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Multi-objective topological reconfiguration of a Low Voltage electrical distribution network by optimal repositioning of MV / LV multi-transformers using Elitist Algorithms of the NSGA-II type

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ABSTRACT*: Several transformers in the Low-Voltage (LV) distribution networks of* **Benin Electric Company** *are off-center from the loads's gravity connected to them. This situation is due to the continuous growth of loads on these networks and the extension of LV lines. This paper presents an approach based on the elitist NSGA-II genetic algorithm for optimal relocation of MV/LV multi-transformers in a quasi-sinister distribution network. The results obtained show that the power losses which were 72.6 kW in the basic configuration are reduced for the case of single-transformer positioning by 51.07% and by 91.80% for the multi-transformer positioning of two 400kVA units. The evaluation of the profitability of the two options revealed that the optimal positioning of 400 kVA multi transformers in the Zogbadjè network is economically and technically viable compared to the first option of positioning an 800kVA transformer at node 8.This study also showed that the Return On Investment (ROI) is 5 month 15 days with a Net Present Value (NPV) equal to 315,770,000 CFA . This project of optimal relocation of distribution transformers is highly relevant and effective in reducing losses and operating costs of distribution networks.*

KEYS WORDS : *Position - optimal – distribution transformers - radial network – NPV- NSGA-II*

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I. INTRODUCTION

An electrical power system consists of several segments of differents voltage levels, and essential and capital elements such astransformers.

The 230/400V Low Voltage lines are the result of the transformation of high voltage category A into a voltage level conventionally used to supply lighting, domestic appliances (air conditioning and refrigeration, etc.). These Low Voltage networks are generally the most numerous of the electrical systems and therefore require very rigorous technical and economic planning in order to provide quality service to customers who have become very demanding [1].

Reliability and availability of transformers and power lines are imperative to guarantee a qualitative power energy to adequately supply customers receivers. However they are generally the site of several disturbances such as voltage drops ,untimely tripping of control devices, overloads on certain distribution transformers and on cables in somedevelopping countries. Indeed, in some countries seeking developement, the developement of networks does not follow that of demographic and economic growth [2]. In this context, customers located in peri-urban areas are sometimes forced to resort to makeshift situations to obtain electrical energy. So-called "spider's web" networks develop and are one of the sources of losses and degradation of the voltage delivered to consumers. Better still, the design and construction of some electricity networks do not often comply with the requirements of the relevant standards and norms. Indeed, it has been observed that some LV lines are abnormally long and contribute to moving the centres of gravity of the loads away from the MV/LV transformers supplying customers. The cross-sections of certain cables in these networks are no longer adapted to the active power flows. It has thus been observed that losses are greater in low-voltage networks. Some phases of these low-voltage networks are also overloaded to the detriment of others, thus creating imbalances due to non-uniform connections.

This situation unquestionably leads to critical voltage drops and reactive and active power losses which are below the contractual limits with respect to customers expecting only good power quality and regulators demanding the best performance from power systems.

In the new context of liberalization, those in charge of the electrical industries are more and more interested in the operating competitiveness of their electrical system with the aim of making profits which can enable them not only to make structuring investments but also to satisfy to the dual demands of consumers.

Distribution networks planning consists ofdetermining all of the optimal MV and LV installations that meet the required standard criteria and that best meet operating constraints such as loss, voltage drop and rate limits of voltage distortion [1].

In most cases, the determination of the number of MV/LV distribution transformers, the geographical and spatial position of these transformers and their capacity are based on empirical calculations that often deviate from load predictions and the spectacular growth of Gross Domestic Product (GDP) indices and therefore do not reflect reality. Indeed, the inadequate positioning of a transformer in a distribution network can lead to additional losses, increased operating costs and a deterioration in the quality of service delivered to consumers.

Company Electric of Benin system operators generally do not have any effective tools to optimally position a transformer in a distribution network. In planning electricity distribution networks, its operators often resort to methods based on randomness (availability of receiving space, proximity to an emblematic political figure, etc.) to position distribution transformers. These positions, which are sometimes inadequate, lead to consequences in the operation of the Low-Voltage distributions networks such as voltage drops, early overloads, premature damage which cause very inconvenient interruptions for residential customers and which are at the origin of the counter-performance for energy companies. After a few years of the operation, most of these installed transformers are overloaded before the required terms.In most cases, pole-mounted transformers (H61) are also subject to destructive overloads, the perverse effects of atmospheric discharges, because they are poorly protected from them and their grounding network is generally inefficient (high resistance, discontinuity of the ground circuit), in order to drain surges of atmospheric origin to the ground.

In the LV distribution networks of the Benin Electric Company, it is often observed that the protection of certain transformers (generally compact circuit-breakers both for powers below 160kVA and for H59 type substations) trips in an untimely manner. These interruptions cause undistributed energy , which has economic and social consequences for the managers of electrical systems.Under these conditions, the operators of these networks will find it extremely difficult to maintain the loss, reliability and availability plans of these networks within the limits that match the commitments made contractually to customers by the electricity industries.

Nowadays, and in the perspective of having efficient networks , there are several techniques to improves the reliability of LV distribution networks operation. It is cited for example the optimization of the positioning of the MV/LV distribution transformers, the optimal insertion of the decentralized production in the distribution networks,the compensation of reactive energy at the level of the transformers on pole. Palliatives solutions are explored for positioning that is often in the medium term and imply fianancial implications whose profitability must be reconsidered. These heuristic means of improving the technical performance of low voltage networks are not technically and economically efficient.

Since the liberalization of the energy sector, several scientists have been interested in the development of various methods and means to improve the reliability and availability of low voltage distribution networks.

