8TH SOUTHERN AFRICA
REGIONAL CONFERENCE

14 - 17 NOVEMBER 2017

“ **Electricity Supply to Africa and Developing Economies …. Challenges and opportunities.”**

Type here the Preferential Topic to which your Paper Proposal refers

Understanding the impact of embedded renewable generation and its interaction with local load in the time-domain

Z, LINCOLN & D, RAMSBOTTOM

Eskom Distribution

South Africa

SUMMARY

This study uses measured hourly load and embedded generation data as inputs to a time-domain power systems analysis in DIgSILENT PowerFactory, for a chosen sub-transmission network in the Western Cape province of South Africa. The outputs of the study focus on thermal loading and local asset utilisation, energy and technical losses within the load pocket, and busbar voltage regulation.

KEYWORDS

Renewable generation; distributed generation; time domain; asset utilisation; energy losses; voltage regulation.

BACKGROUND

The South African renewable energy independent power producer procurement programme (REIPPPP) has been recognised as a successful model for accelerated renewables integration and is being used as a blueprint for many other developing economies. With close to 4000 MW of large-scale renewables in operation on the South African grid to date, the transmission and sub-transmission networks of the Cape have seen a dramatic change in power flows and infrastructure utilisation over the past three years.

Historically, Network Planning methodologies for network adequacy studies within the South African grid have been limited to deterministic peak load studies. Requirements for strengthening and firm network status are determined in this way. As embedded renewable generation establishes itself as a more widely spread phenomenon, local supply-demand relationships are changing on a minute-to-minute scale, resulting in very different asset utilisation than is modelled in ‘worst case scenario’ Network Planning studies. There is a need to understand the impact of embedded renewable generation and its interaction with local load within the time domain.

STUDY NETWORK SELECTION

A real sub-transmission network in the Western Cape has been chosen as an ideal study case, given its high penetration of renewables, both wind and photovoltaic (PV), its mostly radial topology, and its variety of load types, ranging from industrial to agricultural and some rural residential. The network comprises 40 substations and 73 lines. Sub-transmission voltage at Substation 1 is 132 kV, with step-down to 66 kV at Substations 2, 21 and 35. Actual substation names have been omitted from the study.

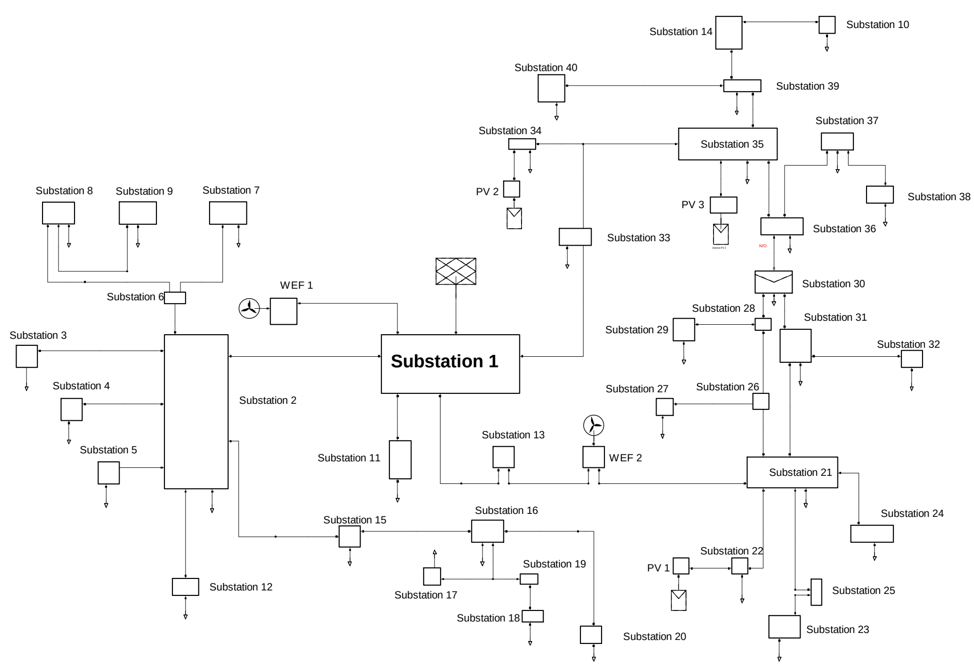

Figure 1: *Network diagram for the 40-substation study area*

Under normal operating conditions, all loads in the area are supplied from one 400/132 kV main transmission substation (MTS) – labelled in Figure 1 as Substation 1, with one exception, where a sub-transmission interconnection exists (at Substation 23). For the purposes of this study, that low capacity interconnection has been removed from the model. The 400 kV infeed into the MTS could thereby be simulated using an external grid modelled as a slack bus, and the sub-transmission network downstream of the MTS could be studied in isolation from the rest of the Western Cape grid.

