# FUZZY LOGIC – GENETIC ALGORITHM BASED MAXIMUM POWER POINT TRACKING IN PHOTOVOLTAIC SYSTEM

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## ABSTRACT

This project is about to carried out the optimization and implementation a fuzzy logic controller (FLC) used as a maximum-power-point tracker for a PV system, are presented. Maximum power point tracking (MPPT) are used to integrate with photovoltaic (PV) power systems so that the photovoltaic arrays are able to deliver the maximum power available. The near optimum design membership functions and control rules were found simultaneously by genetic algorithms (GAs) which are search algorithms based the mechanism of natural selection and genetics. These are easy to implement and efficient for multivariable optimization problems such as in fuzzy controller design that consist large number. The FLC designed and the implementation of photovoltaic model using Matlab/Simulink software package which can representative of PV cell module. Taking effect of sunlight irradiance and cell temperature into consideration, the output power and current characteristics of PV model are simulated and optimized.

## ABSTRAK

Projek ini membentangkan cara untuk mengoptimum dan melaksanakan pengawal logik kabur yang digunakan sebagai pengesan titik kuasa maksimum di dalam solar panel. Pengesanan titik kuasa maksimum digunakan untuk digabungkan dengan sistem kuasa solar supaya system kuasa solar mampu untuk menyampaikan bekalan kuasa maksimum. Nilai optimum terdekat direka untuk fungsi keahlian dan peraturan kawalan ditemui secara serentak oleh algoritma genetik oleh algoritma carian berdasarkan mekanisme pemilihan semula jadi dan genetik. Cara ini mudah untuk melaksanakan dan cekap untuk masalah pengoptimuman pembolehubah seperti dalam rekabentuk pengawal kabur yang terdiri dengan bilangan yang besar. FLC yang direka bentuk dan pelaksanaan model solar menggunakan perisian Matlab / Simulink yang mewakili model solar yang sebenar. Untuk mendapatkan keputusan simulasi dan nilai optimum, ambil kira kesan sinaran cahaya matahari dan suhu sel dalam pertimbangan, keluaran kuasa dan arus ciri-ciri model solar.

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## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| PV | Photovoltaic |
| MPPT | Maximum power point tracking |
| DC | Direct current |
| FLC | Fuzzy logic controller |
| P&O | Perturb and observe |
| $GA_S$ | Genetic algorithms |
| ANFIS | Adaptive neuro-fuzzy inference system |
| INC | Incremental conductance |
| AC | Alternating current |
| GUI | Graphical user interface |
| FIS | Fuzzy inference system |
| IAE | Integral absolute error |
| E | Error of power and voltage |
| $\Delta E$ | Change of the error |
| D | Duty cycle |
| $I_{SC}$ | Short circuit current |
| $V_{OC}$ | Open circuit voltage |
| q | Electron charge |
| k | Boltzman’s constant |
| A | Ideal factor |
| $N_S$ | Series number of cell |
| $T_C$ | Cell’s working temperature |

| | |
|---|---|
| $T_{REF}$ | Cell's reference temperature |
| $E_G$ | Band gap of the semiconductor used in the cell |
| $N_P$ | Parallel number of cells |
| $I_{PH}$ | Photocurrent |
| V | Input voltage |
| $I_{RS}$ | Reverse saturation current |
| $I_S$ | Saturation current |
| I | Output current |
| PWM | Pulse width modulation |
| NB | Negative big |
| NS | Negative small |
| ZE | Zero |
| PS | Positive small |
| PB | Positive big |
| N | Number |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Project background

Photovoltaic (PV) system or “solar electricity” converts sunlight (light energy) into electricity. The electricity is produced silently with no pollution, no maintenance and no depletion of natural resources [1]. PV is compassionate and exceedingly versatile. PV actually in a small scale and reliable that can be use to pump water, provide power for communications and village electrification in remote areas.

This project is basically focused on the charge controller component that consists in PV system. This part will be used to detect the maximum power receive during daylight at right angle. The output power induced in the PV modules depends on solar irradiation and temperature of the solar cells. The PV system has an operating system that can supply maximum power to the load. The point that gathers the power called the maximum-power point (MPP). In order to operate the PV array at its MPP, the PV system can implement a fuzzy logic controller (FLC) that used in a maximum-power point tracking (MPPT) controller.

MPPT is the technology that allows a PV array to deliver the maximum amount of energy to a battery bank. MPPT allowed users to maximise the charging ability of their PV array and reduce the required PV array size for battery charging. The efficient maximum power tracking method is important in order to extract as much as possible power from PV and various MPPT method is used to track MPP of PV. Fuzzy logic is a form of many-valued logic. It deals with reasoning that is approximate rather than fixed and exact. Fuzzy logic control based on operator experience is an ideal solution for applications where mathematical model is known or not precisely known especially for problems with varied parameters and nonlinear models [2]. The fuzzy logic method cannot avoid the output vibration. So, MPPT method is necessary in order to improve the output efficiency of costly PV power system. Furthermore, the DC/DC circuit is used to track the actual MPP, which will consume partial electric power and an efficiency DC/DC circuit is important to track the MPP such as Buck, Boost, Buck-Boost and Sepic circuit have been used in MPPT of PV generating system.

## 1.2 Problem statements

Nowadays, there are many technologies available for photovoltaic system. Malaysia is located just north of the Equator, where the solar irradiation can be extracted optimally. MPPT is usually integrated with PV power system so that PV array is able to deliver the maximum power available. Due to their search nature associated with simplicity and effectiveness, for both linear and non-linear systems, fuzzy logic controller (FLC) methods have showed their outstanding features in MPPT application to get the faster and accurate value when the MPPT collect the power receive. FLC can avoid the oscillation problem of the conventional perturb-and-observe method (P&O) and suitable for any DC/DC topology. Hence, many studies and applications have been proposed, combining MPP tracking and FLC. For example, the experimental results obtained via the fuzzy tracker is presented by Khaehintung and Sirisuk (2004) who have shown that the MPPT was more than eight times better in terms of tracking speed over the conventional MPPT using the P&O method [3]. These results have also revealed that a PV system based upon the proposed controller can reach a power efficiency of about 85%.

