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Review Article

USE OF THE IMPERIALIST COMPETITIVE ALGORITHM IN DETERMINING THE OPTIMAL LOCATION AND CAPACITY OF DISTRIBUTED GENERATION UNITS TO IMPROVE VOLTAGE STABILITY AND REDUCE COSTS OF LOSS IN RADIAL DISTRIBUTION NETWORKS

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ABSTRACT
The objective of the present study was to determine the location and size of distributed generation so as to maximize voltage stability and minimize costs of loss in radial distribution networks. In the proposed algorithm the weighted coefficients method was used to optimize the aforementioned indicators. It is worth noting that minimization of loss costs and maximization of voltage stability was taken into account in the target function based on the weakest voltage busbar and the weakest system link. For optimization purposes, the imperialist competitive algorithm (ICA) was used as a powerful search method. In addition, using the backward/forward load distribution method the optimization problem for time-varying loads was solved and optimization conditions were changed to almost match natural conditions. The resulting program was implemented on a 69-busbar radial network and results were examined.

Keywords: *Distributed Generation; Radial Distribution Systems; Imperialist Competitive Algorithm; Backward/Forward Load Distribution; Multi-Objective Function*

INTRODUCTION
The need of power plants for power systems is growing exponentially and these plants are faced with major challenges. The infrastructure of the existing transmission lines cannot meet this high power demand. Hence, there is either a need for investments in the transmission system so as to increase capacity or a need for meeting the needs of consumers through distributed generation (DG) (Aman *et al.*, 2013). DG can be practiced using different means such as combustion engines that are based on ordinary fossil fuels and renewable energies produced by wind, photovoltaic cells, micro-turbines, small hydroelectric turbines, or a combination of them. The Electric Power Research Institute (EPRI) defines a distributed generation unit as a generation with a capacity varying from several kilowatts to 50 megawatts (Patent *et al.*, 1993).
DG has many advantages over the centralized power generation method. Some of these advantages include reduced power system losses and improved voltage profiles (Ouyang *et al.*, 2010). Optimization of the location and size of DG in the course of planning for the distribution system is necessary for obtaining the desired target function. Non-optimal location and size of DG can lead to an increase in power loss and can affect the system's voltage profile. Anyhow, as a result of optimal positioning of DG, losses along the transmission and distribution lines decline and the overall capacity of the power system escalates (Begovic *et al.*, 2013).
Numerous analytical studies have been carried out which have resulted in algorithms for optimizing the location and size of DG units (Viral *et al.*, 2012). In the proposed algorithm, a multi-objective function is introduced for optimizing the location and size of DG. Minimization of losses and maximization of voltage stability take place by finding the weakest voltage busbar and the weakest system link using the target function. The imperialist competitive algorithm (ICA) was used with the backward/forward load distribution method to solve multi-objective problems. In this research, a comparison was made between

the values of reduction in power system loss, enhancement of voltage profile, and improvement of line and busbar voltage with and without DG in a 69-busbar IEEE radial distribution network.

This paper is composed of the following sections: section 2 provides a brief review of the modeling of different indicators used for finding the weakest voltage busbar and the weakest system link; section 3 introduces the imperialist competitive method using the backward/forward load distribution method; section 4 focuses on formulation of the problem target function required by the imperialist competitive algorithm; in section 5 the proposed program is implemented on a 69-busbar sample network in MATLAB and the results are analyzed; and conclusion is the last section.

Modeling of Voltage Stability Index

In the present study, the target function for optimization of the location and size of DG consisted of minimization of power loss costs and maximization of busbar and line voltage stability. The SI index was used to find the weakest voltage busbar while the L_{mn} index was used to find the weakest link. The weakest voltage busbar and link can cause voltage instability if the load level reaches its critical level. The formula for the SI and L_{mn} indices is as follows (1):

SI is known as the busbar voltage stability index. When load increases the weakest voltage busbar, which can cause voltage instability, is identified. Relation (1).

$$SI = \left|V_s\right|^4 - 4\times\left\{P_r x_{ij} - Q_r r_{ij}\right\}^2 - 4\times\left\{P_r r_{ij} + Q_r x_{ij}\right\}^2 \times \left|V_s\right|^2 \geq 0 \quad \text{Relation (1)}$$

Where, SI denotes busbar voltage stability, V_s is the initial busbar voltage, P_r is the active load, Q_r is the last busbar's active load, r_{ij} is the line resistance and x_{ij} is reactance of the line connecting the first and the last busbars.