II. REVUE OF LITERATURE

Sarjiya et al [1] in 2016, studied the optimal positioning and sizing of a distribution transformer in an electrical network. They applied GA (Genetic Algorithm) based algorithms to a real 20kV/0.4kV Indonesia network. They have had to find that their method is effective and efficientin improving the technical performance of the network. However among the constraints used to keep the voltage and losses within the contractual limits; there is no constraint related to the limit distances coveredby a distribution transformer. MostafaEsmaeeli [3] determined the optimal location, size, and cost of installing a transformer in a power grid using the mixed integer non linear programming method. The minimized objective function integrates the costs of installing LV lines, installing transformers and the costs attributed to line losses and losses in transformers. From the application of their method to a test distribution system in a residential area, relevant results emerge which minimize the costs of losses and installation. However, their method does nottake into account the effect of operating constraints such as undistributed energy due to possible unavailability on distribution transformers. In [4], Haghifam et al. used GA to position a HVB/HVA (High Voltage category B/ High Voltage category A) substation in an electrical network. The optimized objective function integrates equipment costs, MV cables and losses well. The results with their application are very convincing. Hana Jannaty [5] proposed a new planning approach for the establishment, optimal sizing of the capacity of distribution transformers to position in a distribution network. The optimized objective function took into account both electrical constraints (voltage drop, charge rate) and physical constraints (radiality, geographic positioning). Aledjandro et al [6] studied the simultaneous optimization of the positioning of transformers and the network by the method of optimizing the division into micro areas of available geographic space. They have found that their method is efficient for positioning a transformer in a distribution network, but their algorithm does not integrate constraints of radiation length limits from MV / LV distribution stations. Vishwanath Hegde et al. [7] have proposed a method to minimize the total active losses and minimize the voltage drop in a radial distribution network by finding an optimal positioning for the distribution transformer. The method used is a systematic search procedure. However, it does not take into account technical constraints for the optimization problem. Jorge E. Mendoza et al. [8], proposed a solution to the problem of size, number and optimal location of distribution transformers in low voltage distribution networks by a genetic algorithm suitable for optimization, minimizing investment costs and operational. The results obtained for the different cases treated are satisfactory but the priority of this proposed method is not to minimize the total power losses in the network. Shyh-Jier Huang et al. [9], proposed an intelligent approach to flower pollination (FPA) to solve the distribution transformer placement problem. A mathematical model taking into account consumer demand, the cost of installing distribution transformers, the cost of losses in the transformer and the lines is therefore formulated for the optimization problem. The proposed algorithm has been tested on a 20-node and 36-node distribution network and the results reveal the network's performance in this method. In [10], Sunil T. et al. , proposed a technique for the optimal positioning and the optimal size of transformers in an existing distribution network, by the genetic algorithm and the simulated annealing algorithm (SA) based on minimization minimizing the investment cost, the cost maintenance, operational cost, insurance cost. It appears that the cost of the network and the transformers are reduced considerably in the case considering the average demand in load. BelginTurkay et al. [11] have developed a genetic algorithm for optimizing a distribution network. The optimized objective function took into account the total cost of installing the low voltage network. This algorithm developed allowed to find the optimal size and position of distribution transformers in the network. However, the active loss minimization function in the network is not taken into account in the optimization. In [12] Amir Navakhah et al. used the NSGA-II genetic algorithm method to optimize the size and positioning of substations (HVB /HVA) in a distribution network based on economic and technical risk management. The problem is formulated as a multi-objective function taking into account the functions: total cost of the installation as well as the technical and economic functions. They found that the solution proposed for this optimization is efficient. Mohamed Yosef et al [13] used a biogeography-based optimization technique (BBO) to solve the problem of the optimal position and the optimal power of distribution transformers in an MV and LV distribution network. Optimization is done by minimizing the total cost of installing HVB / HVA distribution transformers in the MV network and the total cost of installing the MV /LV transformer in the LV network. Haghifam et al (2002) [14] have optimally studied the location, power and service determination of HVB / HVA transformers in a long-term planning period using pseudo dynamic methods.

III. DESCRIPTION OF ELECTRICAL NETWORK OF ZOGBADJE IN BENIN

3.1 Description of existing network

A source substation is made up of several MV outgoing feeders which are in turn made up of clusters of MV/LV transformers that supply the districts or villages. Figure 1 shows the transformer station supplying the Zogbadjé district located on one of the HV departures from the Maria Gléta HV/HV source substation in Benin. It consists of a 15 kV /0.410kV-400 kVA HVA /LV transformer placed on a chassis.

Figure 1: View of the type post on chassis of the Zogbadje district in Benin

This technique of installing transformers on chassis dates back to the 2000s at Benin Electric Company. It was a palliative solution thought by the technicians to meet the growing and immediate need for capacity reinforcement of a transformer of 160 kVA (induced by the growth installed on pole (H61) in the "Aïmévo" district (Godomey) in the Atlantic region (DRA) and whose protective devices were tripping inadvertently. As this state of the network could not ensure a continuous and sustainable supply of energy to the customers connected to the substation, the operators had to resort to this technique of installing 250 kVA transformers on a chassis manufactured for this purpose to overcome the material and financial difficulties associated with the construction of a cab substation, which naturally requires considerable financial resources and is subject to time constraints.

