Electrical utility distribution network capital planning

A network reliability informed approach to prioritising investment for economic sustainability

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63rd AMEU CONVENTION

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The Context
Service level and Reliability of supply to end customers is dependent on the performance of the overall system:

- Generation
- Transmission
- Distribution

South Africa has a drive for Universal Access (to Electrical and other services)

- Provide as many connections as possible with available capital
- Consequently, electrical network infrastructure provision in South Africa has traditionally been based on a least-initial-cost approach for the last 15-plus years

- Conflict between improving supply performance to those that have versus providing access to electricity by those that don’t
- Keep electricity affordable
- Support economic growth and development
Publically owned utilities typically attempt to design and operate electrical (generation, transmission and distribution) infrastructure in such a way so as to minimize the total cost to the society. 

This approach generally is referred to as **value based planning**.

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**SAIDI**

Avg. Customer Interruption Duration (Hrs)

**Network Performance**

**Better Reliability Performance**

**Worse Reliability Performance**

**Customer costs (e.g. COUE)**

**Total Cost Curve**

**Utility Cost (e.g. Capex & Opex)**

**Area of Optimum Social Welfare**

benefits (maximizing) / costs (minimising)

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*Performance measured e.g. in terms of the duration and number of customers interrupted as measured by System Average Interruption Duration Index (SAIDI)*
Our approach
Combining technical performance models & economics

- Inform decision making based on expected (designed) performance levels (as opposed to e.g. historical or comparative international benchmarks)

- Calculate the expected improvement in network performance for different options

- Combine financial costs and expected economic costs via Cost of Unserved Energy (CoUE)

- Contrasting these costs, changes in performance and economic implications serves to better inform policy and investment decision in a more holistic way
Context:
Key network elements

Key network elements

Power Stations
Transmission Lines
Transmission substations
Customers

Customers

Customers
Context: Key network elements
Sub-transmission lines

Key network elements

Power Stations
Transmission Lines
Transmission substations

Customers

- Sub-transmission lines
Context: Key network elements
Distribution substations

Key network elements

- Sub-transmission lines
- Distribution substations
Key network elements

- Sub-transmission lines
- Distribution substations
- Main MV lines
Key network elements

- Sub-transmission lines
- Distribution substations
- Main MV lines
- Branch MV lines
Context: Key network elements

MV/LV transformers

Key network elements

- Sub-transmission lines
- Distribution substations
- Main MV lines
- Branch MV lines
- MV Transformers

Power Stations

Transmission Lines

Transmission substations

Distribution substations

Customers
Context: Key network elements

Key network elements

- Sub-transmission lines
- Distribution substations
- Main MV lines
- Branch MV lines
- MV Transformers
- Fuses
Key network elements

- Sub-transmission lines
- Distribution substations
- Main MV lines
- Branch MV lines
- MV Transformers
- Fuses
- Switches / Reclosers
Context: Key network elements
LV network

Key network elements

- Sub-transmission lines
- Distribution substations
- Main MV lines
- Branch MV lines
- MV Transformers
- Fuses
- Switches / Reclosers
- LV network
Focus of Reliability Analysis

- Sub-transmission lines
- Distribution substations
- Main MV lines
- Branch MV lines
- MV Transformers
- Fuses
- Switches / Reclosers
- LV network
Network Performance is influenced by:

- **Design / topology**
  - Length, configuration etc.
- **Operations & Maintenance**
  - Planned outages
  - Unplanned outages

Focus on Unplanned supply interruptions

Physical Infrastructure Failures – typical causes

- Incorrect design application
- Poor construction
- Equipment overloading
- Poor condition due to inadequate maintenance / refurbishment
- Environmental factors (lightning, vegetation, pollution)

This results in each component having an “expected” failure rate
Design topology: Urban network

Typical Characteristics
• Short overhead line / underground cable
• Small geographical area
• Small component count e.g. transformers
• Short travel and fault finding times
• High customer density
Design topology: Rural network

Typical Characteristics

- Long overhead line
- Covers large geographical area
- Large no. of components e.g. transformers
- Long travel and fault finding times
- Low customer density
Design topology:
Urban network - Expected SAIDI

<table>
<thead>
<tr>
<th>Typical Urban MV feeder</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Line length (km)</td>
<td>3</td>
</tr>
<tr>
<td>No. of transformers</td>
<td>12</td>
</tr>
<tr>
<td>No. of fuses</td>
<td>12</td>
</tr>
<tr>
<td>No. of customers</td>
<td>600</td>
</tr>
<tr>
<td>No. of reclosers / switches</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical expected performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave no. of faults / yr</td>
<td>2.3</td>
</tr>
<tr>
<td>SAIDI (hours per year)</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Design topology: Rural network Expected SAIDI

Typical: Rural MV feeder

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line length (km)</td>
<td>300</td>
</tr>
<tr>
<td>No. of transformers</td>
<td>240</td>
</tr>
<tr>
<td>No. of fuses</td>
<td>240</td>
</tr>
<tr>
<td>No. of customers</td>
<td>600</td>
</tr>
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Typical expected performance

