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Technical Assessment and Strategic Planning of HV/MV Distribution Networks: Evaluation and Reinforcement of the Liminga Substation

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Abstract

This study presents a diagnostic and strategic planning methodology for the distribution network supplied by the Liminga HV/MV substation in the DRC. Confronted with critical load rates (101.79% for MV/MV transformers, 112% for 6.6 kV feeders) and voltage drops exceeding 20%, the analysis identifies a reinforcement need of 55.56 MVA. The proposed solution includes the installation of eight additional 15 MVA transformers and optimization of the 6.6 kV network topology. Simulations over a 10-year horizon (5% growth rate) validate the improvement in safety margins and power quality.

Keywords: Network Diagnosis; Strategic Planning; Reinforcement; HV/MV Substation; Load Rate; Liminga; DRC

1. Introduction

Strategic planning of distribution networks constitutes a major challenge for electricity operators, particularly in contexts where demand growth regularly exceeds the evolution capacity of infrastructure [1]. The Liminga HV/MV substation, a critical link in the electrical system of Kinshasa, presents clear signs of aging and under-dimensioning faced with urban and economic expansion in its service area [5].

This research adopts a dual approach combining an in-depth technical diagnosis of equipment and strategic planning of reinforcement interventions [3]. The objective is to transform operational data into rational investment decisions, guaranteeing both the immediate reliability of the network and its capacity to absorb future growth under economically optimal conditions [2].

The originality of this study lies in its systemic approach that simultaneously integrates the analysis of main equipment (HV/MV transformers), secondary substations, and distribution feeders, allowing precise identification of bottlenecks and potential synergies between different reinforcement solutions [6].

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2. Methodology

The adopted approach follows a sequential analytical procedure :

- Diagnosis of existing infrastructure: Collection and analysis of technical data from power sources (220/30 kV HV/MV transformers), MV/MV substations (30/6.6 kV and 30/20 kV), and their feeders.
- Calculation of load indicators: Determination of average load rates for transformers and 20 kV and 6.6 kV feeders.
- Identification of reinforcement needs: Calculation of remaining load rate (T_{xr}) and remaining apparent power (S_r) to be supplied to comply with IEC standards (admissible load rate of 80% for transformers, 83% for feeders).
- Future projection: Calculation of future apparent power (Sf) over a 10-year horizon, integrating an average consumption growth rate of 5%.
- Sizing of solutions: Determination of the number and power rating of additional transformers required.
- Performance verification: Calculation of voltage drop on the critical network to validate the impact of reinforcement on power quality.

3. Strategic planning

3.1. Diagnosis and Analysis of Existing Infrastructure

The diagnosis and energy assessment of the Liminga distribution network is an analysis based on the power supply sources of the substation, the cables and feeders that convey the demanded power, and the load rates.

3.2. Power Supply Sources

The Liminga network is supplied by three power transformers connected to the 220 kV Extra High Voltage line of the Inga-Kimwenza, Kimwenza-Liminga (Limete 15th Street) transmission network.

Table 1 Characteristics of Liminga HV/MV Transformers

Substation	No.	Voltage (kV)	Power (MVA)	Output Current (A)
LIMINGA	I	220 / 30	75	1403
	II	220 / 30	75	1403
	III	220 / 30	75	1403

(Source: SNEL/DDK/DEM/EXK/AST) [6]

3.3. Liminga MV/MV Transformers

The network served by the Liminga substation is composed of 7 substations or MV stations including: 6 long-distance substations and one substation whose installations are located within the Liminga Substation enclosure. Table 2 below presents the energy situation of these substations.

Table 2 Energy Assessment of Substations Served by Liminga Substation

ITEM	SUB-STATION	TFO	Service Voltage (kV)	P rated (MVA)	I rated (A)	I att (A)	P att (MVA)	Load Rate (%)
3	C.D. A	I	30/6.6	15	1312	1500	17.14	114%
		II	30/6.6	15	1312	1680	19.20	128%
		III	30/6.6	15	1312	1260	14.40	96%
11	LEMBA	I	30/6.6	15	1312	1260	14.40	96%
		II	30/6.6	15	1312	1390	15.88	106%
		III	30/20	15	420	395	13.68	94%

