Applying simplified network feeder reliability modelling as basis for pragmatic strategic management decision making regarding capital and operational investments

– a large scale application case study for Eskom Distribution

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23rd AMEU TECHNICAL CONVENTION

26 - 28 September 2011

Cape Town
Examples of questions asked by utilities and regulators:

- What is the expected (designed) network performance and how does it vary from the actual performance?
- Which networks are performing worse than expected, and why?
- What options should be considered to improve performance, how much will they cost and what performance improvement can be expected?
- What portfolio of options will maximise benefit with limited resources?
Introduction: The challenge...

This presentation (and paper) focuses on illustrating the application of

- a simplified reliability centred approach
- to inform strategic and tactical engineering management decision making
- for a large scale electrical medium voltage network.
Eskom Distribution 11kV – 33 kV feeders

- A significant logistical challenge…
How to address this challenge?

Each feeder and the total integrated network needs to be modelled in sophisticated technical modelling software (e.g. Digsilent PowerFactory).

These sophisticated electrical models poses challenges e.g.:

- Eskom system contains > 6,800 MV (11kV – 33kV) feeders
- Data requirements for detailed electrical models is onerous
- Implications on resource (time and people) to model system of feeders is massive
How to address this challenge?

Hence the requirement for a simplified approach that considers the following three major aspects:

- (a) The engineering design and make-up of the feeder itself
- (b) The operational environment the feeder is exposed to
- (c) How changes to these areas (a + b) will impact performance

An 8 Step process was implemented to develop a simplified approach
Step 1: Classified Operating Environment

Create a composite operating environment classification

Step 1
Classify all blocks for country surface

Step 2
Combine Modifiers

Step 3
Combine Environment & Demand

Vegetation
Corrosive Pollution
Lightning
Population Density
MV Capacity
Combined Environment Modifier Types 1 - 8

Example Blocks (2-4) = Type 8
High Lightning (LI=H)
High Vegetation (VG=H)
High Corrosive Pollution (PO=H)

Combined Demand Zones = Population Capacity Density

Zone C Type 8 = C8
Zone D Type 3 = D3
Zone D Type 1 = D1
Zone D Type 4 = D4

Zone C = High density network + population
Zone D = Low density network + population

REFERENCE

Combined Environment Modifier Types

Type 1: LI= L, VG= L, PO= L
Type 2: LI= H, VG= L, PO= L
Type 3: LI= L, VG= H, PO= L
Type 4: LI= H, VG= H, PO= L
Type 5: LI= L, VG= L, PO= H
Type 6: LI= H, VG= L, PO= H
Type 7: LI= L, VG= H, PO= H
Type 8: LI= H, VG= H, PO= H

Create a composite operating environment classification
Step 2: Classify 11kV-33kV MV Feeders

Example feeder category classification

<table>
<thead>
<tr>
<th>Feeder traverses following area types</th>
<th>Total length = 37.9 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>C = 53.3% = 20.2km</td>
<td></td>
</tr>
<tr>
<td>D = 46.7% = 17.7km</td>
<td></td>
</tr>
<tr>
<td>D3 = 14.0% = 5.3km</td>
<td></td>
</tr>
<tr>
<td>D5 = 19.3% = 7.3km</td>
<td></td>
</tr>
<tr>
<td>D6 = 13.5% = 5.1km</td>
<td></td>
</tr>
<tr>
<td>C3 = 53.3% = 20.2km</td>
<td></td>
</tr>
</tbody>
</table>

Key:
- Zone: C = High Population Capacity
- D = Low Population Capacity
- Li = Lightning
- VG = Vegetation
- PO = Pollution

Types:
- Type 1: Li = L; VG = L; PO = L
- Type 2: Li = L; VG = L; PO = H
- Type 3: Li = H; VG = L; PO = L
- Type 4: Li = H; VG = L; PO = H
- Type 5: Li = L; VG = H; PO = L
- Type 6: Li = L; VG = H; PO = H
- Type 7: Li = H; VG = H; PO = L
- Type 8: Li = H; VG = H; PO = H

MV 11 kV Conductor Feeder (37.9 km)
Step 3: Sample-based approach

3 Select sample networks
- Statistical stratification of feeder types across country
- Selected 229 feeders = 3% sample
- Provides > 90% confidence sample is representative of population
- For each sample feeder compiled:
  - Engineering Single Line Diagrams
  - Geographic data
  - Performance data
Step 4: Construct Electrical models

4 Construct Digsilent PowerFactory models for 229 feeders

- Combined with equipment failure rates & response + repair times
- Calculate expected Network Performance Indices to report on e.g.
  - SAIDI (Sum of Customer Interruption Durations / Nr Customers Served [hours per year])
Step 5: Adjusted for operating environment factors

Allow for operational environment impacts

Lightning ground flash density

Vegetation

Corrosive pollution

Source: South African Weather Service – CSIR

Biome map based on CSIR vegetation type data

Source: Dr Wallace L Vosloo
Eskom Research and Innovation Department (ERID)
Step 6: Developed simplified reliability model

