1.0 INTRODUCTION

The Eskom electrification programme was driven by the lack of access to electricity in former Black Townships. Nearly 2 million customers have been connected since 1989. The estimated future number of connections to address the electrification backlog is 250 000 connections/year for the next 5 years. Most of the connections will be to domestic customers, clinics and schools in rural areas.

Rural customers are normally very low consumers of electricity and their load growth is gradual. The capital cost of the connection is unlikely to be recovered under the consumption tariff. The revenue earned contributes to the costs of servicing the customers. The loads of the new customers are uncertain and the customer base is unstable due to migration and the high incidence of diseases like AIDS.

The capital cost must be kept to a minimum by: (1) Reducing the risk of having under-utilised assets by phased construction of only the assets needed for the first 5 years of load growth and making provision for upgrading if the loads grow and prove to be stable. (2) Ensuring technically optimal and appropriate designs, using previous experience to estimate the loads and modelling them with the best methods and tools.

Experience to date has shown that the cost per customer increases significantly with decrease in customer density and the cost of the LV is the most significant component.

The methods and tools that provide the closest estimate of the real situation are expected to help to define the most appropriate design and business cost. The development of a probabilistic method called the Herman Beta method and a load forecast tool called DT PET appeared to provide a closer estimate of reality than the existing methods and were investigated by Eskom.

This paper assumes that the reader understands the concepts of coincidence and after diversity maximum demand (ADMD) [3] for domestic consumers.

2. SIZING OF LV FEEDERS

2.1 Background

For rural domestic customers the cost of providing access to electricity is closely related to the voltage regulation standards. This is because the voltage regulation governs the size and length of the low voltage feeders, which in turn affects the number of transformers required to serve the electrification project area. The designer of an electrification project pays particular attention to voltage regulation.

The voltage compatibility levels for domestic consumers with a low voltage supply are defined in the quality of supply standard NRS048[2]. They are:

- Upper compatibility level: +10%
- Lower compatibility level: -10%.

The standard or nominal voltage is 231V.

Electronics technology made it practical to measure individual domestic customer loads and learn more about them. A National Load Research project has been collecting and analysing domestic customer load data in South Africa since 1993. This project has contributed to the following significant developments [3]:

- Simultaneous load data collection Derivation of a load model to represent domestic loads
- Transformation of the load model into a probabilistic voltage drop calculation method.

Eskom has used two approaches to calculating the voltage drop in feeders for the selection of feeder sizes. The deterministic method is based on characterising the customers loads as average demand, and the probabilistic approach considers a distribution of possible loads.

2.2 Deterministic method

With this method, the after diversity maximum demand ADMD (or average customer demand at the time of system maximum demand, referred to as ADMD) is used to estimate the load currents in a feeder at maximum demand, and correction factors are applied to correct for diversity and unbalance. Rural electrification feeders often have small numbers of customers (<15) and the correction factors become more uncertain with smaller numbers of customers. The feeder voltage drop, and therefore the size selected, depends on the choice of the unbalance and diversity correction factors. The design is particularly sensitive to assumptions made in respect of the final service connection supplying only one customer.

2.3 Probabilistic method

The method uses a probability-based description of the loads at the 5-minute period of system maximum demand to estimate the voltage drops along a feeder. Herman and
Kritzinger [4] showed that the Beta probability density function represented the customer loads appropriately. Herman developed a transform of the Beta distribution of currents into a Beta distribution of voltage drops. The voltages along a feeder could then be determined for a given level of confidence. [11,12]. The algorithm was found to give a better estimate of the voltage drop than other approaches using the ADMD and correcting factors [1]. The algorithm has been developed further, to allow for feeders supplying both balanced three-phase and single-phase loads, and has been used to investigate various conditions of feeder configuration [13,14,15]. This approach is generally referred to as the Herman Beta method.

The beta distribution of currents is described by the parameters $\alpha$ and $\beta$ and a scaling factor $c$. These parameters can be calculated from the mean ($\mu$) and standard deviation ($\sigma$) for a set of data. The National Rationalised Standards (a South African standards organisation) project was established to collect representative load data from a variety of communities for application of the Herman Beta method, based on the load measurement techniques already developed during the early load studies.