However, in order to get better results than the previous mentioned methods, the major drawback of the FLC employed that practicing the trial and error approach in optimizing MPPT has to be overcome. Thus, a guided approach will be proposed in this project which utilising Genetic Algorithms (GAs). The GA is based on concept of evolutionary theory and provides an effective way of searching a large and complex solution space to give close to optimal solution.

## 1.3 Project objectives

The main objective of this project is to introduce a guided approach for FLC based MPPT in improving the trial and error approach.

Its measurable objectives are as follows:

i. To maximise the computation time for fuzzy logic controller.
ii. To enhance the calculation accuracy by using genetic algorithms.

## 1.4 Project scopes

This project is primarily concerned with the implementation between FLC and MATLAB-Simulink. The scopes of this project are:

i. Consider fuzzy inference system to describe FLC rule.
ii. Design coding for GA is in converge condition
iii. Using input data according to MSX 60 specifications

## 1.5 Expected results

The expected results of this project are:

i. Guided approach can reduce the computation time in simulation result.
ii. Genetic algorithm can be used as tools for FLC to get accurate calculation.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter discusses about the literature discourse and review of photovoltaic system. Subtopic 2.2 discusses about the previous study that has been done about the concept and implementation of this system which that use in suitable applications. Subtopic 2.3 is about the project review that presents the description of photovoltaic system and solar radiation. Lastly, subtopic 2.4 is about the theory for this project such as PV modules, MPPT, fuzzy logic and genetic algorithm. Prior to the installations, proper studies, research and developments have to conduct to ensure the optimum implementation of various technologies. Literature reviews are based on information obtained from valid sources such as books, articles of relevance, published papers or others.

## 2.2 Previous study

This subtopic discusses about the previous study that has been done about the concept and implementation of this system which that use in suitable applications. Sub-subtopic 2.2.1 discusses about the fuzzy logic controller that usually used in one of the method to find MPPT in PV system. Sub-subtopic 2.2.2 discusses about the functionality of genetic algorithm in fuzzy logic. Sub-subtopic 2.2.3 discusses about the comparison of the method to find maximum power point tracking. Sub-subtopic 2.2.4 discusses about the design model for photovoltaic system.

### 2.2.1 Fuzzy logic controller

M.A.S. Masoum and M. Sarvi proposed new fuzzy maximum power point tracker (MPPT) for photovoltaic system. This project used fuzzy controller input parameter dP/dI , Δ (dP/dI) and variation of duty cycle (ΔDC) are used to generate the optimal MPPT converter duty cycle such that solar panel maximum power is generated under different operating conditions [4].Fuzzy logic controller for maximum power point tracking (MPPT) in photovoltaic system. This paper make a comparison performances between perturb & observe (P&O), proportional integrated (PI) - controlled system and fuzzy logic controller [5].

Then fuzzy logic controlled and buck boost DC-DC converter for solar energy-battery system. This paper also compared the performance between fuzzy logic and PI controller [6]. Implementation of fuzzy logic in solar photovoltaic. This project based on the change of power, dp and change of power with respect to change of voltage, dp/dv and fuzzy determines the size of the perturbed voltage. The performances of fuzzy logic with various membership function to facilitate the tracking of maximum power faster and minimize the voltage variation [7].

### 2.2.2 Genetic algorithms

Intelligent control method for the maximum power point tracking of a photovoltaic system under variable temperature and irradiance conditions. A fuzzy logic controller based MPPT has shown better performance than P&O MPPT approach. So to improve the proposed FLC, genetic algorithm has been proposed for optimization [8].

M.Mohammadian and R.J.Stonier presents general method in how to develop the fuzzy rules by using genetic algorithm and fuzzy logic controller. By using GAs the learning procedure and a FLC as the system performance evaluator. The proposed architecture can construct as input-output mapping in the form of fuzzy IF-Then rules [9].

### 2.2.3 Maximum power point tracking

This research is about fuzzy logic controller gives a closed loop control method, by use adaptive neuro-fuzzy inference system (ANFIS). The given model operator very fast in comparison on with available methods and has proper accuracy in maximum power point tracking [10]. Other paper proposed to improved efficiencies of power electronics converter, to operate PV system at MPP. This paper presents a fuzzy control method for tracking the MPP based on the fuzzy control methd is developed in the MATLAB. This is suitable for fast changing environmental conditions [11].

An intelligent control method for the maximum power point tracking of a photovoltaic system under variable temperature and insolation conditions by using fuzzy logic controller applied DC – DC cuk converter connected with the DC water pump as a load for the system [12]. Then conventional MPPT methods such as P&O and incremental conductance (INC) have a drawbacks an oscillation at the MPP during power fast tracking and power divergence under rapidly changing atmospheric condition. However FLC also have disadvantages because FLC tuning difficulty of membership function scaling factor and control rules [13].

### 2.2.3 Photovoltaic system

Circuit model of photovoltaic module that can be used as a common platform for the material scientists as well as as power electronic circuit designer to develop the better PV power plant. The developed model is integrated with DC – DC boost converter with closed loop control of maximum power point tracking algorithm [14]. PV module for stand-alone PV system, where a one diode equivalent circuit based versatile simulation model in the form of masked block PV module. By the model, it is allowed to estimate behavior of PV module with respect changes on irradiance intensity, ambient temperature and parameters of the PV module. In addition, the model capable of function to detect MPPT which can be used in the dynamic simulation of stand-alone PV system [15].

Circuit-based simulation model for a PV cell in order to allow estimate the electrical behavior of the cell with respect changes on environmental parameter of temperature and irradiance. An accurate PV module electrical model based on the Shockley diode equation. The general model was implemented on matlab script file and accepts irradiance and temperature as variable parameters and outputs the I-V characteristic [16]. Implementation of generalized photovoltaic model using Matlab/Simulink software, which can be representative of PV cell module and array for easy use on simulation platform. The proposed model is designed with a user-friendly icon and a dialog box like simulink block libraries. This makes geberalized PV model easily simulated and analyzed in conjuction with power electronics for a MPPT [17].