12	LIMETE	I	30/6.6	15	1312	1400	16.00	107%
		II	30/6.6	15	1312	1051	12.01	80%
		III	30/6.6	15	1312	1160	13.26	88%
16	MASINA	I	30/6.6	15	1312	1180	13.48	90%
		II	30/6.6	15	1312	1457	16.65	111%
		III	30/20	15	420	294	10.18	70%
		IV	30/20	15	420	500	17.32	119%
21	SENDWE	II	30/6.6	15	818	940	10.75	115%
		III	30/6.6	15	875	902	10.31	103%
23	UPN	I	30/6.6	15	1312	1230	14.06	94%
		II	30/6.6	15	420	500	5.71	119%
Average				**15**	**1047.35**	**1064.64**	**13.79**	**101.79%**
Total				**255**	**17805**	**18099**	**234.4**	

(Source: SNEL/DDK/DEM/EXK/AST) [5]

The feeders of these transformers have an energy situation described by the following tables:

Table 3 20 kV Feeders of Liminga Substation

ITEM	DESIGNATION	CABLE SECTION (mm^2)	I rated (A)	I att (A)	LOAD RATE (%)
1	MASINA - FC6	150 mm^2 - AL	250	10	4%
2	MASINA - FC7	150 mm^2 - AL	250	200	80%
3	MASINA - F1	-	340	150	44%
4	MASINA - NDOMBI	150 mm^2 - AL	250	95	38%
5	MASINA - SONAPANGU	150 mm^2 - AL	250	161	64%
6	MASINA - MASINA 7	150 mm^2 - AL	250	87	35%
7	MASINA - DEP LUNDULA	150 mm^2 - AL	250	33	13%
8	LEMBA 677	150 mm^2 - AL	250	140	56%
9	LEMBA 678	150 mm^2 - AL	250	180	72%
10	LEMBA 679	150 mm^2 - AL	250	113	46%
11	LEMBA 680	150 mm^2 - AL	750	80	11%
Average		**303.6**	**113.5**	**42%**	

(Source: SNEL/DDK/DEM/EXK/AST) [6]

Table 4 6.6 kV Feeders of Liminga Substation

S/STATION	ITEM	FEEDERS	SECTION mm^2	I rated (A)	I att (A)	LOAD RATE (%)
SENDWE	1	F 229	95	210	HS	-
	2	F 228	95	245	HS	-
	3	F 227	150 AL	250	48	19%
	4	F 263	95	210	220	105%

	5	F 200	50	142	123	87%
	6	F 254	95	210	330	157%
	7	F 212	95 Cu	210	244	-
	8	F 230	150 AL	300	HS	-
	9	F 271	95	210	198	94%
	10	F 12	50	352	95	27%
	11	F 272	95	210	0	0%
	12	F 214	150 AL	300	126	42%
	13	F 265	95	210	310	148%
MASINA	1	F C B	150 AL	250	90	36%
	2	F 9SC	150 AL	250	220	88%
	3	F C 9	240 AL	340	240	71%
	4	F 1095 A	95 Cu	210	110	52%
	5	F 1095 B	95 Cu	210	250	119%
	6	F 1068 A	95 Cu	210	260	124%
	7	F 1068 B	95 Cu	210	300	143%
	8	F 1074	150 AL	250	200	80%
	9	F 95 A	95 Cu	210	187	89%
	10	F 95 B	95 Cu	210	80	38%
KINGABWA	1	F 1675	95 Cu	210	190	90%
	2	F 1676	95 Cu	210	267	127%
	3	F 1673	150 AL	250	240	96%
	4	F 1672	95 Cu	210	240	114%
	5	F 1668	95 Cu	210	180	86%
	6	F 1649	95 Cu	210	270	129%
	7	F 1674	95 Cu	210	240	114%
LIMETE	1	F 60	95 Cu	210	168	80%
	2	F 61	95 Cu	210	184	88%
	3	F 61 B	95 Cu	210	HS	-
	4	F 63 A	95 Cu	210	210	100%
	5	F 64	95 Cu	210	170	81%
	6	F 65 A	95 Cu	210	190	90%
	7	F 67	75	210	159	76%
	8	F 68	95 Cu	210	239	114%
	9	F 69	95 Cu	210	170	81%
	10	F 70	95 Cu	210	200	95%
	11	F 71	95 Cu	210	98	47%
	12	F 72 A	240 AL	340	222	65%

