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AN ALGORITHM BASED ON THE CLUSTERING TECHNIQUES FOR THE OPTIMAL PLACEMENT OF THE DISTRIBUTED GENERATION SOURCES IN DISTRIBUTION SYSTEMS

BY

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Abstract. The aim of this paper is to find the optimal placement of distributed generation (DG) sources using clustering techniques, so the effects on the operation and control of the distribution system to be minimal. To determine the optimal placement of distributed generation sources into a 20 kV electrical distribution network was considered the loss sensitivity factor and the voltage values in the network nodes, parameters which has been grouped using hierarchical clustering techniques. The validity of the proposed method is observed through tests on the different electric distribution networks.

Key words: clustering techniques; distributed generation sources; loss sensitivity factor; voltage levels.

1. Introduction

Energy is the solution to development, yet more than 1.5 billion people worldwide still lack access to it. According to the International Energy Agency, global energy demand is projected to grow by about 50% by 2030, with a

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concurrent rise in greenhouse gas emissions. To meet the world's urgent and growing need for power, a reliable and clean energy supply is crucial. IFC (International Finance Corporation) believes that greater reliance on water, wind, solar, biomass and geothermal sources, as well as more efficient energy use, can help faster economic growth while also addressing climate change.

Nowadays the distributed generation (DG) sources are taking more relevance and it is anticipated that in the future it will have an important role in electric power systems.

The definition of DG takes different forms in different markets and countries and is defined differently by different agencies (Hemdan *et al.*, 2009). International Energy Agency (IEA) defines DG as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages. CIGRE defines DG as the generation which has the following characteristics: a) it is not centrally planned; b) it is not centrally dispatched at present; c) it is usually connected to the distribution network; d) it is smaller than 50… 100 MW. Other organization, like Electric Power Research Institute, defines distributed generation as generation from a few kilowatts up to 50 MW. In general, DG means small scale generation. The term DG also implies the use of any modular technology that is sited throughout a utility's service area (interconnected to the distribution or transmission system) to lower the cost of service (Waseem, 2008). Due to their high efficiency, small size, low investment cost, modularity and ability to exploit renewable energy sources, are increasingly becoming an attractive alternative to network reinforcement and expansion.

The benefits of DG are numerous and the reasons for implementing DG are an energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital costs of smaller plants and proximity of the generation plant to heavy loads, which reduces transmission costs.

Interconnecting a DG source in the distribution network can have significant effects on the system such as power flow, voltage regulation, reliability, etc. Because in the last five years the use of the DG sources was growing, it is critical to study the impacts on the distribution system operation. A DG source installation increases the complexity of the system and impacts the power flow and voltage conditions of the system (Mendez *et al.*, 2011). The planning of the electric system comprises several factors: types of DG, capacity and number of the DG units, the installation location, etc. Depending on these factors, the DG can have positive or negative impacts on the system.

The distribution planning problem is to identify an optimal location of the DG sources without violating any system and operational constraints. DG sources exercise an impact concerning technical and economic aspects of distribution planning depending on the reached penetration level (the ratio between the DG capacity and the load) (El-Khattam *et al.*, 2004). For example, the relationship between DG penetration and the effect on power and energy losses is still a debated question. Generally speaking, it may be argued that the higher is the DG penetration level the higher is the probability that the DG sources causes an increment of losses, but the optimal location of the DG sources can completely change this situation. In this sense, in this paper, the optimal location of the DG sources was determined using hierarchical clustering methods.

Regarding the placement of DG sources, in the literature there are many solutions proposed, namely using fuzzy techniques, heuristic optimization algorithm, mixed integer nonlinear programming, Evolutionary Programming (EP) optimization technique and others. In this sense, a new approach is proposed in this paper. Based on hierarchical clustering techniques the optimal placement of DG into electrical distribution network is determined using two variables: the loss sensitivity factor (LSF) and the nodal voltage values.

2. Clustering Techniques

Clustering techniques is the name of a group of multivariate techniques whose primary purpose is to identify similar entities from the characteristics they possess. In the literature there are several ways of classifying methods of clustering. Thus, there are two major methods of clustering (Cârțină *et al.*, 2005):

a) hierarchical methods;
b) *K*-means method.

Hierarchical clustering methods are subdivided, as the sense of deployment, in methods of agglomeration and divide methods. In case of agglomeration method, for example, starts from the n groups, each containing a single object, and by successive fusions arrive at one group, containing all the objects. In the case of the division method, sense of deployment is reversed, namely starting from a single group containing all the objects, get to n groups, each containing a single object. Agglomeration techniques are usually more used.

