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Optimization of the number, size and placement of D-STATCOM in radial distribution network using Ant Colony Algorithm

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ABSTRACT

This paper investigate an approach based on Ant Colony Optimization to identify optimal size, number, cost and placement of D-STATCOMs in radial distribution systems. Objective functions integrating power loss, voltage deviation and cost minimizations are solved by Ant Colony algorithm developed in MATLAB. This algorithm is tested on the IEEE 33- bus system and on a real distribution network of SBEE (Beninese Society of Electrical Energy). As results, it is observed that losses are reduced to 22.42 percent for IEEE 33-bus system with five D- STATCOMs and global installation and operating estimated cost of 3546762.35 dollars in first, and then, losses are reduced to 61.63 percent with four D-STATCOMs and cost of 2493146.29 dollars for a real distribution system of SBEE.

Keywords: D-STATCOM, optimal placement, radial network, ant colony optimization, power loss

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INTRODUCTION

The economic development of a country depends on the availability of energy and its consumption.

In distribution systems, energy demand is continuously growing with the increase in population and changing life style in some developing countries. The energy demand, in recent years, makes serious problems related to the reliability, the technical and economic security of electrical systems. Indeed, several distribution transformers are not installed at the center of gravity of the loads and most of the lines are very overloaded and very long. For the most part, the improvement of these distribution networks require heavy investments.

As result for the operation of these networks, it is noted excessive power losses that lead to a poor quality of service offered to customers and recurring equipment failures. Indeed, some studies have recently shown that losses in some networks are close to 13 to 20% [1]. The overall losses is technical and commercial losses and represent indicators of profitability and quality of the distribution networks. However, a loss of 1% in a distribution network increases the cost of the company by 2% in order to cover the costs incurred [2].

Technical losses are the resistive losses in the windings of the transformers and in the lines. They are inherent to the operation of networks. They can therefore be reduced but can not be eliminated. As for commercial losses, they consist of fraud on electricity meter, illicit connections, billing errors.

The Beninese Society of Electrical Energy (SBEE), operator of Benin's national electricity system, has in recent years opt for the generalization of prepayment metering systems in order to reduce non-technical losses and thus improve its cash-flow. In the implementation of this directive, it was very early faced with difficulties related to the catastrophic weakening of the voltage in some areas which is not supported by these new electronic meters.

These electricity meters would reduce non-technical losses normally and increase the financial profitability of the company.

The reduction of losses in electrical systems represents an economic interest for the electric power companies and contributes to the improvement of the voltage profiles.

The conventional means of voltage regulation in distribution networks, capacitors, regulators in charge of power transformers of source substations are nowadays unreliability to cope with the growing constraints of distribution networks hence the need to resort to solutions that optimize the operation of energy systems such as the use of devices based on power electronics components known as FACTS.

D-STATCOM, a component of this family of FACTS is the most widely used for efficiently reducing the line power losses, correcting power factor and improving voltage profile of distribution systems especially [3]. The D-STATCOM (Distributed-STATCOM) is a shunt connected voltage source converter which have more technical features such as fast response time, small footprint, high operational flexibility and excellent dynamic characteristics to meet various operating conditions.

However, its inappropriate placement for a node and / or inadequate sizing can limit its technical performance and more weaken the operation of the network in which it would be installed.

The installation and operation cost of D-STATCOM can also limit its application in networks [3].

For a quasi-weakened network in which a D-STATCOM is installed and which during its operation is to be defective, this network will then fall into a catastrophic situation hence the need to provide for redundancies in order to ensure the guarantee of maintaining voltage parofile in the contractual ranges and while seeking an optimality of the cost.

Nowadays, lots of research work is carried out for finding the optimal location of D-STATCOM in distribution systems but few have looked into

the question of the number of D- STATCOMs in distribution networks.

Indeed, in [4], an analytical method has been developed for determining the optimum position of a D-STATCOM in a distribution network. The proposed method was tested in a 33 bus radial distribution system.

Jain et al. [5] proposed a voltage sensitivity-based method for voltage profile and losses improvements by a D- ST

Tolabi et al. [6] applied fuzzy-based ant colony optimization (ACO) for optimal allocation of photovoltaic arrays and D-STATCOM.ATCOM.

In [7], Farhoodnea et al. used firefly algorithm to identify a D-STATCOM optimum position.

In [8], a hybrid of genetic algorithm and ant colony optimization algorithm were designed for optimal allocation of D-STATCOM's. Three D-STATCOMs was applied to IEEE 30-bus system.

In this paper an effective algorithm based on ant colony behavior is developed in MATLAB for giving optimal number, size and placement of D-STATCOMs in radial distribution networks. The real 41-bus system of Togba of SBEE is taken as a test case in order to illustrate the proposed method.