The geographic area of the study network covers over 14 000 km². The peak load over the year was approximately 370 MVA. Due to the aggregation of various load types, dominated by large industry, the load profile is often fairly flat, with area peak occurring at unusual times. Embedded generation maximum contracted export capacity totals 245 MW (when all five embedded generators had been commissioned), with roughly 36% PV and the remainder wind generation.

STUDY METHODOLOGY

Data handling

The model uses 2016 data, being the latest complete calendar year, with four of the five renewable plants being in commission for the full year. The fifth plant was commissioned around midyear 2016.

Statistical half hourly metering is recorded in Eskom's MV90 database for all MV aggregated loads and generation in this study area. Each half hourly reading represents the average load (kW and kvar in both directions) for the half hour preceding the timestamp.

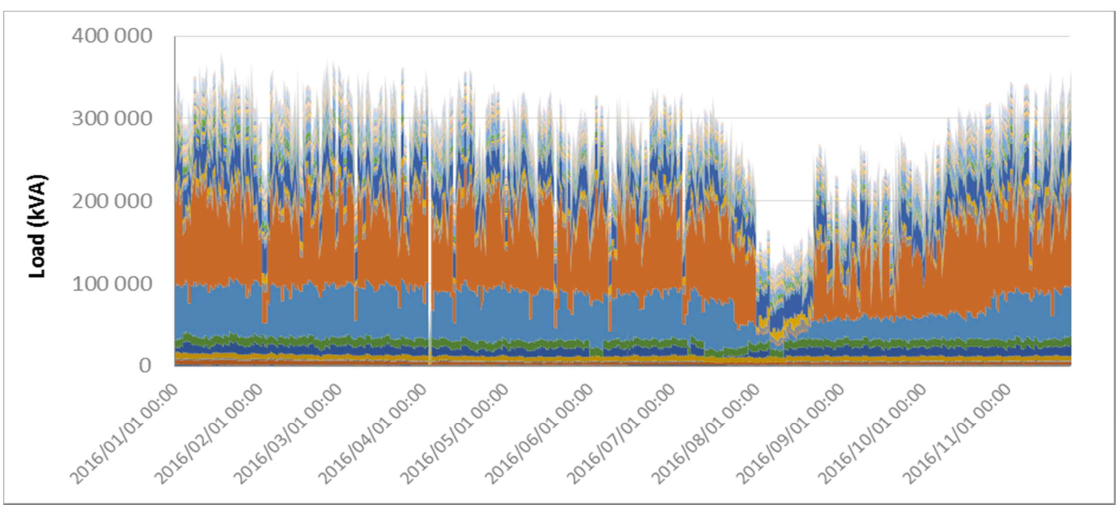

Figure 2: *Stacked loads for the study area for January – December 2016*

Once extracted from the MV90 database, this data was uploaded into the DIgSILENT PowerFactory database for the chosen network, as time-based characteristics to each load and generation parameter (P and Q) at each busbar. The most granular standard characteristic timescale which PowerFactory accommodates over a year is hourly readings, and thus the half hourly data had to be further averaged to limit inputs to 8784 data points – 2016 was a leap year - per parameter characteristic.

Time domain simulation

A DIgSILENT Programming Language (DPL) script was used to run 8784 simulations, stepping through the parameter characteristic data on each execution of a load flow.

The time-domain study was run for two scenarios – one with all embedded generation in service, and another with all generation switched out. The first scenario was set up to simulate the real conditions on the network, as they took place in 2016. For this scenario to be simulated, all as-built control elements of the distributed generators had to be removed from the case, so that the hourly metered data could govern dispatch and reactive power support as it did over that time period. Operational changes to the network configuration, such as altering of normally open points on interconnected MV feeders or sub-transmission lines (though there are very few opportunities for this) are not reflected in the network model; however, since the loads modelled were aggregated at MV level, and were still true metered loads, this would not compromise the legitimacy of the simulation. It may alter the thermal loading of upstream sub-transmission components from what they were in real life.

The second scenario was set up as a fictitious case against which to compare the first scenario's results. Using another year's data, prior to the emergence of distributed generation could have been studied instead of this; however, loading would likely be sufficiently different across the two selected years that comparisons may have lost meaning.