## 2.3 Project review

This subtopic is discusses about review project that will be used in this project. Sub-subtopic 2.3.1 is about the explanation in photovoltaic system in daily life. Sub-subtopic 2.3.2 is about solar radiation and the effect in photovoltaic system.

### 2.3.1 Photovoltaic system

A photovoltaic system broadly normally consists of photovoltaic array is comprise a few numbers to a few hundreds of modules. The sun pointed to PV array and the charge controller will regulate the power. Then the power will stored at the battery bank that consisting of deep cycle batteries. Lastly, the inverter will convert the dc power from array into ac power.

The daily energy output from PV array will vary depending on its size, orientation and location, season of the year and the daily weather conditions. Energy storage is required for the power when sun is not shining. Battery sizing depends on the application, the daily solar radiation, the total load, peak load and the number of days which storage required.

The charge controller is placed between the PV array and the storage battery to prevent the battery from being damaged either due to overcharging or over-discharging to enhance its life. The power from the PV system is dc and most electrical appliances work on ac. The inverter is used to convert 12 volts or 24 volts dc power into 220 volts or 110 volts ac power that usually used in electrical appliances. Figure 2.1 shows the elements in PV system.

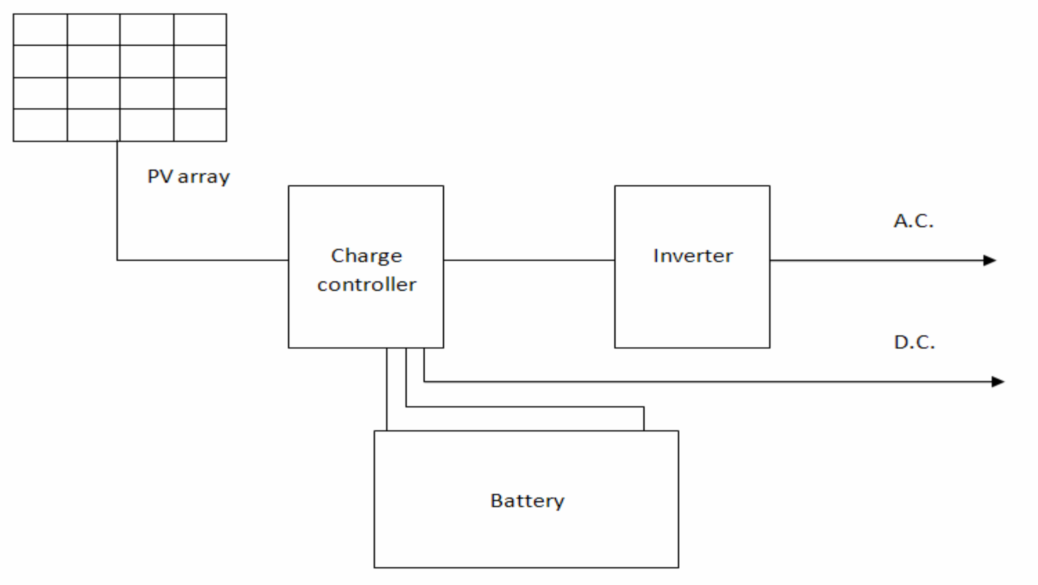


Figure 2.1: Elements of PV System

### 2.3.2 Solar radiation and photovoltaic effect

The design of a photovoltaic system relies on a careful assessment of solar radiation at a particular site. Although solar radiation data have been recorded for many locations in the world, they have to be analyzed and processed before a sufficiently accurate estimate of the available solar radiation for a photovoltaic system can be made.

About half of the scattered energy from a clear sky reaches the earth in the form of diffuse radiation. The sum of the diffused, reflected and direct radiation on a horizontal surface is known as total radiation or global radiation. Then, the total power from a radiant source falling on a unit area called irradiance, which means solar radiation intensity.

The amount of radiation that reaches the ground is variable. In addition, the regular daily and yearly variations due to the apparent motion of the sun, irregular variations are caused by the cloud cover. For this reason, the design of a photovoltaic system relies on the input of measured data close to the site of the installation. Other factors include the response of various PV types to the solar energy wavelength as well as the physical positioning of the module itself.

Normally, the solar modules are placed on the roof or any other part to absorb the maximum possible solar energy. These converters will generate direct current from the sun's ray, solar irradiance. When the sun falls on solid-state, it causes an electrical charge and direct current flows. There are two systems of utilization, either the DC power is used directly or the DC power is inverted for AC application. Figure 2.2 shows the direct sunlight to PV modules and convert the sunlight into electricity.


Figure 2.2: PV modules on the roof

The photovoltaic effect is the basic physical and chemical process through which a PV cell converts sunlight into electricity. Sunlight is composed of photons – packets of solar energy. These photons contain different amounts of energy that correspond to the different wavelengths of the solar spectrum. When photons strike a PV cell, they may pass through it. The absorbed photons are photons are the ones responsible to generate electricity.

## 2.4 Theory for the whole system

This subtopic is about the knowledge about the whole system. Sub-subtopic 2.4.1 is about the common types of PV modules that usually used this day. Sub-subtopic 2.4.2 is explanation about the maximum power point transfer technology (MPPT). Sub-subtopic 2.4.3 is explanation about the fuzzy MPPT for PV system and subtopic

2.4.4 is explanation about the genetic algorithms (GAs) as a tool of FLC optimisation for a MPPT.

### 2.4.1 Common types of PV modules

PV cells are generally made either from crystalline silicon, sliced from ingots or castings, from grown ribbons or thin film, deposited in thin layers on a low-cost backing. Figure 2.3 shows the process to make a PV cells.

