Notice of Retraction

After careful and considered review of the content of this paper by a duly constituted expert committee, this paper has been found to be in violation of IEEE’s Publication Principles.

We hereby retract the content of this paper. Reasonable effort should be made to remove all past references to this paper.

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Technical and economic assessment of voltage sag based on stochastic prediction

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Abstract—The technical and economic assessment of voltage sag are analyzed in this paper. Specially, on one side, the sag conditions of customers are got by Monte Carlo prediction considering about randomness of sag event, on the other side, the equipment failure rate is counted by probability method due to the uncertain sensitivity and different tapes and the composition of sensitive equipment. Then the sag situation for customer can be evaluated using the date from both system and equipment. This paper adopts NPV to choose the most appropriate improvement plan which has a better balance between the technical effect and economic effect for specific customer. Finally, the method is applied to a manufacture plant. Taking into account the uncertain unit sag loss of customer, different section of best solution are also given. It has been convinced by the example that the assessment process is clear and easy to operate.

Keywords- Voltage sag; Stochastic prediction; Sensitive equipment; NPV; Technical and economic assessment

I. INTRODUCTION

In recent years, voltage sag has been considered to be the most serious problem among various dynamic power quality problems and it has brought huge economic losses\(^1\). A single voltage sag may cause the same loss as short duration interruption or sustained interruption and even the loss of individual industry caused by sag may achieved million of dollar, which is higher than interruption losses. Therefore it has realistic sense to study on technical and economic assessment of voltage sag.

The special features of voltage sag when compared to other power quality problems are analyzed from two aspects: On one side, voltage sag is random and non-recurrent event, so if we get sag date for assessment only from measuring, we need a very long monitoring period to achieve high accuracy of assessment\(^2\). On the other side, the immunity of customers’ sensitive equipment has great impact on customers’ losses due to voltage sag, while it is difficult to built a single standard for equipment sensitivity because different sensitive equipments have different reactions for voltage sags.

It will bring significant economic benefit when using appropriate mitigation programs for customers which have suffered serious influence by voltage sag. The program should be determined based on the customer's voltage sag condition and program’s input costs, then according to programs' economic effect choose the most optimal mitigation programs\(^3\).

At present, it has been many studies on the assessment of voltage sag in both home and abroad. Three stochastic prediction methods of fault positions, critical distance and Monte Carlo are separately used in [3-5] to analyze voltage sag condition of system. However, when customers’ influence by sag in the system are assessed it only adopt fixed threshold to judge the immunity of sensitive equipment, which doesn’t take into account that the immunity of equipment affected by the type of equipment, production process and load levels and other factors, so it has great uncertainty. The immunity of sensitive equipment is studied in [6-9]. The method of different probability distribution functions are used in [6-8] and the method of establishing fuzzy rules based on expert experience are used in [9] to evaluate equipment’s immunity, but both two methods cannot combine system side condition to get comprehensive assessment of customers. The procedure of economic assessment and choosing the optimal improvement measures which is decided by their minimum annual cost are presented in [10-11], but it doesn’t seen from a technical and economic view, so it can not fully meet the requirements of market.

Integrated content of the above, this paper combines voltage sag from system and sensitive equipment condition from customers, then carry out economic and technical assessment aiming at customers to choose the most optimal mitigation plan in the selectable plans. Specifically, the system data are got by the method of stochastic prediction, customer’s equipment failure rate in statistical region and sag condition are got by immunity of sensitive equipment which are evaluated using stochastic model with type and composition of customer’s equipment. On base of this, NPV is adopted to complete the economic and technical assessment and the optimal plan is given in different interval with the change of customer’s unit sag loss. The assessment process can be described as the following four steps:

(1) Assessment of customer’s sag condition from both system side and equipment side
(2) Assessment of customer’s loss caused by sag
II. ASSESSMENT OF CUSTOMER’S SAG CONDITION

A. Assessment of sag condition from system side

When using stochastic prediction method, the occurrence of short circuit fault is seen as random event and its’ probability is used to assess the expect number of sag event. The advantage of Monte Carlo method is that it can reflect the random characteristics of power system and almost be independent of the system complexity constraints. So it is adopted in this paper. In this paper, after the sag characteristics of the bus with customer are got, the recommendation table in IEC61000-2-8[12] is used to classify sag event including voltage sag magnitude, duration and frequency of key node.