2.4 Application of the probabilistic method

Eskom has required the use of the Herman Beta method for low voltage electrification designs since 2000. However, to use the Herman Beta approach a designer needs to choose the most suitable $\alpha$, $\beta$ and $c$ parameters i.e. those that represent the distribution of load currents for a particular community. The scaling factor $c$ is taken as the circuit breaker rating for the majority of the customers connected to the feeder. Guidance is needed on the selection of the other two parameters so that designs are not unacceptably over or under designed.

Figures 1 and 2 show the distributions for the load currents of two communities. They demonstrate that the community in Figure 1 has fewer customers with load currents greater than 5 A than the community of Figure 2 with the same system maximum demand. The parameters corresponding to the mean and standard deviation are also shown.

The beta parameters are related to the socio-demographics of the community. The NRS Load Research project links the load data to the characteristics of the communities [6]. Annual load research reports are produced by NRS to disseminate the information. Papers [16] and articles [17] have also been written. A load and parameter estimation tool [10], based on the results of the load research project, enables a designer to fingerprint a community from information gathered through a survey.

The use of the Herman Beta method is quite different from the use of the deterministic methods:

- It reflects uses the load parameters directly, instead of derived parameters like diversity and unbalance factors
- It is based on substantial measurements of local customers’ loads, linked with socio-economic parameters like household income.
- It allows modelling of alternative technologies such as single- and bi-phase feeders.

However, the practical implications of these differences needed to be investigated in detail, for the effects on the sizing of feeders, the cost implications and the business processes, before the approach could be adopted as a standard design method.

3. THE INVESTIGATION APPROACH

The primary aim of the investigation was to establish the impact of replacing the deterministic method with the Herman Beta method for sizing the LV cables. The main concern was the impact on the capital cost per rural customer connection and how this may affect the rural electrification targets.

An experiment was designed and performed. It involved the redesign and re-costing of a deterministically designed rural electrification project using the probabilistic method [7].

3.1 Design tool used

A network analysis tool called Reticmaster, which is presently used in most Eskom planning and project engineering offices, was used. This tool could be used to capture the network in schematic form right down to the load
(230V) point. It provided the design consistency required for the project.

3.2 Project chosen

An actual rural project, the Antioch Electrification project, was used for cost comparisons. This project was originally designed using the deterministic method. The design was optimised using the Eskom standards prior to implementation. The completed rural electrification project design was chosen due to:

- One author’s role in the project design and management and in depth knowledge of its layout and costs.
- The opportunities to make realistic design decisions during the experiments.

3.3 Experiment Description

It was necessary to establish what change in the cost per connection could be expected using the probabilistic method instead of a deterministic method for sizing the networks. In fact, two deterministic methods, very similar in structure but differing in the correction factors were used to represent the original design.

For each design method and set of parameters, the initial design implemented at Antioch was loaded until any customer experienced a voltage level of 231V minus 10% (208volts). The transformer loading was also monitored. When the voltage at any node on the network went below 208 volts, or a transformer became overloaded, the design was upgraded by:

- Increasing conductor size i.e. adding a second parallel conductor to the feeder route.
- Splitting existing transformer zones by adding transformers and MV feeders.

The extent of modification was recorded and costs calculated. Table 1 shows the results.

4. INVESTIGATION RESULTS

For the purpose of drawing charts the set of alpha/beta and the associated ADMD has been called a study point.

This is because the deterministic and probabilistic methods are not directly comparable. They use data differently to describe a load condition. Table 1 demonstrates this in that the mean (ADMD) of 0.6 kVA has two different sets of beta parameters for different communities. The one’s load is dispersed differently from the other.

The cost/connection derived per method at a particular “study point” (load condition) has then been depicted on a line graph, Figure 3 in order to clarify the results obtained.

