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# Analysis of Energy Loss in an Electrical Energy Distribution Network

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***Abstract:*** *The electrical energy produced by the large generating stations must first pass through the transmission network, then through the distribution network to finally reach the consumer. The passage of this energy through the various elements of a network such as cables, transformers or other devices, leads to energy losses which can be classified as transmission losses and/or distribution losses (the case of our study) . In any electrical system, energy losses are inevitable. They represent an operating cost necessary to move energy from the point of production to the points of consumption. Our article aims to propose a fast and reliable approach for the analysis of energy losses in the distribution network of electrical energy, with the application in the distribution network of electrical energy of the city province. from Kinshasa. With an electrical energy distribution system, generally confronted, on a recurring basis, with many operating problems, causes of its deterioration, this network suffers from significant energy losses. We know that in the electrical energy distribution network, energy losses are directly linked to voltage drops. Therefore, there is a relationship between energy losses and voltage drops. Since it is easier and cheaper to measure the voltage drops than the energy losses in the lines, if we have the voltage drops, we can determine the energy losses. The application of this method will facilitate the knowledge of the nodes of the network which will involve the reliable determination of voltage drops with as a consequence the detection of thefts or fraudulent connections as well as the increase of the economy of the energy distributing company electric.*

***Keywords:*** *Electrical energy, distribution, voltage drop, electrical network, energy losses.*

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## I. INTRODUCTION

To transport electrical energy from the generator to the points of consumption, it must necessarily pass through a series of devices that make up the electrical energy transmission network. Indeed, the electrical energy produced by the large generating stations must first pass through the transmission network, then through the distribution network to finally reach the consumers.

The passage of this energy through the various elements of a network such as cables, transformers or other devices, leads to energy losses which can be classified as transmission losses and distribution losses (case under examination). In any electrical system, energy losses are inevitable. They represent an operating cost necessary to move energy from the point of production to the points of consumption. From the point of view of the distribution of electrical energy, these losses reduce the overall efficiency of the networks.

Thus, according to Mendez, V., et al. (2000), it is desirable to reduce these energy losses as much as possible, but this involves many inversions to the network which must be compared to the actual cost of the losses.

According to Vunda, N., C. (2005), it is said that in any electrical energy distribution network, energy losses are inevitable and directly related to voltage drops. Therefore, there is a relationship between energy losses and voltage drops. As it is easier and cheaper to measure the voltage drops than the energy losses in the lines, if we have the voltage drops, we can determine the energy losses.

According to Snel (2019), the network of the Electric Power Distribution Department of the city of Kinshasa contains 82 MV sectioning stations, 1,202 km of MV cable network, 1,638 MV/LV transformation centers, including 925 transformation centers distribution network with 1,014 transformers, 26,980 km of LV cable network and 1,239 LV sectioning stations.

## II. STATUS OF ENERGY LOSS ANALYSIS TECHNIQUES IN THE ELECTRICAL ENERGY DISTRIBUTION NETWORK

The total losses of electrical energy at the national level have increased considerably in recent years. The main causes are, in particular, the supply of electrical energy to the urban-marginal population through non-standard and clandestine connections.

The increase in the costs of electrical energy and the high level of energy losses, estimated in the primary and secondary distribution systems, have prompted studies and planning of distribution of electrical energy, with the aim of evaluating the energy losses.

### II.1CLASSIFICATION OF LOSSES IN THE NETWORKS

According to Pressoz, H. (1984), Roldan, P., C. et al. (1990), the passage of electrical energy in different elements of a network such as: cables, transformers or any device, involves energy losses. Taking into account the nature of the elements of the electrical system where energy losses occur, these can be classified as transmission losses and/or distribution losses. In this regard, in this study, we opt for distribution losses. In any electrical system, electrical losses are inevitable.

These can be considered as an operating cost necessary to transport electrical energy from the place of production to the place of consumption. Thus, it is desirable to reduce them to the permissible values.

The energy losses of the distribution system can be classified according to their origins into Technical Losses and Non-Technical Losses.

According to Mendez, V., H. et al. (2000), Herrera, M. (2004) and the Organization Internationalof the Francophonie(2006), for the entire electricity system, from production to distribution, the threshold of global losses considered acceptable by international experts is 15 to 16%. This percentage includes technical losses and non-technical losses.

