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### Capacitor Placement Optimization of Power Distribution Network using Genetic Algorithm

For

### Choba Distribution Network, Port Harcourt.

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#### ABSTRACT

Power loss and poor voltage profile have been identified among the biggest problems facing the Port Harcourt power distribution. The high power loss has led to decreases in power availability thereby resulting to undesirable power outages. The study is aimed at presenting a distribution network with optimal placement of shunt capacitors using genetic algorithm to achieve substantial power loss reduction as well as voltage profile increment. The approach adopted is of two stages which are the loss sensitivity factor analysis and genetic algorithm. Loss sensitivity factor analysis is applied on load data obtained from the Port Harcourt Electricity Distribution Company through log book to determine optimum locations and sizes of shunt capacitors to be installed and then genetic algorithm is applied on load data working on MATLAB Simulink to run simulation. Simulation is investigated in the Port Harcourt Choba feeder and the result shows an annual power savings of N325, 435.56. Similarly, from the above network, there is a considerably high voltage improvement from 121volts to 142volts for minimum voltage.

**Keywords:** Load flow analysis, Optimization, Power system, Loss sensitivity factor analysis, Genetic algorithm.

#### **1.0 INTRODUCTION**

The Choba Port Harcourt power distribution system is currently faced with an epidemic of supply inadequacy typically arising from high power losses. Being of radial configuration, the network has very low supply reliability due to limitations inherent in radial networks as compared to loop and network configurations with higher reliability. In this regard, these enormous losses have led to depletion in power availability and therefore disrupting supply to both domestic and commercial consumers. Current research has revealed that reactive power in distribution system can lead to power losses and energy cost increment. On the other hand, the power equipment such as transformers, power switches and distribution lines are under overload and in order to solving these problems, capacitors are installed in power distribution networks. Capacitors are such economical devices providing required reactive power in the network and capacitor installation can decrease losses; improve voltage profile and freeing up the extra capacity of the generators. (Swarup, 2005)

In this paper, we study the performance of loss sensitivity factor analysis LSFA and genetic algorithm GA applied to the Port Harcourt Choba 30bus distribution network.

To identify the location for capacitor placement in distribution system, loss sensitivity factors have been used as it is able to predict which bus will have the biggest loss reduction when a capacitor is placed. Therefore, these sensitive buses can serve as candidate buses for the capacitor placement. (Ramachandra et. al 2010). GA is applied on load data to run simulations. A simple GA is an interactive technique which involves a stochastic transition rules applied and its five operators applied on each string during each generation to produce a new and improved population from the old one. A simple GA consists of five basic operators (representation or coding), evaluation string, reproduction (selection), crossover and mutation (Longson, 2016).

#### 2.0 LITERATURE REVIEW

Several works has reviewed in the literature investigating the various approaches and techniques adopted for the optimization of power distribution network. Maju and Leena (2016), Ogbogu and Anaemeje (2011) proposed that the goal of optimization of an electric power distribution system is to minimize objective functions subject to operational constraints of the power system. Claudius and Awosope (2014), Maju et al. (2016) revealed that one of the techniques that have been applied to reduce the losses in large distribution network is reconfiguration system which are meant for power losses mitigation.

Alao and Amoo (2014), Sanni and Airoboman (2011) mentioned that researchers have used different optimization approaches for network reconfiguration in the past to find the most configuration which suitable consists of that will contribute to minimized switches power losses as well as to improve active of the system. Presented power was a distribution network reconfiguration based on bacterial foraging optimization algorithm (BFOA) along with backward-forward sweep (BFS) load flow method and geographical information system (GIS) aimed at finding the radial structure that minimize network power loss while satisfying all operating constraints. performed on the Simulation was 33-bus system and the results were compared with other approaches. Rama and Sivangaraju (2010) analyzed network reconfiguration of distribution system using plant growth simulation algorithm with a view to enhancing speed and robustness of the system. The method was tested to reconfigure 69-node radial distribution system for loss minimization and load balancing.