Hierarchical clustering method can be represented by a two dimensional diagram named *dendrogram*, which illustrates the fusion or division made at each successive stage of analysis (Fig. 1). As indicated above, hierarchical spatial clustering is a process of agglomeration through a series of fusions of groups, P_n, P_{n-1}, ... , P_1. First stage, P_n, consists of n “groups” with a single object, and the last, P_1, consists of a single group containing all n objects. At each step method coupled two close groups (the first level, however, this means coupling two objects that are close to each other (in distance), whereas the initial stage each group has an object).

The difference between methods is how to define the distance between groups. One of the most used clustering method is *the average distance method*. In this method the distance between two groups is defined as the average distances between all pairs of objects, where each pair contains one object in each group.

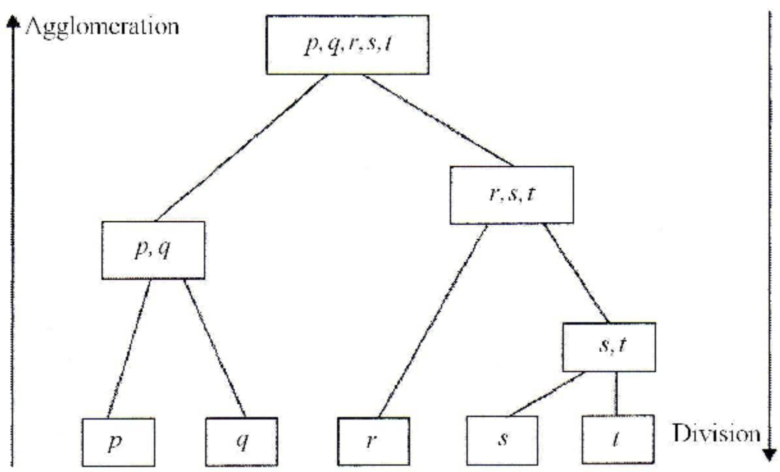

Fig. 1 – Example of dendrogram.

Thus, the distance $D(r, s)$ is determined by the relationship:

$$D(r,s) = \frac{T_{rs}}{N_r N_s}, \tag{1}$$

where: T_{rs} is the sum of the all the possible distances between the elements of the group r and the group s; N_r, N_s – the dimensions of groups r, respectively s.

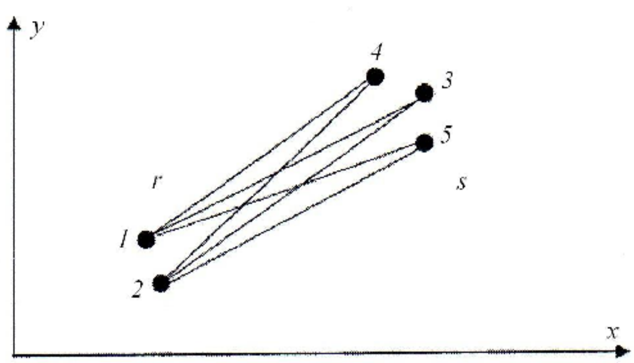

Fig. 2 – The average distance between two groups.

At each stage of hierarchical spatial clustering, the groups r and s for which $D(r,s)$ is minimal, are grouped. Fig. 2 illustrates the mode of definition of the average distance.

3. Calculating the Loss Sensitivity Factors

Sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce the number of solution space. Loss sensitivity factor method has been widely used to solve the capacitor allocation problem but now can be used successfully to determining the optimal place of DG (Greatbanks *et al.*, 2003). To calculate the loss sensitivity factors (LSFs) into a radial distribution networks is necessary to know the real and reactive power loads, the real and reactive power losses in network nodes and branches, that can be determined with power flow calculation.

The real and reactive power loss in any branch, *jj*, can be considered as the loss at the receiving end bus, *b*, of the same line. The real power losses, $P_{\text{line loss}}(b)$, and the reactive power losses, $Q_{\text{line loss}}(b)$, at the end node, *b*, of the branch are calculate with the expressions

$$P_{\text{line loss}}(b) = \frac{R(jj)\left[P^2(b) + Q^2(b)\right]}{\left|V^2(b)\right|}, \tag{2}$$

$$Q_{\text{line loss}}(b) = \frac{X(jj)\left[P^2(b) + Q^2(b)\right]}{\left|V^2(b)\right|}, \tag{3}$$

where: $P(b)$ is the sum of the real power loads of all the nodes beyond node *b* plus the real power load of the node *b* itself plus the sum of the real power loss of all the branches beyond node *b*; $Q(b)$ – sum of the reactive power loads of all the nodes beyond node *b* plus the reactive power load of the node *b* itself plus the sum of the reactive power loss of all the branches beyond node *b*; $V(b)$ – the voltage value at the end bus *b*.