### II.2TECHNICAL LOSSES

Regarding technical losses, according to ERDF/EDF (2009), the process of conveying electrical energy itself consumes energy. This largely corresponds to heat dissipation by heating of conductors (we speak of losses in copper) and transformers (we speak of losses in iron).

According to Felice, E. (2012), the technical losses correspond to the losses on the networks by Joule effect (heating of the cables), by corona effect (electric discharge caused by the ionization of the medium surrounding a conductor) as well as the losses in iron from transformers.

All the energy losses of a system caused by physical phenomena are those called "Technical Losses". They have an influence on the economy of the company distributing electrical energy.

Technical losses generally come from generation and transit on the network:

- Technical losses due to production are linked to means of production and auxiliaries; improving the efficiency and operation of production tools reduces these losses.
- Technical losses due to transmission and distribution come from transit on the network.

Technical losses are linked to poor network performance due to load imbalance, active and reactive losses, poor power factor, etc., to name just some of the possible causes. These losses are evaluated by making the difference between the injections and the withdrawals between the different levels.

According to Gomez, A. (2002) and the International Organization of theFrancophonie (2006), technical losses represent 3% to 10% of total losses. Forecasting methods, thanks to simulations (Load flow), make it possible to ensure control. However, it is important to note that the analysis and decision support tools for transport and distribution are not the same as the problems encountered at each level are of different natures.

Technical losses only have reference with the structure of the network and the transmission, transformation and distribution elements, as well as with the electrical energy metering system used. However, errors in the design or choice of equipment or instruments increase the normal values expected in this part:

- Substation transformers;
- Transmission, sub-transmission and distribution lines;
- Cables;
- Power transformer at distribution level;
- Measuring devices, whether current or voltage.

Technical losses refer to all losses which are the consequences of the heating of conductors, motors, transformers and the power dissipated between conductors and ground. These losses vary according to the equipment and the length of the circuits. They include losses due to the Joule effect in lines and transformers, and no-load losses in transformers and those caused by the supply of auxiliaries necessary for the operation of transformer centers and substations. Their amplitude depends on the characteristics of the networks and the amplitude of the load provided by these networks.

### II.3NON-TECHNICAL LOSSES

According to EDF (1996), ERDF/EDF (2009) and Aurian de Maupeou, X. (2010), the term “non-technical losses” is a periphrasis to designate the theft of electricity from the network. Non-technical losses essentially consist of energy consumed without being recorded by electricity meters. This can be consumed in a household subscribed to electricity without the meter not counting it, or outside, directly on the electricity network.

In less developed, underdeveloped, developing and/or developing countries, electricity theft is common, and losses of a non-technical nature can reach 50% of the total amount of electricity fed into the grid especially because of the problem of corruption.

Non-technical losses constitute a part of the electrical energy actually consumed by an end customer and which is not attributable to him because not detected by the distributor: printing or metering fault, fraud and/or human error.

According to the Organization International of theFrancophonie (2006) and Gueye, I., Y. (2006), the unrecorded electrical energy consumed is the main component of non-technical losses. While it seems easy to estimate the overall level by deducting the overall losses or the difference between the electrical energy actually billed, the origins of these losses are not always obvious and they cannot be precisely measured.

Endogenous factors (poor mastery of invoicing, dishonest or corrupt agents at the level of meter installation or reading, blocking of the electric meter, etc.) and exogenous factors (fraudulent use of electrical energy, etc.) to electricity distribution companies, are considered. Also, the means to fight and/or reduce them are to be imagined. Measurements and controls on the ground contribute to these means. These are relatively difficult and complex operations that require organization and method.

By definition, for a given electricity distribution company, the non-technical losses are the algebraic difference between the total energy losses and the technical energy losses in a given period of time. At the same time, the total energy losses in a determined period of time are calculated as the difference between the total energy supplied by the distributing company and the energy billed by it. The calculation of technical losses corresponds to the energy losses that occur in electrical networks mainly by the Joule effect (transformation of electrical energy into heat) and the production of electromagnetic fields (in primary and secondary distribution transformers).

It is important to separate the different natures of these two types of electrical losses. While technical losses are a profusion or "SCRAP3" inherent in the electrical process that can be reduced to an economic minimum, non-technical losses are always the consumption of electrical energy that is either not billed, or is billed erroneously or out of time; for this, these losses are considered as entry losses.

