

## **Determining a relationship between Eskom Distribution network performance and capital investment**

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**A project is presently underway within Eskom Distribution to develop a relationship between network performance and investment expenditure. The results are expected to be used to revise Eskom Distribution network planning and design criteria, and inform future Incentive Based Regulation mechanisms linked to capital expenditure.**

### **Introduction**

#### *History*

Since the early 1990's Eskom Distribution connected over 3 million homes to the South African electricity distribution network. The network planning and design criteria adopted by Eskom Distribution maximised the number of customers that could be connected with the available funding. This resulted in lengthy radial distribution and sub-transmission networks supplying numerous customers (in cases more than 10 000 customers on a single MV feeder) with little or no alternative supply options in the event of network faults.

#### *Drive to improve distribution network performance*

The reliability of supply to end customers is dependent on the performance of the generation, transmission and distribution systems. Prior to the generation shortage induced load shedding that started in December 2007, outages in the Eskom Distribution network accounted for the significant majority of the total outage duration experienced by Eskom Distribution customers. Efforts to improve the performance of the distribution network are critical in ensuring reliable electricity supply to end users.

#### *Distribution network planning reliability criteria*

In order to maximize connections with available funding, the historical Eskom Distribution planning and design criteria were focused on compliance with minimum power quality standards (specifically voltage regulation limits and ensuring that equipment thermal and fault level limits were not exceeded). Continuity of supply was not explicitly taken into consideration.

A balance needs to be met between investment cost and network performance. The Eskom Distribution network planning criteria were subsequently revised to include specific reliability criteria for equipment redundancy, loading levels and customers per network [1]. The revised planning criteria are based on experienced based rules and the analysis of the characteristics and performance of existing networks. The exact impact of these revised planning criteria on the long term performance of the Eskom Distribution networks has not been comprehensively quantified.

### **Regulating Eskom Distribution Quality of Supply**

#### *Minimum standards*

Certain aspects of Power Quality, such as voltage waveform quality, are managed from a regulatory point of view by minimum standards [2] e.g. Low Voltage (LV) magnitude must be between 90% and 110% of nominal voltage. Minimum standards are appropriate in regulating these aspects as customer appliances are designed to work within these limits, and there is little or no benefit in meeting stricter standards.

Minimum standards are not appropriate in regulating continuity of supply performance as there is no incentive for a utility to improve performance in networks where minimum standards are already being met [2]. As such there has been an international move towards Incentive Based Regulation (IBR) for the regulation of continuity of supply [2].

#### *Incentive Based Regulation*

Under IBR schemes utilities are financially rewarded or penalised based on a change in performance level [2]. Improved performance (typically based on the average total outage time experienced by customers) can, for example, be rewarded by an allowed increase in tariff. Reduced performance would result in an associated reduction in tariff *i.e.* less revenue.

The first IBR scheme in South Africa was initiated by the National Energy Regulator of South Africa (NERSA) for a 3 year (2006 -2009) multi year price determination for Eskom Distribution. This incentive scheme (as is described in [2]) is focused on short term improvements in reliability via OPEX activities such as live line, maintenance and vegetation management.

The potential performance of a network, while influenced by OPEX, is mainly determined via the inherent design characteristics of the network e.g. lengths of feeders, number of customers supplied per feeder, inter-connectivity between feeders and redundancy of equipment. These structural issues are influenced by CAPEX investment decisions, as are made via network planning and design. A well maintained and operated network can only perform as well as is dictated by its inherent design characteristics. For any given network with a set of possible maintenance interventions, there is a point beyond which additional expenditure via CAPEX solutions will result in improved performance as compared to OPEX expenditure [3].

It is possible that future South African incentive schemes could extend to also include CAPEX considerations.

### **Need Statement**

In light of possible future CAPEX linked incentive schemes and the Eskom Distribution drive to improve network performance, it is important that the relationship between Eskom Distribution capital investment and network performance be quantified. Eskom Distribution need to understand how much it will cost to achieve a range of improvements in network performance e.g. how much will it cost to achieve a 20%, 40% or 60% improvement in network performance and what are the most cost effective options to achieve these improvements?

