but however harnessing its energies leads to a major drawback due to the inconsistency as it fluctuates in nature. Therefore integration with other power generation sources such as diesel generator is required to obtain a reliable and stable power supply system [1].

Climatic condition and fluctuation of solar insolation are the major setback for *PV* power generator system. It completely disappears when nightfall arrive. As a result, a standby generator set is required to integrate with *PV* system as it meets the load energy demand at various conditions. Sizes of a diesel generator are available in wide range from $1kW$ to several hundred kilowatts. Furthermore, it is commonly known for its required back-up power supply operation and thus, it is widely use in either small or medium range size of power generation as an electrical energy production scheme [2]. Diesel generator is meant to operate during high load demand period simultaneously charging the storage battery to reach the highest generation efficiency and to reduce the fuel consumption [3].

Hybrid system is often known as an alternative off-grid power supply, conventional generation system and islanded power supply. In order to design the hybrid system, consideration factors like weather condition, operation and maintenance has to be considered. Hence, the design and control operation of hybrid system is constructed in such a way to adapt the non-linear variable with a large number of components [4]. Unfortunately, most of the classical optimisation methods proposed is not suitable for problems in optimal design dispatch regarding to fuel consumption [3].

Hybrid *PV-Genset* power generation performance is dependent on factors like cell temperature, fault level of *PV* array, output power, insolation level, operation and fuel consumption of diesel generator. In *PV* system, a constant cell temperature with a higher insolation level results higher generation on power and voltage. If cell temperature rises, the lower open circuit voltages effect the power generation. The power output increases with a steep gradient which is almost proportional to the solar radiation depending to the cell temperature of the system. Other adverse performance of the *PV* arrays could be affected by aging of the system, dust and mechanical damage [5].

As the solar radiation varies with time, such as year, month and hour, the insolation level needs to be forecasted to make full use of the solar energy. Likewise, a certain method is needed to develop in order to optimise the power generation of the *PV* system under various condition. Then, a certain optimal power dispatching strategies is required when the hybrid system is used to supply energy to some random load. Therefore, this research presents a method of optimisation and dispatching power strategy for *PV-Genset* hybrid system using bio-inspired approach. The general overview of this research is illustrated in a block diagram shown in Figure 1.1.

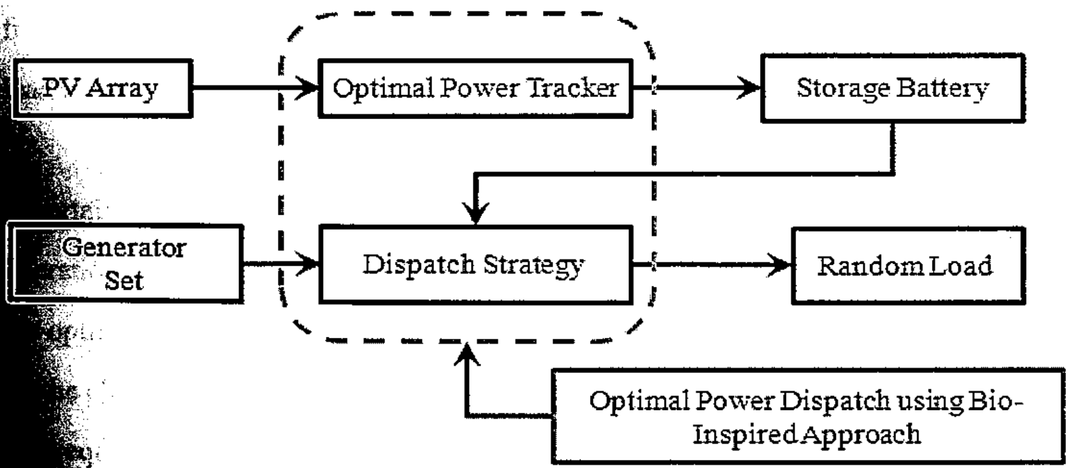


Figure 1.1: Overview of main component in *PV-Genset* hybrid system using bio-inspired approach

1.2 Problem statement

Even though *PV-Genset* hybrid system are classified as one of the reliable renewable systems in power generation, yet improvement are still attain from time to time. The main concern of this system is power optimisation and random load dispatch strategy under various operating conditions.

Power optimisation plays an important factor in a hybrid system because it reflects the performance and the generated power efficiency of the system. Without this consideration, the maintenance of the hybrid system components is costly due to no alternate operation between the *PV* and the generator set under various conditions [1]. Generators set are meant to operate during high load in order to attain the maximum power generated efficiency. If the operation period is longer during high load, the generator achieves the best efficiency, fuel consumption reduction [3] and frequency of generator start is minimised. If this is not considered as well, this will lead to battery wear [6] and the system lifecycle will be shortened [7-8].

