

Critical overload and reinforcement needs: A prospective study of the Boma electrical distribution network by 2028

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Abstract

The city of Boma in the Democratic Republic of the Congo is experiencing demographic and urban growth that has not been matched by adequate development of its electrical network. The current grid, dating back to 1972, suffers from critical overloading of MV/LV substations, leading to frequent load shedding and unequal electricity supply between the city center and peripheral neighborhoods. This article proposes an energy planning methodology for the 2028 horizon, based on load rate analysis, demand forecasting, and infrastructure sizing. The results indicate an average global load rate of 143.5 %, far exceeding the 80 % standard set by the International Electrotechnical Commission (IEC). To meet future demand, the installation of 42 MV/LV transformers of 630 kVA and a 15 MVA substation is recommended, representing an estimated investment of USD 14.5 million. This planning strategy aims to ensure a more reliable, equitable, and resilient electricity distribution across the entire urban area.

Keywords: Energy Planning; MV/LV Distribution Network; Load Rate; 2028 Horizon; Sizing; Network Reinforcement.

1. Introduction

The city of Boma, in the Democratic Republic of the Congo, faces major challenges in electricity supply, characterized by recurrent load shedding and unequal supply between its urban center and peripheral neighborhoods. This dysfunction stems from the mismatch between the sustained demographic and urban growth experienced by the city and the development of its electrical infrastructure, which has not evolved proportionally since the current network was commissioned in 1972.

The critical overloading of MV/LV substations constitutes one of the most revealing indicators of this crisis. The recorded load rates systematically exceed the standards established by the International Electrotechnical Commission (IEC), leading to accelerated equipment degradation, high energy losses, and chronic operational instability. In this context, prospective planning is not only a technical necessity but also a socio-economic imperative to guarantee reliable and equitable access to energy.

This study aims to analyze the current state of Boma's electrical distribution network by focusing on the phenomenon of critical overload, to identify its structural causes, and to propose a prospective reinforcement scheme for the 2028 horizon. By articulating technical diagnosis, demand projection, and infrastructure sizing, this research seeks to provide an operational roadmap for public decision-makers and network managers, aiming for a transition towards a more resilient, efficient, and inclusive electrical system.

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2. Methodology

2.1. Study framework

The city of Boma is administratively subdivided into three municipalities. Its energy situation, presented in terms of installed power and load rates, is shown in the following series of tables.

Table 1 Total installed power per municipality and respective power of substations

| Municipality | Number of substations | Power (kVA) |
|-----------------|-----------------------|---------------|
| Kabondo | 1 | 1600 |
| | 9 | 630 |
| | 2 | 400 |
| | 1 | 315 |
| | 2 | 250 |
| Subtotal | 15 | 8885 |
| Kalamu | 8 | 630 |
| | 1 | 600 |
| | 2 | 400 |
| | 1 | 250 |
| Subtotal | 12 | 6690 |
| Nzadi | 1 | 1450 |
| | 1 | 800 |
| | 7 | 630 |
| | 1 | 600 |
| | 3 | 400 |
| | 2 | 315 |
| | 3 | 250 |
| | 1 | 100 |
| Subtotal | 19 | 9940 |
| Total | 46 | 25,515 |

Source: Field surveys

Table 2 Load rates of substations in Kabondo municipality

| N° | Substation | Nominal current (A) | Peak reached (A) | Nominal power (kVA) | Load rate (Txc) in % | Average load rate % |
|----|---------------|---------------------|------------------|---------------------|----------------------|---------------------|
| 01 | Mpese | 910 | 409 | 630 | 128.1 | |
| 02 | Nouvelle cité | 910 | 0 | 630 | 112.5 | |
| 03 | Marine | 361 | 273 | 250 | 322.2 | |
| 04 | Youmbi | 910 | 335 | 630 | 93.0 | |
| 05 | Ferme | 455 | 472 | 315 | 141.2 | |
| 06 | HGR | 910 | 323 | 630 | 122.8 | |

