Reliability Analysis of Suichatar Substation along with Cost Analysis
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Abstract: The basic function of an electric power system is to supply customers with electricity. Modern society demands that electrical energy should be as economical as possible with a reasonable degree of continuity and quality. This requires the investment in improving reliability of system to be compensated or oversubscribe by the benefit obtained from the improved reliability. This can be evaluated by reliability cost/worth analysis. This study attempts to analyze reliability of suichatar substation. Proposes a method to improve its reliability and presents a reliability and cost analysis for various of substation and finally gives an optimum solution point that gives improved reliability with minimum cost.

Failure mode and effect analysis have been used to evaluate the reliability of suichatar substation. Revenue loss to utility, customer damage cost in a present situation of substation have been computed. For improvement in reliability, this thesis has proposed two solution one is replacement of old and obsolete with new one and other is to make provision of spare unit. It is found that current transformer, potential transformer and disconnecting switch have been in use for very long and are old and gets faulted frequently. An attempt has been made to carry out liability and cost analysis of this substation for various scenario considering these old equipment. Finally optimum configuration of these current transformer, potential transformer and disconnecting switch that improves reliability with minimum cost is found. A program has been written in matlab for all these computation and genetic algorithm has been used for cost minimization.

Keywords: Reliability, substation, reliability cost/worth analysis

DS=disconnecting switch
L=load point of substation
S=series block

1. Introduction

The basic function of an electric power system is to supply customers with electricity. Modern society demands that electrical energy should be as economical as possible with a reasonable degree of continuity and quality. To build an absolutely reliable power system is neither practically realizable nor economically justifiable. The continuity of energy supply can be increased by improved system structure, increased investment during the planning phase, operating phase or both. Over-investment can lead to excessive operating costs, which must be reflected in the tariff structure. Consequently, the economic constraint will be violated although the probability of the system being inadequate may become very small. On the other hand, under-investment leads to the opposite situation. It is evident therefore that the reliability and economic constraints can compete, and this can lead to difficult managerial decisions at both the planning and operating phase.

A power system can usually be divided into the subsystems of generation, transmission, and distribution facilities according to their functions. In a vertically integrated power system, one Company often owns all the subsystems. In this case, a power system planner can relatively easily access most of the required information and decide when and where to perform generation expansion, line and station reinforcement to meet future load growth and satisfy the corresponding reliability requirements. The balance between reliability and economic constraints is usually judged by the system planner.

1.1 Power System Reliability

Power system reliability evaluation can be used to provide a measure of the overall ability of a power system to perform its intended function. The concept of reliability can be subdivided into the two main aspects of system adequacy and system security. System security relates to the ability of the system to respond to disturbance arising within the system. System adequacy relates to the existence of sufficient facilities within the system to satisfy the customer demands within the system operating constraints. This includes the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities to transport the energy to the actual customer load points. The three subsystems of generation, transmission and distribution are designated as power
system functional zones. Reliability evaluation can be conducted in each of these functional zones or in the combinations that gives the hierarchical levels.

HL1 = reliability evaluation of generation
HL2 = composite reliability evaluation of generation and transmission
HL3 = composite reliability evaluation of generation, transmission & distribution

1.2 System Adequacy

The reliability indices that have been evaluated are the three primary ones of average failure rate, average outage duration and average annual unavailability or average annual outage time. These are not deterministic values but are the expected or average values of an underlying probability distribution and hence represent only the long run average value.

2. Problem Statement

Generation and transmission system reliability has gained greater attention compared to distribution system and substation over decade. A study showed that much of interruption of supply is because of problem in distribution system nevertheless the substation originated outage cannot be neglected as it also play a significant role in supply interruption for customer. This give rise to need to carry out reliability assessment of substation.

There is a rare practice of assessing reliability in nepal Reliability of system can be improved by increasing the investment cost, but up to what degree of reliability to achieve and with what level of investment? And does the investment worth it? The answer to this question can be obtained by reliability cost verses reliability worth analysis.

