Development of a Power System Simulation Model for a South African Commercial Entity's Reticulation Network

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***Abstract*— Increasing electricity prices and the declining cost of renewables have led to several industrial, commercial and residential customers in South Africa pursuing the installation of generation "behind the meter" in order to reduce their electrical energy costs. This paper presents the process followed in developing a case file for a commercial entity to conduct steady-state power system studies to ensure safe, reliable and sustainable connection of distributed energy resources (DER) to the commercial entity's grid. Field work was undertaken to develop the model parameters in DIgSILENT. It is observed that for existing connections it is not always easy to retrieve the correct information, leading to the need to make assumptions regarding some of the essential parameters. The methodology outlined in this paper can serve as a base for any entity needing to build a network model to gain insight into the grid impacts of DER on their network.**

Keywords*— *embedded generation; distributed generation; network modelling

I. INTRODUCTION

A South African commercial entity is pursuing a combination of solar photovoltaic (PV), energy storage technologies and biogas generation. The ultimate aim is to create a microgrid which will still remain connected to the utility while fully meeting its energy requirements. The focus of this paper is on the grid-integration of DER. The objective is to develop a power system simulation model based on the existing grid infrastructure that can then be used to assess the impact of the various supply, demand and storage initiatives as required.

There has been a phenomenal growth in the inclusion of distributed generation as part of the electricity supply. This, in part, has been motivated by the drive to promote clean energy, security and reliability of supply. It is however evident that the introduction of distributed generation leads to challenges such as reverse power flow, voltage rise and fluctuations, variations in reactive power, overloading of feeders and stability effects amongst others [1]. Moreover, many authors have conducted reviews that point out some of these changes in the grid, and subsequently the technical challenges that will be experienced [2]–[5]. In addition, [6] conducted a worthwhile review of these technical challenges, concluding with a number of comprehensive recommendations in dealing with challenges.

It is evident that the changes in the architecture of distribution networks require the evaluation of technical impacts [7]. The IEEE Standard's Coordinating Committee 21 has documented the guidelines for conducting impact studies [8]. In this guideline, templates of the precise information required for different types of studies are furnished. Furthermore, the type of studies that are recommended are detailed, leading to a clear definition of criteria, scope, and extent of the required engineering studies. As a minimum, distributed generation should comply with the South African Grid Code (SAGC) [9], and detailed studies are required to demonstrate compliance at the point of connection (POC). Furthermore, grid challenges could be experienced within an entity's network, therefore it is important to have a proper assessment over and above the grid code requirements. Accurate representation of the power system using actual data is thus fundamental to generating valid study results.

A variety of proprietary tools are available for conducting grid studies, and [10] eloquently compares some of these tools. In this paper, modelling of the entity's grid using DIgSILENT will be achieved. Many studies in literature have demonstrated that DIgSILENT is a reliable power system tool for impact studies [11]–[13]. This modelling approach will support the robust business case development as any constraints or unintended effects of a planned DER project can be identified early on and addressed during the initial stages of the project plan.

The introduction has provided the necessary background on the importance of accurate modelling. The rest of the paper is arranged as follows: Section II describes the methodology followed for this study. Section III reports the data collection process and challenges that the authors came across onsite; Section IV and Section V deal with the discussion and conclusion, respectively.

II. METHODOLOGY

This section presents the methodology followed to build the model. Only high level information about the network was available as summarised in TABLE I. and Fig. 1. This facility was established in the 1950s thus it is not too surprising that detailed records are not available.

TABLE I. : HIGH LEVEL OVERVIEW OF THE ELECTRICAL NETWORK TO BE MODELLED

Item	**Details**
Main supply	2 x 132 kV in feeds from local electricity supplier
Main substation	2 x 132/11 kV 15 MVA transformers 6 x 11 kV shunt capacitors
Reticulation network	5 x 11 kV rings
Low voltage (LV) supply	400 V via various 11 kV/400 V step down transformers
Embedded generation	1 x Single Axis Tracking PV plant– integrated at 11 kV 1 x Dual Axis Tracking PV plant – integrated at 400 V 1 x Rooftop PV – integrated at 400 V
LV/MV loads	± 60 loads as captured on the entity's online metering platform. Recorded peak consumption of ~6 MW in 2016.

