Reliability Improvement
Outline of Reliability

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1. Outline of Reliability

Introduction

Feature of Electricity
- Just in time
- Cannot save

Perception of Reliability
- Variable among customers and utilities
- Change over the years
- Load sensitivity of electrical equipment
1. Outline of Reliability

Introduction

- Reliability
  - Number of Interruption
    - Frequency of Interruption
  - Duration of Interruption
    - Size of Interruption Area
    - Search of Fault Point and Restoration
1. Outline of Reliability

Reliability?

- Probability of energy supply interruption
  - Ability of a product to perform its intended function for a stated period of time under specified operating conditions

- 4 Important Elements
  - Probability
  - Time
  - Performance
  - Operating Conditions
1. Outline of Reliability

Reliability?

Classification

- Inherent reliability
- Achieved reliability

Indicator of evaluating distribution system

- Determination of electricity tariff
- Assessment of operational efficiency of Power Company
- Indicator of service level of Power Company
1. Outline of Reliability

Definition of Terminology

- Temporary vs. Permanent Fault
  - Temporary by nature fault: Y
    - Does Device use automatic reclosing? Y
      - Momentary Outage
    - N
      - Sustained Outage
  - Permanent by nature fault: N

- Outage vs. Interruption
- Interruption
  - Instantaneous interruption: 0.5 ~ 30 cycles
  - Momentary interruption: 0.5 ~ 3 s
  - Temporary interruption: 3 s ~ 1, 3 or 5 min
  - Sustained interruption: over 1, 3 or 5 min

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### 1. Outline of Reliability

#### Reliability Indices

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIDI</td>
<td>System Average Interruption Duration Index</td>
</tr>
<tr>
<td>SAI FI</td>
<td>System Average Interruption Frequency Index</td>
</tr>
<tr>
<td>CAIDI</td>
<td>Customer Average Interruption Duration Index</td>
</tr>
<tr>
<td>CAIFI</td>
<td>Customer Average Interruption Frequency Index</td>
</tr>
<tr>
<td>MAIFI</td>
<td>Momentary Average Interruption Frequency Index</td>
</tr>
</tbody>
</table>

※ Others: ASAI, ASUI, CT AIDI, ASIFI, ASIDI, SARFI
1. Outline of Reliability

Reliability Indices

- **System Average Interruption Frequency Index**
  - Designed to give information about the average frequency of sustained interruption per customer over a predefined area
  - \[ \text{SAIFI} = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}} = \frac{\sum N_i}{N_t} \]
1. Outline of Reliability

Reliability Indices

System Average Interruption Duration Index

- Designed to provide information about the average time of sustained interruption per customer over a predefined area

\[ \text{SAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}} \]

\[ = \frac{\sum t_i \cdot N_i}{N_T} \]
1. Outline of Reliability

Reliability Indices

Customer Average Interruption Duration Index

- Average time required to restore service to the average customer per sustained interruption

\[ \text{CAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customer Interruptions}} = \frac{\sum \Gamma_i \cdot N_i}{\sum N_i} = \frac{\text{SAIDI}}{\text{SAIFI}} \]


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1. Outline of Reliability

Reliability Indices

- Momentary Average Interruption Frequency Index
  - Very similar to SAIFI
  - track the average frequency of momentary interruptions
  - \[ MAIFI = \frac{\text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customers Served}} = \frac{\sum ID_i \cdot N_i}{N_T} \]
1. Outline of Reliability

Reliability Indices

Average Service Availability Index

✓ Represent the fraction of time that a customer has power provided during the defined reporting period

✓ \[ \text{ASAI} = \frac{ \text{Customer Hours Service Availability} }{ \text{Customer Hours Service Demand} } \]

\[ = \frac{N_T \cdot (\text{No. Hours / Year}) - \sum T_i \cdot N_i}{N_T \cdot (\text{No. Hours / Year})} \]

