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Enhancement of Voltage Stability and Line Loadability by Reconfiguration of Radial Electrical Power Distribution Networks on the Basis of Seasonal Load Change

Kultar D. Singh

Department of Electrical Engineering, Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab, India
kultar22@yahoo.com

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Abstract— This paper investigates the concept of network reconfiguration by considering the seasonal load change on feeders. The author tried to establish that the reconfiguration of networks can be carried out for load balancing during the seasonal change in loads depicted by the chronological load curves of the feeders. In electrical power distribution systems, some feeders supply consumers with the same type of loads in particular areas. Like the feeders dedicated to supply residential areas, the dominated loads are domestic and commercial. While some feeders may be dominated with industrial loads, some with agriculture etc. By examining the chronological load curves the possibilities of feeder reconfiguration are identified. Seasonal reconfiguration will increase the reliability of supply, reduce line losses and improve voltage profile.

Keywords— Line loadability index, Line losses, Voltage stability index, Reconfiguration, Radial networks.

I. INTRODUCTION

In electrical power distribution systems, the issue of reliability and losses reduction is always very important. Power distribution engineers and researchers consider these points as the topic of their research. Network reconfiguration is a way out to increase reliability and reduce line losses. The solutions proposed by earlier researchers regarding the above said issue are summarized as: Merlin and Back [1] proposed network reconfiguration for loss reduction in distribution networks. The radial network was first converted to mesh by closing all the tie-lines and applying branch-and-bound-type optimization technique for loss minimization. The radial configuration was again restored. Civanlar *et al.* [2] used the heuristic approach for network reconfiguration but they proposed a branch-exchange technique to keep the network radial in nature throughout the procedure. They proposed that when a tie-switch was closed, a sectionalizing switch should be opened to keep the network radial. Baran and Wu [3] used the load-balance index and proposed the approximate load flow method which was used in network reconfiguration. Chiang *et al.* [4] and Chiang *et al.* [5] used simulated annealing algorithm for the reconfiguration. Chen and Cho [6] suggested a branch-and-bound method for network reconfiguration by using binary integer programming for optimal switching scheme to loss minimization. Zhou *et al.* [7] used fuzzy technique and heuristic approach for optimization. They proposed network reconfiguration for service restoration and load balancing. Zhou *et al.* [8] proposed a method to minimize the operating cost of distribution network by reconfiguration. Lin and Chin [9] used voltage index, ohmic index, and decision index to determine the switching operation for network reconfiguration. Venkatesh *et al.* [10] proposed a fuzzy adaptation of the evolutionary programming algorithm for optimal reconfiguration due to the discrete nature of the problem of radial distribution networks to maximize loadability. Das [11] used the fuzzy multi objective approach using heuristic techniques for feeder reconfiguration. Savier and Das [12] proposed a quadratic-loss allocation scheme for allocating losses to consumers connected to a radial distribution system

Corresponding author's e-mail: kultar22@yahoo.com

before and after reconfiguration. The algorithm used was based on a heuristic rule and fuzzy multi-objective approach. Khodr *et al.* [13] used a specific approach of the generalized benders decomposition algorithm for reconfiguration to achieve loss minimization and load balancing in distribution networks within the applied constraints of current limit and voltage limit. Leonardo *et al.* [14] proposed a solution technique by using a mixed integer non-linear programming approach, in which a continuous function was used to handle discrete variables. The primal-dual interior point technique is applied to solve the optimization problem at each step. The Lagrange multipliers were used to evaluate a newly proposed sensitivity index for distribution system reconfiguration. Amanulla *et al.* [15] used the binary particle swarm optimization-based search algorithm for maximizing reliability and minimizing power losses. Load point reliability was evaluated by probabilistic reliability models. Kumar and Jayabarathi [16] proposed a bacterial foraging optimization algorithm for distribution network reconfiguration and loss minimization. They formulated the non-linear optimization problem. The radial nature of the network was finally restored. Zin *et al.* [17] proposed a heuristic approach for the reconfiguration of radial distribution networks and minimization of the branch current.