This technique does not comply with the normative prescriptions contained in the NFC 13-100 standard which governs the construction of HV/LV substations.Since then, this technique has been adopted by all Benin Electric Company regions and can be found in most of its networks when it comes to the solution to a need to increase the power of a pole-mounted transformer. This technique, which has become common on Benin Electric Company networks, has many advantages but also consequences such as the dangerous dispersion of the potential in the event of an atmospheric discharge, the infiltration of water into the ends fitted out for their MV connection, the flatness difficulties of the laying platform. In fact, sometimes the technicians are not able to lay the equipment properly and the equipment ends up tilted on the chassis. In this case, the cooling oil will be on one side only and part of the winding may not be cooled. Abnormal overheating of this part could cause the transformer to malfunction.

Diagnostic study of Zogbadje LV network

3.2. Materials and methods

As part of this study, we took load and voltage and harmonic measurements on Zogbadje's post. The material we used illustrated by Figures 2 and 3 is a CA8335 network analyzer by Chauvin Arnould. These measures have been taken at two levels. First, we took load and voltage measurements at the MV/LV distribution transformer at the foot of Station N°8 and then after the measurements are taken at a customer in the end in the peak time zone.

Figure 2: View of analyzer installation for measurements.

Figure 3 shows the tension and harmonic curves at the transformer terminals.

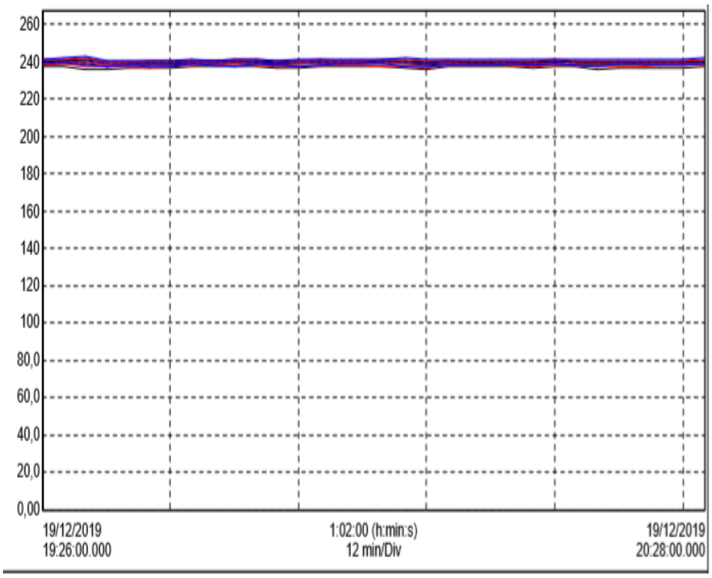

Figure 3: Voltage profiles taken at the terminals of the MV /LV transformer of 630kVA.

It is observed that the lowest voltage is 238V and the highest is 241V. These voltage values are well within the normative ranges. They show that the internal voltage drops of the transformer are normal and no deviation is found in the three-phase voltage system delivered by this transformer.

Figure 4 shows the measurement voltage profiles of a consumer connected to the low voltage network of Station 8. It is observed that the single voltage taken in the peak time slot is in the ranges of 155V to 186V. These values violate the limits of ∓10% Vn provided by NFC 50160 standards for LV distribution networks.

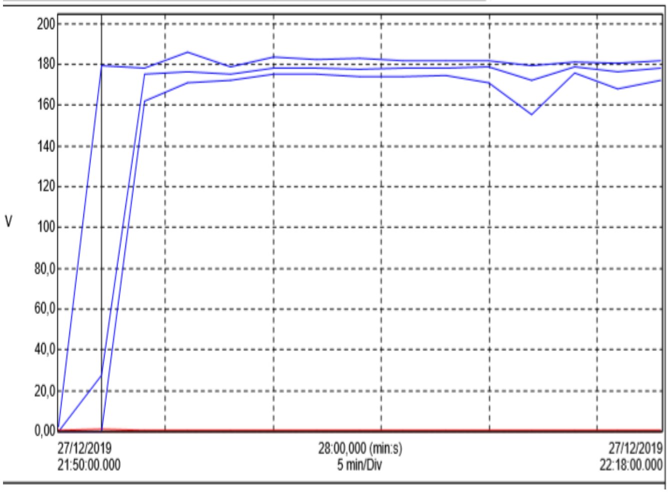

Figure 4: Simple tension profile for a consumer of Zogbadje's post.

Therefore, it is established that in the LV network of the Zogbadje substation, the receivers of several Benin Electric Company customers connected to this substation are not supplied as provided in the terms of the contractual commitments. Indeed, some customers who have electronic meters will not be able to feed properly in the peak time slot. From these measurements it is also noted, the presence of severe harmonics on this LV network. Figure 5 shows the proportions of harmonics recorded by the analyzer we used.

