THE PROGRAMMING METHOD OF CUSTOMER FRIENDLY DISTRIBUTION SYSTEMS CONSIDERING THE UNCERTAINTY OF SHORT TIME POWER QUALITY DISTURBANCES

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ABSTRACT

Under the concept of smart grid, a novel programming method is proposed in the paper for customer friendly distribution system considering the uncertainty properties of power quality. Due to the uncertainty of short time power quality during the change of power system structure, the assessment of potential cost caused by customers' equipment failures under possible disturbances for different planning schemes is proposed. The programming method based on customer cost including the potential costs is correlated with the disturbances and voltage tolerant level of customer equipment. Based on maximum entropy principle and fuzzy analysis method, the compatibility between system disturbance and equipment is studied also. This method has been applied to RBT Bus2 distribution system. The results validate that the planned distribution system considering the customer potential losses is with more comprehensive benefit.

INTRODUCTION

Smart Grid has become energy security and national strategies in many countries[1], while the planning is the first step among many aspects such as system planning, operation control and management decision-making which should be researched in the implementation. Smart grid's basic characteristics include self-healing, resiliently against attack and natural disaster, high power quality for the digital economy, participation by consumers, selectivity, market-oriented and optimize asset utilization and operate efficiently. Therefore, the important contents should consist of the compatibility between customer and system, customer satisfaction degree, in addition to construction and operating costs, measure indexes also contain customer cost. According to marketing principles of power market, customer satisfaction degree which is determined by the difference between total cost and customer value and is the measurement of value determination in customers, being important as objective function in system planning.

On the basic characteristics and requirements of modern power system,customer friendly distribution system means not only safe, reliable, economical, but also friendly for human and environment power system. The key measurement of customer satisfaction degree is the possible disturbance in power system and the influence of disturbance. It is friendlier for customers to add uncertain loss due to voltage tolerance level of equipment (IEEE Std. 1346) to customer cost, which emphasize the assessment of uncertainty[2]. So the uncertainty of disturbance in power system and voltage tolerance level of equipment should be considered comprehensibly during the planning of distribution systems.

Voltage sags, which cause huge economic losses and serious complaint to utilities' customers, have been identified to be the most severe problems among different types of power quality problems[3]. The sensitive equipments, such as personal computers (PCs), adjustable speed drives (ASDs), programmable logic controllers (PLCs), and AC-contactor (ACCs), are very sensitive to voltage sags which lead to scrap of the whole industrial processes caused by a single failure. Not only outage cost included in the customers cost due to disturbance of power system, even more the voltage sag cost, resulting in potential cost, therefore, both outage cost and potential cost should be considered during planning of power system.

In view of above, this paper begins with construction and operating costs in system, outage and potential cost of customers from the planning systems, investigating the uncertainty of disturbance and different potential cost, finally validating its correctness in RBT Bus2 distribution system by the model of customer friendly distribution systems which consider customer potential cost.

THE CUSTOMER FRIENDLY DISTRIBUTION SYSTEMS AND PLANNING IDEA

Customer Friendly Distribution Systems

The definition of customer friendly distribution systems means a flexible, controllable, intelligent power distribution system of actual performance to smart grid which consider the demand of energy resources and environment, and the requirement of power quality, safety, reliability, self-healing, participation and satisfaction by customer in premise of minimum in construction costs, operating costs and customer cost. The resource friendly, environment friendly and customer friendly are the focus of systematic programming, in particular, the satisfaction degree of customer.

The potential cost depends on multi-uncertain short time disturbance in system and types of equipments[2]. As recommended by IEEE Std.1346, the planned distribution system measured with uncertain voltage tolerance level is able to meet requirements of different customers. Thus, it is necessary to calculate the customer potential cost besides the cost of construction and operating, index of outage cost.

Planning Idea of Customer Friendly Distribution Systems

The basic idea of customer friendly distribution systems with synthetically considering of cost including utility and customers is as following, definiting the required objective function and the planning scheme, confirming the customer potential cost combined with uncertain disturbance in system and tolerant capacity of equipment , establishing the planning model of system which consider construction cost, operating cost and customer cost, finding the optimal planning scheme.

CUSTOMER FRIENDLY DISTRIBUTION SYSTEM PLANNING

Modeling of Planning System

In order to elucidate principle of the model, the objective function is provided as:

$$\min Z = f_1 + f_2 + f_3 \tag{1}$$

$$s.t.\ \ U_k \in u_k \tag{2}$$

$$F(x_k) \le 0 \tag{3}$$

$$G(x_k, y_k) \le 0 \tag{4}$$

Where: parameters f_1, f_2 and $f_3$are the annual construction costs, operating cost (involve network loss and depreciation per year) and customer cost (outage and potential cost), U_k is the project of construction at k_{th} year (u_k is the sets of planning scheme), x_k , y_k is the optimization variable of structure and operation in system.

