Indonesian Journal of Electrical Engineering and Computer Science
Vol. 6, No. 3, June 2017, pp. 730 ~ 736
DOI: 10.11591/ijeecs.v6.i3.pp730-736

Application of Immune Log-Normal Evolutionary Programming in Distributed Generation Installation

M. H. Mansor*[1], I. Musirin[2], M. M. Othman[3], S. A. Shaaya[4], S. A. Syed Mustaffa[5]
[1,5]Department of Electrical Power Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia, +60389212020
[2,3]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40000 Shah Alam, Selangor, Malaysia, +60355435107
[4]Department of Electronics & Communication Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia, +60389212020
*Corresponding author, e-mail: mhelmi@uniten.edu.my

Abstract

Nowadays, the location and sizing of distributed generation (DG) units in power system network are crucial to be at optimal as it will affect the power system operation in terms of stability and security. In this paper, a new technique termed as Immune Log-Normal Evolutionary Programming (ILNEP) is applied to find the optimal location and size of distributed generation units in power system network. Voltage stability is considered in solving this problem. The proposed technique has been tested on the IEEE 26 bus Reliability Test System to find the optimal location and size of distributed generation in transmission network. In order to study the performance of ILNEP technique in solving DG Installation problem, the results produced by ILNEP were compared with other meta-heuristic techniques like evolutionary programming (EP) and artificial immune system (AIS). It is found that the proposed technique gives better solution in term of lower total system loss compared to the other two techniques.

Keywords: *optimal location and sizing, distributed generation, evolutionary programming, artificial immune system, voltage stability*

1. Introduction

In recent years, the number of distributed generation units penetrated into power system network has increased rapidly due to the power system deregulation and increment in number of large capacity distributed generation units. Furthermore, the government policy to increase the dependability on renewable energy sources to power up the country also lead to this phenomenon. Distributed generation sources are normally from renewable energy like small hydro, biomass, biogas, solar power, wind power, and geothermal power. The source of the renewable energy is different for every country depending on their geographical feature and climate.

Many researchers and engineers interested in studying the impact of distributed generation to the power system network for the past ten years. They proposed numerous optimization techniques to find the optimal location and size of distributed generation units in power system network. The existing optimization techniques to find the optimal location and size of distributed generation can be divided into two categories which are mathematical techniques and heuristic technique. The mathematical techniques that have been proposed are quadratic programming [1], teaching–learning based optimization [2] and Langrangian based approach [3]. While heuristic techniques are Ant Lion Optimization [4], Artificial Bee Colony [5], Flower Pollination [6], Intelligent Water Drop [7], Particle Swarm Optimization [8], [9] and Evolutionary Programming [10]. All these techniques basically focusing on minimizing the power system loss and improving voltage profile. The techniques are mixed with single and multi-objective problems.

Evolutionary Programming (EP) is a focus in this paper to solve this distributed generation problem as it has been well established to solve many power system problems such as economic dispatch problem [11], reactive power planning [12] and distributed generation

Received February 21, 2017; Revised May 4, 2017; Accepted May 16, 2017

placement [10]. Researchers also came out with hybrid techniques. After studying the performance of evolutionary programming and artificial immune system optimization techniques, this paper proposed to hybrid these two techniques to form a new hybridized optimization technique termed as Immune Log-Normal Evolutionary Programming (ILNEP) to find optimal location and size of distributed generation units in transmission network. The advantages of these techniques are gathered in the ILNEP algorithm. ILNEP have been developed by [13] to solve economic dispatch problems and proven to give best optimal solution for non-convex objective function of economic dispatch problems. Cloning operator used in ILNEP increases the probability of finding the fittest individuals for the optimal solution. ILNEP uses log-normal mutation instead of Gaussian mutation in original EP.

The results produced by ILNEP technique for this DG installation problem is promising compared to other two meta-heuristic techniques.