Eze and Uzoechi (2016) presented a branch exchange method and derived a simple formula estimate reduction the loss with to reconfiguration algorithms based on the heuristic optimization techniques as realistic and powerful solution schemes to obtain the global or quasi global optimal. Oni (2015) discussed the application of modified form of particle swarm optimization as an optimization

technique to the reconfiguration of electric distribution systems. The work used a novel strategy for the reconfiguration of a distribution system through the use of an optimized reconfiguration and multi-objective particle swarm optimization (MOPSO). However, the algorithm did not perform well in terms of better convergence time.

In order to study the net effects of network reconfiguration in a distribution power system by changing the switching states of normally closed (sectionalizing) switches and normally opened (tie) switches, script codes were written in MATLAB and simulations was carried out on standard IEEE 13-bus and 25-bus distribution test feeder. The total active power and system losses were calculated by distributed power flow analysis and tabulated. Uzoechi et al. (2016), Anthony and Ojo (2013) An algorithm for distributed generation model proposed by Raju (2018):

1. [Start] Generate random population of n chromosomes (i.e. Suitable solutions for the problem).

2. [Fitness] Evaluate the fitness f(x) of each chromosome x in the population.

3. [New Population] Create a new population by repeating following steps until the new population is complete.

a. [Selection] Select two parent chromosomes from population according to their fitness (better

the fitness, bigger the chance to be selected).

b. [Crossover] with a crossover probability, crossover the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.

c. [Mutation] with a mutation probability, mutate new offspring at each locus (position in chromosome).

d. [Accepting] place new offspring in the new population.

i. [Replace] Use new generated population for a further run of the algorithm

ii. [Test] if the end condition is satisfied, stop, and return the best solution in current population

iii. [Loop] Go to step 2.

Bixby and Fenelon (2000) postulated that the efficiency of Mixed Integer Linear Programming (MILP) have been significantly increased mainly by the adoption of cutting-plane capabilities. Danna and Rothberg (2005) proposed that mixed integer quadratic programming (MIQP) is a special case of Mixed [Integer Non- Linear Programming (MINLP). At a first glance, the MIOP problem looks similar to the ordinary QP problem. There is however one important difference, the optimization variables are not only allowed to be real values, but also integer values. This "slight" modification turns the easily solved QP problem into an NPhard problem. A common special case of MIQP is when the integer variables are constrained to be 0 or 1.

#### **3.0 MATERIALS AND METHODS**

This section presents the details of the problem and the solution methods, loss sensitivity factor analysis and genetic algorithm on MATLAB Simulink.

3.1 Loss Sensitivity Factor Analysis LSFA

Loss sensitivity factor analysis is the first step in the optimization of a radial distribution network. LSFA is used to identify the location for capacitor placement in distribution system. LSFA is able to predict which bus will have the biggest loss reduction when a capacitor is placed. Therefore, these sensitive buses can serve as candidate buses for the capacitor placement. The estimation of these candidate buses basically helps in reduction of the search space for the optimization problem. As only few buses can be candidate buses for compensation, the installation cost of capacitors can also be reduced. Consider a distribution line with impendence R + jX and a load of  $P_{eff} + jQ_{eff}$ connected between 'I' and 'j' buses as given below.

Distribution lines with an impendence R + jX and a load of  $P_{eff} + jQ_{eff}$  connected between 'I' and 'j' buses as given below

$$S_j = P_j + Q_J S_J = P_j + Q_j \tag{1}$$



## Fig 1: Distribution line with impendence and a load

Real power loss in the line of the above Fig. 3.2 is given by  $[I_K 2]^*$  [R K], which can also be expressed as:

$$P_{lineloss} = \frac{(P_{eff(j)}^2 + Q_{eff(j) \times R_k}^2)}{(V[J])^2}$$
(2)

Similarly the reactive power loss in the line is given as

$$Q_{lineloss(j)} = \frac{P_{eff[j]}^2 + Q_{eff[j]}^2 \times X_K}{(V_j)^2}$$
(3)

Loss Sensitivity Factors can be calculated as

$$\frac{\delta P_{lineloss}(j)}{\delta Q_{eff(j)}} = \frac{(2 \times Q_{eff(j) \times R_k}}{(Vj)^2} \tag{4}$$

The Loss Sensitivity Factor ( $\delta$ Ploss / $\delta$ Qeff) as given in above equation, has been calculated from the base case load flows.

