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A GRAVITATIONAL SEARCH ALGORITHM-BASED OPTIMIZATION APPROACH APPLIED TO CAPACITOR PLACEMENT IN DISTRIBUTION SYSTEM

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ABSTRACT

The power distributed into the network has losses, which is greater in distribution system compared to transmission system. Capacitors have been employed to provide reactive power compensation in distribution systems to resolve this problem. These are used to reduce power losses and to maintain the voltage profile within acceptable limits. The benefit of compensation depends greatly on how the capacitors are placed in the system, specifically on the location and size of the added or placed capacitors. So for this adopts two methods where the first method being the sensitivity analysis and the second method is the Gravitational Search Algorithm (GSA). Sensitivity analysis is a methodical technique, which is used to reduce the search space and to arrive at an accurate solution for recognizing the locality of capacitors. Capacitor values are allocated for the respective locations using GSA. The performance of the proposed method is scrutinized on distribution systems. It is applied to IEEE-33 and it is found that power losses in distribution system have been minimized. Due to which a significant amount of annual savings maximized. The techniques has been implemented in MATLAB R2014b environment.

Keywords: CBs-Circuit Breakers, DGs-Distribution Generators, GSA - Gravitational Search Algorithm, PGSA – Plant Growth Search Algorithm, RDN-Radial Network

I. INTRODUCTION

Electrical energy is produced in generators, transformed to an appropriate voltage level in transformers and then dispatched via the buses on the transmission lines for final distribution to the loads. The circuit breakers allow the tripping of faulty elements and also sectionalizing of the system. High voltage is being generated, transformed, transmitted and distributed as three phase AC power. However AC power has several distinct disadvantages. In AC circuits, the power factor is the ratio of the real power that is used to do work and the apparent power that is supplied to the circuit. The power factor can get values in the range from 0 to 1. When all the power is reactive power with no real power (usually inductive load) - the power factor is 0. Reactive power is either generated or consumed in almost every component of the system, generation, transmission, and distribution and eventually by the loads. In fact, reactive power is a liability on the source because the source has to supply the additional current (i.e., I sinØ).

Most of the loads (e.g. induction motors, arc lamps, fluorescent lamps etc.) are inductive in nature and hence have low lagging power factor. The low power factor is not desirable as it cause an inflation in current, resulting in additional losses of active power in all the elements of power system from power station generator down to the utilization devices. In order to ensure most favorable conditions for supply system from engineering and economical standpoint, it is important to have power factor as close to unity as possible.It is economical to supply this reactive power closer to the load in the distribution system. This can be achieved by installing capacitor at appropriate location with suitable size. Capacitor Banks are commonly employed to provide reactive power compensation in distribution network. The installation of capacitor banks involves determination of size (kVAr ratings), location of capacitors. Selecting the best location for the capacitor will reduce the requirement of the reactive power, which consequently maximizes the net savings and also used to maintain voltage profile within permissible limits. To find out the potential locations for compensation, Loss Sensitivity Factors (LSFs) are used. These factors are computed using sensitivity analysis. Using LSF, the candidate number of buses are recognized. Gravitational Search Algorithm (GSA) employed in this paper is to choose the optimized capacitor settings to be installed in the respective candidate buses which are obtained through LSF. The proposed algorithm.

In 2015 Mohamed Shuaib adopted two method first was sensitivity analysis to find out the location of capacitor and second one was GSA that determined the size of placed capacitor. Computational outcomes showed that the proposed method is capable of generating optimal solutions.[1] K.R. Devabalaji et.al proposed a new long term scheduling for optimal allocation of capacitor bank in radial distribution system with the objective of minimizing power loss of the system subjected to equality and in equality constraints. In the proposed method the new integrated approach of Loss Sensitivity Factor (LSF) and Voltage Stability Index (VSI) were implemented to determine the optimal location for installation of capacitor banks. Bacterial Foraging optimization algorithm (BFOA) was proposed to find the optimal size of the capacitor in 2015. [2] During 2013 Mohd Sabri et.al analyzed a Gravitational Search Algorithm (GSA) which is a recent algorithm that hasbeen inspired by the Newtonian's law of gravity and motion. Sinceits introduction in 2009, GSA has undergone a lot of changes to thealgorithm itself and has been applied in various applications. The authors were intended to dig out the algorithm's current stateof publications, advances, its applications and discover its futurepossibilities. This review is expected to provide an outlook on GSAespecially for those researchers who are keen to explore thealgorithm's capabilities and performances. [3]

