Optimization method for the internal distribution network of a photovoltaic plant using Genetic Algorithm

Abstract

Solar energy has grown exponentially around the world because it is clean and renewable, with this, photovoltaic plants are installed for its consumers as well as to relieve the electrical system of the country and guarantee the reliability. In this way, carrying out a correct dimensioning and finding a layout for the execution of a solar plant is important because it can increase or minimize the electrical losses as well as the investment. This study uses the genetic algorithm in order to find better layout to optimize the energy loss on an implanted solar power plant and resize the conductors by current capacity and voltage drop, the study shows how to program Excel to solve the multi-positioning problem through the genetic algorithm in a solar power plant. The results show that the optimization proposed by the genetic algorithm was able to reduce electrical losses by 75% and the net present value over a period of 25 years was reduced by 25%. Future research will be carried out considering 3D plans covering solar plants that are installed on the roof.

Keywords: Optimization, genetic algorithms; energy loss; solar power plants; renewable energy

Introduction

Solar energy has grown over the last 10 years around the world, today there are more than 1,500GW in the world energy matrix and in 2027 it is expected to surpass natural gas and coal [1]. China is the leader in solar energy usage adding 100 GW in 2022, 60% increase over 2021, European Union added 38 GW in 2022, 50% increase over 2021, India added 18 GW, being 40% more than the previous year, and Brazil has also seen great growth in solar energy, adding 11 GW compared to 2021 [1]

The main element of a solar power plant is its photovoltaic panels and its inverters, and for the connection to the electricity grid of the power company, the transformer to connect to the meter [2]. Carrying out the execution of an efficient project with the lowest possible losses and sizing correctly improves costs and maximizes the production of electric energy. Seen this configures a problem of optimization of multiple variables, where the method of genetic algorithm is used to solve complex problems.

Nature solves complex optimization problems for species evolution, the genetic algorithm is based on Charlis Darwin's theory of evolution, which is based on the evolution of the fittest individuals. This solution is implemented in computational intelligence through genetic operators, they carry out the mutations and choices of solutions through interactions until a convergence result is obtained [3-5]. The Evolutionary mode is active in the Excel spreadsheet system and is based on the genetic algorithm to solve nonlinear problems through genetic operators [6-7]. This work constituted the use of this tool, not developing the method itself. The Figure 1 explain the way how genetic algorithm operates.

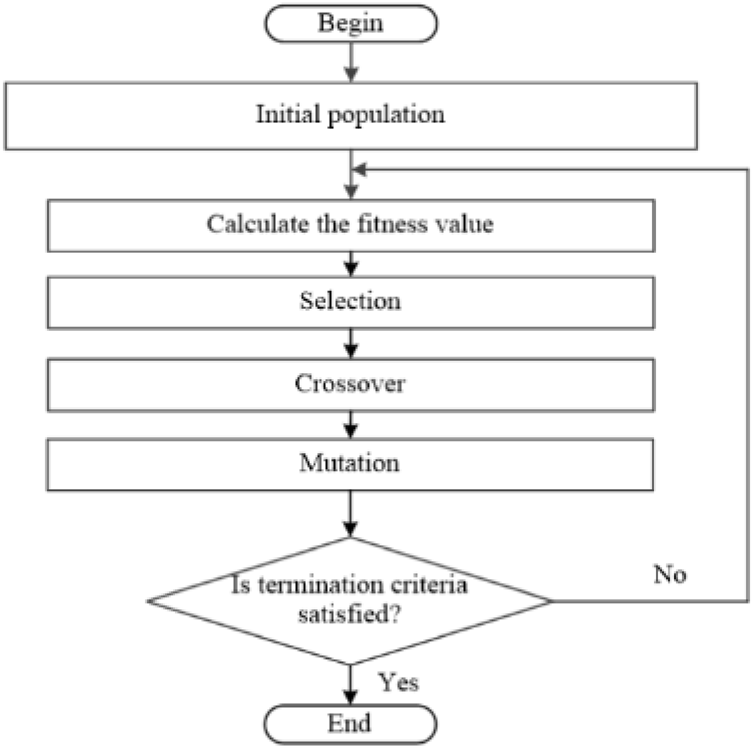

Figura 1: Genetic Algorithm

Many studies use the genetic algorithm to solve optimization problems and as well as other methods, in [8 - 9], the authors use the optimization method proposed in wind farms to maximize the production of electric energy for different heights of turbines, in [10] a genetic algorithm was used to obtain the solution considering economic, technical and environmental performance factors, optimizing the layout and operation of the system to maximize the results for a photovoltaic plant with charge storage for demand control. In [11] the authors carried out a study on the storage system of a photovoltaic system in order to optimize the energy demand using the genetic algorithm.

The authors in [12] use the genetic algorithm to locate the best installation point of a photovoltaic plant to supply energy to cities in India, configuring an external redistribution problem, in [13] it is using the proposed method to maximize the efficiency of the solar cells through the optimization of silicon doping, whereas the authors in [14] use the genetic algorithm to build inverters through the control of electronic components.

In [15 – 17] a genetic algorithm is used to control electricity through power transmission towers for city services, thus minimizing losses and costs. In [18 – 20] the optimization method is used to maximize energy in internal distribution networks, showing great results compared to traditional methods.