Likewise, the problem gets complicated for a hybrid system to operate under uncertain renewable energy supplies and load demand. This is because the optimal operation of the hybrid system is interdependent between the operation strategies and the optimum sizing of the components [9]. Thus, hybrid systems are developed based on the chosen operation algorithm and strategy depending on the area of deployment and requirement.

Furthermore, dispatch strategy is essential in a hybrid system as it manages the distribution of the generated power supply to the load depending on the systems capability and load demand. Power dispatch system refers to a control system approach of supplying consistent power depending on the system components ability [6]. Without a dispatch strategy introduced into the hybrid system, the system operation and maintenance are costly. The power generated from the hybrid system are not fully utilised either. Thus, the problems arise when the hybrid system operates under a non-linear operating condition during uncertain load demand.

Therefore, the importance of this research is to optimise the power using bio-inspired approach and dispatch the power to the load based on the hybrid system parameters such as the efficiency and cost.

1.3 Research objectives

The major objective of this research is to propose an integrated scheme for optimal power dispatching and utilisation of the *PV-Genset* hybrid system with random load. Its measurable objectives are as follows:

1) To forecast the solar insolation using artificial intelligence (*AI*).

2) To develop a control algorithm that will dispatch the optimal power of the *PV-Genset* hybrid system with battery storage and supply power to the load.

3) To analyse the parameters that influence the performance of the *PV-Genset* hybrid system.

1.4 Research scopes

It is too vast for any single research work under a given time frame to cover all the topics related to the optimal power dispatch of the hybrid *PV-Genset* system using bio-inspired approach. Therefore, this project will focus on certain parameters of the system.

1) The solar insolation, temperature and other collected data are carried out nearby the placed solar panel at *UTHM* electrical power laboratory about 12 hours long from 7 am to 7 pm.

2) The control module design is based on the inter-operation of *PV-Genset* hybrid system components capability and ability while dispatch the optimal generated power to the load demand.

3) The conducted analysis is for a small scale *PV-Genset* hybrid system where each parameter is analyse such as the system components operation characteristics, the diesel generator power and the fuel consumption level, the energy gap production, the power feed of the storage battery and the excess power contribution of the *PV* generator supplied to the load.

1.5 Thesis Outline

In this subsection, a general overview of chapters compile in thesis is elaborated in stages corresponding to the research work that has been done. The thesis chapter comprises of six main outline, introduction, literature review, optimal power tracker for photovoltaic system using artificial neural network *(ANN)* and particle swarm optimisation *(PSO)*, modelling of hybrid photovoltaic-diesel generator set system using fuzzy logic controller *(FLC)*, simulation results analysis and discussion, conclusion and recommendation for future works.

Chapter 1 highlights the introduction and importance of this research as a head start. With the provided information, collective facts for the problem statement are discussed, followed by the research objective, scopes, thesis outline and summary.

Chapter 2 discuss about the theory, application and previous works done by other researches related to the hybrid *PV-Genset* system. The background studies helps to elaborate and understand the possible improvement of the hybrid system in detail.

Chapter 3 explains the implementation of the optimal power tracker using artificial neural network (*ANN*) and particle swarm optimisation (*PSO*). The approach begins with the explanation of the artificial neural network used as solar insolation forecast. Then, the forecasted data is implemented to search the optimal photovoltaic power using particle swarm optimisation algorithm. MATLAB is used as a simulation tool in both approaches.

Chapter 4 describes the modelling of the hybrid photovoltaic-diesel generator set system using fuzzy logic controller (*FLC*). The hybrid system modelling is developed for real time simulation using both approaches in Chapter 3. Each of the system component and the dispatch strategy is given in details. SIMULINK is used as a simulation tool to verify the *PV-Genset* system modelling.

Chapter 5 expound the simulation results, analysis and discussion of the hybrid *PV-Genset* system. This chapter discuss the characteristic behaviour on how the hybrid system adapt with the various operating condition. Then, each hybrid system component is analysed and review using a define parameters.

Last but not least, Chapter 6 presents the research conclusion and recommendation for future works. This chapter concludes the research work along with some future recommendation for further improvements.

1.6 Summary

The synopsis of this chapter emphasises the introduction of the whole research. In the beginning, the research background is elaborated with the importance of the ...ntage and drawback of the hybrid *PV-Genset* system. Then, the explanation ...es and discussed the potential obstacles occur during the hybrid system ...tion. Later, the objective and scopes are asserted to specify the goal and the limitation of the research work. Finally, the thesis outline is included as it explains the general overview of each chapter for the ease of the reader to aid the clarity of the research work.