Shaw et al. in the year 2012 proposed a Gravitational search algorithm (GSA) that was based on the law of gravity and interaction between masses. Authors proposed a novel algorithm to accelerate the performance of the GSA. The analyzed opposition-based GSA (OGSA) of the work employed opposition-based learning for population initialization and also for generation jumping. In the presented work, opposite numbers have been utilized to improve the convergence rate of the GSA. The results obtained confirm the potential and effectiveness of the proposed algorithm compared to some other algorithms surfaced in the recent state-of-the art literatures. Both the near-optimality of the solution and the convergence speed of the proposed algorithm were promising.[4] In the year 2012 Mohammad Khajehzadeh and Mahdiyeh Eslami developed a heuristic global optimization algorithm called gravitational search algorithm (GSA). It is applied for the optimization of retaining structures. The comparison between the results of the new method and other algorithms indicated that, the proposed method could provide solutions of high quality, accuracy and efficiency and outperforms other methods for optimum design of retaining structure.[5] The success of Plant Growth Simulation Algorithm (PGSA) with loss sensitivity factor to solve optimization problem was applied to capacitor placement by R. Srinivasas Rao et.al in 2011, in which the objective function and the constraints separately handled and avoided the trouble to determine the barrier factors. The proposed method has outperformed the other methods in terms of the quality of solution. [6]

II. PROBLEM FORMULATION

The objective is to minimize the annual cost incurred due to kW losses and the annual cost due to capacitor installations, subjected to certain operating constraints. The objective function does not include the operation and maintenance costs of the capacitor placed in Radial network. The three phase system is considered as balanced and loads are assumed as time invariant.

Mathematically, the objective function of the problem is described as:

$$\min f = \min(COST) \quad (1)$$

Where COST is the objective function which includes the cost of power loss and the capacitor placement. The voltage magnitude at each bus must be maintained within its limits and is expressed as:

Voltage constraints will be taken into justification by stipulating the Lower and Upper bound between Vmin = 0.95 p.u. and Vmax = 1.0 p.u.

$$V_{min} \leq |V_i| \geq V_{max} \quad (2)$$

The total kW losses of RDN having 'N' buses and 'N-1' branches is given by:

$$P_{Totalloss} = \sum_{\substack{1 \leq n \geq N \\ 1 \leq m \geq N}} P_{mn\,(loss)} \quad (3)$$

The total energy loss cost (E_{cost}) has been calculated as:

$$E_{cost} = P_{Totaloss} * K_p \quad (4)$$

In general, the cost per KVAR varies with respect to their size. The available capacitor sizes and their cost (K) were given in table 1. The total cost of the distribution system is given in Eq. (5).

$$C = E_{cost} + C_{qcost} \quad (5)$$

Where,

$$C_{qcost} = K_{fc}^{c} * Q_i \quad (6)$$

The percentage saving of the annual operating cost has been calculated using the Eq. (7) shown below,

$$\%saving = \frac{(inital\ operation\ cost - final\ operating\ cost)}{(initial\ operating\ cost)} \quad (7)$$

The mathematical statement of the problem can be conveyed by the following expression. [1]

$$Minimize\ F\left[\sum(P_{Totalloss}) * K_p\right] + [K_{fc}^{c} * Q_i] \quad (8)$$

III. OBJECTIVES

The objectives of thesis are summarized as:

1) To identify the optimal location and size of capacitors to minimize the losses and cost of power loss in radial distribution system.

2) Implementing Gravitational search Algorithm to find the optimal solution.

IV. METHODOLOGY

The solution methodology has two steps:

1) In first step sensitivity analysis [6, 7]is considered in order to reduce the search space and to arrive at an accurate solution for recognizing the locality.
2) In second step Gravitational Search Algorithm (GSA) is used to estimate the optimal size of capacitor.

Load flow

Load flow analysis is concerned with describing the operating state of an entire power system. Computational procedure required to determine the steady-state operating characteristics of a power system network is termed load flow. The aim of load flow calculations is to determine the steady state operating characteristics of power generation/transmission system for a given set of bus bar loads. The main information obtained from the load flow study is:

1) Magnitude and phase angles of load bus voltages
2) Reactive powers and voltage phase angles at generator buses
3) Real power and reactive power flow
4) Power at the reference bus

Here Newton-Raphson is used to calculate the losses of the network and power flows in the line. [8]

Sensitive analysis

The sensitivity analysis is a methodical technique to find out those locations with maximum influence on the system active power losses with respect to the node reactive power. Sensitivity analysis is carried out also to find the Loss Sensitivity Factor. The Loss Sensitivity Factoris so important that the candidate number of buses are recognized.