Under stable operation conditions, SI should be larger than zero for all busbars. When SI approaches 1, all busbars become more stable. In the proposed algorithm, the SI for each busbar in the network is calculated and the results are sorted in a descending order. The busbar with the lowest SI is used in the target function.

L_{mn} is known as the line voltage stability index. When load increases, the weakest link that can cause possible voltage instabilities is identified. Relation (2).

$$L_{mn} = \frac{4xQ_r}{\left[V_s \sin\left(\theta - \delta\right)\right]^2} \leq 1.00 \quad \text{Relation (2)}$$

Where L_{mn} is the line voltage stability index, V_s shows the first busbar voltage, θis the line impedance angle, Q_r is the last busbar active load, x is the reactance of the i-j line, and δ is the difference between the angles of the first and the second busbars.

In stability conditions, L_{mn} shall be smaller than one unit. When L_{mn} exceeds one unit, the system demonstrates instability. Therefore, the formula for L_{mn} is obtained by reversing the formula for SI.

Figure (1) depicts a single-line diagram for a two-busbar system.

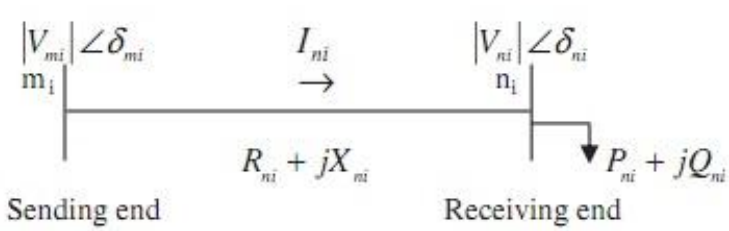

Figure 1: The single-diagram for a 2-busbar system

In this study, the both indices were combined to create the line-busbar voltage stability index (CBL_VSI) (Relation 3). To formulate the problem, CBL_VSI is considered the first target function which requires minimization.

$$CBL\_VSI = 0.5 \times Min\left\{SI\left(nbus\right)\right\} + 0.5 \times \frac{1}{Max\left\{L_{mn}\left(nbr\right)\right\}}$$ Relation (3)

Where CBL_VSI is the line-busbar voltage stability index, nbus is the total number of buses and nbr is the total number of links in the system under study.

The Proposed Imperialist Competitive Algorithm based on Backward/Forward Load Distribution

One of the most important and common methods for distribution system analysis is the load distribution analysis method. Optimization of every power system calls for solving the load distribution problem consecutively. Hence, the method used for load distribution shall be highly powerful and shall provide a high convergence speed.

Due to the wide range of resistance values and inductances as well as their radial structures, distribution networks are classified as networks with unsatisfactory conditions. The algorithm proposed for solving the load distribution problem is the backward/forward load distribution method (Wu *et al.,* 2008). In this method, the relationships between nodal currents and branch currents as well as the relationships between nodes voltages and the primary voltage are determined using full non-simplified relations without an admittance matrix. The problem of load distribution is thus solved quickly using the advantages of radial networks where nodes voltages are equal to the network power loss capacity and feeders' transmission capacity.

Backward/Forward Load Distribution

Backward Distribution

In the backward path, given the amount of power consumed in each node, the current in each branch is calculated by assuming an initial nominal voltage for each node. In this case, voltages are assumed to be invariant and the current in each line ending to a busbar is calculated using relation (4) throughout the backward load distribution process for the entire path to the feeder.

$$\vec{I}_r = \frac{\vec{V}_s - \vec{V}_r}{\vec{Z}} = \frac{\vec{P}_r - j\vec{Q}_r}{\vec{V}_r^{\,*}}$$ Relation (4)

Where, I_r is the current for the link between busbars s and r, V_s denotes the first busbar's voltage, V_r is the last busbar's voltage at each point of the line, and Z is the impedance of the line connecting the two busbars. P_r is also the total active capacitance of loads associated with busbar r and its subsequent busbars along with the losses along the subsequent lines. Q_k is the total reactive capacitance of loads associated with busbar k and its subsequent busbars along with the power consumption along the subsequent lines.

Forward Distribution

In this case, the objective is to determine the voltage at each node from the beginning of the feeder to the end of the network. The resulting voltage value is assumed to be invariant. Current values determined in the previous state are assumed to remain invariant while in the forward path the voltages of subsequent busbars are obtained using Relation (5).

