American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-4, pp-155-165
www.ajer.org
Research Paper Open Access

Multi-objective Optimization of the Voltage Static Stability Margin of a Distribution Network by Genetic Algorithms

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Abstract: *Since the liberalization of electricity sector and to meet the requirements of restrictive clauses stemming from the successive conferences on the climate, the managers of the electrical networks are constrained to exploit their electric system to the limits. This situation generates voltage instability and sometimes its collapse which turns out to be major problems which can collapse the whole system in normal operation or in the event of contingencies occurring. This work consisted in optimally inserting a D-FACTS to the effect of improving the static stability margin of a real distribution network. This problem has been formulated in the form of multi-criteria optimization whose objectives are the maximization of power losses, voltage deviation and the cost of D-STATCOM device. The Non-dominated Sorting Genetic Algorithm (NSGA-II) associated with the implemented Continuous Power Flow (CPF) program yielded relevant results. Indeed, before the compensation, 68% of the nodes of Cotonou 4 network are unstable with a minimum voltage value of 0.9164 p.u at the node 51 and the active losses amount to 528 kW. After the optimal placement of the D-STATCOM at node 37, the active losses are reduced by 48.6%, and the voltage profiles are improved significantly within the normative limits. The stability margin has increased by 4.29 MW, with an additional load of 2 MW that can be distributed on the grid before reaching the lower limit (0.95 p.u). The relevant results obtained clearly show the effectiveness of the tools developed in this work.*

Keywords: *Voltage stability margin, NSGA-II, D-STATCOM, positioning, size*

Date of Submission: 31-03-2020 Date of acceptance: 18-04-2020

I. INTRODUCTION

The reliability of the electrical systems is a major concern for the planning engineers in order to guarantee a quality service to the demanding clientele. As policies and technology evolve, electrical systems become complex to manage. The integration of intermittent energy sources into electricity grids, the opening of the electricity market, the disintegration of electrical systems, the emergence of regulators with their requirements are all reforms that lead operators to the management of electricity. at the limits of their installation.

In fact, the maintenance of the voltage quality parameters (amplitude, frequency, pulses) and current of branches or lines in the contractual ranges becomes a difficult task. Also, in recent years, voltage instability has been identified as one of the consequences of operating power systems to the limits of stability. Indeed, the growing concern of the public authorities regarding the depletion of fossil resources and the disastrous consequences of greenhouse gases emission on the climate, (abnormal rise of water, acidification of the oceans), construction new fossil-fueled primary power lines and power plants have become very complex to implement for these managers. To this end, several alternatives are multiplying to decarbonize the energy mix and encourage the use of ot her techniques to defer the investments to be made to improve the technical performance of electrical networks. Among these are the insertion of GEDs, FACTS installation and networks reconfiguration. Most distribution grids are obsolete and require funding to improve their technical performance. It is observed that several voltages on some network bus are below the contractual limits of the electrical system of the Beninese Society of Electrical Energy (SBEE) thereby creating several areas of instability on these networks. The operation of these distribution networks under these conditions causes the abnormal growth of current in the branches thus causing uncontrolled and drastic drops in voltage. This situation causes voltage instability in networks that can often be the cause of failures.

Several researchers have been interested in this very worrying issue for network managers. There are several ways to optimize the voltage stability margin in an electrical network. Examples are FACTS, EDMs, reconfiguration, compensation equipment such as capacitors, load controllers for power transformers. Capacitors have an oscillatory character on network parameters. Load regulators used on power transformers that operate under current constraints and which consist in modifying the transformation ratio as a function of the secondary voltage. They help to adjust voltages in a range of 10 to 20%. Their disadvantage is that they wear out quickly and their operation generates electric arcs which are at the origin of their imprecision and of an early wear. Faced with the imperfections of this equipment, power system operators use FACTS from the technological development of power electronics and sometimes GEDs to improve the efficiency of their networks and increase the voltage stability.

In this paper, away to improve the voltage stability margin is analyzed, so that during daily variations, the system does not enter a state of instability or voltage drop. This increase in voltage stability margin was achieved by inserting a D-STATCOM (Static Synchronous compensator) into the network. The D-STATCOM is obviously a FACTS intended for the improvement of the distribution networks performances.