Develop Simplified Network Performance Model

**Network component** information applied in the algorithms:

\[
\begin{align*}
#LL_{FDR} & = \text{Total MV line length [km]} \\
#Trfrs_{FDR} & = \text{No. MV/LV transformers on feeder} \\
#Fuses_{FDR} & = \text{No. MV fuses on feeder} \\
#Discs_{FDR} & = \text{No. MV isolators on feeder} \\
#Brkrs_{FDR} & = \text{No. MV reclosers & sub breaker} \\
#Cust_{Total} & = \text{No. customers supplied on feeder} \\
Subst_{FDR} & = \text{Substation type impact on feeder}
\end{align*}
\]

**Failure rates** were applied for major classes of equipment

**Benchmarked against DigSilent results**

SAIDI error:

- 50% model feeders < 30% error
- 80% model feeders < 45% error
Step 7: Implemented model in Excel

7 Construct Excel Model for ±6800 MV (11-33kV) feeders
- Report on SAIDI, SAIFI, CAIDI, RSLI
- Various financial variables (Revenue, Cost of Un-served Energy, Capital requirements etc)
- Various reports and performance dashboards to assist analysis
- Added GIS visualisation ability (MapWindow) for spatial context
The solution supports the analysis of a range of options to improve network performance, including but not limited to:

**Network topology and equipment:**
- Feeder design improvements (e.g. shortening of MV feeder lengths, MV fusing philosophy, redundancy, customer density etc.)
- Addition of MV reclosers and other Distribution Automation equipment
- MV interconnections to facilitate back-feeding
- MV Feeder splitting
- Additional HV/MV substations
Step 7: Options for network performance improvement (2)

**Operations and maintenance practices / activities (impact through reduced failure rates and restoration times):**

- Preventative maintenance actions (e.g. line inspections, transformer load monitoring, ensuring proper insolation and earthing etc.)
- Vegetation management
- Optimised work order batching (can reduce travel time)
- Network operating for fault finding philosophy
- Technical support centre placement / locations (impact on response time)
Step 8: Apply model to strategic & tactical questions

Some examples of questions addressed:

- What is the expected system performance levels based on the modelled system?
- What are potential investment requirements towards achieving a system SAIDI of for example 1 hour or 15 hours?
- What are the possible implications to the system SAIDI performance levels due to the expansion of the network as a result of a planned additional 1.3 million electrification customers?
- What are the performance implications of reducing the length of typical major SAIDI contributing long MV feeders?
Outcomes need to be viewed in the context of the aim of this initiative, namely the Pareto principle:

- For less than 20% of the effort compared to constructing detailed models for the more than 6,800 individual MV feeders in the Eskom Distribution network, currently a more than 70% accurate answer can be obtained with the simplified approach.
Implementation examples

Two examples of application for strategic engineering management investment decision-making:

• Example 1: Reliability Centred approach for directing operational focus in support of a SAIDI Step Change Initiative

• Example 2: A small area illustrative example of the impact and cost of reducing MV feeder lengths
Example 1: Approach for directing operational focus.

Reliability Centred approach - basic underlying principle:
- Comparison of realistic “Design” expected performance (adjusted for operational environment) relative to actual operational “Performance”
Example 1: Performance and Design focus concept …

- Basic data concerns
- NOT major SAIDI contributor
- MAJOR SAIDI contributor
- MAJOR SAIDI contributor & outlier i.t.o. both expected SAIDI and SAIFI performance
- MAJOR SAIDI contributor & outlier i.t.o. both expected SAIDI and SAIFI performance & not supporting SAIDI regime from design point of view
- MAJOR SAIDI contributor & outlier i.t.o. both expected SAIDI and SAIFI performance & not supporting SAIDI regime from design point of view

Filter 0
Basic Data Validation Rules

Filter 1
Contribution to SAIDI hours

Filter 2a – Deviance from Est. expected Performance Norm (SAIDI & SAIFI)

Filter 2b – does not support SAIDI regime i.t.o. estimated expected Design Norm (although in line with Est. Expected Performance Norm)

Operational & Refurbishment focus

Combination required – but first address operational issues before implementing Capex Network Planning focus

Capex Network Planning focus

Data issues – fix and return to population
Filter outcomes adjust accordingly

Flag to Party Accountable for Data element
Example 2: Small area feeder length reduction example..

SAIDI and capital implications of halving MV feeders with length > 100 km

Small area example shows how the model was applied to select feeders based on the following criteria:

a) Feeders in area (black)

b) Where feeder length > 100 km (indicated in red)

c) Where feeder length > 100 km and feeder contributing > 16,500 customer interruption hours per annum (indicated in green)
Example 2: Illustrative SAIDI/CAPEX cost curve ....

SAIDI Reduction vs Capex
Substation (incl. line-split)

1. Total SAIDI Reduction
   Improvement: 28%
   Feeder Count: 14
   Capex: R 2.0 bn

2. Optimised SAIDI Reduction
   Improvement: 24% (81% of 28%)
   Feeder Count: 8 (57% of 14)
   Capex: R 1.2 bn (58.9% of R2.0 bn)
Overall business benefits & value obtained

Key outcome for Eskom Distribution business:

- A **pragmatic methodology** to generate a “norm” for expected performance for different **types of MV feeders**
- as well as **individual MV feeders**
- against which reported feeder performance can be compared or “benchmarked” with **relatively modest effort**
- to **inform strategic management decision making**
- regarding both **operational** (Opex) and **infrastructure** (Capex) decisions.

The approach developed:

- is **generic in nature**
- can be applied in other electrical distribution utilities
- with only a modest investment in terms of resources and
- with limited technical information.
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Thank you