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Maximum Power Point Tracking Using FLC Tuned with GA

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***Abstract*—**The pursuit of the MPPT has led to the development of many kinds of controllers, one of which is the Fuzzy Logic controller, which has proven its worth. To further tune this controller this paper will discuss and analyze the use of Genetic Algorithms to tune the Fuzzy Logic Controller. It will provide an introduction to both systems, and test their compatibility and performance.

***Keywords*—**Fuzzy logic controller (FLC), fuzzy logic (FL), genetic algorithm (GA), maximum power point (MPP), maximum power point tracking (MPPT).

I. Introduction

IN order to achieve the maximum rendering from a PV panel different techniques have been developed to track the maximum power point (MPP), one of these techniques is the P&O (Perturb Observe). Unfortunately, this technique is based on the oscillation around the MPP, which requires a lot of calculations. Another method that proved more efficient and more adapted to such a task is the MPPT using FLC (Fuzzy Logic Controller). Because of its simplicity it doesn't require a high computational power, however, it doesn't achieve the optimal solution, and in order to use this system optimization must be done. In this paper we will introduce the optimization on the MPPT with FLC, using genetic algorithms (GAs) that proved to be efficient and resilient. This paper will first introduce the MPPT and the FLC system adapted to it, then a method to optimize it using a GA, and finally, test this system and discuss the results, before coming to our conclusion.

II. Maximum Point Tracking Approach

A. Maximum Power Point Tracking

The MPPT is not solely the weather conditions, such as temperature or light intensity, which affect the functioning of a PV panel, but also the charge connected to it. The MPP (maximum power point) is where the panel's adaptation to the surrounding conditions is at its optimal, when there is a charge with a resistance – as shown in the Fig. 1.

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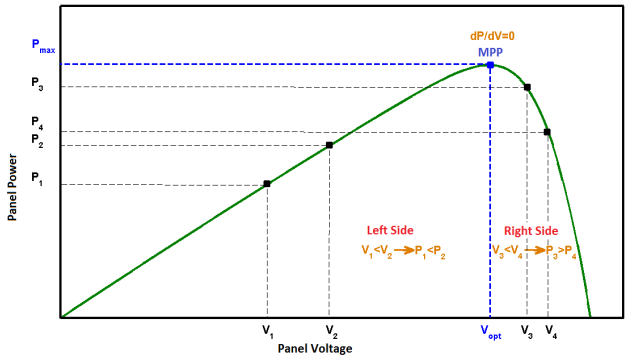


Fig. 1 Maximum Power Point

In order to overcome this problem, we use a converter between the source and the charge. By changing the switching time of the converter depending on the variation of atmospheric conditions, the output tension of the panel changes, and consequently, the power produced. The changes in the output tension can be either augmented or diminished, in response to the cyclic rapport. For example, a diminished cyclic report would result in a rise in tension.

In order to track the MPP automatically in this way, several types of algorithms have been published [1]. And two main methods defined:

- Indirect method, the MPP is estimated from the power curve of the PV generator.
- Direct method, the MPP setting is obtained from the measurement of the instant power at the photovoltaic generator.

The calculations of the indirect method are based on the knowledge of the nonlinear characteristic of the PV generator, which aren't precise. The most common technique used in the direct method is the P&O (Perturb&Observe), but the first inconvenience we face is that we always impose an oscillation around the MPP [1]., and there is a risk it may fail when the atmospheric conditions change rapidly.

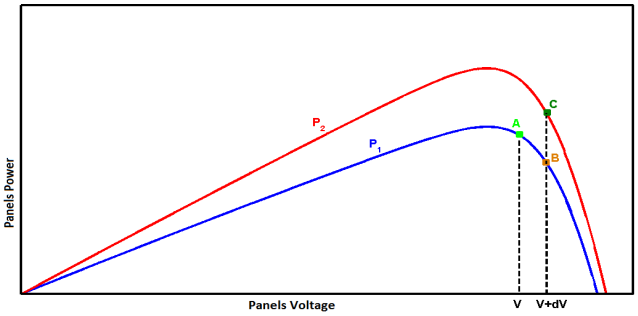


Fig. 2 Maximum power point change

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In order to overcome all these problems, the use of a Fuzzy controller provides a robust system that will take the P&O model to another level, providing it with stability and less computation, which will be discussed in detail in the next section.

