

OPTIMIZING RELIABILITY OF DISTRIBUTION NETWORKS USING A METHOD BASED ON NONLINEAR PROGRAMMING

Sh. Mojtahedzadeh¹ S. Najafi Ravadanegh²

1. Azarshahr Branch, Islamic Azad University, Azarshahr, Iran, mojtahedzadeh@azaruniv.edu

2. Smart Distribution Grid Research Lab, Electrical Engineering Department, Azarbaijan Shahid Madani University, Tabriz, Iran, s.najafi@azaruniv.edu

Abstract- Because the world is developing, people need more energy day by day and to supply this energy need, there are found new solutions. But there is a big handicap while the energy system is working called failure. Because of the radial configuration of the distribution network, system faces higher failure rates. To increase the system reliability, there is a need for optimization of reliability main indices. In this work, an algorithm presented for distribution system optimization based on non-linear programming and software is developed in GAMS environment to solve the problem, which is applicable for any radial distribution network.

Keywords: Distribution Network, Reliability, Outage Cost, Optimization.

I. INTRODUCTION

Reliability evaluation of distribution system has been the subject of many research works and is an important technique for measuring the adequacy of power supply. In the past, an acceptable level of reliability has often been rather arbitrarily assigned on the basis of judgment and experience [1, 2] for distribution system planning. The costs and reliability of power distribution systems are beginning to receive as much attention as those of power generation and transmission systems. With the increase in market competition pressures due to the deregulation of the utility industry, utilities must provide electrical energy to customers as economically as possible and with an acceptable level of reliability.

In general, the more invested in the capital equipment of a utility, the higher the service reliability customers will receive. However, customers must pay additional costs to receive a higher reliability of electrical energy supply. The damages resulting from power outages vary widely among various kinds of customers, hence, the reliability levels required also differ accordingly. As such, it is necessary to perform reliability cost/worth assessment in the planning and expansion of distribution systems. The goal of distribution system is to satisfy the load demand within operational constraints, economically, reliably and safely. Recently, many studies have been undertaken on value based distribution systems reliability planning [3-9].

Most of them quantify the value of service reliability in terms of customer interruption costs. A sector customer damage function can be used to evaluate monetary loss incurred by customers associated with power outages and is usually expressed as a function of outage duration. Distribution system reliability cost/worth evaluation can provide information for decision making on system expansion or reliability reinforcement projects. The indices commonly used to describe distribution system reliability are failure rate and interruption duration. The basic function of an electric power system is to supply customer with acceptable degree of continuity and quality.

Analysis of the customer failure statistics has shown that because radial configuration of feeders and high failure rates in equipment and feeder sections, distribution systems make the greatest contribution to the unavailability of power supply to customers [10]. There are two main ways to improve the reliability of power distribution networks. The first one is to reduce the frequency of customers' interruptions and the second is to reduce the outage duration once the failure occurs [11-12].

In this paper, we present a method to calculate the optimal values of reliability indices for electric distribution systems. The optimization problem is usually very complicated, considering the scale of the system and the many inter-related factors. In order to reach a better completeness of reliability planning of distribution system, this paper employs optimization techniques, which are intended to offset the insufficiency of traditional planning style. For large systems, although a rather powerful and efficient optimization technique, the Generalized Reduced Gradient, is employed, the multi-level hierarchical optimization procedure [13] is needed to solve problem.

II. GENERALIZED REDUCED GRADIENT METHOD

The research is formulated as an optimization problem and also evaluated by the generalized reduced gradient method [14]. Of course, the most direct approach to solve a nonlinear programming problem would be to linearize the problem and successively apply linear programming techniques, i.e. successively linearize the constraints and objective function of nonlinear problem as successive improved feasible solutions are reached.