Convergence Measure

This algorithm is repeated for each iteration according to the last two paragraphs until the range of voltage in each busbar becomes acceptable as compared to the range of voltage in the previous iteration. When load distribution becomes convergent, values of busbar voltage as well as active and reactive capacitance and losses at each part of the network are calculated.

The Proposed Imperialist Competitive Algorithm

In the recent decades, optimization algorithms inspired by the nature have been used as significantly successful intelligent optimization methods along with the existing classic methods. Some of these methods include the genetic algorithms (which are inspired by human and other beings' biological evolution), ant colony optimization algorithms (which are based on the optimal movement of ants), and the simulated annealing methods (which are inspired by the refrigeration of metals). The proposed algorithm, which was developed by Ismail Atashpaz and Karlocosr, was inspired not by a natural phenomenon but by a social-human phenomenon. In particular, this algorithm considers colonialism to be

a part of human's social-political evolution and uses it as the source of inspiration for a powerful optimization algorithm based on mathematical modeling of this historical process (Gargari *et al.*, 2007).
Similar to other evolutionary optimization methods, the proposed algorithm starts with an initial population. In this algorithm, countries are classified into two groups: colonies and imperialists. Every imperialist country possesses and controls a number of colonies depending on its power. The imperialist absorption and competition policy forms the core of this algorithm. According to the historical absorption policy, this algorithm implements this policy by moving the colonies of a specific empire based on a certain pattern (Figure 2).
If during the displacement one colony gains advantage over the imperial power, they switch positions. In addition, the total power of an empire equals the sum of its own power plus an average percentage of the power of its colonies.
As mentioned, imperialist competition forms another important part of this algorithm. In the course of imperialist competition, weak empires gradually lose power and finally vanish when they totally lose power (Figure 3). As a result of imperialist competition eventually only one empire remains to run the world. At this point the imperialist competitive algorithm stops after finding the optimum of the target function.

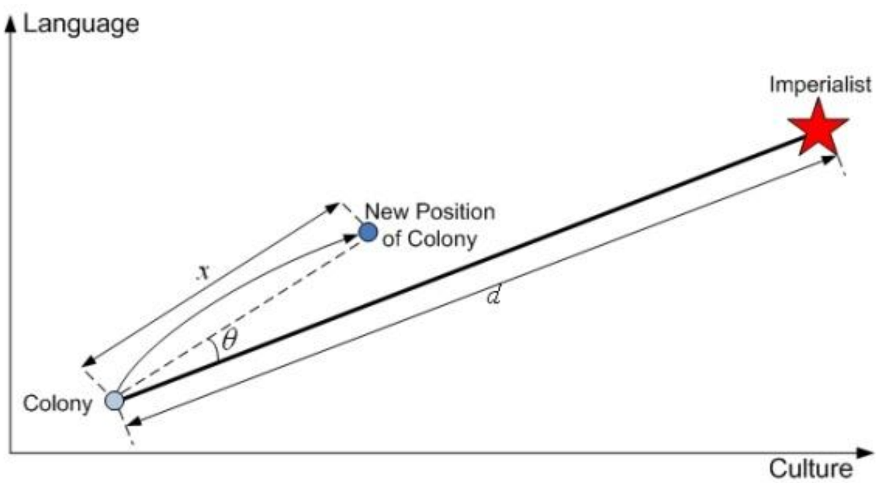

Figure 2: The absorption policy in the imperialist competitive algorithm

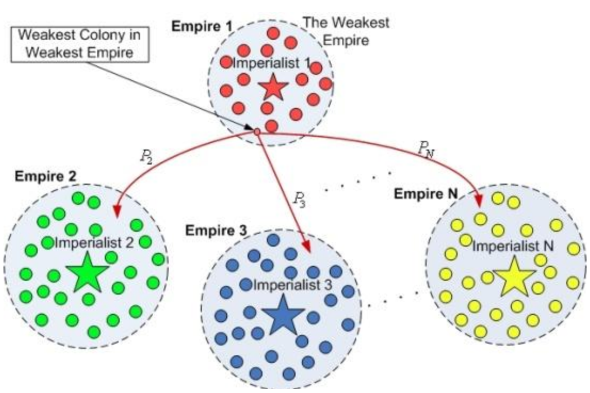

Figure 3: The schematic of imperialist competition

Formulation of the Proposed Algorithm's Target Function
Optimization Assumptions
- Time-varying load pattern (Figure 4)
- Invariant power factor for all network loads