In [21] the authors carry out comparisons between evolutionary algorithms and their proposed algorithm to analyze a solar plant and reduce losses. In [22] combinations of clean energy and applying the genetic algorithm were shown to increase the energy efficiency of combined systems, showing an increase of almost 20MW. In [23] the authors identify the problem of voltage sagging between solar plants and the connection to the grid, they use the genetic algorithm to identify the point and correct it, thus increasing the grid efficiency by approximately 6%.

This work aims to use the genetic algorithm to optimize energy losses and minimize the energy lost in conductors, also combined with a dimensioning of conductors, thus avoiding excesses and unnecessary costs.

Unlike other studies that deal with modeling transmission, distribution, wind farms and technology improvement, this work is innovative because it works the internal redistribution of an existing photovoltaic plant adding a resizing of conductors and costs over a period of 25 years.

The work shows how to carry out the correct sizing of cables according to national and international standards, and later apply the genetic algorithm in the variables of the photovoltaic plant, which works by positioning the inverter and transformer, showing the difference between the initial layout and the new model of execution in a practical way, showing the different comparisons between the cases.

The study brought great results showing a great reduction in electrical losses, a new proposed execution layout, value in the investment during 25 years of useful life of the photovoltaic system at present value, showing in the results section the comparisons between the case studies, and showing a reduction of 75% electrical losses between cases and improvement in net present value of 25%.

The novelty of this work is to use a practical tool used by any reader worldwide, the Excel spreadsheet program, where it has the native genetic algorithm in the tool, to solve multi-position problem of electrical components, adding with a new sizing of cables. If readers of the world can replicate this study. Normally, the layout on the solar farms is made by high experienced professional based on the own experience, which now, can use this tool to solve and calculate the system easyly.

The work is limited to an analysis of a ground plant, which can be replicated for any ground plant, as they work in X and Y coordinates, but making it impossible to analyze roof plants, where they work with the X, Y and Z axes and have space limits with conditions as well.

Materials and methods

1.1 *Methodology* . First, this article presents the criteria for sizing cables buried directly in the ground, following the criterion of current capacity and maximum allowable voltage drop, later, it presents mathematical foundations for cabling losses calculations, later the cabling cost is calculated and how much the losses affected the system during the 25-year lifetime of a solar plant, the net present value method is used. It is demonstrated how to use and parameterize the genetic algorithm to optimize the variables and improve the performance of the photovoltaic system, applied directly in a case study and making comparisons with projects carried out in Brazil. To proof the results shown, PVsyst, a world-renowned program for analyzing solar power plants, will be used.

Figure 2 shows how the work is structured for development and better reading and understanding.

Figure 2. Structured of paper

The basic theory presents the mathematical foundations for calculation, which the reader could use to replicate and manually calculate the results that are presented in a table during the study. Subsequently, the way to perform the initial configuration of Excel's evolutionary mode is presented, explaining its working parameters. Finally, the cases are presented, where the first presents the work source with its existing data and generates it in the comparative model and the second shows the results used using the genetic algorithm. Note that the work can be replicated manually using the theoretical basis presented.

1.2 *Theoretical foundation* . The correct sizing of cables is of paramount importance to guarantee the correct operation and safety of the system for years. The proposed sizing follows national regulations in Brazil NBR 5410 and international regulations IEC 60364-5-52 [24-25]. Formula 1 shows the correct current correction of a base project. [24-25]

After correcting the rated current, the cable manufacturer must be chosen and its respective rated conductor current informed by the manufacturer respecting the installation method must be greater than the corrected project current, according to Formula 2.[24-25]

$$Ib = Ip\,/(k1 *\ k2 *\ k3) \qquad (1)$$

$$Ic > Ib \qquad (2)$$

Where:

Ib = Corrected design current (A);
Ip = Nominal design current (A);
Ic = Rated current of the conductor according to the manufacturer's specification (A);
K1= Correction factor related to temperature;
K2 = Correction factor in relation to the ground
K3 = Correction factor in relation to cable bundling;

The voltage drop in a cable must be calculated to ensure compliance with technical standards, and it is also one of the criteria that the cable must meet to ensure the safety of the entire system. [25-26]. Formula 3 and 4 show how to calculate the voltage drop of a conductor and the percentage voltage drop should never exceed 5%.[25-26]

$$Vd = \sqrt{3} * Ip * L * R \qquad (3)$$

$$5\% > \frac{Vd}{Vn} * 100 \quad (4)$$

Where:

Vd= Voltage drop (V) in AC, for DC circuit the factor √3 is not used
Ip = Nominal design current (A);
L = Conductor distance (m);
R= Conductor impedance (Ω/m);
Vn = Nominal voltage (V);

Carrying out a correct sizing of conductors is very important to guarantee the safety of the electrical system and also to minimize electrical losses, large distances to be run increase these losses drastically. Formulas 5, 6 and 7 show how to calculate electrical losses in conductors [27-28].

$$Pcc = 2 * R * I^2 * D \quad (5)$$

$$Pca = 3 * R * I^2 * D \quad (6)$$

$$P\% = \frac{P}{Pn} * 100 \quad (7)$$

Where:

Pcc = Direct current losses (W);
Pca = Losses in alternating current (W);
P% = Percentage losses (%);
R = Resistance of the conductor used in the section (Ω/m);
I = Rated current of the section (A);
D = Distance of the section (m);

For application in photovoltaic systems, direct current losses must be multiplied by the number of strings, and all losses must be considered a factor of 60%, since a solar energy system does not remain constant depending on the sun [27].

