DISTRIBUTION SYSTEM OPTIMAL PLANNING FOR RELIABILITY BASED ON GENETIC ALGORITHM

Hong LIU, Shaoyun GE
Key Laboratory of Power System Simulation and Control (Tianjin University)
Tianjin,300072–China
liuhong@tju.edu.cn, syge@tju.edu.cn

Ning LIU
Tianjin West Power Supply Corporation
Tianjin, 300113–China
hdln512@126.com

Jing XU
Tianjin Electric Power Research Institute
Tianjin, 300384–China
phoenix.Xujing@gmail.com

ABSTRACT

Reliability, the criteria to assess durability on power supply, is affected by many factors. Therefore, planning and expansion of distribution systems for the purpose of reliability reinforcement with limited investment are a quite complex problem. A genetic algorithm based optimization method of reliability planning on distribution system is presented. Firstly, the projects that could possibly improve the reliability are proposed in according with current deficiencies on power supply; secondly, the relations among the projects and their coding and regulation strategy are generated; at the end, planning solution among the available combinations of projects are optimized by genetic algorithm with respect to the reliability requirement and the constraint of maximum investment. Case study shows that the proposed method is capable to provide reasonable planning solution for the weak infrastructure of existing distribution networks in the country and its optimal solution improve distribution system reliability.

1 INTRODUCTION

Power supply reliability is the criteria to measure a power system to continuously supply electric power to users, and indicates the equipment integrity and management ability of a utility [1]. With the rapid development of the economy and living condition, reliability requirement for electricity becomes higher. Therefore, the continuous improvement of reliability is not only expected by the user but also an important objective of the electric utilities [2]. The statistics [3] shows that 80% of the power outage happened in distribution system. Considering such circumstance, optimization of distribution system planning is significant to enhance the reliability.

Two problems need be resolved in the reliability planning of distribution system: how to estimate system reliability taking planning projects into account, how to choose a group of projects with coordinating their relations to reach an optimal tradeoff between high planning quality and low investment cost. Literature [4] presented the feeder partition method to divide the network into automatic and manual isolated zones according to the isolation devices. And, a zone-based failure-mode-and-effect analysis (FMEA) technique was applied to system reliability evaluation based on the partition. Literature [5] stored adjacency matrix using the sparse technology in terms of the radial structure of medium voltage electrical distribution system, and then applied the fault-spreading-method to determine the activities of breaker and switching devices and used a section, instead of a single component, as a unit during the computing process of reliability evaluation. However, methods mentioned previously are only able to analyze certain network and not able to solve the problem when the structure of planning network and the faults of its elements are unknown. Literature [6] applied cost-benefit analysis to select the best scheme of breaker operations with minimizing overall investment, operation and maintenance cost, outage losses. Literature [7] introduced reliability cost-benefit regressive model in considering of reliability cost and unserved energy cost. But the papers just performed optimization for certain projects and can not take complex relations among the projects into account. Moreover, the benefit of reliability isn't just about decrease of interruption loss, and the benefit of high electric price and the advantage of attracting investment are hard to be assessed. Therefore, it is not that practically meaningful to equate reliability and economy.

As a result, in the paper, a reliability planning method is proposed, the new method can harmonize the relations of different projects and form the plan with the restriction of required investment and the objective of reachable reliability.

2 SUMMARY OF OPTIMAL PLANNING FOR RELIABILITY

2.1 Basic definition

Because of the difficulty of technology implementation and the uncertainty of investment amount, the planning with reliability as objective only can be conducted for the near future consequentially. Based on the existing infrastructure, therefore, building and reconstructing network equipment, improving related technology and management skill are the important means to resolve reliability based planning. The paper introduces two involved basic definitions as follows:

Definition 1 Project: According to any current deficiency, a proposed method for improving reliability is defined as a project.

Definition 2 Plan: a combination of several projects is called a plan for advancing reliability.

Therefore, the reliability planning is transformed to a group-optimization problem with many projects through the proposal conception of project and plan.

2.2 Relations among the projects

In fact, there are many influences [8] among the projects, for example, the operation sequence and the superposition of object and process. The plan is not only simply combination of the projects, but also guarantees rationality of the combination. Consequently, logical definition of the relations among the projects is the premise to achieve the reliability planning. The paper defines three relations as follows:

Definition 3 Independence: if there are no influences between project *i* and project *j*, it is called that the projects is independence.