\[ = \frac{8760 - \text{SAIDI}}{8760} \]
## Calculation of Reliability Indices

- **Total Customer**: 10,000
- **Sustained interruption**: over 3 minutes

<table>
<thead>
<tr>
<th>Date</th>
<th>Time of Outage</th>
<th>Time of Restoration</th>
<th>No. of Customer</th>
<th>Load (kVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 3</td>
<td>12:12:20</td>
<td>12:22:20</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Apr. 15</td>
<td>18:23:40</td>
<td>18:24:40</td>
<td>500</td>
<td>1600</td>
</tr>
<tr>
<td>May. 5</td>
<td>00:23:10</td>
<td>01:13:10</td>
<td>600</td>
<td>1500</td>
</tr>
<tr>
<td>Jun. 12</td>
<td>23:17:00</td>
<td>23:47:00</td>
<td>200</td>
<td>700</td>
</tr>
<tr>
<td>Jul. 6</td>
<td>09:30:10</td>
<td>09:32:10</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>Aug. 20</td>
<td>15:45:40</td>
<td>17:45:40</td>
<td>300</td>
<td>1000</td>
</tr>
<tr>
<td>Aug. 31</td>
<td>08:20:00</td>
<td>09:20:00</td>
<td>500</td>
<td>1400</td>
</tr>
<tr>
<td>Sep. 3</td>
<td>17:10:20</td>
<td>17:30:20</td>
<td>1500</td>
<td>3000</td>
</tr>
<tr>
<td>Oct. 27</td>
<td>10:15:00</td>
<td>10:55:00</td>
<td>700</td>
<td>1500</td>
</tr>
<tr>
<td>Dec. 10</td>
<td>20:30:20</td>
<td>20:33:20</td>
<td>500</td>
<td>1000</td>
</tr>
</tbody>
</table>
2. Example & Exercise

Calculation of Reliability Indices

1. SAIDI =
2. SAIFI =
3. CAIDI =
4. ASAIF =
5. MAIFI =

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3. Overseas Status

Reliability Indices Used Worldwide

More than 80% of the electric power companies surveyed used
3. Overseas Status

United Kingdom

<table>
<thead>
<tr>
<th>Reliability Index</th>
<th>SAIFI, SAIDI, MAIFI, Survey of public opinion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>Interruption: over 3 minutes Source side interruption - SAIFI: not included - SAIDI: included 10% of interrupted time</td>
</tr>
</tbody>
</table>

Survey of public opinion

- Kindness of employees
- Their willing to help
- Accuracy of information provided
- Usefulness of information provided

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3. Overseas Status

Italy

<table>
<thead>
<tr>
<th>Reliability Index</th>
<th>SAIFI, SAIDI, MAIFI</th>
</tr>
</thead>
</table>
| Standard          | Instantaneous: below 1 second  
|                   | Momentary: 1 second ~ 3 minutes  
|                   | Sustained: over 3 minutes |

CEER (Council of European Energy Regulators)

Survey the reliability status in European power companies

- Trust
- Fast recovery of interruption
- Quick & Reliable information provided
3. Overseas Status

PacifiCorp (Washington, USA)

Reliability Index
SAIFI, SAIDI, MAIFI

Standard
Instantaneous : below 1 second
Momentary : 1 second ~ 5 minutes
Sustained : over 5 minutes

CPI (Circuit Performance Indicator)

\[(\text{SAIDI} \times 0.3) + (\text{SAIFI} \times 0.3) + (\text{MAIFI} \times 0.2) + (\text{Circuit Lock-Out} \times 0.2)\]

- Select 5 lower ranked feeders in each B/O each year
- Try to reduce 20% of interruption
3. Overseas Status

SDGE (San Diego Gas & Electric, USA)

- Reliability Index
  - SAIFI, SAIDI, MAIFI

- Standard
  - Instantaneous: below 1 second
  - Momentary: 1 second ~ 5 minutes
  - Sustained: over 5 minutes

PG&E (Pacific Gas & Electric, USA)

- Reliability Index
  - SAIFI, SAIDI, MAIFI

- Standard
  - Instantaneous: below 1 second
  - Momentary: 1 second ~ 2 minutes
  - Sustained: over 2 minutes
# 3. Overseas Status

## Japan

<table>
<thead>
<tr>
<th>Reliability Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIFI, SAIDI</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous: below 0.3 second</td>
</tr>
<tr>
<td>Momentary: 0.3 second ~ 2 seconds</td>
</tr>
<tr>
<td>Sustained: over 2 seconds (re-closing time)</td>
</tr>
</tbody>
</table>