COLLECTION AND ANALYSIS OF RESULTS

Utilisation of assets

By initial analysis of the load and generation data (for the period starting once all five embedded generators were fully commissioned), it is evident that the intermittent nature of the wind and PV generation in this area cannot always be relied upon to reduce peak load. Figure 3 provides an example from 24 November 2016: one of the highest load days, with a peak area load of 349 MVA at 06:00 at which time 0 MVA of embedded generation was evident. Later in the day, as the PV plants began to increase output, these offset the local load to reduce the required external infeed. Note that the continuation of load offset into the evening indicates that the embedded wind generation increased in output towards the afternoon. Thus from 12:00 to 21:00, a consistent average hourly upstream asset utilisation reduction of at least 100 MVA was enjoyed on the network.

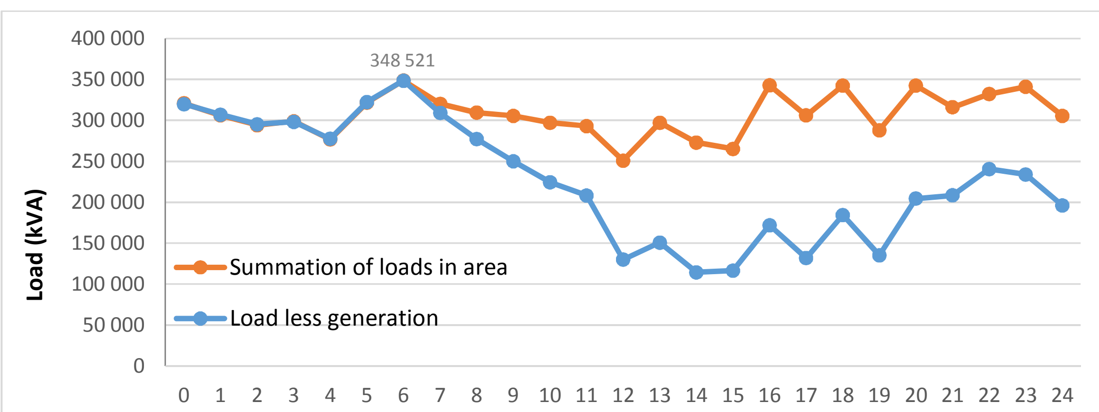

Figure 3: *Hourly load data for 24 November 2016*

Energy and losses

Table 1 below shows the high-level summary of results obtained for the two scenarios studied in PowerFactory.

Table 1: *Summary of results of simulations*

	Scenario 1 : **With embedded generation**	Scenario 2: **Without embedded generation**
Total external infeed	2518060 MWh	3081903 MWh
Total generation	563508 MWh	0 MWh
Total load	2986148 MWh	2986148 MWh
Total losses	95420 MWh	95755 MWh

Local generation supplies 19% of the energy needs in the area over the year, which, unsurprisingly, reduced the sub-transmission losses; but only by 335 MWh – a very small number (approximately 0.01%, on a loss figure of approximately 3%). The simulation case does not show the change in transmission system losses, as this is represented by an external grid.

Voltage regulation

The PowerFactory time sweep allows analysis of voltages, hourly over the year, on any busbar in the case, on all three conductor phases. This produces a vast quantity of data. To visualise the data, box plots have been drawn up, with boxes showing the 10^{th}-90^{th} percentile of voltages, and whiskers reaching to the minimum and maximum voltage experienced during the year. Figure 4 shows this data for relevant busbars, in the scenario with generation, while Figure 5 shows the same without generation. Busbars are separated into 132 kV and 66 kV groups.