Aggelos *et al.* [18] investigated the effect of load alterations on distribution systems and optimal configurations for loss minimization. Network reconfigurations were implemented utilizing heuristic techniques while load variations were simulated by stochastic procedures. González *et al.* [19] presented a heuristic reconfiguration algorithm to minimize the Non-Delivered Power of distribution networks. The thermal limits and radial nature of the network were taken as constraints. Ding and Loparo [20] decomposed the network on the basis of connectivity and they applied the heuristic algorithm for optimization. Switch states were taken as decision variables. Larimi *et al.* [21] modeled the financial risk involved to maintain reliability by network reconfiguration. The particle swarm optimization technique is used to optimize of the problem.

In all the above discussed reported work on network reconfiguration, the problem was flexibly investigated. In practical distribution networks, the chances of network reconfiguration are very limited because distribution networks are erected in the residential, commercial and industrial areas, etc. The feeders may or may not be touching each other; and even sometimes the tie-lines cannot be stretched from any one point to another point due to various constraints. Thus, the application of optimization techniques is not justified in this case as it leads to theoretical exercises only. In spite of these constraints, network reconfiguration is considered to optimize the available capacity of the distribution network.

In this paper, the author tried to establish that the reconfiguration of networks can be carried out for load balancing during the seasonal change in the load depicted by the chronological load curves of the feeders. The same type of loads is usually concentrated in particular areas like the feeders dedicated to supply residential areas. The dominated loads are domestic and commercial, but some feeders may be dominated with industrial or agricultural loads. By examining the chronological load curves the possibilities of feeder reconfiguration are identified.

II. PROBLEM FORMULATION AND CONSTRAINTS

The first step is to find the chances of network reconfiguration and the location of tie-switches by drawing the annual chronological load curves of candidate feeders or laterals. Examining the annual chronological curves and the location of feeders develops the position of tie-lines and switching scheme. While fixing the location of tie-lines and developing the switching schemes, line loadability limits of feeders or laterals should not be violated. It is assumed, for simplicity, that the length and type of the conductor of the tie-lines are the same as that of the branch, which is disconnected by corresponding isolating switch. The constraints are:

- Only the practically possible locations of tie-lines should be considered because it is not possible to set a tie-line to connect any two locations of the distribution network.
- The Line loadability index (LLI) should be maximized.
- The radial nature of the network should be maintained. When a tie-line is connected, an isolator switch is opened to avoid mesh configuration.
- The direction of the current flowing through branches should be the same as before reconfiguration. This is necessary because the conductor size of the branch is selected according to the current flowing through this branch.

III. PROCEDURAL STEPS FOR NETWORK RECONFIGURATION

The procedural steps for network reconfiguration on the basis of seasonal load change are as follows:

1. Draw the annual chronological curve for each lateral from annual load data.
2. Make the curves in discrete form.
3. Identify the location of tie-lines between laterals or feeders which are practically possible.
4. Identify the most suitable options of tie-lines by computing load-flow solution and LLI.
5. Develop the annual switching scheme for tie-lines from step 4.
6. Print the results of various parameters like voltage stability index (VSI) [22], LLI [22], voltage profile at each node, current through each branch and losses.

An example of 30-node typical Indian radial distribution network is considered to illustrate the proposed procedure for network reconfiguration and enhancement of the loadability of the radial distribution networks. Line and load data is given in Table 1. The data related to various conductor sizes is given in Table 2. Single line diagram of 30-node radial distribution network is shown in Fig. 1.