#### **3.2** Genetic Algorithm Solution

A GA is a meta- heuristic and interactive technique which begins with a randomly generated set of solutions referred as initial population. Genetic operators which are a stochastic transition rule, is applied by GA and these operators applied on each string during each generation to produce a new and improved population from the old one. A simple GA consists of five basic operators, which are (representation or coding), evaluation string, reproduction (selection), crossover and mutation. GAs generates a population of point at each iteration and the best point in the population approaches an optimal solution.

Random Generation:  

$$x_{ij} = x_{\min j} + rand[0, 1](x_{\max j} - x_{\min j})$$
(5)

Fitness Value (FV):  

$$x_{ij}^{j} = x_{ij} + \phi_{ij} \left( x_{ij} - x_{kj} \right)$$
(6)

Probabilistic FV solution selection:

$$prob_{i} = \frac{fitness_{i}}{\sum_{i=1}^{SN} fitness_{i}}$$
(7)

Where:

 $x_{ij}$  = Position of food source *i* in direction *j* 

 $x_{\min j}$  = Lower bound of  $x_i$  in direction j

 $x_{\max j}$  = Upper bound of  $x_i$  in direction jSN = Food source number D = Dimension of the problem

 $\phi_{ij}$  = Random number between -1 and +1  $fitness_i$  = Fitness value of solution *i* 

#### **3.3** Objective Function

The aim of this study is to find out the location and sizes of the shunt capacitor so as to maximize the net saving by minimizing the energy lost cost for a given period of time and considering cost of shunt capacitors. Therefore, the objective function consists of two main terms: energy loss cost and capacitors cost. Mathematical formulation of the terms used in objective function is given below: Term 1: Energy loss Cost (ELS);

If I, is the current of section –I in time duration T, then energy loss in section-i is given by

$$EL_i = I_i^2 \times R_i \times T \tag{8}$$

The Energy loss (EL) in time T of a feeder with n sections can be calculated as:

$$EL = \sum_{i=1}^{n} ELi$$
(9)

The Energy loss cost (ELC) can be calculated by multiplying equation (8) with the energy rate (Ce)

$$ELC = C_e \times EL \tag{10}$$

Where

Eli= energy loss (kW) in section –I in time duration T. L= current of section –i R= resistance of section –i

T = time duration Ce = energy rate

ELC = energy lost cost

Term 2 Capacitor cost (CC)

Capacitor cost is divided into three terms; constant installation cost, variable cost which is proportional to the rating of capacitors and annual maintenance cost. Therefore capacitor cost is expressed as:

$$CC = C_{ci} + C_m + (C_{cv} \times Q_{cv})$$
(11)

Where

Cvi =constant installation cost of capacitor Ccb = rate of capacitor per kVAr.

Qck = rating of capacitor on bus-k in kVAr.

Cm =Annual maintenance cost

The cost functions are obtained by combing equations (8) and (9). This cost function is considered as the objective function to be minimized in the present work. The cost function 'S' is therefore expressed as:

Minimize

$$S = Ce \times EL_i + C_{ci} + C_m + (C_{cv} \times Q_{ck}) \quad (12)$$

Constraint is represented by norm[i]= [V[i]/0.95<Vref

By minimizing the cost function, the net saving due to the reduction of energy loss for a given period of time including the cost of capacitors is given below.

$$Net Saving = BEL - CC$$
(13)

$$BEL = ELC_{(without \ capacitor) -} ELC_{(with \ capacitor)}$$
(14)

*Where* S= cost function for minimization. BEL is benefit due to energy loss reduction. ELC(*without capacitor*)= energy loss cost without capacitor.

