The impact of small scale embedded generation on existing networks

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Load forecasting methods are based on selecting ADMD values for various load classes, summatng the load class load profiles and the application of diversity factors while looking ten to 20 years into the future. These factors, especially diversity, are altered through EEDSM and small scale embedded generation initiatives.

Throughout the world there is a drive to improve energy efficiency, reduce electricity demand and encourage renewable energy generation. The public is generally informed through media that this is good for the environment, will prolong generation and grid assets as well as natural resources such as fossil fuels and water. However, it may be possible that these initiatives change the performance of planned (future) and designed (existing) networks without engineers reconsidering past assumptions or traditional methods. Quite a number of assumptions are made in the selection of suitable parameters and combinations of parameters to predict future load and to plan and design infrastructure accordingly. If parameters are affected and the impact of a change is not considered, unexpected or even degraded performance of networks may result while utilities and municipal electricity re-sellers may have to lay out unplanned capital to rectify or address problems caused.

Distribution networks are not designed to cater for reverse power flow or a diversity-less scenario [e.g. solar PV power injection at rooftop level into the grid]. The paper will investigate the impact EEDSM and small scale embedded generation may have on these parameters used for master planning and designs, how it will affect existing networks and which concerns we should address for our future cities in this regard.

The South African Grid Code has defined several classes of embedded generation [1]. For this paper, embedded generation of Class A1 (i.e. <13,8 kVA) and EEDSM initiatives for the low voltage domestic load class will be considered. This form of generation is called embedded generation, because it cannot be controlled by the national system operator.

In this paper, only the technical impact on distribution network design and planning parameters are considered. Power quality and financial impact to revenue streams are not considered. While energy saving and demand side management (EEDSM) initiatives are fairly well implemented by many utilities, most utilities do not allow the connection of small scale embedded generators at present to their distribution networks pending further regulations, by-laws and certainty about the impact it will have on their networks and revenue streams. In spite of utilities not allowing small scale embedded generation, it exists in the distribution networks already in South Africa, and the location thereof in the networks are not only unknown to utilities, but can also not be controlled by utilities.

NRS 097-2-1:2010 Grid Interconnection of Embedded Generation [2] attempts to provide some guidance to the implementation and compliance of embedded generation.

Load forecasting, related planning and design parameters

In electricity distribution network designs and master planning, various assumptions have to be made while the designer or planner considers future loading and scenarios. Load forecasting is an integral part of any network design and considers a saturated maximum demand state 15 to 20 years into the future. The load forecast is determined by considering a combination of diversity factors, load factors, load profiles, loss factors, growth rate and other diversity maximum demand (ADMD). Once the end state load is known, network elements can be sized based on voltage drop, current carrying capability and fault level considerations.

Load forecasting, related planning and design parameters

In electricity distribution network designs and

\[
\text{Coincidence} = \frac{\text{total MD}}{\sum \text{MDs}} \quad (1)
\]

where

\[
\text{MD} = \text{Maximum demand},
\]

\[
\text{Diversity} = \frac{1}{\text{Coincidence}} \quad (2)
\]

Boggis [4] and Mcqueen [5] related maximum demand, ADMD and diversity factor (DF) as:

\[
\text{MD} = N \times \text{DF} \times \text{ADMD} \quad (3)
\]

Fig. 1: Beta distribution curve with parameters \(\alpha=1.37, \beta=3.39, c=80\), ADMD=5.3 kVA (NRS034 Table 2; LSM 8 high end).

Fig. 2: Domestic 24-hour load profile.
ADMD change  |  Revised ADMD kVA  |  $\alpha$  |  $\beta$  |  $C$
---|---|---|---|---
5.3 kVA Designed | 5.3 | 1.37 | 3.39 | 80
5.0 kVA + 11.6% | 5.8 | 1.29 | 2.83 | 80
5.0 kVA + 25% | 6.25 | 1.21 | 2.37 | 80

Table 1: Ripple control impact to Beta distribution curve modelling parameters.

$$ADMD = \lim_{N \to \infty} \frac{\sum_{i=0}^{N} M D_i}{N}$$  \hspace{1cm} (4)
$$DF = 1 + \frac{k}{N}$$  \hspace{1cm} (5)
where
- $k$ = Coincidence
- $N$ = Number of consumers

Voltage drop calculations were initially based on empirical formulae (deterministic methods) such as British and AMEU diversity correction curves with neutral unbalance compensation, followed by statistical distribution curves (probabilistic methods) such as the Herma-Beta method [7, 8]. Lately, the USA and Australia are considering stochastic methods as opposed to the probabilistic methods, considering a larger dependency on other factors such as time, temperature, humidity, cloud cover, etc. [9].