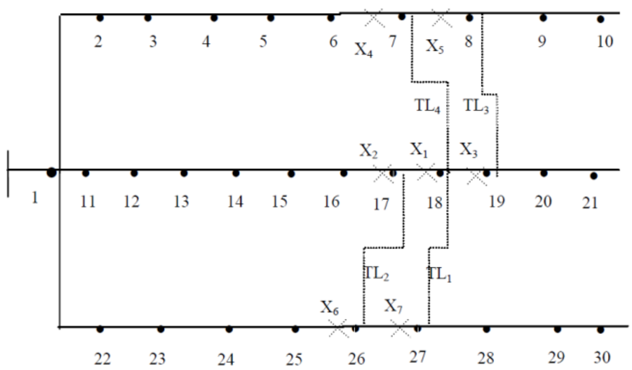

Fig. 1. Single line diagram of a 30-node network

TABLE 1
LINE DATA AND LOAD DATA FOR A 30-NODE NETWORK

Sending-End Node	Receiving-End Node	Length of Segment, km	Conductor Type	Load, kVA
1	2	0.2	1	100
2	3	0.2	1	100
3	4	0.43	2	100
4	5	0.6	2	300
5	6	0.22	3	100
6	7	0.16	5	100
7	8	0.3	5	250
8	9	0.1	5	50
9	10	0.4	5	50
1	11	0.6	1	150
11	12	0.24	2	250
12	13	0.24	3	100
13	14	0.6	4	350
14	15	0.5	5	250
15	16	0.25	5	100
16	17	0.11	5	350
17	18	0.11	5	160
18	19	0.32	5	150
19	20	0.25	5	100
20	21	0.1	1	100
1	22	0.2	1	100
22	23	0.3	1	100
23	24	0.1	2	150
24	25	0.5	3	150
25	26	0.1	3	50
26	27	0.43	3	150
27	28	0.25	5	50
28	29	0.15	5	100
29	30	0.2	5	110

TABLE 2
CONDUCTORS DATA

Code Name	Resistance, Ω/m	Reactance, Ω/m	Area, mm^2	Diameter, mm	Weight of Al/m, kg	Weight of Steel/m, kg	Current Carrying Capacity, A
Mink	0.4565	0.366	72.64	10.98	0.173	0.082	234
Rabbit	0.5449	0.3772	61.7	10.05	0.145	0.069	208
Ferret	0.6795	0.376	49.48	9	0.117	0.055	181
Weasel	0.9116	0.382	36.88	7.77	0.087	0.041	150
Squirrel	1.374	0.3915	24.48	6.33	0.058	0.027	115

Lateral 1, which is dedicated to serve residential and commercial loads consists of 20% florescent lamps, 15% incandescent lamp, 30% air conditioner load, 15% resistance space heater and 30% pump set and fan. Lateral 2, which is dedicated to serve the agricultural load, consists of 95% pump set load and 5% incandescent lamp load. Lateral 3 is dedicated to serve the industrial load. The industrial load is considered to be agriculture-based industry like cotton mills, sugar mills and rice mills. The industrial load consists of 50% large industrial motors, 10% compact florescent lamp, 10% air conditioner, 20% small industrial motor load and 10% pump set and fan load. Chronological load curves, which are developed from the annual load data of the laterals, are shown in Fig. 2. Curve 1 depicts the domestic load. Domestic load is high in India during the summer season from June to September. Curve 2 shows the monthly percentage load for the agricultural load dominated lateral. The agricultural load is high during the paddy season from May to September. Curve 3 shows agriculture-based industrial load, which is also a seasonal type of load. Fig. 3 shows the approximated chronological load curves for 30-node radial distribution network. To improve the load factor, the service utility encourages such an industry to use more power in off-peak months. The load on such feeders is high during the winter season. The curves indicate that the load can be shifted from one lateral to another. By following the above discussed steps for network reconfiguration, connection of tie-lines, and opening of the main branches to maintain the radial nature of network are shown in Table 3. The reconfigured 30-node network during various periods of the year is shown in the Appendix.

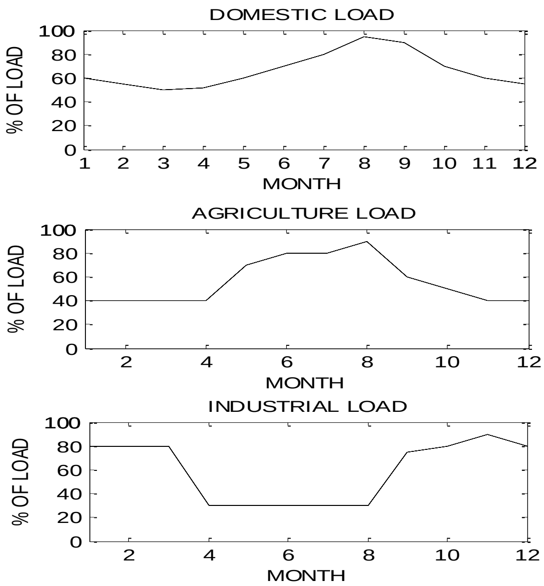

Fig. 2. Actual chronological load curves for a 30-node network

The comparison of various system parameters like minimum voltage, minimum LLI, minimum VSI, power losses and energy losses are also shown in Table 3. The comparison of the results of the base network and the reconfigured network shows voltage profile, VSI, LLI, line current and line losses for a different group of months of the year in Fig. 4, Fig. 5 and Fig. 6. The improvement in all the parameters is noted after the reconfiguration of the network on the basis of seasonal load change. It is very evident from the curves shown in Fig. 4, Fig. 5 and Fig. 6 that there is a substantial improvement in various parameters after network reconfiguration.

