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Simulation of the Power Flow State of the Main Electrical Distribution Grid of Abomey-Calavi (BENIN) and Lomé Golfe (TOGO)

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Abstract: This work consists in a simulation study of the power flow state of the electricity distribution grid of Abomey-Calavi and the Lome Golfe. For this purpose, the CYME software was used to construct the single line diagrams of each grid based on the actual modeled parameters and data of the generators, busbars, transformers, lines and loads of the network. This power flow resulted in determining the power transits on the sections and the technical losses along the cables and in the transformers. It appears that the distribution grid of Abomey-Calavi and that of Lome Golfe respectively comprise a set of power plants totaling 127MW and 130 MW, a medium voltage system of 93 km spread over three (03) departures and 930 km spread over twenty-eight (28) departures, at the end of 2019. These grids respectively experience technical losses of 12.16% and 9.09% of the total transit power. The purpose of this work is first of all to show the effective existence of enormous losses in the electrical distribution grids in TOGO and BEBIN, then to give some recommendations necessary to reduce these losses. The reduction of these technical losses requires a study of the behavior of the existing grid and a better optimization of the design of subsequent grids.

Keywords: Electrical Distribution, Transit Power, Technical Losses, Flow, Simulation

1. Introduction

Electric power is one of the most important discoveries that contributed to industrial and economic development in the world. It is very essential both in domestic and industrial use.

Electricityis characterized by a number of parameters such as: current, voltage, power, energy, etc. The role of power distribution lines is to convey energy to end consumers, with stages of voltage drop in transformer stations [1, 2].

As electrical energy is consumed as it is produced, matching supply and demand, reliability and safety of an electricity distribution network becomes a permanent requirement. To do this, a distribution network must continuously maintain excellent performance over time and generate less loss of electrical energy in order to meet this requirement of equal supply and demand [3].

The distribution of electricity through an electrical network generates inherent losses, energy which is not sold by the Electricity Company, in the operation of the equipment constituting this grid [2]. This energy is dissipated mainly in the form of heat and cannot be saved, but can be controlled in order to guarantee a better efficiency of the energy system [4]. These excessive technical losses are at the origin of the voltage drops on the busbars [2, 5]. Some studies have recently shown that losses approach the proportions of 13 to 20% in certain grids [6], while ideally these losses should be in the ranges of 3 to 6% in distribution grids [5].

Indeed, the Beninese Electricity Energy Company (SBEE) covering the distribution grid of Abomey-Calavi and the Togo Electricity Energy Company (CEET) covering the distribution grid of Lome Golfe are generally confronted with this problem, the magnitude of which constitutes a waste of electricity.

The study of power flow or power flow is an essential step in the study and design of these electrical networks. This study is necessary for planning power exchanges between production centers and economic dispatching. It is also essential for the evaluation of transient stability, dynamic stability and the estimation of the state of the networks as well as the taking of adequate measures for possible unforeseen [7].

The transit of power in electrical distribution networks depends on the voltage, current and power factor at the source and at the load [8]. So the calculation of the power flow also known as the load distribution calculation makes it possible to determine the complex voltages at the levels of the various nodes [9], the powers transmitted from one node to another, the powers injected into a node and the active and reactive losses in the electrical grid [10-12]. The active and reactive power are used to determine the setting instructions for the machines on the network [10, 13].

In a distribution grid, estimating separate loss rates becomes complex insofar as several factors can influence these rates at the same time, including the load transited, the configuration and mode of operation of the grid, the period of l year, climatic conditions, etc [14].

The overall losses in the distribution grid of Abomey-Calavi and that of Lome Golfe are mainly due to energy theft, poor billing and technical losses in distribution networks caused by overloads of distribution transformers, imbalance on MV networks., the incorrect positioning of transformers in relation to the center of gravity of the loads, and the inadequacy of the transits in relation to the thermal limits of the cables [5].

Consumption receipts are mainly based on active power. Therefore, reactive power plays a very important role in maintaining the security of the network and this energy must be valued both for the normal regime and for the disturbed regime. The architecture of the electrical network is the basis of the conditions for the flow of power and therefore energy to the various points of consumption. This architecture is accompanied by: the condition, type and location of power plants, size, types and lengths of lines; territorial distribution of transformer substations and loads of departures from substations; efficiency of power transformers in the network and their mode of operation; etc [1].

The main objective of this research is to show through CYME's world-class power grid analysis software, how important are the electrical losses by simulation of the power flow state of the main electrical distribution grid of Abomey-Calavi (BENIN) and Lomé Golfe (TOGO). Furthermore, the novelty in this paper, is to show the lack of energy efficiency in the electricity grid system of TOGO compared to that of BENIN and give some recommendations.

