Determination of the voltage profile of a LV distribution network: case of the Marie-Jose cabin LV distribution network Naviundu district, Lubumbashi, DRC

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Abstract: **Poor energy quality has considerable economic and societal consequences; the destruction of expensive equipment, the shortening of their lifetime, etc. Therefore, the need to have reliable and economical electricity networks is an increasingly important issue. However, in many electricity networks, the growth in electricity demand is not accompanied by an increase in the capacity of electrical energy supply. In this work, we addressed the question of determining the voltage profile in order to evaluate the voltage drops with a view to integrating reactive power from the capacitor banks to improve the voltage profile of the network. This is how, after integrating different percentages of reactive power, we found that the injection of a power of 50%, improves the voltage profile of our network according to the IEC-60038 standard which recommends a margin of +/- 10%.**

Keywords: **voltage profile, low voltage distribution network, reactive power.**

I. INTRODUCTION

Nowadays, electrical energy is a consumer good in its own right that has become essential, not only for daily life of anyone but also for the economy of countries. Indeed, poor energy quality has considerable economic and societal consequences; the destruction of expensive equipment, the shortening of their lifetime, etc. Therefore, the need to have reliable and economical electricity networks is an increasingly important issue. Energy networks have the role of transporting electricity from production centers to places of consumption, often over long distances. However, in many electricity networks, the growth in electricity demand is not accompanied by an increase in the capacity of electrical energy supply. For example, the extension of networks to rural areas or the construction of new networks in distant sites encounters significant economic constraints. Decentralized production introduces radical changes to the generation, processing and distribution of electrical energy and calls into question the planning, design, operation and operation of these networks.

Furthermore, this form of production, by its distributed nature, has the potential to enable better security of infrastructures. The insertion of these new productions is not without negative effects on networks to which they are interconnected and which have not been designed for this purpose. The integration and determination of the optimal size and location of the reactive power with capacitor batteries in distribution networks aims to reduce power losses as much as possible, improve the voltage profile and thereby increase the transmission capacity of the lines.

In this paper, first we will talk about the methodological approach, a guide to carrying out this work and the collection of data which will allow the identification of the environment and its distribution network. Then we will address the determination of the voltage profile of the distribution network of the chosen area and the determination of the reactive power of the capacitor batteries to be injected into the network to improve the voltage profile.

II.   METHODOLOGY

We started this work by determining different network parameters (the transformer, the structure of the network, determining the load rate, etc.) of the Marie-José distribution station which is supplied from a feeder (ZIL station). The table 1 below gives us the characteristics of the Marie-José cabin.

Table 1: Network characteristics.

MARIE JOSE CABIN	
APPARENT POWER	**500 kVA**
OPERATING VOLTAGE	**15/0,4 kV**

Knowing the relation of the apparent power:

$$S = \sqrt{3}.Un.In \tag{1}$$

We can thus determine the nominal current of the transformer by drawing its expression from the relation of the apparent power:

$$In = \frac{S}{\sqrt{3}.Un} = \frac{500}{\sqrt{3}.0,4} = 721,68\ A \tag{2}$$

Figure 1 illustrates the network configuration of the Marie-José cabin.
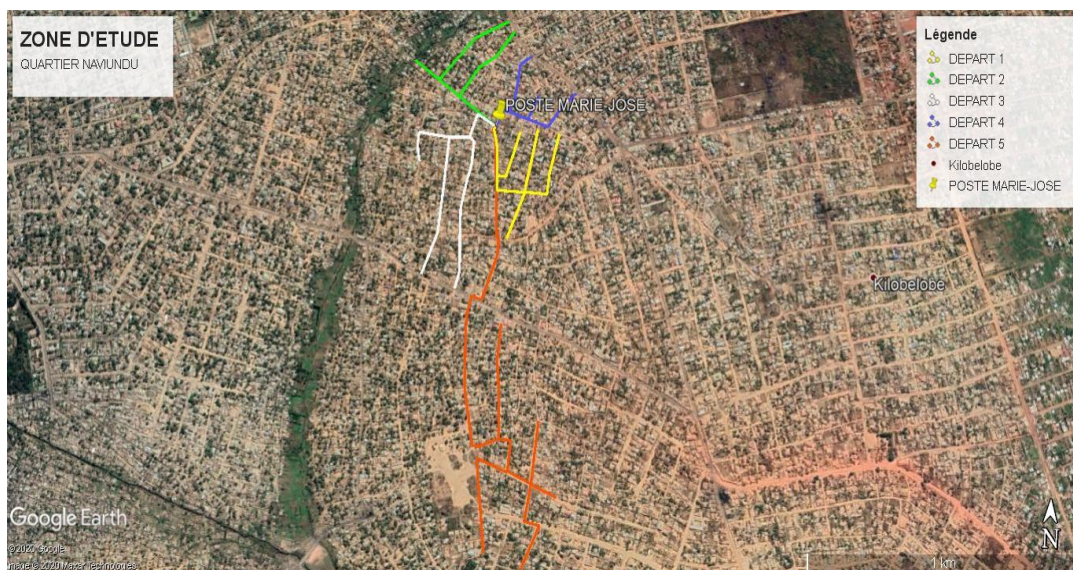