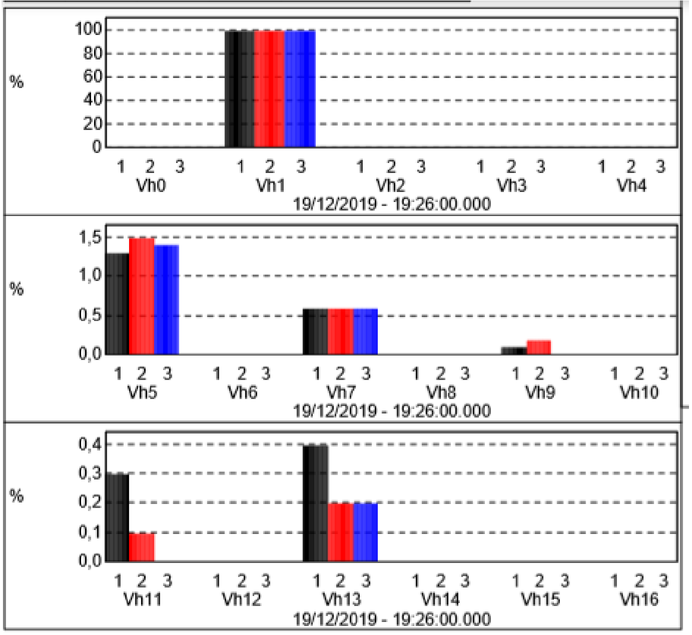

Figure 5: Voltage harmonics recorded at the Zogbadje substation

It is noted that there are rank 1, rank 5, rank 7, rank 11 and rank 13 harmonics on this network which remarkably disturb voltage waves and degrade the quality of service to the consumer. Indeed, the harmonics are created by the introduction of distorting charges whose voltage/current characteristics are not linear in the network. The harmonic currents generated flow through the impedances of the networks, and thus create harmonic voltage which can disturb the operation of devices and equipment connected to the same source. The harmonic components are superimposed on the fundamental voltage wave. They have adverse effects on equipment such as capacitors that are exposed to premature aging, overheating and breakdown by the resonance phenomenon which may result.Harmonical pollution also has effects on engines such as losses, additional heating and abnormally sound vibrations. Breakers and transformers also suffer the effects of harmonics. Transformers, for example, cause abnormal joule and iron losses, followed by harmful mechanical sound vibrations. As for circuit breakers, they can trigger inadvertently for reasons of exceeding peak values.

The harmonics observed on this LV network are due to the proliferation of power electronics devices such as rectifiers used by charger workshops, arc welding stations used by welders and inverters used by administrative services wanting to protect their receivers against micro cuts.

3.3. Calculation of the electrical status of the Zogbadjè network

The power flow of this network is calculed using Matpower modules. Matpower was developed by Ray D. Zimmerman [15]. The power flow calculating process is done in three steps consisting of the input of the loads, branches and generators data, then after the second stage consists in the calculation of the flow by the method of Newton-Raphson or other chosen method depending on the characteristics of the network. The final step in this process is to display the results on the screen.

Figure 6 shows the diagram of the single-wire draw of the LV network of Zogbadje. It consists of a source node which is the 400 kVA transformer and 67 load node representing the consumers connected to this network.

The power flow is calculated taking into account the different load profiles. The simulations are carried out at a load rate of 50%, 57.5%, 75% then at 100%. This method made it possible to determine at which charge rate, the voltages begin to deviate from the admissible limits and the losses begin to become excessive.

Table 1 shows the simulation results of the power flow of the Zogbadje network.

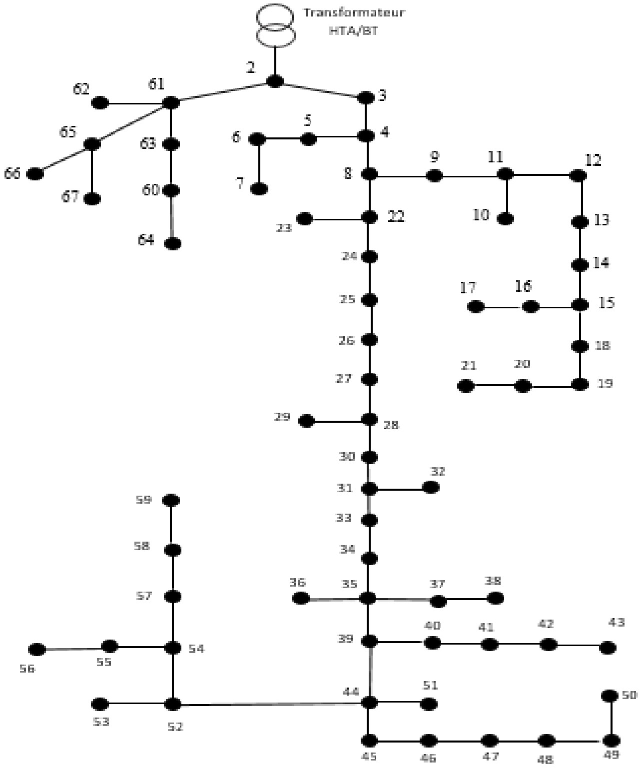

Figure 1 :Sheme of Zogbadje network

Table 1 : Results of simulations power flow of Zogbadje network

Topics	50	57.5	75	100
Active losses(kW)	15	20	36.8	72.6
Reactive losses(kVar)	6	10	14.7	29
Minimum voltage (pu)	0.91/59	0.89/59	0.86/59	0.80/59
Number of unstable nodes	0	2	30	34
Proportion of unsatble nodes(%)	0	2.98	44.78	50.5

It is observed that several nodes violated the voltage limits from a transformer load rate of 57.5%. Indeed from this rate, 2.98% of the nodes become unstable and the losses are evaluated at 10KW. The minimum voltage for this rate is 0.89 p.u at node 59 of the network, or 204.7V in single voltage. This voltage value is already out of the normative range.

Regarding the 100% transformer load, it is found that the power losses become 72.6 kW, an increase of 86.22%. To ameliore the performance of this network, we considered the most unfavorable case which is that of the load rate of 100% which corresponds to the permanent realities on the transformer of this district. Figure 7 shows the voltage profiles at this charge rate.