Based on cabling costs, investment in conductor acquisition and electrical losses, the Net Present Value (NPV) formula is used for investment analysis. This method brings future revenues to present value, according to Formula 8 [29-31].

$$NPV = FCo + \Sigma FCt/((1 - i)^n) \quad (8)$$

Where:

NPV = Present Net Value (R$);
FCo = Initial investment (R$);
FCt = Investment according to the year (R$);
i = Attractiveness rate
n = Year in question;

The present article presents a solution in solar energy, so it is of great importance to perform against the estimated annual generation of the system, with this, we use Formula 9.

$$G = P * 365 * a * f \tag{9}$$

Where:

G = Estimated annual generation (kWh)
P = Power (kW);
a = Hours of full sun;
f = Loss factor;

The present study works with the Genetic Algorithm implemented in the Excel spreadsheet system, which will use the Solver in the Evolutionary mode. Defining the step by step for its use as follows:

Step 1: In the Data tab, enter Solver, and choose the solution mode in Evolutionary;

Step 2: Define the objective function;

Step 3: Define the variables and constraints as solution search limits;

Step 4: Perform the configuration of the Evolutionary mode of the Genetic Algorithm depending on the complexity of the problem, that is, increase the population number, or iterations for convergence;

In this study it is applied to the defined theoretical foundations applied directly in the analysis of two case studies of photovoltaic plants executed and in operation in Brazil, carrying out the comparison with the cable gauge defined by the designer, calculating its losses, generation analysis during the period of 25 years, and the losses involved during that time, perform the optimization using the genetic algorithm to reposition the variables, compare the results found with the real case and highlight the differences found.

1.3 *Case 1* . The project in question was installed in Rio de Janeiro, Brazil. Table 1 shows the plant parameters as used in the project.

Table 1: Preliminary data of the solar plant.

	Data
Number of modules	270
Manufacturer/model	ERA SOLAR / ESPHSC550
Panel power	550W
Number of inverters	1
Manufacturer/model	Goodwe/GW120K-HT
Power	120kW
Expected energy	201 MWh/year

The total size of the plant is 148.5 kWp of photovoltaic module installation. The solar modules from the Chinese manufacturer ERA Solar, have high performance quality according to the useful life of the modules. Table 2 shows the module parameters under nominal STC operating conditions and without NOCT operating conditions.

Table 2: Preliminary data of the solar panel.

	STC	NOCT
Power	550W	416W
Voltage operation Vmp	41.95V	39.65V
Current operation Imp	13.12A	10.51A
Voltage open circuit Voc	49.80V	46.80V
Current short circuit Isc	13.98A	11.11A
Efficiency	21.3%	21.3%

The inverter power is 120 kW and is responsible for protecting the system in connection with the power grid and for converting direct current to alternating current. Table 3 shows the technical data of the used inverter.

Table 3: Preliminary data of the inverter.

	STC
Max Power Panels	180kW
Max Voltage Panels	1100V
Number of MPPT	12
Number strings per MPPT	2
Max output current	191.3A
Grid Connection Voltage	380V

Figure 3 shows the simplified connection diagram used for this project with the electrical parameters of the sized cables, it can be verified that a 120mm² conductor was used for the section between the module and the inverter. and between the transformer and the meter a conductor of 16mm².

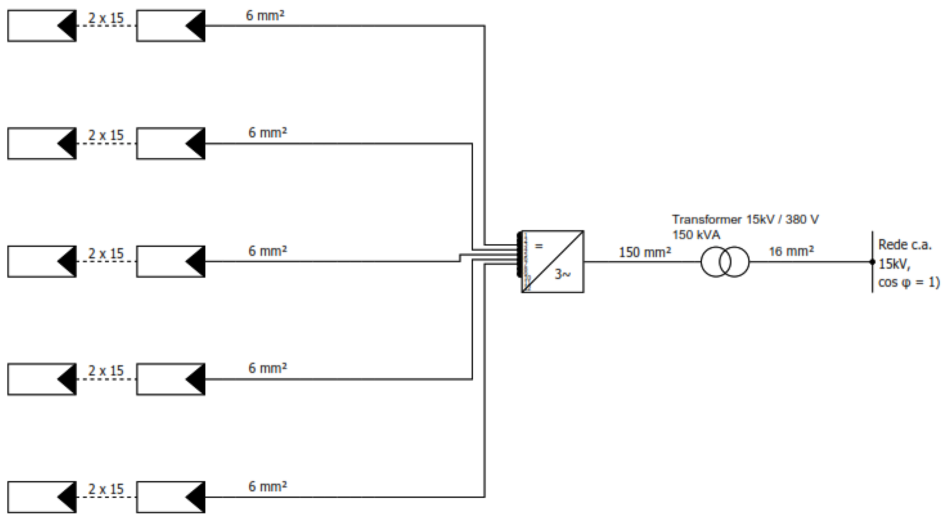

Figure 3. Electric Connection Diagram – Solar System On grid of 148.50kWp

Table 4 shows the connection details presented according to the electrical arrangements used.

Table 4: Preliminary data of the solar system configuration.