	13	F 73	95 Cu	210	145	69%
	14	F 74	240 AL	340	214	63%
	15	F 75	95 Cu	210	HS	-
	16	F 76	95 Cu	210	176	84%
	17	F 63 B	150 AL	250	147	59%
	18	F 72 B	95 Cu	210	186	89%
	19	F 72 C	70 Cu	200	188	94%
LEMBA	1	F 668	150 AL	250	225	90%
	2	F 647	150 AL	250	260	104%
	3	F 641	150 Cu	300	200	67%
	4	F 648	150 AL	250	240	96%
	5	F 661	95 Cu	210	205	98%
	6	F 645	150 AL	250	270	108%
	7	F 649	150 AL	250	200	80%
	8	F 667 B	150 AL	250	180	72%
	9	F 646	150 AL	250	180	72%
	10	F 676	95 Cu	210	168	80%
	11	F 667 A	95 Cu	210	280	133%
	12	F 669	95 Cu	210	230	110%
	13	F 643	95 Cu	210	250	119%
	14	F 675	150 AL	250	210	84%
C D A	1	F 16 A	50	284	-	-
	2	F 916	50	142	75	53%
	3	F 106	150 AL	250	150	60%
	4	F L 9	150 AL	250	140	56%
	5	F 14	50	142	170	120%
	6	F 905	175	142	36	25%
	7	F 5	50	142	HS	-
	8	F 18	50	284	60	21%
	9	F 918	150 AL	250	0	0%
	10	F 38	95 Cu	210	-	-
	11	F 938	150 AL	250	-	-
	12	F 937	150 AL	250	15	6%
	13	F 101	150 AL	250	-	-
	14	F 102	150 AL	250	60	24%
	15	F 912	50	142	-	-
	16	F 12	50	142	120	85%
	17	F 4	50	142	150	106%

	18	F 920	150 AL	250	150	60%
	19	F 914	50	142	20	-
	20	F 904	50	142	87	61%
	21	F 917(915)	150 AL	250	107	43%
	22	F 919	150 AL	250	-	-
	23	F 924	95	210	170	81%
	24	F 16 B	150 AL	250	84	34%
	25	F 37	95	210	-	-
Average				**221.1**	**186**	**112%**

(Source: SNEL/DDK/DEM/EXK/AST) [6]

The diagnosis reveals the necessity to define a load relief plan for the installations served by Liminga substation, ranging from MV/MV transformers to 20 kV and 6.6 kV feeders.

3.4. Determination of Installed Network Power

The total installed apparent power of the network to be reinforced is determined by the following formula:

$S_{nt} = \sum_{i=1}^{k} S_i = S_{n1} + S_{n2} + S_{n3} + \cdots + S_{nk}$ (1)

Where:

- S_{nt}: total installed apparent power of the electrical network [MVA]
- S_i: apparent power of the i-th transformer [MVA]
- k: total number of transformers

$$S_{nt} = 255 \text{ MVA}$$

See Table 2.

3.5. Determination of Average Installation Load Rate

The average load rate of the electrical network to be reinforced is determined by the following formula:

$$T_{xmoy} = \frac{1}{n}\left(\sum_{i=1}^{n} T_{xci}\right) \ (2)$$

Where:

- T_{xmoy}: average substation load rate [%]
- T_{xci}: load rate per substation [%]
- n: number of substations

3.5.1. For Substation Transformers

$T_{xmoy} = 101.79\%$ (3)

See Table 2.

3.5.2. For 20 kV Feeders

$T_{xmoy} = 42\%$ (4)

See Table 3.

3.5.3. For 6.6 kV Feeders

$$T_{xmoy} = 112\% \ (5)$$

See Table 4.

3.6. Determination of Remaining Load Rate

The remaining load rate T_{xr} to be projected for the network to be reinforced is determined by the following formula:

$$T_{xr} = T_{xmoy} - T_{xAdm} \ (6)$$

Where:

- T_{xr}: remaining load rate of the electrical network to be reinforced [%]
- T_{xmoy}: average load rate of the electrical network to be reinforced [%]
- T_{xAdm} : admissible load rate [%]

3.6.1. For Substation Transformers

The admissible load rate for transformers according to IEC standards is 80% [3].

$$T_{xr} = 101.79 - 80 = 21.79\% \ (7)$$

3.6.2. For 20 kV Feeders

The load rate for a feeder is defined by:

$$T_x = \frac{I_L \times 100}{I_n} \ [\%] \ (8)$$

Where:

- T_x: feeder load rate [%]
- I_L: line current [A]
- I_n: rated current [A]

The admissible load rate for a feeder considering the safety coefficient of 1.2 is:

$$T_{xAdm} = \frac{I_L \times 100}{I_n \times 1.2} \ [\%] = \frac{1}{1.2} T_x = 0.83 T_x \ (9)$$

Thus, the admissible load rate for a feeder is 83%.

$$T_{xr} = 42 - 83 = -41\% \ (10)$$

The negative sign indicates that power equivalent to 41% must be added to the network; the feeder can be loaded.