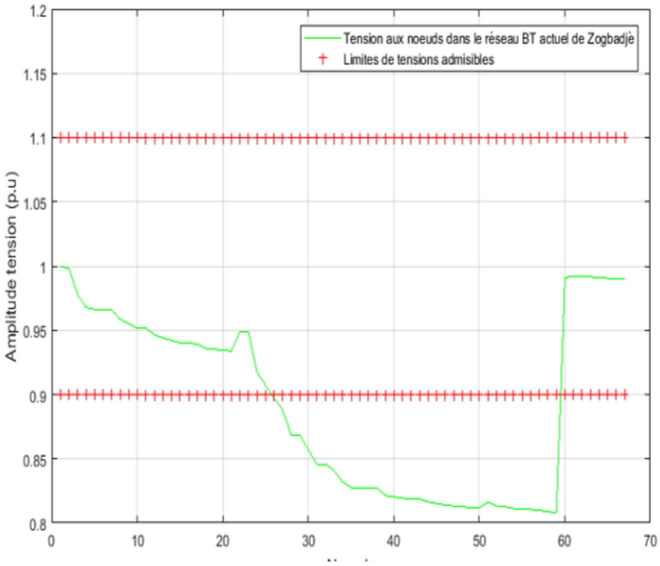

Figure 7: Voltage profiles on the low voltage network busbars

It is observed that the minimum voltage is noted at node 59 and it is 0.808 p.u or a voltage of 185.84 V which corresponds well to the values measured at one of the customers connected to this network.

The lowest voltages are found identically at node 59 of the network. The transformer is installed at node 2 of this network. It can be concluded that the MV/LV distribution transformer in this Zogbadje district is offset from the center of gravity of the loads and generates in its operation excessive losses due to the excessive lengths of the lines and the distances from the injection point compared to other charges.

IV. MATHEMATICAL MODELING OF THE OPTIMIZATION PROBLEM OF THE REPOSITIONING OF A TRANSFORMER IN A RADIAL DISTRIBUTION NETWORK

In a distribution network there are some issues that are of fundamental concern to the dealer. These include the issue of power losses, voltage drops and operating costs.

4.1 Objective functions

4.1.1. Actives losses

Since the liberalization of the energy sector,the electric power companies, concerned about maximization their profitability index, have relied, among other things, of the reduction of losses in electrical systems to make a profit. This criterion is therefore one of the components on which action is required to reduce overall losses in an electrical power system. This criterion based on the improvement of the transit quality of active and reactive powers is shown by the equation (1).

$$f_1 = \sum_{i=1}^{nb} R_i \frac{{P_i}^2+{Q_i}^2}{{V_i}^2} \quad (1)$$

R_i : is the resistance of the branch i
P_i ,Q_i : respectively the active power and reactive power of the branchi
V_i : voltage of the final node of the branch
nb: total number of branches in the network

4.1.2 Voltage deviations

The reduction of voltage deviations on bar sets is a contractual commitment that binds the dealer to its customers. In order to ensure the operation of the receivers in normal voltage ranges, the distributor will have to commit to maintaining voltages within limits of more or less 10% in Low Tension. The voltage deviation should therefore be reduced to a minimum. This objective isillustrated by the equation (2).

$$f_2 = DT = \sum_{i=1}^{n} \left(\frac{V_i - V_i^{ref}}{V_i^{max} - V_i^{min}} \right)^2 \qquad (2)$$

V_i^{ref}=1 p.u,voltage of reference
V_i^{max} , the maximun voltage representing +10% of the nominal voltage
V_i^{min}minimum voltage representing -10% of nominal voltage
n ,number of nodes in the network
Using the aggregative method we formulate the first objective function by expression (3):

$$F_1 = \alpha_1 * f_1 + \alpha_2 * f_2 \ (3)$$

With :$\alpha_2 = \alpha_1 = 0{,}5$

4.1.3 Cost function

In the planning of electrical network, the costs of the components must be minimized in order to achieve economic gains that can allow for investments to be made and resources to ensure the operation and maintenance of installed equipment. As part of our study, we incorporated costs per km from MV lines and distribution transformers. This feature includes capital and operational costs.

4.1.3.1. Investments costs

The investment cost consists of the acquisition costs of MV/LV distribution transformers and the cost of building an MV line. It isexpressed by equation (4).

$$C_{inv} = C_{DT} + C_{HTA} \qquad (4)$$

with :
C_{inv} :investments costs ;
C_{DT} : distribution transformer cost

$$C_{HTA} :\ Cost\ of\ building\ the\ MV\ line$$

4.1.4. Operational costs

The operational cost represents the financial valuation of copper and iron losses in the transformer and the losses joule in the LV cables of the low voltage lines. It isexpressed by the equation(5).

$$C_{operationnel} = C_{eLLV} + C_{eLDT} \qquad (5)$$

$$C_{eLLV} = 8760 * p * \sum_{j=1}^{T} P_{lossLV} * \frac{(1+g)^j}{(1+r)^j} \qquad (6)$$

$$C_{eLDT} = 8760 * p * \sum_{j=1}^{T} \Big(P_{fer} + P_{cui} + F_u \qquad (7) * \ (1+g)^{2j} \Big) * \frac{1}{(1+r)^j}$$

C_{eLDT}, the cost of energy loss in the transformer ($)

C_{eLLV}, the cost of energy losses on LV lines in dollar ($)

P , the cost of unit losses ($/kWh)
T , the projected number of years (10 years in our study)

P_{cui}, copper losses in transformer (kW)
P_{fer}, iron losses at the transformer (kW)
r, annual discount rate
F_u, use factor
g, estimated growth factor in expenses
$C_{operationnel}$, the operating cost
P_{lossLV}, the loss of active power in BT lines
"8760" represents the number of hours of use per year.