3. Methodology

Reliability of substation and improvement in reliability of substation can be obtained by following proposed methodology

**Governing equation:**

**Series equation**

When two or more components are connected in series, their equivalent failure rate gets added and total unavailability also gets added which is shown below

\[
\Lambda = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n \\
U = U_1 + U_2 + U_3 + \ldots + U_n \\
R = U / \Lambda
\]

Where \( n \) = no of components connected in series

\( \Lambda \) = equivalent failure rate of all series connected components

\( U \) = equivalent unavailability of series connected components

\( R \) = Equivalent outage duration of series connected components

**Parallel equation:**

When two or more components are connected in parallel their equivalent failure rate, outage duration and unavailability can be obtained as

\[
\lambda_{pp} = \frac{\lambda_1 \lambda_2 (r_1 + r_2)}{1 + \lambda_1 r_1 + \lambda_2 r_2} \\
r_{pp} = \frac{r_1 r_2}{r_1 + r_2} \\
U_{pp} = \lambda_{pp} r_{pp}
\]

Expected energy not served (EENS) of load point is given by the product of load demand at that load point and unavailability of that load point.

**Cost minimization:**

In order to improve the reliability of Suichatar substation, two options are proposed in this thesis which is either making a provision of spare part or replacement of faulty component. Both of this option tends to improve the substation reliability but requires certain investment to be done. Normally reliability increases with investment and customer damage cost decreases with improved reliability. Inadequate reliability of electric power supply ultimately costs the customers much more than good reliability. It is therefore important to determine the optimal reliability level at which the reliability investment achieves the best results in reducing the customer damage costs due to power supply interruptions. Therefore the cost expression to be minimized is as follows

\[
\text{Total cost} = \text{equipment cost} + \text{installation cost} + \text{interrupted energy asessment rate} \times \text{EENS}
\]

Where \( \text{Iear} \) = Interrupted energy asessment rate

**Solving strategy:**

In order to compute reliability of Suichatar substation, failure rate and outage data were collected from substation along with single line diagram of substation. From single line diagram reliability block diagram was constructed by replacing component connected in series by their equivalent series block and parallel
connected equipment by their equivalent parallel block which is as shown below:

1) Equivalent failure rate of sample series blocks is obtained using equation for series connection

2) load point of substation are identified For each of load point of substation, identify the failure of component or combination of component failure.ie overlapping failure of two or three component that cause outage of load point that are termed as failure modes of load point overlapping of four or more component is not considered because the value is negligible.

The failure modes of all the load point are computed as below:

load point 1 gets failed when any of the below mentioned condition appears which is also termed as failure modes of load point 1

I) Failure of series block S7 and S8

II) Failure of series block S7 and failure of DS12 and DS13

III) Failure of series block S8 and failure of DS10 and DS11

IV) Failure of bus bar 1 and failure of DS11 and DS13

V) Failure of busbar2 and failure of DS10 and DS12

VI) Failure of 11kv bus bar

VII) Failure of 132kv bus bar

VIII) Failure of series block S4 and S5

IX) Failure of series block S4 and S8breaker

X) Failure of series block s5 and s7

XI) Failure of series block s4,ds6 and ds7

XII) Failure of series block s5,ds4 and ds5

Similarly failure modes for all the other load point are identified

The failure modes that are identified in this way represent component outages that must overlap to cause a load point outage. The events are therefore defined as overlapping outages and the associated outage time is defined as the overlapping outage time. Each overlapping outage is effectively a set of parallel elements and its effect can be evaluated using the equations for parallel components. Also, since each of these overlapping outages will cause system failure, all the overlapping outages are effectively in series from a reliability point of view. The system indices can therefore be evaluated by applying the equations for series components in order to combine all the overlapping outages.