	Data
Number of strings	18
Number of panels per string	15
Current per strings	10.51A
Voltage per string	594.75V
Max input voltage inverter	1100V
Max current output of inverter	191.3A
Voltage output of inverter	380V
Transformer power	150kVA
Output voltage of transformer	380V
Input voltage of transformer	15kV
Input current transformer	4.85
Electric factor power of system	1

Figure 4 shows the geographic positioning of the components within the land area where the project was installed, where the modules, the inverter and the transformer can be seen.

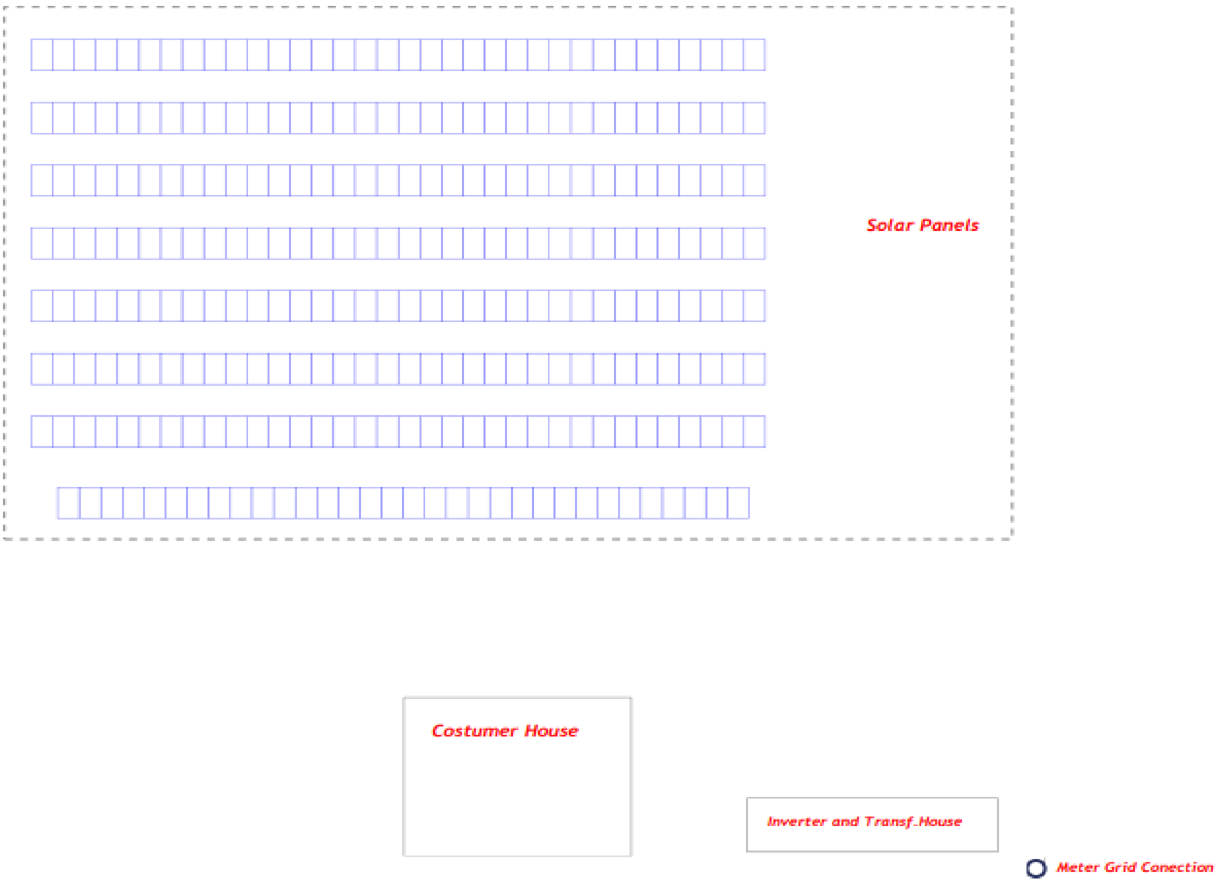

Figure 4. Layout of the solar system

In Figure 5, the installation of the panels for the proposed plant can be seen.

Figura 5. Instalation of the panel

Table 5 presents data on resistance and cost of each conductor used and Table 6 presents the calculation of losses per section of the solar plant, showing the average distance per conductor. Formulas 5, 6 and 7 are used to calculate the electrical losses presented in the project of this solar plant, totaling a loss of 1.45 kW representing almost 1% of the total generation. It is necessary to use a 60% utilization factor in the formulas, as the solar system does not work constantly and oscillates during the day according to solar irradiation.

Table 5: Resistance and Cost of cables

	Resistance (Ω /m)	Cost (BRL/m)
6mm² solar cable	0.0034	5.50
150mm² cable 1kV	0.000 17	172.60
16mm² 15kV cable	0.0015	236.00

Table 6: Losses of the solar system

	Cable (mm²)	Distance (m)	Losses (kW)	losses (%)
Panel to invert	6	164	1.34	0.90
Inverter to transf.	150	11.2	0.10	0.08
Transf. to meter	16	9	0.0005	0.00

To valiData the results shown in Table 6, Pvsyst was used, a world-renowned and renowned software for sizing and configuring solar plants to valiData their generation performance, evidencing losses. Figure 6 shows the DC and AC losses of the system, where 0.88% were found for DC losses and 0.07% and 0.00% for AC losses, totaling approximately 1%, proving the results shown in Table 6.