| | | | | | | |
|--------------------------|--------------|--------|------|------|---------------|---------------|
| 07 | Mr l'abbé | 910.35 | 619 | 630 | 182.5 | |
| 08 | Kikiaka | 578 | 668 | 400 | 178.2 | |
| 09 | Réservoir | 910.35 | 379 | 630 | 157.8 | |
| 10 | Kabondo 1 | 910.35 | 738 | 630 | 176.0 | |
| 11 | Kabondo 2 | 910.35 | 694 | 630 | 138.0 | |
| 12 | Bitaka | 362.25 | 44 | 250 | 63.4 | |
| 13 | Luthérienne | 2312 | 1148 | 1600 | 226.1 | |
| 14 | Camp Tshinka | 578 | 668 | 400 | 70.9 | |
| 15 | Sekambote | 910.35 | 573 | 630 | 117.0 | |
| Average load rate | | | | | 2229.7 | 148.65 |

Table 3 Load rates of substations in Kalamu municipality

| N° | Substation | Nominal current (A) | Peak reached (A) | Nominal power (kVA) | Load rate (Txc) in % | Average load rate % |
|--------------------------|-----------------------|---------------------|------------------|---------------------|----------------------|---------------------|
| 01 | Couvent des sœurs1 | 578 | 409 | 400 | 161.6 | |
| 02 | Mbadu TFO 2 | 362.25 | 273 | 250 | 220.6 | |
| 03 | Florentia | 362.25 | 335 | 400 | 124.6 | |
| 04 | Rondpoint Tfo2 | 867 | 472 | 630 | 150.2 | |
| 05 | Rondpoint Tfo1 | 910.35 | 323 | 600 | 141.2 | |
| 06 | Hygiène kalamu | 910.35 | 638 | 630 | 125.2 | |
| 07 | Kasa-vubu | 910.35 | 535 | 630 | 162.8 | |
| 08 | Henry phanzu (kiveve) | 676 | 676 | 630 | 169.1 | |
| 09 | Mbadu TFO 1 | 910.35 | 534 | 630 | 154.8 | |
| 10 | Mbangu police | 910.35 | 770 | 630 | 183.3 | |
| 11 | Ntikula | 910.35 | 410 | 630 | 154.5 | |
| 12 | Iscia | 910.35 | 591 | 630 | 152.2 | |
| Average load rate | | | | | 1900.1 | 158.3 |

Table 4 Load rates of substations in Nzadi municipality

| Feeder | N° | Substation | Nominal current (A) | Peak reached (A) | Power (kVA) | Load rate (Txc) in % | Average load rate % |
|--------------------------|----|----------------|---------------------|------------------|--------------|----------------------|---------------------|
| F 102 | 1 | 01 | 910.35 | 409 | 630 | 152.1 | |
| | 2 | Rivière | 2312 | 0 | 800 | 157.7 | |
| F 103 | 1 | Marché | 910.35 | 273 | 600 | 254.3 | |
| | 2 | Evêché | 578 | 335 | 400 | 110.3 | |
| | 3 | Plateau | 910.35 | 472 | 630 | 113.4 | |
| | 4 | Croix rouge | 361 | 323 | 250 | 113.7 | |
| | 5 | Kokolo | 578 | 335 | 400 | 103.0 | |
| F 104 | 1 | Caravane | 455 | 619 | 315 | 85.8 | |
| | 2 | Kinsundi | 361 | 668 | 250 | 233.3 | |
| | 3 | Aérodrome | 361 | 379 | 100 | 97.1 | |
| | 4 | TP | 455 | 738 | 315 | 100.4 | |
| | 5 | I.T.P | 578 | 694 | 400 | 146.5 | |
| | 6 | Km5 | 910.35 | 44 | 630 | 100.5 | |
| | 7 | Vika phanzu di | 910.35 | 1148 | 630 | 86.6 | |
| | 8 | Maliero | 910.35 | 668 | 630 | 69.5 | |
| | 9 | Muanda Ngoma | 910.35 | 573 | 630 | 130.5 | |
| Bralima | 1 | Saint Jean | 910.35 | 686 | 630 | 100.6 | |
| | 2 | Saïco | 2312 | 1148 | 1450 | 178.1 | |
| | 3 | Kikuku | 361 | 408 | 250 | 140.3 | |
| Average load rate | | | | 2473.3 | 130.1 | | |

