Application of Genetic Algorithm to Solar Panel Efficiency; A Case Study of Port-Harcourt Metropolis

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Abstract

This study focuses on the evaluation of solar panel efficiency used within Port Harcourt environment. A major factor affecting the efficiency of solar panels is the difference in region or weather and the ability of the solar panel to convert incident radiation into electrical energy. Solar panels have varying efficiency levels under different weather conditions. Most times solar panels fall short of expected efficiencies. It is therefore important to have adequate knowledge of the performance characteristics of a panel under specific weather to ensure maximum output. For this research work, the panel whose efficiency was evaluated is China Solar 125W. The panel is a Polycrystalline solar panel made of Gallium Arsenide having a very high surface recombination ability. The panel has 72cells and a cross sectional area of… To evaluate the efficiency of the panel two methods were adopted to establish the response of the panel specific to Port Harcourt weather. The first method involved taking hourly reading of the parameters of the panel by subjecting the panel to outdoor atmospheric condition and recording the values obtained and comparing the result with that on the manufacturers sheet. The second method involved the collection of weather data. The weather data for Port-Harcourt was collected from the center for data collation Rivers State University. The peak radiation value obtained from the weather data for the year under consideration is used to calculate the efficiency of the panel and the value obtained compared with the maximum efficiency stipulated by the manufacturer. This efficiency was found to be low. Genetic Algorithm was then used to determine the optimal parameters of the cells making up the panel to obtain an optimized cell to improve the efficiency of the panel. To do this the cell initial properties were extracted and tabulated genetic algorithm used to improve this properties achieving better efficiency in the process.

Keywords: Genetic Algorithm, Solar Panels, Weather, Optimization, Efficiency.

1. Introduction

The issue of power generation still remains remarkably an issue of concern especially in the developing countries. The current practice in the electrical industry according to Balzhiser and Richard (1977) favors a shift from the conventional power generation techniques to a much more modern one, (renewable energy). Chief among the various renewable energy sources is the sun. In order to harness this energy effectively the use of specially designed solar panels is required. Solar panels are made of solar cells designed to trap incoming solar radiation and convert them into useful energy in the form of electricity. The efficiency of the solar cell is very important in defining the overall performance of the panels itself.

1.1 Aim and Objectives

The aim of this research work is to improve the efficiency solar panels using genetic algorithm.

The objectives are:

To evaluate the selected solar panel for cell efficiency.

To use genetic algorithm to determine the most appropriate parameters of the cell to give maximum efficiency**.**

1.2 Limitation

The cell efficiency is influenced by a number of factors including the weather of the immediate environment of installation. Panel performance in Port Harcourt is found to be usually poor and therefore an improvement in the efficiency of the panel is desired if proper use is to be made of the abundance of sunlight that characterizes this place.

2. Literature Review

In the design of photo voltaic systems, the major challenge has always been to optimize the panel for better efficiency. Therefore, several methods have been employed to attempt an improvement in one aspect or the other using different applications. Among these methods the most popular been HOMER PRO, PVPLANNER, and PV-F CHART.

HOMER PRO

This is most suitable for micro grid systems; it is not designed specifically for pv systems. Though it has the capacity to accommodate a large amount of data, it's major short coming is the fact that it presents results of pv system optimization in a less comprehensible manner.

PVPLANNER

This software provides accurate satellite data making solar radiation and and pv power estimation easy. It also automatically calculates shading. Long term annual and monthly data is included in the basic design. The software therefore has the constraint of preventing data from other sources.

PV-F CHART

The pv chart calculates power based on generic module and inverter. The data must be inputted manually making quick comparison of generation data difficult. Its major constraint though is that it is not suitable for power calculation in real world situation.

Genetic algorithm is defined as a robust search parameter technique that is based on Darwins principle of natural selection and survival of the fittest (Anisha et al 2014). Genetic algorithm differs from the conventional algorithms in the sense that it can handle a larger set of data than the conventional algorithm. This makes Genetic algorithms to more robust in nature than the conventional method. Genetic algorithms are also very easy to use (as compared to the other methods). This is because genetic algorithms eliminate the burden of solving complex derivatives associated with differential algorithms.