B. Fuzzy Logic Controller

Developed by ZADAH in 1965, it allows imitation of human reasoning by exploiting the different information collected in linguistic form. The main use of the Fuzzy Logic is to issue commands, through the use of linguistic rules and the human expertise to the controller. Therefore it is possible to transfer the expert knowledge to the controller by transforming the knowledge to simple rules. The Fuzzy Logic can only be used if there is human know-how that can be interpreted as 'Fuzzy rules', therefore it is useless to use these rules if we do not know exactly how the system functions. The Fuzzy Logic exploits the linguistic knowledge of the human expert describing the system reaction or the command strategy, to both ensure the best performance and have enough flexibility during the conception of the controller. This system is based on three steps:

- The Fuzzification: Transforming the numeric to the linguistic.
- Inference: Applying the rules created by the human expertise.
- Defuzzification: Switching from linguistic to numeric.

This method provides the best solution for tracking the MPP.

1. Fuzzification

In this step we move from real to Fuzzy, it requires determining the membership degree of an input variable, for a membership function. There are many types and forms of these functions, the simplest of which is the triangular one. At any given time two functions are active for each input, which limits the calculation times of all parameters, and simplifies the command. The number is very important, a high number results in a sensitive controller and a higher set of rules.

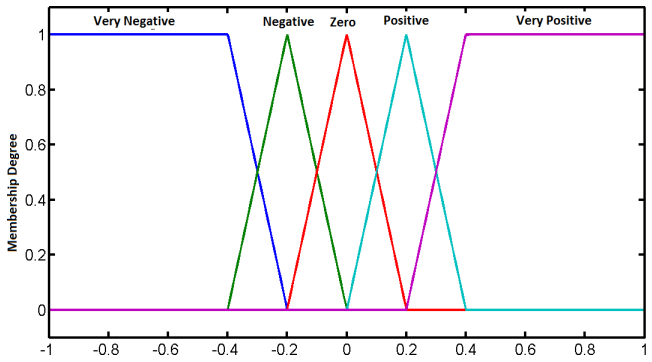


Fig. 3 Fuzzy logic membership functions

In order to further simplify our system, we normalize the discourse universe by using the interval -1, +1, and the extreme membership functions are fixed to these limits.

2. Inference

In order to set the rules, we have first to set the type of system, in this case Takagi-Sugeno. In this phase the human expertise is interpreted and the rules set, depending on the variation on the MPP. The use of this type of system allows us to have a crisp output, and facilitates the calculation, for a rapid and precise command.

TABLE I
MPP TRACKING RULES

		d^2P/dV^2		
		Negative	Zero	Positive
dP /dV	Negative	Decrease V	Decrease V	Nul
	Zero	Nul	Nul	Nul
	Positive	Nul	Increase V	Increase V

3. Defuzzification

In this step we go from the Fuzzy to the real domain. From the membership function representing our output we calculate a numeric value for the final output, the most common method uses the gravity center [2], which calculates an average estimated value - this is simple, and thus fast to calculate.

In order to further improve on the Fuzzy controller for the MPP Tracking, finer tuning can be added to the Fuzzy Logic. A common algorithm for optimization called genetic algorithm, which is in the evolutionary family, is adapted to such a task. It could be utilized for shaping and setting the parameters of the membership functions in the discourse universe, and will be discussed further in the next section.

C. Genetic Algorithms

Genetic algorithms are inspired from biological theories of evolution, through natural selection. Based on Darwinian Theory, its components copy the randomness in nature. The working of this algorithm is based on a set of chromosomes, encoded using strings of possible values and can be made up of real values or binary strings. A set of potential solutions is firstly prepared, and called a population. Each member of this set is an individual, encoded using the parameter values from the chromosomes, and applying them to the problem. The objective is to optimize them and achieve an optimal or near-optimal solution, and this determines its fitness. Once the fitness is determined, the individuals are used to create the next population; this process is called the selection, and is based on the fitness rate. The crossover is part of the process that takes two selected individuals to create a new pair of individuals that have characteristics of the previous one. To complete the copying of nature mutations have to be included, these are random changes in the individuals (chromosomes), which have to be random and kept at a low probability. This mutation allows us to create new individuals with new characteristics.

