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Research Paper

Reducing electrical energy losses in photovoltaic source distribution networks

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Abstract

In this paper, solutions to both practical and theoretical problems of reducing electrical energy losses in a distribution network using photovoltaic (PV) source are proposed. Two aspects of the problem are considered: the optimum choice of the cables and the Technique of Load Distribution Centre (TLDC). These solutions are applicable to any distribution network. However, the TLDC is mostly used for renewable energy sources, particularly for PV networks. It consists to determine the centroid of the system made up of supplied energy points weighted by the power rating of the various electrical loads. The method was applied to a mini-photovoltaic power generator located in Nganha (7°25‘59"N, 13°55‘59"E) in the Adamawa region of Cameroon. Results showed that, up to 39 % of joule losses are reduced by making a good choice of cables, while the combination of the two methods gives a reduction of 54 % in the distribution network.

Keywords: *Energy Losses, Photovoltaic System, Energy Centroid, Load Distribution Centre.*

1. Introduction

Power grids have primarily been concerned with the satisfaction of their consumers [1], [2], but this is not always easy to achieve. The problems of energy losses are encountered at different levels of the network (production, transmission and distribution). The solar photovoltaic (PV), which is the direct conversion of sunlight into electricity, using solar cells, represents an attractive and well suited mean to produce energy [3]. In spite of its simplicity of implementation, its weak environmental impact and the low maintenance which it requires, a PV system is not competing any more when energy request increases, thus a rigorous study is necessary to make the best choice with the lowest possible costs [1].

PV is an interesting source of energy best suited to remote areas. It can help to considerably reduce the lengths of lines (cables); thereby directly reducing the losses due to the transport of electrical power in the network. Moreover, line losses imply a significant increase in the number of module to be used, and thus will result in an increase in the cost of power production. In order to minimize these losses and reduce investment, it is important to determine where the Load Distribution Center (LDC) [4] should be located. This is the energy center of gravity of the system and it is the place from which the distribution should be. In addition to this, a careful selection of cables will help to reduce energy losses in an electrical distribution network supplied by the photovoltaic generator.

The aim of this study is to present the technique of LDC and show how it helps to reduce Joule losses in PV networks. The specific case of the mini-photovoltaic station implanted in Nganha (7°25‘59"N, 13°55‘59"E) is presented.

2. Evaluation of network losses

Most of the energy losses in an electrical distribution network are due to joule losses. The linear resistance of a cable is obtained from [5], [6]:

$$R = \frac{\rho L}{S} \tag{1}$$

Where ρ is the electrical resistivity in $\Omega.mm^2/km$, L the length of the cable in m, and S the section of the cable in m^2.

The Ohmic losses are given by [7]:

$$P = RI^2 \tag{2}$$

With I the intensity of the current in A.

3. Load distribution centre (LDC) method

To reduce losses in power lines distribution systems powered by photovoltaic generators, one approach is to find the point where we must place the generator. This position is called the Load Distribution Centre (LDC) [4]. This is also the energy barycenter of the system. Technical load distribution centre allows obtaining optimal length of electrical cables for the distribution of the energy produced by the PV generator. The determination of the energy centroid of the system has several steps:

Step 1: Mapping the area cartogram and electric charges:

Electric charges (receivers, users) are devices that convert electrical energy into another form of energy (mechanical, chemical, thermal). Loads cartogram presents all charges in the area, respecting as much as possible their actual disposal site (in space or in the plane). The work consists to identify all buildings (or the point of consumption), energy consumers, make their balance sheets, and represent a cartogram.

The principle is to replace the electric charges by circles with surface proportional to power consumption and whose center coincides with the geometric center of the building. The radius of each circle representing the electrical load of the building is given by the following formula [4]:

$$R_i = \sqrt{\frac{P_i}{\pi \times m}} \tag{3}$$

with R_i (cm) the radius of the circle corresponding to the ith building respecting the scale of the electrical load of the building; P_i (kW) the nominal power corresponding to the ith building; m (kW/cm^2) the scale chosen for the cartogram charges.