CHAPTER 2

A REVIEW OF AN ABSTRACT ACCOMPLISMENT / LITERATURE REVIEW

This chapter provides detail information of previous research and development of *PV-Genset* hybrid system that has a paramount impact in the engineering society today. Thus, this chapter forms the backbone of this research as it contributes the vital information needed for improvement. The chapter sections are described as introduction, solar insolation forecasting, hybrid PV-Genset system and summary.

2.1 Introduction

Malaysia is one of the tropical countries in South East Asia and is blessed with abundance of sunlight. Due to its strategically situated on the equatorial region, the country experienced only two monsoon seasons and approximate 6 hours of sunshine per day [10]. Based on the average scale of solar insolation receives in Malaysia, it is ranges between 4.21 *kWh/m²* to 5.56 *kWh/m²* [10]. As for the ambient temperature, it remains uniformly through the year as it average scale ranges between 26 *°C* to 36 *°C* [10]. Therefore *PV-Genset* system is viable in Malaysia for electrical production scheme if corresponding study and research on climate condition are considered despites on the system cost.

As the result of the increasing demand of electrical energy, there are numerous researches on hybrid *PV-Genset* power generation system. Most of the hybrid *PV-Genset* system improvements are made based on the discovery of the uncertain factors of hybrid systems operation such as climate, operation and maintenance which disrupts the electrical energy production scheme. Next section discusses the difference, gap and importance of this research based on the different approach implemented by other researcher in their previous works. The explanations are divided into two subsections which is solar insolation forecasting in section 2.2 and hybrid *PV-Genset* system in section 2.3.

2.2 Solar insolation forecasting

Solar energy is utilised as electrical energy conversion production scheme for power generation purposes. This solar energy is also known as solar insolation as it is measured through the suns energy that shines on the surface of the earth during a particular time. Solar insolation data is important as it illustrates the pattern of the insolation level and designates a potential location with the highest solar insolation [illegible]. Unfortunately, these data are not always available due to cost and difficulty constraints in measurement because there are existences of only few meteorology [illegible] especially in remote areas. Hence, there is an alternative method on estimating this data [12-14]. Due to the solar insolation pattern changes periodically and demand growth on solar energy, modelling and forecasting is essential. Likewise solar insolation forecasting, maximises the usage of solar energy [5] as it improve the operation control for solar energy harvesting and energy optimisation [12] in *PV* system.

Artificial Intelligence (*AI*) is a biological technique that is adopted from living creatures and has been applied in many areas in stand-alone and hybrid *PV* systems. *AI* such as artificial neural network (*ANN*) is one of the most common successfully method applied in modelling and forecasting of solar insolation data as to curb the non-linear meteorological condition [14]. Hence, *ANN* is effortless applied by most researches on this application in order to study the change of solar insolation throughout a potential location on solar energy. The following subsection explains further on the forecasting application using *ANN* in correspond with the selected previous works of few researches in different areas applied.

2.2.1 Artificial neural network (*ANN*) in solar insolation forecasting

In the human brain lies the central component of the human nervous system which consists billions of neurons [15]. These neurons are interconnected trough synapses as to establish a communication link in between. The structure of each neuron comprises of a body, an axon and dendrites. Each structure plays a significant role of receiving and transmitting signals in a human brain. The functions of dendrites are receiving incoming signals from other neurons. Then this signal is combined in the cell body and transmitted through an axon. Finally, the axon releases or generates a synaptic connection with the other neurons [15]. Figure 2.1 illustrates the biological neuron model [15].

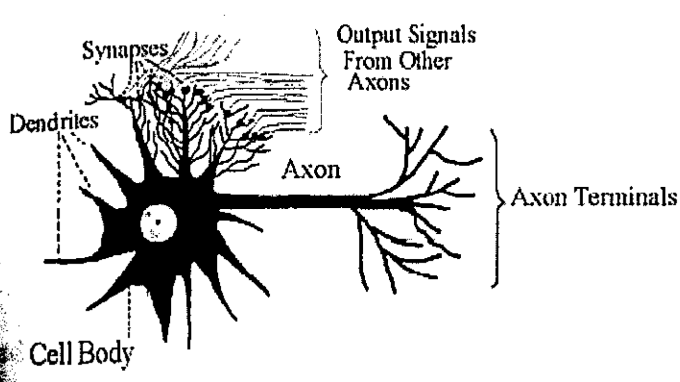


Figure 2.1: The biological neuron [15]

ANN mimics the human brain biological nervous system [15]. There are five elements in an artificial neuron such as inputs, weights, summing function, activation function and output [15]. Each function of the *ANN* imitates the four important biological operation of the human brain. These operations are to receive input signal from other neurons, combine them, execute the information process and produce an output result [12] as shown in Figure 2.2.