1. Selection Algorithm

This algorithm establishes a fitness rate for every chromosome; it is based on a stochastic sampling with replacement. A random number generator is used to select the individual and the selection is proportional to the fitness rate,

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i.e. if it is high the selection rate is high; if it is lower the selection rate is lower. The limitation of this technique is that it doesn't ensure that the fitter individuals will be represented in the next generation. In order to remedy this problem another algorithm uses a special identification of above average chromosomes, which ensures the selection of those individuals as many times as their fitness allows.

2. Crossover Algorithms

There are many types of selection algorithms [3],in which all individuals are paired for mating, and by mixing their strings new individuals are created. The most basic is called the single point crossover, as shown below.

TABLE II
CROSSOVER SINGLE POINT

Parent 1	1	0	1	1	1
Parent 2	1	1	0	1	0
Child 1	1	0	1	1	0
Child 2	1	1	0	1	1

A multiple crossover algorithm works by selecting multiple crossover points, as shown below.

TABLE III
CROSSOVER MULTIPLE POINT

Parent 1	1	0	1	0	0
Parent 2	1	1	0	1	0
Child 1	1	0	0	1	0
Child 2	1	1	1	1	0

A more complicated crossover algorithm is called uniform cross-over, and is based on a random string, of the same length as the parent. It works in this way: if the bit in this string is 1, it takes a bit from the first parent and gives it to the first child, and if it is zero it gives it to the second child, as shown below, it is the best performing algorithm.

TABLE IV
RANDOM CROSSOVER

Parent 1	1	0	1	1	1	1
Parent 2	1	1	0	1	0	0
Child 1	1	0	0	1	1	1
Child 2	1	1	1	1	0	0

3. Mutation Algorithms

The mutation creates new individuals with new characteristics using a random number generator. The method it uses is simple: for each bit, we generate a random number, and if it is less than the specified mutation probability, flip the bit, if it is 1, change it to zero, and vice versa. It is important to keep the mutation rate low, and constant through the lifetime of the GA.

After looking at the genetic algorithms the next step is to introduce them to the Fuzzy Logic controllers, and it will be used to set the membership functions [4], [5] in our system for tracking the MPP, and the next section will detail this.

III. MPPT USING FLC CONTROLLER WITHOUT AND WITH GA TUNING

Solar panel characteristics:

TABLE V
PANEL CHARACTERISTICS

Short circuit current of a module at 1000W/m^2	1 A
Open circuit tension of a module at 1000W/m^2	19.44 V
Optimal tension of a module at 1000W/m^2	15.12 V
Optimal current of a module at 1000W/m^2	0.902 A
Number of modules in series N_s	20
Number of modules in parallel N_p	20

A. MPPT Using FL

As we saw in the previous section, in order to track the MPP we can use different techniques, the most common of which is P&O [1]. In order to overcome its limitations, we introduced Fuzzy Logic.

Tracking the MPP using Fuzzy Logic is done with consideration of the variation of perturbations. If the tension V increases in positivity, and creates a raise in power P, this means that the function point is to be on the left of the MPP ($dP/dV>0$) ($dP^2/dV^2<0$) means we are approaching the MPP, and ($dP^2/dV^2>0$) means we went far from the MPP, in order to achieve it the tension V must be increased. And vice versa, if ($dP/dV<0$) ($dP^2/dV^2>0$) means we are approaching the MPP, ($dP^2/dV^2<0$), which means we went far from the MPP, in order to achieve it the tension V must be decreased - as the table below explains.

Using Dr. Minh [1] we set our Fuzzy Logic system in this way:

1. Fuzzification

For each input we use five membership functions of a triangular form, the extremities are set to -1 and 1, and all membership functions are symmetric at the zero point. The output is of a crisp value membership function.

2. Inference

Using Human expertise we have 25 rules, e.g. If dP/dV is positive and dP^2/dV^2 is positive then ΔD_1= -1%.