We must also pay attention to unrecovered billed consumption, which does not appear in the energy balance but plays the role of a communicating vessel with clandestine connections.

The high level of non-technical losses can burden the meters of electricity suppliers. The reduction of non-technical losses is therefore a priority objective for electricity suppliers in Third World, underdeveloped, developing and/or developing countries, even before the construction of new production capacities. The various causes of non-technical losses are (i) billing problems, (ii) dishonest or corrupt agents at the meter installation or meter reading level and (iii) meter blockage.

## III. VOLTAGE DROP METHOD

### III.1 PREAMBLE

Losses result, among other things, in voltage drop. There is therefore a cause and effect relationship between the voltage drop and the energy losses. It is thus possible, from knowledge of the voltage drop at an instant (t), to determine the energy losses at the same instant under the environmental operating conditions of the network and vice versa.

This procedure can only give valid results if voltage readings are available at all times and simultaneously at the starting node and at the arrival node. The calculation of averages at fixed horizons is then possible. To do this, a computer network is essential given the distances between nodes. The voltage drop method makes it possible to quantify energy losses in power lines via voltage drops. The application of this method facilitates the knowledge of the nodes of the network which will involve the reliable determination of voltage drops with as a consequence the detection of thefts or fraudulent connections, the assurance of the good quality of supply of electrical energy, the continuity of service as well as the increase in the economic capacity of the company distributing electrical energy

According to Roldan, P., C. et al. (1990) and CENERGIA (1992), there is no single methodology applied to the solution of this problem, which requires many components in different proportions and in different states in the distribution systems.

According to the documentation of Aznar, F. (1999), the author developed the determination of the points of the measurements. In this document and that of Vunda, N.,C. (2020), the authors have developed a method for analyzing technical losses in electrical energy distribution networks. We know that in all electrical energy distribution networks, energy losses are inevitable and are also directly linked to voltage drops. Therefore, there is a relationship between energy losses and voltage drops. Since it is easier and cheaper to measure the voltage drops than the energy losses in the lines, if we have the voltage drops, we can determine the energy losses in the power lines. For the calculations of losses in the lines, we consider that the current intensities are balanced in the lines, that is to say, we start from the assumption of the equal distribution of the charges in the lines.

### III.2 RELATIVE VOLTAGE DROP IN THE LOW VOLTAGE LINE

The relative voltage drop in a negligible reactance line (BT line in which X =0) whose representative equation is written:

$$\Delta_{ur} = \frac{R_L P}{U^2{}_L} \qquad \text{(III.1)}$$

Avec: $\Delta_{ur}$ =Relative voltage drop;

$U_L$ =Line phase-to-line voltage;

$R_L$ =Line resistance;

P =Active power.

### III.2.1RELATIVE VOLTAGE DROP IN THE MEDIUM VOLTAGE LINE

As in an overhead medium voltage line $R_L \cong X_L$, the voltage drop relative to the voltage is:

$$\Delta_{Ur} = \frac{R_L P}{U^2{}_L} + \frac{X_L Q}{U^2{}_L} = \frac{R_L(P+Q)}{U^2{}_L} \qquad \text{(III.2)}$$

### III.2.2RELATION BETWEEN VOLTAGE LOSSES AND DROP

After studying the different line voltage drops, we can now establish the correlation between relative losses in the line and relative voltage drop in the line. We can determine the relationships between the relative power losses to the active power that the line transmits and the voltage drop relative to the line voltage.

### A)THREE-PHASE LOW VOLTAGE LINE (Knowing that $X_L$ =0)

Through the expressions $P_{\Pr} = \frac{3R_L I^2{}_L}{\sqrt{3}U_L I_L Cos\varphi}$ and (III.1), by correlation of two expressions, we can find the relative losses in the line by the following expression:

$$P_{\Pr} = \Delta_{Ur} \cdot \frac{1}{Cos^2\varphi} \qquad \text{(III.3)}$$

### B) MEDIUM VOLTAGE THREE-PHASE LINE (Knowing that R ≈X)

The medium voltage network of the Department of Electrical Energy Distribution Regions of the city-province of Kinshasa is made up of 6.6kV, 20kV and 30kV overhead lines.