ELC(*with capacitor*)= energy loss cost with capacitor.

CC= total capacitor cost as expressed by equation (9).

Experiments were conducted using the MATLAB Simulink

The simulation parameters are:

- 1. No. of generation G = 3 (1G = 100)
- 2. Population size = 100
- 3. Crossover probability pc=1
- 4. Mutation Probability Pm = 0.006
- 5. Energy rate = =N=24.91/kwh
- 6. Capacitor rate = =N=500/kvar
- 7. Capacitor installation = =N=1500/ unit
- 8) Annual capacitor maintenance cost= =N=20,000
- 9) Power availability of 24hours/day for 30days



### Fig.2: Single line diagram of case study

# 3.4 Network Power Flow Analysis before Optimization

From fig.2, the power flow in the network can be determined. Since the network is an existing one, direct measurement of load current at each node (bus), distance between nodes and area of network sections was taken. With the bus current known, the voltage and resistance at the far end can be calculated using equations (15) and (16) respectively.

$$V = Ri/Di \ge \sum_{i=1}^{n} (Ii \ge \sum_{i=1}^{m} Di)$$
(15)

Where

V = voltage at each node (volt)

I = load current measured (amperes)

D= measured distance between each bus (meters)

R= resistance calculated using

 $\rho = 2.65 \text{ x} 10^{-6}$ A = 100 x 10<sup>-6</sup>

where

 $R = \rho \frac{l}{c}$ 

l= distance between buses (meters)

A= Area of the network sections (Square meter)

R = Resistance at different nodes (ohms)

 $\rho$  = Coefficient of proportionality

With the above parameters and taking a power factor of 0.85, real power P and reactive power Q can be calculated as;

$$\mathbf{P} = \mathbf{IV} \times \mathbf{0.85} \tag{17}$$

$$Q = PSin (\cos' 0.85)$$

(18)

Power loss = 
$$\frac{Ri(Pi^2 + Qi^2)}{|Vi|}$$
(19)

Where P= Real power (KVA) Q = Reactive power (KVA)

Table 4.1 below shows the line and load data for 30 bus radial distribution network (RDN) with power losses in all buses. This table is formed with the above formulas and the measured load current values.

#### 4.0 RESULTS AND DISCUSSION Reference voltage = 220v

#### Table 1: Line and Load Data

Bus no	Load Current I(A)	Resistance R(ohms)	Voltage V(v)	Real Power P(kva)	Reactive Power Q(kva)	Power loss Pl(W)
1	23	0.03	219	4.3	2.3	12
2	25	0.07	217	4.6	2.4	27
3	18	0.11	215	3.3	1.7	27
4	16	0.13	213	2.9	1.5	25
5	19	0.18	210	3.4	1.7	49
6	17	0.21	206	2.9	1.5	43
7	28	0.24	199	4.7	2.4	138
8	21	0.29	193	3.5	1.8	99
9	27	0.32	184	42	2.2	170
10	24	0.35	176	3.6	1.8	151
11	26	0.38	166	3.6	1.9	185
12	30	0.41	154	3.9	2.0	272
13	20	0.46	145	2.4	1.3	133
14	27	.0.49	132	3.0	1.5	261
15	30	0.51	121	3.08	1.6	334
16	15	0.17	217	2.8	1.4	30
17	19	0.19	213	3.5	1.8	53
18	29	0.24	206	5.1	2.7	153
19	19	0.27	202	3.3	1.7	74
20	18	0.30	196	2.9	1.5	70
21	21	0.33	189	3.4	1.8	110
22	26	0.36	180	3.9	2.1	176
23	16	0.39	213	2.9	1.5	75
24	19	0.43	206	3.3	1.7	114
25	21	0.46	196	3.5	1.8	152
26	15	0.49	189	2.4	1.3	86
27	21	0.52	178	3.2	1.6	173
28	24	0.55	164	34	1.7	245
29	18	0.57	154	2.4	1.2	147
30	20	0.60	142	2.4	1.3	178
						3762