Figure 3.1.a: Reliability Block diagram of suichatar substation

Figure 3.1.b: Reliability block diagram of suichatar substation

Where ds is disconnecting switch, s is equivalent series block, br is breaker, b is bus bar
load demand on every load point was collected from substation expected energy not served (eens) of every load point was evaluated as

Eens(Mwhr/yr) of load point = unavailability of load point(hr/yr) * load in mw

Then old and aged, obsolete component of substation are identified.

In this thesis two reliability improvement scheme are suggested

i. Making provision of spare parts for old and faulty component that will reduce the outage time. Outage time will be replacement time for no spare availability but if spare parts are available outage time will be equal to the time to replace the faulty unit by the spare unit.

ii. Replacement of faulty component with newer component. The newer component will have improved failure rate. The component tends to fail infrequently in long duration.

It is not economically justifiable to replace all the old equipment, or make provision of spare unit for all faulty component.

In an attempt to improve the system reliability, this require increase in investment cost, but the question arise whether the cost is compensated by the benefit obtained from the improved reliability, in order to solve this issue, GA tool in MATLAB have been used and develop fitness function in MATLAB. This code finds the optimum configuration of DS, CT PT which DS/CT/PT to replace? Which DS/CT/PT should be given spare so that the reliability gets improved significantly with minimum cost. Cost is composed of the overall investment cost and the customer damage cost.

Reliability indices for every load point of substation for recent three consecutive year is shown below

<table>
<thead>
<tr>
<th>notation</th>
<th>load in MW</th>
<th>2068 BS</th>
<th>2069 BS</th>
<th>2070 BS</th>
<th>unavailability(hr/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>load point 11</td>
<td>all 11kv</td>
<td>8.029</td>
<td>8.58</td>
<td>9.854</td>
<td>64.418</td>
</tr>
<tr>
<td>load point 12</td>
<td>Pat-1</td>
<td>6.705</td>
<td>6.954</td>
<td>7.188</td>
<td>3.2245</td>
</tr>
<tr>
<td>load point 13</td>
<td>Pat-2</td>
<td>6.7848</td>
<td>7.281</td>
<td>7.9018</td>
<td>2.7160</td>
</tr>
<tr>
<td>load point 14</td>
<td>teku</td>
<td>8.207</td>
<td>9.033</td>
<td>9.4514</td>
<td>2.8118</td>
</tr>
<tr>
<td>load point 15</td>
<td>k3</td>
<td>6.7452</td>
<td>8.083</td>
<td>8.622</td>
<td>4.1601</td>
</tr>
<tr>
<td>load point 17</td>
<td>bal 2-66</td>
<td>5.636</td>
<td>7.647</td>
<td>8.1848</td>
<td>3.621</td>
</tr>
<tr>
<td>load point 18</td>
<td>bal 1-66</td>
<td>7.27</td>
<td>8.24</td>
<td>8.619</td>
<td>3.919</td>
</tr>
</tbody>
</table>

Table 5: EENS for all the load points of substation

<table>
<thead>
<tr>
<th>Notation</th>
<th>EENS (Mwhr/yr)</th>
<th>2068 BS</th>
<th>2069 BS</th>
<th>2070 BS</th>
</tr>
</thead>
<tbody>
<tr>
<td>load point 11</td>
<td>517.032</td>
<td>552.9005</td>
<td>634.5541</td>
<td></td>
</tr>
<tr>
<td>load point 12</td>
<td>21.6222</td>
<td>22.424</td>
<td>23.1777</td>
<td></td>
</tr>
<tr>
<td>load point 13</td>
<td>18.4275</td>
<td>19.776</td>
<td>21.4615</td>
<td></td>
</tr>
<tr>
<td>load point 14</td>
<td>23.079</td>
<td>25.401</td>
<td>26.575</td>
<td></td>
</tr>
<tr>
<td>load point 15</td>
<td>28.061</td>
<td>33.628</td>
<td>35.869</td>
<td></td>
</tr>
<tr>
<td>load point 17</td>
<td>20.41445</td>
<td>27.69936</td>
<td>29.6445</td>
<td></td>
</tr>
<tr>
<td>Load point 18</td>
<td>28.496</td>
<td>32.312</td>
<td>33.783</td>
<td></td>
</tr>
<tr>
<td>Total EENS</td>
<td>657.132</td>
<td>714.144</td>
<td>805.0656</td>
<td></td>
</tr>
</tbody>
</table>
All the above result shows that the system was unable to meet the expected energy accounting to the failure of different substation component. However, improving the performance of substation by either replacing the obsolete component or making provision of spare part might reduce the volume of unserved energy. Cost of improving the substation performance must be compensated or oversubscribed by the energy lost cost to the utility as well as to the society otherwise, it will not be meaningful. For this we require reliability cost worth analysis which is under study.