Eskom Distribution has a diverse mixture of networks, the characteristics and performance of which are influenced by a range of factors including:

- Customer and load density: High load densities will tend to result in short MV feeders as is the case in urban networks. Low load density rural areas tend to have comparatively long MV feeders. The number of faults increases with increased feeder length resulting in reduced performance of rural networks as compared to urban networks.
- Terrain and rainfall: Very hilly terrain and poor access increase outage duration times.
- Vegetation and lightning: Networks in high vegetation/lightning areas will experience more faults as compared to low vegetation/lightning areas.
- Environment: The presence of forestry, rivers, dams, environmentally sensitive areas etc influence the layout of the network which in turn affects network performance e.g. the ability to build inter-connectors between feeders will influence outage restoration times.

For different types of networks (ranging from short urban cable networks to long rural overhead networks) in different operating conditions, Eskom Distribution need to understand which investment options may result in the best level of improvement per Rand spent, and what optimal combinations of investment options will result in a specified targeted improvement in performance for minimum cost.

### **Project overview**

#### *Team/Expertise*

In order to gain an understanding of the relationship between investments and potential performance improvements Eskom engaged a combined team consisting of resources from EON Consulting and NetGroup Solutions in order to constitute a multi-disciplinary team to research the topic. The team provides relevant local expertise combined with that of international experts to assist in a strategic and advisory role. The international<sup>1</sup> team members have experience in market regulation, rate cases, quality of service and performance improvement as well as asset strategy, investment planning and electric reliability assessment with a focus on fact-based decision making.

The duration of the project is from October 2007 to August 2008.

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<sup>1</sup> The international experts include Claudio Guidi (PA Consulting) and other authors of [3] and Cheryl Warren, VP Asset Strategy & Investment Planning, NationalGrid (USA).

### *Primary study objective*

The overall aim of the project is to aid in the move from a historical least initial capital cost planning philosophy towards optimal lifecycle cost planning philosophy. The overall objective is further qualified as follows:

- For each relevant infrastructure<sup>2</sup> option to understand the contribution to specific calculated Network Interruption Performance (NIP)<sup>3</sup> taking into consideration operating environments.
- Determine (based on expected NIP performance ranges) which infrastructure option(s) are most optimal (achieving a particular performance range with the least cost solution subject to the relevant NIP range).

### *Initial assumptions*

Two basic assumptions underpin the study namely:

1. The study does not address OPEX options in detail.
2. The study assumes that networks are reasonably maintained and operated normally.

In addition to the above basic assumptions the following additional assumptions were defined as part of the mobilisation and fact finding phase of the project:

1. The project assesses the link between performance and infrastructure for relevant sub-transmission high voltage (HV) and reticulation medium voltage (MV) networks.
2. The project excludes low voltage (LV) networks although the impact of MV/LV transformation will be taken into consideration.
3. The cost of un-served energy (CUE) to customers is excluded from the analysis.

The major activities identified are:

- Information collection and processing.
- Network operational environment classification.
- Specific network sample selection.
- Modeling of the selected networks.
- Updating of reliability guidelines.

### *Final deliverables from the project*

The final deliverables are summarized as follows:

- A set of documented criteria to be used to select adequate samples of representative HV and MV networks with substations.
- A set of sample networks to be used for the study.
- Specific metrics and dependencies forming part of the framework for the evaluation of various network options to improve the performance of the network.
- Estimated national Eskom network reliability performance improvement and associated cost implications.
- Updated Eskom reliability guideline.
- Project study report and all relevant data and models in electronic format.
- Report on gaps identified and recommendations to address these gaps.

## **Project methodology**

### *Overview of project methodology*

Fig. 1 summarises the project methodology as is described in more detail in subsequent sections.

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<sup>2</sup> Infrastructure in the context of this study refers to a combination of specific network components, irrespective of whether these are classified in accounting terms as CAPEX or OPEX.

<sup>3</sup> Network Interruption Performance measures applied include SAIDI, SAIFI, D-SLI (currently <33kV) , R-SLI, and Energy Not Supplied (kWh) (ENS).

