USING OF CLUSTERING TECHNIQUES FOR PLACEMENT OF DISTRIBUTED GENERATION SOURCES IN ELECTRICAL DISTRIBUTION SYSTEMS

Eng. **Florina SCARLATACHE**[1],
Lecturer Eng. **Gheorghe GRIGORAŞ**, PhD[1], Prof. Eng. **Gheorghe CÂRȚINĂ** PhD[1],

[1] "Gheorghe Asachi" Technical University of Iasi, Department of Power Systems

REZUMAT. În ultimii ani, sursele de generare distribuită (GD) au luat o amploare deosebită şi se anticipează că în viitor acestea vor avea un rol important în sistemele electroenergetice. O alegere nepotrivită a locului şi dimensiunii acestor surse poate conduce la o înrăutăţire a condiţiilor de exploatare referitoare la creşterea nivelului pierderilor de putere activă şi scăderea valorilor tensiunilor în noduri, în raport cu situația în care nu sunt amplasate surse de GD. Obiectivul acestei lucrări este de a găsi locul şi numărul optim a surselor de GD folosind tehnicile de clustering în aşa fel încât efectele în conducerea şi controlul sistemului de distribuţie să fie minime. Validitatea metodei propuse este aratată printr-o serie de teste pe rețele electrice de distribuție.

Cuvinte cheie: surse de generare distribuită, amplasare optimală, tehnici de clustering, rețele de distribuție.

ABSTRACT. Nowadays, the distributed generation (DG) is taking more relevance and it is anticipated that in the future it will have an important role in electric power systems. But, an inappropriate selection of location and size of DG sources can lead to power losses greater than the losses without DG. The objective of the paper is to find the optimal number and placement of DG sources using clustering techniques, so the effects on the operation and control of the distribution system to be minimal. The validity of the proposed method is observed through tests on the different electric distribution networks.

Keywords: DG sources, optimal placement, clustering techniques, distribution networks.

1. INTRODUCTION

Nowadays, distributed generation (DG) is playing a significant role in the electrical energy systems. The definition of distributed generation takes different forms in different markets and countries and is defined differently by different agencies [1]. International Energy Agency (IEA) defines distributed generation 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: It is not centrally planned; It is not centrally dispatched at present; It is usually connected to the distribution network; 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 [2]. 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 and distribution costs [3-7].

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 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 [8-12].

The planning of the electric system comprises of 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 impacts technical and economic aspects of distribution planning depending on the reached penetration level (the ratio between the DG capacity and the load) [13].

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.

Regarding the placement of DG sources, in the literature there are many solution proposed, namely using fuzzy techniques, heuristic optimization algorithm, mixed integer nonlinear programming, Evolutionary Programming (EP) optimization technique and others.

The objective of this paper is to find the optimal number of DG sources using clustering techniques, so the effects on the operation and control of the distribution system to be minimal. The validity of the proposed method is observed through tests on the different electric power networks.

2. CLUSTERING TECHNIQUES

Cluster analysis is the organization of a collection of objects (usually represented as a vector of measurements) into cluster based on similarity. It is a wonderful exploratory technique to help us understand the clumping structure of the data.

There are two major methods of clustering: hierarchical clustering and k-means clustering [14-16].

Hierarchical clustering is subdivided into agglomerative methods, which proceed by series of fusions of the n objects into groups, and divisive methods, which separate n objects successively into finer groupings. Agglomerative techniques are more commonly used. Hierarchical clustering may be represented by a two dimensional diagram, known as dendrogram which illustrates the fusions or divisions made at each successive stage of analysis. An example of such a dendrogram is given in Fig. 1.

In the case of agglomerative hierarchical clustering, differences between methods arise because of the different ways of defining distance (or similarity) between clusters. Several agglomerative techniques will now be described in the following [14-18].

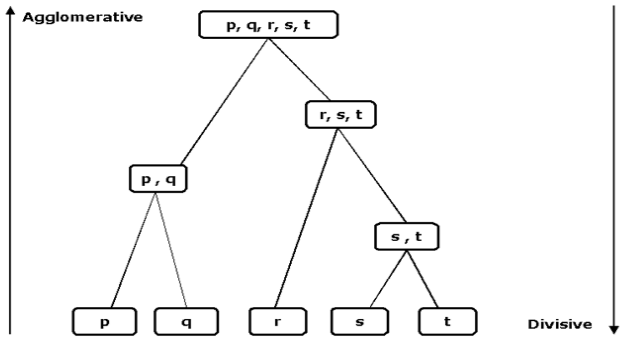

Fig. 1. Example of dendrogram.