2. Immune Log-Normal Evolutionary Programming

Immune Log-Normal Evolutionary Programming (ILNEP) is formed after combining log-normal based mutation EP with AIS. The main optimizer is Log-Normal Evolutionary Programming (LNEP), while cloning operator of AIS is adopted into the LNEP. The overall structure of the ILNEP algorithm is as shown in Figure 1.

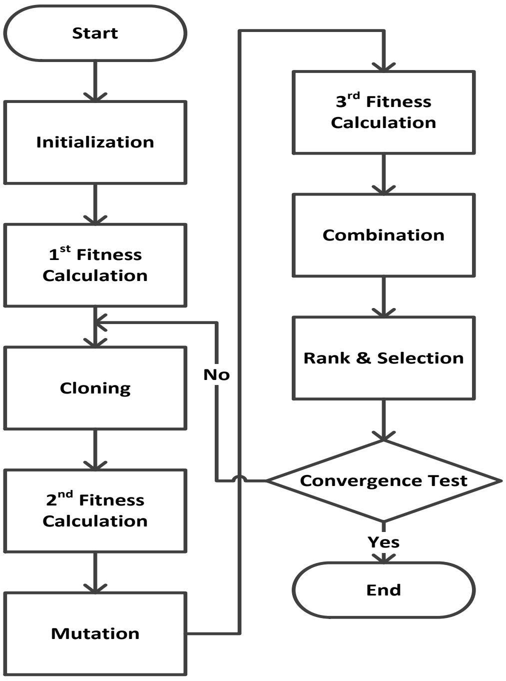

Figure 1. Overall structure of ILNEP

The ILNEP algorithm starts with initialization process where control variables and its strategic parameters are randomly generated. The control variables for this problem are location and size of DG units. The generated control variables must satisfy the following constraints:

$$total\ system\ loss \leq loss_{initial} \quad (1)$$

$$0.95 \leq |V| \leq 1.05 \quad (2)$$

The total system loss must be less than initial loss and voltage level must be within the allowable range. In initialization process, a population with size of 20 individuals is formed.

Fitness is then calculated for the first time before undergoing cloning process. The fitness for this problem is total system loss. During cloning process, number of initial population is multiplied 10 times to become 200 individuals. Subsequently, the fitness is calculated for the second time. The cloned population is then undergo mutation process using log-normal mutation operators as follows:

$$x'_{ij}(t) = x_{ij}(t) + \sigma_{ij}(t)N_{ij}(0,1) \tag{3}$$

$$\sigma_{ij}(t+1) = \sigma_{ij}(t)e^{(\tau N,(0,1)+\tau' N_{ij}(0,1))} \tag{4}$$

Where

$x'_{ij}(t)$ is mutated parent (offspring)
$x_{ij}(t)$ is parent
$\sigma_{ij}(t)$ is step size
τ and $\tau'$are operator set parameters which are calculated using the following equations:

$$\tau = \frac{1}{\sqrt{2n}} \tag{5}$$

$$\tau' = \frac{1}{\sqrt{2\sqrt{n}}} \tag{6}$$

Where n is number of control variables

The fitness is calculated for the last time before the combination process. In combination process, parent population and offspring population are combined which means the parent and the offspring matrices are cascoded as follows:

$$Combined\ population = \begin{bmatrix} parent \\ offspring \end{bmatrix} \tag{7}$$

The combined population is ranked ascendingly based on the fitness values and then twenty fittest individuals are selected for the convergence test. The optimization is converged if the difference between maximum and minimum values the calculated fitness of the best twenty individuals is less than 0.00001 which is shown in (8).