Loss Sensitivity Factor (LSF)

To identify the location for capacitor placement in distribution system Loss Sensitivity Factors is used. LSF 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 placement of capacitor. The estimation of these candidate buses basically helps in reducing of the search space for the optimization problem. As only few buses can be candidate buses for compensation, the installation cost on capacitor scan also be curtailed.

Consider a distribution line with an impedance (r + jx) and a load of (P_{eff}& Q_{eff}) connected between (i) and (j) buses. (P_{eff}& Q_{eff}) are the active and Reactive power beyond the receiving end bus.

KW loss in the line is given by ($I^2_{ij} * R_{ij}$), which can also be expressed as, [1]

$$P_{lineloss} = \frac{(P^2_{effj} + Q^2_{effj})*r_{ij}}{(V_j)^2} \quad (9)$$

Similarly the Reactive power loss in the line is given by:

$$Q_{lineloss} = \frac{(P^2_{effj} + Q^2_{effj})*r_{ij}}{(V_j)^2} \quad (10)$$

Where

P_{eff}= Total effective active power supplied beyond the bus ‘j’.

Q_{eff}= Total effective reactive power supplied beyond the bus 'j'.

Now, the Loss Sensitivity Factor (LSF) can be calculated as:

$$\frac{\partial P_{linelossij}}{\partial Q_{ij}} = \frac{2*Q_{effj}*r_{ij}}{(V_j)^2} \quad (11)$$

Algorithm for sensitivity analysis

Step 1: Calculate the Loss Sensitivity Factor:

$$LSF = \frac{\partial P_{loss}}{\partial Q} \quad \text{@ all the buses.} \quad (12)$$

Step 2: LSF in Descending Order: Arrange the value of Loss Sensitivity Factor in descending order. Also store the respective buses into bus position vector.

Step 3: Normalization: Calculate the normalized voltage magnitudes

$$\text{Norm (i)} = \frac{V[i]}{0.95} \quad \text{@ all the buses.} \quad (13)$$

Step 4: Choose Candidate Buses: The buses whose Norm (i) = $\frac{V[i]}{0.95}$ is less than 1.01 are selected as candidate buses for capacitor placement. [1]

Gravitational Search Algorithm (GSA)

In this chapter, GSA is applied to minimize the feeder losses in RDN. It is formulated as loss minimization problem subject to operational and electrical constraints. GSA is based on the law of gravity and mass interactions. The search agents are a group of masses which act together with each other based on the Newtonian gravity and the laws of motion. It consider agents as objects consisting of different masses. All the agents move due to the gravitational attraction force acting amongst them and the advancement of the algorithm directs the movements of all agents globally headed towards the agents with heavier masses. Every agent in GSA is specified by four parameters: Position of the mass in dth dimension, inertia mass, active gravitational mass and passive gravitational mass.

GSA algorithmic steps

Step 1: Initialization of the agents: Initialize the positions of the N number of agents randomly chosen within the given search interval using Eq. (14).

$$X_i = (x_i^1, \ldots, x_i^d, \ldots, x_i^n), \quad \text{For I = 1, 2, 3, …, N.} \quad (14)$$

Where x_i^d presents the position of ith agent in the dth dimension.

Step 2: Compute gravitational constant G: Determine gravitational constant G at iteration t using the Eq. (15).

$$G(t) = G_0 e^{(-\alpha t/T)} \quad (15)$$

Step 3: At a specific time't', we define the force acting on mass 'i' from mass 'j' as following:

$$F_{ij}^d(t) = G(t)\frac{M_{aj}(t) * M_{pi}(t)}{R_{ij} + \epsilon}(X_j^d(t) - X_i^d(t)) \quad (16)$$

Step 4: Fitness evolution and best fitness computation for each agent: Perform the fitness evolution for all agents at each iteration and also find the best and worst fitness at every iteration developed for minimization problems in the Eqs. (17) and (18).

