Cost and performance implications of infrastructure investment options in the Eskom Distribution network

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Asset Management
Introduction

• **History (least initial cost):** Eskom Distribution planning and design criteria maximised the number of customers that could be connected with available funding. Resulted in long radial sub-transmission and distribution networks supplying large numbers of customers.

• **Planning and design criteria:** Focused on compliance with minimum requirements for Power Quality standards. Continuity of supply was not explicitly taken into consideration.

• **Reliability improvement drive:** Performance of the sub-transmission and distribution network accounts for the vast majority of the total outages experienced by customers (prior to Gx induced load shedding).

• **Revised planning criteria:** A balance is required between investment cost and network performance. Eskom Distribution network planning criteria were subsequently revised. Long term impact has not been comprehensively quantified.
Regulating Eskom Distribution Quality of Supply

- **Minimum standards**: Suitable for regulation of aspects such as waveform quality. No significant benefit in meeting stricter standards. Minimum standards not appropriate for regulating continuity of supply performance. There is no incentive to improve performance in networks where minimum standards are already met.

- **Incentive Based Regulation (IBR)**: Utility is rewarded or penalised based on a change in performance level. The present Eskom Distribution IBR scheme is focused on OPEX activities to improve SAIDI.

- **Potential performance**: Is determined by inherent design characteristics e.g. feeder lengths, customers per feeder, interconnectivity between feeders and equipment redundancy.

- **CAPEX versus OPEX**: A well maintained network can only perform as well as is dictated by its inherent design characteristics. There is a point beyond which it is more effective to spend CAPEX rather than OPEX. Future IBR schemes in South Africa may extend to include CAPEX considerations.

Note: Refer to paper by R Koch on IBR
Need statement

• Eskom Distribution need to understand the relationship between infrastructure investment and network performance:
  - **Cost** to improve performance (e.g. SAIDI) by say 10%, 20%, 60%?
  - **Options** that result in best improvement per Rand spent

• Need to consider a range of factors e.g.:
  - **Customer and load density:** Urban vs Rural
  - **Terrain and rainfall:** Impacts outage duration
  - **Vegetation and lightning:** Impacts outage frequency
  - **Environment:** Ability to construct inter-connections
Project overview

- **Team:** Multi-disciplinary team consisting of Eskom, EON Consulting and NetGroup Solutions, with international expertise from PA Consulting and NationalGrid (USA)

- **Assumptions:**
  - Focus is on infrastructure options, not OPEX
  - Confined to sub-transmission (HV) and distribution (MV) networks
  - Excludes LV

- **Major activities:**
  - Information collection and processing
  - Network operational environment classification
  - Selection of sample networks
  - Modelling sample networks
  - Extrapolation to National level analysis
  - Planning and design recommendations

Focus of this paper
Reliability modelling of a sample distribution network feeder

Methodology overview
Data and modelling process
Reliability modelling
  Approach and software
  Basic assumptions applied
  Example test system
  Results
Summary and conclusion
Spatial analysis of South Africa
• 500m * 500m blocks
• Classify all blocks (customers and environment)
Select Sample Networks
- Selected geo-areas
- Identify networks
- Sub Transmission / Distribution
- Demarcate network

Model Sample Networks
- Load flow Model
- Reliability Model
- Reliability Analysis
- Reliability Performance Reporting

Extrapolate Results
- Capital cost of Reliability Improvement
- Benchmark Network Performance
- Based on national network characteristics
- Scale to National Level

Planning & Design Recommendations
- Revise Planning Guideline documents
- Revise Reliability Guideline documents
- Revise Design Standards
Data and modelling process (1)

Network Feeders (> 6000)
Stratified based on the following aspects:
• Technology (e.g. overhead or underground)
• Voltage level (e.g. 6.6 kV, 11kV, 22kV)
• Length ranges (e.g. 11kV:0-40 km, 40-80 km, > 80 km, 22kV:0-135 km, 135-315 km, > 315km)

Network operational environment information
• Human population combined with installed capacity (4 zones):
  Zone A: no people + no Eskom network
  Zone B: people + no Eskom network
  Zone C: high density people + Eskom network
  Zone D: low density people + Eskom network
• Lightning [LI] (Low, High),
• Vegetation [VG] (Low, High),
• Pollution [PO] (Low, High).