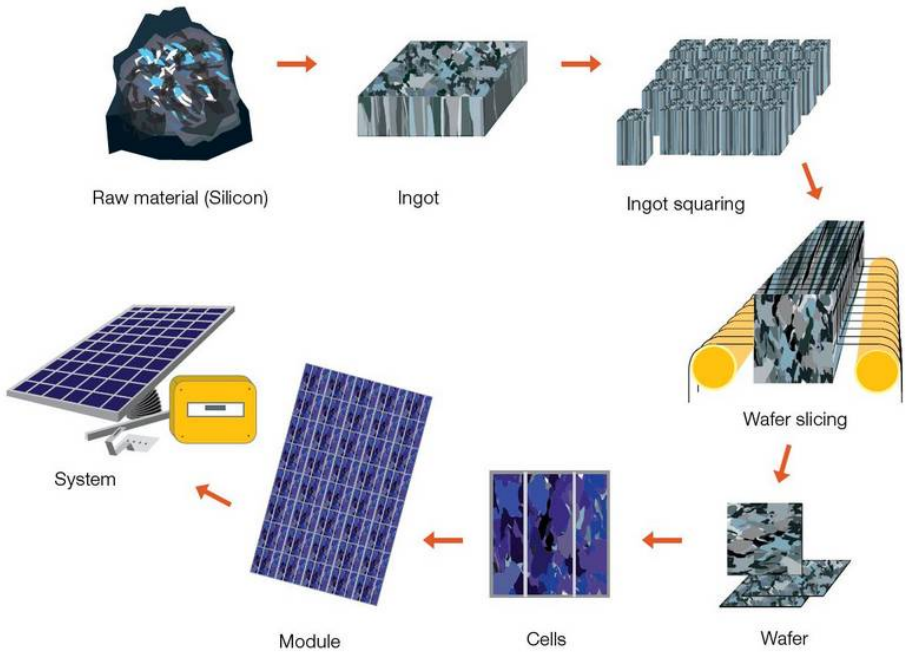


Figure 2.3: Diagram for make a PV cells

Electricity generated from PV modules that can do a lot for people such as for electrical appliances. PV modules are like the heart of any PV system. The PV market is expanding rapidly and manufacturers are constantly introducing new and emerging technologies. The common types that usually used is crystalline modules and thin film modules.

Crystalline PV modules, which are made by grouping a number of individual solar cells together, are currently used for residential and commercial applications. One of the reasons why crystalline modules are used so frequently is that they're more efficient than other PV technologies. Typical crystalline modules are rated at 11 to 14 watts per square ($W/ft^2$). Some of the higher-efficiency modules are rated in excess 0f 17 $W/ft^2$, which allows a consumer to generate a greater amount of energy in limited space, like on roof.

Thin film technologies vary in their raw materials and exact manufacturing processes the thin film only that material on the substrate is extremely thin, ranging from just nanometers (nm) to a few micrometers (µm) thick.

### 2.4.2 Maximum power point transfer technology (MPPT)

MMPT is the technology that allows a PV array to deliver the maximum amount of energy to a battery bank. MPPT charge controllers gained popularity in the early 2000s when manufacturers released highly reliable and accurate version that allowed users to maximize the charging ability of their PV array and reduce the required PV array size for battery charging compared to some of the older technology.

#### 2.4.2.1 MPPT works

The maximum power point is the product of $P=V_{mp}$ x $I_{mp}$ and the units associated with it are watts (W). The MPP is used to determine the rated power output of the entire array and the components that connected and the expected energy production of the PV array. MPPT controllers take the power from PV array at the MPP, regardless of the required battery voltage and deliver that same amount of power to the battery because the voltage is reduce from array to the batteries required level. If the voltage is decreased, the current is increased in order to keep the same power level. MPPT controller boost current into the battery bank in relation to the current received from array [8].

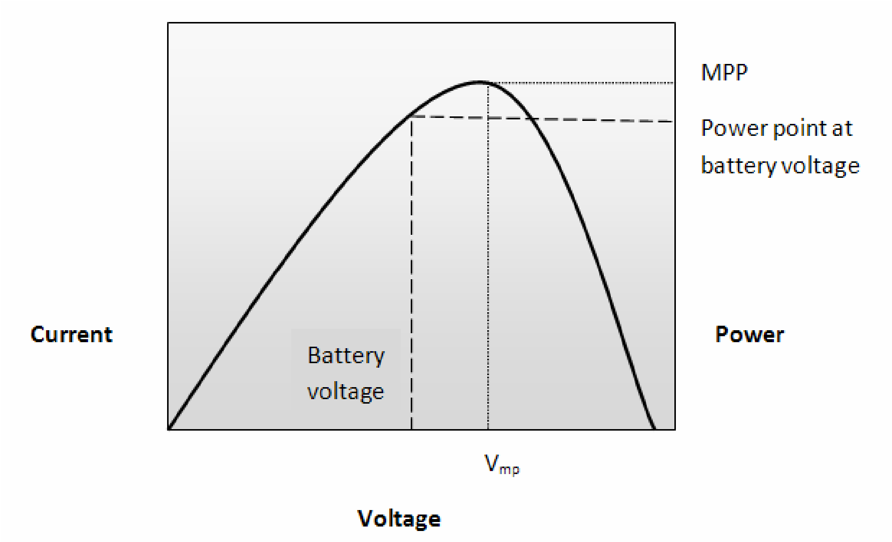


Figure 2.4: The power gained through the use of MPPT controller

Figure 2.4 shows the location of a typical battery charge set-point. When the point straight over to the right from that point, the power level associated at the battery-charging voltage. The difference in the MPP and the power level associated with the battery-charging voltage represents the increased power output due to the use of the MPPT technology. The PV array's power levels move throughout the day depending on the environmental conditions and MPPT controllers adjust right along them.

### 2.4.3 Fuzzy MPPT for PV systems

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL.

Fuzzy Logic Toolbox™ software is a collection of functions built on the MATLAB® technical computing environment. It provides tools for user to create and edit fuzzy inference systems within the framework of MATLAB. User can also integrate their fuzzy systems into simulations with Simulink® software and build stand-alone C programs that call on fuzzy systems user build with MATLAB. This toolbox relies heavily on graphical user interface (GUI) tools to help user accomplish their work. FLC contains four main components as shown in Figure 2.5 [9]:

a) The fuzzifier that maps crisp values into input fuzzy sets to activate rules.

b) The rules which define the controller behavior by using a set of IF–THEN statements.

c) The inference engine which maps input fuzzy sets into output fuzzy sets by applying the rules.

d) The defuzzifier that maps output fuzzy values into crisp values.