## Korea

<table>
<thead>
<tr>
<th>Reliability Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIFI, SAIDI, CAIDI, MAIFI</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous: below 1 minute</td>
</tr>
<tr>
<td>Momentary: 1 minute ~ 5 minutes</td>
</tr>
<tr>
<td>Sustained: over 5 minutes</td>
</tr>
</tbody>
</table>
3. Overseas Status

Comparison of Reliability Indices

SAIDI (min/customer yr)

<table>
<thead>
<tr>
<th>Country</th>
<th>SAIDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea</td>
<td>18.6</td>
</tr>
<tr>
<td>USA</td>
<td>68.36</td>
</tr>
<tr>
<td>England</td>
<td>57.6</td>
</tr>
<tr>
<td>Italy</td>
<td>51.02</td>
</tr>
<tr>
<td>France</td>
<td>138.47</td>
</tr>
<tr>
<td>Austria</td>
<td>141</td>
</tr>
<tr>
<td>Spain</td>
<td>137.8</td>
</tr>
</tbody>
</table>
3. Overseas Status

Comparison of Reliability Indices

SAIFI (frequency/customer yr)

<table>
<thead>
<tr>
<th>Country</th>
<th>SAIFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea</td>
<td>0.45</td>
</tr>
<tr>
<td>USA</td>
<td>1.24</td>
</tr>
<tr>
<td>England</td>
<td>0.72</td>
</tr>
<tr>
<td>Italy</td>
<td>2.79</td>
</tr>
<tr>
<td>France</td>
<td>1.35</td>
</tr>
<tr>
<td>Austria</td>
<td>0.78</td>
</tr>
<tr>
<td>Spain</td>
<td>2.69</td>
</tr>
</tbody>
</table>
3. Overseas Status

Comparison of Reliability Indices

CAIDI (min/customer yr)

<table>
<thead>
<tr>
<th>Country</th>
<th>CAIDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea</td>
<td>41.3</td>
</tr>
<tr>
<td>USA</td>
<td>107.7</td>
</tr>
<tr>
<td>England</td>
<td>94.97</td>
</tr>
<tr>
<td>Italy</td>
<td>49.63</td>
</tr>
<tr>
<td>France</td>
<td>42.67</td>
</tr>
<tr>
<td>Austria</td>
<td>65.41</td>
</tr>
<tr>
<td>Spain</td>
<td>52.42</td>
</tr>
</tbody>
</table>
3. Overseas Status

Comparison of Reliability Indices

ASA1 (%)

<table>
<thead>
<tr>
<th>Country</th>
<th>ASA1 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea</td>
<td>99.79</td>
</tr>
<tr>
<td>USA</td>
<td>98.43</td>
</tr>
<tr>
<td>England</td>
<td>99.22</td>
</tr>
<tr>
<td>Italy</td>
<td>98.42</td>
</tr>
<tr>
<td>France</td>
<td>99.34</td>
</tr>
<tr>
<td>Austria</td>
<td>99.42</td>
</tr>
<tr>
<td>Spain</td>
<td>98.39</td>
</tr>
</tbody>
</table>
Improvement Strategy

Based on KEPCO’s Case
4. Improvement Strategy

Establishment of Interruption Statistic Management System

- Use the international standard reliability index
  - SAIDI, SAIFI, CAIDI, MAIFI etc.
- Analyze the accurate cause of interruption
- Interruption Classification
  - Source side interruption vs. distribution side interruption
  - Scheduled interruption vs. unscheduled interruption
  - Secondary side interruption
- Utilize IT technology for the system

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KEPCO’s Case

KEPCO’s Interruption Statistic Management System

[Image of a screenshot of the KEPCO’s Interruption Statistic Management System interface]
KEPCO’s Case

New Distribution Information System (NDIS)
KEPCO’s Case

New Distribution Information System (NDIS)

System circuit diagram
Single line diagram
KEPCO’s Case

KEPCO’s Interruption Analysis

Interuption status of KEPCO by month

- Sustained
  - January: 71
  - February: 75
  - March: 96
  - April: 90
  - May: 93
  - June: 119
  - July: 152
  - August: 200
  - September: 163
  - October: 135
  - November: 146
  - December: 147

- Momentary
  - January: 464
  - February: 621
  - March: 849
  - April: 706
  - May: 530
  - June: 566
  - July: 1103
  - August: 1128
  - September: 851
  - October: 482
  - November: 508
  - December: 519


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KEPCO’s Interruption Analysis