From expressions $P_{\Pr} = \frac{3R_L I^2{}_L}{\sqrt{3}U_L I_L Cos\varphi}$ and (III.2), by correlation of two expressions, we conclude that the relative losses in the medium voltage line are worth:

$$P_{\Pr} = \Delta_{Ur} \cdot \frac{1}{Cos\varphi(Cos\varphi + Sin\varphi)} \qquad \text{(III.4)}$$

It should be noted that this voltage drop can be calculated with data from the electricitydistribution company or be measured using measuring devices to be placed upstream and downstream of the power line to be studied. Next, with some applications and with data from Snel, we will demonstrate how this method is more reliable in determining energy losses in power lines.

## IV.APPLICATION OF THE VOLTAGE DROP METHOD TO THE KINSHASA DISTRIBUTION DEPARTMENT NETWORK

We proceed to the analog applications: of the whole low voltage line and some samples of the medium voltage lines of the said network (one case per type of MV lines: 6.6; 20 and 30kV), with the parameters provided by the database data from the National Electricity Company (2019).

### IV.1FOR THE ENTIRE LOW VOLTAGE LINE (380V)

WithX= 0; $I_{max}$ = 210 A; L= 0,13km ; Number of conductors (n) =3 ; Cos φ = 0,9 and R= 0,13 X 0,236 = 0,0306 Ω/phase

Losses/conductor= $RI^2 = 0{,}0306X(210^2)$=1349,46 W

Losses/line= 1349, 46 X3 =4048,38 W

Knowing that the network of the Department of Distribution of Electric Energy of the city province of Kinshasa has 1014 Transformers of the transformation centers (cabins) with an average of 8 departures each.

So:

Total Losses /B.T= Losses/line X Departs X Transformers

Total Losses /B.T = 4048,38 W X 8X1014 = 32840458,56W

$$S_{max} = \sqrt{3}UI_{max} = \sqrt{3}X\,380X\,210 = 138217{,}65\ \text{VA}$$

$$P_{max} = S\cos\varphi = 138217{,}65X\,0{,}9 = 124395{,}88\ \text{W}$$

$$\Delta_{ur} = \frac{R_L P}{U^2_L} = \frac{\sqrt{3}U_L I_L R_L Cos\varphi}{U^2_L} = \frac{\sqrt{3}X\,380X\,210X\,0{,}0306X\,0{,}9}{144400}$$

=0,026pu = 2,6%

$$P_{Pr} = \Delta_{Ur}.\frac{1}{Cos^2\varphi} = \frac{0{,}026}{0{,}81}$$

= 0,032 pu =3,2%

### IV.2FOR SOME SAMPLES OF MEDIUM VOLTAGE LINES

### IV.2.1LINE6.6kV

F60/ LIMETE Substation: 3X95cu

With: $I_{max}$ = 140 A

R= 2,901 X 0,236 = 0,684 Ω/phase

Number of conductors (n)= 3

Losses/conductor = $RI^2 = 0{,}684X(140)^2 = 13406{,}4$ W

Losses/line = 13406,4 W X 3 = 40219,2 W

$$S_{max} = \sqrt{3}UI_{max} = \sqrt{3}X\,6600X\,140 = 1600414{,}946\ \text{VA}$$

$$P_{max} = S.\cos\varphi = 1600414{,}946X\,0{,}9 = 1440373{,}4514\ \text{W}$$

$$Q = S.\sin\varphi = 1600414{,}946X\,0{,}435 = 696180{,}501\ \text{VAR}$$

$$\Delta_{ur} = \frac{R_L P}{U^2_L} + \frac{X_L Q}{U^2_L} = \frac{R_L(P+Q)}{U^2_L} = \frac{0{,}684(1440373{,}4514 + 696180{,}501)}{43560000}$$

= 0,033 pu = 3,3%

$$P_{Pr} = \Delta_{Ur}.\frac{1}{Cos\varphi(Cos\varphi + Sin\varphi)} = \frac{0{,}033}{1{,}2}$$