The Herma-Beta distribution curve [7] still relies on an ADMD parameter to be selected, while diversity correction is applied through the selection of $\alpha$ and $\beta$ parameters to model the probability of a consumer drawing a specific current at peak time.

Present ADMD is still the best determined by measurement, while future ADMD draws on the experience of the planner to combine load growth, income level and other factors to produce a suitable figure. Consider the following 1-minute domestic load profile:

For this load profile, the maximum demand of 7617 kVA was recorded at 18h47 on a given day. For 1511 domestic consumers and streetlight load of 62 kVA, the present ADMD is:

$$(7617 - 62) / 1511 = 5.0 \text{ kVA} / \text{household.}$$

It is to be noted that the measurement interval plays a significant role in the ADMD measurement. The longer the measurement interval, the larger the error between the integrated peak and the instantaneous peak.

The projection of this ADMD into the future requires the application of S-curve load growth theory, as well as knowledge of network load maturity. If this network was designed at a 5.3 kVA ADMD, it is 94% mature at present.

Following determination of a final load, the network can be designed. What happens when design parameters change? The following two sections of this paper examine simple changes to e.g. ADMD through residential load control, such as ripple controlled geyser switching, as well as small scale embedded generation such as solar PV.

**EEDSM**

EEDSM generally refers to energy efficiency and demand side management. Generally, the following figure is used to explain the various techniques:

Energy efficiency, or conservation, generally reduces the demand and energy, which does not have a negative effect on the distribution network. This is already deployed by many utilities and customers, such as more energy efficient streetlights, domestic CFL roll-out, replacement of fluorescent lamps in offices with more efficient lamps, replacement of conventional geysers with heat pumps and solar geysers etc.

Demand side management usually involves load shifting, which is in effect a combination of peak clipping and valley filling. Domestic ripple control is one such example rolled out to domestic users to reduce the maximum demand during the morning and evening peak. In this case, no energy is conserved, just moved. When load profiles containing ripple controlled geysers are investigated, it has been observed that the cold load pick-up resulting from the load shift sometimes exceeds what would have been the original peak. By definition, the ADMD has increased and the load factor decreased due to lack of diversity on a certain load portion of the network, in this case the geyser load. In many cases, the utilities save on their revenue bills purely by consuming the energy at a more cost effective time. Consider a typical recent example, Fig. 4, where the load profile a controlled day is superimposed on the profile of an uncontrolled day.

From this observation, the ADMD has increased by 11.6% while studies by an Italian distributor have indicated as much as a 25% increase [8]. Very often, control does not take place at the 11 kV level, but at the billing level, e.g. 132 kV, in which case occurrences such as these can be expected. The discussion of improved control algorithms at multiple network levels are excluded from this study.

It must be noted that measurement error, when considering for instance 30-minute integrated data vs. 1-minute integrated data, can be as high as 15% (specifically observed for the load-controlled profile in Fig. 4).

By considering an example low voltage feeder, designed at 5.3 kVA ADMD, the impact of an ADMD increase can easily be observed through load flow analysis.

The Beta distribution curve parameters based on the design ADMD as well as the revised
ADMD for two scenarios, should an increase of 11,6% and 25% respectively occur to present day ADMD of 5 kVA, are as follows:

For an example low voltage (LV) feeder system, two scenarios are considered:

A: A tapered LV feeder with only certain cable sizes used. Here, a circuit breaker is required at each change in cable size.

B: An LV feeder with the same size right through. Here, a circuit breaker is only required at the transformer to protect the cable.

All LV cables in these two scenarios are copper cables. Service connections are 1,6 mm² two-core, 30 m when on the same side of the road as the LV distribution or metering kiosk, and 43 m when on the opposite side of the road.

Two additional feeders are shown connected to the transformer secondary wind in order to correctly simulate voltage drop across the transformer.