II. OPERATING ISSUES IN DISTRIBUTION NETWORKS OF SBEE

The operation of the SBEE's distribution networks generates technical losses exceeding the operating network limits and which are an origin of the poor quality of voltage profiles. Indeed, these losses are due to overloads on distribution transformers, imbalances, the inadequacy of some line sections compared to the transit of load. Several customers connected to the SBEE's distribution system have concerns about the quality of the voltage served. Investments have not kept pace with population growth to the point where the limits of existing networks constraints were violate. Several household appliances are damaged by the drop in voltage. The investments to be made to renew certain old equipments of these installations require heavy budget means requiring the

support of financial partners. Given too long delays in implementing these assistance, it is necessary to resort to other innovative solutions for electrical systems optimization.

III. PROBLEM FORMULATION

The optimized criteria in this paper are the active losses in the networks, voltage deviations and cost of D-STATCOM under two constraints of voltage safety and thermal line safety.

A. Objective functions

Power losses

$$\min f_1 = \sum_{l=1}^{NL} R_l \left(\frac{P_l^2 + Q_l^2}{V_l^2} \right) \quad (1)$$

$$\min f'_1 = \sum_{l=1}^{NL} X_l \left(\frac{P_l^2 + Q_l^2}{V_l^2} \right) \quad (2)$$

R_l, X_l , are resistance and reactance of l th branch, P_l and Q_l are power losses of l th branch, V_l is l th node voltage, NL is number of overall branches.

Voltage deviation

$$\min f_2 = \sum_{i=2}^N \left(\frac{V_i - V_i^{sp}}{V_i^{max} - V_i^{min}} \right)^2 \quad (3)$$

V_i^{max} and V_i^{min} are the voltage limits of nodes, V_i is i th node voltage, N is number of overall nodes, V_i^{sp} is i th specified node voltage.

Installation and operating cost

The installation and operating cost of D-STATCOM in a distribution network is a very important factor and could limit the operators in their choice. This criterion includes the cost of installation, operation and the annual maintenance cost.

$$\min Cop = \sum_{y=1}^{y_{life}} C_{ann} \left(\frac{100 + \lambda}{100} \right)^{y-1} + k_q * Q_c \quad (4)$$

Cop : the total operating cost (USD)

C_{ann} : the annual maintenance cost (USD)

λ : the annual percentage increment of the maintenance cost (%)

y_{life} : the lifetime of the D-STATCOM to be installed (years)

k_q : the per unit cost of the reactive power (USD / kVar)

Q_c : the size of the reactive power of D-STATCOM to be installed (kVar)

B. Constraints

Safety constraint on node voltages

While safeguarding the distribution system, all voltages must be maintained in such a range that the rate of weak nodes is equal to zero. Indeed, the RUVMN [9] is defined as the rate of the weak nodes in the network, the rate of the nodes not having their voltage in the range $\pm 5\%$ of the nominal voltage. Explicitly, the RUVMN at the i th iteration is written :

$$RUVMN_i = \frac{n_{in_i}}{n_T} \quad (5)$$

n_{in_i} : the number of weak nodes at i th iteration

n_T : the overall nodes of network

This equality constraint is defined as :

$$g_1 = RUVMN_i = 0 \quad (6)$$

Current constraint

$$g_2 = \frac{I_i}{I_{max_i}} < 1 \quad (7)$$

I_i : the current flowing through the i th branch

I_{max_i} : the maximum allowable current of the i th branch.

The losses minimization in distribution network require load flow which is an important and basic method for analysis, operation and planning

studies of any power system in a steady-state condition.

IV. RADIAL DISTRIBUTION SYSTEM LOAD FLOW

The load flow is an important tool for planning energy system. It shows stats of voltages, currents and losses, and if they are in normative ranges for expected future loads. The information provided by the load flow computation is the active and reactive power losses, voltage amplitude and their phases. Power flow equations are nonlinear and classical resolution methods, including Gauss Seidel, Newton Raphson and fast decoupled method that converge easily for transmission networks are not easy for radial distribution networks due to high R/X ratio for distribution networks.

A. Backward and Forward Sweep load flow

The backward / forward sweep is one of load flow computation method which converges very well for radial distribution networks. It is based on the laws of ohm and Kirchhoff and can be considered from the family of iterative methods of power flow. It requires the recognition of the network by the construction of a configuration matrix and then the application of a two-step process consisting of backward sweep to compute the powers in all the branches, the currents and the losses then a forward sweep to compute voltage profiles of network. Once the new values of voltages of all nodes are computed, the convergence criterion is checked. The convergence criterion is, in successive iterations, the maximum difference in voltage magnitudes.