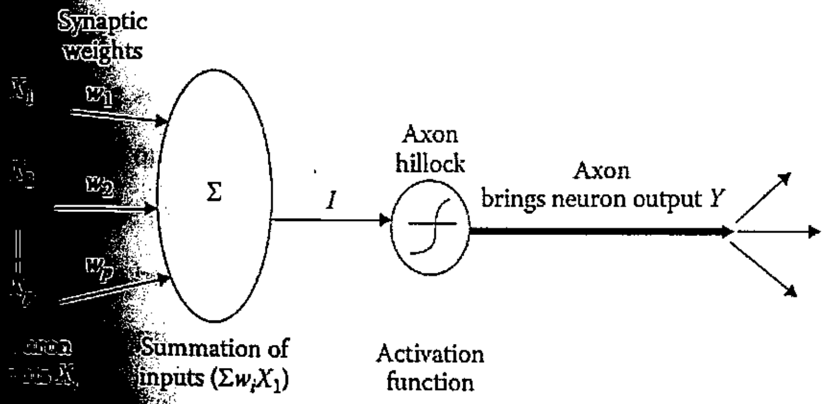


Figure 2.2: Operation of *ANN* architecture

ANN is classified by it network structure, training or learning algorithm and activation function. The structure comprise of input layer, a few hidden layer and an output layer [16]. There are various types of *ANN* network structure and Multilayer Perceptron (*MLP*) is one of them. *MLP* is used in many solar insolation forecast [5], since it is the cheapest method that uses a certain input parameters such as latitude, longitude, altitude and sunshine duration [11], sunshine ratio [12], mean daily solar irradiance, mean daily air temperature, day and month [13], sunshine accuracy and mean average temperature [11]. Multi-Layer Perceptron (*MLP*) is preferable in most solar insolation modelling and forecasting [13] due to its well-known feed-forward structure.

MLP network has different connection styles and learning algorithms as it is adapted to its structure and convergence time. There are two types of learning algorithm, supervised and unsupervised [11]. With supervised learning, weights in the network are adjusted to produce the desired output [11]. On the contrary, unsupervised learning does not depend on the target data to achieve the desired output as the aim is to find the core structure of the data [11]. One of the common supervised learning algorithms used is back-propagation algorithm [17]. Back-propagation algorithm is applied in the network design as it is to train the network subset data. Likewise, most insolation level forecast [11, 12, 13, 14, 15, 16, 17] uses back-propagation algorithm. Besides *MLP* topology, Radial Basis Function (*RBF*) is another well-known topology which offers a better result than *MLP* restrictedly if there are more input parameters [11-12].

The activation function refers to the output relation of the network to the ...put based on the input activity level. Sigmoid function is widely used as activation ...nction due to its non-linearity function whose output lies in between 0 and 1 [18]. ...t is used in between each hidden layers in the network structure. As the activation ...ction is applied in the network, a new summary output neuron is obtained [15]. In ...research, *MLP* with back propagation topology is used to forecast the solar ...tion which will be discussed further in Chapter 3.

Several studies for the solar insolation forecast using *MLP* topology have ...d [10-15]. M.Mohandes, A.Balghonaim, M.Kassas, S.Rehman and O.Halawani, ... [10], used radial basis function (*RBF*) network to develop monthly mean daily ...diation falling on the horizontal surface and compare the performance ...with multilayer perceptron (*MLP*) network and classical regression model. ...network parameters comprise from 41 different locations in Saudi Arabia. ... also included an extra input indicating the number of months into *RBF* network. Hence, as the results from their research shows that *RBF* outperformed *MLP* as average mean absolute percentage error (*MAPE*) for *RBF*, 10.1 is lower than *MLP*, 12.6. Moreover, empirical regression model such as Angstrom (1924) and Rietveld (1978) does not surpass *RBF* as it gives a better result [10].

Atsu S.S. Dorlo, Joseph A. Jervase, Ali Al-Lawati, (2002)[11], proposed both *MLP* and *RBF* network to compare the performance of the solar radiation estimation by first estimating the clearness index. The input network parameters are taken from eight different stations in Oman. Their results have concluded that both network performed well based on root mean square error (*RMSE*) as *RBF* error ranges from 0.83 to 10.08 $MJ/m^2/day$, while *MLP* error ranges from 1.01 to 9.41 $MJ/m^2/day$. Consequently, they concluded that the best *MLP* network uses 3 hidden layers due to minimal mean and standard deviation of the root mean square errors. As their research conclusion, *RBF* is the best network due to less computation time [11].

Adel Mellit and Alessandro Massi Pavan, (2010) [12], implemented and tested using K-fold cross validation method in 24 solar irradiance forecast as to improve the *MLP* network generalisation capability in four different experiments based on sunny and rainy weather. The preeminent *MLP* structure obtained is two hidden layers as the first contains 11 neurons and the second contains 17, {3×11×17×24}. As their results, the coefficient of determination, (R^2), for sunny weather ranges from 0.95 to 0.99 while cloudy weather ranges from 0.92 to 0.97. In addition, the effectiveness of the forecast network is compared with the grid connected photovoltaic plants which give a good correlation of determination result [illegible]0. Thus, the result shows that the mean absolute error (*MAE*) is less than 5% [illegible] correlation coefficient ranges from 90% to 92% [12].