Step 2: Calculation technique of the energy centroid of the system

The technique used to define the energy barycentre in the site is based on the method of determining center of gravity of geometrical figures. In this case, the site will be considered as a figure whose buildings (point of consumption) are weighted by corresponding electrical power points. In the presence of multi-storey buildings, it may deviate considerably from the flat configuration closer to a more or less complex configuration. Therefore, it will take into account a third coordinate that characterizes the centroid sought. Considering that the desired center point G (X_0, Y_0, Z_0), we can write [4]:

$$X_0 = \frac{\sum_{i=1}^{n} X_i \times P_i}{\sum_{i=1}^{n} P_i}\,;\ Y_0 = \frac{\sum_{i=1}^{n} Y_i \times P_i}{\sum_{i=1}^{n} P_i}\,;\ Z_0 = \frac{\sum_{i=1}^{n} Z_i \times P_i}{\sum_{i=1}^{n} P_i} \tag{4}$$

The triplet (X_i, Y_i, Z_i) represents the position of the i^{th} building (or point of consumption) at the site and n is the total number of buildings (or point of consumption) to be supplied by the PV plant. P_i is the active power consumed by the i^{th} building (point of consumption). According to the type of electric charge (active or reactive powers), we have conditional center of active load and conditional center of reactive load. In the last case, the active power P_i is replaced by reactive power Q_i [4].

4. Study area

The city of Nganha (7°25‘59"N, 13°55‘59"E) is located in the Adamawa region in Cameroon. The climate is of the Sudanese type (wet tropical). The mean temperature is about 29 ^{o}C while the mean insolation is 4.7 kWh/m^2.day the wind speed is 6.9km/h.

The distribution network is powered by a mini solar power plant with a capacity of 10 kWp. The energy that is produced feeds about 72 households and the entire administrative infrastructure in the area. The network is divided into three lines: Line 1, Line 2 and Line 3. Table 1 presents some characteristics of the lines.

Table 1: Characteristics of the Lines

Lines	Total active power (W)	Lengths (m)
1	4805	300
2	7250	1400
3	4862	300

5. Results and discussion

5.1. Optimum choice of the cable

The electrical distribution system of the PV plant of Nganha is made up of aluminum cables (ρ = 36.232 Ω.mm^2/km) with sections of 4x25mm^2. The supply voltage is V = 230 volts.

Table 2 and 3 presents the values power factor, Resistance, current and ohmic losses in each line respectively for Aluminum and Copper (ρ = 21.983 Ω.mm^2/km) cables.

Table 2: Joule Losses for an Aluminum Cable

Lines	Power factor (cos φ)	Resistances (Ω)	Current (A)	Number of supplied lines	Joule losses (W)
1	0.9	0.434784	23.213	1	234.28
2	0.8	2.028992	39.402	1	3105.04
3	0.85	0.434784	24.870	1	268.92

Table 3: Joules Losses For Copper Cables

Lines	Power factor (cos φ)	Resistances (Ω)	Current (A)	Number of supplied lines	Joule effect losses (W)
1	0.9	0.264	23.213	1	142.25
2	0.8	1.231	39.402	1	1911.15
3	0.85	0.264	24.870	1	163.29

It could be seen that the use of copper reduces Joule losses on the power lines. This is due to the fact that Aluminum has higher resistivity than copper.

Table 4 presents the variation of the power losses by replacing the Aluminum cables by copper ones.

Table 4: Losses Variation

Lines	Cable losses before change (W)	Cable losses after change (W)	Loss Difference (W) $\Delta P_j = (P_j)_{before} - (P_j)_{after}$
1	234.28	142.25	92.03
2	3105.04	1911.14	1193.9
3	268.92	163.29	105.63
Total (W)	3608.24	221.68	1391.56
Total (%)	21.33	13.10	8.23

It could be seen that the replacement permits to gain an active power of 1391.56 W, i.e. a reduction of 38.57% of the total losses.