B. Modeling of load flow

The distribution networks have a radial structure with low reliability and their operating voltages are between 1kV and 50 kV. At these voltage levels, only resistors and inductors predominate and capacitors are negligible. They consist of a number of branches and each branch is composed of a resistor and an inductor as shown in Figure 1.

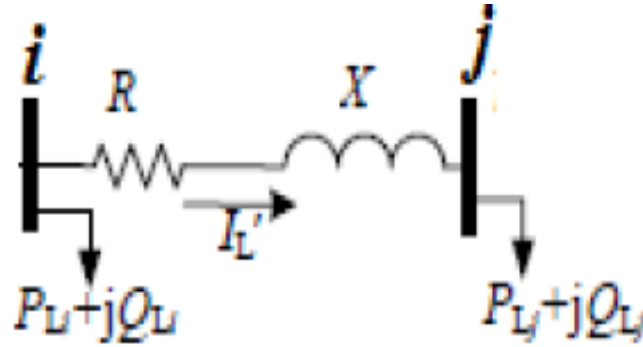


Figure 1 : Single line diagram of distribution network

The impedance of the whole branch of the electrical network has for expression :

$$\bar{Z}_i = R_i + jX_i \tag{8}$$

The apparent power of the load connected to *i*th node is :

$$\bar{S}_i = P_i + jQ_i \tag{9}$$

$$P_i = P_{Li} + P_{di+1} \tag{10}$$

$$Q_i = Q_{Li} + Q_{di+1} \tag{11}$$

P_{di+1}, Q_{di+1} : active and reactive powers at the beginning of the outgoing branch of the *i*th branch

$$P_{di} = P_i + P_{lossi} \tag{9}$$

$$Q_{di} = Q_i + Q_{lossi} \tag{10}$$

$$\frac{S_{di}^*}{V_{i-1}} = \bar{I}_i \tag{11}$$

$$P_{lossi} = R_i \frac{P_i^2 + Q_i^2}{V_i^2} \tag{12}$$

$$Q_{lossi} = X_i \frac{P_i^2 + Q_i^2}{V_i^2} \tag{13}$$

P_{di}, Q_{di} : active and reactive powers at the beginning of the *i*th branch

S_{di}^* is the conjugate of S_{di}

P_{lossi}, Q_{lossi} : active and reactive power losses

The currents in the different branches being determined, node voltages are computing by :

$$\bar{V}_i = \bar{V}_{i-1} - \bar{Z}_i \bar{I}_i \tag{14}$$

\bar{V}_{i-1} is the node voltage of the incoming node of the *i*th branch

Finally, the convergence criterion is :

$$10^{-4} \text{ p.u}$$

C. Test on real 41-bus system of Togba of SBEE

The single line diagram of Togba of SBEE, 15kV, 41-bus, has a 19 MVA - source substation and is shown in Figure 2.

This distribution system is applied to the load flow program and results are shown in Figure 3.

It can be seen that the lowest voltage is 0.8498 p.u at node 37 and the maximum voltage is 0.9999 p.u at node 2. The active and reactive losses are respectively 403.3832kW and 355.4047kVar.

This HVA network is out of balance because there are 24 nodes whose voltages are not in the normative ranges of 0.95 p.u to 1.05 p.u as shown in Figure 3.

Customers connected to distribution transformers whose voltages are out of range will not be properly powered. In most cases, the operators, in their attempt to correct the voltage offered to customers, have already settled the plugs of these transformers at the last positions.