B. Assessment of sag condition from equipment side

The sag condition of bus with customer cannot represent specific customer’s loss caused by sag because the loss relate to immunity of customer’s sensitive equipment. Sensitive equipments include PLC, PC and ASD and so on. Tests showed that the voltage tolerance curves of these equipments are generally rectangular. But the immunity to sag of these equipments subject to many factors such as their own characteristics, operation status, the production process, etc and many different types of sensitive equipment may included by customer, therefore, the immunity is uncertain in a certain region. In this paper, probabilistic method[13] is used to solve the above problem. As follows, assessment method is proposed in this paper to estimate equipment failure rate and frequency of sag.

(1) A broad tolerance curve is established to define Vmax, Vmin, tmax, tmin showed in figure 1 based on experience data for different equipments. The four data divided plane into three parts, region of P represents that sag event will certainly not result in equipment failure (p = 0), while region of R represents that sag event will certainly result in failure (p = 1). The middle Q is the region needing assessment, which is divided into three regions of A, B, C. The immunity of sensitive equipment in A, B region is assessed using one-dimensional function respectively with variable of magnitude V and duration T of voltage sag and in the C region is assessed using two-dimensional function with variable of V and T.

(2) This paper adopts normal probability density function characterized the randomness of V and T in base of literature[6-8] by the randomness of load to respectively establish the probability density function f(x) and f(y) in area A and B, and joint probability density function f(x,y) in area C, as shown in the following (1),(2),(3).

\[ f_x(V) = \frac{1}{\sqrt{2\pi\sigma_x^2}} e^{-\frac{(V-V_0)^2}{2\sigma_x^2}} \]  
\[ f_y(T) = \frac{1}{\sqrt{2\pi\sigma_y^2}} e^{-\frac{(T-T_0)^2}{2\sigma_y^2}} \]  
\[ f_{x,y}(V,T) = f_x(V)f_y(T) \]  

The equipment failure rate P of customer in statistical area can be counted using probability density function of immunity in different regions.

(3) If customer contains different sensitive equipment, when \( P_j \) and \( P_{trip} \) respectively represents the composition ratio equipment failure rate of jth sensitive equipment, the composite equipment failure rate \( P_{trip} \) as shown in the following formula (4).

\[ P_{trip} = \sum_{j=1}^{n} \alpha_j P_j \]  

The number \( N_i \) of customer affected by voltage sag every year is shown as formula (5).

\[ N_i = \sum \sum P_{trip}(V,T) \cdot N(V,T) \]  

\( N(V,T) \) is the frequency of voltage sag and \( P_{trip} \) is equipment failure rate in statistical area.

III. ASSESSMENT OF CUSTOMER’S LOSS CAUSED BY SAG

The loss caused by voltage sag change in wide range, which wasn’t only due to the different condition of industry type and equipment , but also affected by market[10]. The loss 

\[ C_{sag}(i) = N_i \cdot C_i \]  

IV. TECHNICAL AND ECONOMIC ASSESSMENT OF MITIGATION PLAN FOR VOLTAGE SAG

Power companies, customers, equipment manufacturers need to take certain measures to reduce loss. Power companies can reduce the number of faults and shorten the fault clearing time to decrease the occurrence of sag event and change system design to meet customers’ needs; customers can install mitigation equipment such as UPS and DVR; equipment manufacturers can minimize the immunity of sensitive equipment.

The methods of improvement plan for voltage sag varied, and the corresponding improvements in costs and effects are also different. If sensitive load is isolated from the general load and to be protect by special measures, it can significantly save the cost. In general, the cost of improvement plan would be increases as its effectiveness. The quality of a project not only depends on technical efficiency, but also on economic efficiency. It is likely to be widely adopted when the plan is...
technically feasible and economically reasonable, it may not be the most advanced technology, but the most appropriate technology.