Figure 1: MARIE JOSE cabin network configuration

As illustrated in Figure 1, the Marie-José substation has five departures, and Table 2 gives us the current measurements on each departure:

Table 2: Current measurements in Amps

	R	S	T	Imoy
General arrival	652	697	712	687
Departure 1	180	186	185	183,67
Departure 2	159	122	92	124,33
Departure 3	21	230	11	87,33
Departure 4	121	150	125	132
Departure 5	198	98	210	168,67

The loading rate of a transformer is the ratio of the average total current to the transformer's admissible current.

The table below shows a model of a transformer load rate reading.

Table 3: Loading rate statement template

Departure	R	S	T	Total
1	a_1	b_1	c_1	$a_1+b_1+c_1$
2	a_2	b_2	c_2	$a_2+b_2+c_2$
3	a_3	b_3	c_3	$a_3+b_3+c_3$
Total	$a_1+a_2+a_3$	$b_1+b_2+b_3$	$c_1+c_2+c_3$	

$$R=a_1+a_2+a_3+\ldots+a_n \qquad (3)$$

$$S=b_1+b_2+b_3+\ldots+b_n \qquad (4)$$

$$T=c_1+c_2+c_3+\ldots+c_n \qquad (5)$$

$$I_{Tmoy}=\frac{R+S+T}{3} \qquad (6)$$

The transformer loading rate is:

$$Tx=\frac{I_{Tmoy}}{I admissible\ du\ transfo}. \qquad (7)$$

Thus we can determine the loading rate from the data provided by table 2:

$I_{Tmoy}=183.67+124.33+87.33+168.67+132=696$ A

Having already determined the nominal current In=722A

$Tx=\frac{696}{722}\cdot 100$

Tx=96.3%

Carson's equations giving the expression for the self-impedance of conductor i and the mutual impedance between conductors i and j.

$$\hat{z}_{ii} = r_i + 0{,}079418 + j0{,}1011 \left(\ln \frac{1}{GMR_i} + 8{,}0252\right) \ \Omega/mile \qquad (8)$$

$$\hat{z}_{ij} = 0{,}079418 + j0{,}1011 \left(\ln \frac{1}{D_{ij}} + 8{,}0252\right) \ \Omega/mile \qquad (9)$$

The four conductors are made of identical material, copper with a section of 16 mm2. The resistance at 25°C of this type of conductor and the geometric mean radius can be found in Turan Gonen from the modified Carson equations (8) and (9), let us establish the impedance matrix of this line, considering an operating frequency of 50 Hz and 100 Ωm as earth resistivity value (this value is considered standard Glover and Sarma). So using the data in Figure 5 we determine the line construction characteristics.

Table 4: line construction characteristics

Conductor	X(m)	Y max (m)	Y min(m)	Type of conductor
Phase 1	0	10	9,7	1
Phase 2	0,5	10	9,7	1
Phase 3	0	10,3	10	1
Neutral	0,5	10,3	10	2

From the data in the table 4, we used Matlab software to allow us to more quickly determine the matrix of resistances, inductances and capacitances.