Several methods have been used to optimize one aspect of solar photovoltaic systems or another with huge success for instance, Nanget2010 carried out a research with the aim of establishing the correct angle of tilt for a solar panel to attract maximum sunlight. In Nangets work differential algorithm was employed with success and it was established that inclining panels relative to the sun produced better result and hence aided in the improvement of efficiency. However, the difference in latitude means no angle is absolutely ideal. Therefore, panel installers still have to maximize output by locating and placing the panels at the correct angle within the installation site.

Rizala, Hasta and Feriyadi (2013) in their research applied genetic algorithm successfully to track sunlight. This method ensures maximum ray is incident on the panel at all times. It is important to point out here that exposing panels to excessive sunlight may increase the top and ultimately destroy the cell.

2.1 Applications

Genetic algorithms find useful applications in sciences, Engineering and even management. They have successfully been used for timetabling and scheduling operations such as job shop scheduling, scheduling in printed circuit board assembly among many other useful applications examples are climatology, bioinformatics as well as design of anti-terrorism systems. They are also key components of mobile communication infrastructure optimization.

Genetic algorithm has also been used to optimize the cost of solar panels. Bernal and Lopez (2009 used genetic algorithm in their research work to minimize the cost of solar pv arrays. The positioning of sun trackers to maximize the collection of the solar radiation on the panels is another area where genetic algorithm has been used extensively with high degree of success.

3. Materials and Methodology

The method used in this paper involved selection of the solar panel taking into consideration its efficiency in relation to the Port Harcourt weather. This is important for establishing varying latitudes on the panel performance. This is because a panel offering high efficiency in one area may not necessarily do same in another area due to the latitudinal differences.

Port Harcourt is the capital and largest city of Rivers State, Nigeria, with coordinates latitude 4 46' 38" and longitude 7 00' 48". Port Harcourt has an elevation of about 52fts above sea level. The driest month is January and the month with the highest precipitation is September. It lies along the Bonny River and is located in the Niger Delta.

As of 2016, the Port Harcourt urban area has an estimated population of 1,865,000 inhabitants, up from 1,382,592 as of 2006. The dense population of Port Harcourt makes for very high demand in electrical energy

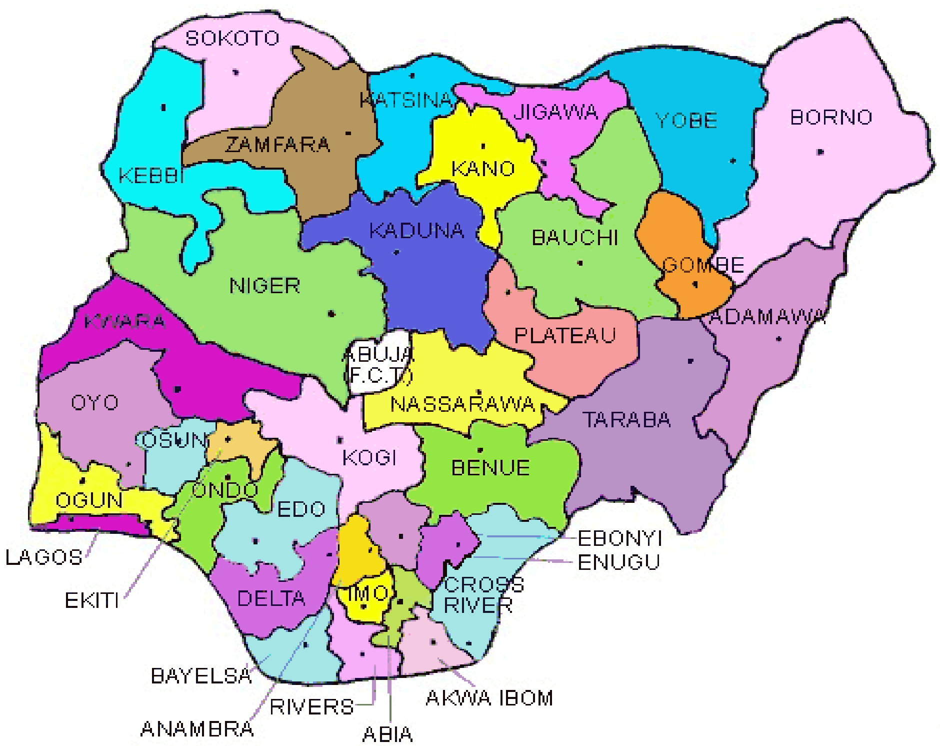

Fig. 1. Map of Nigeria highlighting the position of River State at the bottom.

