# AN APPROACH BASED ON ANT COLONY OPTIMIZATION FOR DISTRIBUTION FEEDER RECONFIGURATION CONSIDERING DISTRIBUTED GENERATORS

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## ABSTRACT

*This paper presents an approach for distribution feeder reconfiguration considering Distributed Generators (DGs). Due to private ownership of DGs, a cost based compensation method is used to encourage DGs in active and reactive power generation. The objective function is summation of electrical energy generated by DGs and substation buses (main bus) in the next day. An Ant Colony Optimization (ACO) algorithm is used to solve the distribution feeder reconfiguration problem. The approach is tested on a real distribution feeder.*

## INTRODUCTION

Distributed generation, the small-scale production of electricity at or near customers' homes and businesses, has the potential to improve the reliability of the power supply, reduce the cost of electricity, and lower emissions of air pollutants. Distributed generation can come from conventional technologies, such as motors powered by natural gas or diesel fuel, or from renewable technologies, such as solar photovoltaic cells. Over the past two decades, declines in the costs of small-scale electricity generation, increases in the reliability needs of many customers, and the partial deregulation of electricity markets have made distributed generation more attractive to businesses and households as a supplement to utility-supplied power. The studies carried out by the research institutes indicate that the electricity generated by DGs will be about 25% of the new generations in the future [1]. Therefore, it is necessary to study their impacts on the power systems. The distribution systems are the first part of power systems, which can be affected by the DGs. The distribution feeder reconfiguration is one of the most important control schemes in the distribution networks that the impact of DGs on this problem should be studied. Generally, the distribution feeder reconfiguration is defined as altering the topological structure of distribution feeders by changing the open/closed states of sectionalizing and ties switches.
Many researchers have investigated distribution feeder reconfiguration [2]-[9]. In most of them, the impacts of DGs on distribution system performance have not been studied in detail yet. In this paper, the distribution feeder reconfiguration at distribution network considering DGs is presented. Since distribution feeder reconfiguration problem is a nonlinear optimization problem, one of the optimization algorithms should be used.
Evolutionary methods can be used to solve these sorts of problems owing to independence on the type of objective function and constraints. In this paper, an ant colony optimization is used to solve the distribution feeder reconfiguration in the distribution networks.
In the following, the formulation of the proposed distribution feeder reconfiguration, evaluation cost of DGs, ant colony optimization and simulation results are presented.

## DISTRIBUTION FEEDER RECONFIGURATION CONSIDERING DISTRIBUTED GENERATION

From a mathematical standpoint the reconfiguration of distribution network with regard to distributed generation is an optimization problem with equality and inequality constraints. The objective function is the summation of electrical energy generated by DGs and substation bus as follows:

$$Min \quad f(\overline{X}) = \sum_{t=1}^{N_d} \left\{ \sum_{i=1}^{N_{Sub}} P_{subs,i}\, \Delta t_t * MCP^{t} + \sum_{i=1}^{N_g} C_{Pgi}(P_{gi}^{\ t}) * \Delta t_t \right\} \qquad (1)$$

$$\overline{X} = [\overline{Tap}, \overline{U_C}, \overline{Sw}, \overline{\mathrm{P}_{\mathrm{Sub}}}, \overline{P_G}]$$

In above-mentioned equation:

$N_{sub}$ $N_c$, $N_g$, $N_{Sw}$, $N_{bus}$, $N_d$ and $N_t$ are the number of substations, capacitors, DGs, switches, buses, load variation steps, transformers respectively. ***t*** is an index which represents time steps of load level. $\overline{X}$ is the state variables vector. $\overline{Tap}$ is the tap vector representing tap position of all transformers for the next day. $\overline{P_{sub}}$ is the substation active power vector including active power of all substations for the next day. $\overline{U_C}$ *is* the capacitors switching state vector including state of all capacitors for the next day. $\overline{Sw}$ is the switching state vector including state of all switches for the next day. $\Delta t_t$ is

time interval. $MCP^{t}$ is the Market Clearing Price(MCP) for the t[th] load level step. $C_{Pgi}\left(P^{t}{}_{Pi}\right)$ is the cost of active power generated by the i[th] DG during time "t".
In this problem, it is assumed that tap position of transformers changes stepwise.
Constraints are defined as follows:

- active power constraints of DGs:

$$(P_{gi}{}^{t})^{2}+(Q_{gi}{}^{t})^{2}\leq S^{2}{}_{gi,\max} \qquad (2)$$

$P_{gi}{}^{t}$ and $S_{gi,\max}$ are active power for t[th] load level step and apparent power of i[th] DGs respectively.

- Distribution line limits:

$$\left|P_{ij}^{Line}\right|^{t} < P_{ij,\max}^{Line} \qquad (3)$$

$\left|P_{ij}^{Line}\right|^{t}$ and $P_{ij,\max}^{Line}$ are absolute power flowing over distribution lines and maximum transmission power between nodes $i$ and $j$ respectively.

- Tap of transformers:

$$Tap_{i}^{\min} < Tap_{i}^{t} < Tap_{i}^{\max} \qquad (4)$$

$Tap_{i}^{\min}$, $Tap_{i}^{\max}$ and $Tap_{i}^{t}$ are the minimum, maximum and current tap positions of the $i^{th}$ transformer respectively.

- Unbalanced three-phase power flow equations.
- Maximum allowable daily operating times of transformers:

$$DOT_{i}^{Trans} \leq MADOT_{i}^{Trans} \qquad (5)$$

$DOT_{i}^{Trans}$ and $MADOT_{i}^{Trans}$ are the daily operating times and maximum allowable daily operating times of the i[th] transformer respectively.

- Maximum allowable daily operating times of capacitors:

$$\sum_{t=1}^{Nd} U_{ci}^{t} \leq MADOT_{i}^{Cap} \qquad i=1,2,3,\ldots,Nc \qquad (6)$$

$MADOT_{i}^{Cap}$ is the maximum allowable daily operating times of the i[th] capacitor.

- Substation power factor

$$Pf_{\min} \leq Pf^{t} \leq Pf_{\max} \qquad (7)$$

$Pf_{\min}$, $Pf_{\max}$ and $Pf^{t}$ are the minimum, maximum and current power factor at substation bus during time t.

## EVALUATION COST OF DISTRIBUTED GENERATION

Generally, costs of distributed generation to customers include the installed cost of the equipment, fuel costs, non-fuel operation and maintenance (O&M) expenses, and certain costs that the customers' utility imposes.
Generally, the cost of DGs (per kWh/$) can be defined as follows:

$$C(P)=a+b*P \qquad (8)$$

In mentioned equation a & b coefficients can be evaluated as follows:

$$a=\frac{CapitalCost(\$/kW)*Capacity(kW)*Gr}{LifeTime(Year)*365*24*LF}$$

$$b=FuelCost(\$/kWh)+O\&MCost(\$/kWh) \qquad (9)$$

where Gr and LF are yearly rate of benefit and DG loading factor.

## ANT COLONY SYSTEM MECHANISM

Ants are insects, which live together. Since they are blind animals, they find the shortest path from nest to food with aid of the pheromone. The pheromone is the chemical material deposited by the ants, which serves as critical communication media among ants, thereby guiding the determination of next movement. On the other hand, ants find the shortest path, based on intensity of pheromone deposited on different paths [10-17]. For better understanding, assume that ants want to move from A to B and vice versa, to obtain food (Fig1).