Classification results
• 30 Categories represents 6194 Feeders
  52 % = C3 36 % = D3 5 % = C3D3
Data and modelling process (2)

**Network Feeder Schematics**
- Obtained from Eskom’s Smallworld geospatial system (GIS)
- Network Operating Diagrams (ENS / Reni) from Engineering

**Intervention cost (ZAR) estimates**
Includes aspects such as:
- Civil works
- Equipment (e.g. feeder bay, transformers, sectionalisers, reclosers etc.)
- Line conductor length
- Transport
- Labour
- Contingency
- External services
Reliability modelling

In general reliability modelling

- is based on failure and restoration models
- defines the way in which specific components and systems fail (failure rate) and
- what the average restoration / repair time is (repair time).

Three basic approaches to distribution system reliability modelling:

- Markov modelling,
- Monte Carlo simulation, and
- State enumeration.

Software – various providers e.g.

- DISREL©
- DlgsILENT© PowerFactory
- CYMDIST© (RAM)

Approach applied for this analysis

- Markov modelling combined with state (contingency) enumeration.
- DlgsILENT© PowerFactory
Reliability modelling – Basic assumptions applied

Network state

- Networks are reasonably maintained, and
- Networks are operated normally.

Component failure rates

- $\lambda_s$: Sustained failure rate
  - the average frequency of components faults or failures per annum
- MTTR: Mean time to repair
  - the expected time (hours) to repair a component outage and restore the system to a normal operating state.

Major network components identified

- Main lines
- Branch lines
- Switches
- Fuses
- Transformers

Network Performance Indices to measure

- SAIDI (Sum of Customer Interruption Durations / Nr Customers Served [hours per year])
- SAIFI (Nr of Customer Sustained Interruptions / Nr Customers Served [per year])

<table>
<thead>
<tr>
<th>Type of Network Equipment</th>
<th>$\lambda_s$</th>
<th>MTTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main lines</td>
<td>0.19</td>
<td>4.00</td>
</tr>
<tr>
<td>Branch lines</td>
<td>0.19</td>
<td>3.00</td>
</tr>
<tr>
<td>Switch</td>
<td>0.02</td>
<td>4.00</td>
</tr>
<tr>
<td>Fuse</td>
<td>0.03</td>
<td>4.00</td>
</tr>
<tr>
<td>Transformer</td>
<td>0.09</td>
<td>4.00</td>
</tr>
</tbody>
</table>
Reliability modelling – Example test system

Test system sample feeder

- Example feeder Western Cape region (Slagboom Farmers 2 11kV feeder)

- Exported from Smallworld

- Imported into DigSilent - prepared and linked with reliability libraries

- Applied network operating environment classification for specific feeder

- Assumptions of impact of the feeder classification (type D3 environment) on failure parameters

- Assumptions on possible infrastructure interventions

Typical infrastructure options that a predictive reliability model can simulate include

- Replacement of aging equipment
- Line reclosers
- Feeder automation
- Sectionalizing switches
- Undergrounding circuits
- New feeder tie points
- Load transfers between feeders
- New substation and substation expansions
- New feeders and feeder expansions

### Attributes

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Nr of Customers</td>
<td>68</td>
</tr>
<tr>
<td>Nr of Transformers</td>
<td>66</td>
</tr>
<tr>
<td>Nr of fuses</td>
<td>61</td>
</tr>
<tr>
<td>Nr of Switches</td>
<td>2</td>
</tr>
<tr>
<td>Nr of Breakers</td>
<td>1</td>
</tr>
<tr>
<td>11kV line length</td>
<td>34.9km</td>
</tr>
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</table>

### Network

<table>
<thead>
<tr>
<th>Network</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Technology</td>
<td>Overhead</td>
</tr>
<tr>
<td>Voltage level</td>
<td>11 kV</td>
</tr>
<tr>
<td>MV Length range</td>
<td>0 – 40 km</td>
</tr>
</tbody>
</table>

### Modifiers

<table>
<thead>
<tr>
<th>Modifiers</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Capacity</td>
<td>Eskom Low Density (D)</td>
</tr>
<tr>
<td>Modifier Category</td>
<td>3</td>
</tr>
<tr>
<td>Pollution</td>
<td>Low</td>
</tr>
<tr>
<td>Lightning</td>
<td>High</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Type of Network Equipment