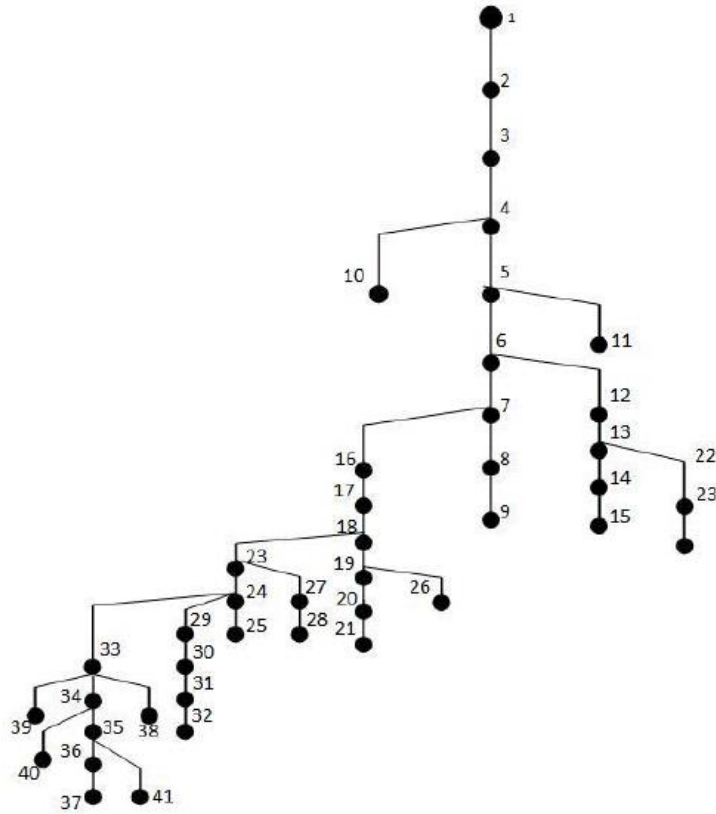


Figure 2 : Single line diagram of 41-bus system of Togba of SBEE

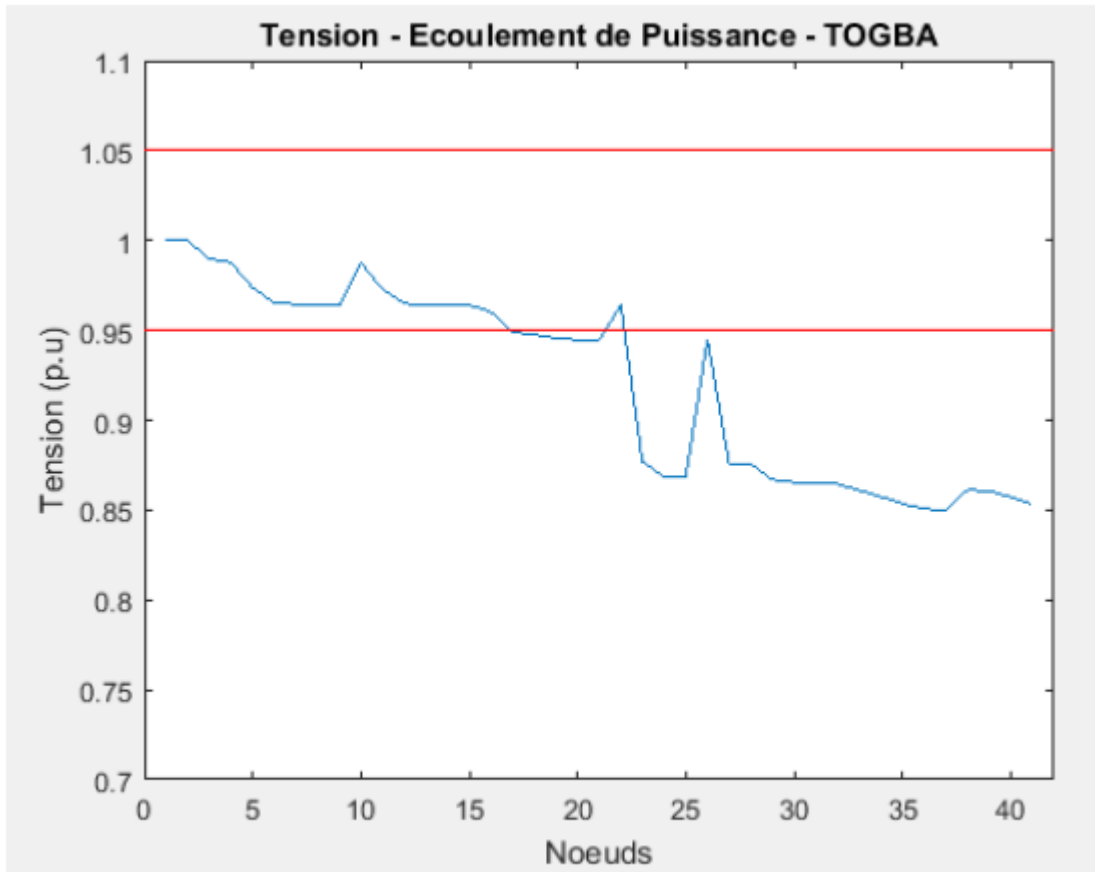


Figure 3 : Voltage profile in uncompensated Togba 41-bus network

V. OPTIMAL PLACEMENT OF MULTIPLE D-STATCOMS IN DISTRIBUTION NETWORK

The optimal placement of a D-STATCOM in a distribution network enhance performance of this network. Indeed, properly placed on a node, it reduces harmonics, compensates voltage fluctuations and helps to reduce losses.

However, sometimes, only one D-STATCOM can not be effective for a network whose almost all the node voltages are out of normative range. Then, the performance of system will become more damaged if a damage occurred on the only

one installed. Hence, it would be interesting to proceed to the optimal placement of multiple D-STATCOMs in the distribution networks.

A. Steady-state modeling of D – STATCOM

D-STATCOM is a shunt device which has the capability to inject or absorb reactive current. Its use on the distribution networks is more interesting because its power is proportional to the voltage rather than the square of the voltage as for a capacitor [9]. The model of D-STATCOM then consists of a DC voltage source (capacitor), an AC voltage converter and a network coupling transformer as shown in Figure 4.