The selected solar panel has a rating of 125 W and is made of gallium arsenide cells. The panel in consideration has a dimension of 67cm x 147cm and is made up of 36 cells. The panel data sheet was obtained and the data collected and recorded. The panel was then subjected to test by placing it on a roof top and taking hourly measurements using a Multimeter. Consequent results showed a variation in parameter values indicative of the effect of the different intensity on the panel efficiency though these changes were only small.

Table 1. showing hourly variation in open circuit voltage against time from 6am to 6pm

Time	6	7	8	9	10	11	12	1	2	3	4	5	6
Voc	15.1	16	17.6	18.8	19.2	19.2	18.04	18.7	18.8	18.4	18.4	18.0	15.0

3.1 *Efficiency Evaluation of a (125W) Gallium Arsenide Solar Panel*

Next, the weather data comprising amount of rainfall, wind speed, relative humidity, and solar intensity spanning a year was collected from the Centre for Data Collation and Analysis Rivers State University Port Harcourt. The peak radiation value obtained from the collated data was used to evaluate the efficiency of the panel. A section of the table of weather data showing the peak radiation value for the period in consideration is extracted and given in the table 1 below due to the volume of the data.

The peak value was chosen to maximize output. From table 2 this value is 606 W/m^2. The area of the panel in meter was calculated and recorded as 0.9849 m^2

Table 2. showing an extract of Port Harcourt Weather Data

TOA5	**PORT HARCOURT**									
RECORD	**Batt_Volt_Min**	**Rain_mm_Tot**	**SlrW_Avg**	**AirTC_Avg**	**RH**	**T107_C_Avg**	**WS_ms_Avg**	**WindDir**	**Bar Press_Avg**	**VW**
RN	**Volts**	**Mm**	**W/m^2**	**Deg ^0C**	**%**	**Deg ^0C**	**Meters/ Second**	**Degrees**	**mV**	
	Min	Tot	Avg	Avg	Smp	Avg	Avg	Smp	Avg	Smp
51818	13.98	0	606.6	33.49	49.15	29.11	1.903	41.87	1047	0.131
51819	13.96	0	594.8	33.65	48.5	29.12	0.957	26.87	1048	0.13
51820	13.95	0	596.5	34.17	46.22	29.18	1.206	62.7	1049	0.13
51821	13.95	0	599.9	34.41	45.99	29.18	0.913	190.7	1049	0.131
51822	13.93	0	592.5	34.9	45.48	29.21	0.757	32.84	1051	0.131
51823	13.78	0	491.2	34.45	48.23	29.26	1.6	354.8	1052	0.13
51824	13.84	0	548.2	34.58	46.09	29.25	1.995	345.3	1052	0.131
51825	13.81	0	395.2	34.31	47.21	29.25	2.122	8.99	1052	0.131
51826	13.82	0	270.6	33.87	48.53	29.25	2.221	21.51	1050	0.131

Source: *Centre for Data Collation Rivers State University*

In the design of photovoltaic panels, the efficiency is defined as the ability of the panel to convert incoming solar radiation into useful energy. Efficiency is therefore dependent on the cells ability to trap and convert the incident radiation. It is important to determine the efficiency of panels so that manufacturers and installers or solar panels would easily be able to define what panel would be suitable for installation for a given power.

Manufacturers define the efficiency of a panel to be the ratio of the power to the product of the incident radiation and area. For the panel in consideration, Max Efficiency = $\frac{P_{max}}{S \times A_C}$ (3.1)

$$eff = \frac{125}{\frac{(67 \times 147)}{10{,}000} \times 1000} = 12.7\% \quad (3.2)$$

Efficiency evaluation of the proposed optimized model of solar cell

The cell structure is basically an NP GaAs cell. Between the substrate and cell is sandwiched a doped P+ with the primary function of creating an electric field delayed rear face. This is to lower the recombination rate and improve the electrical characteristics of the cell.

The efficiency of the cell is dependent on the following factors:

- The short circuit current density
- Open circuit voltage
- The current density due to intensive concentration of GaAs.