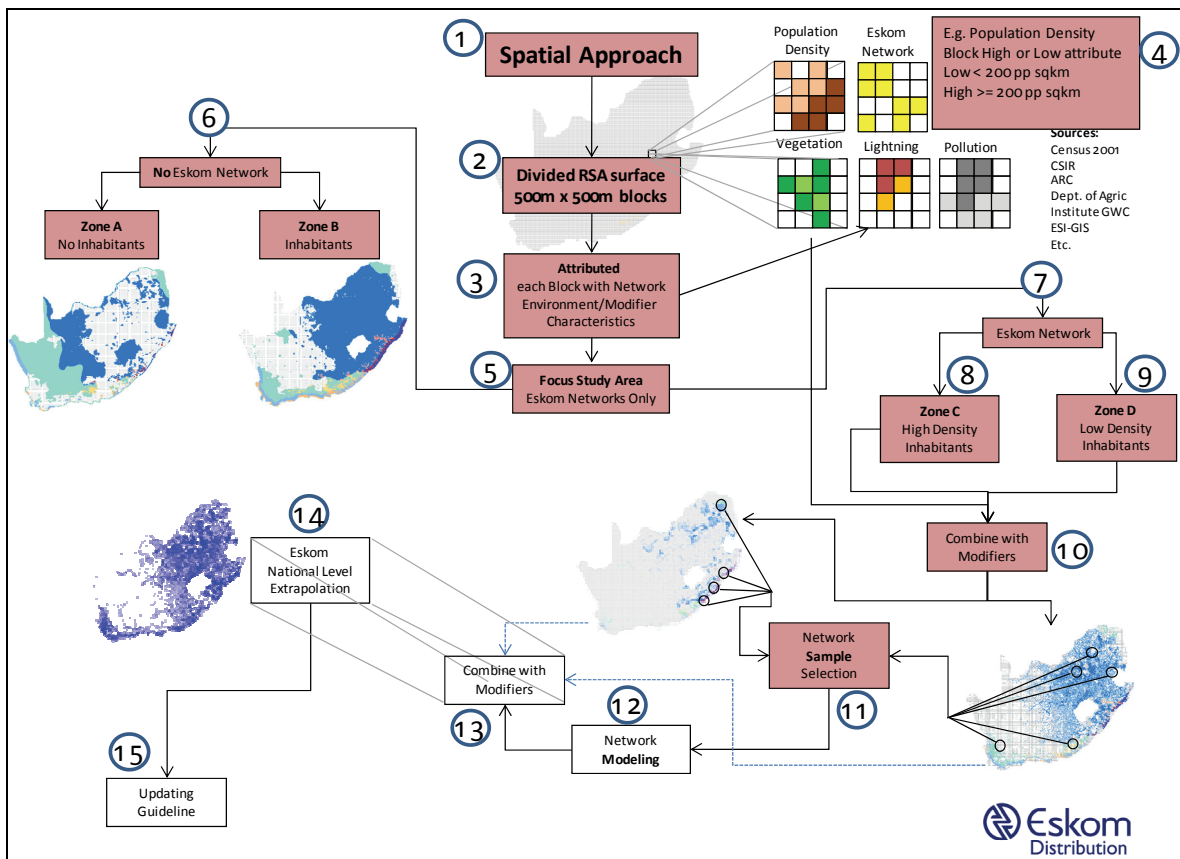


Fig. 1: Project methodology.

*Operational environment classification*

- (1) Network performance has a significant spatial element as environmental and geographic characteristics influence reliability performance and differ from location to location. A spatially focused approach is therefore required.
- (2) The approach followed is first to subdivide the surface of South Africa into 500 meter x 500 meter blocks in GIS terms.
- (3) Modifiers, characteristics and Eskom networks are identified and processed in GIS format to the extent that each block on the “grid” making up the surface of South Africa could be allocated a “High” or “Low” (contains or does not contain network) quantification for each particular modifier, creating “layers” for each modifier.
- (4) E.g. if a block had an attribute Population Density it would have an associated quantification as “Low” for an area with a population density of lower than 200 persons per square kilometer, while it would have a “High” value for Population Density of more than 200 persons per square kilometer. In this way Vegetation, Lightning Density etc. were classified. Each block on the grid of South Africa’s surface has a “High” or “Low” value allocated for each modifier.
- (5) The study area is confined to only focus on areas containing Eskom network.
- (6) Areas containing NO Eskom network are further divided into 2 zones. Zone A contained no Eskom network and no population, while zone B contained no Eskom network but do have people living there. No further actions are applied to this set of information, as the focus is on the areas containing Eskom network.
- (7) The areas (500m x 500m blocks) containing Eskom network are further split into 2 zones, namely
- (8) Zone C: Areas containing Eskom network with relatively high density population ( $\geq 200$  persons per square kilometer).
- (9) Zone D: Areas containing Eskom network with relatively low density population ( $< 200$  persons per square kilometer).
- (10) These two zones are combined with information from the modifiers such as vegetation, lighting etc. to produce a combination of factors which allow
- (11) Sample network selections based on environmental combinations such as e.g. an area with high population density, with high vegetation density, high lightning density and high pollution levels.