In practice, the best current general algorithm using iterative linearization is the GRG algorithm. The GRG algorithm is an extension of the reduced gradient method for linear constraints modified to accommodate both non-linear objective function and nonlinear constraints. In essence, the method employs linear or linearized constraints, defines new variables that are normal to the constraints, and expresses the gradient (or other search direction) in terms of this normal basis.

$$\text{minimize } f(x)$$

$$\text{subject to: } \begin{cases} g_j(x) \geq 0, j = 1, \dots, m \\ l_i \leq x_i \leq u_i, i = 1, \dots, n \end{cases} \quad (1)$$

Be transferred to:
minimize $f(x)$

$$\text{subject to: } \begin{cases} h_j(x) = g_j(x) - \sigma_j = 0 \\ l_i \leq x_i \leq u_i \end{cases} \quad (2)$$

where, σ_j is a slack variable. The GRG algorithm [14] can be briefly summarized as follows:

- 1- Initialize and find a feasible solution.
- 2- Compute the Jacobian of the constraints, J .
- 3- Select a set of n basic variables, x_b , such that B , the sub matrix of basic column from J , is nonsingular. Factorize B . The remaining variables, x_n , are called non-basic.
- 4- Solve $BT u = df/dx_b$ for the multipliers u .
- 5- Compute the reduced gradient, $r = df = (dx - J^T u)$. r will by definition be zero for the basic variables.
- 6- If r projected on the bounds is small, then stop. The current point is close to optimal.
- 7- Select the set of super basic variables, x_s , as a subset of the non-basic variables that profitably can be changed, and find a search direction, ds , for the super basic variables based on r_s and possibly on some second order information.
- 8- Perform a line search along the direction d . For each step, x_s is changed in the direction ds and x_b is subsequently adjusted to satisfy $g(x_b, x_s) = b$ in a pseudo-Newton process using the factored B from step 3.
9. Go to 2.

The individual steps are of course much more detailed in a practical implementation.

III. RELIABILITY MODELING AND OPTIMIZATION

The improvement in system reliability level or the decreasing of outage costs. Usually demands an increase in investment costs. The goal of the reliability optimization is to search for the minimal equilibrium, as indicated in Figure 1. The reliability optimization is incorporated into the overall optimization in this paper. Thus the value, which combines network utility unavailability data with customers' view on unavailability of supply can be used as reliability criterion in optimization task. However, if the information about the customer interruption cost is not available, the Energy Not Supplied (ENS) itself can serve as reliability criterion.

Due to these, the objective function of the distribution system optimization that we used can be written as:

$$\begin{cases} ENS = \sum_{i=1}^n \sum_{j \in m(j)} \lambda_j r_j P_i \\ \lambda_{\min} \leq \lambda_j \leq \lambda_{\max}, r_{\min} \leq r_j \leq r_{\max} \end{cases} \quad (3)$$

where, unavailability is calculated for each node in the network as a sum of interrupted energy due to possible failure of each upstream element $m(j)$ (number of sections on a distribution network) from the node to the feeding point (substation). The λ_j is the failure rate of element j , r_j is its average outage time and P_i is load at load point i on feeder.

The reliability attribute must be calculated for each load. Therefore, to start optimization and achieve best value for repair time and failure rate, we considered some points:

- 1- Consider each load point of the system.
- 2- Consider each failure mode of the load points.
- 3- Service can only be restored by repair.

Table 1. Network data

Section Number	Length (m)	Failure Rate (f/yr)	Repair Time (h)
1	630	0.94	2
2	375	0.56	2
3	441	0.657	2
4	616.5	0.92	2
5	285	0.425	2
6	285	0.425	2
7	510	0.76	2
8	165	0.246	2
9	186	0.277	2
10	45	0.067	2
11	186	0.277	2
12	300	0.45	2
13	210	0.313	2
14	156	0.232	2
15	250.5	0.373	2
16	283.5	0.42	2
17	49.5	0.075	2
18	207	0.308	2
19	721.5	1.075	2
20	300	0.45	2
21	435	0.65	2

IV. IMPLEMENTATION

Based on the model and algorithm presented before, we used GAMS software environment for optimization. Then we used Generalized Reduced Gradient (GRG) method to optimize our objective function and wrote needed codes to develop our proposed software to reliability optimization task. Our developed software takes distribution network information as an input, with all its connectivity and available data. The required data is:

- 1- Physical connections between the different buses of distribution network.
- 2- Location of branches and their length.
- 3- Failure rates and other reliability data of sections of feeders.
- 4- Load of buses.

