Optimal Operation for A Faulted PV System Using Genetic Algorithm

التشغيل الأمثل لنظم الطاقة الشمسية الفوتوفولتية مع وجود أعطال باستخدام الطريقة الجينية

Sahar S. Kaddah MIEEE'02
Department of Electrical Engineering,
Mansoura University, Mansoura, Egypt

الخلاصة
إنشاء نظم الطاقة الشمسية الفوتوفولتية باهظ التكاليف ولا يحتاج لوقود و على مستخدمى هذه الأنظمة العمل على تشغيلها عند نقطة التشغيل الأمثل منحنى القدرة لهذه النظم عند وجود أعطال منحنى متعرج وبالتالى فان الطرق التقليدية المستخدمة فى ايجاد نقطة التشغيل الأمثل غير مناسبة والطريقة الجينية هى المناسبة لمثل تلك المهمة لأنه يجرى البحث عشوائيا . تم اختبار الطريقة المقترحة على نظام طاقة شمسية فوتوفولتية ذو ثلاثة مصفوفات من لوحات الخلايا الشمسية مع وجود أخطاء مختلفة. نتائج النظام المقترح حددت نقطة التشغيل الأمثل فى كل الحالات المقترحة

Abstract

The need to optimize the operation of PV systems is justified by the fact that PV systems are expensive to build, fuel- free source, and it is therefore natural that user of such systems would want them to perform at their most optimal point. Under the faulted condition, the power curve has a multi-peak nature; conventional optimization techniques can easily fall down in local optimal and initial point problems. Genetic algorithm as a global optimization technique is adopted to optimize photovoltaic power system under different faulted conditions. The proposed PV system and GA scheme is tested for the three-array PV system under different faulted conditions and the simulation results shown in the paper. It is shown from the results that the genetic algorithm captured the exact optimization point accurately.

1. Introduction

Photovoltaic. PV. system continues to gain wide acceptance as one of the energy solutions in the future This has necessitated the need for research efforts aimed at improving the performance of such systems As the photovoltaic power system is a free-fuel source of electric power, tracking the optimal operating point is a very important issue. Many researchers have discussed this in a normal operating condition.

The power characteristic of PV panel is dependent on the *Insolation* level, cell temperature and array voltage [1]. The power output increases with a steep gradient, proportional to solar *radiation*. At constant temperature. the higher *irradiance* level results in higher power and higher voltage. Temperature increase on the other hand has negative effect on the power generation of a PV system Higher cell temperature results in lower open circuit voltages. The PV rating is usually specified at insolation level of 1000W/m² and cell temperature of 77°F.

The output of the PV system is function of the solar radiation, operating voltage, and the status of the PV cell, as the solar radiation is varying on hourly basis. seasonally basis, etc [2-4] Hence. we need to predict it so as to we can know the expected value of energy we will get And the most important thing is to decide what is the operating voltage should be. which can provide us with the maximum output power of the PV system at each situation

The existing PV fault analysis methods are limited because of their inability to determine the multiple optimal points which. may lead to sub-optimal or local optimal and the control techniques are not adequate and has limited ability for self-tuning and stabilization. Our method used Genetic algorithm plans to overcome these weak points for optimal power tracking.

The classical optimization techniques do not provide global optimization and can easily be trapped in local optimization. To avoid this. several emerging

techniques such as genetic algorithm and annealing methods are used. Genetic algorithm is a global optimization technique [5] it is a stochastic searching algorithm, flexible and efficient. It combines an artificial survival of the fittest with genetic operators abstracted from nature to form a surprisingly robust mechanism that is suitable for a variety optimization problem. GA hops randomly, thus it escapes from the local optimum problem. Therefore, the global optimum of the problem can be approached with high probability. Also, GA searches for many optimum points in parallel. GAs are part of evolutionary computing, which is growing area of artificial intelligence.

