KKU Engineering Journal
http://www.en.kku.ac.th/enjournal/th/

Reconfiguration of distribution system with distributed generation using Firefly algorithm

Yordthong Lowvachirawat[1)], Bongkoj Sookananta*[1)], Mongkol Pusayatanont[1)] and Panhathai Buasri[2)]

[1)] Department of Electrical and Electronics Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani 34190, Thailand.

[2)] Department of Electrical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand.

Received August 2014
Accepted January 2015

Abstract

This paper presents a reconfiguration technique for distribution system with distributed generation (DG) using Firefly algorithm (FA). The objective is to minimize total power losses of the system. In this paper, the technique is tested on the IEEE 33-bus radial distribution system. The result shows that the method can be applied to practical system using switching for reconfiguration. In comparison to the other techniques, it is also capable to find good solution. Therefore, it can be used as an alternative to the other reconfiguration techniques.

Keywords : Distribution network reconfiguration, Optimization, Firefly algorithm

1. Introduction

The network reconfiguration is normally performed by changing the statuses of sectionalizing and tie switches. Main purposes are to reduce the system power losses and relieve the overloads of the system due to load variation. In Thailand, the importance of reconfiguration has been increasing since the government launched a policy about electricity trading between the Electricity Generating Authority of Thailand (EGAT) and private companies in 1989 [1]. Subsequently the DG is introduced to the Thai distribution system. The penetration of the DG associated with load variation alters the power flow and leads to the inappropriate of feeder configuration.

There are various types of DG connected to the Thai distribution system such as solar PV, wind, biomass and biogas. Different DG technologies have different operation behaviors. The solar PV and wind turbine power plants do not supply reactive power but the biomass and biogas power plants do. These behaviors have influence to power flow in their connecting system.

Without the consideration of DG, system losses are used to measure quality of system configuration in [2, 3]. A load balancing index is also utilized in [3] with branch exchanges method to search for location of the sectionalized switches.

With the presence of DG in the distribution feeder, the branch exchanges method is used to refine the solution of the reconfiguration problem in [4]. The solution space is firstly narrowed using sensitivity index and the method is claimed to be simple and efficient. However, searching procedure using heuristic optimization algorithm becomes topical interest over a systematic procedure. The Genetic algorithm (GA) is used to find real-time switching

* Corresponding author. Tel.: +66-45-353-326; fax: +66-45-353-333
Email address: yordthong@hotmail.co.th (Lowvachirawat, Y.), bongkoj.s@ubu.ac.th* (Sookananta, B.), tapt1ubu@hotmail.com (Pusayatanont, M.), panbua@kku.ac.th (Buasri, P.)
doi: 10.14456/kkuenj.2015.11

statuses for maximum loss reduction [5]. The tabu search (TS) is used to find the optimal system reconfiguration in [6] in order to obtain the cheapest generation from DG and Grid. The ant colony search (ACS) [7] and the harmony search (HS) [8] are also utilized in the reconfiguration problem.

The firefly algorithm (FA) is one of the effective meta-heuristic optimization techniques. It provides less computational burden than the classical heuristic optimization, GA and can be alternative to the other meta-heuristic optimization techniques. The FA has been employed to solve the optimal DG problem [9, 10]. It is utilized in this paper to obtain the optimal reconfiguration of the distribution network in presence of the DG as the corresponding problem formulation is presented in section 2. The FA and its application to the reconfiguration problem considering in this paper are described in section 3. Not only the numerical examples of the FA application to selected test system reconfiguration are showed in section 4 but the following solutions are also discussed. Finally, the last section contains conclusion.

2. Problem formulation

This paper considers the reconfiguration of the distribution network with existing DG. The objective is to minimize the system power losses subject to voltage constraint, thermal limit constraint and system power balance. The formulation is showed as follows. The objective is to minimize

$$f(z)=\sum_{k=1}^{M}P_L(k) \tag{1}$$

Subject to

$$V_i^{\min}\le V_i\le V_i^{\max} \tag{2}$$

$$P_{ij}\le P_{ij}^{\max} \tag{3}$$

$$P_i=\sum_{j=1}^{N}|V_i||V_j||Y_{ij}|\cos\left(\theta_{ij}-\delta_i+\delta_j\right) \tag{4}$$

$$Q_i=-\sum_{j=1}^{N}|V_i||V_j||Y_{ij}|\sin\left(\theta_{ij}-\delta_i+\delta_j\right) \tag{5}$$