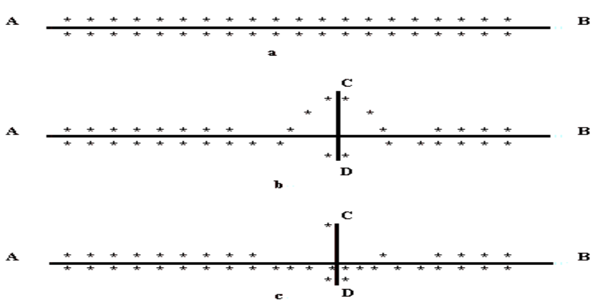


Fig.1. An example of finding the shortest path by ants

At first, if there is no obstacle, all of them will walk to the straight path (Fig 1.a). Now, assume that there is an obstacle; in this case, ants will not be able to follow the original trial in their movement. Therefore, randomly, they turn to left (ACB) and to right (ADB) (Fig 1.b). Since ADB path is shorter than ACB, the intensity of pheromone deposited on ADB is more than the other. So ants will be increasingly guided to move on the shorter path (Fig 1.c). This behavior forms the fundamental paradigm of ant colony system.
As it was indicated in (Fig.1), the intensity of deposited pheromone is one of the most important factors for ants to find the shortest path. Therefore, this factor should be used to simulate behavior of ants. Generally, the following

factors are used to simulate ant systems:

- Intensity of pheromone
- Length of path

To select the next path, state transition probability is defined as follows:

$$P_{ij} = \frac{(\tau_{ij})^{\gamma_1}(1/L_{ij})^{\gamma_2}}{\sum (\tau_{ij})^{\gamma_1}(1/L_{ij})^{\gamma_2}} \quad (10)$$

After selecting the next path, trail intensity of pheromone is updated as:

$$\tau_{ij}(k+1) = \rho\tau_{ij}(k) + \Delta\tau_{ij} \quad (11)$$

Where:

$\tau_{ij}$ :intensity of pheromone between nodes i and j, $L_{ij}$: length of path between nodes i and j,

$\rho$ : a coefficient such that (1-$\rho$ ) represents the evaporation of trail between time k and k+1.

$\gamma_1$ and $\gamma_2$: control parameters for determining weight of trail intensity and length of path.

To apply ant colony algorithm for solving optimization problems, at first, it should find global and local movement based on equation 10. In other words, determination of next path for each colony of ants depends on the direction of global and local paths as follows:

$$X_i(k+1) = X_i(k) + rand*(X_{Local} - X_i(k)) + rand*(X_{Global} - X_i(k)) \quad (12)$$

## SIMULATION

In this section the proposed method is applied to distribution feeder reconfiguration on a realistic radial distribution test feeders (Fig.2).

It is assumed that there are 3 generators whose specifications are given in Table I.

Daily energy price variations and daily load variations are shown in (Figs.3 and 4).

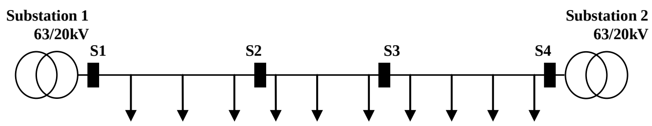


Fig.2. Single Line Diagram

TABLE I
CHARACTERISTIC OF GENERATORS

| | Capacity (kW) | Max Reactive Power ( kVar) | Min Reactive Power (kVar) | Capital cost ($/kW) | Life time (Year) | Fuel cost ($/kWh) | O & M cost ($/kWh) |
|---|---|---|---|---|---|---|---|
| G1 | 300 | 240 | -180 | 3674 | 12.5 | 0.029 | 0.01 |
| G2 | 500 | 400 | -300 | 1500 | 20 | 0 | 0.005 |
| G3 | 1000 | 800 | -600 | 715 | 20 | 0.067 | 0.006 |

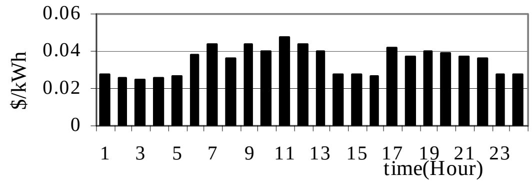


Fig.3. Daily energy price variations

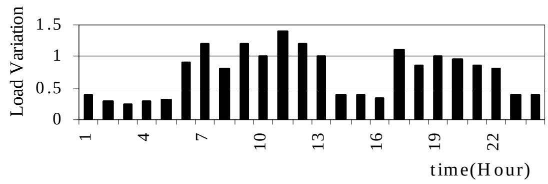


Fig.4. Daily load variations

Some results of simulation present in Tables II, III and IV.