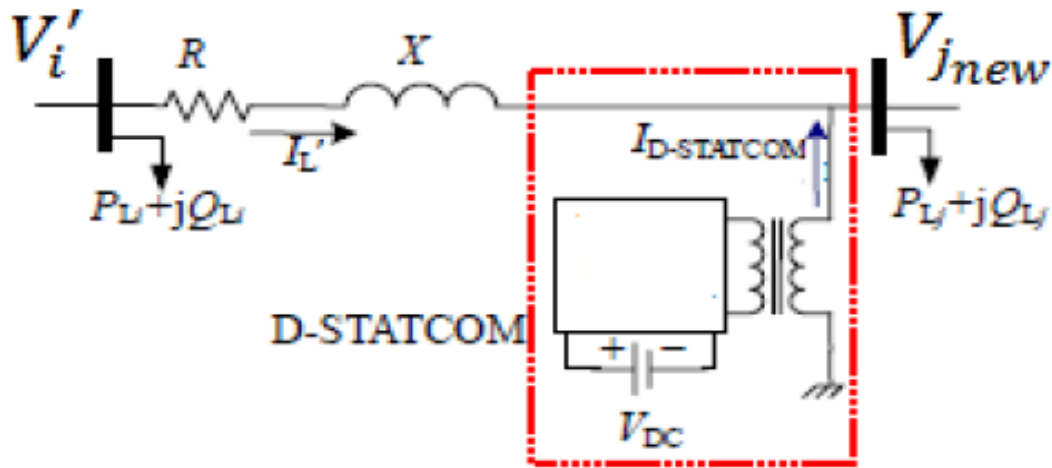


Figure 4 : Single line diagram of two bus distribution system with DSTATCOM

The Figure 4 shows an elementary network of two nodes of a distribution network on which the D-STATCOM is installed at the *j*th node for voltage profile regulation.

The voltage at this node *j* changes from V_j to V_{jnew} when the D-STATCOM is set, and the phase diagram of system is shown in Figure 5.

$$\angle I_{DST} = (\alpha_{new} + \pi/2), \alpha_{new} < 0 \tag{15}$$

$$V_{jnew} \angle \alpha_{new} = V_i' \angle 0 - (R + jX) I_L' \angle \theta' - (R + jX) I_{DST} \angle (\alpha_{new} + \pi/2) \tag{16}$$

with $I_{DST} \angle (\alpha_{new} + \pi/2)$ et $V_{jnew} \angle \alpha_{new}$ which are respectively the current injected by the D-STATCOM and the voltage at the node *j* after compensation; $V_i' \angle \delta'$ et $I_L' \angle \theta'$, the voltage at the node *i*, respectively the current transit of branches after placement of D-STATCOM. $V_i' \angle \delta'$ et $I_L' \angle \theta'$ are obtained by power flow computation.

Separating real and imaginary parts from equation (16) :

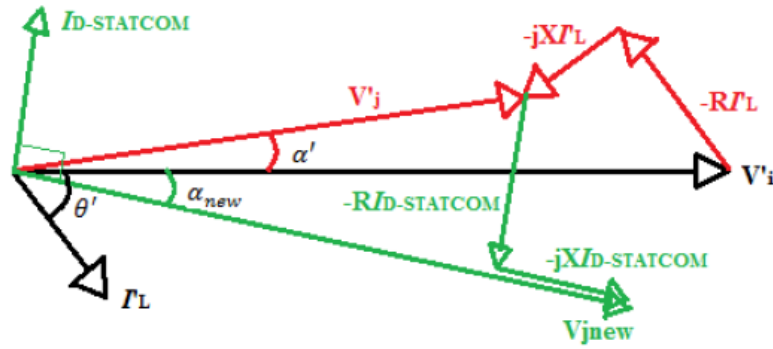


Figure 5 : Phasor diagram of voltages and currents of system

$$V_{jnew} \cos \alpha_{new} = \text{Re}\{V_i' \angle 0 - (R + jX)I_L' \angle \theta\} - R I_{DST} \cos(\alpha_{new} + \pi/2) + X I_{DST} \sin(\alpha_{new} + \pi/2) \quad (17)$$

$$V_{jnew} \sin \alpha_{new} = \text{Im}\{V_i' \angle 0 - (R + jX)I_L' \angle \theta\} - R I_{DST} \sin(\alpha_{new} + \pi/2) - X I_{DST} \cos(\alpha_{new} + \pi/2) \quad (18)$$

Using the notations below :

$$\begin{aligned} d &= V_{jnew} \\ a &= \text{Re}\{V_i' \angle \delta - (R + jX)I_L' \angle \theta\} \\ b &= \text{Im}\{V_i' \angle \delta - (R + jX)I_L' \angle \theta\} \\ c_1 &= -R \\ c_2 &= -X \end{aligned}$$