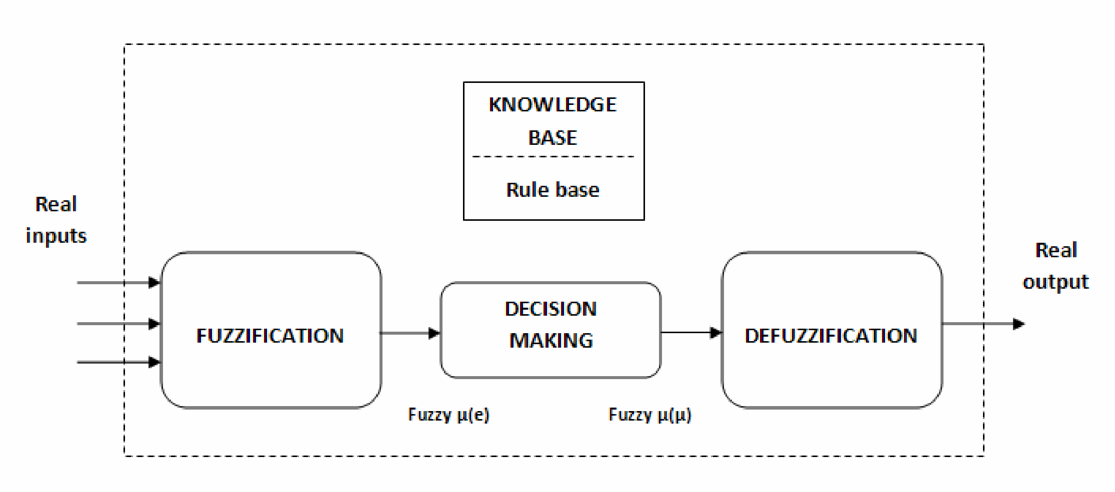


Figure 2.5: Fuzzy inference system

The rules describing the FLC operation are expressed as linguistic variables represented by fuzzy sets. The controller output is obtained by applying an inference mechanism [10] which defines:

1) The kind of membership functions.

2) The connections used to link the rules antecedents.

3) The implication function chosen.

4) The rule aggregation operator.

In the case of fuzzy controllers hardware implementation, which is of interest here, the shapes of the membership functions associated to the FLC linguistic variables are often piece-wise linear functions (triangular or trapezoidal).

It should be noted that the number and shape of the membership functions of each fuzzy set as well as the fuzzy logic inference mechanism was initially selected based on trial-and-error methods, in a manner that the region of interest is covered appropriately by the input data. The idea behind the chosen reasoning in this paper was, if the last change in the control signal (D) caused the power to rise, keep moving in the same direction. Otherwise, if it has caused the power to drop move it in the opposite direction. Subsequently, as it will be explained in the following sections, a genetic algorithms (GAs) technique was used to tune both of membership functions and the rule-base set.

The MPPT using the Mamdani's FLC approach, which uses the min–max operation fuzzy combination law, is designed in a manner that the control task try to continuously move the operation point of the solar array as close as possible to the maximum power point (MPP) [3]. The two inputs of the proposed fuzzy controller are the tracking error (E) and the change of the error (ΔE), which are defined by:

$$E(n) = \frac{p(n) - p(n-1)}{V(n) - V(n-1)} \tag{2.1}$$

$$\Delta E(n) = E(n) - E(n-1) \tag{2.2}$$

where E and ΔE are the error and change in error, n is the sampling time, p(n) is the instantaneous power of the PV generator, and V(n) is the corresponding instantaneous voltage. These inputs are chosen so that the instantaneous value of E(n) shows if the load operation power point is located on the right or in the left compared to the Pmax actual position. While ΔE(n) expresses the moving direction of this operation point (see Figure 2.4).

The output variable is the pulse width modulation (PWM) signal called D, which is transmitted to the boost DC/DC converter to drive the load. After the rules have been applied, the center of area as the defuzzication method is used to find the actual value of (D) as a crisp output.

### 2.4.5 Genetic algorithms (GAs) as a tool of FLC optimization for a MPPT

The genetic algorithms are based on concepts of evolutionary theory, and provide an effective way of searching a large and complex solution space to give close to optimal solutions much faster than random trial-and-error methods. They are also generally more effective at avoiding local minima than differentiation-based approaches. The basic mechanism of a GA can be simply described as follows [9]:

1) *Define the string of a chromosome*: The string of searching parameters for the optimization problem should be defined first. These parameters are genes in a chromosome, which can be binary coded or real coded. Different chromosomes represent different possible solutions.

2) *Define the fitness function:* The fitness function is the performance index of a GA to resolve the viability of each chromosome. The design of the fitness function is according to the performance requirements of the problem such as convergence value, error, rise time and others.

3) *Generate an initial population:* A set of chromosomes should be randomly generated before using a GA operation. These chromosomes are called the initial population. The size of the population is chosen according to the complexity of the optimization problem. Generally speaking, larger values require fewer generations to converge to a solution. However, the total computation time depends also on the number (N) of used generations to reach the algorithm's convergence.

4) *Generate the next generation or stop:* GAs use the operations of reproduction, crossover and mutation, as detailed in figure 2.6 to generate the next generation. From generation to generation, a maximum value of the fitness value is achieved.