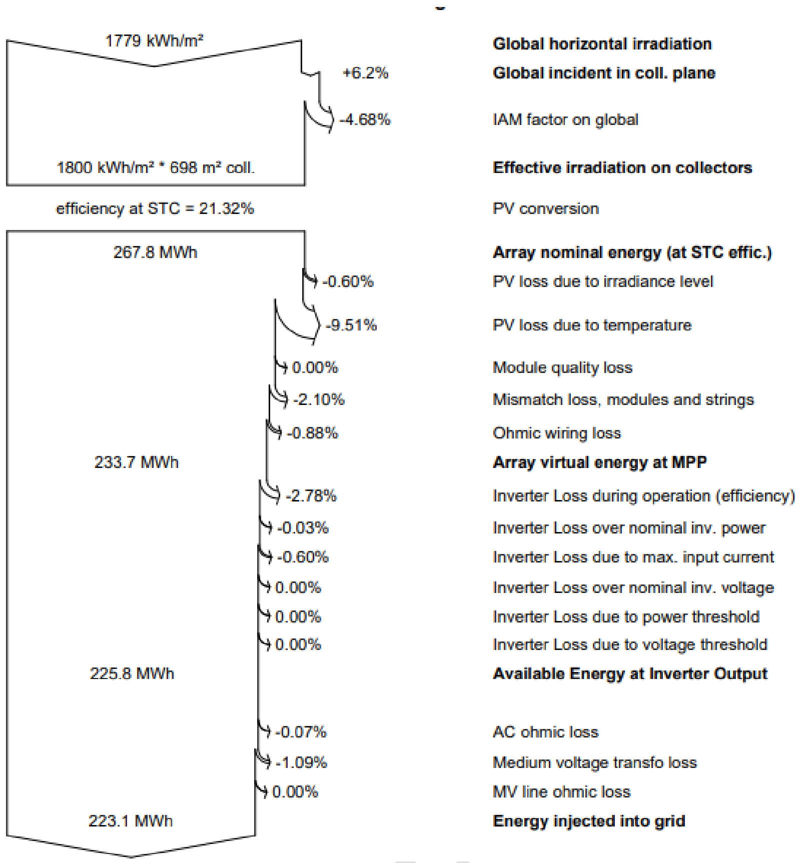

Figure 6. Pvsyst Loss Diagram

Table 7 shows the cost of the conductor for each stretch, this is the investment amount to acquire the conductors for the project, thus generating a total initial cost of R$44,643.40. In this work, neutral and ground cables are ignored.

Table 7: Cable cost of the solar system

	N. Cables	Distance (m)	Total Cost (BRL)
panel to invert	2*18	164	32,472.00
inverter to transformer	3	11.2	5,799.40
transformer to meter	3	9	6,372.00

The value of injected energy is considered at R$1.20 per kWh with annual tariff readjustments of 8% per year, full sun hours quantified at 5 and photovoltaic system loss factor at 0.8, these assumptions being used to calculate the cost of generation lost in the conductors presented in Table 6 during the period of 25 years using Formula 9, which is the useful life of a solar energy system, disregarding module degradation due to operation and cabling degradation. Table 8 shows the decrease in generation caused by conductor losses.

Table 8: Loss energy of cable

Year	Loss (kW)	Energy Loss (kWh/year)	kWh (BRL)	Total (BRL)
0	1.44	2102.4	1.20	2522,880
1	1.44	2102.4	1.30	2724,710
2	1.44	2102.4	1.40	2942,687

3	1.44	2102.4	1.51	3178.102
4	1.44	2102.4	1.63	3432,350
5	1.44	2102.4	1.76	3706,938
6	1.44	2102.4	1.90	4003,493
7	1.44	2102.4	2.06	4323,773
8	1.44	2102.4	2.22	4669,675
9	1.44	2102.4	2.40	5043,249
10	1.44	2102.4	2.59	5446,709
11	1.44	2102.4	2.80	5882,445
12	1.44	2102.4	3.02	6353.041
13	1.44	2102.4	3.26	6861,284
14	1.44	2102.4	3.52	7410,187
15	1.44	2102.4	3.81	8003.002
16	1.44	2102.4	4.11	8643,242
17	1.44	2102.4	4.44	9334,702
18	1.44	2102.4	4.80	10081,478
19	1.44	2102.4	5.18	10887,996
20	1.44	2102.4	5.59	11759.036
21	1.44	2102.4	6.04	12699.758
22	1.44	2102.4	6.52	13715,739
23	1.44	2102.4	7.05	14812,998
24	1.44	2102.4	7.61	15998.038
25	1.44	2102.4	8.22	17277,881

Table 9 shows that a total of R$201,715.39 is lost during the 25 years of operation of the solar plant, this loss is caused by the cabling in the proposed layout, where the inverter and the transformer were allocated. Thus, Formula 8 is used to calculate the Net Present Value using a rate of 4%, which is commonly applied for investment in Brazil.

Table 9: Net Present Value

	Cost (BRL)
Initial cable cost	44,643.40
Lost energy in Cable	201,715.39
Present net value	144,071.09

1.3 *Case 2* . The same project presented previously is used, but computational intelligence is used to find or valiData that the layout and dimensioning could be improved in order to find a solution that minimizes electrical losses.