*Interruption status of KEPCO by facility*
KEPCO’s Case

KEPCO’s Interruption Analysis

Interruption status of KEPCO by cause

<table>
<thead>
<tr>
<th>Cause</th>
<th>First Quarter</th>
<th>Second Quarter</th>
<th>Third Quarter</th>
<th>Fourth Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing Setup</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Contact with Vendor</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Natural Disasters</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Internal Errors</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Failed Power</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Other</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Total</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

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4. Improvement Strategy

Improvement of the Fault Prevention System

- System interconnection and division
  - Overhead
  - Underground
  - Ideal
    - Radial
    - Loop
    - Network

<table>
<thead>
<tr>
<th>System interconnection and division</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo Electric</td>
</tr>
<tr>
<td>General : 3/3</td>
</tr>
<tr>
<td>Large capa : 6/6</td>
</tr>
<tr>
<td>Underground : 2/2</td>
</tr>
</tbody>
</table>

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4. Improvement Strategy

Improvement of the Fault Prevention System

- System interconnection and division of KEPCO
- Reduce fault recovery duration & area

Legend:
- Circuit Breaker: ■
- Switch ON: □
- Switch OFF:
- Subsection division section switch: •
4. Improvement Strategy

Improvement of the Fault Prevention System

- Use Infrared light Camera for Facility Diagnosis
  - Portable Instruments & Diagnosis Vehicle

- Analysis Program

koci
4. Improvement Strategy

Improvement of the Fault Prevention System

- Introduce Fault Indicators
  - Underground Line Fault Indicator
  - Overhead Line Fault Indicator
4. Improvement Strategy

Prevention of the Underground Cable Fault

- **Diagnosis of Underground Cable Deterioration**
  - Diagnosis and then replace bad condition cable
  - RVM (Return Voltage Method) for paper insulated Cable

![Diagram showing the process of DC 1 kV, Cable, Return Voltage, and PC Analysis with states: electrified, discharged, measured.]

- **Deterioration Determination Criteria**

<table>
<thead>
<tr>
<th>Condition</th>
<th>DC Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1.65</td>
<td>Cauterious</td>
</tr>
<tr>
<td>1.65~1.86</td>
<td>Good</td>
</tr>
<tr>
<td>Over 1.87</td>
<td>Good</td>
</tr>
</tbody>
</table>
4. Improvement Strategy

Prevention of the Underground Cable Fault

- Non-Contact Infrared Thermometer
  - Deterioration Determination Criteria
    | Deteriorated | Cautionary | Good |
    |-------------|------------|------|
    | Over 15 °C  | ± 10 °C    | 0 ~ 5 °C |

- Prevent Damage to Cable by External Shock
  - Underground line mark & marking post
  - Cable protection plate & Protective cable alarm sheet
4. Improvement Strategy

Prevention of the Underground Cable Fault

- Strengthen the Patrol of Excavation Site
- Hold a periodic conference with other utilities

Use highly Reliable & Endurable Cable

|-------|------|--------|------------|-----------|

![Cable Images]
4. Improvement Strategy

Prevention of Tree Contact

- Tree Trimming
- Insulated Wire & Aerial Bundled Cable
- Curved pole
4. Improvement Strategy

Establishment of Quick Fault Recovery Process

Electrical facility monitoring system & DAS

Generation - Substation - Substation - Switch

EMS - SCADA - DAS - AMR
4. Improvement Strategy

KEPCO’s New Work Process

- Hot line work
- Maintenance techniques without power interruption

[Graph showing KEPCO's Work Process over years with labels for Scheduled, Direct hot line, Interruption, and Outsourced hot]
4. Improvement Strategy

Miscellaneous

- Introduce internal competition
- Permanent emergency mobilization process
- Secure major materials for emergency
- Prevent Faults Attributable to 3rd Party-owned Facilities
  - refer to fault propagated from electrical facilities owned by customers or other 3rd party
  - ask to improve their old facilities and take appropriate measures
4. Improvement Strategy

Reliability Improvement

- Power Companies: Provide high quality power by technology development and devices
- Better Service Satisfaction
- Customers: Eliminate elements causing reliability problem
- High Reliability
- Develop equipment with longer life and stronger against reliability problem
- Highly reliable Equipment
- Device Manufacturers

KOICA
Thank you for your attention!