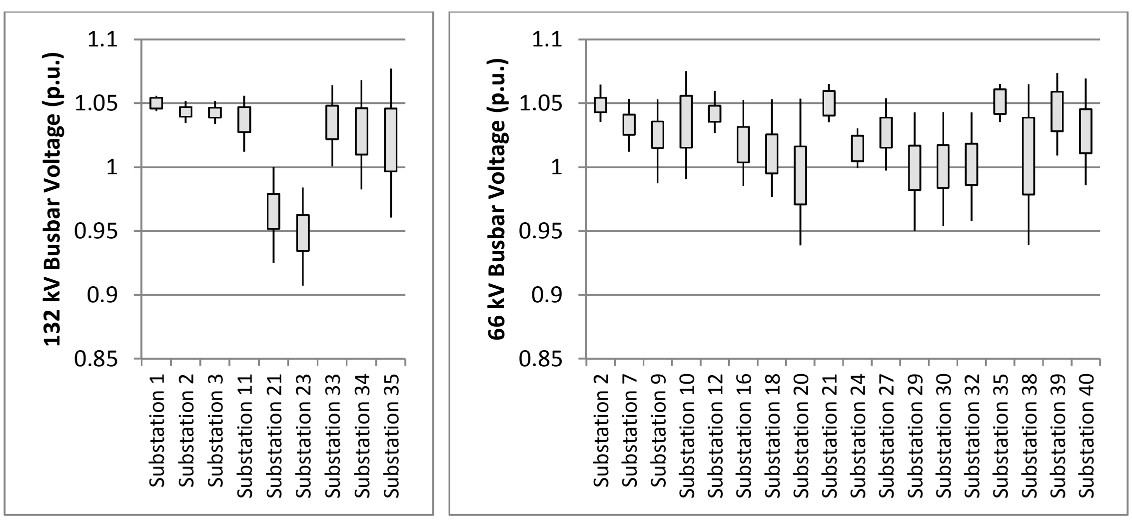

Figure 4: *Box plots of 132 and 66 kV busbar voltages with generation*

It is interesting to note that there is almost no difference in the plots of the two scenarios. Particular attention was given to the 132 kV busbar at Substation 35, as this is an area which is known to be susceptible to low voltages, and a hub for various far-outlying 66 kV substations, which in turn would suffer from low voltages. It is also the infeed point to PV 3.

It is noted that no low voltage concerns are apparent in the box plot for this busbar without generation – probably due to the ideal and very narrow regulation at Substation 1, which may not be occurring in the field.

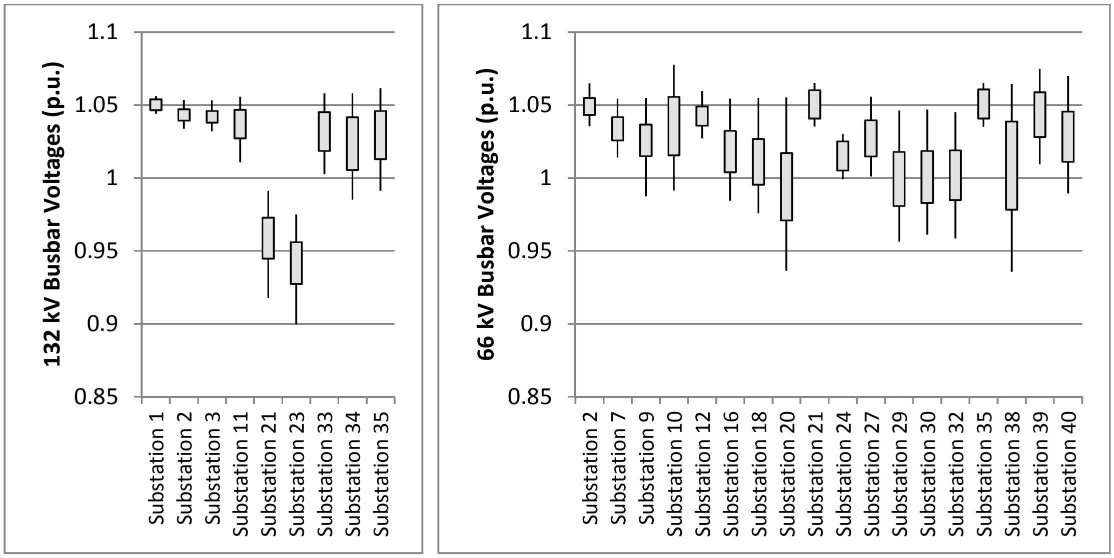

Figure 5: *Box plots of 132 and 66 kV busbar voltages with generation*

Figure 6 shows a closer look at the 132 kV busbar at Substation 35 for the last quarter of the year. All three phases (line-line voltages) are shown. It is evident that the generation creates a much broader spread of voltages at this point, and increases the maximum voltage (which repeats regularly, on weekends during the daytime). Whilst this is not a concern at this particular 132 kV busbar, as there are no customers supplied at this voltage, it is likely resulting in much more aggressive tapping on the 132/66 kV transformers to maintain the 66 kV busbar voltage within its narrow band.