The NPV method has been widely accepted as a method of calculating the profit of investment opportunities, which discounts the annual net income to project’s starting point value according to discount rate, and makes the best choice by summation and comparison of NPV value. When the NPV value is positive, the project is valid for the investment income summation and comparison of NPV value. When the NPV value according to discount rate, and makes the best choice by discounts the annual net income to project's starting point calculating the profit of investment opportunities, which that be the most advanced technology, but the most appropriate technically feasible and economically reasonable, it may not

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The result using the assessment method proposed in this paper and the above date are as follows(only part of the data are given due to page limitations): If the sag condition of the node connected of customer by Monte Carlo method showed as Tab.2. Fig.3 is the customer’s integrate failure rate distribution. On base of the above, the number due to voltage sag of customer counted by formul(5) is 10.67 every year.

If the customer needs to improve the sag effect, the expense and improvement effect of considered measures are showed in Tab.3[11]. On the assumption that the financial losses of customer is $25,000 due to each voltage sag ,and the calculation of equipments’ fees is on base of 10 year life and the interest rate of 5%,the assessment result is showed as Tab.4 by NPV method. From the result, the fourth plan is the most optimal one. If the financial losses of customer is $250,000 of each voltage sag, the result is showed in Tab.5 which indicate the UPS plan is the most optimal one. Seen from the comparison of above, the unit sag losses of customer influences the option of optimal plan.

<table>
<thead>
<tr>
<th>Tab.1 sensitive equipment condition of customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive equipment</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>PLC</td>
</tr>
<tr>
<td>ASD</td>
</tr>
<tr>
<td>PC</td>
</tr>
</tbody>
</table>

Tab.2 Statistical data table of voltage sag magnitude, duration and frequency

<table>
<thead>
<tr>
<th>Voltage sag magnitude (%)</th>
<th>duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5cy&lt;t≤0.1</td>
</tr>
<tr>
<td>80≤U&lt;90</td>
<td>1.8</td>
</tr>
<tr>
<td>70≤U&lt;80</td>
<td>2.3</td>
</tr>
<tr>
<td>60≤U&lt;70</td>
<td>1.4</td>
</tr>
<tr>
<td>50≤U&lt;60</td>
<td>11</td>
</tr>
<tr>
<td>40≤U&lt;50</td>
<td>7.6</td>
</tr>
<tr>
<td>30≤U&lt;40</td>
<td>3</td>
</tr>
<tr>
<td>20≤U&lt;30</td>
<td>0.8</td>
</tr>
<tr>
<td>10≤U&lt;20</td>
<td>0.8</td>
</tr>
<tr>
<td>0≤U&lt;10</td>
<td>2</td>
</tr>
</tbody>
</table>

Tab.3 Expense and improvement effect of improvement measures

<table>
<thead>
<tr>
<th>Tape of sensitive equipment</th>
<th>Typical cost/$</th>
<th>Operating and maintenance cost per year/$</th>
<th>Sags with Min voltage &lt;10%</th>
<th>Sags with Min voltage 50%</th>
<th>Sags with Min voltage 50%-70%</th>
<th>Sags with Min voltage 70%-90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS</td>
<td>500KVA</td>
<td>75 KVA</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>DVR</td>
<td>300KVA</td>
<td>15 KVA</td>
<td>20</td>
<td>90</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>static switch</td>
<td>60000</td>
<td>3000</td>
<td>100</td>
<td>80</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Fast transfer switch</td>
<td>150000</td>
<td>750</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

According to the third part in this paper, the financial losses are unable to get an accurate estimate for it is affected by various factors. So Fig.4 is the changing curve of NPV when customer’s unit sag loss changed. In the Fig.3, horizontal axis represents unit sag loss while vertical axis is the NPV value. When the unit loss in [0- 68,874], the fourth
plan is the optimal plan; when it is in \([68.874−∞]\), the first plan is the best; when it is in the interval around 68.874, the plan 1, 3, 4 has the similar result.

In this paper, it combines the condition of system by stochastic prediction and customer’s sensitive equipment to assess customer’s sag condition and adopts NPV method to determine the optimal improvement plan. The assessment process is complete and clear, but each part of assessment still needs intensive study. Such as in the part of stochastic prediction, the accuracy of system model and the reliability of fault data both affect the accuracy of the results; the losses caused by sag needs further investigation; the effectiveness and cost of the improvement plan also need more accurate assessment.

**REFERENCES**

[14] Fu Jia-ji, Quan Yun-huan, technical economics of industry; Tsinghua Press, 2004