The third criterion for optimizing of this problem is an economic criterion. It is formulated by the expression of the equation (8).

$$f_3 = C_{inv} + C_{operationnel} \quad (8)$$

We formulated the second objective function of this optimization problem by expression (9).

$$F_2 = f_3 \quad (9)$$

4.2. Constraints

The constraints are those related to the normal working conditions of the low voltage lines. They specifically relate normal voltage ranges, compliance for nominal currents in cables.

4.2.1. Voltage constraints

$$V_{min} \leq V_i \leq V_{max} \text{ , } i = 1,2, \ldots . n \quad (10)$$

4.2.2. Currentconstraints

$$g = \frac{I_k}{I_{max,k}} \leq 1 \quad (11)$$

Where :

I_k Current in branch k;
$I_{max,k}$ the maximum allowable current in branch k

V. ALGORITHM NSGA-II

5.1. NSGA-II process

Genetic algorithms are part of the family of revolutionary algorithms, the most used. They have the particularity of evolving populations of coded individuals (chromosomes) through chains of fixed length using genetic operatoes of mutation and crossove. The algorithm NSGA II (Non Dominated sorting Genetic algorithm II) is proposed by Deb et al [16] and is originally designed to determine an optimum Pareto, a space in which the population cannot improve without causing degradation a portion of individuals, meeting multiple objectives. It is an elitist algorithm which performs a selective tournament to select the individuals to cross and mutate. Its process begins with a set of solutions of size N called "parent P" created within the specified lower and upper limits of each variable in the optimization problem. The non -dominated solutions are saved to maintain the diversity of the population. The distance crowing technique is used to preserve the diversity of solutions on the Pareto front and is applied on the last front of Pareto, to complete the size of the parent population for the next generation.

5.2. NSGA II Algorithm of positioning of MV/LVtransformer

Step 1 :
- Read network data and run power flow
- Read NSGA-II algorithmic simulation sets
- Start-up of the generation counter

Step 2 :

Creating the Parent population P_o N-size randomly from the information read in Step 1. Each individual of the population is represented by the variables in the size, number and position of the distribution transformer in the network.

Step3 :

For each individual in a P_t population, execute the network power flow program by integrating the distribution transformer into the network

Step4 :

Sorting of the population according to the non-dominance criterion after the evaluation of objective functions

Step 5:

Generation of the daughter population Q_t from the parent population P_t

As long as *t* number of generations do:

1. Apply genetic operators (selection, crossing, mutation) to obtain an intermediate population $R_t = P_t \cup Q_t$ of size 2N where N is the number of individuals in the population
2. Sort individuals from the population R_t into multiple pareto fronts in ascending order
3. Create the new parent population $P_{(t+1)}$for the next generation using the crowing distance technique to select the best N individuals from the population R_t fronts. Individuals larger than size N are rejected.
4. Execute the power flow program by integrating the transformer for each individual taken from the population $P_{(t+1)}$.
5. Evaluate the objective functions again
6. Create the new daughter population $Q_{(t+1)}$ from the population $P_{(t+1)}$ by crossing and mutation selection operators.

Step 6:

Display optimal solutions with objective function values.

VI. RESULTS AND DISCUSSIONS

Table 2 shows theoptimal relocation and size parameters of the transformer existing in this LV network of Zogbadje in the municipality of Abomey - Calavi in Benin.

Table 2: Parameters simulation of relocation

Parameters	Value
Numbers of generations	80
Size of population	50
Numbers of constraints	2
Probability of croisement	0.9
Probability of mutation	0.3

Following the simulation of this relocation, the objective function representing the actives losses and the voltage deviation has the value 20.85 and the function representing the total cost has the value 368124. Table 3 shows the results of one MV/LV distribution transformer in the Zogbadje network.

Table 3 : Results of single-transformer repositioning in the Zogbadjè network

Topics	Network status before optimization	Network status after optimization
Active losses (kW)	72.6	35.1
Reduction rate (%)		51.65
Minimum voltage (pu/nœud)	0.808/59	0.919/59
Reduced voltage deviation rate(%)		76.03

Proportion of unstable nodes (%)	50.75	0
Transformer power (kVA)	400	800
Position of the new transformer (node)	2	26
Costs (cost of losses and transformer) in US dollars		361362

Following this optimization of the repositioning, it is observed that the optimal power of the corresponding transformer to adequately supply the customers connected to this network is evaluated at 800 kVA instead of 400 kVA initially installed. The new position of this transformer is identified at node 26. The proportion of unstable nodes which was 50.75% in the case of basic configuration passed to 0%. The voltage deviation improved by 76.03%. It can then be deduced that the optimal repositioning and sizing of a transformer in an existing Low Voltage network contributes to significantly improving the technical performance of this network. This repositioning at node 26 of this network is very close to the center of gravity of the loads and made it possible to reduce losses by 51.65%. Figure 8 illustrates the voltage profiles obtained on the busbars following optimization.

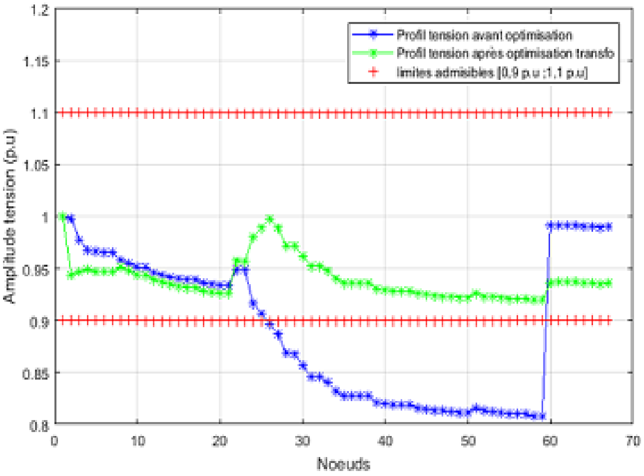

Figure 2 : Voltage profiles on LV busbarsafter positioning 800kVA transformer atnode 26

It is observed that all the voltages are within the normative ranges recommended by the standard NFC 15-100 and EN 50160 governing the voltages at the terminals of the receivers. The voltage deviation is reduced by 76.03% compared to the basic state of the network. The proportion of the unstable nodes increased from 50.75% to 0%. It can then be deduced that the transformer of 400kVA repositioned at node 26 at a power of 800kVA is very well positioned at the epicenter of gravity of the charges and no more voltage deviation is observed and could allow to supply the subscribers who are connected to it under the contractual conditions provided in the standards.