2. Material and Methods

2.1. Description of CYME Software

There are several power grid analysis software programs in the frequency regime that allow power flow calculations to be performed [1]. Among these softwares, CYME was chosen for this work because it is designed based on loss assessment algorithms and is used by an entire configuration of the electrical network.

CYME software can accurately calculate medium and low voltage network losses and identify overloaded devices to help plan and improve the system later. The user enters the electrical parameters of the lines, transformers as well as the nominal voltages of the nodes, the output of the generators and the amount of load at a given time.

The software then determines the voltages and angles at all the bars, and therefore the amplitude and direction of the power exchanges between the busbars, thus making it possible to verify that there are no lines or overloaded generators, and that the grid can withstand the load and production conditions well. Still in the frequency domain, there are other calculation functions such as the calculation of short-circuit currents, harmonics, adjustment of protection systems, and so on.

CYME's world-class power grid analysis software [13] is a robust and comprehensive suite of advanced simulation tools of great utility to transmission, distribution and industrial network engineers [15].

2.2. Presentation of Electrical Distribution Grids

An electrical grid is made up of several elements including generators, lines, cables, transformers, measuring and protection devices, and so on.

2.2.1. Presentation of the Abomey-Calavi Medium Voltage (MV) Distribution Network

The city of Abomey-Calavi's MV distribution grid has essentially tree structures. It consists of a source substation and three (03) MV feeders which supply the various localities covered by this grid.

Also, there is a 127MW power station of Maria-Gleta which works as a backup to the main power source of the municipality of Abomey-Calavi in electrical energy or in autonomy to partially resume the supply of the city in the event of total disappearance from the main source. The 127MW power station of Maria-Gléta is composed of seven (07) MAN 18V60DF motors with a unit power of 18.5MW, a 161KV evacuation station extendable to 400MW of capacity, a 161KV interconnection station of 400MW of capacity, a system of connection to the gas network and an access road of 3Km.

Some important characteristics specific to the distribution grid of Abomey-Calavi can be cited: The MV distribution lines are three-phase, without a neutral conductor; the voltage level dedicated to MV distribution in this city is 15 kV; the public distribution stations connected to this grid are 50 kVA, 100 kVA, 160 kVA, 250 kVA, 400 kVA, 630 kVA, 800 kVA, 1000 kVA. There are 158 transformers on the City's MV network: Pole mounted (H61) and Cabine (H59). The large loars on this grid are asynchronous motors.

2.2.2. Presentation of the MV Distribution Grid of Lome Golfe

CEET has nine MV source substations distributed mainly in certain towns in the territory, including three in Lome, which constitute the study framework for our subject, given its demand which represents 80% of the national peak.

The MV distribution grid of the municipality of Lome consists of the following power plants:

The Lome B Thermal Power Plant (CTL site) with a current production capacity of 14 MW composed of two (02) DIESEL engines of 7MW power each.

Lome Plant - Headquarters (Sulzer) with a current production capacity of 16MW composed of two (02) DIESEL engines of 8MW power each.

The 100 MW thermal power plant called the Contour Global TOGO S. A plant is made up of six (06) DIESEL engines with a power of 16.6MW each. This power station works in back-up to Lomé's two main sources of electrical energy or in autonomy to partially resume supply to the city in the event of total disappearance of the main source.

Some important characteristics specific to the distribution grid of Lome Golfe can be cited: The MV distribution lines are three-phase, without neutral conductor; the voltage level dedicated to MV distribution in this city is 20kV; the public distribution stations connected to this grid are 50 kVA, 100 kVA, 160 kVA, 250 kVA, 400 kVA, 410 KVA, 630 kVA, 750 KVA, 800 kVA, 1000 KVA, 2000 KVA,. There are a total of 890 transformers on the MV grid of the City of Lome: Pole mounted (H61) and Cabine (H59). The large loars on this grid are asynchronous motors.

The Lome Golfe distribution grid includes a set of power plants totaling 130 MW, and a medium voltage system of 930 km spread over twenty-eight (28) departures at the end of 2019.

2.3. Data Collection for Grid Simulation

The collection of data and information to meet the needs of the calculation software and the analysis of the electrical system was done in the field and in the database of each electrical structure. The information necessary for the analysis of the electrical system concerns in particular the general and detailed architecture of the electrical grid, the characteristics of the generating sets of the power stations, the characteristics of the transformers present in the electrical network and characteristics of the medium voltage lines: nature, length and cross-section.