Melit, Shaari, H.Mekki and N.Khorissi, (2008) [13], introduced real time [illegible]ing application using a reconfigurable field programming gate array (FPGA) [illegible] (Xilinx and VirtexII) and hardware description language (VHDL) to [illegible] the daily solar radiation based on ANN architecture. The performance of [illegible] program environment for the back-propagation MLP network forecaster using VHDL and MATLAB is compared to determine the results accuracy.

In MATLAB simulation, the best architecture obtained resulted 98%, coefficient of determination comprise of a single layer with 9 neurons. On the other hand in VHDL environment, the data is coded in 18 bits fixed point and simulated in (MODELSIM) which gives an acceptable result. As a conclusion, they remark a good agreement between the data simulated from MATLAB and VHDL simulation environment [13].

Mónica Bocco, Gustavo Ovando and Silvina Sayago, (2006) [14], developed a back-propagation type neural network to estimate the solar radiation. Three layer network and five neurons in the hidden layer is use to simulate 8 types of forecast result models, M1-M8. The estimation result indicates the root mean square error ranging between 3.15 to 3.88 $MJ\,m^{-2}\,d^{-1}$. The 14 hours cloudiness records of the M6-M8 models result a pertinent error in estimation in each model. On contrary, the temperature and precipitation information of the M3 and M4 model result a greater error in the estimation and the difference are irrelevant to each model. M1 and M2 obtained the best estimation results as the model present a better adjustment. In the M1 model observation result, the underestimation percentage reaches 15% when the daily radiation exceeds 25 $MJ\,m^{-2}\,d^{-1}$ through an analysis dispersion diagram of the [illegible]served and estimated value as it shows a seasonal behaviour pattern correctly to [illegible]e of the observed ones [14].

Özgür, Humar, Ali and Muammer, (2010) [15], proposed a standard [illegible]-propagation and back-propagation with momentum training algorithm in daily [illegible] radiation prediction. The network topology consists of 5 inputs, a hidden layer [illegible] 10 neurons and an output. Therefore number of iteration and coefficient of [illegible]mation results from both standard and momentum back-propagation is 15000, [illegible] and 7500, 0.9821 as momentum back-propagation compute faster with better [illegible]ion. In contrast, the *MAE* and *RMSE* result of a standard back-propagation [illegible] the momentum back-propagation by 1.02% and 0.8% difference. Therefore, [illegible]luded that the standard back-propagation gives a better result with slow [illegible]al time than the momentum back-propagation as the mean relative error [illegible]ith 8.96% and 10.12% each [15].

2.3 Hybrid *PV-Genset* system

The hybrid *PV-Genset* system fulfils the objective and electricity demands to the consumers while conserving the nature, the environment and the system itself. In general, hybrid *PV-Genset* system is the integrated *PV* system with another form of fossil fuel driven power generation system as back-up supplementary power generation, such as diesel generator [19]. As to ensure a consistent supply of electrical power at all time, rechargeable storage batteries are integrated into the hybrid system as well [19].

Hybrid *PV-Genset* system is the combination number of electrical power generators and storage elements as to meet the electrical energy demands of a remote facility [19]. In addition, this hybrid system must fit in the local geography and other specifics [19]. Thus in most cases, it is ideal for remote applications such as communication stations, military installations and rural areas [19].

Meanwhile, a hybrid *PV-Genset* system can be identified either stand-alone or grid-connected. In remote and rural areas, stand-alone hybrid system would assist in [illegible]nding the electricity access in the isolated region [20]. Therefore, stand-alone hybrid system is most often found on island. As for grid connected system it is [illegible]nected to a large independent grid typically for public electricity grid and feed the [illegible] back into the main grid. This is also known as decentralised electricity [illegible]tion [20].

In many cases of hybrid *PV-Genset* system, it offers a clean and more [illegible]ective efficient power than sole diesel generator system. Ultimately, it serves [illegible] utilise the available solar energy for electrical power generation and to [illegible]el consumption of the diesel generator. As a result, renewable energy is a [illegible] solution for either grid-connected or stand-alone system [20]. Thus, the [illegible] subsection aids to elaborate the further understanding and the previous [illegible] components, connection topologies and dispatch strategy used in the [illegible]*nset* system.