$$best(t) = (min_{j \in \{1 \ldots N\}} fit_{j(t)}) \quad (17)$$

$$worst(t) = (min_{j \in \{1 \ldots N\}} fit_{j(t)}) \quad (18)$$

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Step 5: Calculate the mass of the agents: Find gravitational and inertia masses for each one of the agents at iteration (t) by the set of Eq. (17).

$$M_{ai} = M_{pi} = M_{ii} = M_i, i = 1, 2, \dots \dots N$$
$$m_i(t) = \frac{fit_i(t) - worst_i(t)}{best\,(t) - worst\,(t)} \quad (19)$$
$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)}$$

Step 6: Calculate accelerations of the agents: Compute the acceleration of the ith agents at iteration t, Eq. (20).

$$a_i^d(t)\frac{F_i^d(t)}{M_{ii}(t)} \quad (20)$$

The total force acting on ith agent is calculated as in Eq. (21)

$$F_i^d(t) = \sum_{j \in kbest, j \neq i} rand_j F_{ij}^d(t) \quad (21)$$

Step 7: Update velocity and positions of the agents: Compute velocity and the position of the agents at the next iteration (t + 1) using Eq. (22).

$$v_i^d(t+1) = rand_i * v_i^d(t) + a_i^d(t)$$
$$X_i^d(t+1) = X_i^d(t) + v_i^d(t+1) \quad (22)$$

Step 8: Reprise from Steps 2–7 until iterations reach their maximum limit. Return the best fitness computed at final iteration as a global fitness of the problem and the positions of the corresponding agent at specified dimensions as the global solution of that problem. [1, 9]

Table 1 Capacitor size & cost ($/kVAr)

Sr no.	Capacitor value	Capacitor cost
1	150	0.5
2	350	0.35
3	450	0.253
4	600	0.22
5	800	0.276
6	900	0.183
7	1050	0.228
8	1200	0.17
9	1350	0.207
10	1500	0.201
11	1650	0.193
12	1800	0.87
13	1950	0.211
14	2100	0.176

Table 2 GSA parameters

GSA parameters	33 Bus	141 Bus
N = number of agents	2000	1500
Max iteration	5,10,15,40	5,10,15,40
Alfa	20	20

The positions of N number of agents with ‘n’ number of capacitor values are initialized randomly using the values of capacitors given in Table 1.

The fitness of each population is calculated using the objective function and the population which has the best and worst fitness is taken into account for further calculations. The gravitational constant ‘‘G’’, the gravitational and inertial masses of each agent at each iteration and acceleration of the agents are calculated using Eq. (15), Eq. (19) and Eq. (20) respectively. Update the velocity and position for (t + 1) generation using the Eq. (22). Check whether the last iteration is reached or not. If not reached the new population is selected from the old population randomly.

To get an optimal solution using GSA algorithm, the list of parameters (Table 2) has been used to find optimum capacitor values due to which the resulting solution yields the minimum cost and the best voltage profile.

The performance of GSA in capacitor placement problem is estimated. Twenty independent trials have been made with 2000 agents and iterations (as per given in the table 2) per trial for 33 Bus test system. The value of Alfa (α) and the gravitational time constant (G_0) for all the cases are set to 20 and 100 resp.[1]

To calculate cost of power and the capacitor placement equation (8) is used. Value of K_p selected is 168 [6]. Values of k^c_{fc} are shown in Table 1. [1]

V. RESULTS ANALYSES

IEEE 33-bus system:

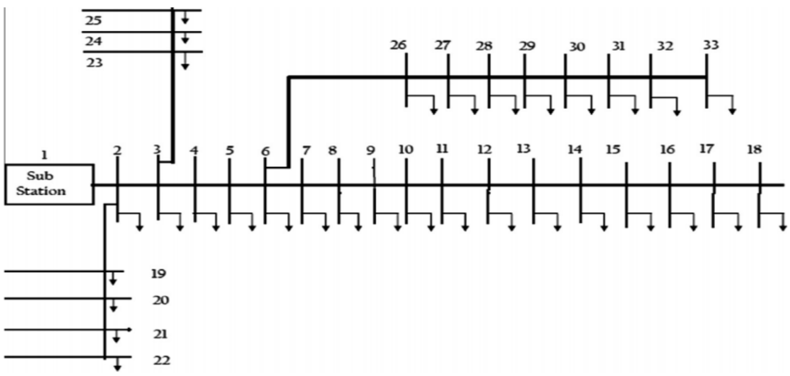

Fig. 1: Single line diagram of 33-bus system

Single line diagram of 33-bus system shown in Fig 1.