Generators, medium voltage feeders, transformers and busbars have been modeled to meet the structure of the analysis software.

The single-line diagrams of the Abomey-Calavi and Lome electrical grids are constructed following the actual modeled parameters and data of the generators, busbars, transformers, lines and loads of these grids.

The configuration of the modeled networks represents the physical networks. It is from these networks that the various simulations are done.

3. Results and Discussion

The simulation of the power flow state at the level of the cables and transformers on the two MV grids was carried out by considering the maximum loads injected into these grids from the source substation in order to assess the extent of the phenomena. This leads to the results below.

3.1. Results of the Study of the Technical Losses of the MV Distribution Grid in the Municipality of Abomey-Calavi

Table 1 shows the simulation result of the power distribution at the cable level on the Abomey-Calavi distribution grid. This allowed us to estimate the losses generated in the conductor cables.

Table 1. *Power distribution results at cable level (Abomey-Calavi).*

Equipement name	Section mm²	Number of Stump	Length Km	Mean transit power (kW)	Mean transit power (kVA)	Total Losses (kW)	Total Losses (kvar)
17 CU	17	7	2.326	5086.14	6373.57	259.7	26.3
54.6 AL	54.6	125	53.847	8595.9	9618.69	5182.1	866.4
34.4 AL	34.4	9	1.885	15364	15643.11	32	3.6
1x3x35 AL	105	5	0.98	686.4	1378.4	0	0
93 AL	93	27	9.61	11797.7	12023.7	27.9	7.6
75.5 AL	75,5	48	22.192	7597,63	8394.6	732.9	162.5
117 AL	117	9	0.75	31111.44	38146	788.2	257.2
1x3x50 AL	150	1	0.95	77500	78797	28.9	11.7
TOTAL		231	92.54	157739.21	170375.07	7051.7	1335.3

It can be noted that at the level of cables, the total losses on the Abomey-Calavi electricity network are estimated at 7.0517 MW, or 4.47% of the total transit power at the cables.

These cable losses would be due to several factors such as: the length of the cable; the section of the cable and the current on the section. This is verified by $P_g = \rho \frac{L}{S} I^2$ (1), with P_g the power generated by the Joule effect (in Joule), ρ the resistivity of the cable (in ohms square millimeter per meter), L the length of the cable (in meter), S the section of the cable (square millimeter) and I intensity of the current (in ampere) [16].

Figure 1 shows the evolution of power losses along copper cables with a 17 mm² section (denoted 17CU).

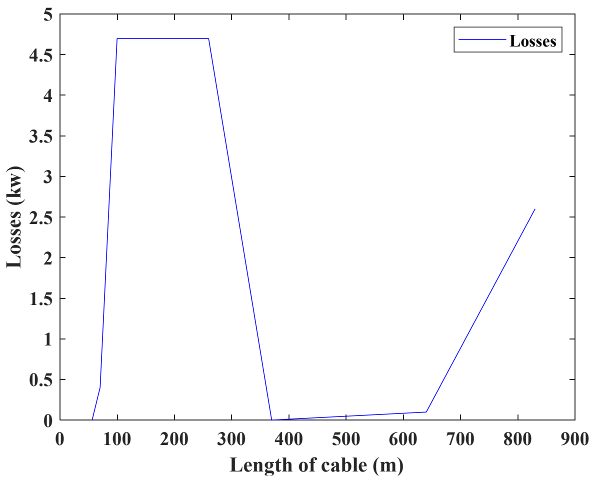

Figure 1. *Variation of losses along the 17CU cable (Abomey-Calavi).*

Figure 1 depicts a significant increase in losses which remains constant over the lengths of 100m to 300m. So, this type of 17CU cable causes a lot of technical losses on the Abomey-Calavi power grid.

Figure 2 shows the evolution of power losses along Aluminum or Almelec cables with a section of 34.4 mm² (noted 34.4AL).