However, its inadequate positioning in a network can cause overvoltage or abnormal currents in branches. The distribution networks being characterized by a large number of nodes and very severe operating constraints, the choice of the node to receive a D-FACTS will have to be done by optimization approach.

The analytical methods formerly used are abandoned in favor of metaheuristics. In fact, metaheuristic methods make it possible to choose solutions in a range of potential solutions and avoid local pitfalls.

Non-dominated Sorting Genetic Algorithm was combined with continuous power flow program to improve the stability margin of the network by optimal insertion of D- STATCOM

II. REVIEW OF LITERATURE

In several studies as in [1], [2] and [3], the subject of voltage stability has been addressed. In [1] and [2], the voltage stability was analyzed using the stability indices namely FVSI, Lmn and LQP. Stability indices give important information about the proximity of voltage instability. The authors evaluated these indices after calculating the conventional power flow with PSAT software. The stability index method does not make it possible to evaluate the voltage stability margin to be respected in order to avoid voltage collapse.

In [3], the proximity of the voltage instability of an electrical network was studied by modal analysis based on singular values decomposition of the Jacobian matrix. Singular values define the stable or unstable state of the studied system [3]. At the point of collapse, the minimum singular value is zero and becomes negative beyond this point. The major disadvantage of modal analysis is its non- linear behavior near the critical point [4]. The proposed approach in [3] requires a series of power flow, so the calculation time is too long. In this paper, we will adopt the continuous power flow proposed by Ajjarapu [5] and which remains conditioned even at the point of collapse while avoiding the singularity of the Jacobian matrix. Continuous power flow has also been applied to a distribution network in [6].

To solve the problem of optimizing the insertion of FACTS in an electrical network, several approaches have been used, including Evolution Strategies (ES) [7], Particle Swarm Optimization (PSO) [8,9], harmony search algorithm (HS) [10, 11] and genetic algorithms (GA) [12,13] and [14]. In [9, 10, 12, 13], the optimization is solved with the aim of minimizing voltage deviation and active losses. Moreover, in this article the optimization aims to improve in addition to these parameters, the voltage stability margin. In [12], the optimization problem has been converted to a single- objective problem where the functions are combined into a single function to be minimized. The combination of objective functions doesn’t allow a separate assessment of each of them. For this purpose ,the voltage stability margin is considered in this article as a criterion to be optimized by the NSGA-II algorithm in addition to the others (active losses, voltage deviation, and D-STATCOM cost). It has been demonstrated elsewhere in [14] that the fuzzy logic+ NSGA-II approach gives satisfactory results compared to the fuzzy logic +NSPSO approach in terms of minimizing criteria such as voltage deviation and active losses.

III. CONTINUOUS POWER FLOW

The objective in this paper is to evaluate the stability margin and find voltage collapse point of a specific network. Continuous power flow is implemented for this purpose. The Newton-Raphson algorithm used in other cases allows to calculate the solutions of conventional power flow equations given by:

$$\begin{cases} P_i = P_{gi} - P_{Li} i = 1 \ldots \ldots n \\ Q_i = Q_{gi} - Q_{Li} i = 1 \ldots \ldots n \end{cases} \quad (1)$$

where P_{gi} et P_{Li} denote the active powers generated and requested at node i, Q_{gi} and Q_{Li} denote the reactive powers generated and requested at bus i and n is the number of bus. The powers injected at node i are givenby equations (2) and (3).

$$P_i = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) \quad (2)$$

$$Q_i = \sum_{j=1}^{n} V_i V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) \quad (3)$$

$V_i \angle \delta_i$ and $V_j \angle \delta_j$ are respectively the voltages at nodes i and j, j, $Y_{ij} \angle \theta_{ij}$ is the element (i, j) of nodal admittance matrix $[Y_{bus}]$.

Although the Newton-Raphson algorithm finds solutions for load levels far from the point of collapse, attempts to obtain solutions near this point make Jacobian matrix singular. In contrast, CPF algorithm was designed to find solutions to a series of successive power flows while keeping the Jacobian matrix conditioned even at the point of collapse. To do this, the algorithm uses a prediction- correction scheme for all reformulated power flow equations by inserting a new parameter λ, the load factor. It starts from a solution known as the base load and proceeds to a series of power flows to the point of collapse [5].

