Design and implementation of a microgrid for the transmission and distribution of electrical energy for practical training at the Higher Institute of Technology of Mamou, Republic of Guinea

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Abstract - The modernization of electrical systems and the development of microgrids are major challenges for developing countries, particularly in the context of energy transition and the decentralization of electricity production. In Guinea, the training of engineers and technicians in energy sciences continues to face a lack of experimental infrastructure adapted to the realities of electricity transmission and distribution. This study proposes the design and implementation of a microgrid for educational purposes at the Higher Institute of Technology (IST) in Mamou. The main objective is to develop an experimental platform to simulate the real-world operation of an electrical network integrating a power generation source, a substation, medium and low-voltage lines, protection and measurement devices, and renewable energy sources. The methodology adopted is based on an analysis of educational needs, the technical sizing of equipment, the modeling of the microgrid architecture, and the evaluation of its techno-economic feasibility. The main results obtained include: a 100kVA 50Hz transformer, four (4) 12m concrete poles for the medium voltage, twelve (12) 9m concrete poles for the low voltage, and 66m of trench length for the underground low voltage. The technical cross-section of the selected cables is 54.6mm² for the medium voltage, (4x70mm², 4x35mm² and 4x16mm²) for the overhead low voltage line, and 4x25mm² for the underground low voltage cable. For lighting, twelve 250W lamps are planned for the overhead low voltage. The project cost is six hundred forty-four million eight hundred nine thousand five hundred twelve Guinean francs (644809512 FG). These results demonstrate that a microgrid designed for educational purposes significantly improves the acquisition of practical skills in the design, operation, and maintenance of electrical networks, while also fostering applied research and technological innovation. This initiative serves as a replicable model for other technical institutions in Guinea and sub-Saharan Africa, thereby contributing to the strengthening of local capacities in the field of decentralized electrical systems.

Keywords - Electrical microgrids, energy transmission and distribution, practical training

I. INTRODUCTION

Access to reliable, sustainable and high-quality electricity is a key driver of socio-economic and industrial development [1]. In a global context marked by the energy transition, the decentralization of electrical systems and the increasing integration of renewable energies, microgrids appear as an innovative technological solution enabling the improvement of the resilience, flexibility and performance of distribution networks [2]. These systems, capable of operating in connected or isolated mode, offer significant potential for both the electrification of areas with poor coverage and for experimental and educational applications [3].

In Guinea, despite considerable energy potential, particularly hydroelectric and solar power, the national electricity system continues to face challenges related to grid stability, technical losses, service interruptions, and insufficient modern training infrastructure. Furthermore, the increasing adoption of decentralized generation technologies and smart grids necessitates an adaptation of curricula in technical higher education institutions to better prepare future engineers and technicians for real-world applications [4].

The Higher Institute of Technology (IST) of Mamou, through its Department of Energy Sciences, provides training for students in the transmission and distribution of electrical power. However, the training remains largely theoretical due to a lack of experimental infrastructure to replicate the real-world operating conditions of a medium- and low-voltage electrical network. This situation limits the acquisition of essential practical skills such as network design, equipment sizing, protection coordination, power flow analysis, load management, and the integration of renewable energy sources.

In this context, the establishment of a micro-grid for educational purposes at the Mamou Institute of Technology (IST) represents a strategic initiative aimed at addressing this structural gap. Such a system would allow for the simulation of a real-world network on a reduced scale, integrating a power source (conventional and/or renewable), a substation, medium and low-voltage distribution lines, and protection, measurement, and monitoring systems. It would thus provide an experimental framework suitable for practical work, final-year projects, and applied research activities.

The scientific value of this study lies in adapting the micronetwork concept to a specific educational environment, taking into account the technical, economic, and institutional constraints inherent to the Guinean context. The aim is not only to propose an optimized micronetwork architecture but also to assess its potential impact on the quality of practical training and the development of students' professional skills.

Thus, the present study aims to design and propose a microgrid model for educational electricity distribution adapted to the IST of Mamou. It seeks to answer the following central question: how to design and implement a high-performing, secure and economically viable educational microgrid capable of significantly improving practical learning in the transmission and distribution of electrical energy?