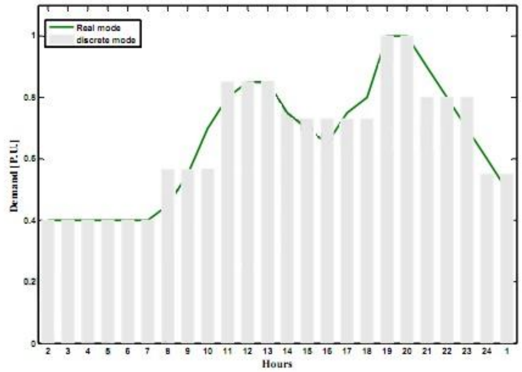

Figure 4: Time-varying load pattern

Optimization Constraints

- Satisfaction of the equations for distribution of actual and non-actual powers
- Busbars voltages (Relation 6)

$V_{min} \leq V_i \leq V_{max}$ Relation (6)

Where:
Vmin: Minimum allowable network voltage.
Vmax: Maximum allowable network voltage.

- DG allowable network capacity (Relation 7)

$\sum_{i=1}^{nbus} P_i^{DG} \leq \sum_{i=1}^{nbus} P_i^{D}$ Relation (7)

Where:
P_i^{DG} : Actual power of DG in busbari.
P_i^{D} : Actual power of load in busbari.

Optimization Target Function

The target function for this research was built according to the following considerations for finding the optimal location and size if DG:

- Reduction in the costs of the power system losses
- Necessary improvement of line stability
- Necessary improvement of busbar voltage stability

In order to minimize the costs of system losses, C(losses) is used as the first target function which is expressed through Relation (8).

$Fitness_1 = Min\{C(Losses)\}$ Relation (8)

Where C(Losses) yields the cost of losses in all busbars. In order to calculate the cost of losses, first the load is distributed and the results are used for calculation of losses. Finally, the resulting values are multiplied by the price of losses. The current price of loss is 900 Rials per kWh.

In order to obtain the maximum line-busbar voltage stability, CBL_VSI is used as the second function which requires minimization. This function is given by Relation (9).

$Fitness_2 = Min\{CBL\_VSI\}$ Relation (9)

Since the target functions employ different units, normalization is necessary. The following relations are used for normalizing the target functions.

$F_1 = Norm\_C_{Losses}(dg_i) = \left|\frac{C_{Losses}(dg_i)}{C_{Losses}(dg_0)}\right|$ Relation (10)

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$$F_2 = Norm\_CBL\_VSI(i) = \left|\frac{CBL\_VSI(dg_i)}{CBL\_VSI(dg_0)}\right|$$ Relation (11)

Where, the function is shown by dg_0 when DG is absent and is shown by dg_i when DG is present. Moreover, in order to obtain the final target function, the normal target functions are combined and weighted based on their significance. This process is expressed through Relation (12),(w_1=w_2=0.5).

$$OF = w_1 \times F_1 + w_2 \times F_2$$ Relation (12)

Numerical Studies, Simulations and Results

The method proposed for finding the optimal location and capacity of distributed generation (DG) units was applied on a 69-busbar IEE radial distribution network. The voltage of the network under study was 12.66 KV and its total load was 4.65 MVA (3800 KW of active load and 2685 KW of reactive load). Other technical specifications of the network including the impedance of lines and associated loads are available in (Hamouda *et al.*, 2006).

Table (1) presents parameters used in the imperialist competitive algorithm.

Table 1: Parameters of the imperialist competitive algorithm

100	Number of country
20	Number of Imperialist
80	Number of Colonies
100	Number of Iteration
1.2	μ
1	α
0.1	P Revolution
0.1	ξ

Table (2) presents the results of examination of the effect of a distributed generation source on the losses of the distribution network as compared to the results obtained by omitting the DG source.

Table 2: Effect of the presence and absence of DG source in the network under study

With DG	**Without DG**	
61	-	Optimal Location
1147	-	Optimal Capacity (KW)
904.614	2.091.340	Cost Losses
0.1548	0.1648	Max Lmn
0.8219	0.6833	Min SI
0.9522	0.9092	Min V (pu)

According to Figure (5), power loss reduces considerably using the proposed algorithm.