Definition 4 dependence: if project *i* must be implemented before project *j*, it is called that project *j* relies on project *i*. But the rotative reliance is not allowed.

Definition 5 exclusiveness: if project *i* realization can lead the project *j* to an unfeasible project, it is called that it is mutually exclusive between project *i* and project *j*.

2.3 Mathematic model

The objective of short-term reliability planning is to reasonably arrange to projects and choose the optimal project-group that achieves the best reliability index with satisfying the relations of the projects and the maximum investment restriction. The main mathematic model is shown in (1):

$$\begin{cases} F = \max\{RS(P_i) \quad | \quad P_i \in P_{total}\} \\ s.t. \qquad C(P_i) \le C_{\max} \\ \qquad \text{the relation constraint } R_1 \\ \qquad \text{other constraint } R_2 \end{cases} \tag{1}$$

In which, $\boldsymbol{F}$ is the objective function; P_{total} is the group of all projects; $RS(P_i)$ is the reliability of project *i*; $C(P_i)$ is the investment of project *i*; R_1 is the relation constraint; R_2 is other constraints, such as the technology difficulty.

3 GENETIC ALGORITHM APPLICATION

3.1 Overall flow chart

As above description, the reliability planning is modeled as group-optimization problem with many projects in order to improve reliability. GA, Tabu and Chaos, etc. are widely utilized in many optimization algorithms due to their predominant searching capability to achieve or close to optimal solution. Furthermore, because whether the project is selected can be expressed as chromosome using “0-1”, GA is applied to choose the best plan in the paper. Flow chart of GA is shown below:

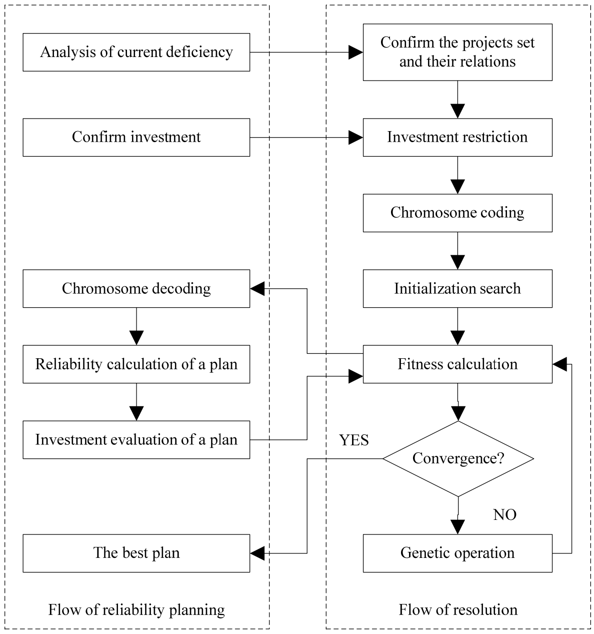

Fig. 1 Flow Chart of the Solution

3.2 Chromosome coding

According to the characteristics of the problem, binary code is applied to describe the reliability plan. The corresponding relation between the plan and the coding is shown as follows:

Tab. 1 The correlation between the projects and the coding

Index	Plan	Coding
1	plan *P*	chromosome *G*
2	project *i* of the plan	gene g_i
3	total number *n* of the projects	number *n* of the genes
4	If project *i* is selected	g_i＝1
5	If project *i* is not selected	g_i＝0
6	If project *i* rely on project *j*	if g_j＝1, g_i＝1
7	if mutually exclusive between project *i* and project *j*	$g_i \neq g_j$

The directional reliance among the projects would lead that the relied gene need be processed in advance. Therefore it can ensure the realization of reliance relation that the sequence is properly arranged.

3.3 Search Initialization

The chromosome is random initialized due to the well searching capability of GA. In order to guarantee the validity of the relations among the initialized genes, the paper creates every gene randomly with the sequence and relations of gene.

3.4 Fitness calculation

Each chromosome would have a fitness that determines its viability in the genetic calculation and is deeply correlative with optimization objective function. In this paper, the fitness function is consistent with the objective function that is shown as function (2).

$$Fitness = F = \max\{RS(P_i)\} \tag{2}$$

3.5 Genetic operation

3.5.1 Operator Selection

The method of selection applies common-used roulette method. It is also called fitness proportion selection, in which the selected probability is positively proportional to the fitness.

