International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2014	Issue 18	Volume 6	Number 1	Pages 160-166

A WAY TO EXPANSION PLANNING OF DISTRIBUTION NETWORKS COMPONENTS

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Abstract- In this paper the new developed Imperialist Competitive Algorithm (ICA) is used for the optimal expansion planning of radial distribution network. By optimal sizing, siting, and timing of medium voltage network main components such as HV substation and MV feeder's route, the topology of Medium Voltage (MV) distribution network as backbone of electric power distribution systems is designed. A multistage expansion planning procedure is presented to consider load growth uncertainty, asset management, and geographical constraints. The Greedy algorithm used to solve the radial configuration of the mesh network. The capability of the algorithm has been tested on an under developed relatively large-scale distribution network.

Keywords: Optimal Distribution Expansion Planning, Optimal Feeder Routing, Optimal HV Substation Placement, ICA, Greedy Algorithm.

I. INTRODUCTION

Recently because of the importance of the distribution systems in deregulated and smart grid environments from both electric utilities and customers viewpoint, the operation, expansion and planning of electric power distribution systems has been in more attention. Load modeling and forecasting are the two first steps in expansion planning of the Optimal Distribution System Planning (ODSP). These uncertainties enforce planning procedures to encounter with many unwanted problems.

To overcome for deficiency of the mentioned problems it is necessary that the planned network is evaluated and resolved at a given periods. A multistage planning procedure can help to solve the non-dynamic expansion planning of network at the previously work. This paper adapts Imperialist Competitive Algorithm as recently developed heuristic algorithms for the optimal design of large-scale electric distribution systems in order to provide optimal sizing and locating of HV substations and MV feeder routing.

In this situation, a hard satisfactory optimization problem with different continuous and discrete constraints should be solve. Special characteristics of large-scale distribution systems in expansion and planning steps considered at each planning stages. The aim of this work is organization of a general framework for large-scale distribution system expansion and planning regarding technical requirements such as electrical, geographical and asset management aspects.

In this paper, a generalized formulation for both optimal HV substation placement and optimal feeder routing problems developed which directly inserts the constraints of two subs problem in a multi-objective multi-constraints optimization problem. The formulation helps to consider all objects of the optimal distribution system planning in a generalized formulated problem that minimizes total costs of the study system.

The new algorithm aims to minimize capital investment and operating costs of expanded and new developed installation considering electrical, geographical, and other constraints in ODSP (Optimal Distribution System Placement) [1]. The proposed model can modify the existing network and determine the new HV substations type, size and location as well as feeder routes regarding future load growth. Paper [2] presented pseudo dynamic methodology approach for optimal placement and determining the service areas of HV and MV substations. Some cost and network improvement functions used as fitness function. LR fuzzy numbers at load points models loads uncertainty.

The complexity of optimal distribution system planning discussed in literature [3, 4]. To find the optimal solution of the modeled complicated problem the ICA optimization algorithm is used [5]. Many attractive papers are prepared about optimal distribution planning [6, 7]. In [8] a multistage model to support electric power system planning considering system uncertainties presented. The method named MIS-REM is expressed uncertainties such as probability distributions and interval values distribution system planning problems.

The introduced method can analyze different scenarios including economic and other penalties when predefined market variables violated. To demonstrate the applicability of model, both at presence of renewable or non-renewable resources, an integrated optimization process developed. A comparing methodology is used to analysis effect and interaction of different variables at system planning.

Paper [9] developed a model based on a two-stage procedure that involves mid and long-term planning. The usefulness of the method is on producing possible evolution trajectories that can be define as satisfactory when the planner accepts a specified risk threshold. The effect of uncertainty in system load studied using an immunological algorithm at planning of electric distribution networks in [10]. Based on this paper the algorithm leads to better results compared with former algorithm. The optimal reconfiguration of distribution systems for minimizing the system loss using Ant Colony Optimization is proposed in [11].

The presented algorithm tested on both classical and real distribution network. Concept of hybrid energy hub applied to Optimal Electric Distribution System Expansion Planning (OEDSEP) in [12]. The problem decomposed into sub-problems reach to for optimal solution considering system constraints. The main goal of this method is increasing of system reliability. The reliability improvement issue is one of major problems in distribution system operation and planning. This can done by reducing either mean repair time or mean failure rate of system elements [13]. In this paper, some customer and energy based indices considered system reliability in two-stages using differential evolution (DE) optimization method.