= 0,0275 pu = 2,7%

### IV.2.2 LINE 20 kV

Section: FUNA – BRALIMA: 3X500Al

With:$I_{max}$ = 260 A

R= 3,6 X 0,072 = 0,2592 Ω/phase

Number of conductors (n)= 3

Losses/conductor = $RI^2 = 0{,}2592 X (260^2) = 17521{,}92$ W

Losses/line = 17521,92 W X 3 = 52565,76W

$$S_{max} = \sqrt{3}UI_{max} = \sqrt{3}X\,20000\,X\,260 = 9006664{,}199 \text{ VA}$$

$$P_{max} = S.\cos\varphi = 9006664{,}199\,X\,0{,}9 = 8105997{,}779 \text{ W}$$

$$Q = S.\sin\varphi = 9006664{,}199\,X\,0{,}435 = 3917898{,}926 \text{ VAR}$$

$$\Delta_{ur} = \frac{R_L P}{U^2{}_L} + \frac{X_L Q}{U^2{}_L} = \frac{R_L(P+Q)}{U^2{}_L} = \frac{0{,}2592(8105997{,}779 + 3917898{,}926)}{400000000}$$

= 0,0077pu= 0,77%

$$P_{Pr} = \Delta_{Ur}.\frac{1}{Cos\varphi(Cos\varphi + Sin\varphi)} = \frac{0{,}0077}{1{,}2}$$

= 0,0064 pu = 0,6%

**IV.2.3 LINE30 kV**

Section: LIMINGA – LIMETE 1: 2X3X120cu

Avec : $I_{max}$ = 510 A (For phase)

$I_{max} = \frac{510}{2}$ =255 A /conductor

R= 2,5 X 0,19 = 0, 475 Ω/phase

Number of conductors (n) = 2 X 3 = 6

Losses/conductor= $RI^2 = 0{,}475 X (255^2) = 30886{,}875$ W

Losses/line = 30886,875W X 6 = 185321,25 W

$$S_{max} = \sqrt{3}UI_{max} = \sqrt{3}X\,30000\,X\,510 = 26500377{,}355 \text{ VA}$$

$$P_{max} = S.\cos\varphi = 26500377{,}355\,X\,0{,}9 = 23850339{,}619 \text{ W}$$

$$Q = S.\sin\varphi = 26500377{,}355\,X\,0{,}435 = 11527664{,}149 \text{ VAR}$$

$$\Delta_{ur} = \frac{R_L P}{U^2{}_L} + \frac{X_L Q}{U^2{}_L} = \frac{R_L(P+Q)}{U^2{}_L} = \frac{0{,}475(23850339{,}619 + 11527664{,}149)}{900000000}$$

= 0,0186pu= 1,86 %

$$P_{Pr} = \Delta_{Ur}.\frac{1}{Cos\varphi(Cos\varphi + Sin\varphi)} = \frac{0{,}0186}{1{,}2}$$

= 0,0155pu= 1,5 %

## V. CONCLUSION

The electrical energy produced by the large generating stations must first pass through the transmission network, then through the distribution network to finally reach the consumers. The passage of this energy through the various elements of a network leads to energy losses which can be classified as transmission losses and/or distribution losses, as is the case of our study. In any electrical system, energy losses are inevitable.

These energy losses can be considered as an operating cost necessary to transport electrical energy from the place of production to the place of consumption. Thus, it is desirable to reduce them to the permissible values.

The most adequate process that leads to the success of this energy loss analysis study involves several parts:

➢ Analysis of the electrical energy distribution network and grouping of similar elements (lines, transformers, consumption areas, etc.). This work must be carried out in collaboration with the experts of the company distributing electrical energy, National Electricity Company in our case;

➢ Selection of a representative element of each group;

- Detailed study of the representative element. It is necessary to have modern and efficient measuring equipment, fixed or portable, which can be installed simultaneously in several points of the element. From these measurements, the model will be established which will have to explain the behavior of each element measured;
- Establish the model with the other elements of the same group as those represented, compare the elements of the model by means of certain measures;
- Extrapolate the model to all the elements of the electrical energy distribution network.

The voltage drop method is more direct and above all more flexible for the evaluation of energy losses in a power line. With it, we obtain in a few lines, not only the energy losses, but also the voltage drops.

In addition, this method requires the simultaneous use of modern and efficient voltage recorders, upstream and downstream of the power line, in order to be able to regularly perform voltage measurements. Finally, the application of the voltage drop method in a distribution network facilitates knowledge of the network nodes which will lead to the reliable determination of voltage drop with the consequence of detecting theft or fraudulent connections, ensuring the good quality of electrical energy supply, continuity of service as well as the increase in the economic capacity of this electrical energy distribution company..

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