$$fitness_{max} - fitness_{min} = 0.00001 \tag{8}$$

3. Problem Formulation

The objective of this optimization problem is to find the optimal location and size of DG units in power system network. In this study, three DG units are introduced to the power system network which are small, medium and large size of DG units. The range of the small, medium and large DG units are (1MW to 5 MW), (5 MW to 50 MW) and (50 MW to 300 MW) respectively. Since there are three DG units, there will be three possible location for the DG units to be placed. The three DG units can be at any load bus which are from bus 6 until bus 25. The optimal size and location of this three DG units are found using the ILNEP technique. The objective function of this problem can be set as to minimize the total system loss which can be mathematically represented as follows:

$$Minimize \sum_{i=1}^{n} P_{loss,i} \tag{9}$$

Where n is number of lines in the system

P_{loss} can be calculated using the following equation:

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \tag{10}$$

Where:

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}cos\left(\delta_i - \delta_j\right) \tag{11}$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}sin\left(\delta_i - \delta_j\right) \tag{12}$$

n is the bus number, and
P_i, Q_i, P_j and Q_j are active and reactive power injections at buses i and j, respectively.
The objective function is subjected to the following constraints:

- Existing generating units operating limits

$$P_{i,min} \le P_i \le P_{i,max} \tag{13}$$

- Distributed generation units capacity

$$DG_{i,min} \le DG_i \le DG_{i,max} \tag{14}$$

- Voltage profile

$$V_{i,min} \le V_i \le V_{i,max} \tag{15}$$

The voltage level for each bus must be within 0.95 pu to 1.05 pu. The reactive power output of distributed generation units at ith bus is calculated using the following equation:

$$Q_i = P_{DG,i}tan^{-1}\theta \tag{16}$$

Where θ is power factor angle
Power factor of this power system is set to be 0.85 as shown in (14).

$$Cos\theta = 0.85 \tag{17}$$

4. Results and Discussion

The ILNEP algorithm was tested on the IEEE 26-Bus Reliability Test System. There are five existing generating units in the test system. The location and operating limits of the units are shown in Table 1. Prior to that test, the problem was solved using AIS and EP techniques to study the effectiveness of the ILNEP technique. It was ensured that the test conditions for EP and AIS are the same with ILNEP. Three DG units have been introduced to the 26-bus test system. Their capacity are shown in Table 2.

Table 1. Generating Units Operating Limits of 26-Bus System

Generating Unit	Operating Limits (MW)	
	Lower Limit	Upper Limit
P_{G1}	100	500
P_{G2}	50	200
P_{G3}	80	300
P_{G4}	50	150
P_{G5}	50	200
P_{G26}	50	120

Table 2. Real Power Output of Distributed Generation Units

Distributed Generation Units	Capacity (MW)	
	Lower Limit	Upper Limit
DG_1 (small size)	1	5
DG_2 (medium size)	5	50
DG_3 (large size)	50	300

In order to get the best solution out of the ILNEP, the developed ILNEP program for DG installation has been run 10 times followed by the other two techniques. Subsequently, the best results of total system loss produced by these three methods are compared. The results produced by ILNEP, EP and AIS are tabulated in Table 3, 4 and 5 respectively. The best results from the three tables are taken out and gathered in Table 6. The best results are based on the lowest total system loss produced by each technique.

From the optimization results of the optimal location and size of DG units in 26-bus system in Table 6, it shows that ILNEP technique gives the lowest total system loss compared to EP and AIS techniques. AIS gives the highest total system loss while the total operating loss produced by EP is slightly higher than ILNEP. The optimal size of the DG units can be seen to be within their capacity which was set earlier as of one the problem constraints. The location of DG units also can be seen placed only at the load busses and not at the intermediate which the value of real and reactive load power are zero.