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<th>Feature</th>
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</tr>
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<tbody>
<tr>
<td>Ave no. of faults / yr</td>
<td>103</td>
</tr>
<tr>
<td>SAIDI (hours per year)</td>
<td>372</td>
</tr>
</tbody>
</table>

Comment:

- All assumptions kept constant
- Customer numbers are the same as for Urban network
- Difference in performance is due to:
  - increased equipment failures (due to there being more equipment)
  - Increased travel time
### Typical: Rural MV feeder

<table>
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<th>Description</th>
<th>Value</th>
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<td>No. of customers</td>
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<td>No. of reclosers / switches</td>
<td>2</td>
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</tbody>
</table>

### Typical expected performance

<table>
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<td>Ave no. of faults / yr</td>
<td>103</td>
</tr>
<tr>
<td>SAIDI</td>
<td>207</td>
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</tbody>
</table>

**Comment:**

- All assumptions kept constant
- Adding reclosers (e.g. 2) can significantly improve performance
Network performance: How can we compare the performance of utilities?

• How should the target performance level of a utility be set?

• If the expected level of performance (SAIDI) is sensitive to network topology, customer numbers, operating environment etc., how can we compare the performance of different utilities?

• Benchmarking is fundamentally flawed if focused on output measures like SAIDI

• Hence our approach…..

To model the expected level of performance given the network topology, customer numbers, operating environment etc., for reasonable assumption for equipment failure rates and repair times
Network performance: How to reduce SAIDI – 3 focus areas

- Reduce the number of faults
- When a fault occurs reduce the number of customers impacted
- When a fault occurs reduce the duration of the outage

Our approach models these three focus areas as will be shown in more detail
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs
Fault is Captured

Customer phones Call Centre
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs
→ Fault is Captured
→

\[ T_{Dispatch} \]

Time duration for the Call Centre to dispatch Field Staff

Call centre contacts Field Staff
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs

Fault is Captured

Field staff travel to substation

T\text{\_Dispatch} \quad T\text{\_Travel}

Time duration for the WMC to dispatch Field Staff

Time for Field Staff to travel to substation
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs → Fault is Captured →

Switching + restoration of some load

\[ T_{\text{Dispatch}} \]
Time duration for the WMC to dispatch Field Staff

\[ T_{\text{Travel}} \]
Time for Field Staff to travel to substation

\[ T_{\text{sectionalising}} \]
Switch Sub Bkrs / Recloser to reconfigure network to restore some load
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs → Fault is Captured → Field team searches for fault

- **T** Dispatch
- **T** Travel
- **T** sectionalising
- **T** Fault find

WMC duration

Travel to Sub / 1st recloser

Switch Sub Bkrs / Recloser to reconfigure network to restore some load

Search for Fault Location / Sectionalising
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs

Fault is Captured

Fault is repaired

WMC duration

Travel to Sub / 1st recloser

Switch Sub Bkrs / Recloser to reconfigure network to restore some load

Search for Fault Location / Sectionalising

Isolate, earth and repair fault

T_{Dispatch}  T_{Travel}  T_{sectionalising}  T_{Fault find}  T_{Repair}
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs → Fault is Captured → All load restored

- $T_{\text{Dispatch}}$
- $T_{\text{Travel}}$
- $T_{\text{sectionalising}}$
- $T_{\text{Fault find}}$
- $T_{\text{Repair}}$
- $T_{\text{restore}}$

WMC duration

- Travel to Sub / 1st recloser
- Switch Sub Bkrs / Recloser to reconfigure network to restore some load
- Search for Fault Location / Sectionalising
- Isolate, earth and repair fault
- Switching to restore network to original state

2012/10/23
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs
Fault is Captured
Switching + restoration of some load
All load restored

Overall Outage Duration

T_{Dispatch}  T_{Travel}  T_{sectionalising}  T_{Fault find}  T_{Repair}  T_{restore}

WMC duration
Travel to Sub / 1st recloser
Switch Sub Bkrs / Recloser to reconfigure network to restore some load
Search for Fault Location / Sectionalising
Isolate, earth and repair fault
Switching to restore network to original state

2012/10/23
Interventions Modelled
Reduce outage duration

Outage Duration:

Fault Occurs
- Fault is Captured
- Switching + restoration of some load
- All load restored

Overall Outage Duration

We can model changes in all of these outage duration components on network performance as may be achieved via people, systems, processes, smart grid etc.
Interventions Modelled
Optimise MV network – fuses and reclosers

Existing network
Interventions Modelled
Optimise MV network – fuses and reclosers

Adding Transformer Fuses

- Install fuses at all MV/LV transformers
Interventions Modelled
Optimise MV network – fuses and reclosers

Installing additional Reclosers

- **Install MV Reclosers**
Interventions Modelled
Optimise MV network – fuses and reclosers

End State: Fuses and Reclosers added
Interventions Modelled
Change structure of MV network - Split Feeder

Existing Distribution Feeder

Transmission substation
Sub-transmission Line
Distribution substation
MV line
Customers
Interventions Modelled
Change structure of MV network - Split Feeder