Using the reactive power loss calculated with the expression (3), it can be determined the LSFs, real power loss ($P_{\text{line loss}}(b)$) with respect to effective reactive power ($Q(b)$), who are given by equation (Ramalingaiah *et al.*, 2009)

$$\text{LSF} = \frac{\partial P_{\text{line loss}}(b)}{\partial Q(b)} = \frac{2Q(b)R(jj)}{\left[V(b)\right]^2}. \tag{4}$$

The LSFs are then normalized into the (0,1) range, with the largest sensitivity having a value of 1 and the smallest one having a value of 0. The normalized loss sensitivity factors, *l*, can be obtained by reference to the maximum value of the LSFs recorded in the network, or the sums of the LSFs in all the nodes of the network, or the medium value of the LSFs in all the nodes of the analysed network.

In this paper the normalization process of the LSFs is carried out by determining the LSFs values obtained in the network nodes and the maximum value of LSF in all the nodes of the analysed network. The normalized nodal voltage magnitudes, *u,* are obtained by considering the voltage magnitudes, *V*, in network nodes and the nominal voltage, V_n, of the analysed network, respectively.

The normalized loss sensitivity factors*,* and nodal voltage magnitudes are used as inputs in the process of clustering illustrated in § **2**, which determine the nodes more suitable for DG installation.

4. Proposed Method to Find the Optimal Place of DG Sources

In this paper, the task of area identifying of DG sources is formulated as a problem of nodes identification from distribution system where they can be placed. In this view, an algorithm to determine the optimal placement, which takes into consideration two operational characteristics (loss sensitivity factor and voltage level) of the every node, is proposed.

A hierarchic clustering method is used, which well overcomes problems concerning formation of coherent and representative clusters (named below *zones*). The main purpose is to compare units (that represent the links of every node with other in terms of the considered characteristics), and to gather them progressively in coherent clusters (zones) in a way that the nodes in the same cluster to belong same zone. Then, a distance between pairs of the nodes *i* and *j* is computed. Common used distance is Euclidean distance. These generated distances are used to determine proximity of nodes to each other. After that, they are linked together in to the new group (zone), *Z*. The newly formed zones are grouped into larger zones until a hierarchical tree is formed. The process is repeated until there is only one zone if all nodes meet the required criterion.

In the next step, the hierarchical tree is divided into coherent zones by cutting off the hierarchical tree at an arbitrary point, α. The number of zones will depend on the value of α and the characteristics of the distribution system. However, the threshold of inconsistency coefficient strongly influences the final number of zones. The DG sources number which can be installed in distribution system will be equal with number of obtained zones.

5. Study Case

The data about the operational characteristics of the distribution nodes were updated and prepared for the clustering process, for a total of 24 medium voltage nodes (20 kV) belonging to a rural distribution network (Fig. 3).

The operational characteristics of the nodes are represented by the loss sensitivity factor (LSF) and voltage level (*V*). The normalized values of LSF and *V* are obtained by considering the maximum value, respectively nominal value of the test distribution network (Table 1). These normalized values are used in the clustering process.

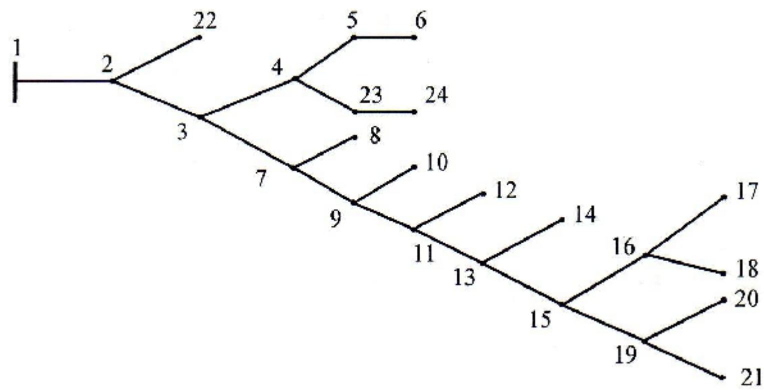

Fig. 3 – The single line diagram of the 20 kV rural distribution network.

Table 1
The Normalized Values of the Loss Sensitivity Factors, l, and Voltage Values, u, of the 20 kV Rural Distribution Network

Bus	l	u, [p.u]	Bus	l	u, [p.u]
1	0.9989	0.9998	13	0.115977	0.9588
2	0.592289	0.98815	14	0.000341	0.9588
3	0.99998	0.969	15	0.018436	0.95845
4	0.169543	0.9655	16	0.004336	0.95835
5	0.016266	0.96515	17	0.032072	0.95775
6	0.000522	0.96515	18	0.021762	0.95795
7	0.089692	0.9674	19	0.014306	0.95815
8	0.001026	0.96735	20	0.002417	0.9581
9	0.223097	0.9634	21	0.010361	0.958
10	0.00024	0.9634	22	0.000318	0.98815
11	0.140317	0.9609	23	0.036749	0.96475
12	0.010702	0.9607	24	0.000522	0.96475

In function of operational characteristics, the nodes are divided in representative clusters (zones), using a statistical clustering method (average distance method). The dendrogram of clustering process is presented in Fig. 4.