Table II
Comparison of Average and Standard Deviation of the objective function values for 300 Trails

| Method | Average | Standard Deviation | Best solution | Worst solution |
|---|---|---|---|---|
| GA | 905.3 | 25 | 961.42 | 1013.47 |
| ACO | 713 | 20 | 701.5 | 943.2 |

TABLE III
COMPARISON RESULT FOR THE BEST SOLUTION

| | DGs are displaceable | DGs are not displaceable |
|---|---|---|
| Objective function Value ($/h) | 701.5 | 1042.1 |
| Losses (Kw) | 843.45 | 1875.36 |

TABLE IV
STATUS OF SWITCHES

| Hour | S1 | S2 | S3 | S4 | Min Voltage | Max Voltage |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 0.995 | 1.003 |
| 2 | 1 | 1 | 0 | 1 | 0.995 | 1.003 |
| 3 | 1 | 1 | 0 | 1 | 0.993 | 1.003 |
| 4 | 1 | 1 | 0 | 1 | 0.992 | 1.003 |
| 5 | 1 | 1 | 0 | 1 | 0.991 | 1.003 |
| 6 | 1 | 1 | 1 | 1 | 0.986 | 1.005 |
| 7 | 1 | 1 | 1 | 1 | 0.986 | 1.005 |
| 8 | 1 | 1 | 1 | 1 | 0.980 | 1.005 |
| 9 | 1 | 1 | 1 | 1 | 0.967 | 1.008 |
| 10 | 1 | 1 | 1 | 1 | 0.984 | 1.004 |
| 11 | 1 | 1 | 1 | 1 | 0.983 | 1.010 |
| 12 | 1 | 1 | 1 | 1 | 0.990 | 1.010 |
| 13 | 1 | 1 | 1 | 1 | 0.982 | 1.010 |
| 14 | 1 | 1 | 0 | 1 | 0.993 | 1.010 |
| 15 | 1 | 1 | 0 | 1 | 0.984 | 1.008 |
| 16 | 1 | 1 | 0 | 1 | 0.966 | 1.009 |
| 17 | 1 | 1 | 1 | 1 | 0.991 | 1.005 |
| 18 | 1 | 1 | 1 | 1 | 0.986 | 1.006 |
| 19 | 1 | 1 | 1 | 1 | 0.980 | 1.006 |
| 20 | 1 | 1 | 1 | 1 | 0.963 | 1.007 |
| 21 | 1 | 1 | 1 | 1 | 0.984 | 1.005 |
| 22 | 1 | 1 | 0 | 1 | 0.998 | 1.007 |
| 23 | 1 | 1 | 0 | 1 | 0.999 | 1.004 |
| 24 | 1 | 1 | 0 | 1 | 0.975 | 1.000 |

The results of these Tables can be summarized as follows:

1. Under the proper control on DGs, the sum of losses in 24-hour duration is 843.45kW. This amount is 1031.9 kW less than that of without control. On the other hands, it can be concluded that the system performance can be improved under proper control.
2. Because most of dispersed generations owned and controlled by private sections, necessary mechanisms must be applied for supervision and control of optimal operation in power systems. In this paper costs pertaining to active and reactive power generation offered by owners of dispersed generations have been used as a decisive factor for optimal control of them. Results achieved in last sections show that we can apply these methods to control dispersed generations and be sure that high benefits will be gained from them.
3. Distributed generations have much better performance and time response than other sources of reactive power generation like capacitors. Thus system performance can be improved with proper factors based on these generations.

## CONCLUSION

Since the number of DGs will be increasing, it is necessary, that impact of DGs on distribution feeder reconfiguration to be studied. This paper presented an efficient algorithm for distribution feeder reconfiguration in distribution with DGs. By using this algorithm the performance of distribution test feeders when DGs dispatched is better than not dispatched. Since the most of DGs owned by private section, active power generation cost of DGs considered as an optimal parameter control of them.

