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Energy efficiency analysis of reconfigured distribution system for practical loads☆

Pawan Kumar[a,*], Ikbal Ali[b], Mini S. Thomas[b]

[a] *Lovely Professional University, Phagwara, Jalandhar, Punjab 144402, India*
[b] *Jamia Millia Islamia, Jamia Nagar, New Delhi 110025, India*

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Summary In deregulated rate structure, the performance evaluation of distribution system for energy efficiency includes; loss minimization, improved power quality, loadability limit, reliability and availability of supply. Energy efficiency changes with the variation in loading pattern and the load behaviour. Further, the nature of load at each node is not explicitly of any one type rather their characteristics depend upon the node voltages. In most cases, load is assumed to be constant power (real and reactive). In this paper voltage dependent practical loads are represented with composite load model and the energy efficiency performance of distribution system for practical loads is evaluated in different configurations of 33-node system.

Introduction

Energy efficiency, in present scenario, is the cost-effective and reliable means of preserving the resources. Energy efficient operation of distribution system is not limited to loss minimization but includes the many other components like loadability, load profile, node voltages, etc. Energy efficiency varies with change in load behaviour. Practical loads are found to be voltage dependent and their behaviour can be represented using static load models (Ali et al., 2015; Kumar and Singh, 2014a).

The energy efficiency of distribution system for these load models varies differently in different configurations. There exist several techniques for configuration management; however, the selection of configuration depends upon the utilities' concern of operation at lower cost and to meet the consumers' requirements. In the past, optimal network configuration based upon soft computing techniques and indices like, Refined Genetic Algorithms (Zhu, 2002), Fuzzy and Ant Colony Optimization (Saffar et al., 2011), Harmony Search Algorithm (Srinivasa et al., 2011), Tabu Search (Zhang et al., 2007), Fuzzy Logics (Venkatesh et al., 2004), and Power Loss Index (Baran and Wu, 1989) have been proposed for distribution system. However, the performance of these configurations varies significantly with different loading patterns (Ali et al., 2012). and reactive power injection (Kumar

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* Corresponding author at: Lovely Professional University, Phagwara, Jalandhar, Punjab 144402, India. Tel.: +91 9911815877.
E-mail addresses: pawanror@gmail.com (P. Kumar), iqali_in@yahoo.com (I. Ali), min_st@yahoo.com (M.S. Thomas).

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and Singh, 2014b). Further, loadability limits in these configurations are found to be different in (Kumar and Singh, 2014c).

Distribution system is the mediator between utilities and consumer. Due to limited expansion they allow to operate on loadability limit and therefore, the chances of system failure increases with slight increase in load. Further, with changed operating conditions system's operation remains no more optimum for voltage dependent loads. Therefore, the performance of various configurations needs to be evaluated for practical load combinations. This paper presents the energy efficiency analysis of distribution system in different configurations using an efficient load flow solution coded in MATLAB environment.

Calculations for evaluating parameters

In practice, loads can be summarized as residential, commercial and industrial loads. Under different operating conditions the energy efficiency performance of distribution system for these loads is not limited to loss minimization and need to be evaluated in terms of several other parameters like load profile, voltage profile, loadability limits and reliability of supplying power.

Load models

Mathematically, voltage dependence of loads can be expressed as follows:

$$P = P_0\left(\frac{V}{V_0}\right)^{\alpha} \tag{1}$$

$$Q = Q_0\left(\frac{V}{V_0}\right)^{\beta} \tag{2}$$

Here, P and Q are the active and reactive components of the load demand. P_0, Q_0 and V_0 are the nominal values of the load demands and system voltage, however; V is the actual voltage at load bus. The value of exponents 'α' and 'β' as 0, 1 and 2 classifies the load as constant power, constant current and constant impedance respectively. The aggregated effect of various load components, as described in Ali et al. (2015) is represented with composite load and the exponents 'α' and 'β' are taken as 1.35 and 3.19 respectively.

Power demands

In a radial distribution system, the total power at respective node includes the power at candidate node plus the sum of power demands and losses beyond that node.

Node voltage

The node voltage at receiving end in radial distribution system is calculated as the difference of the sending end voltage and the line drop.