The application of the genetic algorithm is carried out through the Excel spreadsheet program in solving problems in Solver mode in the evolutionary mode function. Thus, first the genetic algorithm is configured, and the proposed configuration is defined in:

1- Convergence: 0.000000001
2- Mutation rate set to 0.0015
3- Population size set to 950
4- Maximum idle time at 1200
5- The variables will be the X,Y positioning of the inverter and transformer defined later

6- The objective will be to obtain the smallest loss
7- Restrictions on the search space for solutions were defined as the space distance between the connection meter with the distributor and the photovoltaic modules.

Convergence will depend on the computational effort of the machine that will run the application, and it can take from minutes to days to converge.

With the optimization system already in place, it is necessary to build an automatic spreadsheet using basic functions such as addition, addition, subtraction and division, where it will initially size the conductors according to Formula 1 - 4, thus automatically. Table 10 shows the application evidences the calculations for sizing proposed cables considering the installation method directly buried in the ground.

Table 10: Cable Sizing AC, DC, MT

	AC Premises	DC Premises	AC MT Premises
Ip = Current of project (A)	191.30	10.51	4.85
K1 = factor of temperature	1.06	1.06	1.06
K2 = factor of ground	1.28	1.28	1.28
K3 = factor cables together	1.00	0.41	1.00
	Datas	Datas	Datas
Ib = Current adjusted (A)	140.99	18.77	3.57
Cable size (mm^2)	50	4	10
Ic = Current of the cable (A)	153.00	40	55
Voltage drop with 5% tolerance (V)	19	30	750
Power factor of solar farm	1	1	1
Resistance of the cable (Ω /m)	0.00046	0.00 51	0.0024
Max distance of cable (m)	124.60	541.00	62500.00

Shown that the cable under the conditions AC, AC MT and DC cable and its maximum possible distance to obtain a voltage drop of 5%, this distance should be the maximum to calculate the voltage drop.

With the cable gauge already sized, it is necessary to define the distances between each section, observing each one the position of the panels will be fixed as well as the electricity meter of the distributor, and our variables that will be optimized are the position of the inverters, according to Table 11 and 12.

Table 11: Solar Panel configuration, initial and final point and meter location point

	Array configuration, cable +		Array configuration, cable -	
String No.	X	y	X	y
1	10	200	26	200
2	10	198	26	198
3	10	196	26	196
4	10	194	26	194
5	10	192	26	192
6	10	190	26	190
7	10	188	26	188

8	10	186	26	186
9	10	184	26	184
10	10	182	26	182
11	10	180	26	180
12	10	178	26	178
13	10	176	26	176
14	10	174	26	174
15	10	172	26	172
16	10	170	26	170
17	10	168	26	168
18	10	166	26	166
		Meter		
	X	37		
	y	3		

Table 12: Position of the inverter and the transformer

	X	y
Inverter	30	19.5
Transformer	30	8.3

With the defined positions, the excel spreadsheet is used to calculate the distance between the modules and inverter, inverter and transformer and transformer sections to the meter, Formulas 5 – 7 are used to calculate losses. After the calculations of losses already made, the genetic algorithm is applied. Being defined with limits of the solution the space between module and the inverter. Table 13 shows the positioning found proposed by the genetic algorithm using as objective to minimize electrical losses.

Table 13: Position of the inverter and the transformer after optimization

	X	Y
Inverter	30	35
Transformer	183	183

Table 14 shows the distance and the losses found by the proposed solution of the genetic algorithm, showing a total system loss of 0.37 kW representing a percentage of 0.24% of the plant's power.

Table 14: Losses of the solar system

	Cable (mm^2)	Cable Resistance (Ω/m)	Distance (m)	Losses (kW)	losses (%)
Panel to inverter	4	0.0051	16.3	0.20	0.13
Inverter to transf.	50	0.00046	5	0.15	0.10
Transformer to meter	10	0.0024	180	0.02	0.01

Likewise, the results are valiDatad using PVsyst. Correctly validating the presented losses. Table 15 and 16 show the proposed new cabling cost and quantification of the energy produced by the losses and Table 17 showing the net present value, likewise, the same assumptions as in case 1 are used.

Table 15: New cable cost

	Cable Size (mm²)	Cable Cost (BRL)	N. Cables	Distance (m)	Total Cost (BRL)
Panel to invert	4	4.10	2*18	16.3	2,405.88
Invert to transf.	50	59.60	3	5	894.00
Transf. to meter	10	153.00	3	180	82,620.00

Table 16: Loss energy of cable on the optimization

Year	Losses (kW)	Lost generation (kWh year)	Fee (BRL)	Total (BRL)
0	0.37	540.2	1.20	648,240
1	0.37	540.2	1.30	700.099
2	0.37	540.2	1.40	756,107
3	0.37	540.2	1.51	816,596
4	0.37	540.2	1.63	881,923
5	0.37	540.2	1.76	952,477
6	0.37	540.2	1.90	1028.675
7	0.37	540.2	2.06	1110,969
8	0.37	540.2	2.22	1199,847
9	0.37	540.2	2.40	1295,835
10	0.37	540.2	2.59	1399,502
11	0.37	540.2	2.80	1511,462
12	0.37	540.2	3.02	1632,379
13	0.37	540.2	3.26	1762,969
14	0.37	540.2	3.52	1904.006
15	0.37	540.2	3.81	2056,327
16	0.37	540.2	4.11	2220.833
17	0.37	540.2	4.44	2398,500
18	0.37	540.2	4.80	2590,380
19	0.37	540.2	5.18	2797,610
20	0.37	540.2	5.59	3021,419
21	0.37	540.2	6.04	3263,132
22	0.37	540.2	6.52	3524,183
23	0.37	540.2	7.05	3806,118
24	0.37	540.2	7.61	4110.607
25	0.37	540.2	8.22	4439,456