Splitting the Distribution Feeder

- Build new sub-transmission line
- Build new Distribution Substation
- MV connection to new substation
Interventions Modelled
Change structure of MV network - Split Feeder

End State: Two “new” Distribution feeders

- New Transmission Line
- New Distribution substation
- Transmission substation
- Sub-transmission Line
- New Normally Open Point
- “New” MV line
- New MV Line
- Customers
- Distribution substation
Interventions Modelled
Substation configurations

Additional HV/MV transformer

Transmission substation
Sub-transmission Line
Distribution substation
Install additional Transformer
MV line
Customers
Interventions Modelled
Redundant Sub-transmission lines

Additional sub-transmission line

Construct additional sub-transmission line

Distribution substation

Transmit substation

MV line

Customers
Interventions Modelled
Sub-transmission redundancy

End State: Additional Sub-transmission redundancy

Transmission substation
Sub-transmission Lines
Distribution substation
MV line
Customers
Calculating expected performance: A pragmatic approach

- Calculate the expected level of performance given the existing asset base
- Uses basic data
- Sub-transmission and Distribution networks
- For the entire network

- Can model the impact of various Capex and Opex interventions
- Calculate the expected changes in network performance (SAIDI)
- Calculate the economic savings due to reduced outage frequency and duration
Application example
Applied example: Summary of sample network

- Supplies 841,446 customers (19% of Eskom)
- 46,209 MV/LV transformers
- 377 MV feeders
- 36,120 km MV line
- 623 substations
- 2,391 km HV line

Reference SAIDI: 62.1 hours

Historical SAIDI versus Modelled Expected SAIDI
Applied example:
4 illustrative strategies assessed

- **Scenario A**: SAIDI reduction via operational (Opex) improvements

- **Scenario B1**: A + Infrastructure (Capex) interventions with the sole objective of reducing SAIDI

- **Scenario B2**: A + Infrastructure (Capex) interventions conforming to RSA Network Grid Code requirements

- **Scenario B3**: A + Infrastructure (Capex) interventions conforming to RSA Network Grid Code requirements + sole objective of reducing SAIDI AFTER Grid Compliance achieved
Scenario A: Opex interventions

- Component failure rates reduced by 10%
- Despatch and repair times reduced by 10%

Reference SAIDI reduces from 62.1 hours to 57.3 hours (7.8% reduction)
Scenario B1: Capex - SAIDI reduction (SAIDI)

B-1: SAIDI @ 23.5 hrs p.a. (59% improvement)  
Cost @ +R 49.0 bn
Scenario B1: Capex - SAIDI reduction (CoUE)

Cost of Unserved Energy - impact of strategies

- Spending R49bn to save R11bn
  - Does not make economic sense

- B-1: COUE @ R 4.7 bn (70% improvement)
  - Cost @ +R 49.0 bn

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Scenario B2: Capex – Grid Code Compliance (SAIDI)

B-2: SAIDI @ 45.3 hrs p.a. (20.9% improvement)
Cost @ +R 2.1 bn
Scenario B2: Capex – Grid Code Compliance (CoUE)

Spending R2.1bn to save R4.5bn Does make economic sense

B-2: COUE @ R 11.3 bn (28.4%) improvement
Cost @ +R 2.1 bn
Scenario B2: 
Capex – Grid Code Compliance (CoUE) 

Economic business case (Code Compliant) 

No economic business case: 
Justification???? Affordability????
Conclusions
Conclusions from sample study

Summary of illustrative scenario outcomes

• Scenario A [10% operational improvement]:
  - Reduces SAIDI by 7.8%, CoUE by 6% (R 46 million) – cost unknown (may be zero)

• Scenario B2 [Grid Code Compliance] (Optimise cost to utility and economy via CoUE)
  - Reduces SAIDI by 20.9%
  - Capital cost is R2.1bn (R0.17bn per SAIDI hour reduction)
  - Cost to the South African economy (CoUE) reduces by 28.4% (R 4.5bn over 25 years)
  - Further reductions in SAIDI via Capex can not be justified on an economic basis (per intervention)

• Scenario B1 [Pure SAIDI reduction focus] implications are massive:
  - Capital cost of R49bn (keep in mind = network area – not whole of Eskom) for 62% reduction in SAIDI (R1.45bn per SAIDI hour reduction)
  - More than doubling of the asset base
Overall business benefits & value obtained

Key outcomes obtained and demonstrated:

• Pragmatic approach using readily available network information, and a range of inputs relating to equipment failure rates, operational response and repair time

• Demonstrated the practical application of our proposed approach to a real-world section of the Eskom network

• Demonstrated assessment of different reliability centred investment strategies as applied to sub-transmission and distribution networks

• Demonstrated that alternative scenarios and strategies can have very different outcomes and implications (costs and benefits as well as equipment / logistics requirements)

Evident that a coordinated and integrated approach is required to balance operational improvements, capital expenditure, optimise CoUE and consider the political and social implications of SAIDI
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Thank you