3. Defuzzification

The method used for it is the gravity center, and like the membership functions in the input, the output ones are set in a symmetric way.

B. MPPT Using FL Optimized With GA

In order to have a working system we have to fulfill these objectives:

- Use the FL input as the input for the GA to create the population.
- Use the Simulink for the panel and our MPP tracking system to test the optimization result.
- List and determine the optimal solutions for the system and fix it in the system.

We begin by setting the first FLC and introducing the parameters already used in the previous experiment, and

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which will be used in this section as the data to create the first population.

Once the population is created the genetic algorithm begins by calculating the fitness of each member of this population and giving it a value, using the testing platform. (Simulink)

Starting the crossover with a preference towards the population with a higher value of fitness, the next population is created and tested, before being valued like the previous one. The system will run for a number of iterations that we determine.

Finally we list the results in order of fitness, taking the best one and using it for our system.

- Using binary numbers we encode the information of the MFs and use them as the first population.
- Our fitness algorithm represents the optimization function with which we maximize the power production.
- After the crossover the binary code is decoded to MF and the fitness evaluated.
- We use two settings with different iterations and crossover rates, and a fixed mutation rate.

C. Results

The simulation uses five solar radiation measures in order to test the system and it is set as fellow:

TABLE VI
SOLAR RADIATION

Solar radiation W/m^2	900	800	700	600	500

Once the system is operational we set the parameter of the GA as per the table below

TABLE VII
GA SETTINGS

	Iterations no.	Crossover rate (%)	Mutation rate (%)
TEST 1	50	0.1	0.07
TEST 2	100	0.15	0.07

Using the first set of parameters the system, in comparison with only Fuzzy Logic setup, has gained a 5% in power, using the second setting the system has gained 12.8% in power, as shown in the following figures.

The first graph Fig. 4 below represents Fuzzy Logic with GA set for 50 iteration and 0.1% crossover rate with its results.

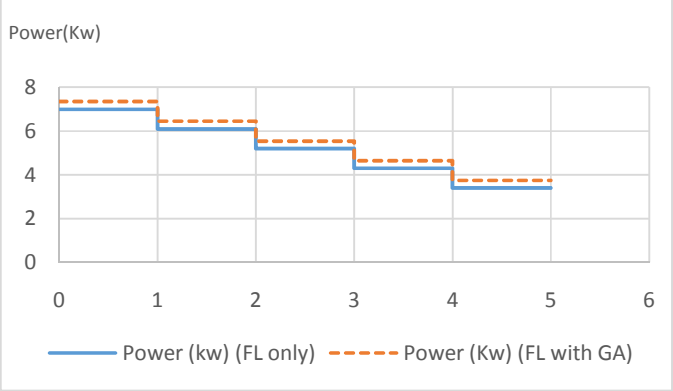


Fig. 4 Power production between FL and FL with GA

The second graph Fig. 5 below represents Fuzzy Logic with GA set for 100 iteration and 0.15% crossover rate with its results.

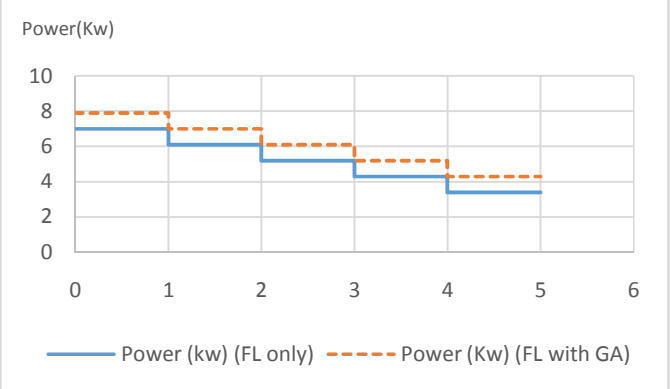


Fig. 5 Power production between FL and FL with GA

IV. CONCLUSION

Using Fuzzy Logic to track the maximum power point provided a positive result and adding GA has given a well-tuned Fuzzy Logic Controller, which in return has provided better results.

In the future work the Fuzzy Logic controller will be tuned using GA not only for the membership functions but also for the rules setting.

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