This paper concentrates on the optimal tracking of the PV system at abnormal conditions. The proposed GA scheme is tested on the three-array PV system based on actual radiation data and the detailed results are shown in the paper.

2. Solar Cell Models

There are different models can represent the solar cell. Here, various mathematical models of PV cell are briefly described as follows [6-8]:

2.1. Simplified Model

A solar cell is usually represented by a simplified electrical equivalent one-diode model [6-7] as shown in Figure 1.
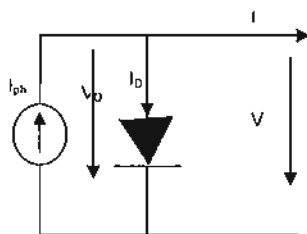

Figure 1. Simplified Equivalent Circuit of a Solar Cell

This simplified equivalent circuit consists of a diode and a current source, which are connected in parallel. The current source generates the photo current I_{ph}, which is directly proportional to the solar radiation. The p-n transition area of the solar cell is equivalent to a big diode. The series resistance R_s represents the resistance inside each cell and in the connection between the cells. The net current is the difference between the photo current I_{ph} and the normal diode current I_D. The V-I equation of the simplified

equivalent circuit could be derived from Kirchhoff's current law [6]:

$$ I = I_{ph} - I_D = I_{ph} - I_s \left[\exp\left(\frac{e\left(V + IR_s\right)}{mkT} \right) - 1 \right] \qquad (1) $$

Where:

I_{ph}:   Photo current
I_D: Diode current
I_s: Diode reverse saturation current
m: Diode ideally factor
K: Boltzmann's Constant
T: Absolute temperature
e: Charge of an electron

The simplified equivalent circuit is moderately accurate and most easy to simulate but does not give an optimal representation of the electrical process at the solar cell.

2.2. Modified Model

At real solar cells voltage loss on the way to the external contacts could be observed. This voltage loss could be expressed by a series resistor R_s. Furthermore leakage currents could be observed, which could be described by a parallel resistor R_p. the current flowing on the parallel resistance R_p is represented as shown in equation (2).

$$ I_p = \frac{V_D}{R_p} = \frac{V + IR_s}{R_p} \qquad (2) $$

Derived from Kirchhoff's first law the equation for the extended I-V curve could be achieved.

$$ I = I_{ph} - I_D - I_p \qquad (3) $$

So, substituting with the value of the diode current and the parallel branch current, the output current could be represented by the following equation:

$$ I = I_{ph} - I_s \left(\exp\left(\frac{V + IR_s}{mV_T} \right) - 1 \right) - \frac{V + IR_s}{R_p} \qquad (4) $$

This implicit equation could not be solved to get V and I in such an easy way as the equation from the simplified equivalent circuit. The equivalent circuit for modified model is shown in Figure 2.
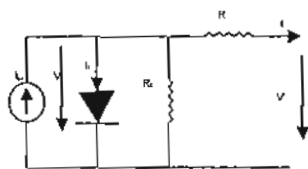
Figure 2. The Modified Equivalent Circuit of a
Solar Cell

2.3. Two-Diode Model

In this model, two different diodes with different diode ideally factors m connected in parallel [6-8]. At the equations of the diode, it was always taken for granted that there is no breakthrough at operation in the inhibited direction of the diode, but at high negative voltages a breakthrough at the solar cell could be observed. This was modeled at Figure 3 by a variable current source I (V_1).
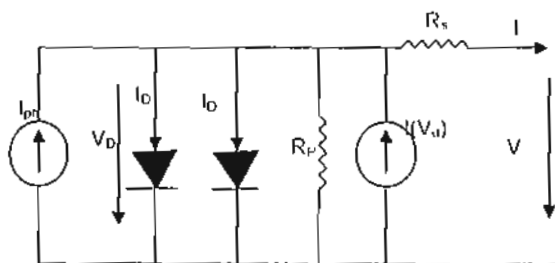

Figure 3. Two-Diode Equivalent Circuit of a solar
cell

The I-V curve of this equivalent circuit can also be derived from the node-law of Kirchhoff. The supplementary term of the equation models when the breakthrough at high negative voltages is represented as follows [8].

$$I = I_{ph} - I_{s1}\left(e^{\frac{V+IR_s}{m_1 V_T}} - 1\right) - I_{s2}\left(e^{\frac{V+IR_s}{m_2 V_T}} - 1\right) - \frac{V+IR_s}{R_p} - a\left(V + IR_s\right)\left(1 - \frac{V+IR_s}{V_{br}}\right)^{-n} \quad (5)$$

Where.