II. IMPERIALIST COMPETITIVE ALGORITHM (ICA)

Imperialist competitive algorithm is a new evolutionary optimization method that is inspired by imperialist competition [5-15]. Like other evolutionary algorithms, ICA starts with an initial population, which is called country and is divided into two types, colonies and imperialists, which together form empires. That is similar to chromosome in genetic algorithm [16] and particle in Particle Swarm Optimization (PSO) algorithm.

Every country could be defined as a vector with socio-political characteristics such as culture, language, and religion. Stages of our proposed algorithm are explained as follow: generating initial empires, assimilation, revolution, exchange between the best colony and imperialist, Imperialistic competition, elimination of powerless empire.

A. Generating Initial Empires

At the beginning of the algorithm, an initial population called countries should be created. In an N-dimensional optimization problem, a country is a $1\times N$ array. This array is defined with:

$$country = [x_1, x_2, \ldots, x_i] \qquad (1)$$

where, x_i is the variable that is to be optimized, x_i is similar to particle in PSO algorithm.

In Equation (1) each country has socio-political features such as culture, language, economic, religion and etc. The cost function of each country is calculated by using variables (x_1, x_2, …, x_i) as follows:

$$cost_i = g(country_i) = g(x_1, x_2, x_3, ..., x_{N_{\text{var}}}) \qquad (2)$$

To start algorithm, initial $N_{country}$ are created that N_{imp} number countries of created countries are regarded as imperialist country and remained countries are colonies of imperialist countries. In order to dividing colonies between imperialists, based on proportional to the power, colonies are given to imperialists. To do this job, by having cost function of all imperialists, the normalized cost of them is considered as follows that $\max_i\{h_i\}$ is the highest cost among the imperialists.

$$H_n = \max_i\{h_i\} - h_n \qquad (3)$$

The imperialist that has the highest cost is the weakest imperialist and its normalized cost is less than others. The normalized cost is calculated as follows and based on these costs, the colonies are divided among imperialists.

$$x_n = \left| \frac{H_n}{\sum_{i=1}^{N_{imp}} H_i} \right| \qquad (4)$$

In addition, the initial number of colonies of an imperialist is calculated as follows:

$$NCol_n = \text{round}\{x_n\ (N_{col})\} \qquad (5)$$

Empires with the bigger power or lower cost have a large number of colonies.

B. Assimilation

The original version of imperialist competitive algorithm operates on continuous problems. Imperialist countries start by improving their colonies. This fact has been modeled by moving all of the colonies toward the imperialist and changing the characteristics of colonies such as culture, social structure, language and etc.

This movement is shown in Figure 1 in which a colony moves toward the imperialist by a random value that is uniformly distributed between 0, $\beta\times d$:

$$\{position\}_{new} = \{position\}_{old} + U(0, \beta\times d)\times\{V_1\} \qquad (6)$$

where, the length of vector V_1 is set to unity. To increase the searching around the imperialist, a random amount of deviation is added to the direction of movement. The new direction, which is obtained by deviating the previous location of the country as great as φ. φ is a random number with uniform distribution as:

$$\varphi = U(-\tau, +\tau) \qquad (7)$$

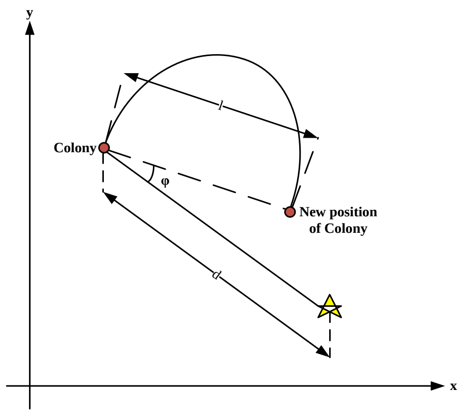

Figure 1. Moving colonies direction

C. Updating Positions of the Imperialists

During the previous stage, a colony may reach to a position with lower cost than that of the imperialist. In such a case, the positions of the imperialist and that colony must be exchanged. Then the rest of the colonies of this empire move toward the new position of the imperialist.