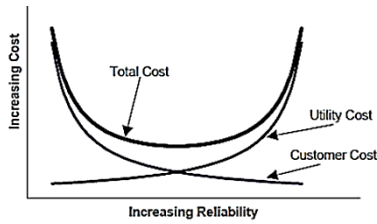


Figure 1. The goal of the reliability optimization is to search for the minimal equilibrium

V. CASE STUDY

The test system is shown in Figure 2. This system is a real distribution network in Tehran utility/Iran [15]. The network has 16 load points and the number of customers and average loads connected at each load point are shown in Table 1. The reliability data are given in Table 2. In the calculation, the average fault location time is taken 2 hour and failure rate is 1.49 failures per year for each kilometer. After insertion data to written script and running software, optimal values for failure rate and repair time for each section of mentioned system feeder sections are achieved and represented in the Table 3.

Table 2. Load data

Load Point	Average Load (kw)	Number of Customer
1	90	137
2	100.1	126
3	18.7	20
4	90	284
5	269.5	210
6	50.6	57
7	87.6	135
8	90	172
9	85	170
10	200	190
11	51.04	56
12	26.4	38
13	16.5	10
14	374	280
15	90	204
16	45.1	49

According to results obtained from experiment, we can see changes in value of failure rate and repair time and differences between optimal values and main values. Due to these results, we can develop a feasible strategy to manage effective asset on system reliability and make decisions to improve system performance and reliability.

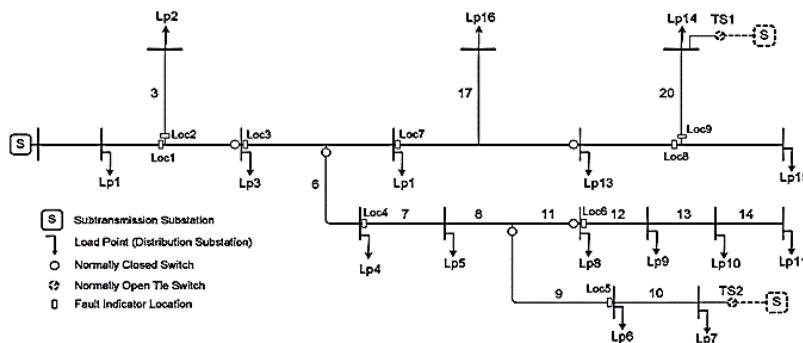


Figure 2. Studied distribution system

Table 3. Network data

Section Number	Failure Rate (f/yr)	Repair Time (h)
1	0.700	2.000
2	0.560	1.979
3	0.657	1.067
4	0.700	2.000
5	0.425	2.000
6	0.424	1.906
7	0.700	1.989
8	0.246	2.000
9	0.277	1.291
10	0.067	1.042
11	0.277	1.124
12	0.450	1.190
13	0.313	1.080
14	0.232	1.176
15	0.373	1.223
16	0.420	1.238
17	0.075	1.003
18	0.308	1.186
19	0.700	1.298
20	0.450	1.226
21	0.650	1.441

VI. CONCLUSIONS

This paper has examined an algorithm to optimize failure rate and repair time of distribution systems. It has described the model and techniques needed to evaluate reliability of distribution system. An optimization problem has been formulated which obtains optimum failure rates and repair times of each section. Then proposed model has been applied to a real Iranian distribution network. After optimization, due to obtained optimal values, the reliability indices will be improved. Electrical power distribution reliability can be improved from different aspects, from planning to operation and maintenance, therefore after obtaining optimal values for failure rate and repair time we can develop a strategy to apply to network and improve reliability to reach optimal values.

REFERENCES

[1] G. Tollefson, R. Billinton, G. Wacker, "Comprehensive Bibliography on Reliability Worth and Electrical Service Consumer Interruption Costs, 1980-1990", IEEE Trans. on Power Systems, Vol. 6, No. 4, pp. 1508-1514, 1991.