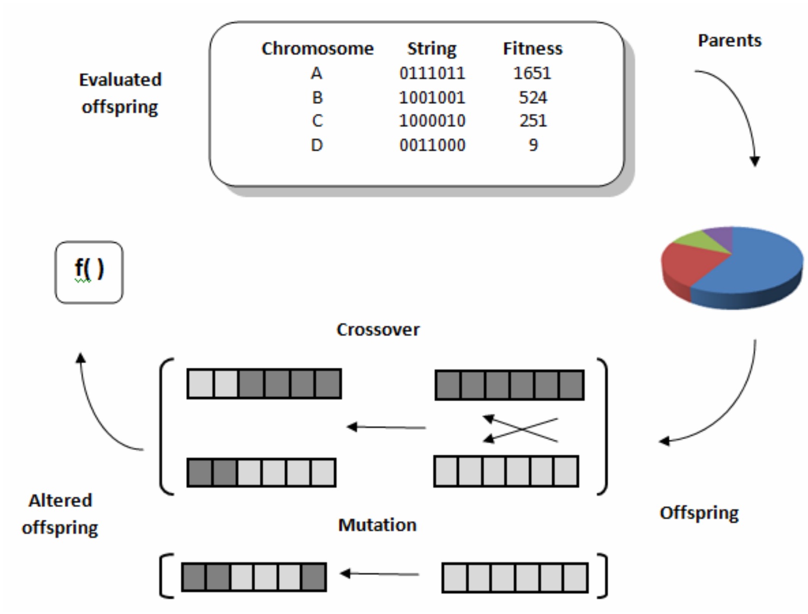


Figure 2.6: Basic mechanism of genetic algorithm

Genetic algorithms as just described can be used to tune the fuzzy controller parameters like the structure of rules and membership functions to find those parameter values that are optimal with respect to the design criteria [11]. The optimization of these two entities can be done separately, which may result in a suboptimal solution, because the design parts are mutually dependent by using GA's to design both parameters simultaneously [12], the two elements of fuzzy controllers can be fully integrated to deliver a more finely tuned, high performance controller.

Generally, designing a fuzzy logic controller involves two major steps; structure identification and parameter identification. Structure identification is the process of choosing a suitable controller structure, such as the size of the fuzzy rule-base. Parameter identification then determines the value of the parameters of a fuzzy controller, such as the shape of the fuzzy membership functions and the contents of the fuzzy rule-base. In the following section a demonstration is given of how to get over the step of parameter identification by using the GAs optimization approach, in a manner that optimal or near optimal fuzzy rules and membership functions can be selected without a human operator's experience or a control engineer's knowledge. The assumptions used and the constraints introduced to simplify this process are also explained.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This chapter will describe the methods in this project. This project implementation will divided into 2 parts in order to make everything more systematic, manageable and easier to troubleshoot. Subtopic 3.2 is about the overall process during project verification and analysis. Subtopic 3.3 is about the detail process to design FLC – GA based structural optimization. Subtopic 3.4 is about the data solar collection that will be used in the photovoltaic system.

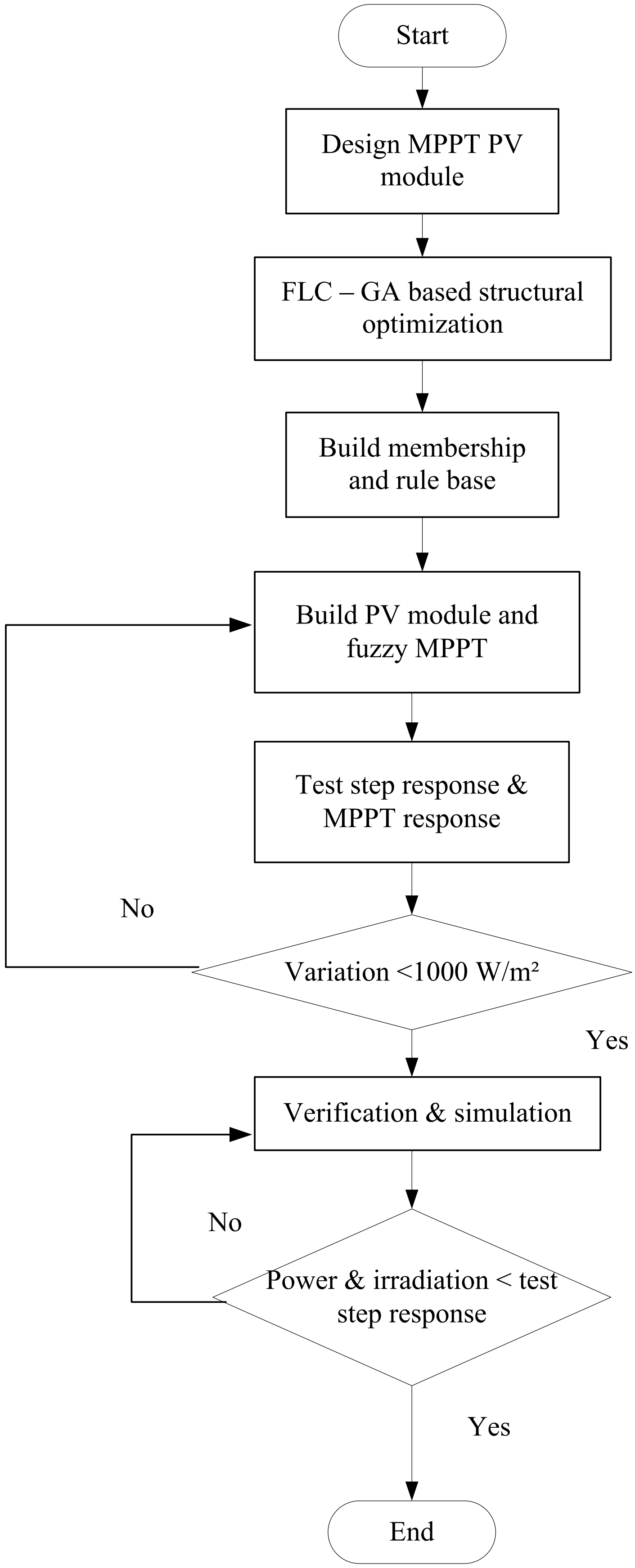


Figure 3.1: Flowchart of overall project verification and analysis

## 3.2 Overall project verification and analysis

In this part, the software that will be used in this project has been work. Fuzzy logic toolbox in the MATLAB Simulink for as one of MPPT method has been studied about it criteria and how to use it. As shown in Figure 3.1, firstly design MPPT PV module. In order to test the robustness of the design fuzzy-based MPPT, the various parts of the PV system will be design using MATLAB-Simulink. Then compute FLC – GA based structural optimization. The system detail will be elaborated in subtopic 3.3. Build the membership function and rule base using Fuzzy Inference System (FIS) editor.

After that, build PV module and fuzzy MPPT in Matlab Simulink. First characteristic for test robustness is test verification of the inter-compatibility of the new design MPPT. The system should response normally to the external excitation. The second characteristic is the controller step response and also GA optimized FLC. The variation should be less than 1000 W/m². To evaluate the MPPT performance a test is carried out, related to the examination of the implemented controller's robustness with respect to the rapid change of the solar irradiation. The power irradiation result should be less or similar with the step response result.