The rest of the method (steps 11 to 14) is explained in more detail in Fig. 2.

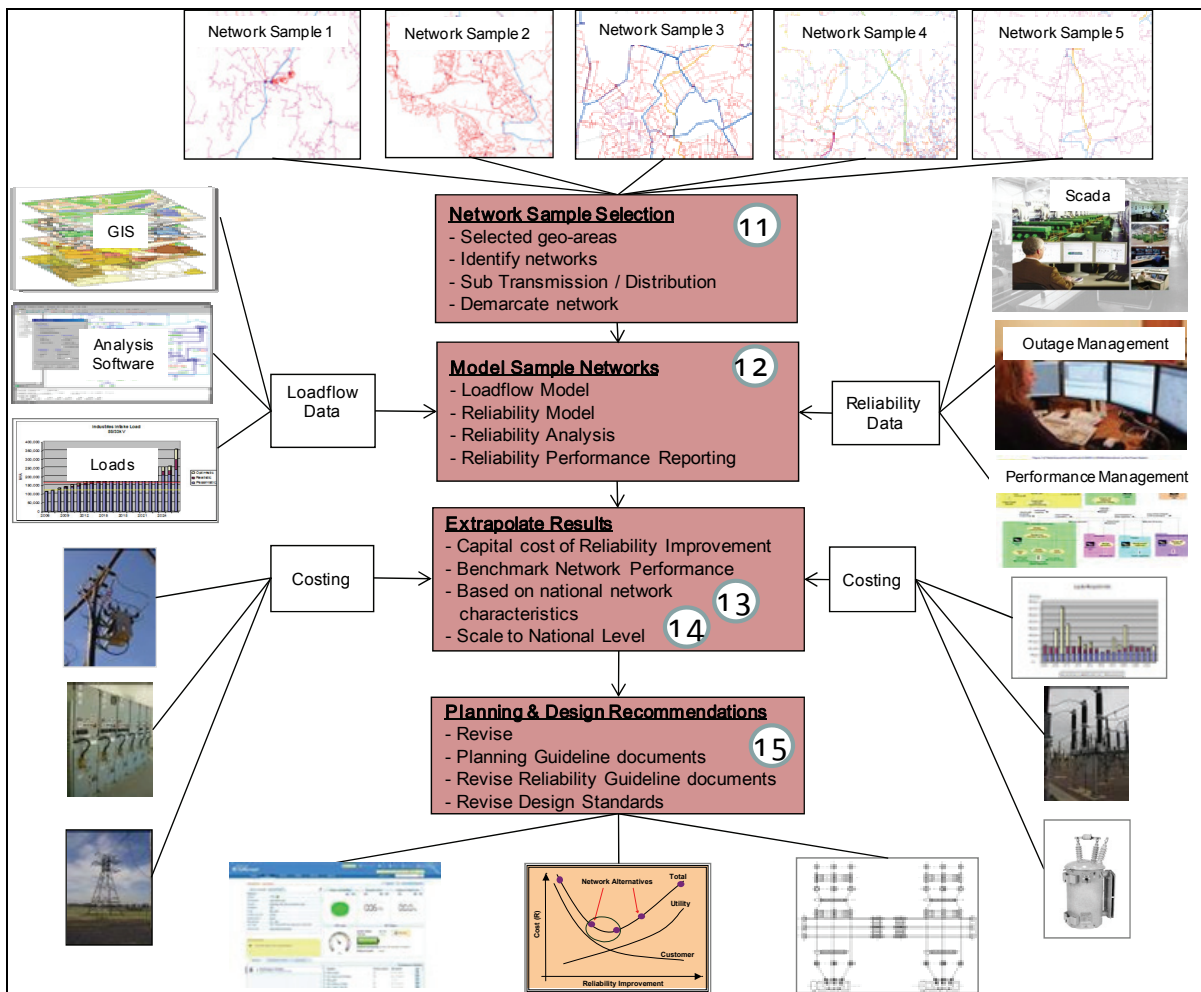


Fig. 2: Project methodology- sample network selection, network modeling, result extrapolation and recommendations.