3.2 Efficiency Optimization with Genetic Algorithm Technique

The optimized efficiency is calculated using the relation below:

$$\eta = J_{sc}(V_{oc} - \beta) / s_{ol} \quad (1.2)$$

$$\alpha = 1 + In(1 + {}^{V}/_{V_T}) \quad (1.3)$$

$$\beta = V_T \times \alpha \quad (1.4)$$

Where

sol = peak optical power density = solar irradiance at temperature of 301K.

This is achieved by the help of the genetic algorithm.

Optimization Technique

The objective function is defined as;

F_{obj} = maximize (eff)

By optimizing the constraint function:

F [x(1), x(2), x(3), x(4) x(5)]

Where

x(1) = Doping of base

x(2) = doping of p-layer

x(3) = doping of n-layer

x(4) = width of base

x(5) = cell voltage.

These are the parameters to be optimized in order to improve and optimize efficiency

Table 3. Range structure of Solar cell before optimization.

S/No	**Parameters**	Range of Values
1	Calculated Efficiency (%)	12.7
2	x(1), Doping of base (cm^{-3})	[1e20 to1e25]
3	x(2), Doping of P-layer (cm^{-3})	[1e20 to 1e25]
4	x(3), Doping of n-layer (cm^{-3})	[1e20 to 1e25]
5	x(4), Doping of width of base (cm)	[1e-7 to 1e-5]
6	x(5), Doping of cell Voltage (V)	[0.5 to 1]

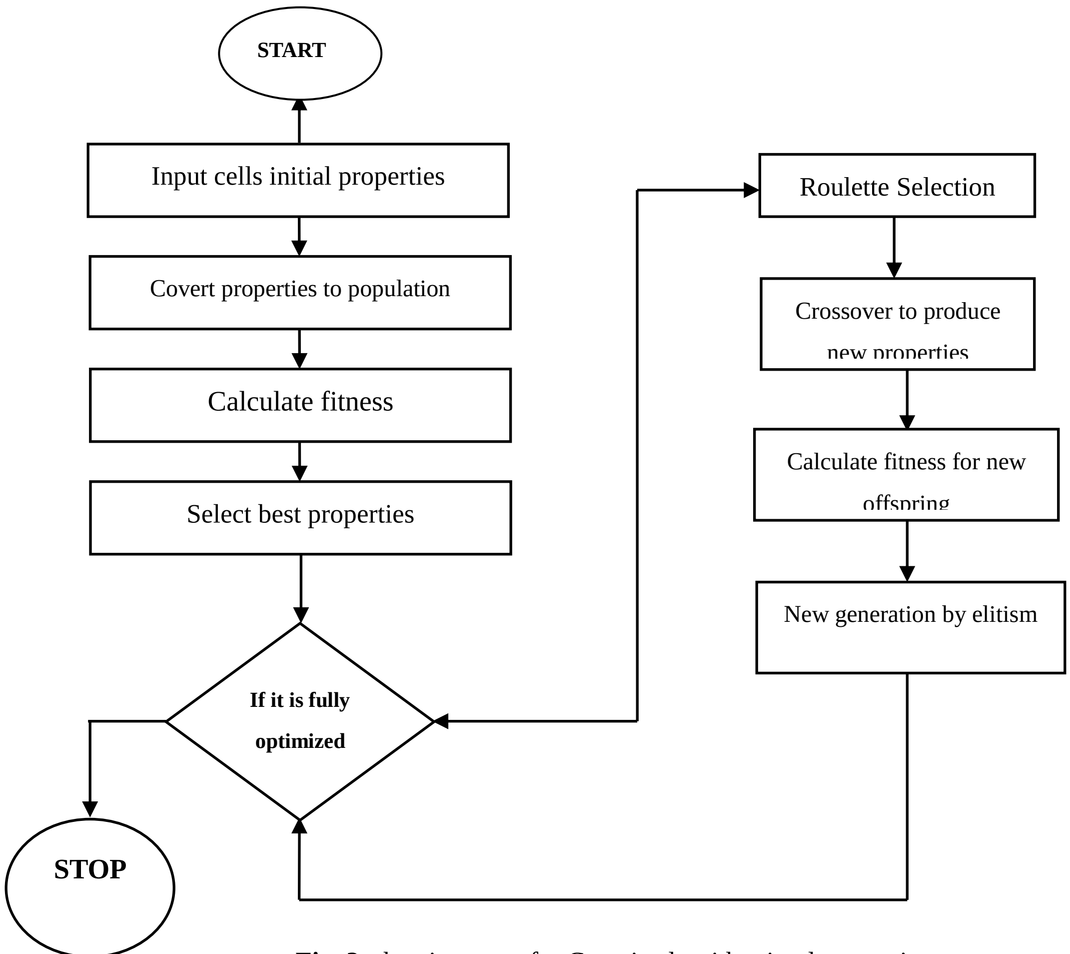

Fig. 2. showing steps for Genetic algorithm implementation

The cell properties given in table 1 above and the weather data in table 2 were fed into the program with the function set to maximize efficiency.