Table 3. Results of Optimal Location and Size of DG using ILNEP for 10 runs

No. of runs	Location of DG (Bus Number)			Size of DG (MW)			Total System Loss (MW)
	DG_1	DG_2	DG_3	DG_1	DG_2	DG_3	
1	25	24	26	4.92	49.79	297.73	6.92
2	17	24	22	4.94	49.75	174.08	7.89
3	19	24	9	4.91	50.00	268.56	7.83
4	25	24	6	4.99	50.00	293.36	6.18
5	25	24	6	4.99	50.00	266.05	7.39
6	25	21	22	4.94	49.74	214.29	8.42
7	25	24	9	4.98	49.90	299.55	7.29
8	19	24	9	4.90	50.00	268.56	7.83
9	19	24	9	4.91	50.00	268.56	7.83
10	25	24	6	4.99	50.00	293.36	6.18

Table 4. Results of Optimal Location and Size of DG using EP for 10 runs

No. of runs	Location of DG (Bus Number)			Size of DG (MW)			Total System Loss (MW)
	DG_1	DG_2	DG_3	DG_1	DG_2	DG_3	
1	25	24	26	4.91	49.79	297.73	6.92
2	16	25	7	2.77	9.80	290.47	9.31
3	21	14	19	4.35	36.90	257.17	8.41
4	16	25	7	2.77	9.80	290.47	9.31
5	14	19	10	4.35	36.90	257.17	8.40
6	14	19	10	4.35	36.90	257.17	8.40
7	14	19	10	4.35	36.90	257.17	8.40
8	14	19	10	4.35	36.90	257.17	8.40
9	14	19	10	4.35	36.90	257.17	8.40
10	14	19	10	4.35	36.90	257.17	8.40

Table 5. Results of Optimal Location and Size of DG using AIS for 10 runs

No. of runs	Location of DG (Bus Number)			Size of DG (MW)			Total System Loss (MW)
	DG_1	DG_2	DG_3	DG_1	DG_2	DG_3	
1	14	19	10	4.35	36.90	257.17	8.41
2	14	19	10	4.35	36.90	257.17	8.41
3	14	19	10	4.35	36.90	257.17	8.41
4	14	19	10	4.35	36.90	257.17	8.41
5	14	19	10	4.35	36.90	257.17	8.41
6	14	19	10	4.35	36.90	257.17	8.41
7	14	19	10	4.35	36.90	257.17	8.41
8	14	19	10	4.35	36.90	257.17	8.41
9	14	19	10	4.35	36.90	257.17	8.41
10	14	19	10	4.35	36.90	257.17	8.41

Table 6. Comparison of Best Total System Loss for ILNEP, EP and AIS

Optimization Technique	Location of DG (Bus Number)			Size of DG (MW)			Total System Loss (MW)
	DG_1	DG_2	DG_3	DG_1	DG_2	DG_3	
ILNEP	25	24	6	4.99	50.00	293.36	6.18
EP	25	24	26	4.91	49.79	297.73	6.92
AIS	14	19	10	4.35	36.90	257.17	8.41

5. Conclusion

The application of Immune Log-Normal Evolutionary Programming (ILNEP) algorithm to solve Distributed Generation (DG) installation in power system network is presented in this paper. Three size of DG have been introduced to the system which are small size, medium size and large size. From the single objective optimization results which to minimize the total system loss, it can be concluded that ILNEP outperformed AIS and EP in term of giving the optimal location and size of DG so that the total system loss is minimal. This technique can be used by the power system operators or regulators in future planning of DG units penetration to their power system network.

For future development, the ILNEP algorithm can be improved by adopting other mutation operators from other techniques for instance adopting the updating operator of Kinetic Gas Molecule Optimization (KGMO) to replace the log-normal mutation. It is hoped that, the updating operator of KGMO will reduce the computational time and at the same time giving better optimal solution. Furthermore, the total system loss can be further reduced by introducing variable injected reactive power of shunt capacitor to the busses in the power system in order to balance the real power injected for voltage stability improvement.

Acknowledgment

The authors would like to acknowledge The Institute of Research Management and Innovation (IRMI) UiTM, Shah Alam, Selangor, Malaysia and Ministry of Higher Education (MOHE) for the financial support of this research. This research is supported by MOHE under the Research Acculturation Grant Scheme (RAGS) with project code: 600-RMI/RAGS 5/3 (187/2014).

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