Where z is a set of switching status

$P_L(k)$ is real power losses in feeder k

M is a number of feeders in the considering distribution system

N is a number of buses in the considering distribution system

i, j are bus numbers

V_i is voltage magnitude at bus *i*

$V_i^{\min}$ is minimum voltage magnitude at bus *i*

$V_i^{\max}$ is maximum voltage magnitude at bus *i*

$P_{ij}^{\max}$ is maximum power flow from bus *i* to bus *j*

P_{ij} is real power flow from bus *i* to bus *j*

Y_{ij} is admittance of line, connecting bus *i* to bus *j*

Q_i is reactive power at bus *i*

P_i is real power at bus *i*

θ_{ij} is admittance angle of line connecting bus *i* to bus *j*

δ_i is voltage angle at bus *i*

3. Firefly Algorithm

The firefly algorithm (FA) is a nature-inspired algorithm for optimization and seems to be more efficient than the particle swarm optimization (PSO) [11]. As in nature, the firefly is attracted to a flashing light produced from the other ones. This is to be mating by the same specie or fatally luring by the other species. One firefly tends to move toward the brightest flashing light and the brightness is varied by the distance.

Three idealized rules are utilized in FA. The first is that all fireflies are unisex therefore they are attracted to the other depending only on the brightness. The attractiveness of a firefly can be calculated as follows.

$$\beta(r) = \beta_0 e^{-\gamma r^2} \tag{6}$$

The second is that the brightness is varied by distance which can be calculated as follows.

$$r_{mn} = \left\| x_m - x_n \right\| \tag{7}$$

Between two fireflies, the less brightness moves to the brighter one. The movement of firefly m attracted to firefly n is calculated as follows.

$$x'_m = x_m + \beta_0 e^{-\gamma r_{mn}^2}(x_n - x_m) + \alpha\left(rand - \frac{1}{2}\right) \tag{8}$$

Where β is the attractiveness or intensity of the firefly's flashing light.

β_0 is the attractiveness at zero distance

r_{mn} is the distance between two fireflies m and n

m and n are firefly numbers

x is the location of firefly

x' is the new location of firefly

γ is a light absorption coefficient of a given medium

α is randomization parameter, $\alpha \in [0, 1]$

$rand$ is a uniformly distribution random number in [0, 1]

The third is that the brightness is affected by the objective function. Therefore, it can be defined in a similar way to the fitness function of the GA.

In this paper, the FA is applied to the reconfiguration problem of the distribution system. A required solution is a set of switching status. However, in a certain system, the number of feeders is fixed and so does the number of open-switches. Therefore, a solution set considered here contains only switch numbers to be open which is encoded as a location of fireflies. The objective function is a system power losses calculated using the power flow solution obtained from the open source Matpower 3.2 [12]. In the FA, the inverse of the objective value is considered as brightness which means the lower losses is the brighter. The solution candidate with the corresponding brightest at the final iteration is considered to be global solution.

4. Numerical example

The FA is applied to solve the optimal reconfiguration problem. Algorithm of the application is shown in figure 1.

The searching process for the optimal reconfiguration of the distribution system using FA starts with system data and parameters readings. The number of firefly population is the number of the solution set. Each set contains different open-switch numbers and refers to a corresponding system configuration. The open-switch numbers in each set are firstly generated uniform randomly. These are the first locations of fireflies.

The brightness of firefly in each location is determined by inverse of objective function, given in equation 1. The brightest one is taken as a local optimum for the first location. This is the best solution ever found and therefore, taken as the global optimum. Each firefly is paired randomly and then moved to the new location due to attractiveness between each other. After the movement, the calculation starts the next iteration. The brightness of fireflies at new location is determined to get the new local optimum which is to compare with the current global optimum. The brighter is taken as a new global optimum. The process is continued until the maximum iteration is met.

In this paper, the fireflies move with β_0 = 1, γ = 0.75 and α = 0.25. The values of these parameters are selected from the calculation experience. Note that for application to another problem, the method might work well with the other values of parameters. Thus, some tests and parameter variations are needed to be done before selection. The number of firefly population is 100 and the maximum iteration is 150.

4.1 Distribution system without DG

The IEEE 33-bus distribution system is used as a test system in this section. The system consists of 37 branches and 5 tie switches as shown in Figure 2. Thus, a solution set to the system reconfiguration problem of the IEEE 33-bus system includes 5 different open-switch numbers. The system data including loads and line impedances can be found in [3].