3.6.3. For 6.6 kV Feeders

$$T_{xr} = 112 - 83 = 29\% \ (11)$$

3.7. Determination of Remaining Apparent Power

The remaining electrical apparent power to be projected S_r to the network to be reinforced is determined by the following formula:

$$S_r = \frac{S_{nt} \times T_{xr}}{100} \quad (12)$$

Where:

- S_r: remaining apparent power to be projected to the network to be reinforced [MVA]
- T_{xr}: remaining load rate of the electrical network to be reinforced [%]
- S_{nt}: total apparent power of the reinforced electrical network [MVA]

3.7.1. For Substation Transformers

$$S_r = \frac{255 \times 21.79}{100} = 55.5645 \text{ MVA} \quad (13)$$

3.7.2. . For 20 kV Feeders

Table 2 shows that the number of transformers supplying 30/20 kV feeders is three, equivalent to an available power of 45 MVA.

$$S_r = \frac{45 \times (-41)}{100} = -18.45 \text{ MVA} \quad (14)$$

The 30/20 kV network offers the possibility of being loaded with 18.45 MVA.

3.7.3. For 6.6 kV Feeders

With S_{nt} being 255 MVA, the 30/20 kV network takes 45 MVA, the 30/6.6 kV network logically takes 210 MVA (the difference between total installed power and power installed in the 30/20 kV network).

$$S_r = \frac{210 \times 29}{100} = 60.9 \text{ MVA} \quad (15)$$

3.8. Determination of Future Apparent Power

The future apparent power (S_f) of the network to be reinforced depends on the desired horizon. This study is conducted over the medium term with a 10-year projection.

$$S_f = S_r(1 + A)^t \quad (16)$$

Where:

- S_f: future apparent power [MVA]
- S_r: remaining apparent power to be projected to the network to be reinforced [MVA]
- A: average consumption growth rate
- t: projection time interval [years]

The growth rate is obtained based on annual energy demand. This rate is 5% according to SNEL/DDK/DEM/EXK/AST [5].

3.8.1. For Substation Transformers

$$S_f = 55.5645(1 + 0.05)^{10} = 55.5645 \times 1.62 = 90.50 \text{ MVA} \quad (17)$$

3.8.2. For 20 kV Feeders

The 30/20 kV network offers the possibility of being loaded with 18.45 MVA. Hence, its reinforcement cannot be studied.

3.8.3. For 6.6 kV Feeders

$S_f = 60.9(1 + 0.05)^{10} = 60.9 \times 1.62 = 98.658$ MVA (18)

3.9. Determination of Number of Transformers to be Installed for Network Reinforcement

The number of transformers to be installed in the network to be reinforced is determined by:

$$N_{Tfo} = \frac{S_f}{0.8 \times S_U} \quad (19)$$

Where:

- N_{Tfo}: number of transformers to be installed
- S_f: future apparent power of the network to be reinforced [MVA]
- S_U: unit apparent power of a load relief transformer chosen by the project engineer to be installed in the network to be reinforced [MVA]
- 0.8: 80% operating range rate for electrical substations required by IEC standard [3]

The unit power is 15 MVA (see Table 2).

$$N_{Tfo} = \frac{90.50}{0.8 \times 15} = 7.541 \approx 8 \text{ Transformers of 15 MVA} \quad (20)$$

3.10. Determination of Substation Elements

The elements of the transformer to be installed in the network to be reinforced are determined as follows:

- Number of feeders
- Conductor section of the main low voltage switchboard (MLVS)
- Conductor section of feeders and protection calculation

This research considers the first case: the hypothesis that the conductor section to be used is defined in advance.

$$N = \frac{I_{nTfo} \times 1.2}{I_{nc}} \quad (21)$$

Where:

- N: number of feeders
- I_{nTfo}: nominal current of the transformer [A]
- I_{nc}: nominal current of the conductor [A]

From Table 2, I_{nTfo} is 1312 A, and from Table 4, I_{nc} is 210 A for a 95 mm^2 copper section.