Variables :

$$\begin{aligned} x_1 &= I_{DST} \\ x_2 &= \alpha_{new} \end{aligned}$$

Then, equations (17) and (18) become respectively equations (19) and (20) :

$$d \cos x_2 = a - c_1 x_1 \sin x_2 - c_2 x_1 \cos x_2 \quad (19)$$

$$d \sin x_2 = b + c_1 x_1 \cos x_2 - c_2 x_1 \sin x_2 \quad (20)$$

We can obtain respectively in equations (19) and (20) :

$$\begin{aligned} x_1 &= \frac{d \cos x_2 - a}{-c_1 \sin x_2 - c_2 \cos x_2} \\ x_1 &= \frac{d \sin x_2 - b}{c_1 \cos x_2 - c_2 \sin x_2} \end{aligned}$$

By equating equations (21) and (22) and considering $x = \sin x_2$, we can observe, after an arrangement, the following :

$$\{(ac_2 - bc_1)^2 + (ac_1 + bc_2)^2\}x^2 + 2dc_1(ac_2 - bc_1)x + \{d^2c_1^2 - (ac_1 + bc_2)^2\} = 0 \quad (23)$$

$$\Delta = B^2 - 4AC$$

Where,

$$\begin{aligned} A &= (ac_2 - bc_1)^2 + (ac_1 + bc_2)^2 \\ B &= 2dc_1(ac_2 - bc_1) \\ C &= d^2c_1^2 - (ac_1 + bc_2)^2 \end{aligned}$$

Thus,

$$x = \frac{-B \pm \sqrt{\Delta}}{2A} \quad (24)$$

where $x = \sin x_2$

After testing network balancing conditions, value of x is :

$$x = \frac{-B + \sqrt{\Delta}}{2A} \quad (25)$$

Therefore,

$$x_2 = \arcsin(x) \quad (26)$$

where $x_2 = \alpha_{new}$.

Then, $x_1 = I_{DST}$ is defined from equations (21) or (22). After determining x_2 and x_1 in this order and from the equations respectively (26) and (21), we can so define the following :

$$V_{j_{new}} = V_{j_{new}} \angle \alpha_{new} \tag{27}$$

$$\overline{I_{DST}} = I_{DST} \angle (\alpha_{new} + \pi/2) \tag{28}$$

Finally, injected reactive power Q_{DST} by D-STATCOM can be written as :

$$jQ_{DST} = \overline{V_{j_{new}}} \times \overline{I_{DST}} \tag{29}$$

where $\overline{I_{DST}}$ is the conjugate of complex current of D-STATCOM.

The D-STATCOM is modeled such that the amplitude of the voltage of the node where it is installed is assumed to 1 p.u. The phase of this node is compute by equation (26), the injected current is computed by equation (21) and the reactive power injected is determined by equation (29).

B. Ant Colony Algorithm

Ants are social insects whose physical or behavioral characteristics have long fascinated humans. The mode of communication, the most prominent in ants is their use of chemicals called pheromones. Pheromones are hydrocarbon mixtures secreted by ants, which are able to deposit their odors on their way and constitute an attractive trace for other ants. Pheromones, depending on their composition, have the property of evaporating more or less quickly with time and a trace that is not maintained is brought to disappear. In case of alarm, pheromones can mobilize a large number of ants to trigger the nest defense.

The ant algorithm is a probabilistic technique that solves difficult optimization problems. It can be reduced in search of the shortest path through graphs based on the behavior of the ants which in their displacement mark the way with pheromones [10]. The shortest path is the most marked by pheromones. The first algorithm was developed in 1991 and then many variants of this principle have been developed such as Max Min Ant System [11].

C. Adaptation of Ant Colony Algorithm to the problem of D-STATCOM placement in electrical network

Ant colony optimization is a metaheuristic method that is inspired by the synergy observed in real ants and that is able to select the shortest way to get from the nest to a food source through the deposition and tracking of pheromones. This optimization problem is put in the form of a graph G such that $G = (n, C)$ where n is the set of nodes and C the set of paths given by active losses in the branches. However, the paths connecting two sets of nodes not successive are not eligible because they can't present losses. High values are assigned to these ineligible paths to get them out of the basic potential solutions. In practice, ant colony algorithms have been implemented on complete graphs, i.e. where each node is connected to all other nodes. This avoids dead ends in the construction of the cycle. If the configuration of the problem requires that some arcs be avoided, rather than eliminate them, as in our example, it is enough to assign them a very large length, so that the ants borrowing them are disadvantaged. From the practical point of view, at each arc (i, j), we associate a quantity of pheromones noted τ_{ij} and we define the probability that the ant k placed in node i choose the node j.