D. Calculating Total Power of an Empire

The imperialist's power and its colonies' power create the total power of the empire. The imperialist's power is more effective than the power of its colonies. The total power of an empire is defined as:

$$TH_n = cost(imperialist_n) + \psi \times \frac{\sum_{i=1}^{NCol_n} Hc_{ni}}{NCol_n} \quad (8)$$

E. Imperialistic Competition

In this stage, the imperialistic competition begins and all the empires try to take possession of the colonies of other empires. At any iteration, at first the weakest colony of weakest empire is determined. Then this colony is given to the other empires, which depend on their total power. Therefore, the more powerful empires have greater chance to possess the mentioned colonies. The normalized total power of each empire is calculated as follows:

$$NTH_n = \max_i \{TH_i\} - TH_n \quad (9)$$

Having the normalized total cost, the possession probability of each empire is calculated as below:

$$x_{x_n} = \left| \frac{NTH_n}{\sum_{i=1}^{N_{imp}} NTH_i} \right| \quad (10)$$

We used Roulette wheel method for assigning the mentioned colony to the empires [39].

F. Eliminating the Powerless Empires

When each empire loses all of colonies, this empire will collapse and its imperialist is considered as a colony and is assigned to other empires.

G. Convergence

After some imperialistic competitions, all the empires except the most powerful one will collapse and all of the countries under their possession become colonies of this empire. All the colonies have the same positions and the same costs and there is no difference between the colonies and their imperialist. In such a case, the algorithm stops. In this work, ICA applied to search for optimal distribution of substation placement problem. Flowchart of imperialist competitive algorithm has shown in Figure 2 [5].

III. HV SUBSTATION PLACEMENT AND FEEDER ROUTING FORMULATION

The goal of feeder routing is to determine the routes of candidates MV feeders regarding the cost of construction and operation considering electrical, geographical and asset constraints. In many distribution systems, the network is planned mesh but operates radially. Since the MV feeders originate from HV substations, it is relevant to solve the optimal HV substation allocation and optimal feeder routing problem simultaneously. The output of optimal MV substation placement is input for this stage and each MV substation are considered as a given load point in this case. It should be mentioned that it assumed the MV substation placement problem solved and the output of this problem is ready for these stages.

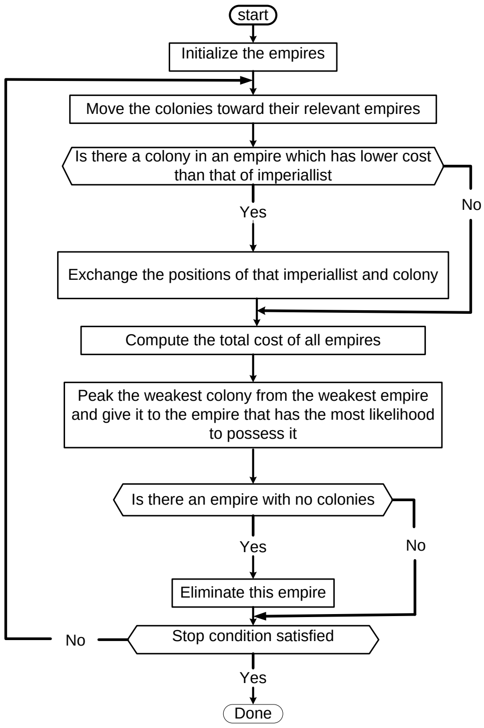

Figure 2. Flowchart of imperialist competitive algorithm

During optimization process to maintain the radial structure of a pre-defined meshed network, at any iteration of the optimization, the vectors (countries) of the ICA manipulated to guarantee the radial structure of the MV network while the probabilistic nature of the problem is preserved. The length of the country is equal to the length of candidate HV substations vector and feasible MV feeder's vector. All loads in the system should be supply by HV substations; hence, MV feeder's string includes set of ones that number of the "1" is equal to number of loads.

