International Journal of Electrical Energy, Vol. 4, No. 3, September 2016

Prospectives of Day-Ahead Network Reconfiguration for Smart Distribution Systems Considering Load Diversity

Praveen Kumar, Nikhil Gupta, K. R. Niazi, and Anil Swarnkar
Department of Electrical Engineering, Malaviya National Institute of Technology Jaipur, Rajasthan, India 302017
Email: {pkagra66, mnit.anil}@gmail.com, nikhil2007_mnit@yahoo.com, krn152001@yahoo.co.in

***Abstract*—In modern smart distribution systems the flow of active and reactive power among distribution feeders is well managed as they are equipped with optimally placed distributed resources such as shunt capacitors, distributed generations and distributed storages, etc. In this context, it is customary to investigate the relevance of conventional Network Reconfiguration (NR) for loss minimization and node voltage profile enhancement. This paper addresses the effectiveness of NR in smart distribution systems while considering intermittency in load and generation among distribution buses. In addition, the load diversity that exists among distribution buses due to load class mix of diverse customers is considered. Proposed method is applied on the benchmark IEEE 33-bus test distribution system to investigate the relevance of conventional NR over day-ahead reconfiguration. The application results reveal that proposed reconfiguration strategy may be more convenient and useful to distribution system operators.**

***Index Terms*—distributed resources, load diversity, network reconfiguration, smart distribution systems**

I. INTRODUCTION

Distribution networks are structured in mesh but operated in radial configuration for effective co-ordination of their protective schemes and to reduce the fault level. Network Reconfiguration (NR) is a process that alters feeder topological structure of distribution network by managing the open/close status of sectionalizing and tie-switches. The aim of distribution network reconfiguration is to find that radial topology which optimizes desired objectives while satisfying several network and operational constraints. The problem of distribution network reconfiguration is highly complex, combinatorial, non-differentiable optimization problem so can be solved efficiently using any population based meta-heuristic technique.

Merlin and Back [1] were the first who proposed NR in 1975. Since then, extensive work has been carried to deal with NR problem of distribution systems by considering a variety of objectives like loss minimization, node voltage profile enhancement, reliability enhancement, etc. The problem has been solved using a variety of analytical methods, mathematical programming, heuristic or meta-heuristic techniques, etc. However, power loss reduction and node voltage profile enhancement remained the prime objectives on account of significant cost of losses and strict regulations imposed by the regulatory bodies. With the advent of fast computing facilities, researchers preferred population-based metaheuristics techniques as are independent of the type and shape of objective function to be optimized and their extensive potential to obtain global or near global solution.

The electric power industries have witnessed many reforms in recent years. The rise of smart grid is a boon not only to society as a whole but to all who are involved in the electric power industry, its customers, and its stakeholders [2]. The existing distribution systems are now taking new shapes so are moving towards smart distribution systems to achieve larger socioeconomic and other non-tangible benefits. In this context, the strategy employed for optimal NR needs to be reviewed.

Modern distribution systems are large and complex. They are now equipped with adequate Distributed Resources (DRs) which involve reactive as well as active components such as Shunt Capacitors (SCs), Distributed Generations (DGs) and Distributed Storages (DSs), etc. The passive distribution systems are now transformed into active distribution systems with bilateral power flows among distribution feeders. The complexity further arises by the excessive integration of DRs that requires real-time control to run the system at their optimum performance. These components placed optimally in the system so as to efficiently manage power flow among distribution feeders to keep the power losses and node voltage deviations at the minimum. In recent years NR is employed in conjunction with the optimal allocation of DRs [3]-[12], and it has been acknowledged that this strategy is very useful to improve the performance of distribution systems. This substantially reduces the margin of improving network performance via NR. Therefore, it is customary to reinvestigate the relevance of conventional NR, which has to be updated with real-time, for loss minimization and node voltage profile enhancement. On the other hand, Distribution System Operators (DSOs) may prefer day-ahead reconfiguration to determine the best network topology a day before the operation. This not only reduces the complexity of the system operation, but also reduces the cost of switching