5.2. Application of the TLDC

5.2.1. Map of the area of the electrical charges and cartogram

The network consists of three lines, each of which supplies a specific area as presented in figure 1.

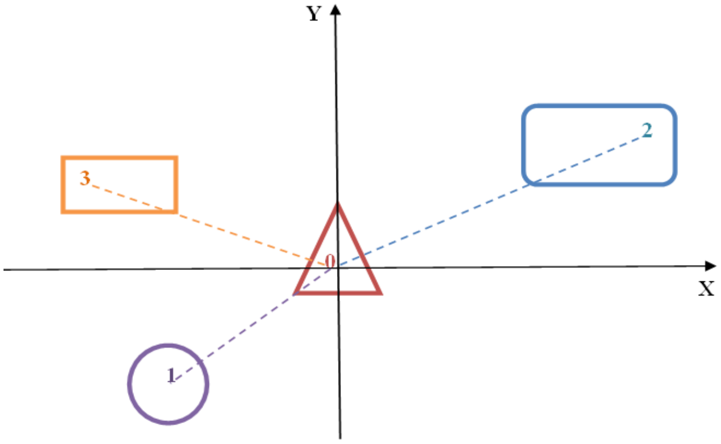

Fig. 1: System Mapping

Table 5 presents the initial coordinates of the lines and the PV generator.

Table 5: Geographical Coordinates Before Applying the Theory of the Center of Distribution of Electrical Charges

Terminal number	Lines	Y-Axis (m)	X-Axis (m)	Active power (W)	Distance contribution to the PV generator (m)
0	-	0	0	-	0
1	Line 1	-212.2	-212,1	4805	300.0254156
2	Line 2	979.8	1000	7250	1400.002871
3	Line 3	165.83	250	4862	299.9993146

The radius representing the electrical loads of each line (fig. 2) are obtained from eqn. 3 as follows, with m = 10 w/cm^2: $R_1 = 12.4cm \quad R_2 = 12.5cm \quad R_3 = 15.2cm.$

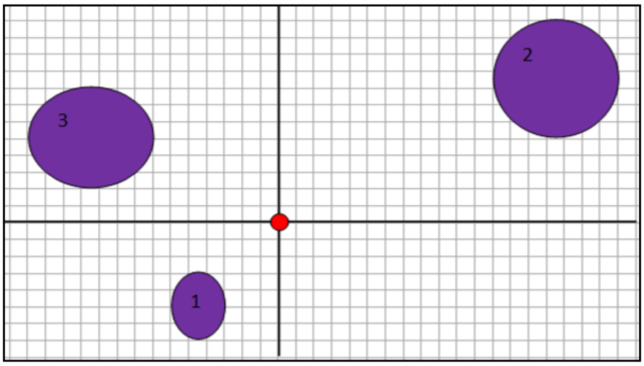

Fig. 2: Geographical Position of the PV Generator (In Red) Before the Application of the Theory of the Center of Distribution of Electrical Charges

5.2.2. Calculating the energy centroid

The represented in fig. 2 is flat since there is no building over three levels. It reduces to a triangle (fig. 3).

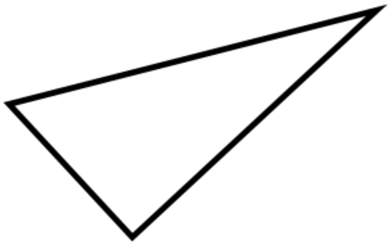

Fig. 3: Triangle Joining the Centers of the Various Circles

The LDC of the system G (X_0, Y_0) is therefore G $(440.1702, 407.2941)$ m.

Table 6 and fig. 4 present the new coordinates after applying the TLDC.