$$p_{ij}(t) = \begin{cases} \frac{(\tau_{ij}(t))^\alpha \cdot (\eta_{ij})^\beta}{\sum_{l \in j_i^k} (\tau_{il}(t))^\alpha \cdot (\eta_{il})^\beta} & si j \in j_i^k \\ 0 & si j \notin j_i^k \end{cases} \tag{32}$$

η_{ij} visibility of ant :

α and β pheromone and visibility influence parameters After a complete turn (T^k), each ant leaves amount of pheromone $\Delta\tau_{ij}^k(t)$ on its entire path, which depends on the quality of the solution found.

$$\Delta\tau_{ij}^k(t) = \begin{cases} \frac{Q}{L^k(t)} & si (i,j) \in T^k(t) \\ 0 & si (i,j) \notin T^k(t) \end{cases} \tag{33}$$

Table 1 describes the ant algorithm proposed for multiple placements of D-STATCOMs.

Table 1 : Proposed Ant Colony Algorithm

Algorithm (1) : Developed Ant Colony Algorithm

Cost_of_Best_Previous_Solution(CBPS)

Cost_of_Best_Current_Solution(CBCS)

CBPS = 1.000.000 // High value

$n_{DSTATCOMs} = 0$

- 1) Do while (CBCS < CBPS)
 - 2) Update CBPS after comparing previous and current solutions
 - 3) $t = 1$
 $n_{DSTATCOMs} = n_{DSTATCOMs} + 1$
 Initialize pheromones: $\tau_{ij} \leftarrow \tau_0 \forall i, j = 1, \dots, n$
 Initialize an array of $n_{DSTATCOMs}$ positions to find
 - 4) For each ant $k = 1$ to m

 Build a cycle $T^k(t)$
 Find $n_{DSTATCOMs}$ positions in the current cycle
 Evaluate size of the D-STATCOMs at the positions found and the power flow of network with the D-STATCOMs placed at the positions found
 - 5) For each ant $k = 1$ to m

 Compute cost function $L^k(t)$ of $T^k(t)$
 Update the best global solution
 - 6) For each arc (i, j)

 Update pheromones τ_{ij} while confining them in $[\tau_{min}, \tau_{max}]$
 - 7) $t = t + 1$

 If $t < NC_{max}$ then
 Go to step 3
 else
 Update the whole best solution found (CBCS)

End while

Return the best solution that is the previous best solution (CBPS)

Table 1 presents the main parameters used in the ant algorithm developed for the multiple placement problem of D-STATCOMs.

Table 2 : Main parameters of the developed ant algorithm

Parameters	Values
Max number of iterations	100
Size of the colony	41
α	1
β	2
Q	100
pMin	0,0005
pMax	0,7
ρ	0,05
λ_1	0,5
λ_2	0,3
λ_3	0,2

VI. SIMULATION AND RESULTS

The developed Ant algorithm is tested on IEEE 33-bus radial distribution system, 12.6kV, 3.72 MW and 2.3 MVars. Its bus data and line data is given in [1].

Table 3 shows the results obtained after placement of multiple D-STATCOMs. In first, it is observed on the 33-bus system that the D-STATCOMs are positioned at nodes 32, 30, 14, 16 and 18 with respective powers of 805.67kVAR - 3.34MVAR - 1.002MVAR - 808.04kVAR - 340kVAR and the losses have become 110.95kW with an optimal cost of 3546762.35 dollars over 20 years.

Figure 6 shows, in reduced values, the voltage profiles on 41-bus system of Togba without D-STATCOM and after placement of multiple D-STATCOMs.