3.1. Reformulation of power flow equation

In order to plot the P-V curves and to evaluate the load margin, the power flow equations are modified to include the parameter λ, which represents the load factor. To simulate the load variation, the requested active and reactive powers are expressed as a function of the parameter λ according to equations (4) and (5) [5].

$$P_{Li}(\lambda) = P_{Lio} + \lambda[K_{Li} S_{\text{Base}} \cos(\delta_i)] \quad (4)$$

$$Q_{Li}(\lambda) = Q_{Lio} + \lambda[K_{Li} S_{\text{Base}} \sin(\delta_i)] \quad (5)$$

where,

$$S_{\text{Base}} cos(\delta_i) = P_{\text{Lio}}$$

$$S_{\text{Base}} sin(\delta_i) = Q_{\text{Lio}}$$

where $\boldsymbol{P_{Lio}}$ and Q_{Lio} represent the base active and reactive powers at bus i, K_{Li} is a multiplier designating the proportion of the variation of load at bus i when λ varies.

In addition, the active power generated is also modified and expressed by equation (8) [15].

$$P_{Gi}(\lambda) = P_{Gio}[1 + \lambda K_{Gi}] \quad (6)$$

Where $\boldsymbol{P_{Gio}}$ is the generated base active power and K_{Gi} is the multiplier of the generation when λ varies.

The substitution of the new expressions of the terms P_{Li}, P_{Gi} and Q_{Li} gives the equations reformulated hereafter:

$$P_i = P_{Gi}(\lambda) - P_{Li}(\lambda) \quad (7)$$

$$Q_i = Q_{Gi} - Q_{Li}(\lambda) \quad (8)$$

If « F » is used to denote all the equations, then the system described above represents a set of nonlinear equations expressed by (11).

$$F(x, \lambda) = 0 \quad (9)$$

where $x = [\delta, V]^T$ and it is applied the process of prediction and correction to solve this system.

3.2. Prediction step

Knowing the basic solution (corresponding to λ = 0, the prediction of the next solution is made by taking an appropriate step in the direction of the tangent vector to the next solution. For this, the first step in the prediction process is to compute the tangent vector. The tangent vector is obtained by deriving the two members of equation (11) [15].

$$d[F(\delta, V, \lambda)] = 0 \quad (10)$$

The factorization of the equation (12), gives**:**

$$[F_\delta F_V F_\lambda] \begin{bmatrix} d_\delta \\ d_V \\ d_\lambda \end{bmatrix} = 0 \quad (11)$$

The left side of equation (13) is a partial derivative matrix multiplied by the tangent vector to the new solution. The insertion of $F\lambda$ increases the number of variables in the power flow equations without changing the number of equations. Adding a new equation in the problem is therefore necessary [5]. This problem can be solved by choosing a non-zero value (usually equal to one of the components of the tangent vector), ie if t denotes the tangent vector, we have:

$$\begin{bmatrix} F_\delta F_V F_V \\ e_k \end{bmatrix} [t] = \begin{bmatrix} 0 \\ \pm 1 \end{bmatrix} \quad (14)$$

Once the tangent vector has been found by solving equation (14), the predicted solution is given by Equation

(15).

$$\begin{bmatrix} \delta^* \\ V^* \\ \lambda^* \end{bmatrix} = \begin{bmatrix} \delta \\ V \\ \lambda \end{bmatrix} + \sigma \begin{bmatrix} d_\delta \\ d_V \\ d_\lambda \end{bmatrix} \qquad (12)$$

3.3. Correction step

After the prediction, the next step is the correction of the predicted solution. For this purpose, a local parameterization is used in which system (12) is completed by an equation which specify the value of one of the state variables of the system. This state variable can be voltage amplitude V, voltage angle δ or load factor λ [5]. As an equation, the local parameterization can be expressed as follows:

$$\begin{bmatrix} F(x) \\ x_k - \eta \end{bmatrix} = 0 \qquad (13)$$

with η the value of x_k

IV. D-STATCOM MODEL

D-STATCOM is a D-FACTS device that performs the control (voltage, power absorbed) of the network while being connected in parallel to one of the bus. This compensator is similar to STATCOM. However, some differences can be observed in term of construction and installation [16, 17]. Thus, D-STATCOM is modeled as a STATCOM for its insertion in power flows [16]. To include the D-STATCOM in the power flow, the control modes used are: control of the voltage at a node, control of the absorbed power [16]. In this study, voltage control was selected. A D-STATCOM typically consists of a coupling transformer, a voltage source converter and an energy storage as shown in Figure 1 [17].