<table>
<thead>
<tr>
<th>STUDY POINT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<tbody>
<tr>
<td>ALPHA</td>
<td>0.12</td>
<td>0.35</td>
<td>0.38</td>
<td>0.42</td>
<td>0.46</td>
<td>0.49</td>
<td>0.49</td>
<td>0.5</td>
<td>0.49</td>
</tr>
<tr>
<td>BETA</td>
<td>2.62</td>
<td>2.88</td>
<td>2.76</td>
<td>2.61</td>
<td>2.31</td>
<td>1.99</td>
<td>1.81</td>
<td>1.6</td>
<td>1.31</td>
</tr>
<tr>
<td>ADMD (KVA)</td>
<td>0.2</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>HB (Rand)</td>
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<td>2600</td>
<td>2709</td>
<td>2709</td>
<td>2820</td>
<td>2853</td>
<td>2853</td>
<td>2858</td>
<td>2868</td>
</tr>
<tr>
<td>DT/DT (Rand)</td>
<td>2600</td>
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<td>2853</td>
<td>2858</td>
<td>2858</td>
<td>2858</td>
<td>2868</td>
<td>2868</td>
</tr>
<tr>
<td>AMEU/N (Rand)</td>
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<td>2600</td>
<td>2600</td>
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<td>2600</td>
<td>2600</td>
<td>2600</td>
<td>2748</td>
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</tbody>
</table>

Figure 3 – Cost vs initial design parameter

Note: Study point 1 is ADMD =0.2 and Alpha-Beta set = alpha (0.12) - beta (2.62)
Figures 3 shows that the use of the different network sizing methods and parameters has an effect on the initial cost per connection in an electrification project of similar nature to that of Antioch. For each study point, whichever “solution” is adopted, the other methods will probably result in over- or under-design. Obviously, since all the methods are only models of reality, it is important to identify the approach that is the most suitable, and the costs of using one of the alternatives.

The results of the probabilistic method are somewhere between the two variants of the deterministic method. The cost difference between the two deterministic methods, which are superficially similar, is bigger than the difference between either deterministic method and the Herman Beta method. Taking the probabilistic method to be the best estimate of network size [1] i.e. 100%, then the use of the other two methods will result in higher or lower initial costs over the range of parameters used in the experiment. Table 2 indicates cost differences up to 8% between the deterministic methods and the probabilistic method.

The deterministic method was most commonly used with the AMEU diversity and neutral current unbalance correction factors. Therefore, for typical rural electrification areas i.e. with more dense main areas and less dense perimeter areas, like Antioch, the use of the probabilistic method is likely to increase cost/connection by around 5% for ADMD>0.5kVA. With ADMD <0.5kVA no cost increase is expected.

The more scientific and confidence boosting probabilistic method could enable this 5% to be discounted as the designer would be using measured data and proven models. There would be no need to put a little “fat” on top of an appropriately modelled design because this feels right from previous experience.

5. BUSINESS DECISION TAKEN

The research and investigation conducted led to a business decision to adopt the probabilistic method because it:

1. has been shown to be a more realistic representation of the actual situation than the deterministic method.
2. is supported by an extensive load research programme which is ongoing and which has resulted in a continually improving load forecasting model.
3. predicts more reliably the need for upgrade investigations through the use of customer revenue data and the load forecast model. This results in a pro-active approach to providing network capability and assists in capital expenditure planning.
4. uses design parameters that can be estimated from customer community characteristics. Post electrification customer information will indicate future network needs.
5. supports higher level network development planning in Eskom.
6. encourages the development of probabilistic network design and management tools that are expected to bring further benefits.

It was decided, from a business point of view, to:

- introduce the method for all electrification designs from January 2000 using a standard set of load parameters for consumers with estimated income less than R1000/month. The parameters chosen must maintain existing cost targets. Areas estimated to have a higher income would need to be surveyed to establish the average income and the appropriate parameters from the load forecast tools.
- design all electrification projects based on a common set of design policies. Previous design methods, parameters and policies were interpreted and applied inconsistently.
- ensure that the different design tools produced the same result for the same set of input parameters through checking of tools/software and applications methods.

This decision required that the load forecast tool, called DT PET [10], be made available to all designers and that the design approach, policies and relevant parameters be documented and communicated to all users. [8]

6. BUSINESS RESPONSE TO THE DECISIONS TAKEN

A decision involving a change in technology affects several aspects of the business, referred to as “factors”. Ideally these factors need to be considered and catered for in the implementation plan. In this case most of the factors were considered, however there were also some surprises.