II. MATERIALS AND METHODS

2.1. Study framework

This work was carried out by research professors, students in their final year of professional bachelor's degrees, alumni of the Energy Department, and in collaboration with partners (Électricité de Guinée, Marie Madeleine Koundouno - Guinea; Flipo-Richir - France; and FormaEltech - France). The Energy Department is one of the six departments of the Higher Institute of Technology of Mamou, established by Ministerial Decree No. 2004/9245/MESRS/CAB of August 25, 2004. It is a public institution of a professional, scientific, technical, and technological nature, under the authority of the Ministry of Higher Education, Scientific Research, and Innovation. Spanning 6 hectares, it is located in the Télico district, 4 km from downtown Mamou and 270 km from Conakry [5, 6]. It is bordered to the east by the Thiewgol district and to the west by ENATEF (the National School for Water and Forestry Technicians), to the north by the Abattoir district, and to the south by the Téliko primary school [7].

2.2. Tools and Equipment

The main tools used for installing a micro-electrical network (low or medium voltage) are: insulated screwdrivers, pliers (cutting, multi-grip, wire stripping), wrenches (open-end, socket, torque), multimeter or voltage tester, spirit level, tape measure, laser level, cable reel, markers (reference stakes), chalk line, plumb line, theodolite or optical level, crimping tool (for ferrules or lugs), wire puller or cable puller, clamp meter, drill, cutter block. Earthmoving tools (shovels, picks, crowbars, manual or mechanical auger, trenchers, and wheelbarrow).

The safety equipment used includes: insulating gloves, a protective helmet, safety shoes, insulating mats, and work area signage.

The network implementation materials include: cable trays, conduits, ICTA tubes, electrical cables and wires, distribution boxes, circuit breakers, switches, sockets, terminals, connectors, terminal blocks, junction boxes

2.3. Methodology

The methodology used focuses on sizing:

- From the medium voltage overhead line which starts from the 30kV medium voltage line of Electricité De Guinée;
- Low voltage overhead lines from the substation output;
- Low-voltage underground cables from the substation output.

2.4. Sizing of the medium-voltage overhead line

The sizing of the medium-voltage overhead line involves the following elements: supports, hardware, conductors, and insulators. The number of poles depends on the total length of the medium-voltage line and the span between two poles. The total length is 201.6 m for the medium-voltage microgrid of IST-Mamou. The chosen span is 70 m (value recommended by Electricité de Guinée). The number of polesfor the medium voltage lineis determined by expression 1 [8].

$$N_p = \frac{L_t}{a_{mt}} + 1 = \frac{201,6}{70} + 1 = 3,88 \approx 4 \qquad (1)$$

With : N_p: number of poles; : span (m); : total line length (m)$a_{mt}L_t$

Four 12-meter prestressed concrete poles were selected: two 320 daN class poles, used in a flag configuration to support the medium-voltage line conductors; one 400 daN class pole, designed to support an IACM (Manually Operated Overhead Switch); and one pole of a suitable class, designed to support a pole-mounted distribution transformer. The pole class was chosen based on the transformer's weight and the resulting mechanical stresses, thus ensuring the safety and durability of the installation. This sizing ensures compliance with current standards and guarantees the long-term reliability of the electrical network.

The placement of the supports (location and depth of excavation) depends on the nature of the soil, the presence of obstacles and climatic conditions in order to ensure the stability and safety of the network.

The depth of the excavations (Pf) is determined as a function of the post height (H) by relation 2 [9].

$$P_f = \frac{H}{10} + 0{,}5 = = \frac{12}{10} + 0{,}5 = 1{,}7\ \text{m} \qquad (2)$$

The excavation depth is 1.7m; the class or force (400 daN), the height (12m); the length of the excavations (a = 120 cm) and the width of the excavations (b = 110 cm).

The supports are installed to carry and organize the electrical conductors on the poles while ensuring their mechanical and electrical stability throughout the electrical network. These supports are of two types, grouped according to the site's obstacles: a) two (02) flag supports, which are chosen according to the site's obstacles; b) two (02) cable tray supports.

Insulators are essential to prevent short circuits and maintain network safety. In Guinea, insulators used in medium-voltage lines are generally made of glass or ceramic. The ceramic type was used in this study.

The conductors ensure the safe and reliable transport of electrical energy between substations and areas of use. They must withstand mechanical and electrical stresses while guaranteeing the performance of the network.