Single linkage clustering method (connectedness or minimum method). One of the simplest agglomerative hierarchical clustering methods is single linkage, also known as the nearest neighbor technique. The defining feature of the method is that distance between clusters is defined as the distance between the closest pair of objects, where only pairs consisting of one object from each cluster are considered. In the single linkage method, the distance $D(r, s)$ is computed as:

$$D(r,s) = \min\{d(i,\ j)\} \tag{1}$$

where $d(i, j)$ is the distance between the object i from cluster r and the object j from cluster s.

At each stage of hierarchical clustering, the clusters r and s, for which $D(r, s)$ is minimum, are merged.

Complete linkage clustering method (diameter or maximum method). The complete linkage, also called farthest neighbor, clustering method is the opposite of single linkage. Distance between clusters is now defined as the distance between the most distant pair of objects, one from each cluster. In the complete linkage method, $D(r, s)$ is computed as:

$$D(r,s) = \max\{d(i,\ j)\} \tag{2}$$

where object i is in cluster r and object j is cluster s. At each stage of hierarchical clustering, the clusters r and s, for which $D(r, s)$ is maximum, are merged.

Average linkage clustering method. The distance between two clusters is defined as the average of distances between all pairs of objects, where each pair is made up of one object from each cluster. In the average linkage method, $D(r, s)$ is computed as:

$$D(r,s) = \frac{T_{rs}}{(N_r \cdot N_s)} \tag{3}$$

where:

T_{rs} is the sum of all pair wise distances between cluster r and cluster s;

N_r, N_s are the sizes of the clusters r and s respectively.

At each stage of hierarchical clustering, the clusters r and s, for which $D(r, s)$ is the minimum, are merged.

Centroid Method. In the centroid method the distance between two clusters is defined as the squared Euclidean distance between their means. The centroid method is more robust to outliers than most other hierarchical methods but in other respects may not perform as well as average linkage method.

$$D(r,s) = \left\| \overline{X}_r - \overline{X}_s \right\|^2 \qquad (4)$$

K-means clustering method. K-means is one of the simplest unsupervised learning algorithms that solve the well known clustering problem. The main idea is to define k centroids, one for each cluster so minimize an *objective function*, in this case a squared error function:

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2 \qquad (5)$$

where $\left\| x_i^{(j)} - c_j \right\|^2$ is a chosen distance measure between a data point $x_i^{(j)}$ and the cluster centre c_j.

3. OPTIMAL PLACEMNT OF DG SOURCES USING CLUSTERING TECHNIQUES

In this paper, the task of area identify of DG sources is formulated as a problem of nodes identification from distribution system where they can be placement. For this, an approach to determine the optimal placement, which takes into consideration two operational characteristics (loss sensitivity factor and voltage level) of the every node, is proposed. The values of these quantities are calculated using a power flow algorithm. Thus, the loss sensitivity factor *LSF* can be determined using the relation [12]:

$$LSF = \frac{\partial \Delta P_{ij}}{\partial Q_j} = \frac{2 \cdot Q_j \cdot R_{ij}}{U_j^{\,2}} \qquad (6)$$

where:

ΔP_{ij} - the active power losses in any branch *ij*;

Q_j – the sum of the reactive power loads of all the nodes beyond node *j* plus the reactive power load of the node *j* itself and the sum of the reactive power loss of all the branches beyond node *j*;

R_{ij} - the resistance of the branch *ij*;

U_j - the voltage value in the end bus *j*.

In the following, *LSF* and *U* are then normalized into the (0, 1) range. These normalized values are used in the clustering process.

In consequence, 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 [14],[15]. These distances generated 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.

Finally, the DG sources will be installed in the nodes that represent the best operational characteristics of the zones in term of the loss sensitivity factor and voltage level.

4. CASE STUDY

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. 2.