<table>
<thead>
<tr>
<th>Type of Network Equipment</th>
<th>Category D3</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda_s$</td>
</tr>
<tr>
<td>Main lines</td>
<td>0.24</td>
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<tr>
<td>Branch lines</td>
<td>0.24</td>
</tr>
<tr>
<td>Switch</td>
<td>0.02</td>
</tr>
<tr>
<td>Fuse</td>
<td>0.03</td>
</tr>
<tr>
<td>Transformer</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Reliability modelling – Results for test system (1)

Results – impact of modifier assumptions

- Modelled basic network design without any changes or modifiers applied, called “Base Case”
- Modelled the environmental operational classification modifiers (category D3) for this feeder “Cat D3”

<table>
<thead>
<tr>
<th>Measure</th>
<th>SAIDI</th>
<th>SAIFI</th>
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</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>10.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Cat D3*</td>
<td>13.0</td>
<td>3.3</td>
</tr>
<tr>
<td>% Change</td>
<td>-25.0</td>
<td>-26.9</td>
</tr>
</tbody>
</table>

* Based on data from PA Consulting for Latin America

Observation

- Type of environment within which a feeder operates can significantly contribute to a change in “theoretically achievable” SAIDI and SAIFI (in this case a change of approximately 25%)
- Consideration of the operating environment is hence critical when analysing network performance
Reliability modelling – Results for test system (2)

Results – impact of infrastructure interventions

• Intervention (IV1) = adding a recloser

<table>
<thead>
<tr>
<th>Measure</th>
<th>SAIDI</th>
<th>SAIFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat D3</td>
<td>13.0</td>
<td>3.3</td>
</tr>
<tr>
<td>IV1 - recloser</td>
<td>12.5</td>
<td>3.14</td>
</tr>
<tr>
<td>% Change</td>
<td>-3.8</td>
<td>-4.8</td>
</tr>
</tbody>
</table>

• Intervention (IV2) = split the circuit by adding a new feeder bay and section of overhead line

<table>
<thead>
<tr>
<th>Measure</th>
<th>SAIDI</th>
<th>SAIFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat D3</td>
<td>13.00</td>
<td>3.30</td>
</tr>
<tr>
<td>IV2 - Line 1</td>
<td>11.80</td>
<td>2.96</td>
</tr>
<tr>
<td>% Change</td>
<td>-9.23</td>
<td>-10.30</td>
</tr>
<tr>
<td>IV2 - Line 2</td>
<td>7.34</td>
<td>1.84</td>
</tr>
<tr>
<td>% Change</td>
<td>-43.54</td>
<td>-44.24</td>
</tr>
<tr>
<td>IV2 – Overall</td>
<td>10.42</td>
<td>2.61</td>
</tr>
<tr>
<td>% Change</td>
<td>-19.83</td>
<td>-20.78</td>
</tr>
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Determining relationship between cost and reliability (SAIDI)

• Initial improvement approx. 3.8% in SAIDI performance achieved by spending approx. ZAR 115,000 (i.e. ZAR 230,000 per SAIDI hour reduction)

• Further improvement approx. 16% in SAIDI performance achieved by spending additional approx. ZAR 1,400,000 (i.e. ZAR 560,000 per SAIDI hour reduction)

• For specific network a significant SAIDI improvement will be obtained with significant investment (12 times investment value results in 5 times SAIDI improvement)
Summary and Conclusions

- Understanding the relationship between performance and cost is a critical part of any network performance improvement strategy.
- This paper illustrated a reliability modelling approach followed by Eskom Distribution in order to better understand this relationship.
- For the particular example network studied:
  a) The environment within which a network operates can impact significantly on the reliability of the network.
  b) Significant improvements in network performance may require topology changes.
  c) There is a diminishing return on investment in terms of additional improvement in reliability for more costly infrastructure investments.
- Fact based decision making must be applied such that the maximum level of performance improvement can be obtained with available funding.
- Results should be used to review planning and design practices.
- Findings are expected to be an important input to any possible future CAPEX linked incentive scheme.
- Further representative samples are being analysed to be able to derive potential implications for entire Eskom Distribution network.
Thank you

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