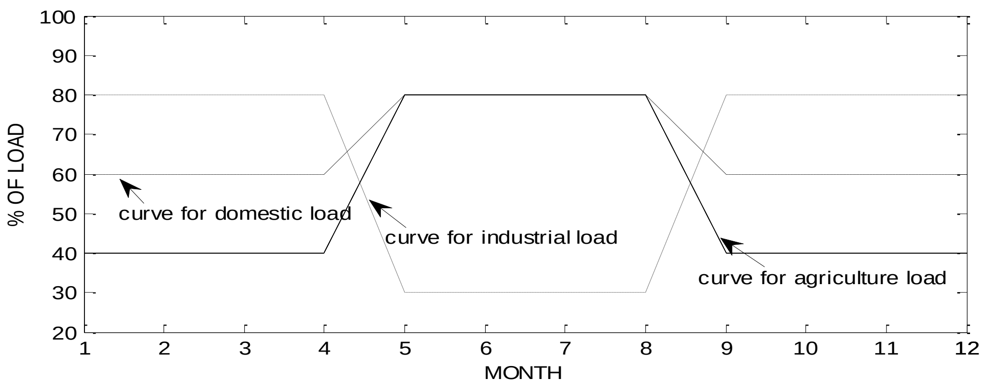

Fig. 3. Approximated chronological load curves for a 30-node network

TABLE 3
SWITCHING SCHEME OF TIE-LINES, ISOLATOR SWITCHES AND COMPARISON OF RESULT WITH AND WITHOUT NETWORK RECONFIGURATION

Months	Isolator Switch Status	Tie-Line Status	Without Reconfiguration				With Reconfiguration			
			Min. Volt., pu	Min. LLI	Min. VSI	Power Loss, kW	Min. Volt., pu	Min. LLI	Min. VSI	Power Loss, kW
Jan.-April	X1 (Open)	TL1 (Closed)	V21= 0.98976	LLI18= 0.49946	VSI21= 0.97963	9.076	V18= 0.99275	LLI18= 0.49973	VSI21= 0.98554	8.6633
May-Aug.	X4 (Open)	TL4 (Closed)	V10= 0.99245	LLI1= 0.49941	VSI10= 0.98496	7.7547	V30= 0.99316	LLI7= 0.49971	VSI30= 0.98637	6.8485
Sep.-Dec.	X2, X3 (Open)	TL2, TL3 (Closed)	V21= 0.98916	LLI7= 0.49943	VSI21= 0.98597	9.1878	V21= 0.99296	LLI7= 0.49968	VSI21= 0.98597	8.5019