I_{s1}, I_{s2}: Saturation current of the first and second diode
R_s: Serial resistance
R_p: Parallel resistance
m_1, m_2: Diode factors of the first and second diode

V_1 Temperature voltage
V_{br} Breakdown voltage
a.   Correction factor
n: Exponent for avalanche breakdown

The two-diode equivalent circuit is more accurate than the modified equivalent circuit but the modeling process is more complicated as well. The two-diode equivalent circuit is given in Figure 3.

In this research, the modified model is used as a considerable accurate model and easy to implement one.

3. Problem Formulation

The main purpose of the PV system till now is to work on a stand alone basics. Tracking the optimal operating point at a specific situation is the key point. The prediction of optimal operating points affected by radiation and temperature and is difficult to predict by classical estimation approaches

During fault, the output of the PV system has multi-peak points So, the optimal PV points are many. This is to consider determining operating points one suffers from the local maximum problem Therefore, we proposed here a Genetic Algorithm scheme that is capable of detecting global optimal point However, the optimal tracking is the implementation of the electronic converter, which can easily affect the output power; a good control scheme is needed to stabilize the output during faults Therefore, the research is aimed also to unifying emerging technologies to improve the robustness of our design. Figure 4 represents a schematic diagram of the proposed PV system-based GA. This scheme is innovative and it involves:

(a) Photovoltaic system model as series parallel of PV cells subject to abnormal conditions such as clouds and partial shadow.
(b) GA optimization model to track the optimal operating point of the total power under different conditions
(c) Control module, in which the controller takes the signal from the genetic algorithm and controls the operating voltage of PV panel to match with the optimal requirements.
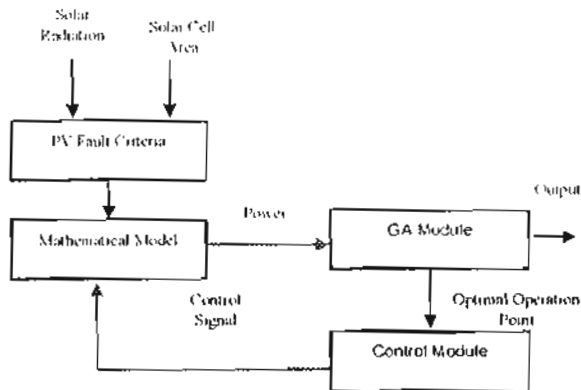
Figure 4. A Schematic Diagram of the PV System-Based GA.

The PV cell is a very small generating unit. A PV System will however consist of several PV modules each with many series solar cells [9, 10]. Such solar cells are known to experience occasional open circuit failures. The solar cell failures will usually not be balanced for the different PV modules, resulting in a dynamic optimal point. The power output is mainly function of the operating voltage. The optimal voltage recommended is used to evaluate the switching parameter of the DC-DC converter. Practical PV system is shown in Figure 5.
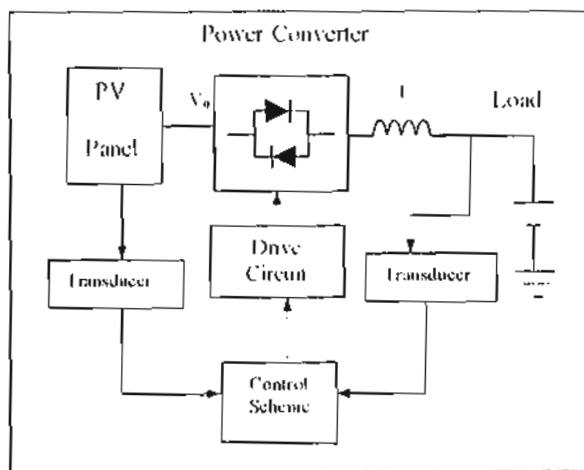