Equations (2) and (3) mean constraint to optimization of structure.Equation (4) shows the constraint to optimization of operation.

Each part of the expression in the objective function is:

$$f_1 = \frac{i(1+i)^n}{(1+i)^n - 1} \sum_{l \in L} c_U l_l \tag{5}$$

Where: i is investment discount rate, n is the period of construction, c_U is line cost of unit length, l_l is the new loops in line l of scheme k_{th}, L is the set of branches.

$$f_2 = T \sum_{l \in L} C_{loss} r_{Ul} P_{Ul}^2 + C_d \tag{6}$$

Where: T is the annual power loss hour of maximum load, C_{loss} is annual operation cost of power loss, r_{Ul} , P_{Ul} are the resistance and active power in line l of No.k scheme, C_d is the annual depreciation cost.

$$f_3 = EENS(U_k) \cdot CIC + C_{sag}(U_k) \tag{7}$$

Where: $EENS(U_k)$ is the annual outage expectation, CIC is outage loss of unit power, C_{sag} is the potential cost by voltage sag.

The Process of Planning Calculation

According to the requirements and model above, the flowchart of customer friendly distribution system is shown in Figure 1.

THE UNCERTAINTY OF CUSTOMER POTENTIAL COST

The Uncertainty of Disturbance in Distribution System

The major factor of customer potential cost is the severity depends on the configurations, functions, loading conditions, and installation sites, and protect set, etc., which reflects its voltage sag on the sensitive equipment of the connection bus[5]. The potential cost depends on operating conditions; similarly the uncertain area of tolerant capacity relies to the type of equipments. Hence, it's necessary to assess the possible potential cost and disturbance characteristics at the same time.

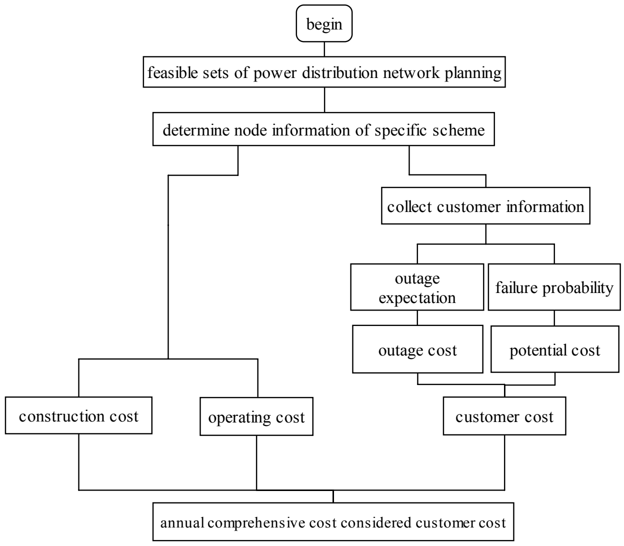

Figure 1. Flow chart of calculation for distribution power network planning

According to the given reliability parameters of different types of lines, if a three-phase fault occurs on transmission line k, voltage magnitude at bus m is obtained by [4]:

$$U_{r,m} = U_m^{pref} - [(1-l)\cdot Z_{mi} + l \cdot Z_{mj}] \cdot U_f^{pref} / [(1-l)^2 \cdot Z_{ii} + l^2 \cdot Z_{jj} + 2l(1-l)\cdot Z_{ij} + l\cdot(1-l)\cdot z_{ij} + Z_g] \tag{8}$$

Where: U_{rm} is the retained voltage of sag in bus m, U_m^{pref}, U_f^{pref} are the pre-fault voltage at bus m and f, the length of line is 1$p.u.$, Z_{ii}, Z_{jj} are the driving-point impedances of buses i and j; Z_{mi}, Z_{mj}, Z_{ij} are transfer impedances between the corresponding couples of buses; z_{ij} the physical impedance of line k. Moreover, if an unbalanced fault occurs on line k, the voltage magnitude of bus m is shown in [5] in detail.

Owing to the stochastic fault in system and distribution of voltage magnitude at bus m caused by line, probability density function of severity for voltage sag at bus m can be calculated by maximum entropy method proposed in [5] as:

$$f(s) = \exp(\lambda_0 + \lambda_1 s + \sum_{n=2}^{N} \lambda_1 (s - E_1)^n) \tag{9}$$

Where, λ_0 to λ_5 are Lagrange multipliers corresponding to each constraint. N can be solved from [5], which is equal to 5.

The variables in (9) depend on distribution of retained voltage magnitude, which being calculated with topological parameters from each scheme combining (8). There can we see, the probability density function of severity of voltage magnitude is the measure of uncertainty of disturbance.