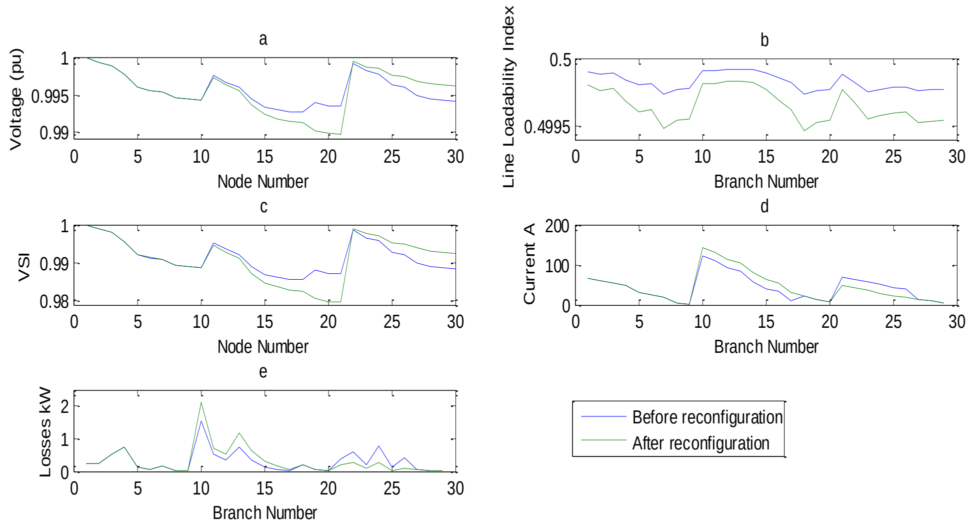

Fig. 4. Comparison of results from January to April for a 30-node distribution network before and after reconfiguration: a) comparison of node voltage in pu, b) comparison of line loadability index, c) comparison of voltage stability index, d) comparison of branch current, e) comparison of branch losses

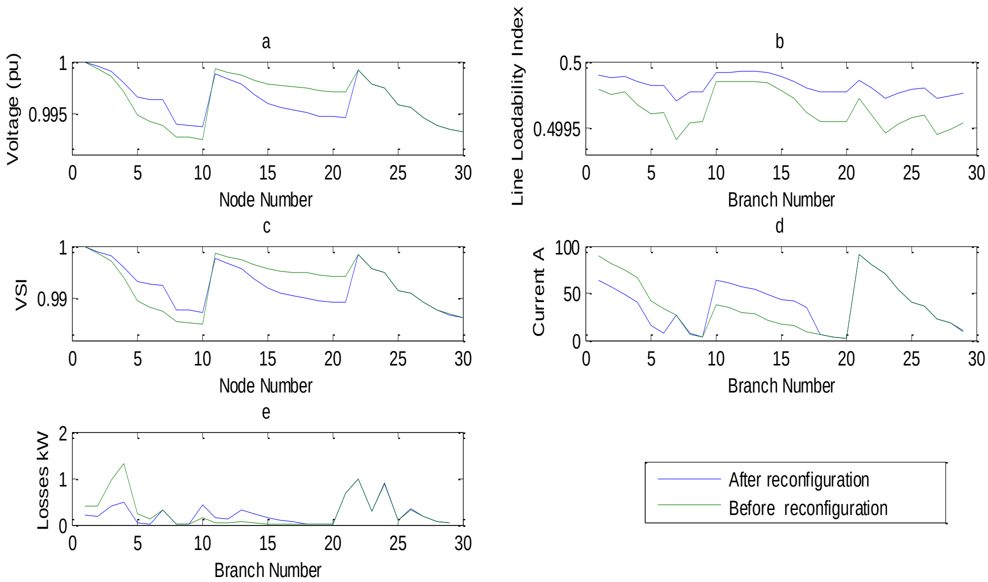

Fig. 5. Comparison of results from January to April for a 30-node distribution network before and after reconfiguration: a) comparison of node voltage in pu, b) comparison of line loadability index, c) comparison of voltage stability index, d) comparison of branch current, e) comparison of branch losses