Table 5: Characteristics of conductors

Conductor	Conductor diameter (cm)	Ratio e/D	GMR	Resistance *(H/km)*	Inductance *(H/km)*	Relative permeability
Phase	0,454	0,5	1,4274	14,0625	0,002659	1
Neutral	0,454	0,5	0,4945	14,0625	0,002659	1

In the modified Forward/Backward Sweep algorithm we consider that the loads are of fixed power type in the form:

$$[Sabc]i = \begin{bmatrix} S_a^i \\ S_b^i \\ S_c^I \end{bmatrix} = \begin{bmatrix} S_a/\theta a \\ S_b/\theta b \\ S_c/\theta c \end{bmatrix} \qquad (10)$$

Where Sa, Sb and Sc are the apparent powers on the three phases. Өa, Өb and Өc are the phase shift angles of the current with respect to the voltage on the three phases.

Figure 2 shows us the network of departure five of the Marie-José substation with its thirty-one houses on which various voltage measurements shown in table 4 were carried out.
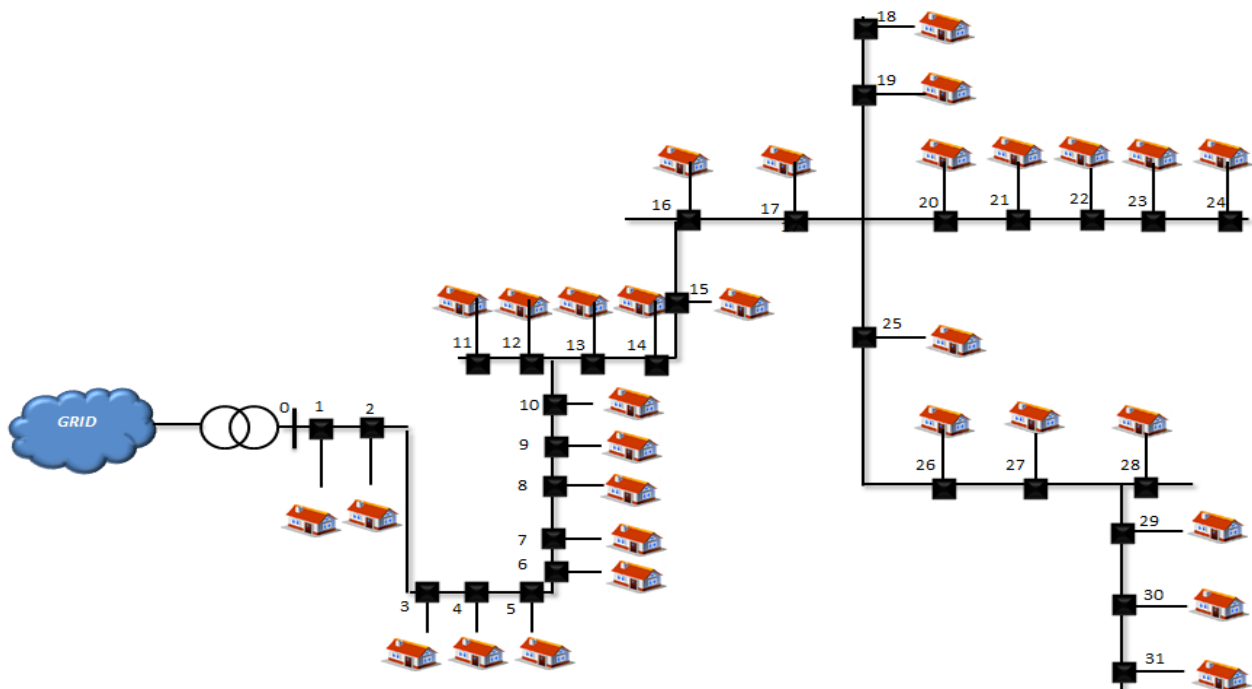

Figure 2: Presentation of the Marie-José substation network

The voltage measurements were carried out on all thirty-one subscribers taken randomly over three days. These voltage measurements covered simple voltages (phase-neutral) and compound voltages (phase-phase). Table 6 gives us the voltage values taken from different subscribers. All these measurements were made using a multimeter which is a measuring device used to measure different electrical parameters (voltage, current, resistance, etc.).