Sample network selection (11)

Representative samples of the networks are used for the study. The selection process is based on the criteria as described in the previous sections. The following activities comprise the selection process:

- Apply the selection criteria to representative sample networks for evaluation and interpretation.
- Involve network planners, project engineering, plant and maintenance personnel on a regional basis to participate in the selection process.
- Present network samples geographically.

Sample network modelling (12)

The technical and operational characteristics of the sample networks are modelled, analysed and interpreted from a reliability point of view in order to develop relationships between performance and infrastructure investment (see Fig. 3). The following steps are part of this exercise:

- Source and interpret performance statistics for the sample networks.
- Decide on failure statistics to be used for the assessment.
- Decide on the range of performance level improvements required per study area.
- Develop reliability models for the representative sample networks (including networks and substations).
- Model, evaluate and interpret generic performance improvement strategies with regards to the impact of these strategies on performance and infrastructure.
- Conduct preliminary reliability assessments on selected samples to correlate theoretical and actual outcomes.
- Benchmark findings and interpretations with international experience.

- Discuss and interpret assessment findings with regional personnel to ensure an understanding of maintenance and operational influences and difficulties.
- Develop a qualified relationship between network performance improvement (e.g. SAIDI) and infrastructure investment options. These metrics are used in the extrapolation to other Distribution networks.

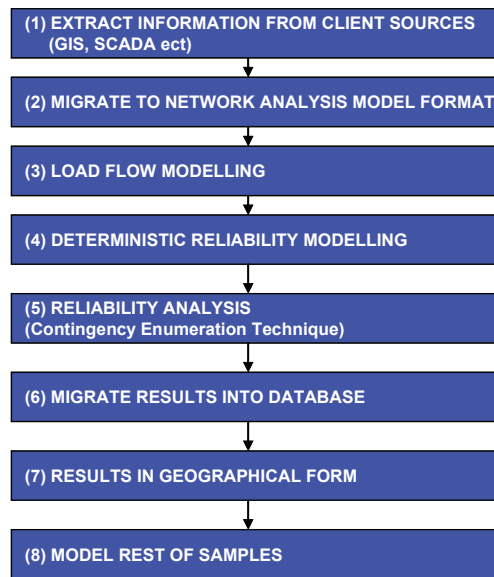


Fig. 3: Network modeling.

The outcome of this exercise is a better understanding of the reliability characteristics of the sample networks in terms of actual vs. modelled performance, and the performance improvement of different investment options.

*Extrapolate results on a national level for Eskom Distribution (13 & 14)*

In order to establish implications for Eskom Distribution networks on a national level, the findings from the sample networks need to be extrapolated to a national level. The network area classification and network class information are used to scale the results up to a national level. This part of the project comprise of the following steps:

- At an aggregate level produce a “theoretical” national Eskom Distribution network based on the network classes identified for modelling purposes.
- Scale the results from the network selection and reliability analysis to the national level by applying network class results to the “theoretical” national Eskom Distribution network.
- Report on the network performance and infrastructure investment implications on a national and regional level.

This part of the project provides an understanding of the various network options and related cost implications to improve the performance of the Eskom Distribution network on a national and regional level.

*Planning & Design recommendations (15)*

Once a quantified relationship between network performance and infrastructure cost for existing and future networks has been established, the Eskom Distribution Reliability Planning Guideline can be updated and discussed with key role-players.

**Results**

As this project is work in progress, example results are provided for illustrate purposes only. Interesting statistics from the operational environment classification process are listed in table 1, followed by a visual example of a sub-transmission network in Fig. 4.