In order to acquire the detailed information required to build a power system simulation model, a two pronged approach was adopted. Initially, a site walk down was conducted. During the site walk down care was taken to record all parameters that are required for accurate representation of the various network components in a power system simulation model. In cases where data was not available from site, assumptions were made regarding those parameters. This process is summarised in Fig. 2.

The methodology followed in this paper focuses on how to model power system components in a DIgSILENT PowerFactory case file, however the same approach can easily be utilised to create a power system model in any other software package.

In terms of the assumptions based on typical data, the sources used, in order of preference are listed below:-

- Typical data as obtained from Eskom's database (a local power utility)
- Typical data as obtained from PowaMaster (a local power system modelling tool)
- DIgSILENT default values

A. *Data requirements for each network component*

There are specific parameters that need to be captured for each network component in order to represent it accurately in a power system simulation model. TABLE II. summarises the requirements per network component. For this paper the focus is on data required for a basic network assessment i.e. load flow analysis and fault level calculations. In order to conduct more detailed analysis, more parameters may need to be captured.

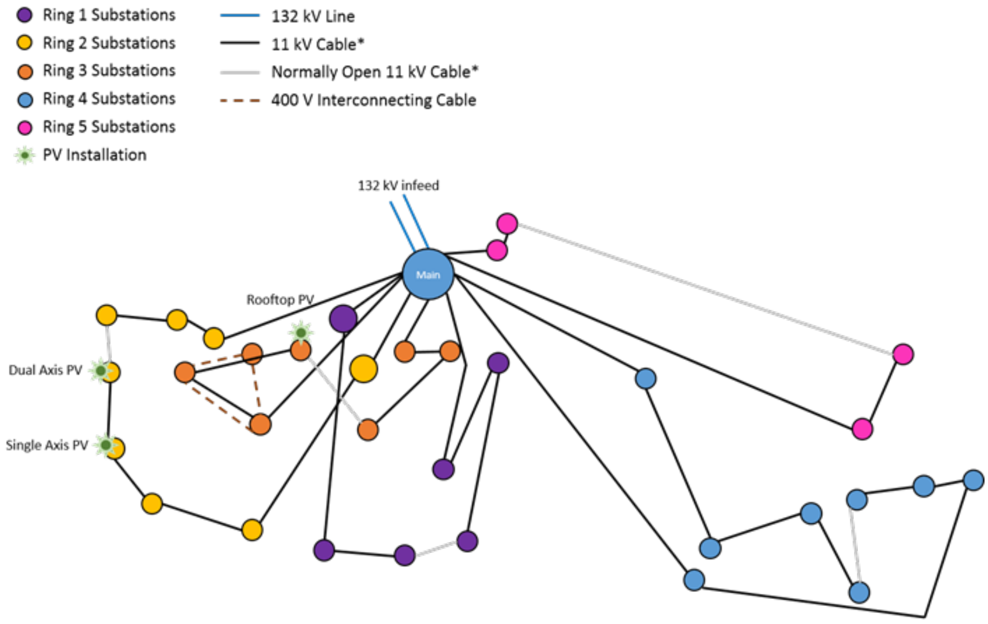

Fig. 1. Layout of the commercial entity's network

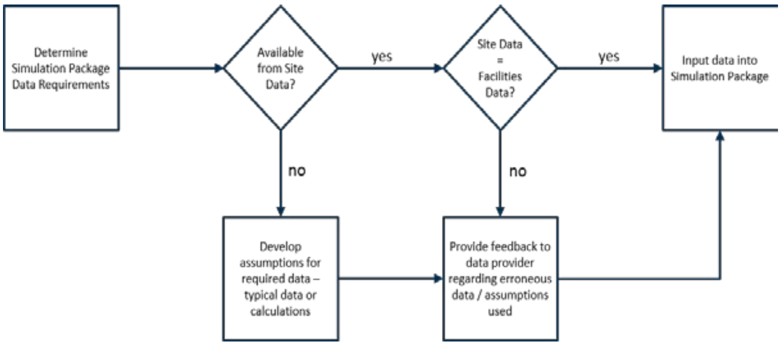

Fig. 2. Process flow of methodology used to build simulation model

TABLE II. SUMMARY OF DATA REQUIREMENTS PER NETWORK COMPONENT

Network component	**Parameters required for model**
External grid (connection to local electricity network)	Max. short circuit current [kA] Min. short circuit current [kA] X/R ratio
Shunt capacitors	Connection voltage [kV] Rating [kVAr]
Transformers	Rated power [kVA] Rated HV and LV voltage [kV] Vector group Positive sequence impedance[%, X/R ratio] Negative sequence impedance [%, X/R ratio] Magnetising impedance (No load current [%], No load losses [kW]) Tap changer parameters (% voltage change, max, min and nominal tap positions)
Cables	Rated voltage Rated current Nominal frequency No. of phases No. of neutrals Positive sequence parameters Zero sequence parameters Max. operational temperature
Distributed energy resources (DER)	Plant rating Control mode Actual plant output