In fact, during simulation process the sum of the "1" for each country is constant and is equal to sum of the system nodes. On the other hand, the "1" in this portion arranging such that the radial structure of the network is preserved. The new countries are chosen such that Equation (1) is satisfied. It is essential that all MV substations connect to HV substations by radial MV feeders. This is a key and important fact that considered in this stage of ODSP for ICA optimization.

$$\sum_{i=1}^{M} "1" = L \quad (11)$$

where, "1" shows the selected feeders.

The cost function for optimal distribution system planning in [1, 2] is modified to Equation (12). Equation (11) explains the system electrical and other constraints for the optimization algorithm.

$$\text{minimize cost function} = \sum_{h=1}^{H} H_{FC}(S_h) + $$
$$+\sum_{f=1}^{F}\left(F_{FC}(F_f)+\beta I^2(F_f)R_f\right) \quad (12)$$
$$\text{s.t.: not (ring in the network)}$$
$$I(F_f) < I_{\max}(F_f), \quad f=1,2,...,F$$
$$\sum_{f=1}^{K}\left(R_f\cos(\theta_f)+X_f\sin(\theta_f)\right)I(F_f) < AVD_{\max} \quad (13)$$
$$\sum_{m=1}^{M}\sqrt{3}V_{LL}I_{LL}(F_m) < MVA(S_h), \quad h=1, 2, ..., H$$

As mentioned, the proposed method designed such that the necessary conditions of the MV network are checked. In Equation (12), the cost of HV substations as well as cost of new feeders and the cost of loss in the feeders should be minimize. The minimization done with respect to electrical constraints in Equation (13) and some geographical constraints that implemented in the candidate feeders' routes and locations of HV substations as input data.

In optimization process, the obtained results at any iteration should be modifying to update of the system equipment according to standard to insure the reliable operation of system at normal operation. The distribution system needs a remarkable investment at system infrastructure to ensure adequate system back up. The constraints on system elements is done such that maximum loading level of the substation and feeders are satisfied and the obtained results from the simulation are de-rated according to nominal rating of standard equipment.

To solve the optimal distribution of system planning problem, all of the possible and candidate routes, and the existing feeders entered as input data. This basic data construct a graph that represents the electric network topology. The topology of the network fully specified by the node-branch connection information or by incidence matrix of the network graph. For each branch or feeder section, there are some essential parameters such as starting and ending of a feeder section that includes load points, cost of feeder section, length, and capacity of feeder section needed to specify.

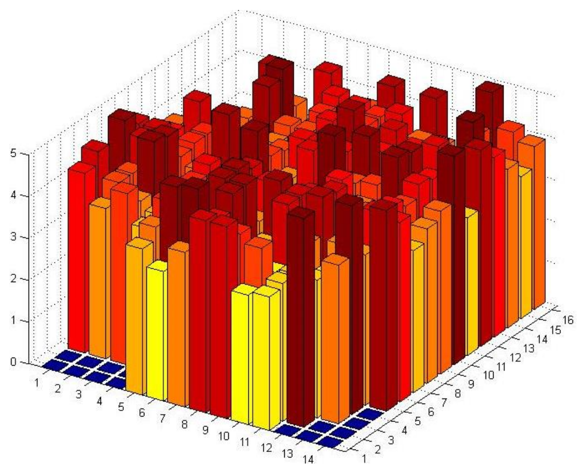

Figure 3. Three-dimensional representation of base case load density

In electric distribution network graph that consists of *k* feeders and *n* substations originated from HV substations, there are many different trees. Among all trees of this network, the minimum spanning tree is the one that total lengths of branches (feeders) are minimum. The radial structure of network has guaranteed by nature of the MST algorithm. This algorithm is used to generation of initial countries as well as new colonies in order to satisfy the two first major constraints of the problem. The Greedy algorithm as a classic approach applied to create a minimum spanning tree. In this section, the Greedy algorithm implemented and illustrated as follow.

IV. RESULTS AND DISCUSSIONS

In this section, the results of simulation of ODSP presented. The optimal feeder routing and optimal HV substation placement are designed using a multistage and step by step manner for three stage namely base, mid-term (5 years) and long-term (10 years) planning. The planning periods may be change according to system constraints especially with asset management problem.