Zone	Description	Percentage
Zone A	Without Eskom Network / Without Population	42.7%
Zone B	Without Eskom Network / With Population	53.3%

Zone C	With Eskom Network / High Density Population	0.8%
Zone D	With Eskom Network / Low Density Population	3.1%

Table 1: Percentage of 500m x 500m blocks in the four zones.

It is interesting to note that in geographic terms Eskom’s customer supplies only cover approximately 4% of the total surface blocks of South Africa (5,073,483). This was calculated based on a 450 meter radius around MV/LV transformers and does not include the geographic coverage of network lines.

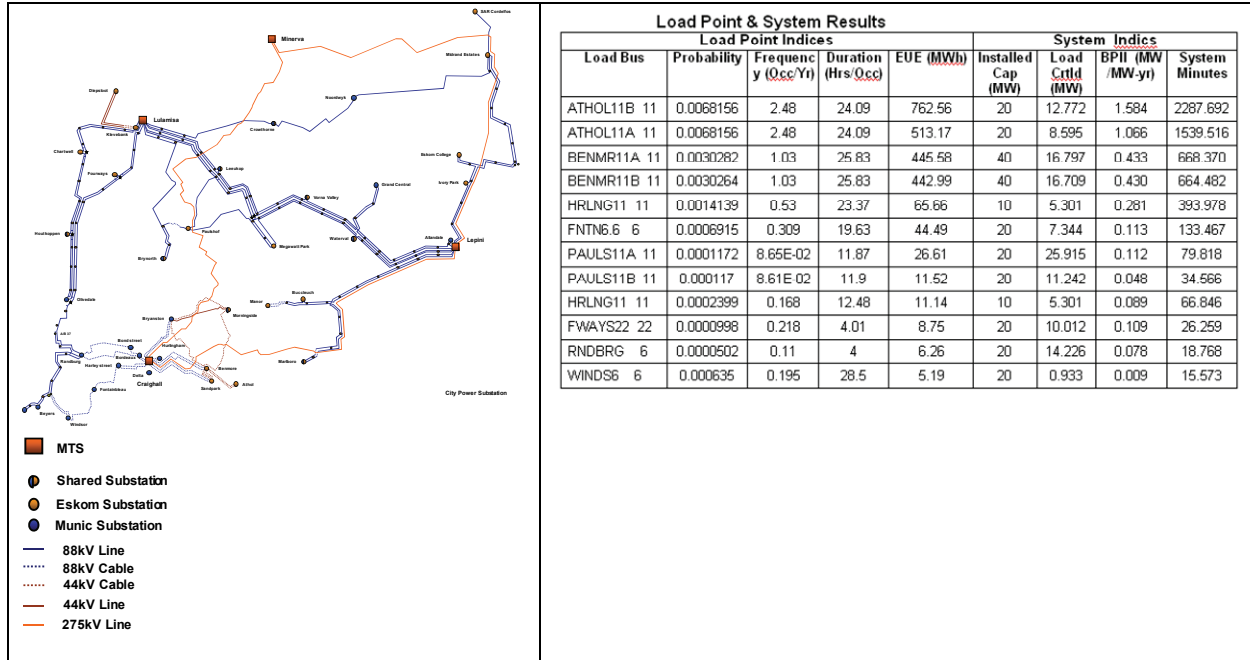


Fig. 4: Example of a sub-transmission network and reliability analysis results.

Steps 11 – 15 of the project are currently in progress.

**Conclusion**

Understanding the relationship between performance and cost is a critical part of any network performance improvement strategy. Fact based decision making must be applied such that the maximum level of performance improvement can be obtained with available funding. This paper has described a project presently underway within Eskom Distribution specifically focused on the performance impacts and costs of infrastructure investments. The results will be used to review planning and design practices. The findings are expected to be an important input to any possible future CAPEX linked incentive scheme.

**References**

- [1] M van Harte, *DGL 34-450 Network planning reliability guideline*, Eskom Distribution, 2007
- [2] R Koch, “Regulating quality of supply in the electricity sector”, *Frontiers in managing reform & regulation of infrastructure utilities in Africa*, Cape Town, August 2007
- [3] C Guidi, J Spain, J Garcia, G Layerenza, “Quality of service approach for risk management and cost optimization for electricity networks”, *CIREN 18<sup>th</sup> International conference on electricity distribution*, Turin, June 2005

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