Characterization of the Radial Structures for the Operation of a Real Medium Voltage Distribution System

Horia Andrei, Gianfranco Chicco, Mircea Popa, and Marius Silaghi

Abstract**—**Distribution system reconfiguration is based on searching for effective radial network structures from the weakly meshed structure of the physical network. For large distribution systems, this search is particularly challenging, due to the extremely high number of possible radial structures. This paper illustrates a suitable technique based on the creation of a reduced weakly meshed network containing the basic information required to apply further numerical techniques for identifying the radial network structures. The network components, including branches, loads and the connections to the supply system, are taken into account to form a layered structure. This layered structure can be used as a reference for identifying the most suitable radial configuration according to a specified objective function, by resorting to deterministic or heuristic methods. An example of application to a large real distribution system is shown.

Keywords**—** distribution system, layers, medium voltage, radial configurations, operational structure, redundant branches, substations.

I. INTRODUCTION

MEDIUM Voltage (MV) distribution systems are typically supplied from the nodes of the High Voltage (HV) transmission system or from the nodes of distribution systems at different (normally higher) voltage levels through the connection transformers. The MV loads are served through a number of branches (overhead lines or underground cables). The MV network by construction has a weakly meshed structure, but its operation is carried out by opening a number of redundant branches so as to create a radial structure, in order to simplify the protection schemes. Various rationales may be used for selecting the strategy for opening the redundant branches. The distribution system operators usually define a base configuration, used for carrying out the general technical evaluations adopted as references for the distribution system operation, also used to provide reference data to the electricity Authority.

In general, it is possible to search for the optimal distribution system configuration according to a specified objective function (e.g., based on the distribution system losses, or formulated in economic terms). Deterministic or heuristic methods can be used for this purpose [1-13]. Given the original weakly meshed network, the solution methods need to explore the various configurations. However, the presence of non-symmetries in the system layout makes it very difficult even to enumerate the possible radial configurations that can be extracted from the original structure. Classical graph theory approaches [14] may be used for this purpose, but for weakly meshed networks it is possible to simplify the calculations by adopting more specific search techniques [15-17].

For a real distribution system, several practical aspects have to be taken into account in building the network configurations, including the location of the supply substations, the presence of different bus bar schemes, the structure of the feeders and the possible identification of independent areas. This paper presents and discusses some criteria for simplifying the initial weakly meshed network structure, in order to build a reduced network, again with weakly meshed structure, to be used for determining the possible radial structures before running suitable distribution system reconfiguration algorithms. A dedicated application case built on the Medium Voltage distribution system of the city of Oradea (Romania) is discussed in detail.

II. BASIC PRINCIPLES FOR THE CONSTRUCTION OF THE REDUCED NETWORK

Starting from the initial structure of the MV distribution system, the reduced network is created, in order to assist the evaluation of the possible radial configurations of the network, according to the following set of principles, derived both from theoretical reasoning and from practical considerations:

1. no load node has to be isolated in any network configuration;

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H. Andrei is with the Valahia University of Targoviste, Electrical Engineering Faculty, Dambovita, Romania (corresponding author to provide phone: +40744 331285; fax: +40245 217683; e-mail: hr_andrei@yahoo.com).

G. Chicco is with the Politecnico di Torino, Dipartimento di Ingegneria Elettrica, Italy(e-mail: gianfranco.chicco@polito.it).

M Popa is with the Electrica Company of North Transilvania, Oradea, Romania (e-mail:mpopa@eldior.ro).

M. Silaghi is with the University of Oradea, Electrical Engineering and Information Technology, Romania (email: masilaghi@uoradea.ro)..

2. concerning the supply side, the HV transmission system constitutes the backbone of the system and is considered to be always available; the possible supply coming from other MV systems are considered to be always available as well; all the supply nodes are then merged into a unique supply node, here called *root node*;
3. possible branches directly connecting two supply points are eliminated from the reduced network, considering them as being part of the supply system in the normal operation under study;
4. possible branches connecting two supply points, in which there are one or more loads in series, are considered separately with respect to the reduced network under construction, since their contribution to the total number of possible radial configurations (equal to the number of branches in series along the path) can be determined independently of the rest of the network;
5. possible branches connecting one or more nodes *in antenna*, that is, with no other return path, are eliminated from the reduced network (Fig. 1), since all these branches have to be always closed in the normal operation under study, for maintaining all the nodes connected to the distribution system;
6. a feeder composed of branches connecting a number of nodes in *series* is replaced by a single branch, storing the information on the number of branches in series as a multiplicity factor m (Fig. 2); in fact, only one branch at a time has to be open along the series path without isolating one or more of the intermediate nodes;
7. possible parallel paths among two nodes are replaced with a single equivalent branch, again storing the information on the number of parallel connections.