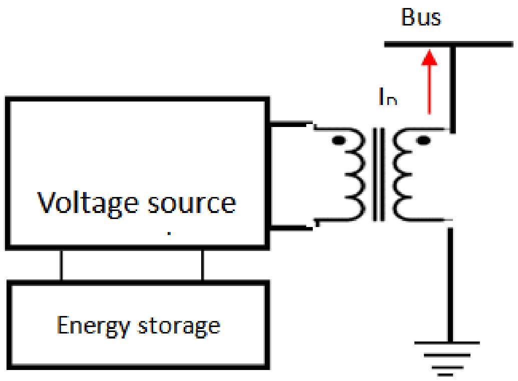

Figure 1.*D-STATCOM model*

The losses in the transformer being neglected, the compensator can be modeled as a voltage source V_{sh} controlled in series with line impedance Z_{sh} [18].

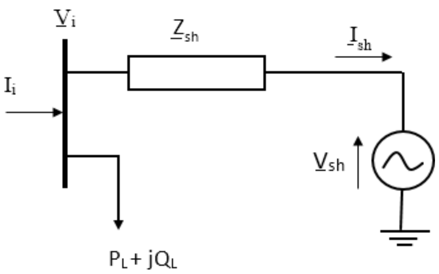

Figure 2. *Simplified model of D-STATCO*

In supposition $V_i = V_i\angle\delta_i$, $V_{sh} = V_{sh}\angle\delta_{sh}$ and $Z_{sh} = G_{sh} + jB_{sh}$, the STATCOM output power are given by (17) and (18) [19].

$$P_{sh} = V_i^2 G_{sh} - V_{sh} V_i [G_{sh} \cos(\delta_{sh} - \delta_i) + B_{sh} \sin(\delta_{sh} - \delta_i)] \qquad (14)$$

$$Q_{sh} = -V_i^2 B_{sh} + V_{sh} V_i [G_{sh} \sin(\delta_{sh} - \delta_i) - B_{sh} \cos(\delta_{sh} - \delta_i)] \qquad (15)$$

The STATCOM connection point is considered as a PV bus which can be converted to a PQ bus in case of violation of constraints [16].

The exchanged active power is assumed to be zero:

$$P_{sh} = V_{sh}^2 G_{sh} - V_{sh} V_i [G_{sh} \cos(\delta_{sh} - \delta_i) + B_{sh} \sin(\delta_{sh} - \delta_i)] = 0 \qquad (16)$$

V. NSGA II

The NSGA-II (Non Dominated Sorting Genetic Algorithm II) algorithm proposed by Deb et al.,is a multi- objective genetic algorithm originally designed to determine a Pareto optimum, that is, a state in which the population cannot be improved without leading to a degradation of a part of individuals, meeting multiple objectives. This algorithm is a successor to NSGA found more complex by the researchers [20]. It has been developed to overcome the NSGA limits using an elitist approach that allows to safeguard the best solutions found in previous generations (preservation of diversity).

5.1. Operation of NSGA-II algorithm

The NSGA-II algorithm is based on a fairly standard mechanism of genetic algorithm; it is an elitist algorithm that makes a selection by tournament to choose the individuals to cross and mutate to generate new populations iteratively. Its principle is described at Figure 3.

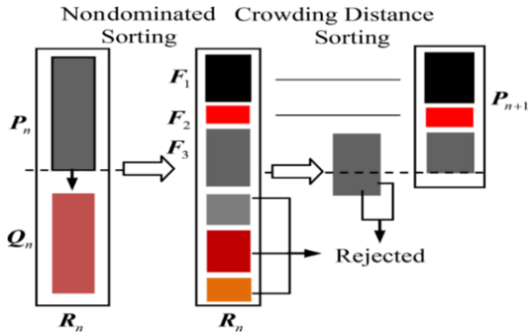

Figure 3. *NSGA-II procedure*

NSGA-II begins with a set of solutions of size N (called "parent population" P) created within the specified lower and upper bounds of each optimization variable [21]. At each iteration t (Fig. 3), the Q_t population is created from the parent P_t population using genetic operators (reproduction, recombination, and mutation). These two populations are combined to form a new Rt population of size 2N. Then, a non-dominated sort is applied to classify the population Rt into a hierarchical number of non-dominated fronts: (F_1, F_2, F_3 ...) ranked in descending order of dominance [21]. The R_t population of 2N solutions is sorted to build the N-size P_{t+1}population using the crowding distance. The R_t solutions that contribute the most to diversity are thus favored in the construction of P_{t+1}.