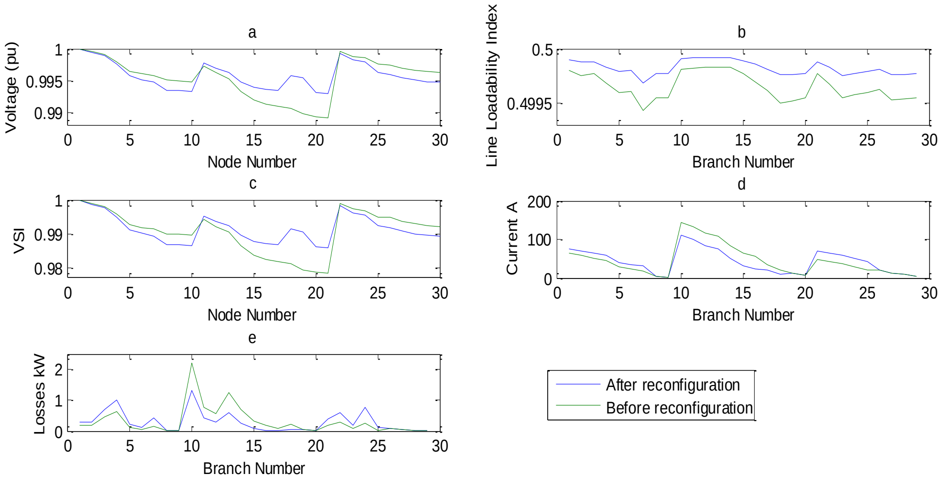

Fig. 6. Comparison of results from January to April for a 30-node distribution network before and after reconfiguration: a) comparison of node voltage in pu, b) comparison of line loadability index, c) comparison of voltage stability index, d) comparison of branch current, e) comparison of branch losses

IV. CONCLUSION

From the above discussion, it can be concluded that rather the chances for reconfiguration are very limited in case of distribution networks, but it has great benefits in the form of reduced losses, increased line loadability, increased voltage stability, reduced branch current and improved voltage profile of the network after reconfiguration. Along with these benefits, the reliability of supply is increased. At the time of outage, supply of some portion of the network can be restored. Through network reconfiguration, the already installed capacity can be best used. The line loadability and voltage stability of distribution networks can be enhanced. The tabulated results and graphical representation showed that the critical loading and voltage stability of the 30-node test network have been improved. The proposed approach is novel; no such approach in the field of network reconfiguration is reported so far.

APPENDIX

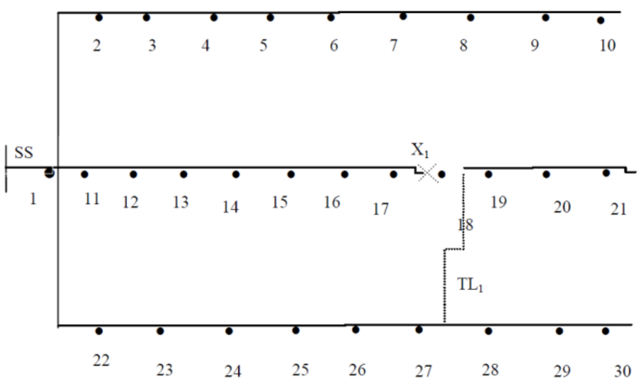

Fig. A1. Single line diagram of a 30-node network after reconfiguration during January and April

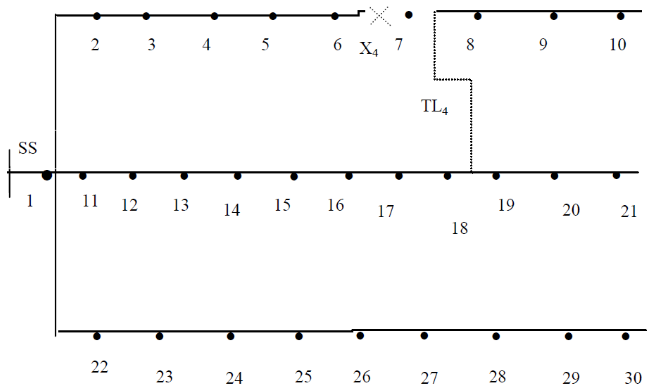

Fig. A2. Single line diagram of a 30-node network after reconfiguration during May and August

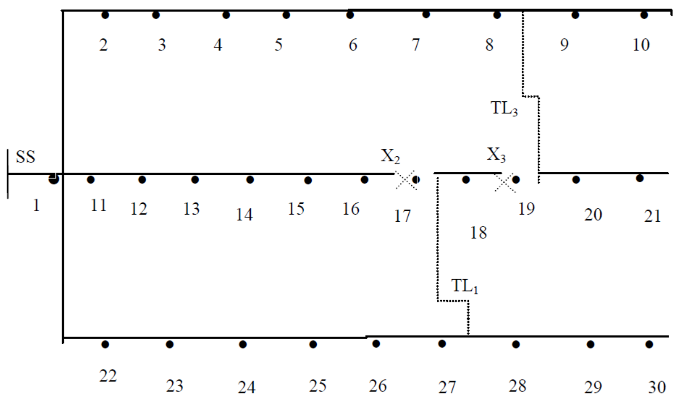

Fig. A3. Single line diagram of a 30-node network after reconfiguration during September and December

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