To demonstrate the suitability of the proposed method for solving ODSP problem, a relatively large-scale network is selected as base test case. Three-dimensional representation of base case load density (kW) is indicated in Figure 3. The locations of the MV substations together with their corresponding supplied areas shown in Figure 4. For base case, there are seven medium voltage substations from number 2 to 5 with different standard capacities.

These substations are the output of optimal MV substation placement algorithm for base case planning. For this case, the feasible MV feeder's route regarding geographical constraints of the network using dashed lines illustrated in Figure 4. In this figure, white points at the end of each selected MV feeders show the MV substations location. The load density for each load block is shown in Figure 4 and blue lines illustrate substation corresponding supplied area boundary. The HV substation is numbered by one and indicated by a white square.

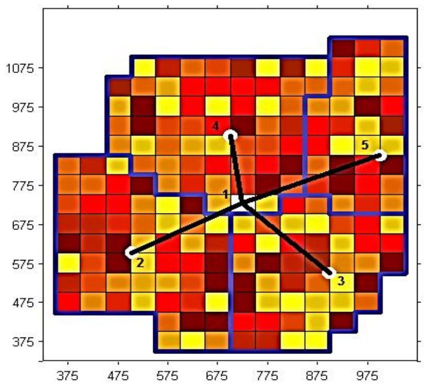

Figure 4. Optimal HV substation and feeder routing for base case

The distance between each two loads indicated as the shortest path. The real values of the distances between each two nodes are measured using GIS system or by onsite inspection and is implemented into the simulation program. In practice, the existing MV feeders installed and may preserve according to distribution system experts.

The routes of new feeder have chosen according to urban environmental and geographical constraints. Figure 4 illustrates the results of optimal planning for MV distribution network (represented by black lines to build future feeder's configuration. As state before the feasible feeder's routes for MV feeders and feasible locations of HV substations are determined considering topological and geographical constraints of the city by network engineers. In this case, there is only one HV substation and therefore the capacity of the HV substation calculated at final step and selected according to the sum of connected loads (MV substations).

The best cost trace of the solution at any iteration of ICA for base case indicated in Figure 5. In order to consider the pseudo dynamic behavior of the project the simulation has done for three cases namely, base load, five years, and ten years load forecasting. The HV substation or five selected feeders which are determined at previous stage may be considered as existing one at the next planning stage because of the high cost of removing of a substation as well as a feeder from its current location.

The graphical representation of planned network is relevant feature of the simulation tools that helps system experts to see readily the location, size and time and other useful data for updated or new installations. The optimization algorithm used for mid-term and long-term system planning with a similar manner. Figure 6 shows the three-dimensional graph of load density at five years horizon. Results of MV substation placement as input data for five-year case. In this stage according to the OSP results, there are nine load points or MV substations that should be connect to the HV substation from MV feeders.

As seen from the figure in this stage in addition of four existing substation, some new substation have been selected in this case. After optimization process, the results has depicted in Figure 7. According to the results, the MV substations connected to the HV substation from four outgoing selected feeders.

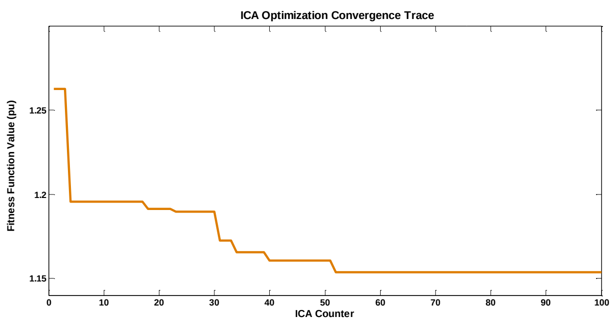

Figure 5. ICA fitness function best cost trace for base case

The configuration of the optimal planned network for mid-term load has represented fully by the Figure 5. Regarding Figure 7, it can be seen that the study area is extended toward the right hand of the figure and some vacant areas are filled by new installations, because the study zone is extended to the east. At the contrary, the center points and west of the study zone developed vertically because the load density in this section of the study zone increased rapidly.