5.2. Adaptation of the NSGA-II to the study problem

To adapt NSGA-II algorithm to the study problem, the genes considered are the location (node number) and the size of the D-STACOM expressed by (18). The power (Qsh) makes it possible to determine the voltage amplitude (Vsh) at the output of the D-STATCOM by supposing that the voltage angle (δsh) is in phase with the voltage angle at the node where the D-STATCOM is connected [13].

The algorithm is described below:
Algorithm:
Input: Number of generations, Population size (N), variables (node, Qsh), Number of constraints
Output: Solutions, Values of objective functions
Start
t = 0 ;
Create a random parent population P of size N
Execute CPF program;
Evaluation of objective functions
Create child population Q
while t < Number of iterations ***do***
a- Combine P_t and Qt to form $R_t = P_t \cup Q_t$
b- Sort the R_t population according to the non-dominated sort criterion to identify all F_i fronts;
c- Create the new parent population P_{t+1} ($P_{t+1} = P_{t+1} \cup F_i$)
d- Execute CPF program;
e- Evaluate the objective functions;

f- Create the child population Q_{t+1} from P_{t+1}

end while

Display the best solutions with the values of their objective functions.

End

5.3. Objective functions

The main aspect in an optimization problem is the definition of objective functions. The different objective functions used to evaluate network performance are to be minimized.

The first objective function to be considered in the improvement is the voltage stability of an electrical network and the voltage deviation at all nodes. This function is defined by the equation (20), where nb is the number of bus and V^{ref} is the reference voltage equal to 1p.u [20].

$$f_1 = \sum_{i=1}^{n_b} |V_i^{ref} - V_i| \qquad (17)$$

The second objective function is, as mentioned in (21), the sum of the active losses in network branches. This function is to be minimized for economic reasons. In (21),n_l is the number of network branches, P_{Li} represent the active losses in the branch i[11].

$$f_2 = \sum_{i=1}^{n_l} P_{Li} \qquad (18)$$

It is necessary to insert an objective function that improves the voltage stability margin. This margin, given by the parameter λ_{max} is the distance between the basic operation point and the collapse point of the network. The parameter λ_{max} is maximized by minimizing the objective function described by (22)[8].

$$f_3 = \frac{1}{\lambda_{max}} \qquad (19)$$

Moreover, it is indicated in [22] that the parameter λ_{max} is maximized only for a maximum size of the FACTS. In order to reduce the cost of the FACTS, a fourth objective function (equation (23)) is taken into consideration [23].

$$f_4 = k_q * |Q_{sh}| \qquad (20)$$

where$k_q$is the unit cost in kVAr and Q_{sh} is the MVAr size of D-STATCOM.

To facilitate the choice of the optimal solution on the Pareto front, the objective functions are combined in two groups F_1 and F_2 as indicated by the system (24).

$$\begin{cases} F_1 = f_1 \\ F_2 = \omega_1 * f_1 + \omega_2 * f_2 + \omega_3 * f_4 \end{cases} \qquad (21)$$

with$\omega_1 + \omega_2 + \omega_3 = 1$

VI. DIAGNOSTIC STUDY OF COTONOU 4 NETWORK

The adopted methodology has been applied to a distribution network in Benin. This network, whose architecture is shown in Fig.4, has51buseswithavoltage of 15kV.

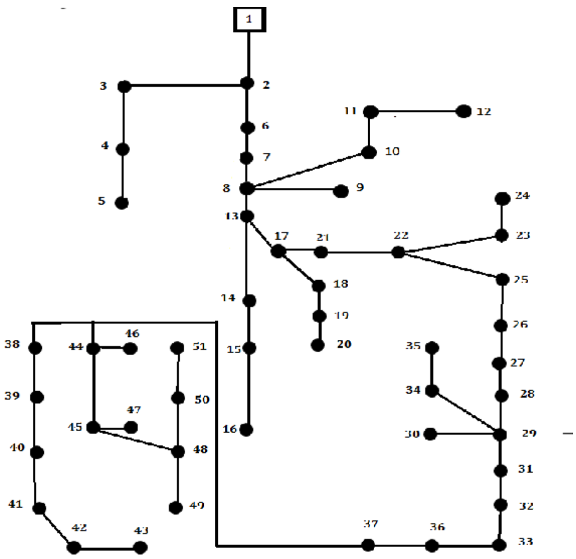

Figure 4.*Topology of Cotonou 4 Network*

Before evaluating the voltage stability margin of the network, it is necessary to evaluate its current state by the power flow analysis. For this purpose, the Newton-Raphson algorithm implemented in Matpower was used.