## REFERENCES

[1]. T. Ackerman, G. Anderson and L. Soder, “Distributed generation: A definition”, Elsevier Science, pp. 195-204, December 2000.

[2]. V. Borozan, D. Rajicic, and R. Ackovski, “Improved method for loss minimization in distribution networks,” IEEE Trans. Power Syst., vol.10, no. 3, pp. 1420–1425, August 1995.

[3]. S. Civanlar, J. J. Grainger, H. Yin, and S. S. H. Lee, “Distribution feeder reconfiguration for loss reduction,” IEEE Trans. Power Del., vol. 3, no. 3, pp. 1217–1223, July 1988.

[4]. T. Taylor and D. Lubkeman, “Implementation of heuristic search strategies for distribution feeder reconfiguration,” IEEE Trans. Power Del., vol. 5, no. 1, pp. 239–246, January 1990.

[5]. Q. Zhou, D. Shirmohammadi, and W. H. E. Liu, “Distribution feeder reconfiguration for service restoration and load balancing,” IEEE Trans. Power Syst., vol. 12, no. 2, pp. 724–729, May 1997.

[6]. E. lopez, h. Opaso, "Online Reconfiguration Considering Variability Demand: Applications to Real Networks," IEEE Trans. Power Syst., vol. 19, no. 1, pp. 549–553, February 2004.

[7]. V. Parada, J.A. Ferland, “Optimization of Electrical Distribution Feeders Using Simulated Annealing” IEEE Trans. Power Del., vol. 19, no. 3, pp. 1135–1141, July 2004.

[8]. A. Augugliaro, L. Dusonchet, M. Ippolito, and E. R. Sanseverino, “Minimum losses reconfiguration of MV distribution networks through local control of tie—Switches,” IEEE Trans. Power Del., vol. 18, no. 3, pp.762–771, July 2003.

[9]. Debaprya Das, "A Fuzzy Multi objective Approach for Network Reconfiguration of Distribution Systems", IEEE Transactions on Power Delivery, vol. 21, no. 1, pp. 202–209, January 2006.

[10]. M.Dorigo, G.D. Caro and L.M. Gambardella, “Ants Algorithms for Discrete Optimization”, Artificial Life, vol.5, no.3, P.P 137-172, 1999.

[11]. S.J.Huang, “Enhancement of Hydroelectric Generation Scheduling Using Ant Colony System Based Optimization Approaches”, *IEEE Trans. On Energy Conversion*, vol.16, no.3,September 2001.

[12]. D.Merkle, M. Middendorf and H. Schmech, , “Ant Colony Optimization for Resource Constrained Project Scheduling”, *IEEE Trans. On Evolutionary Computation*, vol.6, no.4, August 2002.

[13]. A.Bauer, B. Bullnheimer, R.F. Hartl and C. Strauss, *1999*, “An Ant Colony Optimization Approach for Single Machine Total Tardiness Problem”, *IEEE*, P.P. 1445-1450 July 1999.

[14]. N. S. Sisworahardjo and A.A. El Keib, “Unit Commitment Using the Ant Colony Search Algorithm”, *IEEE*, P.P. 2-6, June 2002.

[15]. T.Niknam, A.M. Ranjbar, and A.R. Shirani, “Optimization with Ant Colony Algorithm”, *BARGH Journal of Electrical Science and Technology*, No.36, P.P.11-19.2005

[16]. T. Niknam, A.M. Ranjbar, and A.R. Shirani, “A new approach based on ant algorithm for Volt/Var control in distribution network considering distributed generation” Iranian Journal of Science & Technology, Transaction B, vol. 29, No. B4, pp.1-15, 2005.

[17]. T. Niknam , A.M. Ranjbar and A.R. Shirani, “A new approach for distribution state estimation based on ant colony algorithm with regard to Distributed Generation” Journal of Intelligent and Fuzzy Systems, vol. 16, No. 2, pp.119-131, June 2005.