The length of the medium-voltage line cables (Lc) depends on the length of the overhead line (Ll), with a 5% increase to compensate for various losses (reserves, detours, and accessories). It is determined by equation 3 [10].

$$L_C = 3 \times (L_l + 5\%L_l) = 3 \times (201{,}6 + 30{,}24) = 635m \quad (3)$$

The cross-sectional area (Sc) of medium-voltage cables depends on the sizing standards and the requirements of the electrical network. It is determined by relation (4) [11]. The medium-voltage overhead lines are made of aluminum alloy with a cross-section of 70mm² or 150mm². Based on studies, we chose a 70mm² cross-section, which is suitable for the Guinean electricity distribution network.

$$Sc = \frac{\rho \times L \times I_b \times \sqrt{3}}{\Delta U} \qquad (4)$$

With: ρ [Ω.mm2 /m]: Resistivity; L [m]: Cable length; P[W]: Maximum power; ΔU[V]: Maximum permissible voltage loss.

Medium/Low Voltage Substation: Sizing a medium/low voltage substation involves determining the capacity required to transform medium voltage energy into low voltage, based on energy needs and network constraints. This ensures a stable power supply and minimizes losses to guarantee system safety and reliability. The transformer is the most important component of substations, and its selection depends on its apparent power. For this study, a step-down medium/low voltage transformer is required.

The apparent power (S[kVA]) of the transformer is a function of the active power (P[W]) and the power factor (cos θ).φ), it is calculated by relation (5) [12].

$$S = \frac{P}{\text{Cos}\varphi} \qquad (5)$$

The transformer substation is supplied with a standardized voltage of 30 kV. This supply is overhead and is provided by a single, double, or loop connection. For the micro-distribution network designed for educational purposes, we opted for a pole-mounted 100 kVA transformer. Knowing the transformer's power rating, formula (6) allows us to calculate the corresponding current [13]. Or I_b: Ib[A] Current; Un[V]: Nominal voltage.

$$S \text{ with } (6) = U_n \times I_b \times \sqrt{3} I_b = \frac{S}{Un \times \sqrt{3}} = \frac{100000}{400 \times \sqrt{3}} = 144.3\ A$$

A mechanically broken IACM-type disconnect switch to protect the installationDuring the practical exercises, the following equipment was used: test circuit breakers to evaluate the performance, capacity, and safety of the transformer; surge protectors to protect the transformer in case of lightning; a Type 6 distribution board with a current rating of 165A and two feeders (overhead and underground); and a 165A circuit breaker to protect the lamps.

2.5. Sizing of the low-voltage overhead line

Low-voltage distribution lines are installed on concrete poles. The main components are: supports, conductors, suspended alignment assemblies, anchoring stop assemblies, indicator lights, and grounding.

a) Supports

For low-voltage lines, the average span between two poles is usually 30 m. However, due to site constraints, a length of 74 m was chosen for this practical project, with a reduced span of 13 m for better adaptation to the terrain. Using formula (1), we found six (6) poles per line, of whichThe total length of the low-voltage line is 65m, and there is one gate (amt = 13m). Given the size of the site, the total number of poles is twelve (12) of 9m in height, distributed over two lines, with six (06) per line.

b) Drivers

In low-voltage overhead networks, aluminum cables with cross-sections of 70 mm², 35 mm², and 16 mm² are often used and assembled into twisted-pair cables (ABC) consisting of several insulated conductors carried by a neutral conductor. Aluminum, as a conductive material, offers many advantages: it is lightweight, corrosion-resistant, less expensive than copper, and suitable for long line lengths. To minimize the risk of accidents, these conductors are generally insulated with polyethylene.

Table 1 : Low voltage overhead line section

Single-phase cross-section	Three-phase section	Three-phase with earth
1 x 16 + 54.6 mm²	3 x 16 + 54.6 mm²	5 x 16 mm²
1 x 25 + 54.6 mm²	3 x 25 + 54.6 mm²	5 x 25 mm²
1 x 35 + 54.6 mm²	3 x 35 + 54.6 mm²	5 x 35 mm²
1 x 50 + 54.6 mm²	3 x 50 + 54.6 mm²	5 x 50 mm²
1 x 70 + 54.6 mm²	3 x 70 + 54.6 mm²	5 x 70 mm²

c) Low voltage overhead cable cross-section

Formula 4 is used to determine the cross-section of cables for low-voltage overhead lines. Rigid cables with a cross-section of 2x16mm² were used to supply the lamps; those with cross-sections of 4x35 and 4x70mm² were used for the general power supply.

d) Length of low voltage cables

Formula (3) was used to determine the length of the low voltage cables; with a site length of 130m, we found 137m of low voltage cables.

e) Alignment assembly (suspended) and stop assemblies (anchored)

In the electrical power distribution and transmission network, alignment refers to the general arrangement of poles that support overhead conductors. Alignment typically follows a direct path or one adapted to the terrain to ensure the mechanical and electrical continuity of the line. For this study, we selected eight (8) suspended assemblies on the eight middle poles and two (4) stop assemblies on the first two and last poles of the two lines.

f) Lamps

Lamps in the overhead low-voltage network are not limited to lighting or signaling functions; they serve as indicators of performance, safety, and network operation, contributing to safer, faster, and more controlled operation. We used twelve (12) lamps, one per pole.

g) Grounding

Grounding involves connecting a part of an electrical circuit (usually metal parts or neutral conductors) to earth. It protects people and equipment from hazards related to insulation faults and overvoltages.