---

Manuscript received October 5, 2016; revised December 15, 2016.

doi: 10.18178/ijoee.4.3.184-188

operations and also curtails prospective switching transients to a great extent. Therefore, most of DSOs use day-ahead reconfiguration due to technical problems and lack of real time control system in distribution network [13]. However, due to stochastic nature of most DGs, distribution network day-ahead reconfiguration will be associated with risk arising from DGs power output [14]. The risk may also arise if the load profile of the system does not consider certain realities of power distribution systems. Usually, dedicated feeders are allocated to diverse class of customers, i.e. residential, industrial, and commercial, etc. Each of these customers has specific load pattern. This attributes to specific loadings of distribution buses so causes load diversity among distribution buses. This load diversity is crucial in determining the load profile of the system which eventually decides power losses and node voltage profiles of the system. Therefore, ignoring such realities of distribution system may lead to unrealistic solution for NR, which eventually causes risk in system operation. Most of the previous work considers fixed load level and/or fixed DG power output, and very few have considered intermittency associated with load demand and power generation from DGs to determine optimal reconfiguration. However, the impact of load diversity is yet to be explored while attempting reconfiguration problems of distribution systems.

This paper addresses the effectiveness of NR in smart distribution systems while considering intermittency in load and renewable generation from DGs to provide a more realistic reconfiguration solution. In addition, the load diversity among distribution buses owing to diverse customers has given due consideration while modeling load profile of the system. A day-ahead reconfiguration strategy is proposed to minimize the number of switching operations yet maintains better energy efficiency and node voltage profiles in distribution systems. The problem is solved using Genetic Algorithms (GAs). The application results obtained on benchmark IEEE 33-bus system are investigated and presented.

II. Diversity of Load among Distribution Buses

The modeling of load profile is crucial while dealing with any distribution system optimization problem and should be realistic to a good degree of satisfaction. In practice, a load class mix of various types of customers, i.e. residential, industrial, and commercial, should be investigated, in which every bus of the system has a different type of load connected to it [15]. Therefore, the specific load pattern associated with different distribution buses should be considered while modeling load profile of the system.

However, this introduces definite load diversity among distribution buses, and if considered, provides more realistic scenario for distribution system operation. This reflected in more practical solutions for distribution system optimization problems. A sample load profile of the distribution system can be approximated by the summation of piecewise linearization of residential, industrial and commercial loads as shown in Fig. 1. It can be observed from the figure that the daily load profile of the system consists of several load levels owing to diversities attributed to different class of customers. It may be depicted from the figure that the shape and peak demand of the load profile is a strict function of load diversity among diverse customers.

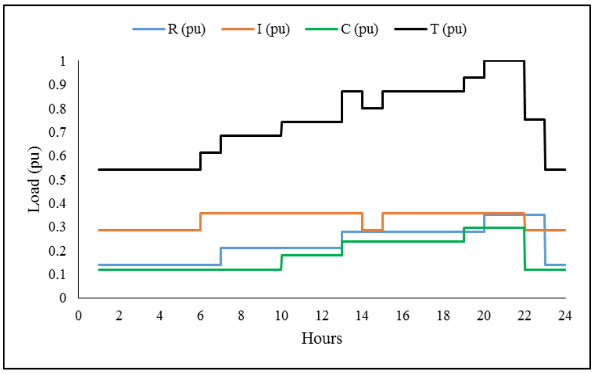

Figure 1. Load profile of the system considering diversity of different types of customers

III. Problem Formulation

The real power loss of distribution feeders for the state t is given by

$$Ploss_t = \sum_{n=1}^{E} R_n \frac{P_n^2 + Q_n^2}{|V_n|^2} \tag{1}$$

Therefore, the energy loss for day-ahead reconfiguration problem is expressed as

$$Eloss = \sum_{t=1}^{24} Ploss_t \tag{2}$$

The reconfiguration problem of distribution networks for day-ahead reconfiguration is formulated as below:

Minimize $$Eloss \tag{3}$$

subject to $$I_n \le I_n^{\max} \tag{4}$$

$$V_{min} \le V_n \le V_{\max} \tag{5}$$

and $$\Phi = 0 \tag{6}$$

where, V_n, P_n and Q_n are voltage, real power and reactive power at the sending end of the nth line respectively, R_n is the resistance of the nth line and E is the total number of lines in the system. Equation (3) corresponds to the objective function to be optimized considering various constraints given by (4) to (6), which corresponds to limit branch current, node voltage constraints and radiality constraint, respectively. In (1) losses are determined while considering load diversity among distribution buses. While optimizing (3), the stochastic nature of load and generation is considered which has not included in this section due to limiting of pages. The NR problem is solved using GAs which is one of the well-known optimization techniques. It has been extensively explained in literature so not discussed in the present work.

IV. SIMULATION RESULTS AND DISCUSSION

The benchmark IEEE 33-bus test distribution system is employed to investigate the proposed method. This is a 12.66 kV three-phase balanced distribution system which consists of 33 nodes and 37 lines including 32 sectionalizing and 5 tie-lines. The base configuration consists of a radial topology by opening all the five tie-lines. The nominal active and reactive loading of the system are 3.715 MW and 2.30 MVAr respectively. All loads are the constant power type. The detailed data of this system may be referred from [16]. It has been assumed that the system is equipped with renewable DGs such as Solar Photovoltaic (SPV) and Wind Turbine (WT), Micro-Turbines (MTs) and SCs as shown in Table I. The power generation profiles of SPV and WT for a day is considered as shown in Fig. 2. The figure shows intermittency in power generation from these renewable sources. The data shown has been obtained after processing the forecasted data for these components using some suitable probabilistic or deterministic approach. In order to consider load diversity, the distribution nodes of this system are arbitrarily divided into residential, industrial and commercial loads as shown in Table II.

TABLE I. ALLOCATION OF DRS USED IN IEEE 33-BUS SYSTEM

SPV (Capacity /Node)	WT (Capacity /Node)	MT (Capacity /Node)	SC (Capacity /Node)
280/14, 840/24, 560/30	420/14, 700/24, 420/30	800/24	300/12, 300/25, 600/30

TABLE II. ALLOCATION OF NODES USED IN IEEE 33-BUS SYSTEM

Customer	Nodes	Active (MW)	Reactive (MVAr)
Residential	1-15	1.295	0.66
Industrial	22-29	1.32	0.63
Commercial	16-21, 30-33	1.10	1.01

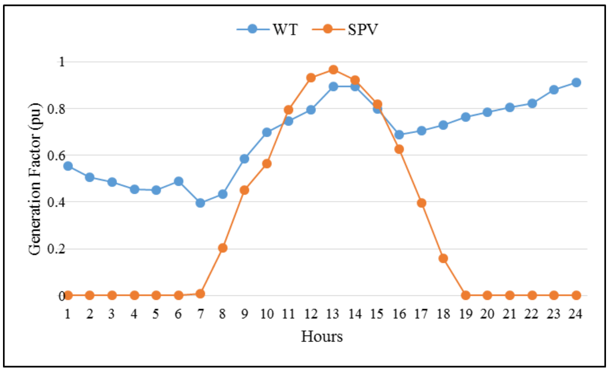

Figure 2. Data for unit power generation from WT and SPV

The load factors and the corresponding load durations for these varieties of loads are considered same as presented in Fig. 1. The problem of NR is solved using GAs with population size and maximum generation at 30 and 50. The crossover and mutation rates of GA are fixed at 0.9 and 0.05, respectively. The algorithm has been developed using MATLAB and the simulations have been carried on a personal computer of Intel i5, 3.2 GHz, and 4 GB RAM.

The simulations are carried for all the 24 states of the system. The distribution network is optimally reconfigured for loss minimization using GA for each system state while optimizing (1). The hourly power or energy loss obtained before and after NR is presented in Table III. The table shows the optimal configurations and also the number of switching required to achieve the same in practice.