The Uncertainty of the Influence to Customer by Disturbance

The uncertainty of voltage tolerance level of equipment is fixed by its types, configurations, functions, loading conditions, and installation sites, etc., which show in Figure 2. For the different customer equipments, the frequency of specific voltage magnitude (50 % [3]) is error to assess the customer potential cost due to multi-uncertainty. So, the evaluation of uncertain state is the important part of finding potential cost.

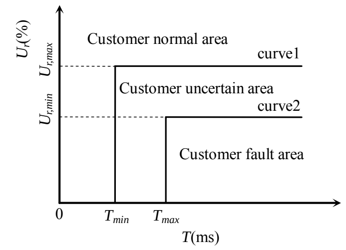

Figure 2. Uncertainty region of failure for consumer

The known probability density function $f(s)$ combines the membership function μ_A, can evaluate the failure probability as:

$$P(A) = P(s > x) = \int_0^{+\infty} \mu_A(s) f(s) ds \qquad (10)$$

Where, s is the severity index of voltage sag (voltage magnitude in this paper, sag duration or composite)[3].
Actually, the failure number of k-class customer at bus m can be get from the planning strategy and customer information as follow:

$$PFN_{mk(x_{mk1}\%-x_{mk2}\%)} = P(A) \cdot L_{ij} \cdot \lambda_{ij} \qquad (11)$$

Where, x_{mk1}, x_{mk2} are the minimum and maximum of tolerant voltage of k-class customer at bus m, L_{ij}, λ_{ij} are the length and failure probability of line i-j.

ASSESSMENT OF CUSTOMER POTENTIAL COST

The Customer Potential Cost Assessment Model

The different planning schemes lead to the change of customer potential cost. Unfortunately the existing planning methods seldom involve the measurement of sag cost since they only consider the serious situation such as outage, restart, and scrap and so on. Likewise, the economic appraise of power quality hold interrupt cost as the most important part, meanwhile researching in customer potential cost.
In actual distribution system, customers are divided into residential, commercial, government, industrial and other types. Known from the plenty of investigation, the industrial customers are much more sensitive to duration than others, which conform to the situation of mass pipelines in industry.
Therefore, industry customers consider instantaneous interruption while the other kinds consider short-time interruption losses as a single potential cost. The data in Table I come from certain utility of Canada[6], which show the potential loss for renewing 1 kW power supply after one disturbance.

TABLE I. SINGLE FAILURE COST OF CUSTOMER

k	1	2	3	4	5
C_{mk}(($ /kW))	0.98	1.88	2.50	0.271	0.312

The annual potential cost of k-class customer at bus m is derived as:

$$C_{p,m} = PFN_{mk} \cdot C_{mk} \qquad (12)$$

Based on this (12), the customer potential costs in the whole system of certain scheme can be expressed as:

$$C_{potential} = \sum_{m \in M} C_{p,m} \qquad (13)$$

Where, M is the congregation of load points in the system.

The Process of Algorithm

1) Determine the potential failure probability using the maximum entropy principle[5] and random-fuzzy method[2] with the topology and tolerant levels of various equipments.
2) Calculate the potential failure numbers at load points for given reliability parameters in system combining (12).
3) Select the optimum planning scheme of the minimum objective function consisted of customer potential cost.

CASE STUDY

The IEEE-RBT bus2[7] distribution system shown in Fig.3 is used to validate the proposed method.
The validity and necessity of the planning model with customer satisfaction degree has been verified by economic loss assessment by comparing the result on whether the customer potential cost should be considered in objective function.

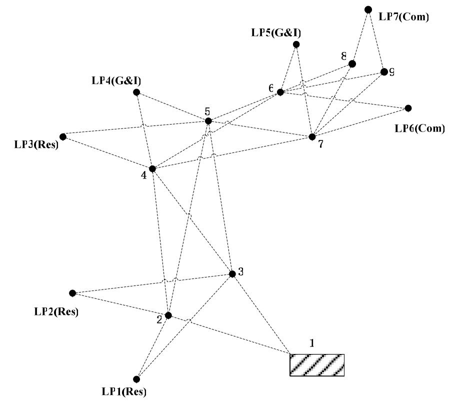

Figure 3. RBT Bus2 distribution network feeder

Seen from Fig.4, scheme one is the customer friendly planning result with the potential cost, while isn't the scheme two.