The configuration parameters of Matpower are shown in Table1.

Table 1. *Simulation parameters*

Parameters	Values
Base power (baseMVA)	100
Power flow algorithm (pf.alg)	NR
Tolerance (pf.tol)	10-5
Maximum number of iterations (pf.max_it)	15

The voltage profile from the conventional power flow is shown in Figure 5.

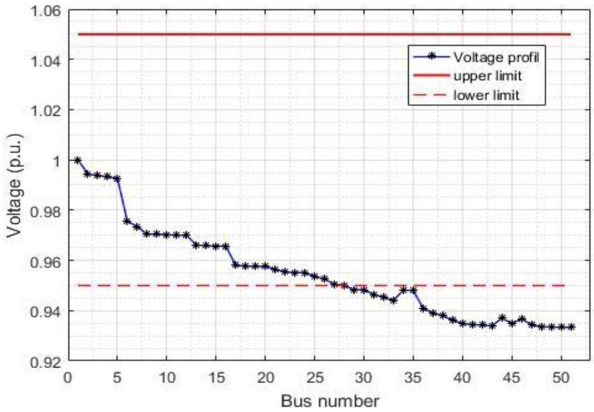

Figure 5. *Voltage profile of Cotonou 4 Network*

Looking at Figure 5, we notice a gradual decrease in voltage when moving away from the slack bus (bus 1). The abrupt variation in the voltage level observed at bus 5 shows that the voltage begins to drop considerably. So, 35 bus (about 68%) are unstable. The lowest voltage is at bus 51 and its value is 0.9164 p.u. This can be explained by the fact that bus 51 is the last bus of the long network.

Voltage drops are between 1% and 8.36% of the nominal voltage, which is not in agreement with the specifications of standard NF 50160. This means that the voltage profile of the Cotonou 4 network does not meet the requirements, and that all the receivers of this network are not properly supplied with power.

Table 2.*Power flow result*

Parameters	Values
Vmin (p.u)	0.9164
Vmax (p.u)	0.9921
Number of unstable nodes	35
Active power generated (MW)	10.6
Reactive power generated (MVAr)	6.07
Active power losses (kW)	527.59
Reactive power losses (kVAr)	409.43

VII. RESULTS AND DISCUSSIONS

In order to test the performance of the established algorithm in section *V.2*, it has been applied to the Cotonou 4 network of Benin. For this network, the goal is to improve the voltage stability margin by optimal insertion (location, size) of a D-STATCOM. The NSGA- II parameters used to solve this optimization problem are shown in Table 3.

Table 3. *NSGA II parameters*

Parameters	Values
Number of generations	50
Population size	40
Number of objective functions	2
Crossover probability	0.2
Mutation probability	0.9

The optimization variable is defined by:

$$x = \{Busnumber, \quad Q_{sh}\}$$

where

$$Busnumber \in [2;51]$$

and

$$Q_{sh} \in [-0.02\ p.u\ ;\ -0.2\ p.u].$$

Optimization is subject to F1 and F2 taking $\omega_1 = \omega_2 = \omega_3 = \frac{1}{3}$.
The Pareto front obtained by NSGA-II algorithm is shown in Figure 6.