The most important responses are discussed below:

Factor : People:
Response and further action: The design groups did not respond with enthusiasm. They were not confident enough to design or check designs with the new method. They were comfortable with the deterministic method and were using it as their yardstick. The challenge was to get the probabilistic method used as the yardstick. A need for more detailed training was identified, and provided. A national standard to direct rural electrification design parameters and processes and design report formats was produced and implemented. This resulted in a better response but it was obvious that the process would need continual attention.

Factor: Analysis Tools
Response and further action: Proprietary design tools had to be re-programmed to enable designers to use the new method. Design groups had to obtain the proprietary tools to design with the new method. These tools had to be checked to ensure that they gave correct estimates. The Herman Beta method developers produced benchmark tests to assist this process. It was evident that the assumptions used for the calculation engines in the various computer programs had significant differences resulting in different outputs, so that one tool would produce a more expensive design than another for the same design parameter input. A work group was set up and a common approach agreed.

Designers considered the proprietary tools costly. Versions with less functionality (sophistication and variation options) were produced to overcome this.

Factor: Load forecast tools
Response and further action: The load-forecast tool, DT PET, uses average community income as its input and provides a load forecast in beta parameters and energy (consumption) as its output. The 1999 version of the tool provided its best estimate of low-income rural communities since insufficient data was available for such communities. Actual operational experience judged the parameters generated to be conservative and the rural designs were costing too much. The design parameters were studied further and reduced to levels similar to those previously used.

Appropriate measured data became available and was incorporated in DT PET 2000. Outputs are now more in line with those expected for these communities. Load research continues to improve this tool.

Factor: Contracts
Response and further action: Most of the Eskom electrification projects are achieved through highly competitive turnkey contracts. The turnkey bidders are very in tune with the cost targets that land contracts. They were extremely resistant to changing design methods. The national standard for rural electrification designs and a national technical adjudication committee convinced them that tenders would have the same base and would be fairly adjudicated. Any bid not in accordance with this standard was rejected.

It became quite obvious that the way in which Eskom’s requirements had been interpreted and modelled provided an advantage to some tenderers. The introduction of the new method, tools and standards resulted in designs with a common base. Tender design reports can also now be generated automatically from the design software files.

Factor: Customer information and design parameters
Response and further action: Prior to the introduction of this method all rural designs were based on an initial ADMD of 0.4kVA per customer. The probabilistic method requires that customer information be obtained through a customer survey and the design parameter generated from the load-forecast tool, DT PET. Customer information showed that some rural areas would require initial designs based on around 1 kVA per customer. This highlighted the importance of accurate customer information through the use of well-trained customer surveyors. A need for a simple check using, e.g. census data, was also highlighted. The use of census data was investigated and further recommendations were provided.

The cost and lead time of customer surveys also presented some problems. This activity was not part of the previous design process and it took time for design groups to include it in the project planning. The use of a model based on census data, adequate for 90% of the communities, should avoid unnecessary pre-engineering costs and reduce this problem.

Factor: Actual designs:
Response and further action: The initial investigation prior to the introduction of the probabilistic method estimated that the initial cost per customer would increase by less than 5%. This has been verified in many large projects (>1000 customers) since the introduction of the method. In most cases the slight increase in the network cost has been discounted by efficiencies in other project activities.

Also, the apparently higher cost is related to providing stronger networks that are less likely to need reinforcement prematurely, reducing the risk associated with the less accurate alternative model.

7. PRESENT STATUS AND FUTURE TRENDS

Eskom now uses the probabilistic method for all electrification designs. Most designers are now familiar with the method and have experience with the tools needed to use it. In fact the conversion to the method has resulted in improved overall knowledge of modelling electrification networks. Designers now appear to understand the nature of models and how they can provide the best estimate of network size.

The probabilistic method has been further developed and its revision is being discussed at present. The knowledge
gained from the implementation of the method over the past 3 years will serve the industry well in the future.

8. CONCLUDING REMARKS

The introduction of a new method of sizing low voltage feeders appears to be largely a technical issue. A lot of effort was spent verifying that the method was in fact an improvement on existing practices. This took a number of years and several papers were published on the subject. The actual introduction of the method into the business environment received a lot less attention.

The actual implementation showed that the feeder conductor sizing method is just one part of a complex business system that should always receive appropriate attention. It also demonstrated how a change in technology can be a catalyst to improving many other business elements, especially user knowledge.

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