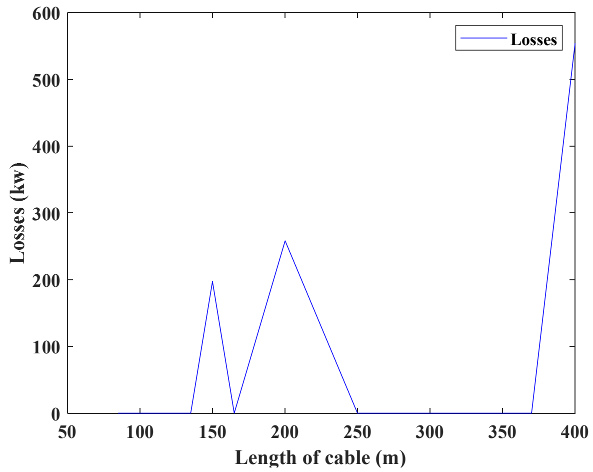

Figure 2. *Variation of losses along the 34.4AL cable (Abomey-Calavi).*

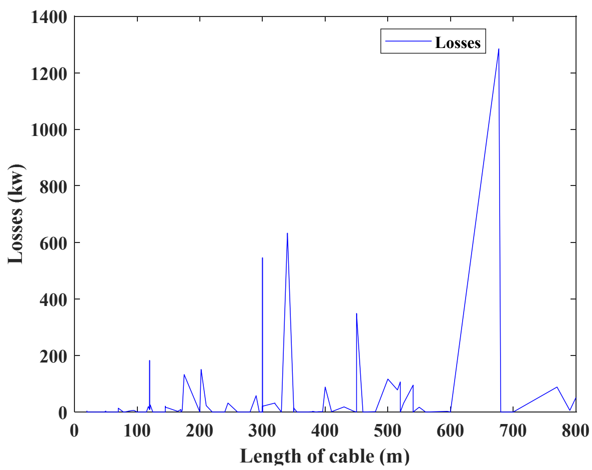

Figure 3. *Variation of losses along the 54.6AL cable (Abomey-Calavi).*

In Figure 2, the curve shows some important peaks of losses, the highest of which is 550 kw obtained on the cables of 4000 m. So, this type of 34.4AL cable also generates a lot of technical losses on the Abomey-Calavi power grid.

Figure 3 shows the variation in power losses along aluminum or Almelec cables with a section of 54.6 mm² (noted 54.6AL). This type of cable is mostly used on this distribution grid.

Some significant peaks of losses can be observed on the curve of Figure 3, the highest of which is 1250kw obtained on the 690 m cables. So, this type of 54.6AL cable causes significant technical losses on the Abomey-Calavi power grid.

Figure 4 shows the variation in power losses as a function of the length of the aluminum or Almelec cables with a section of 75.5 mm² (denoted by 75.5AL).

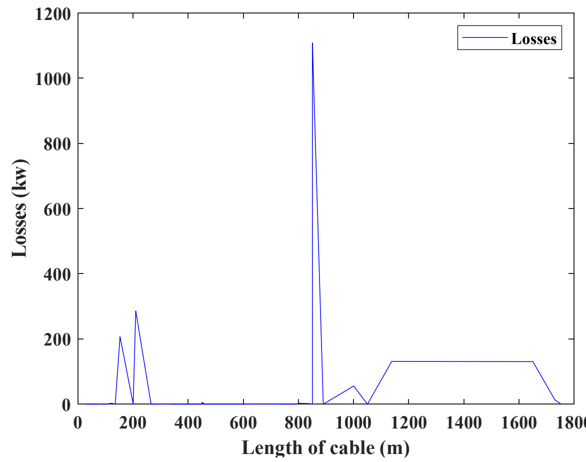

Figure 4. *Variation of losses along the 75.5AL cable (Abomey-Calavi).*

A significant peak value 1100kw of losses is noted on the curve of figure 4 obtained on the cables of 860m and a constant of losses on the lengths of 1100m to 1700m. So, this type of 75.5AL cable generates less technical losses on the Abomey-Calavi electricity network.

Figure 5 shows the evolution of power losses as a function of the length of the aluminum or Almelec cables with a section of 95 mm² (denoted 95AL.

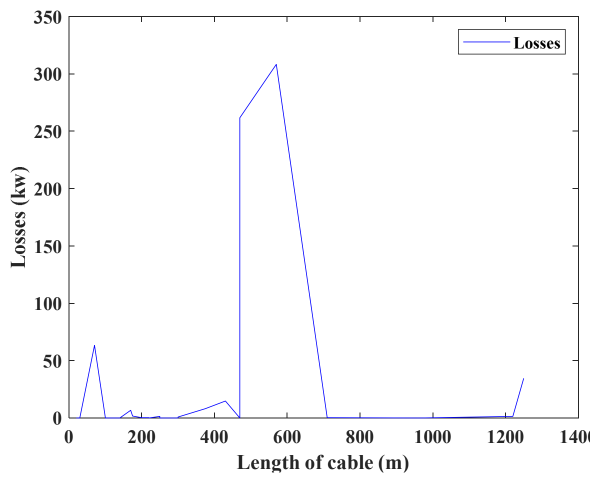

Figure 5. *Variation of losses along the 95AL cable (Abomey-Calavi).*

Some significant peaks of losses are also noted on the 500m and 600m lengths at the level of the curve in Figure 5, the highest of which is 325kw obtained on the 600m cables. So, this type of 95AL cable causes less technical loss on the Abomey-Calavi power grid.