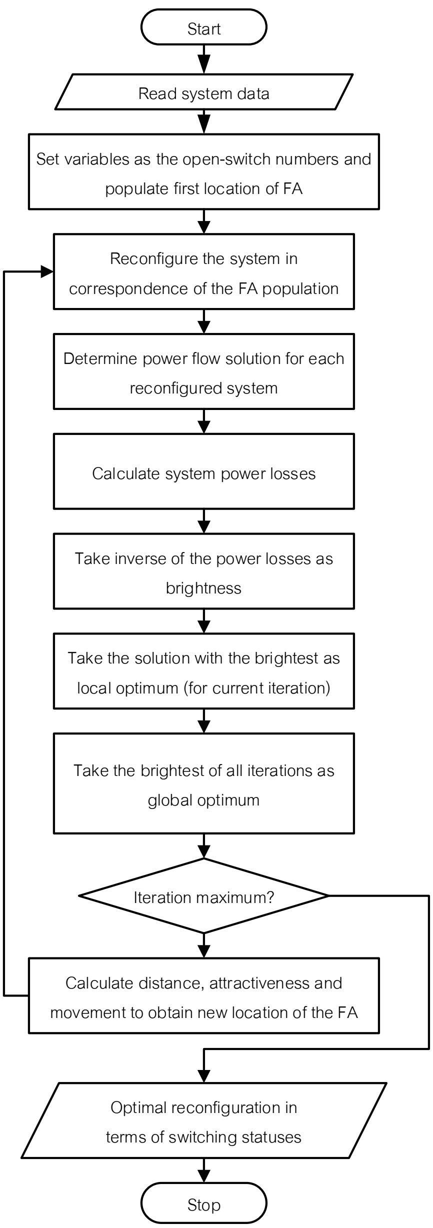

Figure 1 Flowchart of system reconfiguration using FA

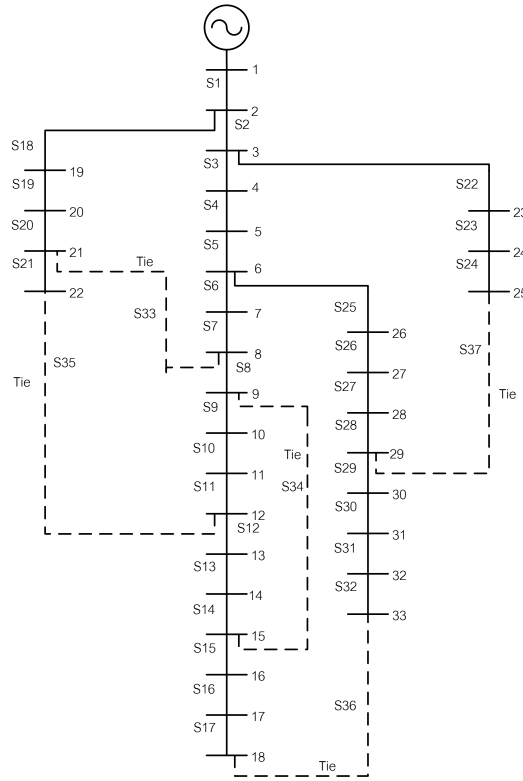

Figure 2 The IEEE 33-bus distribution system

The optimal solution obtained using the FA in this paper is compared to the solution in [7] as shown in Table 1. All cases take the ±10% of voltage constraint. In other words, The minimum and maximum voltage are 0.9 pu and 1.1 pu respectively. The simulation is run 10 times and the best solution found in the 9th run is shown. The calculation takes 9.5 minutes on the intel® core™ i5 CPU M460, 2.53GHz notebook with 4GB RAM.

Table 1 Optimal reconfiguration of 33-bus system without DG

	Open switch	Losses (kW)
Basecase	33,34,35,36,37	202.68
GA	S7,S9,S14,S28,S32	139.97
AS	S6,S9,S14,S26,S31	163.38
ACS	S7,S9,S14,S28,S32	139.97
FA	S7,S9,S14,S32,S37	139.55

In Table 1, the optimal solutions of the reconfiguration problem for IEEE 33-bus system are shown. The solutions obtained using the methods including Genetic Algorithm (GA), Ant Search (AS) and Ant Colony Search (ACS) are given in [7] and listed here to be compare with that obtained using the FA. The configuration of basecase system which the open switches are S33, S34, S35, S36 and S37 results in 202.68 kW of system power losses. In comparison to the basecase, the reconfigured system using AS results in 19.39% reduction of losses. The GA and ACS provide identical solutions which result in 30.94% reduction of losses. Additionally, the FA provides the slightly better solution with 31.99% reduction of losses.

The new configuration also improves the system voltage profile as shown in figure 3.

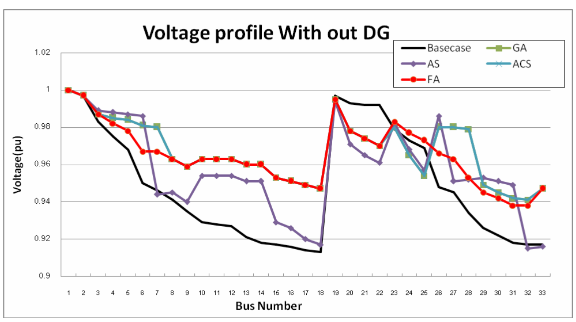

Figure 3 Voltage profile of the IEEE 33-bus distribution system without DG

4.2 Distribution system with DG

In this section, the DGs are taken into account. The DG with biomass technology or the others related to small thermal power plants are considered as there are high amount of them in the practical Thai distribution system. They can deliver both real and reactive powers and are presented in power flow model as dispatchable loads.