Similar to base and mid-term planning the procedure is applied to long-term system planning. The load density at this case is indicated in Figure 8. The simulation results have shown in Figure 9. In this case, 27 MV substations considered as load points. The candidate MV feeders' route has chosen considering distribution system constraints. Black lines originated from HV substation show the optimal network configuration. Based on figure, four MV feeders directly connected to HV substation. The existing HV substation capacity modified with respect to system loading. The backward sweep load of flow algorithm used to calculate voltage at all nodes and the current of the feeders.

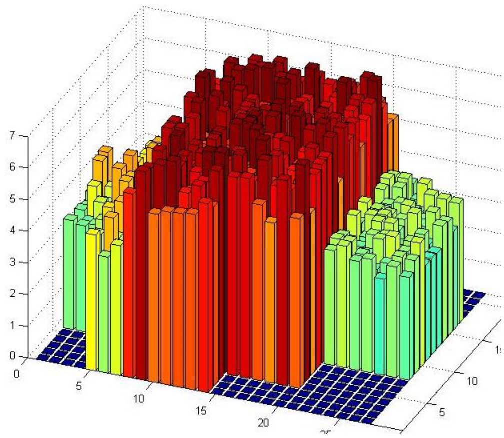

Figure 6. Three-dimensional representation of mid-term load density

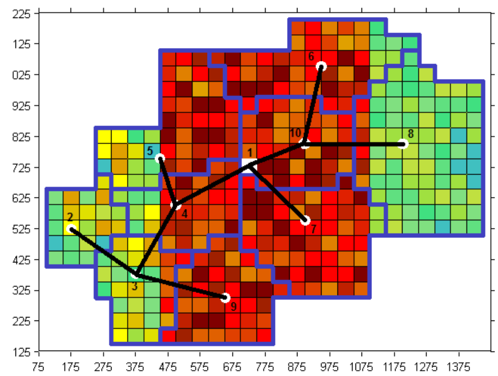

Figure 7. Optimal network configuration for mid-term

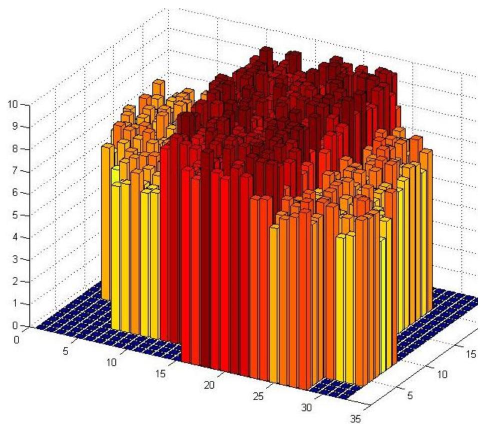

Figure 8. Three-dimensional representation of long-term load density

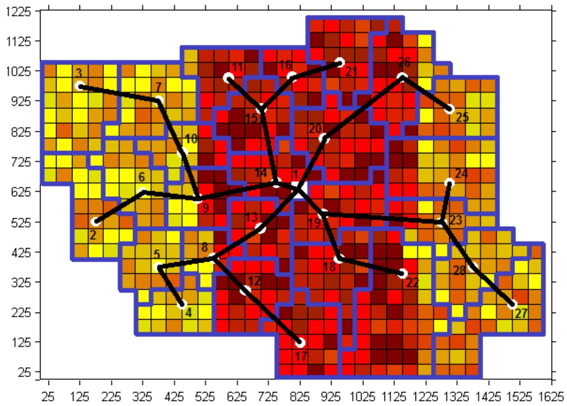

Figure 9. Optimal network configuration for long-term planning

V. CONCLUSIONS

A new developed optimization algorithm based on imperialist competitive is adapted and applied to optimal distribution network expansion planning problem. A framework is proposed for simultaneously optimal planning of HV substations and MV feeders routing. The input data for each stage provided from previous stage of ODSP. The proposed method finds location, size and time of installation of the HV substations and routes of MV feeders simultaneously.

The optimal sizing, siting, and timing of the distribution network at a pseudo-dynamic planning environment considering major planning constraints implemented into cost function that optimized by ICA. Numerical results and figures fully represented for three base, mid-term, and long-term planning cases. The results imply efficiency and capability of procedure that has been test on relatively large-scale real size distribution network.

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