Using GSA following results are obtained:

Before compensation i.e., with no capacitors installed in Radial network, the kW loss is obtained as 205 kW. The annual cost incurred for 205 kW is calculated as $34,440.

Table 3 Results of 33-bus system

Items	Un-compensated	Compensated
Total Losses in KW	205.41	160.37
% Loss Reduction	-	21%
Candidate buses for capacitor placement	-	30, 8, 12
Optimal capacitor size in Kvar	-	350, 1050,450
kVAr Total		1850
Annual cost for kW loss (A) ($)	34,440	26,880
Annual capacitor cost (B) ($/kVAr)	0	475.75
Total annual cost ($) (C = A + B)	34,440	27,417.7534
Net savings ($) (D = 35442.96 - C)	0	7,023.2466
% Savings (E = D/35442.96)	0	20%

Using the proposed method, the capacitors of rating 350, 1050 and 450 kVAr are placed at the optimal locations 30, 8 and 12 respectively. The optimal locations are obtained by sensitivity analysis. As a result, the kW loss is reduced to 160.3691 kW from the base case of 205 kW witnessing a 21% of active power loss reduction as shown in Fig. 2. The yearly cost incurred for active power loss is calculated as $26,942.003. The amount spent over the installation of capacitors is been calculated as $475.75.

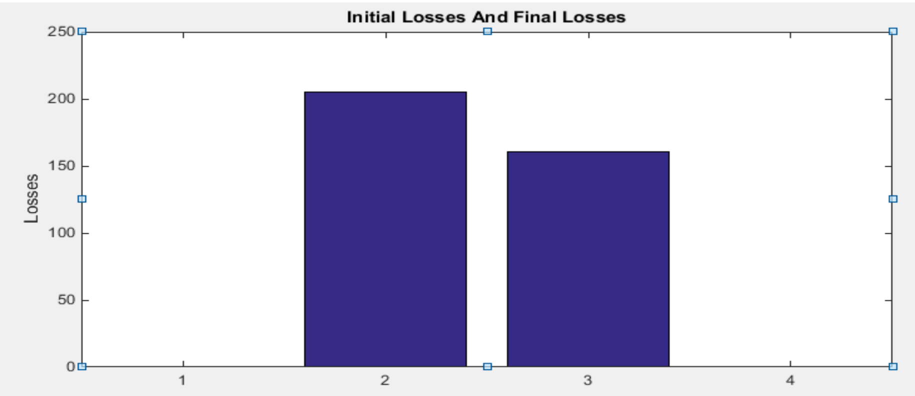

Fig. 2 losses for 33-bus system

Therefore, the overall annual cost will be the sum of yearly cost of kW loss and the annual cost of capacitor installed at optimal candidate buses. Net savings per year will be $27,417.75 which leads to 20% of net savings as shown in Fig. 3.

Fig. 2 represents the losses in KW of 33-bus network. On vertical axis losses are defined and on horizontal axis initial losses and final losses are defined.

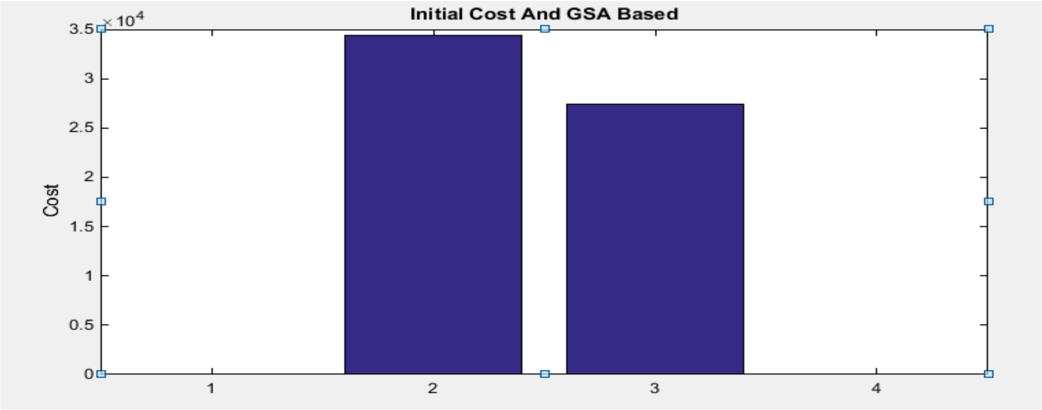

Fig. 3 cost for 33-bus system before and after compensation

Cost of 33-bus system shown in Fig 3. Vertical axis defines cost in $ and horizontal axis defines initial cost before compensation and final cost which is calculated with GSA.