The IEEE 33-bus test system in section 4.1 is augmented by connecting DGs as capacities and locations of the DGs are given in Table 2. It is assumed that the DGs operate at a constant power factor.

Table 2 Buses of connection and capacities of DGs

Bus	Capacity (kW)	Power factor
3	50	0.8
6	100	0.9
24	200	0.9
29	100	1

The optimal solution obtained using the FA in this paper is compared to the solutions obtained using GA, AS and ACS from (7) as shown in Table 3. The installation of DGs in this case benefits in reduction of power losses and improve voltage profile. As it could be seen from Table 1 and Table 3 that the losses value of the basecase configuration with DGs is less than that with DG.

The GA provides reconfiguration solution with 31.86% reduction of losses which is best among the solution found in [7]. The AS and ACS provide solutions with 16.12% and 25.02% reduction of losses respectively. The FA also finds best solution with 31.86% reduction of losses. This solution is found at the 3rd run of 10 simulations.

Table 3 Optimal reconfiguration of the 33-bus system with DG

	Open switch	Losses (kW)
Basecase	S33,S34,S35,S36,S37	169.89
GA	S7,S9,S14,S28,S32	115.75
AS	S6,S9,S14,S26,S31	142.49
ACS	S7,S9,S14,S28,S32	127.38
FA	S7,S9,S14,S28,S32	115.75

The new configuration improves the system voltage profile as shown in figure 4.

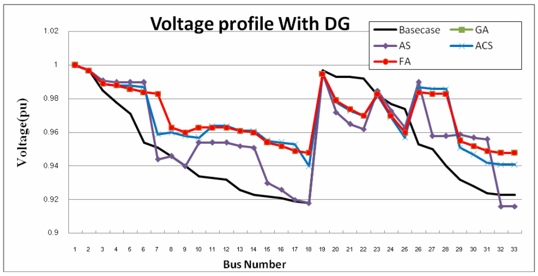

Figure 4 Voltage profile of the IEEE 33-bus distribution system with DGs

5. Conclusion

This paper presents the application of firefly algorithm to distribution system reconfiguration considering system power losses. The optimal solution obtained from the FA is in terms of the open sectionalized switch numbers. The presence of DG in the distribution system is considered in this paper. With DG in the system, the total losses is reduced. However, the reconfiguration can help in further reduction of losses. The reconfiguration solution obtained using the FA is compared to those obtained using GA, AS and ACS as published in the literature. It is found that the FA can also find good solution with largest reduction of system power losses.

6. References

[1] Amranand P. Alternative energy, cogeneration and distributed generation: crucial strategy for sustainability of Thailand's energy sector: Available from: http://www.eppo.go.th/doc/Piya-re-in-thailand.pdf.

[2] Civanlar S, Grainger JJ, Yin H, Lee SSH. Distribution feeder reconfiguration for loss reduction. IEEE Transaction on Power Delivery 1988;3(3):1217-23.

[3] Baran ME, Wu FF. Network reconfiguration in distribution systems for loss reduction and load balancing. IEEE Transaction on Power Delivery 1989;4(2):1401-7.

[4] Qiwang L, Wei D, Jianquan Z, Anhui L, A new reconfiguration approach for distribution system with distributed generation. International Conference on Energy and Environment Technology; 2009. p. 23-6.

[5] Choi JH, Kim JC. Network reconfiguration at the power distribution system with dispersed generations for loss reduction. Power Engineering Society Winter Meeting. 2000.

[6] Rugthaicharoencheep N, Sirisumrannukul S. Feeder reconfiguration with dispatchable distributed generators in distribution system by Tabu Search. Proceedings of the 44th International Universities Power Engineering Conference (UPEC). 2009.

[7] Wu YK, Lee CY, Liu LC, Tsai SH. Study of reconfiguration for the distribution system with distributed generators. IEEE Transactions on Power Delivery 2010;25(3):1678-85.

[8] Rao RS, Ravindra K, Satish K, Narasimham SVL. Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation. IEEE Transactions on Power Systems 2013;28(1):317-25.

[9] Saravanamutthukumaran S, Kumarappan N. Sizing and Siting of Distribution Generator for Different Loads using Firefly Algorithm. The International Conference On Advances In Engineering, Science And Management. 2012.

[10] Nadhir K, Chabane D, Tarek B. Firefly algorithm based energy loss minimization approach for optimal sizing & placement of distributed generation. The 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO). 2013.

[11] Yang XS. Firefly Algorithms for multimodal optimization. The 5th international conference on Stochastic algorithms: foundations and applications, 2009.

[12] MATPOWER Home page [Online] 1997. Available from: http://www.pserc. Cornell.edu//matpower/. Access November 2012.