So, for a subscriber we had to carry out the following measurements in one day:

1. Simple voltage measurements:

➢ Phase R and neutral N (R-N);

➢ Phase S and neutral N (S-N);

➢ Phase T and neutral N (T-N).

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2. Compound voltage measurements:

➢ The R and S phase;

➢ The R and T phase;

➢ The T and S phase.

Table 6: Voltage sampling (in volta)

Subject N°	Single voltage									Compound voltage								
	R-S			R-T			S-T			R-N			S-N			T-N		
	1J	2J	3J	1J	2J	3J	1J	2J	3J	1J	2J	3J	1J	2J	3J	1J	2J	3J
1	90	95	85	90	85	80	102	105	100	50	49	50	60	60	48	72	60	55
2	88	95	85	89	82	79	100	105	98	49	48	50	59	58	47	70	60	53
3	88	93	84	88	82	79	100	100	98	48	48	48	58	57	46	70	58	52
4	86	90	84	87	80	78	98	98	96	47	46	47	56	56	46	69	58	52
5	84	88	80	85	80	75	95	98	94	45	42	45	53	54	42	66	55	50
6	82	86	79	83	79	37	92	97	93	44	40	43	51	52	40	65	55	47
7	82	85	78	81	79	70	90	95	92	41	39	42	50	51	38	65	52	45
8	81	84	78	80	78	69	88	95	90	41	39	41	49	50	37	65	51	43
9	80	82	75	77	76	68	88	93	90	40	39	40	48	49	36	64	50	43
10	79	82	70	76	76	67	88	91	89	40	38	40	47	48	36	63	49	41
11	77	79	69	75	76	65	88	90	88	38	37	39	46	47	36	63	48	41
12	76	79	67	75	74	65	85	90	86	38	36	39	46	48	35	62	48	40
13	74	75	67	73	69	65	85	90	86	35	36	39	46	46	34	61	48	42
14	72	79	68	72	69	62	83	86	84	35	34	37	44	46	33	61	46	42
15	72	74	68	70	69	60	82	85	83	35	33	37	43	46	33	60	45	42
16	70	74	66	70	69	60	82	84	81	34	32	36	43	45	32	59	44	40
17	68	74	64	70	68	06	80	82	80	33	32	36	43	44	31	55	43	40
18	67	72	61	70	65	60	78	82	78	32	32	35	41	44	33	52	43	40
19	65	70	60	66	64	60	78	80	75	30	33	34	40	43	33	50	42	40
20	65	68	58	65	62	58	75	75	70	29	32	34	35	42	33	48	40	40
21	63	65	52	62	60	58	72	72	70	29	32	31	33	42	32	45	40	38
22	60	63	52	60	50	55	72	70	62	25	32	30	30	40	32	43	40	38
23	60	63	52	60	49	53	70	68	60	24	32	29	30	40	29	43	38	38
24	59	62	52	55	45	50	70	65	60	22	30	28	29	35	29	40	38	35
25	55	60	50	51	45	49	62	63	60	20	30	28	27	32	28	35	35	33
26	52	60	50	50	42	48	58	63	55	18	30	28	25	30	25	34	33	33
27	50	58	48	47	42	47	35	60	55	32	29	27	22	30	25	15	31	31
28	49	58	46	45	42	46	30	58	54	30	27	27	22	29	25	16	30	31
29	50	58	46	44	42	45	30	55	53	30	26	27	21	27	24	15	29	28
30	49	55	47	45	40	46	35	55	52	30	27	27	20	26	25	15	30	28
31	47	55	46	45	40	45	35	55	50	28	26	25	20	25	22	16	30	28

III. RESULT

We introduced the characteristics of the line into the Matlab software by using the Forward/Backward Sweep method which gave us the voltage profile showing us the different voltage values on the ordinate and the node on the abscissa axis. On this voltage profile, the voltages are expressed in "pu" which is the unit of measurement used by Matlab.