The initial properties of the cell were converted by the program into population

Fitness for each parameter was calculated with maximum radiation kept at 606w/m^2

The system was programmed to run for 2mins and to repeat until a value representing the maximum for each parameter corresponding to the peak radiation value obtained.

When this values are reached the program ends. The new values obtained represent the maximum and therefore the optimized values of the parameters.

Results and Discussions

Results

The results presented here show the efficiency of the panel at different solar cell parameter variations. The results are presented as below in figure 3 to figure 7.

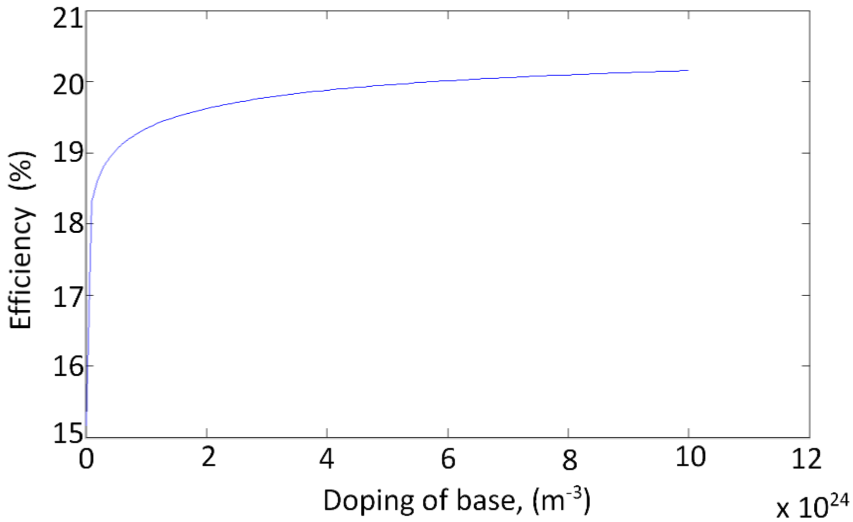

Fig. 3. Optimal Efficiency as function of doping of Base of solar cell

Fig. 3 shows the efficiency of the solar cell as function of optimizing the base layer of the solar cell. The value of the efficiency gotten by optimization of the solar cell is said to be maximum at the point with which the base of the solar cell is doped to optimal position. From the graph the value of the efficiency is measured to be 20.1538% at an optimal base value of $1e^{-25}$ centimeters. The graph confirms that as more and more the base layer of the solar cell is doped, the efficiency becomes improved gradually until it reaches its optimal value