In the next step, the dendrogram is divided into coherent zones. Thus, two zones were obtained using the average distance method: Zone 1 (5 nodes) and Zone 2 (15 nodes) (Figs. 4 and 5).

The approach using clustering techniques has the advantage of partitioning the power system efficiently and in finding the cut-set. Thus, for partitioning of the system, the method does not require any of the additional steps.

In what follows, the average values and the standard deviations corresponding to loss sensitivity factor and voltage level for every zone of nodes are calculated. Beyond determination of the characteristics of the zones, the representative nodes are identified. These representative nodes must characterize the best the peculiarities of the zones, from the loss sensitivity factor and voltage level viewpoint.

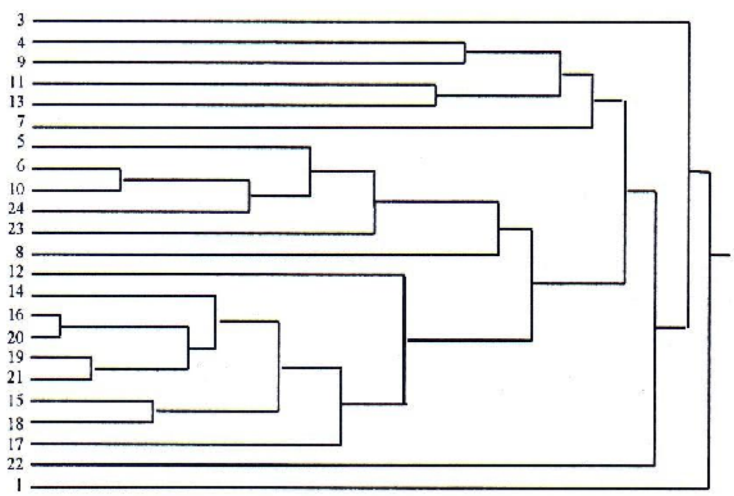

Fig. 4 – Dendrogram of the clustering process.

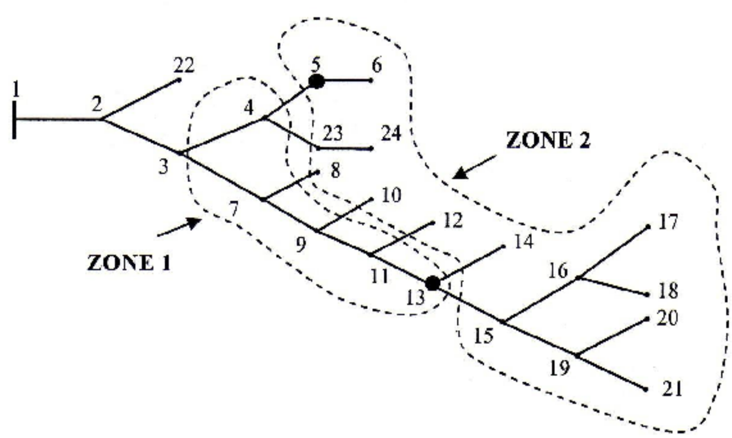

Fig. 5 – The zones of the test distribution network and optimal placement of DG sources.

The representative nodes of the zones are 5 and 13, respectively. Thus, the DG sources will be installed in these nodes (Fig. 5).

6. Conclusions

The benefits of DG sources are numerous and the reasons for implementing DG are the followings: an energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital costs of smaller plants and proximity of the generation plant to heavy loads, which reduces transmission costs. Thus, in this paper a new approach, based on the clustering techniques is proposed for determining the optimal placement of DG sources in electric distribution networks so the effects on the operation to be minimal. The obtained results for a test distribution network demonstrate that the method can be successfully used.

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UN ALGORITM BAZAT PE TEHNICILE CLUSTERING PENTRU AMPLASAREA OPTIMĂ A SURSELOR DE GENERARE DISTRIBUITĂ ÎN SISTEMELE DE DISTRIBUŢIE A ENERGIEI ELECTRICE

(Rezumat)

Se propune un nou algoritm bazat pe tehnicile de clustering pentru amplasarea optimă a surselor de generare distribuită în reţelele electrice de distribuţie. Analiza se

efectuează ținând cont de factorul de senzitivitate a pierderilor de putere activă şi de valorile tensiunii în nodurile rețelei, parametri ce constituie date de intrare în cadrul metodelor de clustering. Rezultatele obținute demonstrează faptul că algoritmul propus poate fi utilizat cu succes în amplasarea optimă a surselor de generare distribuită în rețelele electrice de distribuție.