Table 17: Net Present Value of the optimization system

	Cost (BRL)
Initial cable cost	85,919.88
Lost Energy in Cable	51,829.65
Present Net Value	108,603.85

The proposed new layout and sizing system and the solution found by the genetic algorithm was able to improve the results both in the sizing of cables causing a reduction in gauge, but also improving the net present value of the project, showing that the system was also improved financially with the reduction of proposed losses.

Figure 7 shows the new layout proposed by the genetic algorithm, with the visualization of the layout it can be seen that the inverter and the transformer were allocated to the middle of the physical installation of the modules in the available place to be installed between the meter and the panels.

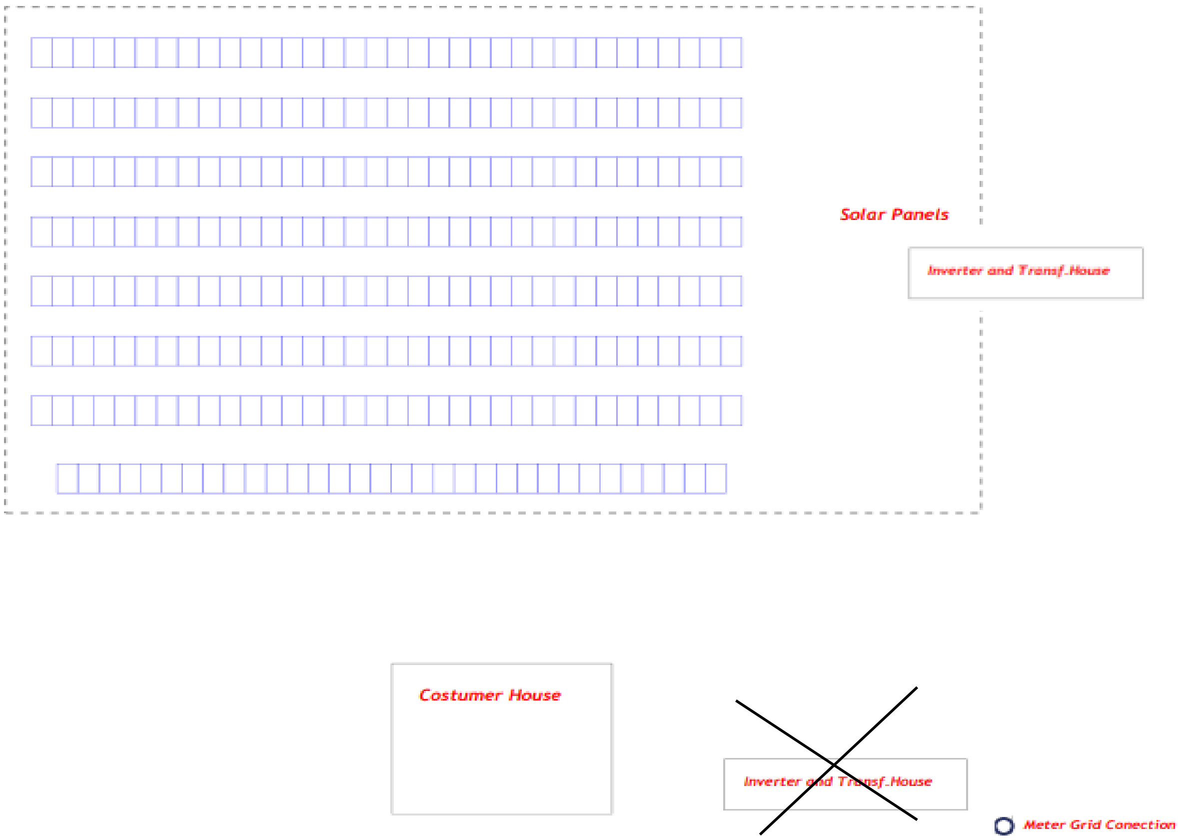

Figure 7. New layout of the solar system

The results showed that the Net Present Value was reduced from R$144,071.69 to R$108,603.85, a reduction of approximately 25% making the project more financially attractive, in addition, the system had a reduction of ohmic losses of 1.45 kW to 0.37kW a reduction of approximately 75% thus making the system more efficient.

It also showed a reduction in the size of the conductors than was initially proposed considering the current capacity installation method, and also, respecting the defined voltage drop, where the cost of initial investment and operation of the plant was also reduced, despite the increase investment in drivers.

The method defined in this study can be applied in any photovoltaic plant around the world, and can help and valiData designer results regarding the efficiency of their projects. A spreadsheet with the calculation memorial is available for any reader to be able to replicate the proposed study and adapt it to their current needs. Access link: https://github.com/eluan1/Hindawi.git

Results and discussion

1.1. *Results* . The present work showed how to carry out a resizing and optimization in a solar plant in order to minimize electrical losses and the energy that will not be produced during the 25 years of a photovoltaic system in a ground plant, also to minimize the costs during this period to have a lower net present value. To prove these results, an analysis was carried out on a 148.50 kWp ground power plant installed in Brazil, showing its electrical parameters and how this photovoltaic system was built as a preliminary analysis. Subsequently, a new design was carried out and the genetic algorithm was applied to valiData the existing layout or find a new system configuration model.