Thus, the number of feeders is:

$N = \frac{1312 \times 1.2}{210} = 7.49$ feeders ≈ 8 feeders per installed transformer (22)

3.11. Voltage Drop Verification Using the Classical Formula

The voltage drop as a function of the network to be reinforced is calculated using the following formulas:

$$S_d = \frac{T_{xmoy} \times S_{nt}}{100} \quad (23)$$

$$P_d = S_d \times \cos\ \varphi \ (24)$$

Where:

- S_d: demanded apparent power of the network to be reinforced [MVA]
- T_{xmoy}: average load rate of the electrical network to be reinforced [%]
- S_{nt}: total installed apparent power of the electrical network [MVA]
- P_d: demanded active power of the electrical network to be reinforced [MW]
- $\cos\ \varphi$: power factor (0.85)

$S_d = \frac{101.79\times255}{100} = 259.5645$ MVA (25)

$P_d = 259.5645 \times 0.85 = 220.6298$ MW (26)

The voltage drop is then given by the relation:

$$\Delta U = \frac{P_d \times l(r + X\tan\ \varphi)}{U^2} \ (27)$$

Where:

- ΔU: voltage drop in the network to be reinforced [%] (≤ 10% in MV and HV according to standards)
- P_d: total demanded active power of the electrical network to be reinforced [MW]
- l: feeder length from the substation to the electrical network to be reinforced [km]
- r: linear resistance of the feeder given by the manufacturer [Ω/km]
- X: linear reactance of the feeder given by the manufacturer [Ω/km]
- $\tan\ \varphi$: tangent of the phase angle between current and voltage of the network
- U: energy transit voltage of the feeder [kV]

The network length from the MV Substation to the farthest load is defined as 11.7 km (see Figure 1), the looping between LIMINGA substation and MALUKU substation at the RVA level via the MASINA substation.

For a 30/6.6 kV network with a 120 mm² copper section as shown in Figure 1, the parameters r and x are:

$$r = 0.26\ \Omega/\text{km} \ (28)$$
$$x = 0.15\ \Omega/\text{km} \ (29)$$

For a $\cos\ \varphi$ of 0.85, $\tan\ \varphi$ is 0.62.

$$\Delta U = \frac{220629800\times11.7(0.26+0.15\times0.62)}{(6600)^2} = 20.9\% \ (30)$$

For a load rate of 80%:

$$S_d = \frac{80\times255}{100} = 204 \text{ MVA} \ (31)$$
$$P_d = 204 \times 0.85 = 173.4 \text{ MW} \ (32)$$
$$\Delta U = \frac{173400000\times11.7(0.26+0.15\times0.62)}{(6600)^2} = 16.44\% \ (33)$$

Despite the reduction of the load rate from 101.79% to the 80% required by IEC, the voltage drop indicator shows that the network still does not meet the standards. As calculations show, for a load rate of 101.79%, the voltage drop is 20.9%, and for a load rate of 80%, the voltage drop returns to 16.44%. A decrease in voltage drop showing the influence of load rate reduction, but 16.44% is still high compared to the 10% voltage drop required for an MV network.