2.3.3 Low voltage underground sizing

The underground low-voltage network refers to all electrical installations that distribute electricity at a voltage of 1000V or less using cables buried in the ground instead of overhead conductors. This type of network is increasingly used in urban and residential areas for reasons of aesthetics, reliability, and safety. The technical characteristics of this type of network include: the cable trench (duct), the underground cables, and the junction and branch fittings.

a) Cable trench (gutter)

The trench allows for the neat and protected laying of cables, shielding them from the elements and mechanical impacts. The chosen dimensions take into account current standards, soil type, cable volume, and accessibility requirements for future maintenance. The dimensions are: length 63m, width 55cm, and depth 65cm.

b) Total cable length

The total length of the cables, according to the formula (3) is 66m, with aTotal line length 63m.

c) Underground cable section

By applying the formula (4), we findcables with a cross-section of 25mm2, with a resistivity of 0.0282 Ω.mm2/m, a length of 63m, a current of 144.3A and a maximum permissible voltage loss of 20V.

d) Junction and branch accessories

In the installation of an underground distribution network, cable connections and junctions play a crucial role in the system's reliability and efficiency. Each installation requires specific accessories to ensure electrical continuity and connection protection.

e) Types of boxes essential for this configuration

The types of boxes essential for this configuration are of two kinds: junction boxes and termination boxes. Junction boxes ensure the connection between the different sections of underground cables, allowing optimal energy transfer and minimizing electrical losses, while termination boxes are designed to connect the cables to other network equipment; they facilitate the integration of underground connections with surface devices.

Images of equipment reception and fixing are shown in Figures 1 and 2. Images in Figures 3 and 4 show the completed micronetwork.

Figure 1: Equipment reception

Figure 2: Post fixing

Figure 3: Medium Voltage Microgrid

Figure 4: Low Voltage Microgrid

III. RESULTS AND DISCUSSION

The main results of this study relate to: the sizing of the different parts of the educational micronetwork, the choice and certification of equipment, the implementation of the network, the techno-economic analysis of the system and the architectural and single-line diagrams of the network.

3.1. Sizing of the different parts of the microgrid

The sizing results for the different parts of the micronetwork relate to: the medium voltage network, the overhead and underground low voltage networks (tables 2 and 3).

Table 2 : Results of the medium voltage network sizing

Designations	Quantities	Features
	Medium voltage overhead power lines (HTA)	
Support	4	2 in high-tensile concrete (400daN-12m) 2 in high-voltage concrete (320daN-12m)
Weapons	10	6 in flags 4 in tablecloths
Insulators	15	Ceramics
Drivers	3	Bare cable (L= 635 m, s=54.6mm2)
Disconnector	1	(IACM) 30 kV complete

High-voltage/low-voltage transformer substation		
Transformer	1	Three-phase, 50Hz, 100 kVA
Disconnector	1	IACM
Surge protectors	3	Air
Electrical cabinet	1	Metallic (L=2m and w=1m)
Circuit breaker	1	I = 160 A

This table lists all the materials required to construct the medium-voltage overhead line and the MV/LV substation. Table 1 shows the quantity of each component, its technical specifications, and its characteristics (type, dimensions, resistance). The selection of these materials was made in compliance with environmental conditions and safety standards.

Table 3 : Results of the low-voltage network sizing (overhead and underground)

Designations	Quantities	Features
Low Voltage overhead		
Supports	12	Concrete (H= 9 m, F=320daN)
Drivers	1	Rigid cable 137m (4 x 70 mm²) (4 x 35 mm²) (4 x 16 mm²)
Alignment sets	8	Suspended
Stop assemblies	4	Inking
Lamps	12	Using sodium vapor (250 W)
Grounding	1	-
Lightning rod	1	-
Underground low voltage		
Cable trench	1	L= 63m, W=55cm, D=65cm
Cables	1	Armed 66m (4x25mm²)
Junction and branching accessories	4	Junction boxes
Cable trench	4	End boxes
	1	L= 63m, W=55cm, D=65cm

Table 3 details all the components of the complete low-voltage power line (overhead and underground), including both the power distribution and lighting components for the center. The technical specifications (dimensions, mechanical strength, trench dimensions, and cross-sections) allow for precise planning of the installation and the necessary supplies. These elements are essential to guarantee a reliable installation and continuity of power. They are sized within a precise framework and comply with safety measures.