5.2. Optimal multi-transformer positioning in an existing LV distribution network

In the case of multi-transformer positioning, the simulation parameters remain the same. Table 4 illustrates the simulation results.

Table 4: Results of simulation of optimal multi-transformer positioning in the LV network of Zogbadjè

Topics	Network status before optimization	Network status after optimization
Active losses (kW)	72.6	5.95

Reduction rate (%)		91.80
Minimum voltage (pu/nœud)	0.808/59	0.975 /21
Voltage Deviation Improvement Rate(%)		99.16
Proportion of unstables nodes (%)	50.75	0
Optimal power of new transformer (kVA)	400	2x400
Position of transformer (node)	2	8 et 52
Costs (cost of losses and transformer) in US dollars / reduction rate		178693/ 50.55%

It is observed from this table that the losses are reduced by 91.80% and that the voltage deviations have improved by 99.16%, an improvement of almost 22% compared to the case of single-transformer positioning. The transformer power in the existing network which was 400kVA at node 2 is optimally positioned at nodes 8 (400kVA) and 52 (400kVA). The new configuration of the LV network is shown in Figure 9.

The transformer positioned at node 8 will then serve the nodes $\{1, \dots\dots\dots..29, 61\dots 66\}$ and the second LV network, the injection of which is a node 52, will supply the points $\{30, \dots\dots\dots..59\}$.

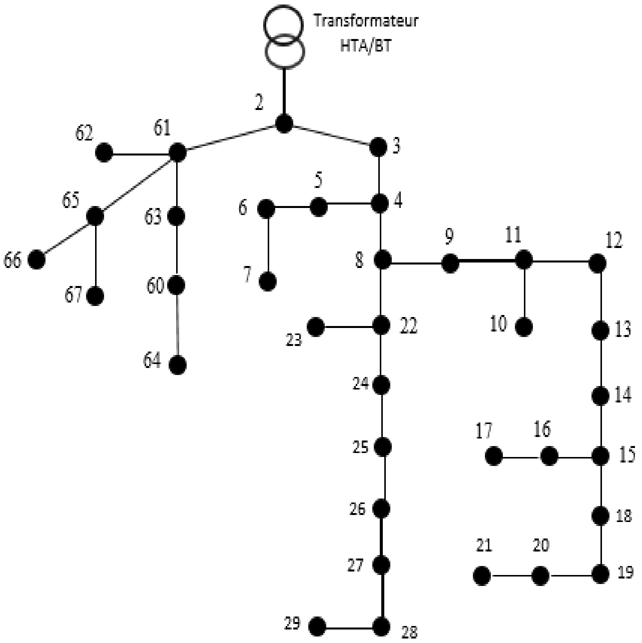

Figure 3 : Topological diagram of LV network of Zogbadje 1

The figure 10 shows the topological diagram of the second LV network resulting from the optimization by integrating the positioning of the transformer at node 52.

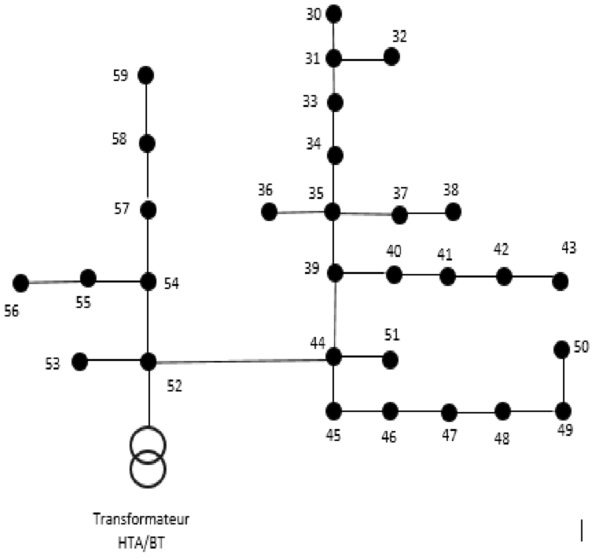

Figure 10: Topological diagram of the LV network of Zogbadjè 2

This topological diagram represents the second part of the LV network of Zogbadjé. It shows the positioning of the 400 kVA transformer at node 52. In this topology, the radius of action of the transformer positioned at node 52 is within the admissible limits recommended by the standards.

The cost of the losses and of the transformer is estimated at one hundred seventy thousand eight thousand six hundred ninety-three thousand dollars (178,693 US dollars), a cost reduction of 50.55% compared to the configuration resulting from the single-transformer positioning. It can then be deduced that the optimal positioning of multi-transformer in a Low voltage network, taking into account its network extent and its electrical state is very beneficial economically and technically for the electrical industries. This new technique for reconfiguring low voltage networks can be exploited by operators who are faced with the problem of continuous growth in losses in distribution networks.