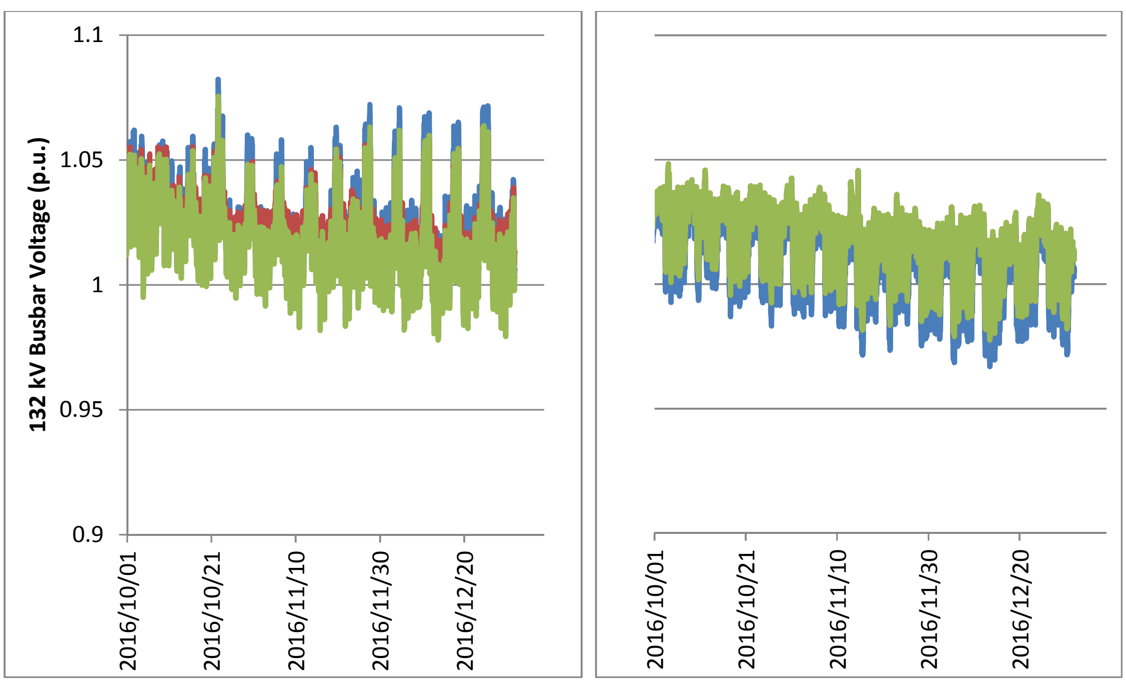

Figure 6: *132 kV busbar voltages for the last quarter of the year at Substation 35, with generation (left) and without generation (right)*

CONCLUSIONS

This method of analysing a network using a sequence of time-domain studies has provided interesting data for analysis.

From the analysis of asset utilisation, it can be concluded that, whilst the embedded generation in this area has the potential to make significant thermal capacity available on existing network assets, additional load may not be able to make use of this capacity, as it cannot be guaranteed at all times of the day, due to the intermittent nature of renewable distributed generation. The wide geographic spread and contrast of technologies (wind and PV) within this network do decrease the overall intermittency to a large extent.

The presence of embedded generation within this local load pocket was confirmed to decrease the sub-transmission losses experienced on the network, however, only to a very small extent. Extension of simulations to the upstream transmission network could be beneficial in identifying additional loss reduction due to the reduced external infeed into this load pocket. Additionally, this study could be extended to analyse losses at locational marginal points on the network to determine how the introduction of additional generation at any given point may decrease, and at some point even increase the losses on this network.

Whilst having a less noteworthy effect on voltage regulation than expected, the inclusion of embedded generation does appear to increase the spread of operational voltages simulated close to infeed points, particularly on weekends, when local load is lower than usual. This would be a concern if sensitive customer loads were connected at the same voltage level as the generation infeed. In this case, of more concern is the likely increased frequency of downstream transformer tapping, which places additional strain on transformers in the field. Also, elevated voltages may lead to additional stress on insulation of system components.

The accuracy of the original study case to reflect busbar voltages in the field is critical to the validity of this study, as the dispatched (metered) reactive power from the distributed generators is directly linked to the operational voltage of the busbar at which it connects, irrespective of whether the generator is operating in voltage control mode or power factor control mode. Additional validation of the model against voltages recorded in the field may therefore be necessary in order to place greater confidence in these results.

The sections of this study focusing on asset utilisation and voltage regulation both show that the fluctuating nature of the distributed renewable generation decreases its potential local value, leaving promising prospects for net load-smoothing, for example by battery energy storage. Being able to even out the fluctuations in generation may allow for more certain availability of unused network assets and therefore higher asset utilisation. Distributed storage for voltage support may also reduce the spread of voltages experienced at generation infeed points and downstream, and therefore improve power quality to customers and decrease tapping operations on transformers.