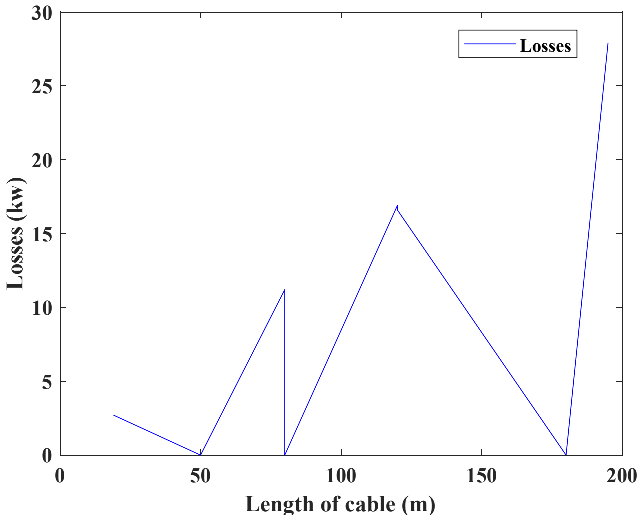

Figure 6. *Variation of losses along the 117AL cable (Abomey-Calavi).*

Figure 6 shows the evolution of power losses along Aluminum or Almelec cables with a section of 117 mm² (noted 117AL).

Some loss peaks are noted on the curve of Figure 6, the highest of which is 28kw, obtained on the 190m cables. So this type of 117AL cable causes less technical loss on the Abomey-Calavi power grid.

According to these different figures, the variation in these power losses is not proportional to the lengths of the cables. This evolution follows a sawtooth loss curve which shows high peaks over a few longer lengths. This could be explained by the intensity of the current which differs on the sections of the distribution grid.

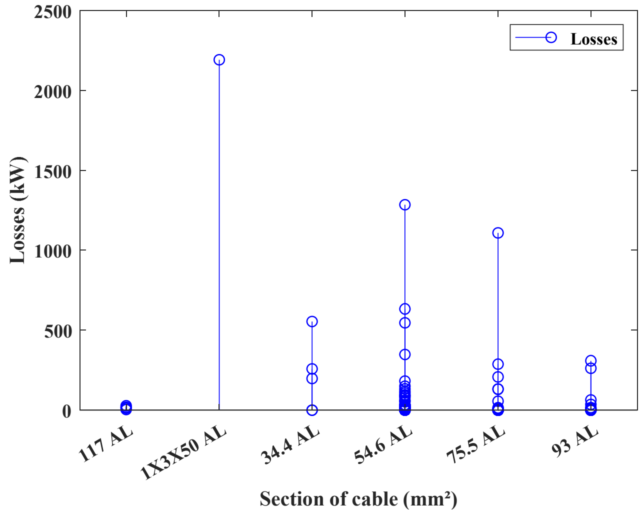

Figure 7. *Evolution of losses according to the section of the cable (Abomey-Calavi).*

Then Figure 7 shows the evolution of losses as a function of the section of the cables.

On figure 7, it can be seen a huge loss on the 1 × 3 × 50 AL type cables (150 mm² section) and on some of the 54.6 AL type cables (54.6 mm² section). The losses generated along the cables and those according to the section of the cables are added.

The simulation results of the power distribution at the level of the transformers are shown in Table 2.

Table 2. *Power distribution results at the transformer level (Abomey-Calavi).*

Equipement name	Capacity (kVA)	Number of transformers	Mean transit power (kW)	Mean transit power (kvar)	Total Lossses (kW)	Total Lossses (kvar)
T50	50	5	858	535	5	20
T100	100	52	876.9	664.79	1869	7475
T160	160	50	875.16	601.84	877,5	3515.6
T250	250	17	860.65	542.71	50,4	198.9
T400	400	11	863.45	554.45	63,6	253
T630	630	21	818.76	517.28	39,8	235.8
T1000	1000	2	857.5	536	0,9	8.7
TOTAL		158	6010.42	3952.07	2906.2	11707

From Table 2, it can be noticed that the total losses on the Abomey-Calavi power grid amount to 2.9062 MW or 48.35% of the total transit power at the level of transformers. The losses encountered are mainly due to: the magnetization of transformers as soon as they are under voltage (iron losses or no-load losses); the heating of the transformer windings when they are traversed by currents (copper losses or load losses) [17].