VII. PROFITABILITY OF THE PROJECT

The calculation of the profitability of this project includes the determination of the cost of the energy saved by the optimizations, the investment cost of positioning the transformers and sections of line to be built if necessary.

7.1. Evaluation of saved energies

The energy absorbed by the joule effect due to losses is calculated from expression (12).

$$E_P = \int_0^T P_j(t)dt = \Delta P_j * (T - T_C) \qquad (12)$$

With :

E_P : Energy absorbed annually by losses;

P_j : Power lost by joule effect

ΔP_j: Difference between the powers lost before and after optimization

In the case of our study, we considered an average outage time of 2 hours per day on this transformer, taking into account the incident analysis report [17].

The financial valorization of the losses is calculated based on the average cost of energy in Benin. This cost, which is estimated at 106 CFA francs [18].

$$R_{an} = C_m * E_p \qquad (13)$$

With :

R_{an} : Annual revenue;

C_m : Average energy cost;

The investment cost consists of the installation cost of the transformer added to the maintenance and operating costs and the study costs. The total fixed cost of installing the transformer includes the cost of acquiring and installing the transformer and that of the MV line required for repositioning.

$$\boldsymbol{C}_{\boldsymbol{inv}} = C_{fixe} + C_{ME} + C_{ET} \qquad (14)$$

$$\mathrm{C_{fixe}} = \mathrm{C_{DT}} + \mathrm{C_{HTA}} \qquad (15)$$

with :
$\boldsymbol{C}_{\boldsymbol{inv}}$ **:** investment **cost**
$\boldsymbol{C}_{\boldsymbol{fixe}}$**:** fixed cost of installing the transformer
$\boldsymbol{C}_{\boldsymbol{ME}}$ **:** cost of maintenance and operation
$\boldsymbol{C}_{\boldsymbol{ET}}$ **:** cost of studying the project
$\boldsymbol{C}_{\boldsymbol{DT}}$ **:** transformer purchase and installation cost
$\boldsymbol{C}_{\boldsymbol{HTA}}$ **:** construction cost of the MV line

7.2. Net annual revenue

The cost resulting from the reduction of losses constitutes the annual revenue. From this cost we deduct the net annual revenue $\boldsymbol{R}_{\boldsymbol{net}}$. It is expressed by the expression (16).

$$\mathrm{R_{net}} = \mathrm{R_{an}} - \mathrm{C_{ME}} \qquad (16)$$

7.3. Return on investment

The return on investment determines the time it takes for the cumulative annual savings to balance the investment. It is an indicator that has the merit of being simple and understandable when it comes to expressing the return on investment of a project. The payback period is evaluated by expression (17).

$$\mathrm{RSI} = \frac{\mathrm{C_{inv}}}{\mathrm{R_{net}}} \qquad (17)$$

7.4. NetPresent Value (NPV)

The net present value consists in calculating the present value of the different financial flows over the duration of the project by integrating the initial investment. This calculation determines the financial gain over the life of the project for a given discount rate [19]. The NPV is calculated by the expression (18).

$$\mathrm{VAN} = -\mathrm{C_{inv}} + \sum_{\mathrm{i=1}}^{\mathrm{T}} \frac{\mathrm{R_{net,i}}}{(1+\mathrm{t})^{\mathrm{i}}} \qquad (18)$$

With :
$\mathrm{R_{net,i}}$: the net annual revenue for the year i
i : year
T : the life of the project (10 years)
t :the discount rate

Table 5 provides a summary of the results before and after the optimization.

Table 5: Summary table

	Basic case	Scenario I	Scénario II
Actives losses (kW)	72.6	35.1	5.95
Minimum voltage (p.u)/node	0.808/59	0.919/59	0.975/21

Size of transformer (kVA)	400	800	2 x 400
Position of transformer	2	26	8 et 52
Voltage improvement (%)	-	20.67	22.65
Active losses improvement (%)	-	93.15	98.50
Return on Investment RSI	-	5 month 16 days	5 month and 15 days
Net Present Value : VAN		177590 000	315770000
Cost of investment (F CFA)		14406480	25497500

It reveals from this table that for scenario I which deals with the case of the optimal positioning of a 800 kVA MV / LV transformer at node 26 of the network, there is a reduction of 51.65% of active losses with an improvement of tensions of around 13.74%. As for scenario II dealing with multi-transformer positioning in the network, we note that the active losses are reduced by 91.80% and an improvement of 20.69% in voltage deviation for the voltages at the nodes of this LV network. This scenario II is therefore more efficient from a technical point of view.

It also appears that the investment cost for scenario I is 144,064,800 FCFA compared to 25,497,500 FCFA for scenario II. Analysis of these results shows that the two senaris are profitable because the delay in return on investment is practically equivalent to a delay of 5 months 15 days with net present values (NPV) which are positive. However from a technical point of view, scenario II is technically preferable than scenario I.

VIII. CONCLUSION

This work of optimal relocation transformer in a distribution network consisted in bringing the distribution transformer of the Zogbadjè MV/LV station closer to the gravity epicenter of the loads connected to it. It was revealed that Scenario II, which is designed to position two 400 kVA transformers at node 8 and node 52, is more technically and economically attractive and is therefore the most optimal option to reduce the technical losses of this network and voltage deviations. Distribution network operators can explore this technology to improve the technical performance of their networks to reduce operating costs that are becoming increasingly excessive. The NSGA II genetic algorithms of the elitist family have been of an effective and effective contribution to optimize the functioning of this low voltage distribution network. With this optimization, all customers connected to this station will be able to be adequately supplied within the contractual limits of voltage.

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