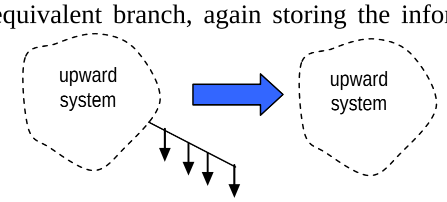

Fig. 1 a feeder composed of a branch in antenna connection to the upward system is eliminated from the reduced system for determining the radial structures

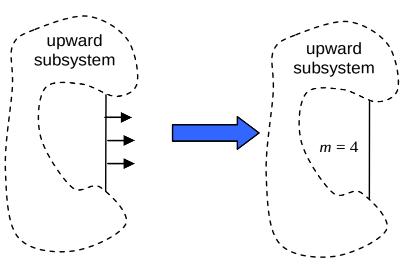

Fig. 2 a feeder composed of branches in series connection is replaced in the reduced system by a single branch with multiplicity m equal to the number of branches located along the feeder

III. Application to a Real Distribution System

The 6-kV distribution system of the city of Oradea is considered. The system is supplied by five HV/MV substations with 110 kV to 6 kV transformation (i.e., Crisul, Iosia, Oradea Centru, Sinteza and Velenta) and by other four connections to the 20-kV distribution system with 20 kV to 6 kV transformations, for a total of S = 9 supply points. The complete structure of the network is not shown here for space reasons.

The reduced network has by definition a single supply point (S_R = 1). Applying the principles indicated in the above section, the resulting reduced network has B = 101 branches and N = 57 nodes (supply point included). The rhomboidal marks along the branches represent the loads connected along the feeder, that determine the branch multiplicity. The structure used to form the reduced network is shown in Fig. 3. The supply points forming the root node are labelled as node 1 in the scheme. The dashed branches represent situations of branches connecting one or more nodes to a supply point, or branches connecting two supply points that can be considered independently in the evaluation of the number of radial configurations. In order to create any radial configuration, it is then necessary to open simultaneously $Q = B - N + SR = 45$ redundant branches. Providing the list of the open branches is sufficient information for representing a radial configuration. With respect to the network in Fig. 3, the reduced network does not contain the dashed branches, and the supply nodes coalesce into the root node (i.e., node 1). According to the principles followed for the construction of the reduced network, the number of redundant branches is the same as the one required for obtaining a radial structure from the original network [15].

IV. Layered Structure of the Reduced Network

The reduced network can be redrawn in such a way to form a layered structure, as indicated in Fig.4, with the first layer formed by all the nodes of the reduced network connected to the root node, the second layer is formed by all the nodes of the reduced network connected to nodes of the first layer, and so forth.

Table I shows the nodes belonging to the various layers. In spite of the relatively large number of nodes and of the weakly meshed structure of the reduced network, the maximum number of layers that can be identified is *three*, and the nodes belonging to the third layer are only *five* (the nodes number 16, 28, 29, 36 and 50).

Table II shows the connections from nodes belonging to the third layer to the nodes of the second layer, with the related multiplicities m.

The interest towards constructing the layered structure of the network is due to the possibility of selecting a number of branches to open for creating the radial system mainly from the layers with the higher order (e.g., 2 and 3, in the case considered). The rationale of this choice is that structurally long feeders are more likely to produce higher losses in the branches connected to the supply points.

This is true especially if the system loads are distributed uniformly, but in general reductions of the network obtainable for instance by merging some nodes of the first layer into the root node can be used to simplify the space of search of the radial configurations that minimize the system losses.

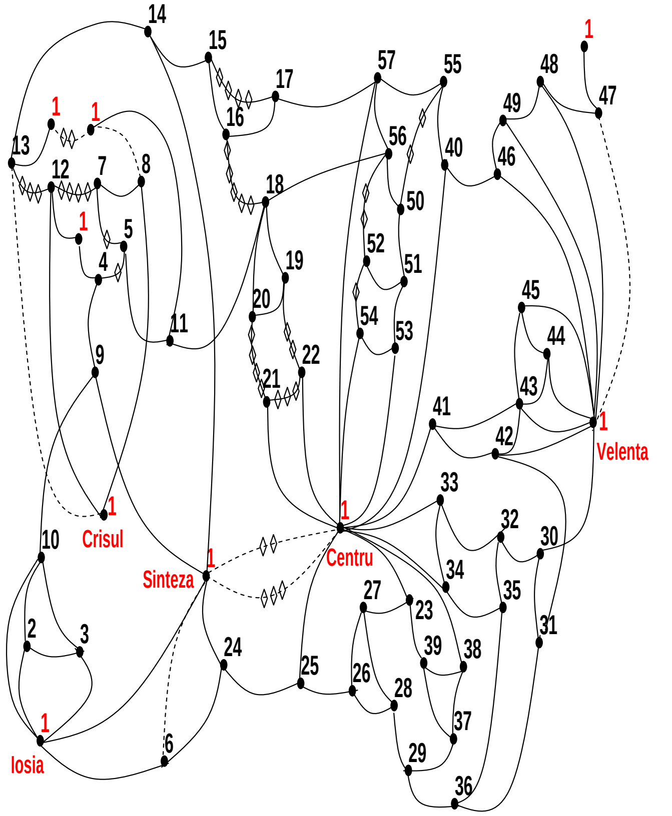

Fig. 3 reduced Oradea 6-kV network

Table I nodes belonging to the various layers (node 1 = root node)

layer	nodes
1	2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 14, 21, 22, 23, 24, 25, 30, 33, 34, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 53, 54, 57
2	5, 7, 15, 17, 18, 19, 20, 26, 27, 31, 32, 35, 37, 39, 51, 52, 55, 56
3	16, 28, 29, 36, 50