2.3.1 Hybrid *PV-Genset* system components

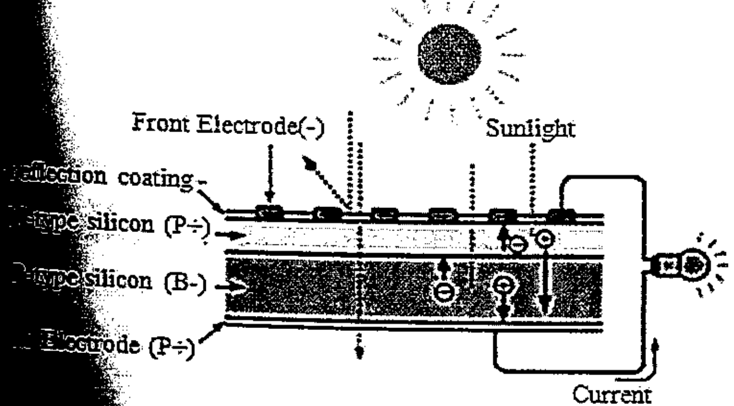
Hybrid *PV-Genset* system consist of photovoltaic array system (*PVA*), battery storage system and generator set. These are the main components that provide electrical power to the load. In order to operate efficiently, all of these components must operate under all conditions. Power condition unit such as switching power converters and inverters are also important as it is used to accommodate the variable nature of power output and prevent malfunction of the hybrid system. These components will be explained further in Chapter 4. Hence, in this subsection the theory of various system development and arrangement for different approaches in parallel of other researches previous work is explained.

2.3.1.1 Photovoltaic array (*PVA*) system development and arrangement

Solar cells are the fundamental element of the photovoltaic system (*PV*) which converts sunlight or solar energy directly to electricity. A solar cell consists of a positive and negative (*P-N*) junction formed in a semiconductor material [21]. They are much similar to any solid-state electronic devices such as diode, transistors and integrated circuits. Generally, solar cells are manufactured into PV modules for practical operations [22]. Various semiconductor materials give a different efficiency and cost. Thus, silicon is one the most common semiconductor material used in solar cells. There are several types of solar cells made from silicon such as mono-crystalline silicon (*c-Si*), poly-crystalline silicon (*poly-Si*) and amorphous-silicon [21].

Solar cells comprise of *P-N* junction that are fabricated into a thin wafer or layer of silicon material. During the dark, the current-voltage (*I-V*) output characteristics of a solar cell has an exponential characteristics same as diode [21]. When the solar cells is exposed to solar energy, it creates photons with energy greater than the semiconductor band gap energy causing an electron-hole pair where the electrons are knocked loose from the atoms in material. These electrons are carried away under the influence of the internal electric fields of the *P-N* junction and create current proportional to the incident radiation. During the short circuited solar cell, the current flows in the external circuit while as for open circuited solar cell, the current is shunted internally by the intrinsic *P-N* junction diode. Therefore, these diode characteristics set the open circuit voltage characteristics of the cell.

During electron-hole pairs are formed, the electron charges reach to the neighbouring junction, causing the electric field in the depletion region push the holes into the positive side (*p-side*) and push the electrons into the negative side (*n-side*) as shown in Figure 2.3. Each of the *p-side* and *n-side* accumulates holes and electrons creating a voltage in between the load and conducts current. If the electrical contacts are attached to top and bottom of the cell, the electrons drift out from the *n-side* into the connecting wire, through the load and back to the *p-side* as shown in Figure 2.3. Since wire cannot conduct holes, the electrons move around the circuit. Therefore, the positive current flows in the opposite direction of the electrons where the current goes from the *p-side* to the load and back into the *n-side*. In general, the conventional current flows in the opposite direction from the electrons.



2.3: Illustration of the *p-n* junction in the solar cell of the PV system

In electrical energy production schemes, solar cells are mass-produced into photovoltaic modules which are integrated into *DC* power-producing unit configuration. Typically in many *PV* systems development uses solar panels, where it is the physical connection of modules with supports to form arrays [22]. Figure 2.4 shows that *PV* system has various categories, starting from cells to arrays.

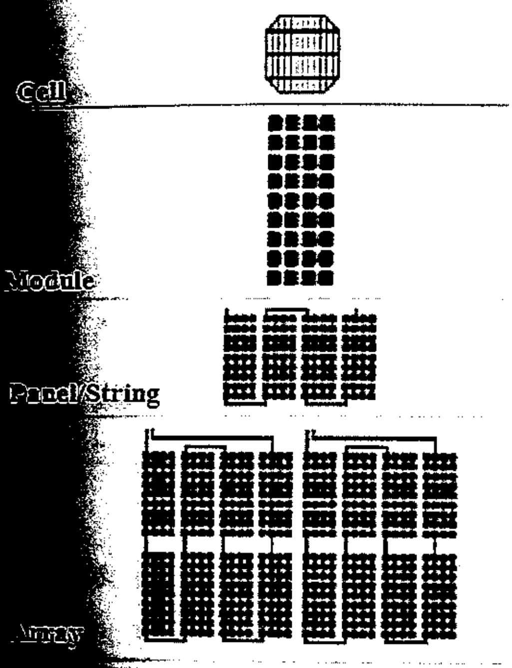


Figure 2.4: The Photovoltaic hierarchy from cell to array [23]