3.5.2 Crossover and mutation operator

The random bus method is utilized in crossover and mutation operator, which creates the stochastic number in the range of [1, n] to appoint the position of gene variation in the chromosome. Furthermore each operation is applied for one gene of the chromosome.

3.5.3 Operator Regulation

The chromosome created by crossover and mutation would not satisfy the relations of their genes, so the genes must be validated and regulated to guarantee the rationality of the plan. The regulation process is shown as follows:

(1) Create the set of all chromosomes that have been operated as crossover and mutation, and select the first one in the set;

(2) Record the altered position k and read the correlative relations in the relation warehouse;

(3) From the first gene to the last one of the chromosome, validate the relation between every gene and gene k. If not satisfied, correct it according to the relation;

(4) If all the chromosomes are validated, the regulation process is accomplished; otherwise, process the next chromosome and jump the step (2).

4 CASE ANALYSIS

4.1 Basic information

The information of partial planning area is shown in figure 2. The planning requirement is to improve reliability within the investment of *RMB* five million.

There are three stations and eleven 10kV feeders that supplies electric power to the area. The information of interruption frequency and repair duration of every device is shown as table 2.

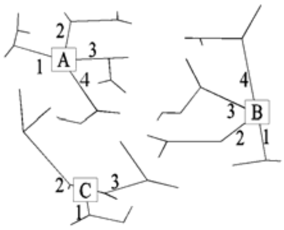

Fig. 2 Power Network of Planning Area

Tab. 2 Interruption frequency and duration of current devices

	units	lines	Switches
Interruption frequency of fault	times/100km (unit)year	15	8
Interruption frequency of prearrangement	times/100km (unit)year	40	30
repair time of fault	h	3	4
repair time of prearrangement	h	6	6
fault searching duration	h	2	

4.2 Preliminary network planning

The area is shown as figure 3 after preliminary network planning whose investment is not considered in optimization. Average length of planning feeders is five kilometers, and average user number of single planned feeders is twenty-four. Load factor is 45% to 50% approximately

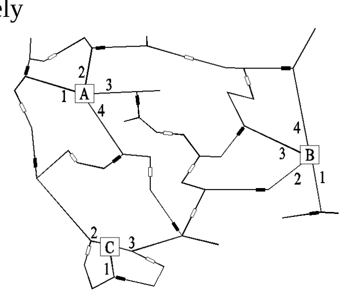

Fig. 3 Power Network after preliminary planning

4.3 Projects for reliability improvement

Seventeen projects are proposed to improve reliability of the area according to current power supply capability. The improvement effect and requiring investment of the projects and their relations is shown as follows.

Tab. 3 Projects for reliability improvement of planning area

Index	Improvement methods	Improvement effects	Investment	Relations
1	Add eleven common section switches	Three sections per feeder	￥440,000	mutually exclusive with project 2/3/4
2	Add twenty-two common section switches	Four sections per feeder	￥880,000	mutually exclusive with project 1/3/4
3	Add eleven automatic section switches	Three sections per feeder	￥880,000	mutually exclusive with project 1/2/4
4	Add twenty-two automatic section switches	Four sections per feeder	￥1,760,000	mutually exclusive with project 1/2/3
5	Add one common connection switch	1 feeder with one connection; 7 feeders with two connections; 3 feeders with three connections.	￥40,000	mutually exclusive with project 6/7/8
6	Add two common connection switches	8 feeders with two connections; 3 feeders with three connections.	￥80,000	mutually exclusive with project 5/7/8
7	Add one automatic connection switches	1 feeder with one connection; 7 feeders with two connections; 3 feeders with three connections.	￥80,000	mutually exclusive with project 5/6/8

8	Add two automatic connection switches	8 feeders with two connections; 3 feeders with three connections.	￥160,000	mutually exclusive with project 5/6/7
9	Realize distribution automatization with two sections	Time of fault searching decrease 1 h； Interruption duration of non-fault section is 0.05h	￥2,760,000	independent
10	Realize distribution automati zation with three sections	Time of fault searching decrease 1.33 h； Interruption duration of non-fault section is 0.05 h	￥2,760,000	rely on project 3 and 7
11	Realize distribution automatization with four sections	Time of fault searching decrease 1.5 h； Interruption duration of non-fault section is 0.05 h	￥2,760,000	rely on project 4 and 8
12	Replacing the old lines	Interruption frequency of lines fault decrease 0.06 times per year	￥1,100,000	independent
13	Apply advanced fault treatment devices	Treatment time of line fault decrease 1 h; Treatment time of switch fault decrease 1.5 h.	￥600,000	independent
14	Add the nameplate of overhead	Interruption frequency of lines decrease 0.015 times per year	￥110,000	independent
15	Improve lightning proof standard of overhead lines	Interruption frequency of lines decrease 0.01 times per year	￥220,000	independent
16	Strengthen the train to decrease prearranging interruption time	Interruption duration of line prearrangement is 1 h; Interruption duration of switch prearrangement is 1.5 h	￥200,000	independent
17	Avoid repeated interruption	Interruption frequency of lines and switch prearrangement decrease 0.08 and 0.06 times per year	￥300,000	independent