The phase allocation is such that each feeder contains an equal number of consumers per phase, although the three feeders are of different length. For Scenario B, the feeder is designed to include as many domestic customers as possible to be just within the maximum allowed voltage drop, considering nominal tap transformer settings and assuming a 1 p.u. MV voltage. The cables were then changed for Scenario A, and covered only four types of cables, as many utilities only stock a certain number of cable sizes in their stores.

The results of a load flow analysis are as follows:

These results demonstrate that:
- The lowest voltage at a customer distribution board drops below the minimum allowed voltage of 0,9 p.u.
- Transformer loading increased by 17%, although in this example the loading is still within the overload conditions allowed by the transformer manufacturer, provided that the overload duration remains below four hours in a 24-hour cycle.
- For scenario B, the conductor section closest to the transformer has exceeded rated capacity.
- For both scenarios, at significant ADMD increase, the allowed maximum voltage drop is reached before the end of the feeder.

**Embedded generation**

Embedded generation in the LV network regions of distribution networks are difficult to control by utilities. With rising electricity prices, it is possible that the levelised cost to install e.g. solar PV may soon outweigh the cost when purchasing from the utility. There are already solar PV panels installed on distribution networks with the possibility of reverse power flow in the case of excess power. Distribution networks were traditionally not designed for reverse power flow since almost all LV feeders in South Africa are radial feeders.

During low load, conditions are such that any excess energy not consumed by the premises itself could flow into the network. According to impedance paths and phase injected on, the energy will flow to the nearest load on that phase. This in itself creates unbalance elsewhere in the network, which increases voltage drop. Generally, the voltage rises where a generator is connected while the distribution network is traditionally designed to mitigate voltage drop. Distribution transformers are on fixed taps, and cannot adjust itself to compensate for increased voltages on the LV network. The networks are further designed with diversity between loads in mind. If the amount of energy injected into the network during low load conditions is not controlled, there exists the possibility of overloading sections of the LV cable network due to a lack of diversity between multiple solar PV embedded generators.

<table>
<thead>
<tr>
<th>ADMD (kVA)</th>
<th>Transformer load (kVA)</th>
<th>Min V (% of nominal)</th>
<th>Highest loaded cable (% of rated current)</th>
<th>% distance reach of LV feeder @ 90% V</th>
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</thead>
<tbody>
<tr>
<td><strong>Tapered LV cable feeder (A)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5,3</td>
<td>478</td>
<td>90,14</td>
<td>77</td>
<td>100</td>
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<td>5,8</td>
<td>519</td>
<td>89,28</td>
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<td>6,25</td>
<td>560</td>
<td>88,44</td>
<td>90,9</td>
<td>60</td>
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<tr>
<td><strong>One size LV cable feeder (B)</strong></td>
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<td></td>
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<td>5,3</td>
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<td>560</td>
<td>89,85</td>
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</tbody>
</table>

Table 2: Results of load flow for two sample feeder designs at 11,6% and 25% ADMD increase.
The effect of solar PV power injected into the network from house-hold level on voltage rise will be demonstrated through load flow analysis. Although fault level generally should increase when generators are connected to the network, the effect on fault level will not be illustrated or discussed further in this paper.

Consider a 5.3 kW load profile, averaged for a single consumer, with a 3 kW solar PV plant (at unity power factor):

From this graph, it is evident that a surplus energy could exist during low load conditions when the energy produced by the solar PV cell is still measured relative to the declared peak power. For the 415 V system, voltage drop per phase is still measured relative to the declared nominal voltage of 230 V in South Africa. The results are shown in Table 3.

The future burdens over which they will have placed on their distribution networks will become overloaded due to a lack of diversity between generators. Under higher embedded generation scenarios are considered at maximum reverse power flow conditions:

- 3 kW solar PV embedded generators for a transformer with 3.75% internal boost (i.e. a 415 V system)
- 9 kW solar PV embedded generators (415 V system)

The results are shown in Table 3.

From these results, it is noted that:

- Voltage rises as generators are added.
- Under higher embedded generation load, and high penetration, the maximum voltage limits can be exceeded and excess power flows across the transformer into the MV network.
- Although no cables were overloaded under any reverse power flow conditions in these examples, under very high embedded generation load (e.g. each house inject 60 A after own utilisation) LV feeder sections will become overloaded due to a lack of diversity between generators.

### Bibliography

1. NERSA: “Grid connection code for renewable power plants (RPPs) connected to the electricity transmission system (TS) or the distribution system (DS) in South Africa,” 2012.

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