In Figure 2.5, it illustrates how the *PV* modules are connected in arrays with *Mp* (Module in parallel) parallel branches each with *Ms* (Module in series) [23]. The arrangement of *PV* module portrays a vital task in terms of efficiency. Figure 2.6 shows that three different types of arrangement donate various efficiencies. The *A* arrangement gives efficiency up to 97.2%, while *B* arrangement at 96.8% and *C* at 96.2% [23]. Besides the photovoltaic array (*PVA*) arrangement affects the efficiency of the system, the output power generation is dependent on the solar insolation level and ambient temperature [2]. This parameter is essential as it influences the output power generation of the *PV* system. Thus, there are solutions and studies proposed by other researches on improving the systems output power generation is followed.

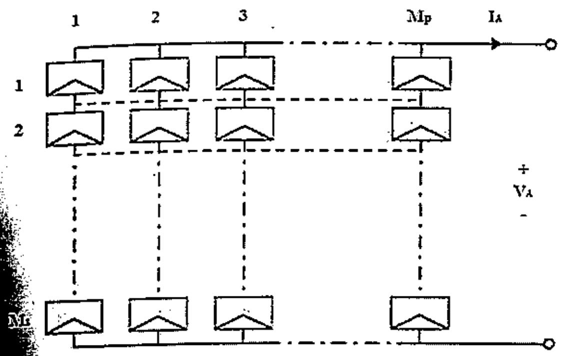


Figure 2.5: Solar Modules in array consist of *Mp* parallel branches each with *Ms* Modules in series [23]

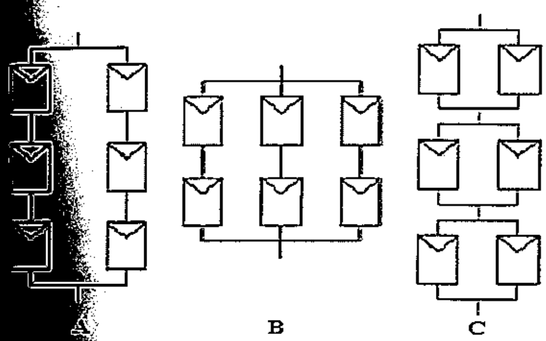


Figure 2.6: Series-parallel configuration for *PV* generator [23]

Kamaruzzaman, Mohd. Yusof and Mohd.Azhar, (2005) [1], develop an adjustable solar regulator with specific minimum power capacity on specific temperature and insolation as to utilise the available solar energy of *PVA* [1]. Ahmed Rashed, A.Elmitwally and Sahar Kaddah, (2008) [2], utilises the available energy by drawing the maximum power from the *PVA* system by using maximum power tracking (*MPT*) method which provided to operate the *PVA* direct (*DC*) voltage also known as voltage source inverter (*VSI*) (*DC*) bus voltage value. This voltage settling value uses the various possible values of insolation and ambient temperature as to analyse the *DC* operating voltage using a multiple linear regression technique via *PVA* mathematical model. In the power extraction, the author ensures that the nominal load voltage is using *PV-VSI* control arrangement subsystem [2]. Rodolfo and José L., presented a method to harness the sun energy by using Rietveld equation program to predict the average clearness index for each month of the year based on the radiation on the horizontal surface and peak sun hours as the data input. Then, the author uses Graham model program to compute the average clearness index to globally hour irradiation *G* (kWh/m^2). Thus, the *PVA* system output power generation is then calculated based on the solar irradiation computation data [4]. James, Wang and Eddy, (2004) [5], proposed that the *PVA* output power generation is computed using *m* number polynomial approximation function of array voltage. This is because the coefficient of *m* order polynomial is easily obtained through the curve fitting as it is based on the efficiency of *PVA* power generation under operation condition such as insolation level cell temperature, fault level of *PV* array and output voltage level in percentage form. Furthermore, they examine the *PV* panel under various operating condition such as different solar insolation and cell temperature. The efficiency of the power generated from the *PV* panel is determined through the data from the maximum power tracked for different insolation level and cell temperature. In addition, they used various fault scenarios for the fault level of the *PV* design to test the power generation system. They utilise the sun energy through an optimal power tracking fixed arrangement *PV* system using artificial neural network (*ANN*) to predict insolation level [5].