It can be observed from the table that daily energy losses are reduced from 501.69 to 359.88 kWh, i.e. about 28%, while conventionally reconfiguring the distribution network for each system state. The table shows that total 46 switching operations are required to achieve the desired optimal network topologies. It is a fact that every switching operation requires definite cost, complex control systems and also causes prospective switching transients which should be taken into consideration against the loss reduction achieved. For this system the daily energy loss reduction by NR is found to be only 142 kWh. This is true because the major loss reduction had already been achieved by optimally placing DRs.

TABLE III. SIMULATION RESULTS

State (t)	$Ploss_t$ (kW)		Optimal configuration	Nos. of switching
	Before NR	***After NR***		
1.	8.87	6.13	7, **8**, 9, 17, **26**	4
2.	9.28	6.13	7, 8, 9, 17, 26	0
3	9.52	6.13	7, 8, 9, 17, 26	0
4	9.89	6.13	7, 8, 9, 17, 26	0
5	9.94	6.13	7, 8, 9, 17, 26	0
6	10.37	7.13	7, 8, **22, 34, 36**	6
7.	17.01	10.90	7, **9, 17, 23, 34**	8
8.	11.47	8.15	7, **8,** 9**, 16, 26**	6
9.	9.86	8.58	7, 9, **15, 25, 33**	6
10.	12.56	11.43	7, 9, **16**, 25, 33	2
11.	18.77	17.12	5, 9, 16, **20**, 33	2
12.	25.47	23.03	5, **10**, 16, **19**, 33	4
13.	28.49	26.86	5, **7**, **9**, 16, **21**	6
14.	31.16	28.50	5, 9, 16, **20, 33**	4
15.	22.21	20.58	9, 16, **21, 25**, 33	4
16.	19.30	15.14	9, 25, **29**, 33, **35**	4
17.	20.49	14.59	**7, 8**, 9, **26**, 35	4
18.	24.77	16.03	7, 8, **17, 27, 34**	6
19.	41.98	25.32	7, **9, 28,** 34, **36**	6
20.	53.17	31.02	7, 9, **17**, 28, **34**	4
21.	52.01	30.41	7, 9, 17, 28, 34	0
22.	17.19	11.44	7, **8**, **14, 25**, 34	6
23.	9.63	7.30	7, **9, 17**, 25, **33**	6
24.	10.02	7.59	**5**, 7, 9, 17, 33	2
Total	**483.43**	**351.77**	--	**90**

Next, simulations are carried for the proposed day-ahead reconfiguration to obtain that single optimal topology which prevails throughout the day yet minimizes daily energy losses of the system. The GA code is modified accordingly and the NR problem is solved by optimizing (2). The results obtained are presented in Table IV.

TABLE IV. SIMULATION RESULTS FOR PROPOSED DAY-AHEAD RECONFIGURATION

Daily energy Loss (kWh)	Single optimal configuration	Energy loss reduction (%)
383.74	7, 8, 9, 17, 25	20.62

It can be observed from the table that by day-ahead reconfiguration, the daily energy losses are reduced by 21%, i.e. about 100 kWh which were reduced by about 132 kWh when it was reconfigured frequently in the conventional way. Therefore, if the distribution network is reconfigured only once during the day rather than reconfigured on the hourly basis, it cost an additional energy losses of about 32 kWh for the system having a peak demand of 3715 kW. Therefore, proposed day-ahead reconfiguration seems to be a better strategy for NR from the point of view of DSOs. However, the actual strategy to be employed for a particular distribution network depends upon the cost of switching operations relative to the cost of energy savings.

In case the load diversity among distribution buses is not considered, the results obtained for the day-ahead reconfiguration for this system under identical load profile and power generation conditions is presented in Table V. The comparison of Table V with Table IV reveals that the optimal network configuration as well as corresponding daily energy loss is greatly affected while considering load diversity. It has been observed that NR causes daily loss reduction from about 791 kWh to about 483 kWh while ignoring load diversity. So such unrealistic assumptions lead to erroneous solution for NR and thus not provide true indication regarding the relevance of NR for modern distribution systems. The same fact can also be depicted from Fig. 3 which compares node voltage profiles during peak load condition.