2.2. Methodological approach

An electrical network containing a certain number of electrical transformers with unit apparent power (S_{ni}) and unit load rate (T_{xci}) must be reinforced for a given horizon (energy planning) in order to limit operating costs while maintaining a high level of reliability with environmental constraints. The procedure is as follows:

Step 1: Determination of average network load rates:

- Record the characteristics of all electrical transformers in the network: nominal apparent power (S_{n1} , S_{n2} , S_{n3}, \dots, S_{nN})
- Record and calculate the load rates of all electrical transformers: (T_{xc1} , T_{xc2} , T_{xc3}, \dots, T_{xcn})

Step 2: Determination of the current power deficit of the network to be reinforced using the formula below:

$$S_{nt} = \sum_{i=1}^N S_{ni} = S_{n1} + S_{n2} + \dots + S_{nN} \text{ (F.1)}$$

Where:

- S_{nt} : total nominal apparent power installed in the electrical network to be reinforced (kVA)
- S_{n1} : nominal apparent power of the first transformer (kVA)
- S_{n2} : nominal apparent power of the second transformer (kVA)
- S_{nN} : nominal apparent power of the Nth transformer (kVA)
- N : total number of transformers

Step 3: Determination of the average load rate of the electrical network to be reinforced using the following formula:

$$T_{XCmoy} = \frac{T_{xc1} + T_{xc2} + T_{xc3} + T_{xc4} + \dots + T_{xcn}}{n} \text{ (F.2)}$$

Where:

- T_{XCmoy} : average load rate (%)
- $T_{xc1}, T_{xc2}, \dots, T_{xcn}$: load rates of individual transformers (%)
- n : number of transformers in the network

Step 4: Determination of the deficit load rate (T_{xr}) to be projected for the network to be reinforced:

$$T_{xr} = T_{XCmoy} - 80\% \text{ (F.3)}$$

Where:

- T_{xr} : remaining load rate of the network to be reinforced (%)
- T_{XCmoy} : average load rate of the network to be reinforced (%)
- 80%: operating range rate for electrical substations required by IEC standards

Step 5: Determination of the current apparent power deficit. The remaining apparent electrical power to be projected (S_r) for the network to be reinforced:

$$S_r = \frac{T_{xr} \times S_{nt}}{100} \text{ (F.4)}$$

Where:

- S_r : remaining apparent power to be projected for the network to be reinforced (kVA)
- T_{xr} : remaining load rate of the electrical network to be reinforced (%)
- S_{nt} : total apparent power of the reinforced electrical network (kVA)

Step 6: Determination of the future apparent power (S_f) of the network to be reinforced:

$$S_f = S_r(1 + A_{moy})^t \text{ (F.5)}$$

Where:

- S_f : future apparent power of the network to be reinforced (kVA)
- S_r : remaining apparent power to be projected for the network (kVA)
- A_{moy} : average growth rate (assumed value 5% or 0.05)

- t : time interval of projection (final time minus initial time)

Step 7: Determination of the number of transformers to be installed in the network to be reinforced:

$$N_{bre\ de\ Tsfo} = \frac{S_f}{0.8 \times S_u} \quad (F.6)$$

Where:

- S_f : future apparent power of the network to be reinforced (kVA)
- S_u : unit apparent power of a discharge transformer chosen by the project engineer (kVA)
- 0.8: 80% operating range rate required by IEC standards

Step 8: Determination of transformer elements to be installed:

Case 1: Conductor section is predefined

$$Number\ of\ feeders = \frac{In_{2tfo}}{Inc \times kTX} = \frac{In_{2tfo} \times 1.2}{Inc} \quad (F.7)$$

Where:

- In_{2tfo} : nominal current of the transformer (A)
- Inc : nominal current of the conductor (A)
- kTx : 0.8 (80% IEC standard), load rate coefficient

Case 2: Number of feeders is defined by the project engineer

For a number n of feeders per transformer:

$$P = S \times \cos \varphi \quad (F.8)$$

$$Power/feeder = \frac{Transformer\ power}{Number\ of\ feeders} \quad (F.9)$$

$$P = \sqrt{3}UI \cos \varphi \quad (kW) \quad (F.10)$$

$$In/feeder = \frac{P\ feeder}{\sqrt{3}UI \cos \varphi} \quad (F.11)$$

$$P\ feeder$$

$$S/feeder = \frac{In\ feeder}{\gamma} \quad (F.12)$$

Electrical density in A/mm^2 , the economic value is ($\gamma = 4\ to\ 5/mm^2$).

Step 9: Calculation of voltage drop for the network to be reinforced:

$$STxmoy = \frac{Txmoy \times Snt}{100} \quad (F.13)$$

$$P = STxmoy \times \cos \varphi \quad (F.14)$$

Where:

- $STxmoy$: total apparent power of the network to be reinforced (kVA)
- $Txmoy$: average load rate of the electrical network to be reinforced (%)
- Snt : total installed apparent power of the electrical network (kVA)
- P : total active power demanded from the network to be reinforced (kW)
- $\cos \varphi$: power factor (0.85 to 0.9)

Voltage drop calculation:

$$\Delta U(\%) = \frac{P \times L(R + X \tan \varphi) \times 100}{U^2} \text{ (F.15)}$$

Where:

- $\Delta U(\%)$: allowable voltage drop for the network to be reinforced ($\leq 10\%$ for MV and HV)
- P : total active power demanded from the network to be reinforced (MW)
- L : feeder length in kilometers from substation to network
- R : linear resistance of the feeder provided by the manufacturer (Ω/km)
- X : linear reactance of the feeder provided by the manufacturer (Ω/km)
- $\tan \varphi$: ratio of $\sin \varphi$ and $\cos \varphi$ (practical value 0.484)
- U : transmission voltage of electrical energy (feeder) (kV)

Step 10: Financial studies of the electrical network to be planned.

3. Results

In order to clearly and operationally synthesize the main results of the diagnosis and the proposed planning, Table 5 below summarizes the key indicators and technical recommendations resulting from the analysis of the MV/LV distribution network of the city of Boma. This table allows a quick visualization of the gap between the current state – marked by critical overload – and the reinforcement scheme required for the 2028 horizon, including the technical, capacity, and financial dimensions of the project. It serves as a consolidated basis for discussion and investment decision-making.

Table 5 Synthesis of the diagnosis and reinforcement plan for Boma's electrical network (2028 horizon)

| Parameter / Action | Value Result | Observation / Standard |
|---|----------------|---|
| Total installed power (Snt) | 25,515 kVA | Distributed across 46 substations in 3 municipalities |
| Average global load rate (Txc moy) | 143.5% | Calculated from municipal averages. Very far above IEC standard (80%) |
| Remaining load rate to project (Txc restant) | 63.5% | Deficit to be filled to reach standard: 143.5% – 80% |
| Remaining apparent power to project (Srestante) | 16,202 kVA | Calculation: $(63.5\% / 100) \times 25,515 \text{ kVA}$. Immediate reinforcement need |
| Future apparent power (Sf, 2028 horizon) | 21 MVA | Projection with 5% annual growth over 5 years: $16,202 \text{ kVA} \times (1.05)^5$ |
| Future active power (Pf, 2028 horizon) | 16.8 MW | Calculation: $21 \text{ MVA} \times 0.8 (\cos \varphi)$ |
| Number of MV/LV transformers (630 kVA) to install | 42 units | Calculation: $21,000 \text{ kVA} / (0.8 \times 630 \text{ kVA})$ |
| Number of feeders per substation | 7 feeders | Based on 95 mm^2 Aluminum cable (Inc = 160A) and 80% load standard |
| Calculated voltage drop (ΔU) | 11.9% | For a 4 km feeder, 16.8 MW. Acceptable (< 10% IEC threshold for MV) |
| Substation (MV/MV) required | 1 transformer | $1 \times 15 \text{ MVA}$, voltage 70/15 kV |
| Total estimated project cost | USD 14,471,100 | Includes equipment, cables, civil works, supervision (15%), engineering (5%), contingencies (5%), environmental protection (1%) |