The simulation studies allowed us to estimate the general losses on the Abomey-Calavi MV distribution grid at 9.95779 MW, or 12.16% of the total transit power. These results exceed the acceptable proportion ranges as presented in reference [5].

3.2. Results of the Study of the Technical Losses of the MV Distribution Grid in the Municipality of Lome Golfe

Table 4 shows the simulation results of the power distribution at the cable level on the Lome Golfe distribution grid. This made it possible to estimate the losses generated at the level of the conductor cables.

Table 3. *Power distribution results at cable level (Lome).*

Equipement name	Section mm^2	Number of Stump	Length Km	Mean transit power (kW)	Mean transit power (kVA)	Total Losses (kW)	Total Losses (kvar)
50 HN	50	4	1,584	1649,5	3072,5	0,1	0
54.6 AL	54,6	564	304,5721	13601,39	41023,19	16067,4	2496,8
55.6 HN	55,6	7	4,895	15136,86	38310,57	20,6	3,4
56.6 AL	56,6	1	1,95	724	5938	0,1	0
70 CU	70	2	0,7641	54078,5	88117,5	11,4	3,9
75 AL	75	64	40,8633	6041,27	24874,41	278,3	61,2
75.5 AL	75,5	4	1,2351	35340,25	58608	43	9,6
95 HN	95	1	130	186656	385109	47	12,8
117 AL	117	82	87,4881	32909,44	96544,11	6099	1989,8
150 AL	150	501	260,7833	31508,77	111975,91	11771,7	4781,9
151 AL	151	7	2,2278	28913,71	87728,57	36,9	15,1
152 HN	152	4	2,6059	431228	81549,75	67,8	27,8
240 HN	240	105	91,2545	61581,85	205769,43	6317,8	3877,9
TOTAL		1346	930,2232	899369,54	1228620,9	40761,1	13280,2

It is noted that at the level of these cables, the total loss on the Lome power grid is 40.7611 MW or 4.53% of the total transit power at the cables.

As in the case of Abomey-Calavi, these losses at the level of the cables would also be due to several factors linked to the length of the cable; their section and the current on the section (see equation 1).

To better understand the influence of these physical quantities on this variation in cable losses on the Lome electrical grid, we also examine, in the following section, the case of each type of cable.

Figure 8 shows the variation in power losses along Aluminum or Almelec cables with a section of 54.6 mm² (noted 54.6AL).

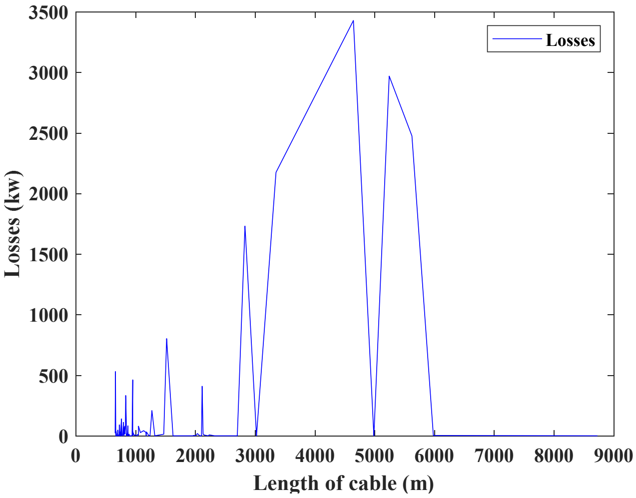

Figure 8. *Variation of losses as a function of the length of the cable 54.6AL (Lome).*

Significant peaks of losses can be observed on the curve of Figure 8, the highest of which is 3480kw obtained on the 4900 m cables. So, this type of 54.6AL cable generates significant technical losses on the Lome electricity grid.

Figure 9 shows the variation in power losses as a function of the length of the aluminum or Almelec cables with a section of 75 mm² (denoted by 75AL).