So to find the value of the voltage in volte it is necessary to multiply the voltage in pu by 400 V which is the value of the base voltage got at the output of the transformer. Thereby, 1 pu corresponds to 400 V. The following figure gives us the voltage profile of the studied network.
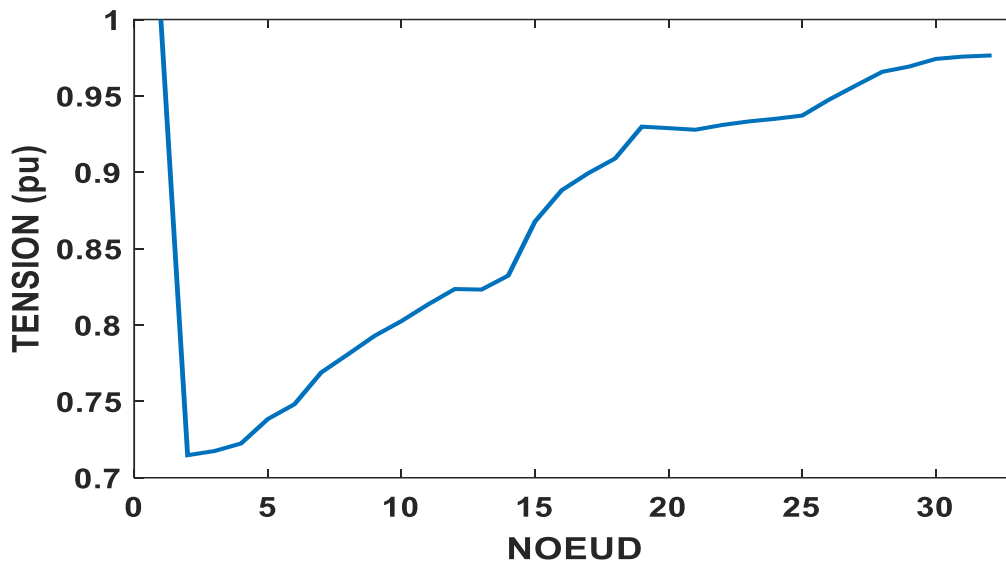
Figure 3: Voltage profile

IV. DISCUSSION

We note that a large voltage drop is at the first node, the voltage goes up to a value of 0.72 p.u which is far lower than the recommended value of the IEC in its CEI-60038 standard. The standards recommends a volue of +/- 10% of the voltage basis. i.e. 0.9 p.u minimum and 1.1 p.u maximum (Schneider, 2010). We see that the characteristic of the line current regarding the nodes is almost falling, it means that the values of the line current decrease as we move away from the source station and the large current is on the section between the transformer and the first node which is approximately 6.5 pu. This causes a large loss of energy on this section and therefore a significant voltage drops. Thus the expression of the voltage at the level of the last subscriber is:

$$|\overline{Vn}| \simeq |\overline{Vg}| + \frac{R.Pn + X.Qn}{|Vg|} \qquad (11)$$

After transformation, we obtain the formula for the apparent power to be injected into the network at the level of the last subscriber (Zeraati, M., Golshan, M. E. H., & Guerrero, J. M., 2018). Distributed Control of Battery Energy Storage Systems:

$$Qp = Qc = \frac{0,05Vg^2}{X} \qquad (12)$$

Whith:

- - Qp: The reactive power to be injected into the network;

- - Qc: The reactive power consumed by the last subscriber;

- - Vg: The voltage at the transformer;

- - X: The inductive reactance of the last subscriber.

Knowing the active power of the last subscriber which is 0.8 kW and the power factor of the network which is 0.86, we determine the reactive power consumed by the last subscriber.

Qc=P× $tan\varphi$

Qc=0,8× tan0,5355

Qc=0,48Kvar

Knowing the inductance obtained from the Matlab software (table 6) and the network frequency, we determine the inductive reactance:

X= $L \times \omega$

L=0, 002659 (H/km)