Figure 5. Maximum power transfer Circuit

The Buck converter has been the converter of choice for *Maximum Power Point Tracker, MPPT,* because of its high efficiency, low cable losses and ease of control. The only parameter of control in a Buck converter is the duty cycle [11].

3.1. Genetic Algorithm

In some instances, solution to multi-dimensional problems by using classical optimization technique is difficult, leading to an increased interest in the evolutionary algorithms Research employs intelligent control systems, such as Genetic Algorithm, Evolutionary Programming, and Evolutionary Strategies.

For classification, diagnosis, and controls, Genetic algorithm is the most widely known technology based on Darwinian thinking of natural selection and natural genetic (for problems where optimal search algorithm with multiple solution is used).

Genetic Algorithm feature are as follows.
- Whereas classical optimization techniques suffer from localization based on the initial point, GA is not subject to the initial point.
- GA searches for the global optimal solution in the entire range of feasible solutions and is insensitive to localized solutions.
- The GA routine involves the following four stages: Selection of initial population, Crossover and mutation to get new population, Reproduction, and Evaluation of the fitness function.

The subroutine for the simple GA is outlined as follows:

Step 1: *Initialize* the number of generations ($Gen: 0$).
Step 2: *Derive* the initial Old Population.
Step 3: *Evaluate* the *Fitness Function*.
Step 4: *Increment* the count ($Gen = Gen + 1$).
Step 5. *Select* candidates from Old Population.
Step 6: *Crossover* and *Mutate* to get New Population.
Step 7: *Evaluate* the *Fitness Function*.
Step 8. *Reproduce* (set Old Population as New Population).
Step 9: If *Termination Criteria* is not met, then go to Step 4, else continue.
Step 10: Display/Save the final solution, and
Step 11: *End.*

3.2. GA Formulation for Optimal Tracking

The PV panel is modeled as a current source consisting of parallel arrays each of series connected solar cell modules. A bypass diode is usually placed across each module to short out a cell that fails by opening it. The output of our mathematical model can be approximated by a 7th order polynomial as a

function of the array voltage. The GA optimization problem is therefore stated as:

$$Max \quad P(V) = \sum_{i=1}^{N} \sum_{j=1}^{7} \alpha_i V_i^{j-1} \quad (6)$$

$$Subject \quad to \quad 0 \le V_i \le V_{oci}$$

Where

$P(V)$: The total power generated

α_i : The polynomial coefficients

V_{oci} : The module open circuit voltage of array i.

N : The number of parallel-connected solar modules.

4. Case Studies and Results

4.1 PV System

Figure 6 shows a PV panel consisting of three parallel arrays each with 30 series modules [11-12]. Each of the series modules is shunted by a bypass diode. The shunt diode serves to complete the array connection circuit when the shunted solar modules experience open circuit failures. The module is rated at a peak power of 80 W, an open circuit voltage of, $V_{oc} = 21.1V$, and I_{sc} has a proportional relationship with the solar radiation and PV cell area. This panel was used to test the proposed scheme. Possible cell open circuit failures were taken into consideration ranging from 5% to 75% of the 3-arrays being faulted.
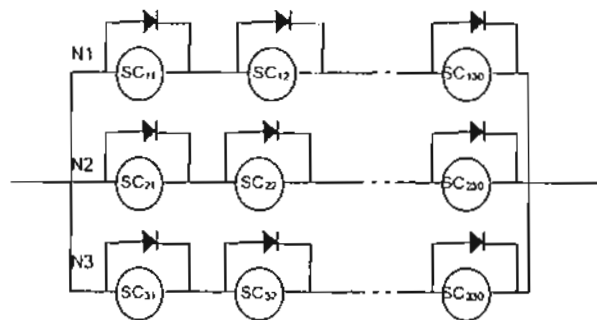