Battery storage system development and arrangement

...ge system is important in the design of hybrid system as it is not only to ... but it also stores the excessive electrical energy when the loading is at ... There are several types of storage battery are use in hybrid system ...cid, Lithium-ion, Nickel cadmium and Lithium Polymer. Each type of ... has its own particular characteristics. Batteries come in variety of ...l configuration [20]:

(a) Lithium and Lithium-Ion

It is the most expensive batteries in hybrid system and often used in many electronic circuits. This battery has the highest "energy density" of almost any other commercial battery as it can retain charge for months or even years, but expensive.

(b) Lithium-Polymer

It is often designed to suit the space available. Initially the cell behaves well, but tends to lose its capacity fairly rapidly on cycling. But however, the cycle-life is improved by operating over a narrower voltage range. The drawback is that the cell has to operate in the temperature range 80 to 120°C which limits its application.

(c) Nickel-Cadmium or "Ni-Cad"

This battery is known for being rechargeable, inexpensive, easy to obtain and often used in vehicles and industrial applications. However, it contains highly toxic material which is harmful to the environment. Despite from its toxic substantial, it is commonly consider for applications that requires high current drain, long cycle-life and wide temperature range during constant power discharge. Nevertheless, this battery does not last long as alkaline and zinc batteries due to slow overnight recharge, relatively high self-discharge rate and memory effect.

(d) Lead Acid

Well known as rechargeable battery and most effective application in many *PV-Genset* hybrid system and uninterruptible power supplies buildings. Although this type of battery is heavy and bulky yet it is economical, compact, powerful and easy to get.

In hybrid power system applications, storage batteries are require to withstand several charge/discharge cycle, a low self-discharge rate and less maintenance. The capacity of the battery is expressed in ampere hour (Ah) where it is the total amount of electricity that is drawn from a fully charged battery at a discharge rate and electrolyte temperature until the voltage drop at a specified minimum [20].

In natural occurrence of the battery, its efficiency and capacity deteriorates as ageing take place as time passes [3]. This is due to the varying temperature of the environment [20] and the alternate operation of charging and discharging from the battery which affects the battery lifecycle. Therefore from the ensued of other previous works, life cycle of the battery storage system is crucial as it can minimise cost and prolong the hybrid system operation. Yasuharu Ohasawa, Shin-ichi Emura and Kenji Arai, (1993) [3], uses the battery state of charge (*SOC*) as hourly sample time that is digitised into 100 steps in between 0.3 to 1.0. The *SOC* of the battery is digitally computed using dynamic programming (*DP*). When the depth of discharged hits 0.7, the storage battery is charge and vice versa. The lifespan of a battery is rolong and monitored through the charging and discharging current from the specify C of the battery as it also minimises the fuel consumption of the generator [3]. dolfo and José L. ,(2004) [4], and G.C.Seeling-Hochmuth, (1997) [9], uses the hmacher battery model method to monitor the efficiency of the storage battery. authors use *SOC* to specify the limit range of the battery charging and harging rate (η) depending on the battery manufacture. Thus, the limit ranges of mum and minimum influences the battery current rate. The battery current rate ds on battery state either negative (discharge) or positive (charge) at each time [9].

2.3.1.3 Generator set system development and arrangement

Generator set often used as a backup generator or secondary power supply incorporated to any hybrid system. This is because it is reliable and available in small or medium size power applications [2]. Diesel generator is one of the most common generator set used in many places without connection to the power grid, as emergency power-supply if the grid fails. The system consist of the combination of a diesel engine with an electrical generator (often called an alternator) to generate electrical energy. In order to maintain its physical condition of the diesel generator set, operating cost and maintenance cost are the standard criteria and indicators to sustain the system. Operating cost of the diesel generator is controlled by its fuel consumption as its maintenance cost is depends on the number of the operating hours and the loading of the engine [20]. Therefore, frequent starting of the diesel generator increases both operating and maintenance cost due to the mechanical wear on the engine [20]. Likewise, to improve the efficiency of the generator set in supplying power, it is recommended to operate on full load while fuel consumption is reduced as it minimises the wear on the engine.

G.C.Seeling-Hochmuth, (1997) [9], uses (Morris,1988) approach for linear diesel generator operation regarding on fuel consumption reduction. This model explains that the user need to enter the data points for each type of diesel generator depending on the entered fuel consumption scale as to understand the fuel consumption level based on diesel generator size. They concluded that diesel generator operates efficiently in high load simultaneously reduces fuel consumption and maintenance [9]. C.Dennis Barley and C.Byron Winn, (1996) [6], assume that the diesel fuel consumption is a linear function to its output power generated presented by (Skastein and Uhlen, 1989). The author studied the relation between the models of diesel generator set and the output rated power generated of the set. They concluded that energy cost per *kWh* is at minimum as rated power at full load while approaches infinity at no load [6].

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