# Table 2: Optimal Capacitor location and sizing using LSFA

Bus no.	Capacitor Sizes
15	3
14	9
30	7
12	12
28	6
29	4

 13
 11

 27
 8

 11
 13

 22
 7

As shown in the above table, the buses with the highest loss sensitivity factor take the corresponding capacitor sizes from the optimal program.

### 4.1 The Optimization Result

The optimized Choba 30 bus radial distribution network is presented with capacitors of optimum sizes installed at optimum locations



Fig.3: Optimized network with capacitor





(6a)

700





## Fig. 5: Simulation interface after Capacitor Placements

### Table 3: Summary of Loss Reduction afterOptimization

Bus No	Loss without capacitor	Loss with capacitor	Loss reduction	% loss reduction
15	579	417	161	48
14	452	298	154	56
10	308	214	94	51
12	471	333	138	29
28	424	275	149	57
29	255	160	95	60
13	230	186	44	34
27	300	188	111	60
11	320	229	91	48
22	305	217	88	49

600 Loss Reduction 500 Loss without 400 capacitor 300 Loss with 200 capacitor 100 0 10 **Bus no.** 20 0

(6b)

Fig 6a-6b: Loss Reduction Graphs with and without Capacitors for Choba 30 Bus RDN



Fig. 7: Loss response to GA

1811

Table 5: Summary of 30 Bus Choba RDN withand without Capacitor

	Without Capacitor	With Capacitor
Total power loss in Kw	6.516	4.567
Minimum network voltage	121	142
Total annual lost cost	₩1,421,866.786	₩996,572.377
Total capacitor cost		₩40,000.00
Total capacitor installation cost		₩60,000
Annual Energy saving		=N= 325,294.409

As shown from table 5, there is an appreciable gain in energy lost cost for one year review. This gain can improve when more years are considered. The above table also shows the improvement in minimum network voltage when capacitors are installed in the network.

# Table 5: Voltage Profile Improvement withOptimal Capacitor Application

Bus No.	Voltage without Capacitor	Voltage with Capacitor
15	121	142
14	132	160
30	142	167
12	154	180
28	164	200
29	154	185
13	145	157
27	178	221
11	166	193
22	180	213



Fig. 8: Voltage improvement with and without capacitor of the 30 Bus Choba network



Fig. 9 Comparison graph of voltage with and without capacitor

# **4.2 Discussion of Simulation Result of 30 Bus Choba RDN**

Tables 3, 4 and 5 above shows the optimal solutions for power loss reduction, voltage profile improvement in the 30 Bus Choba RDN as well as show a reasonably high annual energy saving gotten from reduction of cost of energy lost..

From the above test case, it is clear that the developed algorithm and load sensitivity factor program is effective in producing the optimal loss reduction, voltage profile improvement and reduction of energy lost cost; hence the optimization objectives have been achieved.

### 5.0 CONCLUSION AND FUTURE WORK

This paper presents an approach for the optimization of distribution network by optimal placement of shunt capacitors using algorithm based on loss sensitivity factor and genetic algorithm. The algorithm presented in this study remarkable computation speed has and convergence speed compared to the other optimization methods. The method has been applied to a real network which is the Choba distribution network in Port Harcourt city and the simulation results show a considerable reduction in power loss and improvement in voltage profile as well. Also, simulation result show remarkable annual savings for energy lost cost.

Future work will further explore the potential of the proposed LSFA-GAS power distribution optimization approach for a the three phase unbalance distribution network. These studies should be conducted in comparison with other alternative technique.

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