Figure 6. Arrangement of Solar Modules in the Solar PV Panel

4.2 Case Studies

The mathematical model of PV module in terms of V-I characteristic is developed for PV performance analysis. The power output curves under different radiation effects are studied, the genetic algorithm is employed for analyzing different system topology configurations under faults. The potential of our scheme is demonstrated for different cases. Three cases are illustrated in the paper.

Case I: Operating the PV under different fault criteria

Figure 7 represents a specific case. This particular case can be represented by a 5th order polynomial for each array and the summation of those curves have been used as an input the Genetic algorithm model, which estimates the optimum operating voltage to be 18.93 V and the corresponding optimum power was 48.0154 W.
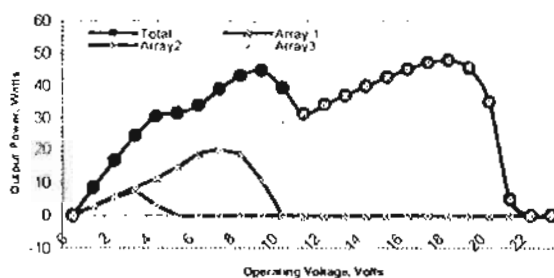

Figure 7. P-V characteristic of PV Panel at Insolation of 750 W/cm² and T= 0° C

Case II: Operating the PV under Different Temperature

Twelve cases were run at a constant *insolation* level of 100%. Different panel array conditions were assumed representing solar modules failures of between 25%-75% Table I summarizes the different cases considered for this constant *insolation* condition and the power generated

Table I: Optimal Operating Conditions for Faulted Photovoltaic Power System at Different Temperature Using Genetic Algorithm

Case	T(°C)	% Age of healthy case			Genetic algorithm Output	
		N1	N2	N3	Popt (W)	Vopt (V)
1	0.0	75	50	100	98	13.6
2		50	25	100	64	17.1
3		75	25	50	58	8.8
4		100	75	25	98	13.6
5	25	75	50	100	97	13.5
6		50	25	100	63	16.9
7		75	25	50	57	8.8
8		100	75	25	97	13.5
9	50	75	50	100	96	13.4
10		50	25	100	62	16.8
11		75	25	50	57	8.7
12		100	75	25	96	13.5

Case III: Operating the PV under different Solar Radiation

The twelve cases were repeated for a constant temperature of 25°C and varying *insolation* levels of 100%, 75% and 50%. The cases are summarized in Table 2. The power generated by each array was determined and the total panel power obtained.

Table 2: Optimal Operating Conditions for Faulted Photovoltaic Power System at Different Solar Radiation Using Genetic Algorithm

Case n	Insolation Level	% Age of healthy case			Genetic algorithm Output	
		N1	N2	N3	Popt (W)	Vopt (V)
1		75	50	100	96	13.5
2		50	25	100	64	16.9
3	100%	75	25	50	59	8.8
4		100	75	25	95	13.5
5		75	50	100	72	13.4
6		50	25	100	48	17V
7	75%	75	25	50	44	8.7
8		100	75	25	71	13.3
9		75	50	100	48	13.6
10		50	25	100	32	17
11	50%	75	25	50	30	8.6
12		100	75	25	48	13.6

5. Conclusions

Genetic Algorithm as a global optimization technique was tracking the global optimal operating point of the faulted PV system as a multi-peak optimization problem. The proposed algorithm is tested for the photovoltaic power system under different faulted conditions. It is shown from the results that the genetic algorithm captured the exact optimization point accurately.

based Genetic Algorithm scheme is tested on a three-parallel array photovoltaic system under different abnormal conditions.

6. References

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