4.4 Optimization of the plan

The best plan is project 3/7/10/13/14/16/17 that is selected by the proposal method. The network using the plan has three sections and is entirely connected. The reliability of planning area will reach 99.9508% and need *RMB* 4.93 million.

If the network has four sections and is fully connected, the best plan will be project 4/8/11/14/16 that will achieve 99.9447%reliability and need *RMB* 4.99 million.

It should be noted that the advantage of the proposed method would be more obvious when facing larger scale network and larger amount of groups and projects.

5 CONCLUSION

The main purpose of urban network planning is to reasonably design the infrastructure of the network to satisfy the requirement of power supply and transfer. Meanwhile, planning for reliability more focuses on the reduction of power outage by promoting and exploring the network, equipment, technology and management of electric utility. Therefore, on the one hand, reliability planning is based on the network planning; on the other hand it is more difficult than the network planning. In the paper, according to the characteristics of planning problem, complex relations among the plans are carefully defined. GA is applied to solve the optimization problem to achieve reliability criterion within the limited investment. Case study shows the feasibility of the proposed method.

REFERENCES

[1] Lixiong JIA, Xiaozheng HU, 2007, "Analysis on Power Supply Reliability for Nation-Wide City User in 2006", *Electrical Equipment*, vol.8, 88-90.

[2] Hua ZHANG, 2005, "Talking about the Reliability of Urban Power Distribution Network", *Sci/Tech Information Development & Economy*, vol.15, 281-282.

[3] R BILLINTON, Peng WANG, 1998, "Reliability Network Equivalent Approach to Distribution System Reliability Evaluation", *IEE Proceedings-Generation, Transmission and Distribution*, vol.145, 149-153.

[4] Yinghua XIE, Chengshan WANG, 2004, "Reliability Evaluation of Medium Voltage Distribution System Based on Feeder Partition Method", *Proceeding of the CSEE*, vol.24, 35-39.

[5] Bosi LIU, Kaigui XIE, Chunlei MA, et al., 2005, "Selection Algorithm of Reliability Evaluation for Complex Medium Voltage Electrical Distribution Networks", *Proceeding of the CSEE*, vol.25, 40-45.

[6] Xukai ZHU, Wenying LIU, Yihan YANG, 2006, "A New Power Network Planning Method by Comprehensively Considering System Reliability Factors", *Power System Technology*, vol.7, 85-88.

[7] Sheng QIU, Yan ZHANG, Jiansheng SUN, et al., 2005, "Measurement of Improving the Reliability of Medium Voltage Power Distribution System and Its Cost/Benefit Analysis", *Relay*, vol.33, 34-38, 49.

[8] Jing XU, Chengshan WANG, Xiaohui LI, et al., 2007, "Reconstruction Scheme Optimization of Distribution Network Based on Adaptive Genetic Algorithm", *Automation of Electric Power Systems*, vol.31, 111-115.

[9] Shouxiang WANG, Chengshan WANG, 2007, *Modern Distribution System Analysis*, Higher Education Press, Beijing, China, 123-145.

[10] Ming ZHOU, Shudong SUN, 1999, *Genetic Algorithms：Theory and Applications*, National Defence Industry Press, Beijing, 50-59.

[11] Chengshan WANG, Saiyi WANG, 2004, "the Intelligent Planning of Urban Mid-Voltage Distribution Network Based on Spatial GIS：Part One Automatic Routing of Radial Network", *Automation of Electric Power Systems*, vol.28, 45-50.

[12] Gang DUAN, Yixin YU, 1999, "an Algorithm for Tie Lines Planning of Power Distribution Systems", *Automation of Electric Power Systems*, vol.23,10-14.