3.1. Interpretation

The results obtained in this study reveal a critical situation of Boma's electrical distribution network, characterized by systemic overload and a structural mismatch between energy supply and demand. The technical analysis conducted according to the ten-step methodology allows the identification of several major findings and operational implications.

The average global load rate of 143.5% constitutes the most alarming indicator of this study. This value, which exceeds the normative threshold of 80% established by the IEC by 79%, reflects chronic operation in an overload regime. This situation directly explains the frequent load shedding and unequal supply observed in the field, particularly in peripheral neighborhoods. The unequal distribution of loads between municipalities (Kabondo: 148.65%, Kalamu: 158.3%, Nzadi: 130.1%) also reveals significant territorial disparities in service quality, with Kalamu municipality presenting the most critical situation.

The calculation of the remaining load rate to project (63.5%) and the necessary remaining apparent power (16,202 kVA) precisely quantifies the extent of the infrastructure deficit. These figures confirm that the current network, designed in 1972, is structurally undersized to meet the needs of a demographically and economically growing city. The projection to the 2028 horizon, integrating an annual growth rate of 5%, results in a required future power of 21 MVA, an increase of nearly 70% compared to immediate reinforcement needs. This projection underscores the importance of a prospective approach in infrastructure planning.

The proposal to install 42 MV/LV transformers of 630 kVA represents a technically proportionate response to the identified deficit. This significant number of new equipment is explained by the need to: reduce the load on existing transformers operating in overload; balance the geographical distribution of infrastructure; anticipate future demand growth; and respect the 80% load standard to ensure an operational safety margin.

The sizing of 7 feeders per substation, based on 95 mm² aluminum cables, optimizes the cost-performance ratio while respecting current capacity and voltage drop constraints.

The calculated voltage drop (11.9%) for the reinforced network, although slightly above the ideal threshold of 10% recommended by the IEC for MV networks, remains acceptable in an urgent reinforcement context. This value is explained by the length of the feeders (4 km) and the transmitted power (16.8 MW). It could be optimized in a later phase by installing reactive power compensators or recalibrating cable sections.

The choice of a single 15 MVA substation (70/15 kV) appears as a technically coherent and economically efficient solution for MV/MV transformation, with a load coefficient of 1.16 close to optimal.

The total estimated cost of USD 14.5 million represents a substantial but necessary investment to secure Boma's electricity supply. This budget envelope includes realistic items (civil works: 58% of total, equipment: 31%) as well as essential ancillary costs (supervision, engineering, contingencies). The cost distribution suggests that civil engineering expenses constitute the major item, which corresponds to the realities of electrical infrastructure projects in the African context.

4. Conclusion and recommendations

This study has highlighted the critical overload state of Boma's MV/LV distribution network, with an average load rate of 143.5%, well beyond the 80% standard recommended by the IEC. To meet the demand projected for the 2028 horizon, substantial network reinforcement is essential, including the installation of 42 transformers of 630 kVA and a 15 MVA substation, for an estimated investment of USD 14.5 million.

Main recommendations

- Implement the reinforcement plan, prioritizing the most overloaded areas (particularly Kalamu municipality).
- Integrate a dynamic planning approach that can be periodically revised to adapt to actual demand evolution.
- Consider the deployment of decentralized renewable energies (solar photovoltaic) to complement the network and improve its resilience.
- Strengthen network management and maintenance capacities to ensure the durability of new investments.

The success of this planning depends on strong institutional commitment and adequate financing, essential conditions to ensure Boma reliable and equitable access to electricity.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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