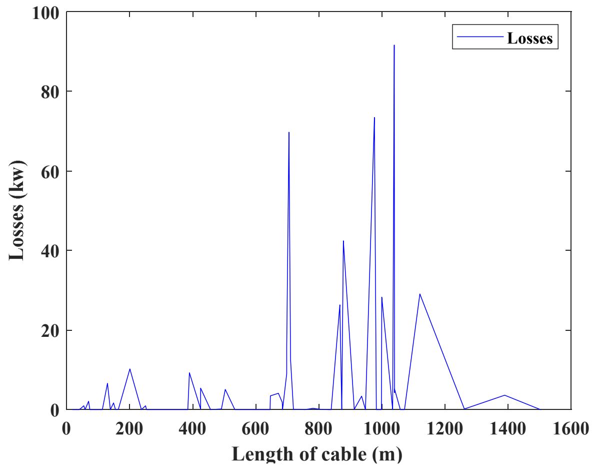

Figure 9. *Variation of losses along the 75AL cable (Lome).*

Significant peaks of losses can also be observed on the curve of Figure 9, but the highest is 95kw obtained on the cables of 1050 m. So, this type of 54.6AL cable generates less technical losses on the Lome electricity network.

Figure 10 shows the evolution of power losses along Aluminum or Almelec cables with a section of 117 mm² (noted 117AL).

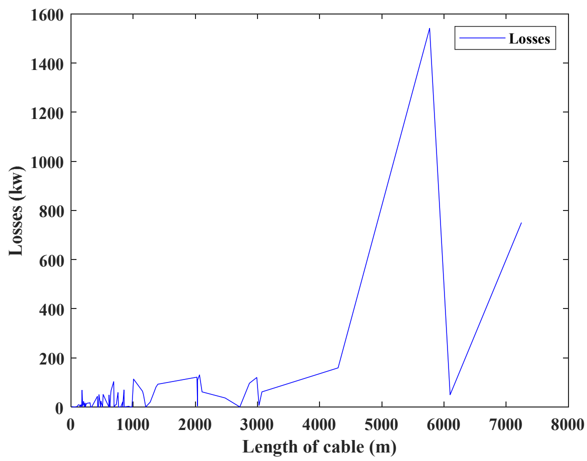

Figure 10. *Variation of losses along the 117AL cable (Lome).*

A peak of losses is noticed on the curve of Figure 10, the highest of which is 1520kw obtained on the 5900m cables. So, this type of 117AL cable also generates less technical losses on the Lome electricity grid.

Figure 11 shows the evolution of power losses along Aluminum or Almelec cables with a section of 150 mm² (denoted 150AL).

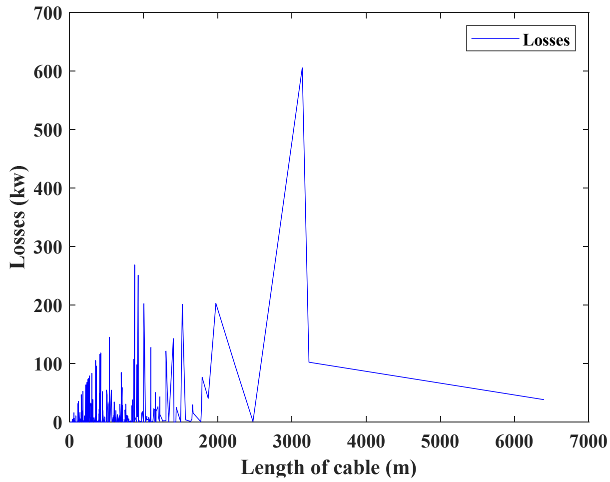

Figure 11. Variation of losses along the 150AL cable (Lome).

Some significant peaks of losses are also observed on the curve of Figure 11, the highest of which is 600kw obtained on the 3000m cables. So, this type of 150AL cable also generates a significant loss on the Lome electricity grid.

Figure 13 depicts the evolution of power losses along Almelec cables with a section of 240 mm² (noted 240HN).

Some significant peaks of losses are noticed on the curve of Figure 12, the highest of which is 400kw obtained on the 2800m cables. So, this type of 240HN cable generates a significant loss on the Lomé electricity grid.

According to these different figures, the variation in these power losses is not as proportional to the lengths of the cables. This evolution also follows a sawtooth loss curve while showing high peaks over some longer lengths. This could also be explained by the intensity of the current which differs on the sections of the distribution grid.

Figure 13 presents the evolution of losses as a function of the section of the cables.

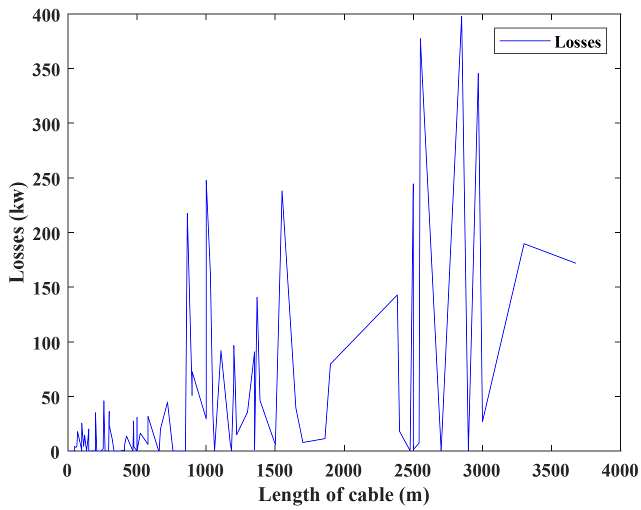

Figure 12. Variation of losses along the 240HN cable (Lome).