Demand	Any 2 of the following for a particular point in time: Power [kW] Apparent power [kVA] Reactive power [kVAr] Power factor

III. RESULTS

In this section the results of the data collection process are presented. Focus is on challenges encountered with site data, as well as the assumptions and calculations used to plug the gaps.

A. 132 kV intake

The 132 kV intake from the local electricity supplier was represented as an external grid i.e. short circuit contribution. A conservative approach was adopted in modelling the external grid, due to lack of data from the electricity distributor. The short circuit parameters of the external grid were thus derived from the ratings of the 132 kV circuit breakers located in the main substation. The X/R ratio used was the default DIgSILENT value.

B. Shunt capacitors

Records showed that there are 6 x 11 kV shunt capacitors located in the main substation, and this was confirmed during the site visit. The capacitors were clearly labelled with their respective kVAr ratings, thus this was captured in the case file.

C. Transformers

As per the example in Fig. 2, the transformer nameplates, where legible, easily provided the rated power, voltage, vector group, positive sequence impedance and tap changer information.

There are 74 transformers of interest located on the premises. However, by grouping these based on rated power, rated voltage and tap changer parameters (number of taps and nominal tap position) it was possible to represent them using 17 generic transformer types.

There were slight variations in the impedance across a group, thus the generic type was modelled using the average impedance of the group e.g. there are 10 x 11.5 kV / 0.4 kV 500 kVA transformers with 5 tap positions and a nominal tap position of 3. Fig. 3 shows the spread of the positive sequence impedance as seen on the various nameplates. The generic transformer has been modelled with a positive sequence impedance of 4.27%.

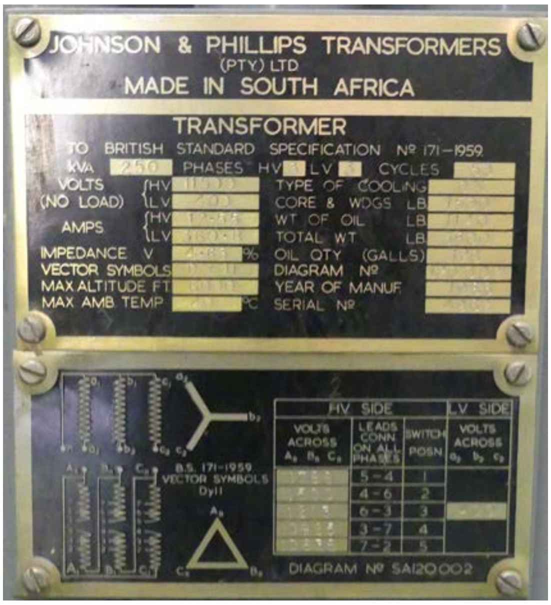

Fig. 3. Transformer nameplate captured during site walkdown

Another challenge encountered was in the vector group. Although some MV/LV transformer nameplates indicated a vector group of Dy11, all MV/LV transformers were eventually modelled as Dyn11, this is due to the fact that the star point on the LV side of the transformer is earthed as seen during the site visits and in order to achieve this in DIgSILENT, the transformer must be modelled with a neutral. This vector group also allows for provision of a neutral on the 400 V busbar which was also observed during the site visit.