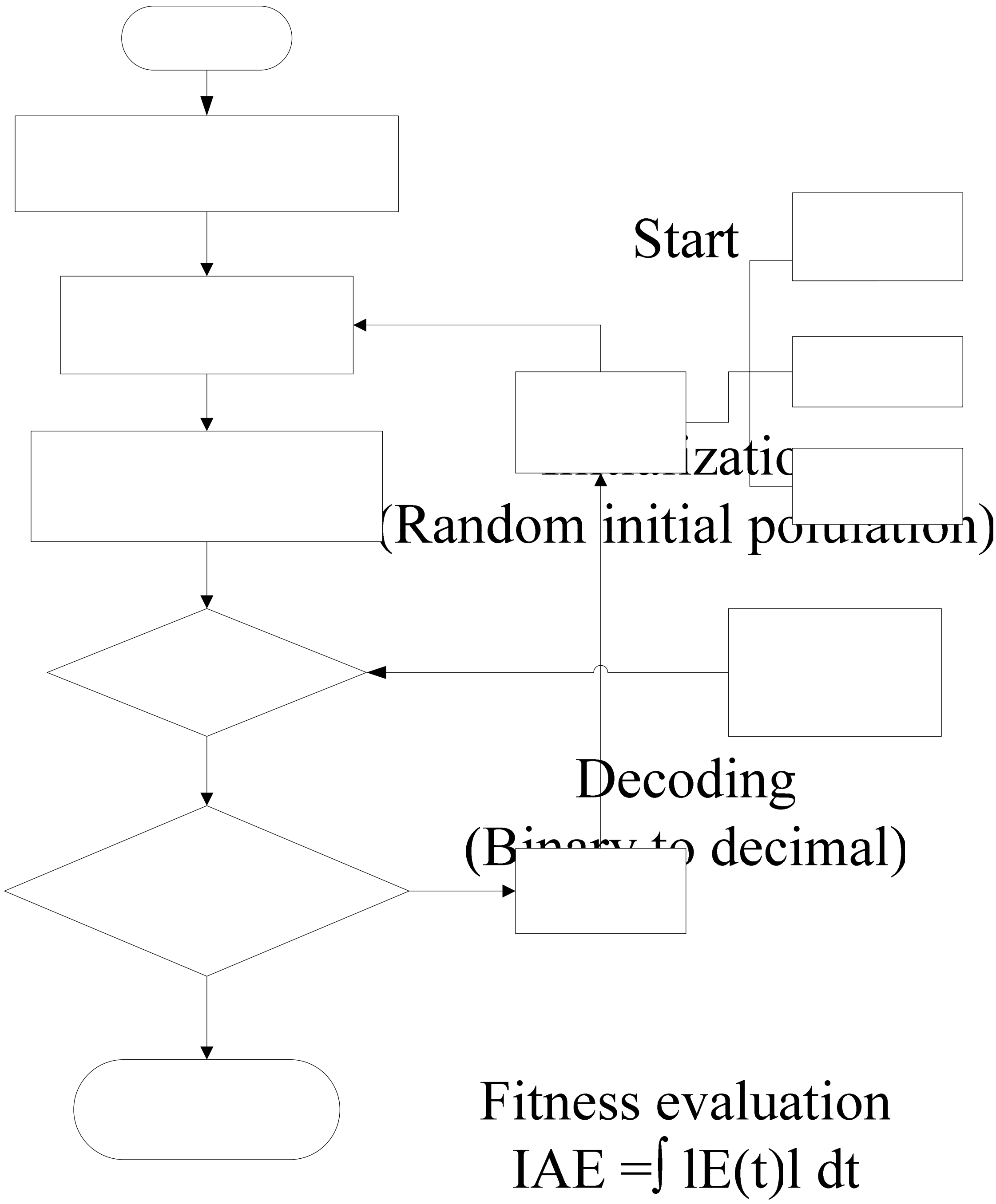


Figure 3.2 : Flowchart of the system detail for FLC – GA based structural optimization

Activate FLC

NO

### 3.3 FLC – GA based structural optimization

Figure 3.2 is explanation about how to optimize the GA value. First, initialize the parameter for GA and FLC. Divide the input and output space of the system to be controlled into fuzzy region. Then set the random initial population of n string (for n parameter) of the length L is created by using bit string (0 and 1) for each input and output region. Each string is decoded into a set of parameters that it represents to find the membership function and fuzzy rule set parameter. This set of parameters is passed through a numerical model of the problem space. The numerical model gives out a solution based on the input set of parameters. By using below equation to find the base value for decode value:

$$X_i = X\,min_i + \frac{b}{(2^L - 1)}\,(X\,max_i - X min_i) \tag{3.1}$$

where

*b* = Number in decimal form that is represented in binary form

*L* = Length of the bit string

$X_{max}$ and $X_{min}$ = User defined constant between which $X_i$ vary linearly

The fitness values are determined for each string in the entire population of strings. The fitness evaluation for GA can be done using fitness function of the GA by using global optimization toolbox in matlab. Therefore, the fitness function of the GA for each individual is defined as follows:

The optimization also can be done by GA on the minimization of integral absolute error ( IAE ) given by :

$$IAE = \int_0^{\infty} |e(t)|\,dt \tag{3.2}$$

where

$e(t) = P(t)_{expect} - P(t)_{PV}$

$P(t)_{expect}$ = Maximal theoretical delivered power i.e., T = 25 $^{o}$C and G = 1000 W/m$^2$

$P(t)_{PV}$ = Instant power provided by the pv module

The fitness values are scaled so as to distinguish the individual for which the fitness value is calculated. The fitness measure defined by:

$$fitness = 1000 - IAE \tag{3.3}$$

The IAE value is relatively small compared to 1000, so minimizing IAE is equivalent to maximize fitness expression. Build the membership function using base value and choose the best fitness value for each string. With these fitness values, the three genetic operators are used to create new generation of string. The new set of strings is again decoded and evaluated using three basic genetic operators. This process is continued until convergence is achieved within population.