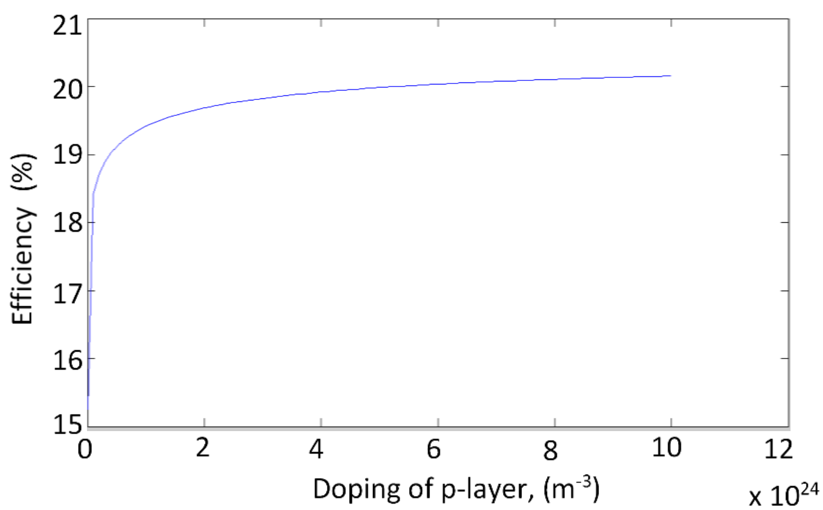

Fig. 4. Optimal Efficiency as function of doping of P-layer of solar cell

Similarly, Fig. 4 also records the efficiency of the solar cell at an optimal doping level of the p-layer of the solar cell. The doping optimizes the p-layer and as such produces the best efficiency at the optimum doped layer of the p-layer. The efficiency is measured to be 20.1538% at an optimal p-layer doped surface of 1e25 centimeters. The graph confirms that as more and more the p-layer of the solar cell is doped, the efficiency becomes improved gradually until it reaches its optimal value. Although, the variation in p-layer doping level did not cause a large change in efficiency as the values of efficiency is almost constant at varying p-layer doping level of solar cell.

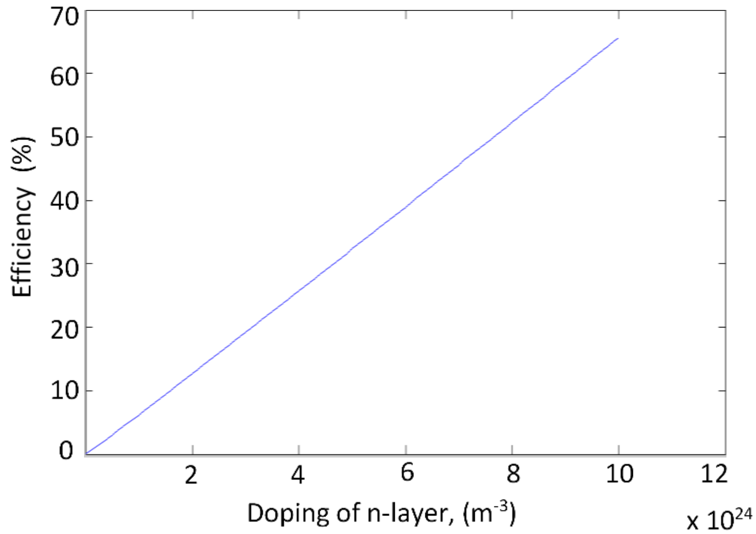

Fig. 5. Optimal Efficiency as function of doping of n-layer of solar cell

Also, fig. 5 shows the evaluated efficiency of the solar cell at an optimal doping level of the n-layer of the solar cell. The doping optimizes the n-layer and as such produces the best efficiency at the optimum doped layer of the n-layer. The efficiency is measured to be 20.1538% at an optimal n-layer doped surface of 4.345e24 centimeters. The graph also shows that as more and more the n-layer of the solar cell is doped, the efficiency becomes improved until it reaches its optimal value. Although, the effect of doping the n-layer on efficiency is minimal compared to the effect on efficiency when p-layer is doped, the efficiency greatly varies at varying n-layer doping level.

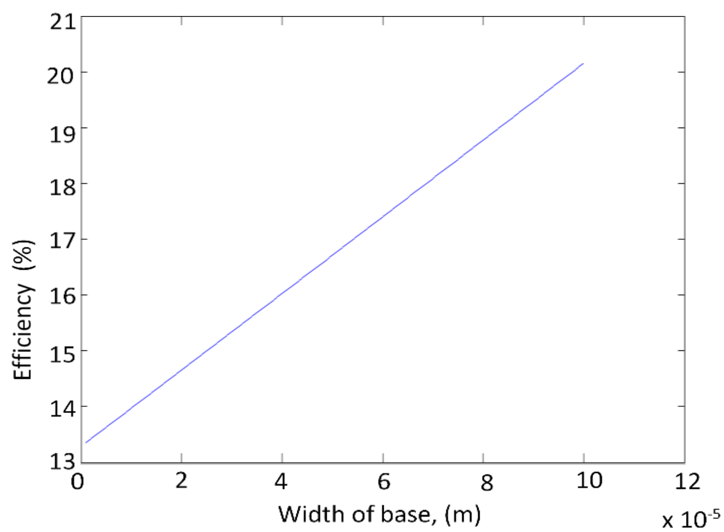

Fig. 6. Optimal Efficiency as function of varying width of base of the solar cell

Fig. 6 shows the variations of the width of the base at optimum efficiency. The efficiency is determined at the point where the value of the optimum solution for the width of the base of the solar cell is achieved. The efficiency is 20.1538% at optimal doped width of the base gotten at 1e-0.5 centimeters. The graph shows that as the width of the base of the solar cell is doped, the efficiency becomes improved rapidly until it reaches its optimal value. The variation effect of the width of the base caused a significant variation in efficiency.