Table 18 shows the first comparison to be carried out by this study, showing that case 1 had an over-dimensioning in relation to the conductors, a common mistake made by many designers.

Table 18: Comparison between the case 1 and case 2

	Case 1	Case 2
	Cable size (mm^2)	Cable Size (mm^2)
Panel to inverter	6	4
Inverter to transformer	150	50
Transformer to Meter	16	10

When the genetic algorithm was applied to carry out the internal redistribution in order to valiData case 1, a new layout was found as shown in Figure 4, therefore, as the model shown by the computational intelligence, new distances were found to be applied with the resized conductors . Table 19 shows the electrical losses of both cables

Table 19: Comparison between the case 1 and case 2 in the loss system

	Case 1				Case 2			
	Cable size (mm^2)	Distance (m)	Losses (kW)	losses (%)	Cable Size (mm^2)	Distance (m)	Losses (kW)	losses (%)
Panel to inverter	6	164	1.34	0.90	4	16.3	0.20	0.13
Inverter to transformer	150	11.2	0.10	0.08	50	5	0.15	0.10
Transformer to Meter	16	9	0.0005	0.00	10	180	0.02	0.01

With Table 19 we can conclude that there was a reduction in losses from 0.98% to 0.24% showing that the proposed new layout is more efficient and was able to reduce electrical losses. It can be seen that the case proposed by the computational intelligence prioritized increasing the distance in medium voltage in alternating current when distributing energy in direct current as in case 1 presented.

Table 20 shows the financial comparison around the conductor investment and the energy that will be lost through loss in conductors, showing that the optimized system was more efficient.

Table 20: Net Present Value of the optimization system between case 1 and case 2

	Cost of case 1 (BRL)	Cost of case 2 (BRL)
Initial cable cost	44,643.40	85,919.88

Lost energy in cable	201,715.39	51,829.65
Present net value	144,071.09	108,603.85

Although the initial cost of cabling increases compared to the two cases studied, the energy that will no longer be produced decreases, thus making the system financially more advantageous in the solution proposed by the genetic algorithm.

In short, it is proven that the proposed layout together with the cable resizing is better during the lifetime of the solar system both in terms of electrical losses and in monetary values.

1.2. *Discussion* . Computational intelligence has been widely used to solve optimization problems in several areas of study, this study showed its use within the engineering area by applying the genetic algorithm method to solve problems of minimizing electrical losses in a soil photovoltaic plant.

The genetic algorithm method is a method that seeks natural evolution based on the evolution of species, in engineering, as shown in the literature review, it is widely used to optimize problems of redistribution of external energy networks and in wind farms, where this article shows the use of this method to carry out an internal redistribution of a component such as the inverter and transformer of a solar plant, being innovative, since the matter of optimization studies in solar energy is carried out to optimize the technology, for example.

In addition, this article evidenced and clarified the method for sizing the conductors, showing that the project was oversized in its cabling. In this way, it was shown that smaller conductors were used, which have lower costs.

The limitation of this study may show that an analysis of ground plants using X,Y coordinates is performed, not being applied to roof plants that are materialized by X,Y,Z coordinates that have space restrictions, such as, for example, a low power residential project. This limitation may be a guide for future studies and behavior both in relation to losses, as well as in the value of financial investments.

For analysis, this study showed that the layout directly influences the distance and investment of conductors, resulting in greater losses and costs over 25 years and the system found can drastically reduce these objectives together with the sizing of the cables.

Conclusions

Solar energy has grown worldwide and contributed to clean energy on the planet and power plants using photovoltaic energy are built to relieve the country's electrical energy system, therefore, to carry out a system efficiently is to maximize the production of electrical energy and better the costs of each photovoltaic system.

With this, the genetic algorithm optimization method is used to optimize a problem of allocation of components of the solar plant, being complex because there are several ways that a designer can allocate such items and also objectively defined how to dimension the conductors in a way to ensure the safety of the photovoltaic system.

It was shown in the case studies presented that the initial project was oversized in relation to its conductors and that the chosen layout was not the best for the case, therefore, listing the results found

1- Reduction of cable gauges;
2- Reduction of electrical losses;
3- Decreased energy lost in conductors;
4- Improvement in net present value over 25 years;

5- How to use the Algorithm Genetic in the Excel tool to minimaze loss in solar farms

In addition, this article showed an efficient way of using the genetic algorithm in a worldwide tool, evolutionary mode in the Solver of the Excel spreadsheet system, so readers from anywhere in the world will be able to replicate the study and still apply directly in the studies of their own plants.

The article showed that the optimization prioritized the transmission of energy in alternating current at medium voltage, as it works with high voltage and low current, using it to minimize electrical losses and consequent losses in the production of electrical energy, despite maximizing the cost of the initial investment.

This study serves as a basis for future work applying in analyzes for three coordinates in X, Y and Z being the objective of future work as well as using an analysis for several energy meters in conjunction with the positioning of the modules as variables, which in this work was treated as assumptions.

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