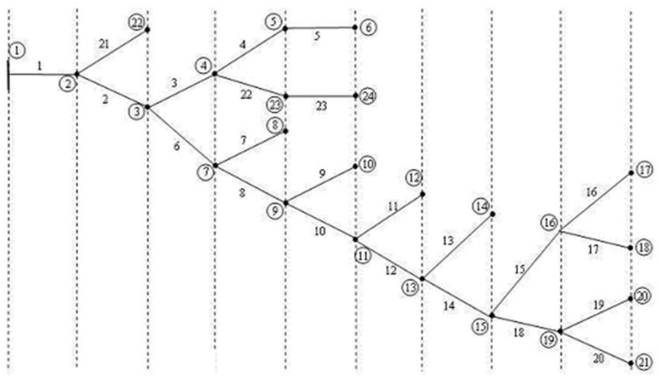

Fig. 2. The test distribution network.

The operational characteristics of the nodes are represented by the loss sensitivity factor *LSF* and voltage level *U*. The normalized values of the loss sensitivity factor and nodal voltages 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.

Table 1

The normalized values of LSFs and V for the nodes of the analyzed network

Node	LSF [p.u]	U [p.u]	Node	LSF [p.u]	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 the clustering process are presented in Figure 3. In the next step, the dendogram is divided into coherent zones, (the cutting coefficient α *is* is two). Thus, two zones were obtained using the average distance method: Zone 1 (5 nodes) and Zone 2 (15 feeders), Figs. 3 and 4.

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 additional steps.

In the following, the average values and the standard deviations corresponding to loss sensitivity factor and voltage level for the every zone of nodes are calculated. Beyond determination of the characteristics of the zones, it identifies the representative nodes. These representative nodes must to characterize the best the particularity of the zones, from viewpoint of the loss sensitivity factor and voltage level. The node of the zone in which the *LSF* is higher and the voltage magnitude is lower is selected to be the representative node. Thus, the representative nodes of the zones are 5 and 13, respectively. Thus, the DG sources will be installed in these nodes, Fig. 4.

But interconnecting of these DG sources in the distribution network can have significant effects on the system operation such as power flow, voltage regulation, etc. Further, it will determine the active power injected by these sources so as to ensure an optimal level of power losses in the system, respectively of the voltages from the nodes. The value of the active power injected in the pilot nodes was considered as the percentage of the power injected into the network at peak load (P^{RN}_{inj} = 2 MW).

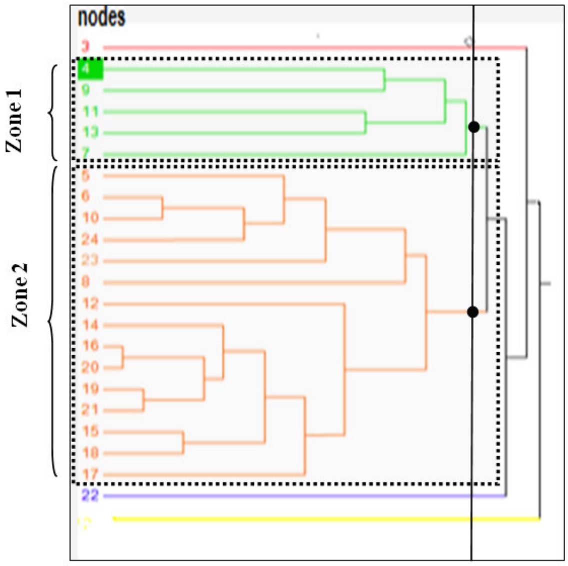

Fig. 3. The dendrogram of the clustering process.

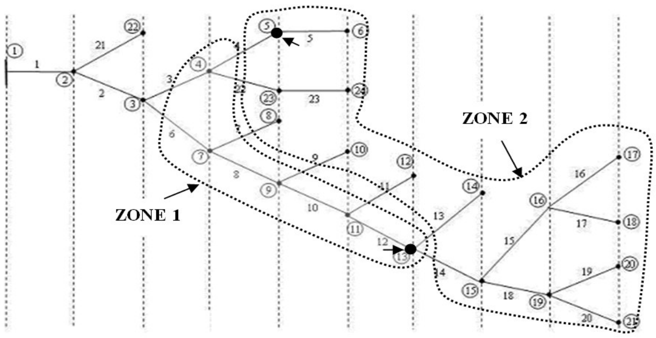

Fig. 4. The zones of the test distribution network and optimal placement of DG sources.

In Fig. 5, the evolution of the voltage in nodes for different levels of the active power injected by DG sources from representative nodes is presented (RN represent normal regime operation - without DG sources installed).