3.12. Overall Scenario Evolution of LIMINGA Power System

3.12.1. Power Evolution

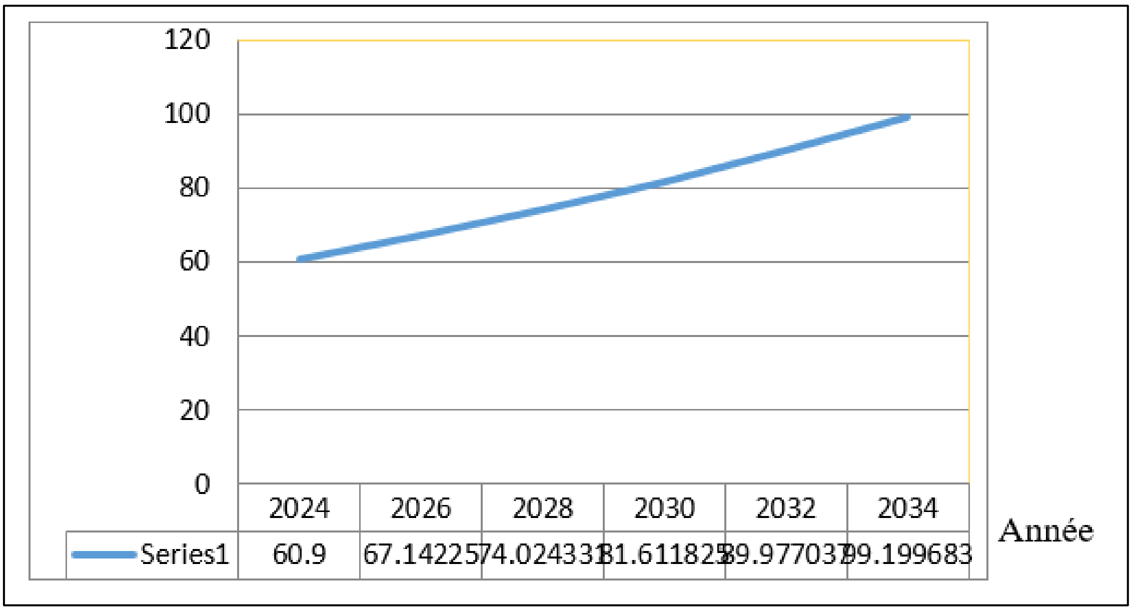

Figure 1 Power evolution projection (2024-2034)

3.12.2. Transformer Number Evolution

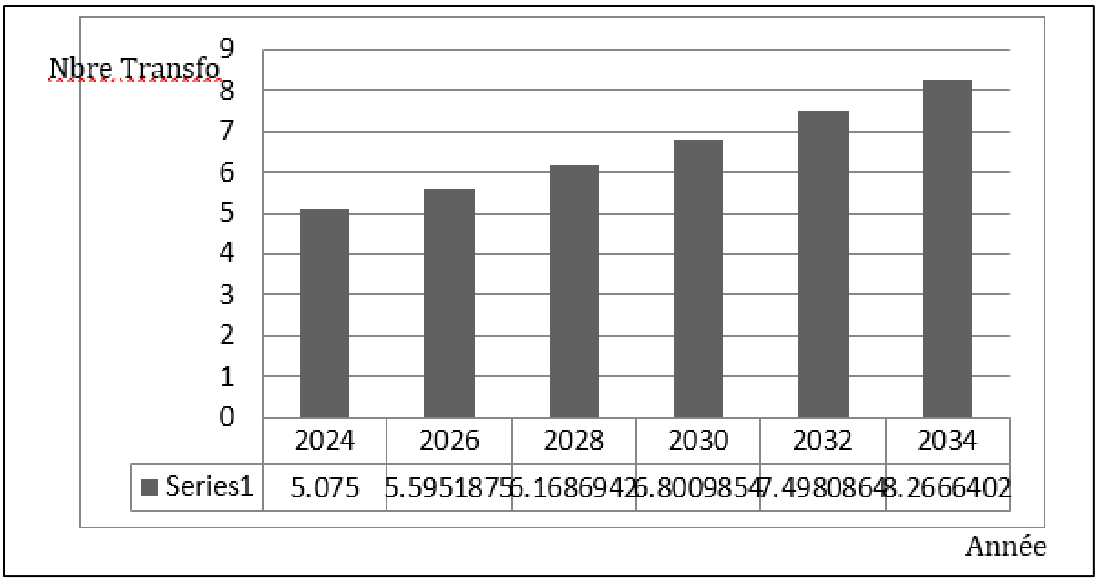

Figure 2 Transformer count evolution projection (2024-2034)

4. Results and discussion

The technical diagnosis of the Liminga substation reveals a critical situation with HV/MV transformers used at their nominal limit and MV substations presenting an average load rate of 101.79% — exceeding the IEC standard (80%) by 21.79 points. The feeders present a structural imbalance: underloaded at 42% at 20 kV but overloaded at 112% at 6.6 kV, with voltage drops reaching 20.9%, well beyond the admissible threshold of 10%.

Strategic planning identifies an immediate reinforcement need of 55.56 MVA, projected to 90.50 MVA over 10 years, requiring the installation of 8 additional 15 MVA transformers. However, analysis shows that conventional reinforcement would reduce the voltage drop to 16.44%, still insufficient to meet standards, revealing structural constraints (excessive feeder length, undersized sections).

The discussion highlights the validity of the multi-level approach to avoid partial solutions and identifies synergies through load transfer toward underutilized 20 kV feeders. Perspectives include the integration of reactive power compensation and the study of local microgrids as complementary solutions for sustainable network optimization.

5. Conclusion

This study demonstrates the urgent need for strategic intervention in the Liminga distribution network, confronted with critical load rates systematically exceeding standards and unacceptable voltage drops. The proposal for reinforcement through the addition of eight 15 MVA transformers, combined with optimized reconfiguration of the 6.6 kV network and exploitation of available margins at 20 kV, constitutes an adapted technical response. However, the extent of structural imbalances requires complementary solutions, such as reactive power compensation and integration of local microgrids, to guarantee long-term stability, reliability, and quality of electricity supply in this priority area of the Congolese network.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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