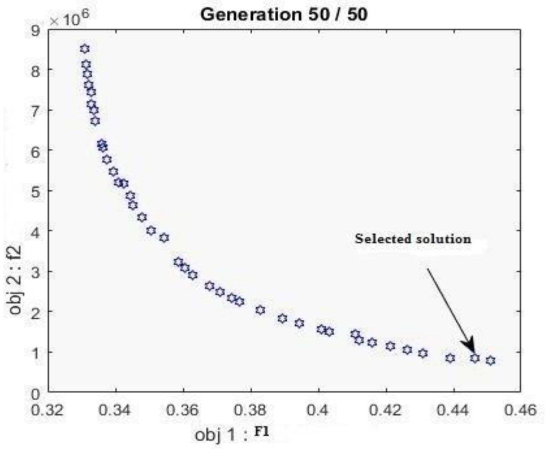

Figure 6. *Pareto front obtained*

The Pareto front shown above contains the forty (40) solutions that correspond to the number of individuals per population originally selected. Each solution has its variables and the values of the objective functions. After having tested the performance of each solution, the optimum solution chosen is that indicated in Fig. 5. For economic reasons, the chosen size does not maximize the stability margin but improves it while reducing the active losses and the cost of D-STATCOM. The characteristics of this solution are presented in Table 4.

Table 4.*Characteristics of optimal solution chosen*

Parameters	Values
Bus location	37
Q_{sh} $(p.u)$	-0.0494
F_1	0.4424
F_1	849356
D-STATCOM cost (USD)	837 837.4

Thus, the optimal location of D-STATCOM is the 37th bus of the network, with a size of 4.94 MVAr. Considering the results from NSGA-II, the voltage profile with D-STACOM is significantly improved compared to the base case as shown in the Figure 7.

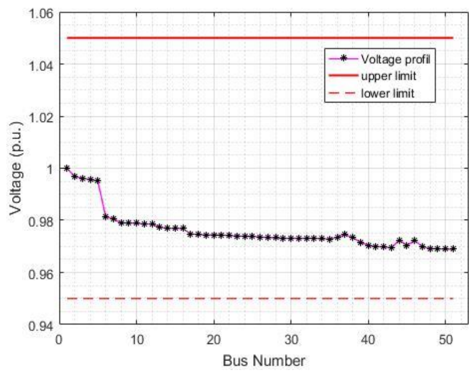

Figure 7. *Voltage profile with D-STATCOM at bus 37*

Figure 7shows that in the presence of D-STATCOM, the voltage profile is in the normative range with a minimum voltage of 0.969 p.u at node 51. The voltage drops are between1%and3.1%. It can be deduced that all the nodes are stable without load variation. For active power losses on the grid, total losses of 527.59 kW without compensation are reduced to 270.83kW.

Continuous power flow is performed by running the Matpower CPF algorithm and we consider the following assumptions:

- the loads increase on all bus except the slack bus;
- active and reactive power at each node increase proportionally to base case.

Table 5 shows the used simulation parameters.

Table 1.Matpower*CPF parameters*

Parameters	Values
cpf.step σ	0.2
corrector tolerance	10-5
cpf.stop_at	FULL

The P-V curves at nodes 8, 13 and 17 show the evolution of the voltage as a function of the load factor λ.

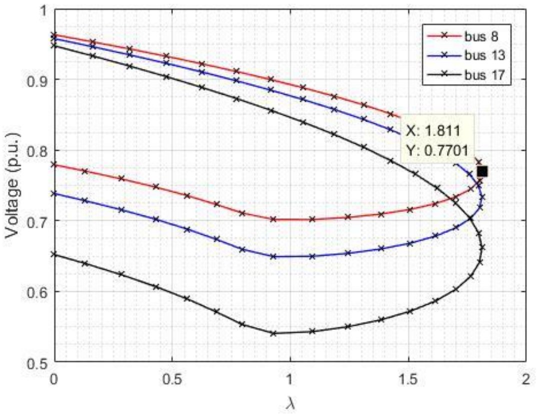

Figure 8. *PV-curve without D-STATCOM*

It is noted on this curve that the maximum load factor is 1.811 p.u. Beyond this value of λ occurs network collapse because the source station reaches its reactive power limit. The load margin of the network is given by the formula (24). [4].

$$Stabilitymargin = \lambda_{max} * P_{base} - P_{base}$$

For a base active power equal to 9.53 MW, the network stability margin is 7.72 MW. This margin is very narrow and thus makes the network very vulnerable.

To increase the voltage stability margin of an electrical network, it is preferable to carry out the reactive compensation by the FACTS because the reactive power is the support of the voltage.

In order to appreciate the influence of D-STATCOM on the stability margin of Cotonou 4 Network, the continuous power flow program was performed taking into account the location and the size of compensator. The P-V curves with compensator are shown in Figure 9.