Power loss

For the radial feeders having resistance of value 'r' and reactance of value 'x' their line power losses can be calculated as under,

$$P_{\text{Loss}} = \sum_{i=1}^{b}\frac{(P_i^2 + Q_i^2)}{V_i^2}r_i \tag{3}$$

$$Q_{\text{Loss}} = \sum_{i=1}^{b}\frac{(P_i^2 + Q_i^2)}{V_i^2}x_i \tag{4}$$

Here, P_{Loss} and Q_{Loss} are the active and reactive line power loss in the radial feeders, respectively, having 'b' number of branches in a given radial structure.

Loadability limit

Loadability limit is defined in terms of the maximum loadability index (MLI). Multiplying MLI with the existing load at candidate node gives loadability limit (Ali et al., 2015).

Solution techniques to obtain evaluating parameters

The solution techniques for the evaluating parameters, as described in section 2 involves the following steps,

Step 1: Read the line and load data and load models.
Step 2: Initially the voltage profile at each node is taken as 1 pu and line power losses are taken as zero. The convergence criterion is taken as $\epsilon = 0.0001$.
Step 3: Compute the load profile at each node using (1) and (2).
Step 4: Compute node voltage, power loss, MLI and load demands.
Step 5: Repeat Step 2 to 4 for the calculation of evaluating parameters in different configuration.

Test results and discussion

For energy efficiency analysis a 12.66 kV, 33-node distribution network is considered. The line and load data are taken from Baran and Wu (1989). The loads are taken voltage dependent and the other assumptions are same as described in Ali et al. (2012).

The configuration described in Zhu (2002), Saffar et al. (2011), Srinivasa et al. (2011) and Zhang et al. (2007) are obtained using different methods. In these configurations power loss is 139.3 kW (Zhu, 2002), 136.8 kW (Saffar et al., 2011), 138.1 kW (Srinivasa et al., 2011), 139.3 kW (Zhang et al., 2007) and minimum voltage is 0.9315 pu (Zhu, 2002), 0.9347 pu (Saffar et al., 2011), 0.9342 pu (Srinivasa et al., 2011), 0.9210 pu (Zhang et al., 2007), as described in the literature. From above analysis it can be noted that power losses and minimum voltage differ in the configurations obtained using different techniques. Therefore, for accurate results, the performance of these configurations is evaluated using efficient load flow solution, and under different practical loads. The next section describes the energy

Table 1 Energy Efficiency analysis under constant power load (Ali et al., 2012, 2015).

Parameters	Base N/W	RGA (Zhu, 2002)	ACO (Saffar et al., 2011)	HSA (Srinivasa et al., 2011)	ITS (Zhang et al., 2007)
Configuration	33,34,35,36,37	7,9,14,37,32	7,10,14,32,37	7,10,14,37,36	7,9,14,37,36
P_{Demand} (kW)	3917.2	3854.4	3855.1	3857.5	3857.0
Q_{Demand} (kVAr)	2435.0	2402.3	2402.8	2403.1	2402.7
$F_{Capacity}$ (kVA)	4612.3	4541.8	4542.7	4544.8	4544.7
Min. V (pu)	0.9131	0.9378	0.9378	0.9336	0.9336
MLI at node 2	84.07	85.37	85.36	85.32	85.33
P_{Loss} (kW)	202.67	139.55	140.28	142.68	142.16
$P_{Released}$ (kW)	–	69.76	62.05	59.66	60.17
$S_{Released}$ (kVA)	–	70.51	69.64	67.48	68.09

Table 2 Energy efficiency analysis under composite load.

Parameters	Base N/W	RGA (Zhu, 2002)	ACO (Saffar et al., 2011)	HSA (Srinivasa et al., 2011)	ITS (Zhang et al., 2007)
Configuration	33,34,35,36,37	7,9,14,37,32	7,9,14,37,36	7,10,14,37,36	7,10,14,32,37
P_{Demand} (kW)	3650.9	3667.4	3667.8	3667.8	3667.1
Q_{Demand} (kVAr)	2067.0	2128.8	2123.5	2123.6	2128.8
$F_{Capacity}$ (kVA)	4195.4	4240.5	4238.5	4238.1	4240.2
Min. V (pu)	0.9240	0.9441	0.9407	0.9407	0.9441
MLI at node 2	92.29	91.33	91.38	91.38	91.34
P_{Loss} (kW)	157.42	117.16	118.46	118.87	117.71
$P_{Released}$ (kW)	–	−16.46	−16.92	−16.73	−16.16
$S_{Released}$ (kVA)	–	−45.06	−42.79	−42.67	−44.77

efficiency performance of different configuration under constant power and composite loads. The results are obtained in MATLAB environment and verified in E-TAP software.