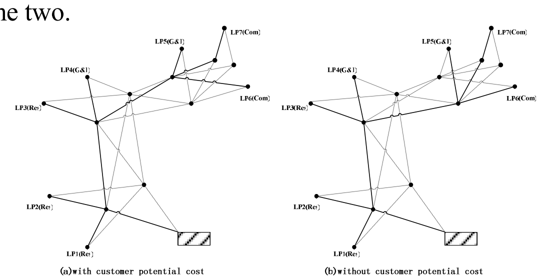

Figure 4. Optimal network structure of distribution system

As is shown in Table IIand Table III, under different schemes, the mutative tendency of coefficients in probability density function of voltage magnitude expresses the intensity of disturbance in programming systems, then the failure probabilities of different customers can be gained integrating the tolerant level of sensitive equipments. According to the customer information, the customer economic losses introduced in section 5 can be calculated, which reflect the customer satisfaction for the given distribution planning schemes. Under the standard of SEMIF47, PCs, ASDs and PLCs respectively represent the typical sensitive equipments in resident, commerce and government, industry; moreover, they are independent among each other.

TABLE II. POTENTIAL FAILURE OF CONSUMERS AT NODE LP5 CAUSED BY PROBABILITY DENSITY FUNCTION OF DISTURBANCE IN LINE 6-8 OF PROGRAMS

coefficient	E_1	λ_0	λ_1	λ_2	λ_3	λ_4	λ_5	Resident failure probability	Commerce failure probability	Industry failure probability
Scheme 1	0.4395	2.8769	-5.6430	25.2753	84.7846	-576.0854	537.3784	0.4063	0.6045	0.5577
Scheme 2	0.4829	3.0414	-5.2341	33.5217	95.1437	-901.5927	916.9575	0.5028	0.7798	0.6503

TABLE III. POTENTIAL FAILURE OF CONSUMERS AT NODE LP4 CAUSE BY PROBABILITY DENSITY FUNCTION OF DISTURBANCE IN LINE 2-4 AND LINE 6-LP5 OF PROGRAM ONE

coefficient	E_1	λ_0	λ_1	λ_2	λ_3	λ_4	λ_5	Resident failure probability	Commerce failure probability	Industry failure probability
line 2-4	0.3264	1.0830	-2.5784	-2.4062	29.0860	38.2374	-185.7046	0.3028	0.4118	0.3869
line 6-LP5	0.0384	3.2304	-25.159	-7.5089	0.6088	-14.2216	11.0046	3.3E-06	8.6 E-05	0.0022

As can be seen from the Table II and Table III:

1) The variation of failure probability density function determined by topology undisputedly causes the variation of customer's failure probability with the difference of planning schemes. Form Table II, the difference of same customer's failure probability is more than 15%, which provides a basis of determination to customer friendly programming project.

2) To the radiate topology of distribution network, the disturbance intensity in system displays the characteristic of rapid descend from above to below. Furthermore, the disturbance in the load bus more comes from the upstream and the surrounding nodes. Therefore, end-user satisfaction degree is closely related to the locations of customers, what's more important, logical network structure is the important and primary target of friendly distribution system.

3) The compatibility of customers at the same bus and disturbance even in the same line exist difference owing to the variance between equipments.

The results of each kind of cost for the two schemes are shown in TableⅤ. And the other reliability parameters for calculating are given in [7].

TABLE IV. POWER NETWORK PROGRAMMING RESULTS OF THE GARVER-6 BUS SYSTEM

Result(million yuan)		Scheme 1	Scheme 2
Annual line investment cost		4.8615	4.8615
Annual construction cost	Power loss	1.5946	1.5957
	Depreciation cost	0.5463	0.5463
Annual customer cost	Outage cost	8.7689	8.6848
	Potential cost	39.9267	42.5716
Annual comprehensive cost		48.6966	51.2564

Comparing with the two schemes, both of them can meet the demand of each load point, only have slight different in the feeders. So the line investment costs of the two projects are almost the same. Yet the potential cost of two schemes is 39.92 and 42.5716(million yuan), which is the part can't be ignored. Meantime, the result of optimization is different. Despite the expense of scheme one in line investment and construction cost is litter higher, the grid obviously reduce the times of potential fault and customer cost. This programming method has much more focused on the customer who lost larger cost. Finally, those can get higher power quality; meanwhile, the customer satisfied degree has been enhanced

CONCLUSION

1) During the process of distribution system programming, the mothed combines the disturbance in the system with equipment tolerance of customer is proposed in this paper. This model considered each kind of customer economic cost gained the most satisfactory topology, which is suitable for any size of network including ring or radiation.

2) Comparison of difference and relationship of economic loss for various customers in the same distribution system reflects satisfaction degrees of different customers. In practice, the customer friendly distribution system is better to blend with the utility and customer.

3) The widely complaints are related to customer economic loss thanks to the unreasonableness of grid structure. The necessity of addition of customer potential cost is also seen in the simulation results. Further studies are still needed in developing the reasonable compensation device to improve disaster resistant of distribution system.

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