L (0-31) =0, 002659× 2,545

L=0, 00676 H

X=0, 00676× 314

X=2, 12 Ω

Qp=480+ $\frac{0,05 \times 400^2}{2,12}$

Qp=4,253 kVAR

So we have just determined the reactive power value of our capacitor bank to be injected at node 31 to improve our voltage profile. The next Figure shows us the voltage profile with injective of 0%, 20%, 40%, 60%, 80% and 100% of the reactive power at node 31 in order to see its impact on the voltage profile.
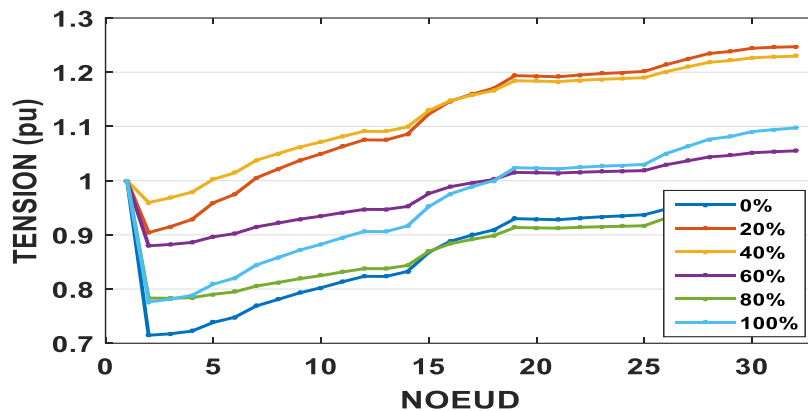
Figure 4: Voltage profile with injection of different percentages of reactive power

Considering the results presented above, we note that the integration of 60% of the reactive power at node 31 better improves the voltage profile up to 0.87 pu, which is not within the standard recommendation. This is how we resolved arbitrarily to gradually inject different levels of reactive power, namely; 0%, 20%, 40%, 50%, 60%, 80% and 100% at node 15 to try to see the impacts that each of the injections can have on the network voltage profile.
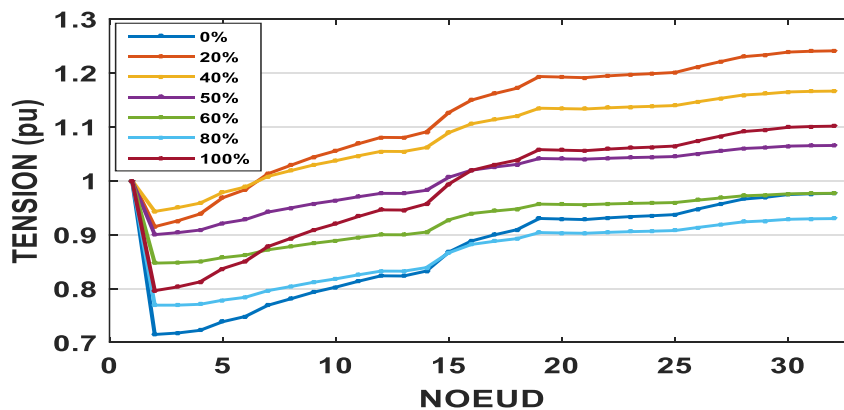

Figure 5: Voltage profile with injection of different reactive powers at node 15

Given the results presented above, we arbitrarily resolved to gradually inject three levels of reactive power, namely; 0%, 20%, 40%, 50%, 60%, 80% and 100% at node 15 to try to see the impacts that each of the injections can have on the network voltage profile. We notice that compared to the scenario without injection the injection of 50% of the reactive power at node 15 better improves the voltage profile compared to other injections because no voltage value is below of 0.9 pu and no longer greater than 1.1 pu, which is in the IEC-60038 standard. Without ambiguity, we deduce that the best voltage profile corresponds to an injection of 50% of the reactive power, i.e. 2.1265 kVAR.

V. CONCLUSION

The increase in energy needs in the DRC and the concern for environmental protection described by law No. 14/011 of June 17, 2014 relating to the electricity sector in the DRC attract investors to take an interest in production distributed in using them either independently or by integrating them into the distribution network. Poor voltage quality causes the rapid destruction of subscriber equipment and shortens their lifespan. This is how the IEC-60038 standard provides for a voltage variation margin of 10%.

The main objective of this work was to determine the voltage profile of our distribution network located in the Naviundu district in order to determine the reactive power to inject into this network to improve its voltage profile. In view of the results obtained, we noticed that the integration of reactive power at node 31 improved the voltage profile but not according to the IEC-60038 standard. This is how we injected different percentages of the reactive power at node 15 and we saw that the injection of 50% of the reactive power improves the voltage profile in compliance with the IEC-60038 standard.

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