Constant power load

The energy efficiency performance for constant power load model is shown in Table 1. From test results, it can be observed that the improvement in node voltages has no effect on load demand and feeder capacity other then reduction in loss. Here, the improvement in load demand, minimum voltage, released powers and the loadability is different in the configurations as obtained in Zhu (2002), Saffar et al. (2011), Srinivasa et al. (2011) and Zhang et al. (2007).

Composite load

Table 2 shows the test result for composite load. The load demands as P_{Denamd}, Q_{Demand}, and $F_{Capacity}$ are reduced to 3650.9 kW, 2067.0 kVAr and 4195.4 kVA for the base network as compared to the results under constant power loads. However, for practical load, i.e. voltage dependent load, these values are found different when network is reconfigured using different methods. It can be noticed that the power losses are less and the MLI decreases from the base network. Further, the negative value of released powers ('*P*' and '*S*') show that the improvement in node voltages improves the load profile and hence the feeder capacity at substation.

Conclusions

This paper presented the energy efficiency analysis of a distribution system in different configurations for practical load. The test results show that the power demand as well as feeder capacity is significantly changed in different configuration if load is voltage dependent. Further it may results in improving the energy efficiency by improving the load profile due to improved node voltages. It is, therefore, necessary to evaluate the energy efficiency performance of the distribution systems under practical loads while performing reconfiguration and finding the size of distributed resources for optimal operation of distribution systems.

References

Ali, I., Thomas, M.S., Kumar, P., 2015. Energy efficient reconfiguration for practical load combinations in distribution systems. IET Gen. Trans. Distrib. 9 (August (11)), 1051–1060.

Ali, I., Thomas, M.S., Kumar, P., 2012. Effect of loading pattern on the performance of reconfigured medium size distribution system. In: Proc. of Fifth IEEE Power India Conference.

Baran, M.E., Wu, F.F., 1989. Network reconfiguration in distribution system for loss reduction and load balancing. IEEE Trans. Power Deliv. 4 (April (2)), 1401–1407.

Kumar, P., Singh, S., 2014a. Reconfiguration of radial distribution system with static load models for loss minimization. In: Proc. of IEEE International Conference PEDES.

Kumar, P., Singh, S., 2014b. Energy efficiency performance of reconfigured radial networks with reactive power injection. In: Proc. of IEEE Sixth India International Conference on Power Electronics (IICPE).

Kumar, P., Singh, S., 2014c. Comprehensive stability analysis of radial distribution system with load growth. In: Proc. of IEEE Sixth India International Conference on Power Electronics (IICPE).

Saffar, A., Hooshmand, R., Khodabakhshian, A., 2011. A new fuzzy optimal reconfiguration of distribution systems for loss reduction and load balancing using ant colony search-based algorithm. Appl. Soft Comput. 11 (March (5)), 4021—4028.

Srinivasa, R.R., Narasimham, S.V.L., Raju, M.R., Rao, A.S., 2011. Optimal network reconfiguration of large-scale distribution system using harmony search algorithm. IEEE Trans. Power Syst. 26 (August (3)), 1080—1088.

Venkatesh, B., Ranjan, R., Gooi, H.B., 2004. Optimal reconfiguration of radial distribution systems to maximize loadability. IEEE Trans. Power Syst. 19 (February (1)), 260—266.

Zhang, D., Fu, Z., Zhang, L., 2007. An improved TS algorithm for loss minimum reconfiguration in large scale distribution system. Electr. Power Syst. Res. 77, 685—694.

Zhu, J.Z., 2002. Optimal reconfiguration of electrical distribution network using refined genetic algorithm. Electr. Power Syst. Res. 62, 37—42.