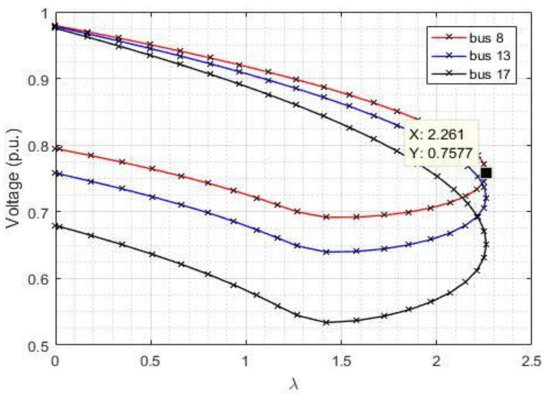

Figure 9. *PV-curve with D-STATCOM*

On the P-V curve of Figure 9, the voltages at the different nodes that were initially above 0.95 p.u gradually decrease to exceed the lower limit (0, 95 p.u). This means that the compensator can no longer satisfy the demand for reactive power for these load levels because the D-STATCOM has been sized taking into account the current state of the network to increase its stability margin. The load factor λ that collapses network is 2.26 p.u, which correspond to a margin of 12.01 MW to the collapse point.

To evaluate the load that brings the voltage of the critical bus near 0.95 p.u the active and reactive powers at the different bus have been increased by 10%. The analysis carried out reveal that this load corresponds to 21% of the basic active power, ie 2MW as shown in Figure 10.

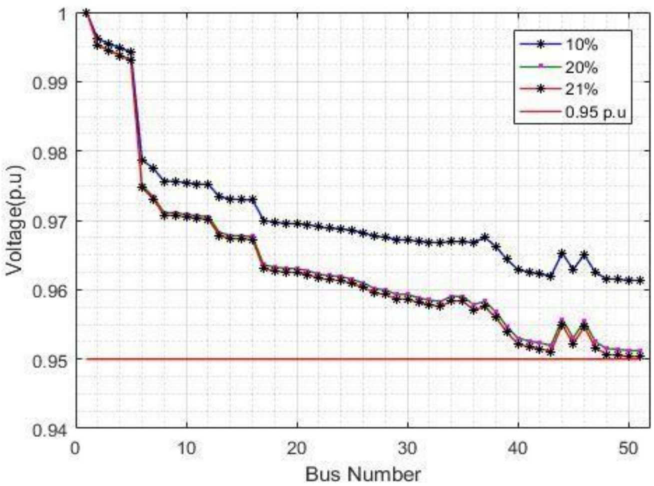

***Figure 10**. Voltage profile with different load factor*

The operator can restart 2MW load on the network while keeping the voltages at all bus in the normative range(0.95 p.u - 1.05p.u).
Simulation results before and after the optimal insertion of D-STATCOM are summarized in Table6.

Table 6.Summarize of simulation results

Comparison	Without D-STATCOM	With D6STATCOM
Number of unstable nodes	0	0
Vmin (p.u)	0.9164	0.9689
Vmax (p.u)	0.9920	0.9968
Active power losses (kW)	527.59	270.83
Loading margin(MW)	7.72	12.01
D-STATCOM location	37	
D6STATCOM size(MVAr)	4.94	

VIII. CONCLUSION

This article presented the multi-criteria optimization of the location and size of a D-STATCOM in a specific power grid to improve its voltage stability margin. For this purpose, the continuous power flow algorithm implemented in Matpower was combined with the NSGA-II genetic algorithm to find the optimal location and size of D-STATCOM. The simulation results showed that the bus where the voltage is lower is not necessarily the ideal place to install the D-STATCOM to increase the voltage stability margin. Optimization by metaheuristic methods leads to relevant and effective results. After insertion of the compensator, the rate of unstable nodes went from 68% to 0% and the active losses are reduced by 48.6%. The load margin increased by 4.59 MW with 2MW to be distributed over the entire network to maintain node voltages in the contract range. This optimal insertion has not only strengthened the static voltage stability of this network but also has made it possible to obtain the technical conditions that can make it possible to continue to connect the customers to said network without the voltage deteriorating up to 2MW. It can be concluded that the optimal insertion of DFACTS into a distribution network by genetic algorithms may well contribute to delaying investments such as strengthening of line sections, increasing the distribution transformer powers, to eliminate the overloads that are among other things the cause of the underperformance of the distribution networks.

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