[2] R. Billinton, M.S. Grover, "Quantitative Evaluation of Permanent Outages in Distribution Systems", IEEE Trans. Power Apparatus and Systems, Vol. PAS-94, No. 3, pp. 733-741, 1975.

[3] A.A. Chowdhury, D.O. Koval, "Value-Based Distribution System Reliability Planning", IEEE Transactions on Industry Application, Vol. 34, No. 1, pp. 23-29, 1998.

[4] L. Goel, R. Billinton, "Evaluation of Interrupted Energy Assessment Rates in Distribution Systems", IEEE Transactions on Power Delivery, Vol. 6, No. 4, pp. 1876-1882, 1991.

[5] R. Billinton, P. Wang, "Distribution System Reliability Cost/Worth Analysis Using Analytical and Sequential Simulation Techniques", IEEE Transactions on Power Systems, Vol. 13, No. 4, pp. 1245-1250, 1998.

[6] R.L. Chen, K. Allen, R. Billinton, "Value-Based Distribution Reliability Assessment and Planning", IEEE Transactions on Power Delivery, Vol. 10, No. 1, pp. 421-429, 1995.

[7] R. Billinton, S.J. Navithula, "Optimal Switching Device Placement in Radial Distribution Systems", IEEE Transactions on Power Delivery, Vol. 11, No. 3, pp. 1646-1651, 1996.

[8] R.E. Brown, S. Gupta, R.D. Christie, S.S. Venkata, R. Fletcher, "Automated Primary Distribution System Design - Reliability and Cost Optimization", IEEE Transactions on Power Delivery, Vol. 12, No. 2, pp. 1017-1022, 1997.

[9] S.J. Navithula, R. Billinton, "Minimum Cost Analysis of Feeder Routing in Distribution System Planning", IEEE Transactions on Power Delivery, Vol. 11, No. 4, pp. 1935-1940, 1996.

[10] R. Billinton, R.N. Allan, "Reliability Evaluation of Power Systems", Plenum Press, New York, USA, 1996.

[11] Y. He, G. Anderson, R.N. Allan, "Determining Optimum Location and Number of Automatic Switching Devices in Distribution Systems", IEEE Power Tech'99 Conference, Budapest, Hungary.

[12] R.E. Brown, "Electric Power Distribution Reliability", Marcel Dekker, Inc., New York, Basel, 2002.

[13] M.W. Gangel, R.J. Ringlee, "Distribution System Reliability Performance", IEEE Trans. Power Apparatus and Systems, Vol. PAS-87, pp. 1657-1665, 1968.

[14] G.V. Reklaitis, A. Ravindran, K.M.R. Sdell, "Engineering Optimization Methods and Applications", John Wiley and Sons, New York, 1983.

[15] H. Falaghi, M.R. Haghifam "Fault Indicators Effects on Distribution Reliability Indices" CIRED, 18th International Conference on Electricity Distribution, Turin, 6-9 June 2005.

BIOGRAPHIES



Shahram Mojtahedzadeh was born in Iran, in 1980. He received his B.Sc. degree in Electronics Engineering in 2003 and his M.Sc. degree in Electrical Engineering in 2006. Now he is a Ph.D. student in Electrical Engineering at Electrical Engineering Department, Azarbaijan Shahid Madani University, Tabriz, Iran. He joined Azarshahr Branch, Islamic Azad University, Azarshahr, Iran in 2008. His main areas of interest are power system operation, smart grids and distribution system.



Sajad Najafi Ravadanegh was born in Iran, in 1976. He received B.Sc. degree in Electrical Engineering from University of Tabriz, Tabriz, Iran in 2001 and M.Sc. and Ph.D. degrees in Electrical Engineering from Amirkabir University of Technology, Tehran, Iran in 2003 and 2009, respectively. Currently, he is an Assistant Professor of Electrical Engineering Department, Shahid Madani University, Tabriz, Iran and responsible for Smart Distribution Grid Research Lab. His research interests include power system stability and control, special protection schemes, power system controlled islanding, evolutionary algorithms and intelligence computing in power systems, distribution system planning, energy management, nonlinear dynamic, and chaos. He is also the author and the co-author of over 33 technical papers.