Reliability and cost analysis for various scenario of improvement schemes are presented below. replacing all the ct of substation reduces the eens to 748.52 Mwhr/yr. revenue loss to utility decreases to Rs 5613954.3 and ECOST reduces to Rs 39176387.9

Similarly for other cases, it is presented below

Table 6: Reliability and cost analysis for various scenario are

<table>
<thead>
<tr>
<th>EENS</th>
<th>revenue loss to utility</th>
<th>ECOST</th>
<th>Equipment cost</th>
<th>total cost (equipment +ecost)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replace all ct</td>
<td>748.52</td>
<td>5613954.36</td>
<td>3742636.42</td>
<td>5100000.0</td>
</tr>
<tr>
<td>Replace all pt</td>
<td>783.52</td>
<td>5876458.19</td>
<td>39176387.96</td>
<td>2200000.0</td>
</tr>
<tr>
<td>replace all ds</td>
<td>739.7</td>
<td>5548243.8</td>
<td>36988292.07</td>
<td>108000.0</td>
</tr>
<tr>
<td>spare all ct</td>
<td>746.4</td>
<td>559314.45</td>
<td>37322096.39</td>
<td>510000.0</td>
</tr>
<tr>
<td>spare all pt</td>
<td>784.97</td>
<td>5887347.41</td>
<td>39248982.07</td>
<td>2200000.0</td>
</tr>
<tr>
<td>spare all ds</td>
<td>696</td>
<td>5220083.45</td>
<td>34800556.36</td>
<td>1080000.0</td>
</tr>
<tr>
<td>replace all ct and pt</td>
<td>725.68</td>
<td>5442648.18</td>
<td>36284321.26</td>
<td>730000.0</td>
</tr>
<tr>
<td>replace all ct and ds</td>
<td>683.62</td>
<td>5127173.34</td>
<td>34181155.06</td>
<td>1590000.0</td>
</tr>
<tr>
<td>replace all pt and ds</td>
<td>673.17</td>
<td>5048777.27</td>
<td>33658515.16</td>
<td>13000000.0</td>
</tr>
<tr>
<td>spare all ct and pt</td>
<td>727.13</td>
<td>5453537.41</td>
<td>36356916.09</td>
<td>7300000.0</td>
</tr>
<tr>
<td>spare all ct and ds</td>
<td>638.6</td>
<td>4789822.4</td>
<td>31932149.3</td>
<td>15900000.0</td>
</tr>
</tbody>
</table>

5. Conclusion

The eens for substation for year 2070 about 800 MWhr/yr. Revenue loss to utility was around Rs 60,00,000 and ECOST was about 400,00,000

EENS = 635.9270 Mwhr/yr

Revenue loss to utility = NRs 47,69,453.209

Annuital investment cost Rs 14,81,709.46

ECOST = NRs. 3,17,96,354.729

Equipment cost = NRs 98,00,000.000

TOTAL COST = NRs. 3,32,78,064.195

This result suggest that the existing reliability can be improved at an investment of around Rs 9800000.00 reducing the revenue loss to utility and expected customer interruption cost to society significantly.

References