TABLE V. SIMULATION RESULTS FOR PROPOSED DAY-AHEAD RECONFIGURATION BY IGNORING LOAD DIVERSITY

Daily energy Loss (kWh)	**Single optimal configuration**	**Energy loss reduction (%)**
474.13	7, 9, 17, 28, 34	40.05

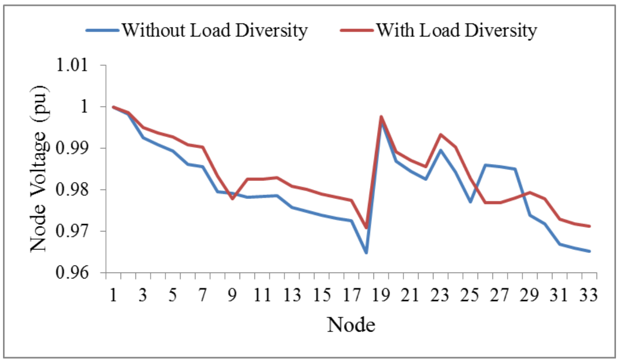

Figure 3. Comparison of node voltage profile

The figure shows that node voltage profile is inferior while ignoring load diversity. Practically most of the loads are of constant power type so the load currents flows through distribution lines are related inversely with node voltage magnitudes. So more power losses power losses would be observed while ignoring load diversity. Such unrealistic assumptions may provide wrong signals for both power loss reduction and node voltage profile enhancement. This may lead to the risk in system operation.

V. CONCLUSION

This paper presents an investigation on the relevance of conventional network reconfiguration in the context of active distribution systems which are equipped with adequate distributed resources. The stochastic nature of load and intermittency in renewables is considered. Further, load diversity among distribution buses has given due consideration in order to provide more realistic scenarios. It has been observed that the ignorance of load diversity among distribution buses may lead to wrong signals for DSOs. The detailed investigation reveals that proposed day-ahead reconfiguration strategy can be an attractive option for the operation of smart distribution systems on account of the economy and convenience in operation.

REFERENCES

[1] A. Merlin and H. Back, "Search for a minimum-loss operating spanning tree configuration in an urban power distribution," in *Proc. 5th Power System Computation Conference*, Cambridge, U.K., 1975, pp. 1–18.

[2] M. E. El-Hawary, "The smart grid—State-of-the-art and future trends," *Electric Power Components and Systems*, vol. 42, no. 3–4, pp. 239–250, 2014.

[3] D. Q. Hung, N. Mithulananthan, and R. C. Bansal, "A combined practical approach for distribution system loss reduction," *International Journal of Ambient Energy*, vol. 36, no. 3, pp. 123–131, 2015.

[4] G. J. S. Rosseti, E. J. D. Oliveira, L. W. D. Oliveira, I. C. Silva Jr., and W. Peres, "Optimal allocation of distributed generation with reconfiguration in electric distribution systems," *Electric Power Systems Research*, vol. 103, pp. 178–183, 2013.

[5] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation," *IEEE Transactions on Power Systems*, vol. 28, no. 1, pp. 317–325, 2013.

[6] Y. K. Wu, C. Y. Lee, L. C. Liu, and S. H. Tsai, "Study of reconfiguration for the distribution system with distributed generators," *IEEE Transactions on Power Delivery*, vol. 25, no. 3, pp. 1678–1685, 2010.

[7] V. Farahani, B. Vahidi, and H. A. Abyaneh, "Reconfiguration and capacitor placement simultaneously for energy loss reduction based on an improved reconfiguration method," *IEEE Transactions on Power Systems*, vol. 27, no. 2, pp. 587–595, 2012.

[8] A. M. Imran, M. Kowsalya, and D. P. Kothari, "A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 63, pp. 461–472, 2014.