VI. CONCLUSION

Thework has been carried out for identification of locations of capacitor to be placed and their size depending upon the requirement of reactive power. At first analysis has been implemented using sensitive analysis method to identify the buses which needs the capacitors most. In second step, GSA has been implemented to find out the size of capacitors. Coding scheme has been developed for above mentioned two steps. The methodology has been implemented for 33 – Bus system and 141 – Bus system. Following conclusions are drawn from the study.

1. The compensation is provided to minimize the losses.
2. The compensation is bearing in to the maximization of annual savings of cost of power losses.
3. The algorithm is effective in deciding capacitor placement and size of capacitors for different number of busses and for different sizes of capacitors

VII. FUTURE SCOPE

1. The work has been carried out for 33 bus system in distribution system. This allocation of capacitors can be extended to other bus system in distribution system.
2. For load flow analysis Evolutionary Computation Method can be used.

VIII. APPENDIX A. NOMENCLATURE

Kp equivalent annual cost of power loss in $/(kW-year)

$\mathbf{k^c_{fc}}$ cost of capacitor spent for one unit of kVAr (Cost/kVAr) or annual capacitor installation cost.

$\mathbf{Q_i}$ reactive power in (KVAR) or fixed capacitor bank rating placed at a candidate bus (kVAr).

M_{aj} active gravitational mass related to agent j.

M_{pi} passive gravitational mass related to agent i.

G(t) gravitational constant at time t, e is a small constant.

$R_{ij}(t)$ Euclidian distance between two agents i and j.

REFERENCES

[1] Shuaib Y.Mohamed, M. Srya Kalavathi and C.Christober Asir Rajan. "Optimal capacitor placement in radial distribution system using Gravitational Search Algorithm", Electrical Power and Energy Systems, Vol. 64, 2015, pp 384–397.

[2] Devabalaji K.R., K. Ravi and D.P. Kothari, "Optimal location and sizing of capacitor placement in radial distribution system using Bacterial Foraging Optimization Algorithm", Electrical Power and Energy Systems, Vol. 71, 2015, pp 383–390.

[3] Sabri Norlina Mohd, Mazidah Puteh, and Mohamad Rusop Mahmood, "A Review of Gravitational Search Algorithm", International Journal Advance Soft Computer Applications, Vol. 5, No. 3, Nov 2013, pp 2074-8523.

[4] Shaw Binod, V. Mukherjee and S.P. Ghoshal, "A novel opposition-based gravitational search algorithm for combined economic and emission dispatch problems of power systems", Electrical Power and Energy Systems, Vol.35, 2012, pp 21–33.

[5] Khajehzadeh Mohammad and Mahdiyeh Eslami, "Gravitational search algorithm for optimization of retaining structures", Indian Journal of Science and Technology Vol. 5 No. 1, jan 2012, pp 0974- 6846.

[6] Rao R. Srinivasas, S.V.L. Narasimham and M. Ramalingaraju, "Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm", Electrical Power and Energy Systems, Vol.33, 2011, pp 1133–1139.

[7] Huang Yann-Chang, Yang Hong-Tzer," Solving the capacitor placement problem in a radial distribution system using Tabu search approach", IEEE Trans Power Delivery, Vol.11, No. 4, 1996, pp 1868–73.

[8] Venkatesh B, Ranjan R,"Data structure for radial distribution system load flow analysis", IEEE Proc-Generation, Transmission Distribution, 2003, pp 150-10.

[9] Rashedi Esmat, Hossein Nezambadi-Pour and Saeid Saryazdi,"GSA: A Gravitational Search Algorithm", Information Sciences, Vol.179, 2009, pp 2232–2248.

[10] Hsiao Ying-Tung, Chen Chia-Hong, Chien Cheng-Chih,"Optimal capacitor placement in distribution systems using a combination fuzzy-GA metho",Elsevier International Journal Electrical Power & Energy System, 2004, 26(7):501–8.