Table II connections of the nodes of the reduced network at the third layer to nodes at the second or third layer and related multiplicities. N3 = node of the third layer; NL = connected node; m = branch multiplicity

N_3	N_L	*m*	N_3	N_L	*m*	N_3	N_L	*m*	N_3	N_L	*m*	N_3	N_L	*m*
	15	1		26	1		28	1		29	1		51	1
16	17	1	28	27	1	29	30	1	36	31	1	50	55	3
	18	6		29	1		37	1					56	1

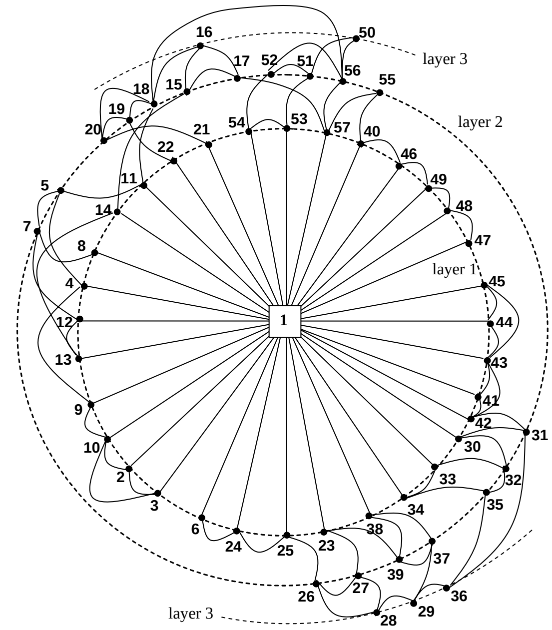

Fig. 4 by-layer representation of the reduced Oradea 6-kV network

V. Conclusions

The creation of the reduced network and of the corresponding layers is a viable starting point for simplifying the application of the solution methods for optimal distribution system reconfiguration.

The real-case example presented in this paper has shown that it is possible to obtain significant reductions in the network structure by applying the criteria indicated, and that the reorganization of the reduced network results into a relatively low number of layers.

These results can be associated to the knowledge of the power flow solutions in order to establish sound criteria for selecting the best radial configuration according to a specified objective function.

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Horia Andrei received the Ph.D. degree in Electrotechnical Engineering, from the Politehnica University of Bucharest, Romania, in 1996. Since 1982 he has been working at the Electrical Engineering Department of Politehnica University of Bucharest until 2002, and currently he is a Professor at the Electrical Engineering Faculty, Valahia University of Targoviste, Romania. His research activities include the design and analysis of circuits, symbolic methods for analogue circuits, applications of computer algebra in analysis and design of circuits and systems, electrical measurements and power systems analysis. Dr. Andrei is a member of IEEE, WSEAS, AMSE, AIEER and SIEAR.

Gianfranco Chicco received the Ph.D. degree in Electrotechnical Engineering from the Politecnico di Torino, Torino, Italy, in 1992. He is an Associate Professor of Distribution Systems at the Politecnico di Torino, Italy. His research activities include power systems and distribution systems analysis, competitive electricity markets, load management, artificial intelligence applications and power quality. Dr. Chicco is a member of IEEE, IREP and AEIT.

Marius Silaghi received the Ph.D. degree in Electrical Engineering, from the Politehnica University of Oradea, Romania, in 1999. Since 1990 he has been working at the Electrical Engineering Research Department of Electrometal Ltd. Oradea until 1992, from 1992 until now at University of Oradea and currently he is a Professor at the Electrical Engineering and Information Technology Faculty, University of Oradea, Oradea, Romania. His research activities include the electromagnetic field analysis, microwave technologies 2D and 3D modeling and simulating, numeric methods used in the analysis of the magnetic field, dielectric materials processing in microwave fields and electrical measurements and power systems analysis. Dr. Silaghi is a member of IEEE, CRE, AMPERE and AGIR.

Mircea Popa graduated in 1989 the Electrotehnic University of Cluj-Napoca and he is doing the courses for the Ph.D. degree in Electrical Engineering, at the University of Oradea, Electrical Engineering Faculty, Romania, beginning this probation in 2004. He has been working at the Electrical Company from Oradea since 1989 until now, momentary being Chief Engineer at this company. His scientific activity include the interaction between the electromagnetic radiations and the human body, inductive mechanisms on the business' market, microwave and global heating, radial structures into a distribution system.