3.2. Implementation cost

The economic analysis of the completed network aims to assess the profitability, cost, and financial viability of its implementation, operation, and maintenance. It generally includes: initial investments, the cost of technical studies, the purchase and installation of equipment (substations, lines, transformers), civil engineering and labor, and connection and permitting fees. The main expenses incurred in this study are shown in Table 4.

Table 4 : Cost of implementation

Designation	Price
High-voltage overhead line	295200000
Low voltage (overhead and underground)	227141260
Grid movement and handling	15000000
Total amount	537341260
Workforce	107468252
Total Amount	644809512

Table 4 shows the cost breakdown for the project: 46% allocated to the overhead medium-voltage line, indicating that a significant portion of the budget is dedicated to medium-voltage infrastructure; 35% allocated to low-voltage (overhead and underground), highlighting the importance of electrical distribution facilities; and 17% allocated to labor, reflecting the costs associated with the workers required for implementation. 2% reserved for grid movement and handling, a relatively small proportion, which may suggest that these activities are less expensive or limited.

3.3. Single-line diagrams of the network

A single-line diagram of the educational micronetwork is the simplified representation of the electrical installation. It shows, using standardized lines and symbols, the general organization of the network (production, transport, distribution, use), the connections between equipment, protections (circuit breakers, fuses, etc.) and electrical devices (transformers, panels, loads, etc.).

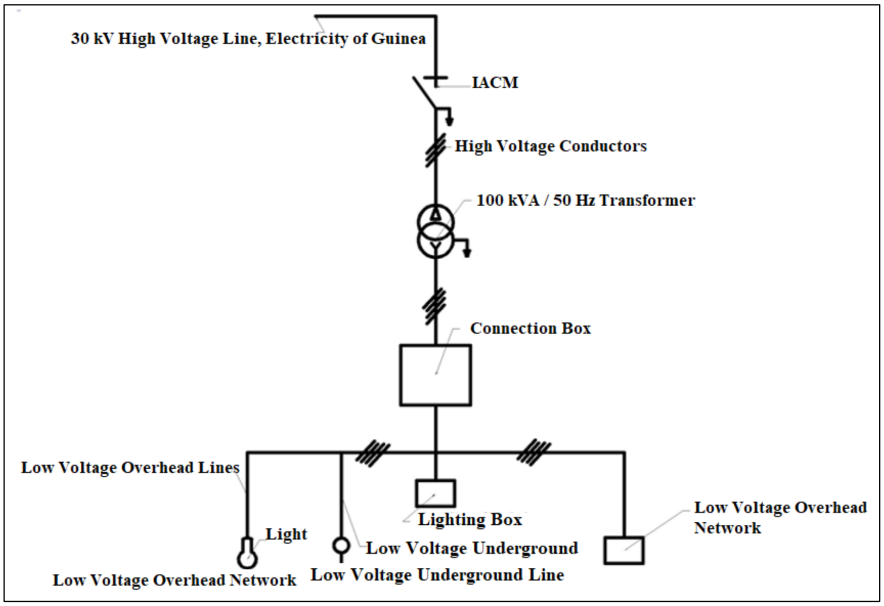

Figure 5 : Single-line diagram of the micronetwork

IV. CONCLUSION

The design and construction of an educational electrical power transmission and distribution network at the Higher Institute of Technology in Mamou aims to address a crucial need for practical training for students in the fields of electrical engineering and energy engineering. This project has enabled the development of a suitable teaching tool, simulating a real network in miniature, to provide learners with a concrete learning environment.

The work carried out covered aspects related to network planning, equipment selection, installation, security, and the implementation of operating and maintenance scenarios. This system thus facilitates the understanding of the phenomena of electrical energy transmission, distribution, protection, transformation, and measurement.

The results obtained are encouraging, both technically and pedagogically. The installed network now provides reliable support for practical work, fostering the acquisition of operational skills and effectively preparing students for real-world situations. To ensure the sustainability of this initiative, it is recommended to strengthen the system by integrating renewable energy sources, automating certain functions, and networking data for intelligent performance monitoring.

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