[9] J. J. Jamian, W. M. Dahalan, H. Mokhlis, M. W. Mustafa, Z. J. Lim, and M. N. Abdullah, "Power losses reduction via simultaneous optimal distributed generation output and reconfiguration using ABC optimization," *Journal of Electrical Engineering & Technology*, vol. 9, no. 4, pp. 1229–1239, 2014.

[10] D. P. Bernardon, A. P. C. Mello, L. L. Pfitscher, L. N. Canha, A. R. Abaide, and A. A. B. Ferreira, "Real-time reconfiguration of distribution network with distributed generation," *Electric Power Systems Research*, vol. 107, pp. 59–67, 2014.

[11] T. T. Nguyen, A. V. Truong, and T. A. Phung, "A novel method based on adaptive cuckoo search for optimal network reconfiguration and distributed generation allocation in distribution network," *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 801–815, 2016.

[12] H. R. Esmaeilian and R. Fadaeinedjad, "Distribution system efficiency improvement using network reconfiguration and capacitor allocation," *International Journal of Electrical Power & Energy Systems*, vol. 64, pp. 457–468, 2015.

[13] K. Yang, M. T. M. Emmerich, R. Li, J. Wang, and T. Back, "Power distribution network reconfiguration by evolutionary

integer programming," in *Parallel Problem Solving from Nature–PPSN XIII*, Springer, 2014, pp. 11-23.

[14] S. M. M. Larimi, M. R. Haghifam, and A. Moradkhani, "Risk-based reconfiguration of active electric distribution networks," *IET Generation Transmission Distribution*, vol. 10, no. 4, pp. 1006–1015, 2016.

[15] A. M. El-Zonkoly, "Optimal placement of multi-distributed generation units including different load models using particle swarm optimization," *Swarm and Evolutionary Computation*, vol. 1, pp. 50–59, 2011.

[16] M. E. Baran and F. Wu, "Network reconfiguration in distribution system for loss reduction and load balancing," *IEEE Transactions on Power Delivery*, vol. 4, no. 2, pp. 1401–1407, 1989.

Praveen Kumar received his B.E. in electrical engineering from University of Rajasthan, Jaipur, India in 1987 and M.Tech. in computer science and technology from IIT, Roorkee, in 1995. Currently, he is pursuing Ph.D. in electrical engineering from MNIT, Jaipur, India. He is presently working as Associate Professor in the Department of Electrical Engineering, MNIT, Jaipur. His research interest is smart distribution systems planning and operations.

Nikhil Gupta received his B.E in electrical engineering from University of Rajasthan, Jaipur, India in 1987, M.E. in power systems, and Ph.D. in electrical engineering from MNIT, Jaipur, India in 2006, 2012 respectively. Currently, he is working with Department of Electrical Engineering as an Assistant Professor. He has published many research papers in reputed journal and conferences. His research interests are planning and operation of distribution systems, power system operations and control, artificial intelligence and microgrids.

Dr. Gupta is a member of IEEE, Life Member of ISTE.

K. R. Niazi received his B.E. in electrical engineering from University of Rajasthan, Jaipur, India in 1987, M.E. in electrical engineering (control systems) from JNV University, Jodhpur in 1997, and Ph.D. in Electrical Engineering from University of Rajasthan, Jaipur in 2003.

Presently he is working as Professor in Electrical Engineering at MNIT, Jaipur. His areas of research interest are power system optimization, security analysis, distribution system optimization and application of artificial neural network to power systems.

Prof. Niazi is Senior Member of IEEE, Life Member of ISTE and Institute of Engineers.

Anil Swarnkar received his B.E. in electrical engineering from Govt. Engg. College, Jabalpur (MP) in 1993, M.Tech. in power systems and Ph.D. in electrical engineering from MNIT, Jaipur, India in 2005 and 2012, respectively.

He is presently working as Assistant Professor in the Department of Electrical Engineering, MNIT, Jaipur. He has published many research papers in reputed journal and conferences. His area of interest is application of AI-techniques in power system optimization, planning, operation and control.