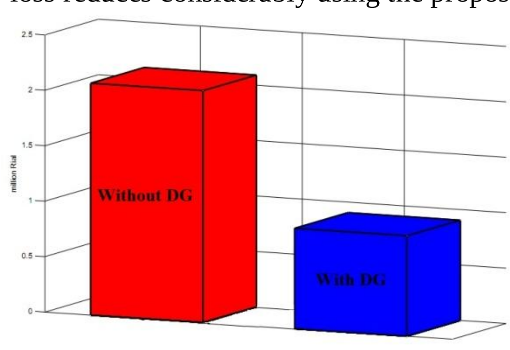

Figure 5: Costs of power losses

Figure (6) shows the effect of a DG source on the voltage profile of the 69-busbar network as compared to the results obtain by omitting the DG source. As seen, all of the busbar voltages fall in the acceptable interval.
According to the results presented in Table (2) it can be concluded that by adding a DG source to distribution networks it is possible to improve the voltage of networked busbars. In this research, using this method the voltage of the weakest busbar was increased from 0.9092 perunit to 0.9238 perunit. On the other hand, this source has a considerable effect on the reduction in losses costs (an approximately 56.7% increase in 24 hours).

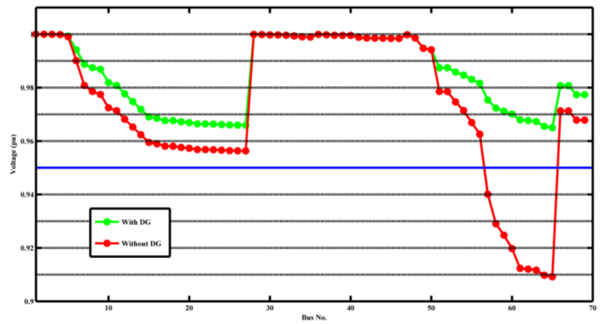

Figure 6: The 69-busbar network voltage profile.

CONCLUSION

Finding the optimal position of distributed generation (DG) sources and determining their capacity in the restructured power system is a new solution used for increasing the capacity of networks under the coverage of the power distribution company. In this research, a method was proposed for finding the optimal location and capacity of distributed generation units in radial distribution networks. The objective of this method was to minimize costs of losses and maximize system voltage stability using the imperialist competitive method. According to the results, the powerful imperialist competitive algorithm not only does reduce costs of losses in networks but also significantly improves busbar and line voltage stability indices as well as voltage profile. It is worth noting that voltage profile has been introduced as an important quantity in terms of network operation in the recent years.

REFERENCES

AlRashidi MR and AlHajri MF (2011). Optimal planning of multiple distributed generation sources in distribution networks: a new approach. *Energy Conversion and Management* **52** 3301–308.
Aman MM, Jasmon GB, Bakar AHA and Mokhlis H (2013). A new approach for optimum DG placement and sizing based on voltage stability maximization and minimization of power losses. *Energy Conversion and Management* **70** 202–210.
Atashpaz-Gargari (2007). Imperialist Competitive Algorithm (ICA): An Algorithm for Optimization Inspired by Imperialistic Competition. *IEEE Congress on Evolutionary Computation, (CEC 2007)* 4661-4667.
Begovic M, Fulton D, Gonzalez MR, Gosens J, Guro EA and Haas RW *et al.*, (1995). Summary of system protection and voltage stability. *IEEE Transactions on Power Delivery* **10** 631–638.
Aman MM, Jasmon GB, Bakar AHA and Mokhlis H (2013). A new approach for optimum DG placement and sizing based on voltage stability maximization and minimization of power losses. *Energy Conversion and Management* **70** 202–210.
Electric Power Research Institute (EPRI) (1993). *Technical Assessment Guide*, edited by Patent TR 102-276.
HamoudaAbdellatif and ZeharKhaled (2006). Efficient load flow method for radialdistribution feeders. *Journal of Applied Sciences* **13** 2741–8.

Ouyang W, Cheng H, Zhang X and Yao L (2010). Distribution network planning methodconsidering distributed generation for peak cutting. *Energy Conversion and Management* **51** 2394–401.

Silva M, Morais H and Vale Z (2012). An integrated approach for distributed energy resource short-term scheduling in smart grids considering realistic power system simulation. *Energy Conversion and Management* **64** 273–88.

Viral R and Khatod DK (2012). Optimal planning of distributed generation systems in distribution system: a review. *Renewable and Sustainable Energy Reviews* **16** 5146–165.

Wu W and Zhang B (2008). A three-phase power flow algorithm for distribution system power flow based on loop-analysis method. *International Journal of Electrical Power & Energy Systems* **30** 8–15.