The operations of reproduction, crossover and mutation are used in order to generate the next generation. Reproduction is the process by which strings with better fitness values receive correspondingly better copies in the new generation. The second operator, crossover, is the process in which strings are able to mix and match their desirable qualities in random fashion. The third genetic operator, mutation is used when reproduction and crossover may not be able to find the optimum solution to a problem. From generation to generation the maximum value of the fitness value is achieved. During the creation of a generation it is possible that the entire population of string is missing a vital bit of information. So the value at certain string location can change (changed to zero or vice versa). Use a FLC to assess the set of fuzzy rules and assign a value to each generated set of fuzzy rules. Stop generating new set of fuzzy rules once some performance criteria are met.

## 3.4 Data solar

Sub-subtopic 3.4.1 is the measured data voltage (real time) from the PV system in Power System Lab. Sub-subtopic 3.4.2 is the measured power for solar. Sub-subtopic 3.4.3 is the measured irradiance for solar irradiation analysis. Each type of data taken

# REFERENCES


[1] A. H. Haris, "Grid-Connected and Building Integrated Photovoltaic : Application Status & Prospect for Malaysia," Master Builder , Pusat Tenaga Malaysia, 2006.

[2] C. Lee, "Fuzzy Logic in Control System : Fuzzy Logic Controller - Psrt I," *IEEE Trans. Syst. Man Cybernet,* pp. 404-435, 1990.

[3] K. N. a. S. P, "Implementation of Maximum Power Point Tracking Using Fuzzy Logic Controller for Solar-Powered Light Flasher Applications," in *The 47th IEEE International Midwest Symposium on Circuits and Systems*, Hiroshima, 2004.

[4] M. a. M.A.S.Masoum, "A new fuzzy-based maximum power point tracker for photovoltaic applications," *Iranian Journal of Electrical & Electronic Engineering,* vol. I, 2005.

[5] S. S. a. G.Balasubramaniam, "Fuzzy Logic Controller for the Maximum Power Point Tracking in Photovoltaic System," *International Journal of Computer Appplications,* vol. 41, no. 12, 2012.

[6] M. E. a. H. I.Okumus, "Fuzzy Logic Controlled Buck-Boost DC-DC Conveter for Solar Energy-Battery System," Turkey, 2011.

[7] P. a. K. C.S.Chin, "Optimisation of fuzzy based maximum power point tracking in PV system for rapidly changing solar irradiance," *Global Hournal of Technology & Optimization,* vol. II, 2011.

[8] S. C. T. a. A. C.Larbes, "Genetic algorithms optimiszed fuzzy logic control for the maximum power point tracking in photovoltaic system," Algeria, 2009.

[9] M. a. R. Stonier, "Genrating Fuzzy Rules by Genetic Algorithm," in *IEE*

*International Workshop on Robot and Human Communication*, Australia, 1994.

[10] A. J. a. M. R.Ahmadian Majin, "Speed Improvement of MPPT in Photovoltaic Systems by fuzzy Controller and ANFIS Reference Model," in *M.S. Student, Shahid Bahanor University of Kerman, Process Control and Optimization Research Center and Technical College of Ilam*, Iran.

[11] a. H. W. Jiyong Li, "Maximum power point tracking of photovoltaic generation on the fuzzy control method," China, 2008.

[12] H. A. m. H. A. E. h. a. M. E. E. K. S. Mohamed M. Algazar, "Maximum power point tracking using fuzzy logic control," *Electric power and energy systems,* pp. 21-28, 2012.

[13] I. P. a. Y. K. Lo, "A fuzzy control maximum power point tracking photovoltaic system," *IEEE International Conference on Fuzzy Systems,* 2011.

[14] R. R. a. R. M. Pandiarajan N, "Application of curcuit model for photovoltaic energy conversion system," India.

[15] C. Q. a. Z. Ming, "Photovoltaic module simulink model for a stand-alone PV system," in *2012 International Conference on Applied Physics and Industrial Engineering*, China, 2011.

[16] F. M. Gonzalez-Longatt, "Model of Photovoltaic Module in Matlab," in *American Student Congress of Electrical, Electronic and Computer Engineering* , 2005.

[17] C. S. T. a. Y. J. S. Huang Liang Tsai, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK," in *Proceeding of the World Congress on Engieering and Computer Science*, USA, 2008.

[18] R. Mayfield, "Photovoltaic Design & Installation for Dummies," in *Wiley Publishing, Inc.*, 2010.

[19] J. R. Timothy, "Fuzzy Logic with Engineering Applications," in *John Wiley & Sons Ltd.*, 2004.

[20] C. S. S. S. B. A. Jime´nez, "Hardware Implementation of a General Purpose Fuzzy Controller," in *IFSA*, 1995.

[21] C. G. E. Karr, "Fuzzy Control of pH using Genetic Algorithms," in *IEEE Transactions on Fuzzy System 1 (1)*, 1993.

[22] A. M. E. Homaifar, "Simultaneous Design of Membership Functions and Rule Sets for Fuzzy Controllers using Genetic Algorithms," in *IEEE Transactions on Fuzzy Systems 3 (2)*, 1995.

[23] R. L. a. S. E. Haupt, Practical Genetic Algorithms, New York: Wiley-Interscience, 1998.

[24] X. Q. a. H. Li, "Application of Fuzzy Logic and Immune Response Feedback for PV Generating System," in *Taiyuan Univerity of Science & Technology*, China, 2010.

[25] A. E.-S. A. Nafeh, "Fuzzy Logic Operation Control for PV-Diesel-Battery Hybrid Energy System," in *Electronics Research Institute*, Egypt, 2009.

[26] S. L. a. D. Rekioua, "Modeling and Simulation of a Photovoltaic System using Fuzzy Logic Controller," in *Department of Electrical Engineering, University of Bejaia*, Algeria, 2009.

[27] S. a. G. V. Pai, Neural Networks, Fuzzy Logic and Algorithms ( Synthesis and Aplications), India: Prentice Hall, 2007.

[28] L. Lin, Network Models and Optimization ( Mulyiobjective Genetic Algorithms Approach), London: Sprienger - Verlag London Limited, 2008.