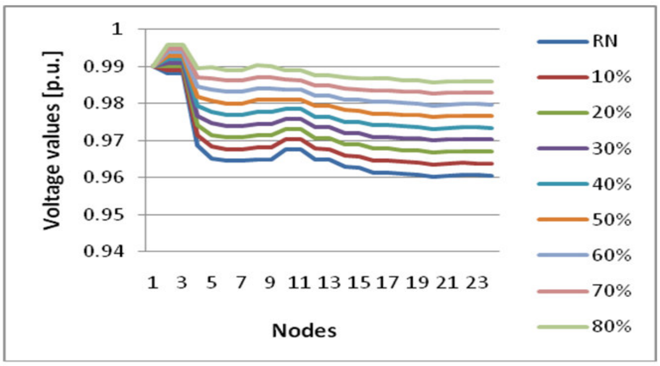

Fig. 5. Evolution of the voltage in nodes for different levels of the active power injected by DG sources (percentage of the power injected into the network at peak load).

In terms of the active power losses for different levels of active power injected by DG sources from representative nodes, these decrease having a minimum value for an injection level of 80%, Fig. 6.

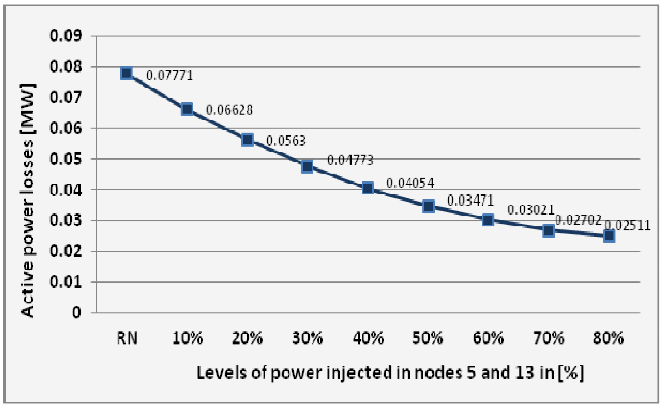

Fig. 6. Evolution of the active power losses in nodes for different levels of the active power injected by DG sources (percentage of the power injected into the network at peak load).

5. CONCLUSIONS

The benefits of DG sources 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. But, interconnecting a DG source in the distribution network can have significant effects on the operation and control of distribution system such as power flows, power losses, voltage regulation, reliability, etc. Installation of the DG source increases the complexity of the distribution system and impacts the power flow and voltage conditions of the system. Thus, in this paper a new approach, based on the clustering techniques is proposed for determination 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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About the authors

Eng. **Florina SCARLATACHE**,
"Gheorghe Asachi" Technical University of Iasi, Romania
Faculty of Electrical Engineering, Department of Power Systems
email:flr_rotaru@yahoo.com

Graduated at the "Gheorghe Asachi" Technical University of Iasi, Romania, Faculty of Electrical Engineering, specialization Power Engineering in 2009. Currently she is Ph.D. student in the Department of Power Systems in same faculty and her research interests are in advanced techniques in modeling and optimal control of power systems.

Lecturer Eng. **Gheorghe GRIGORAŞ**, PhD.,
"Gheorghe Asachi" Technical University of Iasi, Romania
Faculty of Electrical Engineering, Department of Power Systems
email:ggrigor@ee.tuiasi.ro

Gheorghe Grigoras was born in Vatra Dornei, Romania, on February 28, 1976. He received the M. SC. and Ph. D. degrees in Electrical Engineering from "Gheorghe Asachi" Technical University of Iasi, Romania, in 2000 and 2005 respectively. He is currently Senior Lecturer in the Department of Power Systems of Electrical Engineering Faculty at the same university. His main areas of interest are analysis, planning, and optimization of power systems.

Prof. Eng. **Gheorghe CÂRŢINĂ**, PhD.,
"Gheorghe Asachi" Technical University of Iasi, Romania
Faculty of Electrical Engineering, Department of Power Systems
email:gcartina1@yahoo.com

Gheorghe Cârțină (Member IEEE) received the M. SC. and Ph. D. degrees in Electrical Engineering from "Gheorghe Asachi" Technical University of Iasi, Romania, in 1964 and 1972 respectively. He is currently professor in the Department of Power Systems of Electrical Engineering Faculty at the same university. His research interests include especially to monitoring and optimal control of power systems.