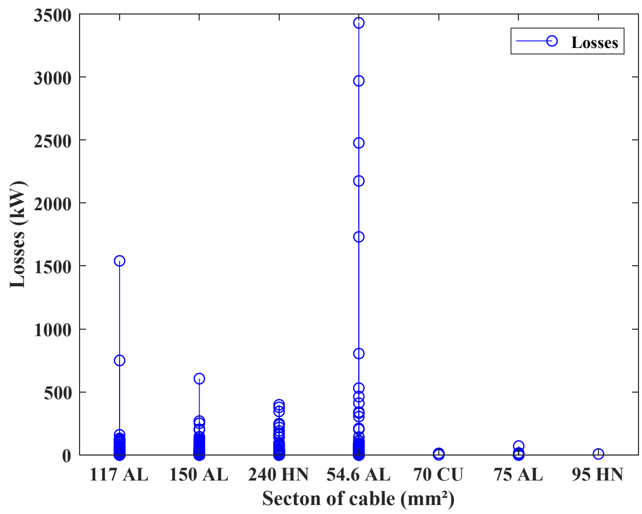

Figure 13. Evolution of losses according to the section of the cable (Lome).

From this figure, it is observed a huge loss on type 54.6 AL (section 54.6 mm²) and type 117 Al (117 mm²) cables.

The losses generated along the cables and those according to the section of the cables are also added.

The simulation results of the power distribution at the transformer level are shown in Table 4.

Table 4. Power distribution results at transformer level (Lome).

Equipement name	Capacity (kVA)	Number of transformers	Mean transit power (kW)	Mean transit power (kvar)	Total Lossses (kW)	Total Lossses (kvar)
T30	30	5	2140	1057	11	109,5
T50	50	39	1017,92	503,08	23,4	229,7
T100	100	71	1967,04	959,94	39,5	412,6
T160	160	117	1799,51	879,59	43,6	463,6
T250	250	108	1878,26	917,77	27,9	299,7
T400	400	270	1979,81	965,53	49,2	496,4
T630	630	183	2010,42	983,14	16,7	220,1
T800	800	42	2109	1024,9	4,1	41,2
T1000	1000	33	2108,03	1026,21	3,2	25,9
T2000	2000	22	2040,82	988,91	0	8,4
TOTAL		890	1905,081	930,607	218,6	2307,1

According to Table 4, the total losses on the Lome Golfe power grid are estimated at 218.6 KW or 11.47% of the total transit power at the level of transformers. The losses encountered are mainly also due to the aforementioned factors [17].

The simulation studies carried out on the Lome Golfe distribution network have shown that the technical losses on this network have a total estimate of 40.9797 MW or 9.09% of the total transit power. These results also exceed the acceptable proportion ranges as presented in reference [5].

4. Conclusion

Studies of the MV distribution grids of the Beninese Electricity Energy Company and the the Togolese Electric Energy Company respectively supplying the municipality of Abomey-Calavi and the municipality of Lome with electricity have enabled us to observe that the operation of these two energy systems (grids) is not optimal and to highlight that these grids are subject to significant technical losses.

The distribution grid of Abomey-Calavi and that of Lome Golfe respectively experience technical losses of 9.95779 MW or 12.16% of the total transit power and 40.9797 MW or 9.09% of the total transit power.

In view of the alarming findings, the sources of which are found in under-dimensioning and too much reactive energy according to our study, we offer loss reduction solutions which boil down to reactive energy compensation coupled with reinforcement of lines on certain sections of these grids.

Optimizing the topology of each distribution grid is one of the best solutions considered. Once the topology is optimized, the more losses on the electrical grids will be controlled and reduced.

At the end of this study, we inform of:

1) Invest to use low resistivity transport cables, which will modify the levels of losses at the level of transformers and thereby optimize the network,
2) Invest in research and development of smart meters,
3) Promote the use of superconductors including superconducting cables and current limiters,
4) Maintain normal voltages on the busbars and nodes while respecting the construction standards of the lines and finally simulate the evolution of the electrical network.

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