Table 6: PV Generator Geographical Coordinates after Applying the Theory of the Center of Distribution of Electrical Charges

Terminal Number	Lines	Y-Axis (m)	X-Axis (m)	Active power (W)	Distance contribution to the PV generator (m)
0	-	407.2942	440.1702	-	0
1	1	-212.2	-212.1	4805	300.0254156
2	2	979.8	1000	7250	1400.002871
3	3	165.83	250	4862	299.9993146

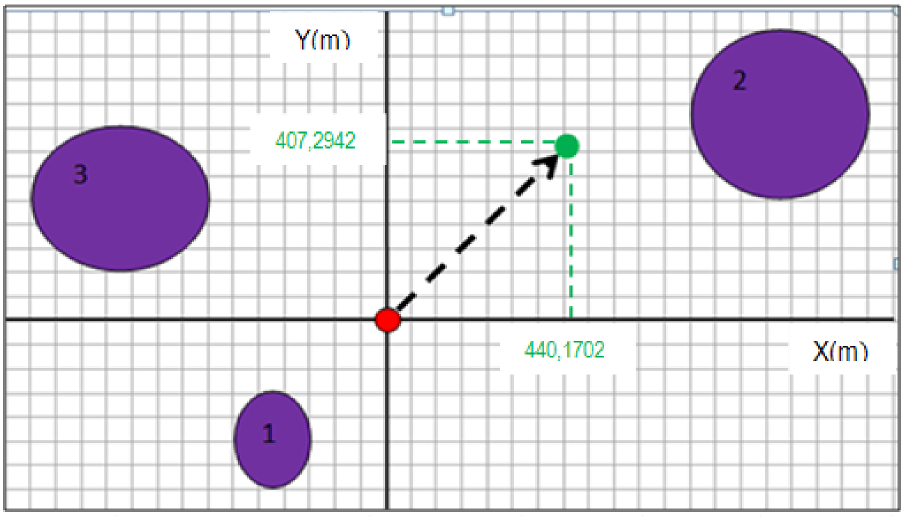

Fig. 4: Geographical Position of the PV Generator (Green) After Application of the Theory of the Center of Distribution of Electrical Charges

5.2.3. Gains after repositioning of the PV generator

5.2.3.1. Cables length ajustments

Table 7 presents the gains in cables after the application of the TLDC.

Table 7: Gain Cable Length after Repositioning of Generating New and Renewable Energy

Lines	Y-Axis after applying the TLDC (m)	X-Axis after applying the TLDC (m)	Length before applying the TLDC (m)	Length after applying the TLDC (m)	Difference ΔL of length $L_{before} - L_{after}$ (m)
-	407.2942	440.1702	0	0	0
1	-619.4942	-652.2702	300.0254156	899.5718302	-599.546441
2	572.5058	559.8298	1400.002871	800.7323498	599.2705212
3	-241.4642	-190.1702	299.9993146	307.3591789	-7.35987440

5.2.3.2. Reduction of losses

Table 8 presents the reduction of power losses after applying the TLDC. It could be seen that the network gains an active power of 1928.79W, i.e. 53.46%.

Table 8: Loss Reduction after Applying TLDC

Lines	Resistances after TLDC application (Ω)	Losses before TLDC application (W)	Losses after TLDC application (W)	Loss Difference $\Delta P_j = (P_j)_{av} - (P_j)_{ap}$
1	0.79	234.28	425.69	-191.41
2	0.70	3105.04	1086.76	2018.28
3	0.27	268.92	167.00	101.92
Total				1928.79

6. Conclusion

The problem of energy losses in power distribution networks is crucial. It plays an important role in the overall efficiency of an installation. While there are many techniques to reduce them, we cannot expect their complete elimination. This paper focused on two techniques: the optimum choice of the cable and the Technique of Load Distribution Centre (TLDC). Results showed that up to 39 % of joule losses are reduced by making a good choice of cables, while the combination of the two methods gives a reduction of 54 % in the distribution network.

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