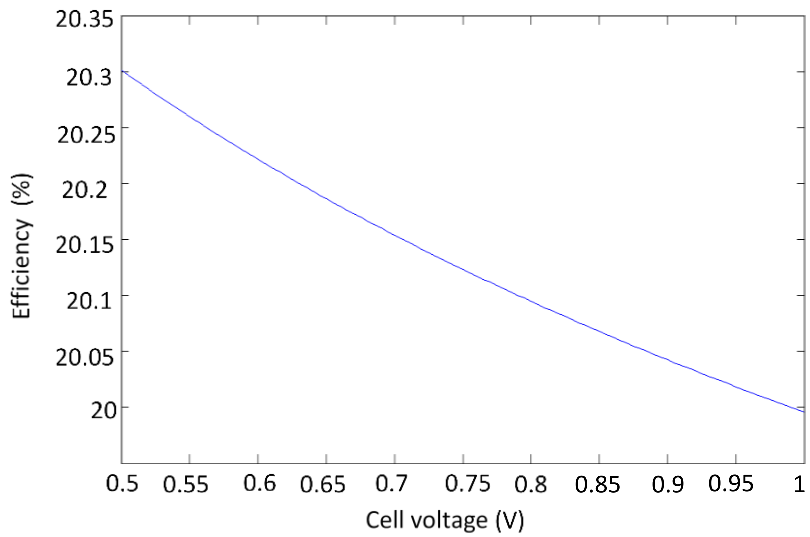

Fig. 7. Optimal Efficiency as function of varying cell voltage of the solar

Finally figure 7 plots the efficiency at varying cell voltage. At the point where the cell voltage is optimum, the maximum solar cell efficiency is determined. The value of efficiency at optimal cell voltage is read from the graph as 20.1538%. The optimal cell voltage is gotten as 0.7V. The graph also illustrates that as one increases the cell voltage above a certain initial threshold value, the efficiency of the cell will drop very insignificantly until it arrives at its optimal point where the value of the cell voltage at that point gives the best efficiency under any operating condition of the panel.

From Table 1 and 2, the value of the optimized efficiency is seen to have improved from 11.17% to 20.15% respectively. This new efficiency value is as a result of optimizing the parameters x(1), x(2), x(3), x(4), and x(5). The optimization of the parameters is referred to as doping of the layers of the solar cell so as to maximize efficiency of the solar cell at any time of the day and peak daily radiation (solar irradiance).

Similarly, the range of the solar parameters shown initially in table 1.1 was optimized and its best optimum point where computed with help of the genetic algorithm as shown in table 4.

Table 4. Results of simulation

S/No	**Optimized Parameters**	**Optimal Values**
1	Optimized Efficiency (%)	20.15
2	x(1), Doping of base (cm^{-3})	1.0e+25
3	x(2), Doping of P-layer (cm^{-3})	1.0e+25
4	x(3), Doping of n-layer (cm^{-3})	4.3e+24
5	x(4), Doping of width of base (cm)	1.0e-05
6	x(5), Doping of cell Voltage (V)	0.7

4. Conclusion

The cell properties as given in table 1 and the solar radiation data as given in table 4 were fed into the program and the function set to maximize efficiency by maximizing component values of the solar cell subject to the maximum radiation. The program was designed to run for two minutes and stop when maximum values are reached.

The result of the research shows an improvement of 2.15% on the initial efficiency of the panel. This improvement is as a result of optimizing the parameters x(1), x(2), x(3), x(4), and x(5). This is achieved using genetic algorithm and hence proves genetic algorithm adequate to optimize solar panel efficiency

5. Recommendation

It is my recommendation that before installation, selected panels should first be evaluated for efficiency as weather varies. Although silicon is widely accepted as the best material for pv panels because of its availability, other materials can give similar results on optimization. Finally, genetic algorithm should be used for parameter selection in the design stage of the panel to give optimal result.

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