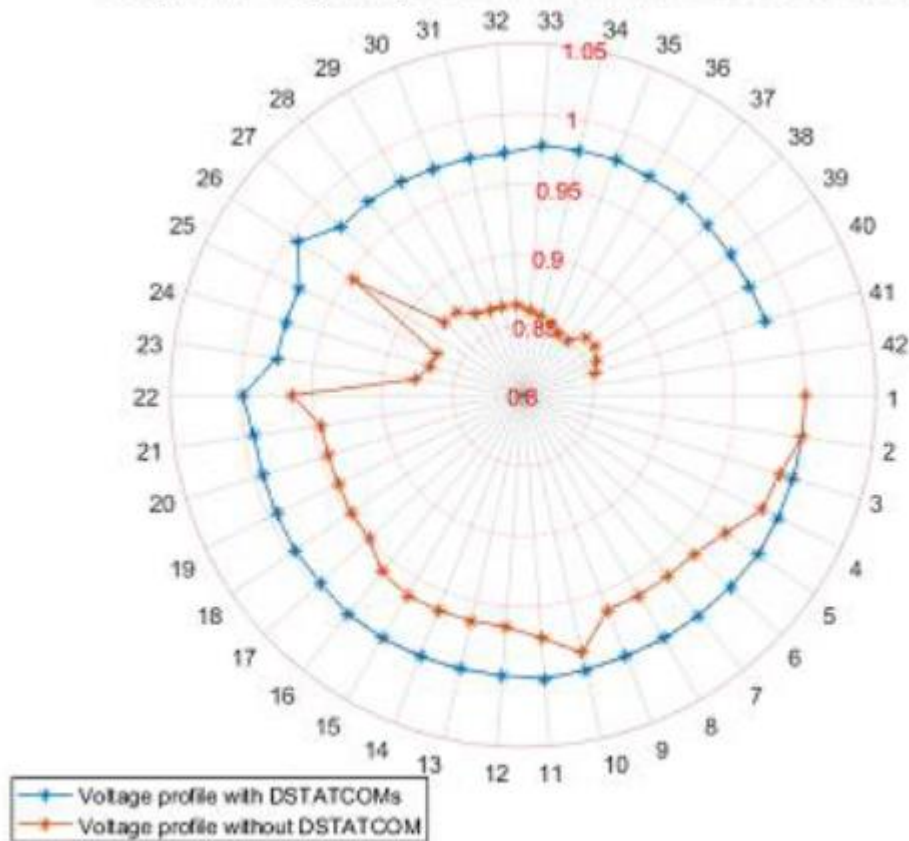
Comparison of system performance before and after DSTATCOMs

Figure 6 : Comparison of voltage profile of 41-bus network before and after placement of multiple D-STATCOMs

From Figure 6, it is observed that all node voltages are significantly enhanced and losses are reduced by 61.63%.

For a 20-year operation, the optimal investment cost is estimated at 2493146.29 dollars. The placement of multiple D-STATCOMs in a distribution network has the advantage of securing the node voltages in the standards in case of a damage on any of the D-STATCOMs positioned. This redundant arrangement normally prevents the network from falling back into a disaster state in the event of any anomaly occurring on one of the installed devices.

From the simulation of the damages that could occur on the D-STATCOMs, it is noted as shown in Table 4 that, when the D-STATCOM of the node 12 is disconnected from the network, active losses become 156.74kW, a proportion of degradation of 1.27%. On the other hand, when the D-STATCOM at position 36 is disconnected,

where the D-STATCOMs at nodes 14, 12 and 38 are in the network and connected, the losses amount to 180kW, i.e. a proportion of 16.3% of degradation. Position 36 is a strategic node of the network. A possible damage of D-STATCOM of the position 36 destabilizes the network but does not bring it back to its initial state where 24 nodes were weak, out of normative ranges. The multiple placement of D-STATCOMs limits the critical degradation of the technical performances in case of possible D-STATCOM damage. Multiple placement of D-STATCOM limits critical damage in the event of a possible D-STATCOM failure.

VII. CONCLUSION

The proposed method in this paper is tested on IEEE 33-bus system and on real 41-bus system of Togba of SBEE. From the obtained results, it can be noted that the optimal sizing and multiple placement of D-STATCOMs in distribution networks contribute for efficiently minimizing of

losses and improving the voltage profiles. With the multiple placement of D-STATCOMs in distribution networks, the security and the stability of node voltages are almost assured

around the strategic node of the network and turns out to be in the case of the network 41-bus of Togba, the node 36.

Table 3 : Comparison of power flow results before and after placement of multiple D-STATCOMs

	IEEE 33-bus system		Togba 41-bus system (SBEE)	
	Reference [1]	Proposed method (ACO)	Without DSTATCOM	With DSTATCOMs (ACO)
Size of DSTATCOM (MVar)	3,386	805,67kVAR 3,34MVAR 1,002MVAR 808,04kVAR 340kVAR	-	814,30kVAR 927,41kVAR 589,49kVAR 2,1MVAR
Number of DSTATCOM	1	5	-	4
Optimal position of DSTATCOM	30	32 -30-14-16-18	-	14- 12 -38-36
Installation and operating Cost (Dollars)	-	3546762.35	-	2493146.29
Active losses (kW)	143.03	110.95	403.38	154.77
Losses reduction (%)	29.15	22.42	-	61.63
Number of weak nodes	0	0	24	0

Table 4 : Impact of possible failure of a D-STATCOM on the electrical system

41-bus network (Togba-SBEE)				
Position of disconnected DSTATCOM	Remaining DSTATCOMs	Number of weak nodes	Active losses (kW)	Degradation (%)
12	14 – 38 - 36	0	156.74	1.27
14	12 – 38 - 36	0	156.50	1.11
38	14 – 12 - 36	0	160.48	3.68
36	14 – 12 - 38	18	180	16.30

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