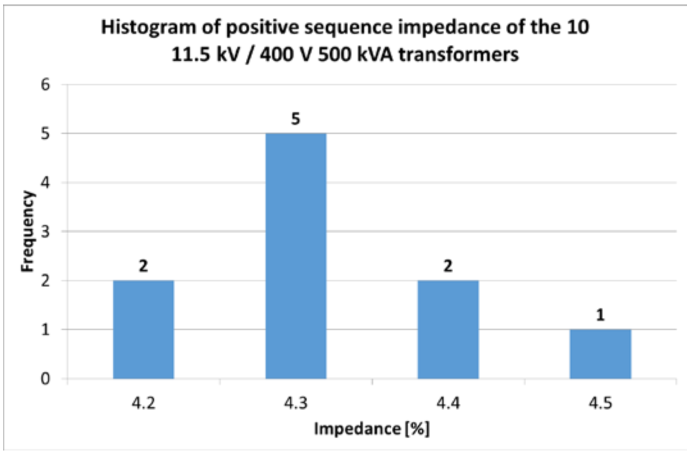

Fig. 4. Spread of positive sequence impedance of 11.5kV/400V 500 kVA transformers (nominal tap 3)

There were no data sheets available for the transformers, thus X/R ratios, zero sequence impedance as well as magnetising impedance data had to be estimated / calculated.

1) X/R ratio

The positive sequence and zero sequence X/R ratios were assumed to be equal. The actual values used in the model were derived from typical data captured in power system modelling tool known as PowaMaster.

2) Zero sequence impedance

For the 132/11 kV transformers in the main substation values were derived from typical data as per PowaMaster database. For the MV/LV transformers the value was estimated as 85% of positive sequence impedance as per the DIgSILENT manual [14].

3) Magnetising impedance

The no load losses values in kW were derived from typical data provided by a local utility. The no load current was then calculated based on an assumption that the no load losses had a power factor of 0.5 as shown in (1) and (2).

$$NL\ Losses\ [kVA] = \frac{NLLosses[kW]}{NLLosses\ pf} \tag{1}$$

$$NLCurrent[\%] = \frac{NLLosses[kVA]}{Transformer[kVA]} \times \frac{100}{1} \tag{2}$$

The manual tap position for each individual transformer was also recorded on site and captured in the model. Where data is available, a measurement report has also been included in the model containing the actual impedance (as per name plate). The impedance is assumed to be the same across all tap positions.

There are a number of substations where parallel transformers are on different tap positions which will result in circulating reactive current.

D. Cables

There was limited data available regarding the required cable parameters. The site visits did not yield much more information as the cables run mostly underground. What could be established was the following:

- The 11 kV cables are paper insulated lead covered 70 mm^2 copper cables
- Varying feeder cable sizes are used at the 400 V level

Due to the lack of information, typical information from the DIgSILENT Power Factory global type library was used to determine the resistance, reactance and capacitance per km of 11 kV and 400 V cable. The types used are the following:

- 11 kV – PILC-CU 3x70 11 kV - A paper insulated lead covered cable with 3 x 70 mm^2 copper cores
- 400 V - NYY 4 x 150SM 0.6/1_kV – A PVC insulated cable with 4 x 150 mm^2 copper cores

There was limited data on 400 V cable layouts, thus only 3 known 400 V interconnections were modelled. The length and in service status of each cable was captured in the model. The distances used were obtained from records kept by the entity and are based on site drawings. The database, had not been recently updated, thus it did not include certain new installations; therefore assumptions had to be made regarding how these installations had affected the cables they had been connected to. The normally open points were also obtained from records kept by the entity and confirmed to be correct on the operating diagram in the main substation.

E. Distributed Energy Resources

There are three solar PV installations in operation as detailed in TABLE III. For the purposes of load flow and fault level analysis, a detailed model is not required. Therefore, the in-built DIgSILENT PowerFactory PV system is used to represent each solar PV installation.

All the plants are between 100 kVA and 1 MVA and thus fall under category A3 of Renewable Power Plants (RPP) as defined in the SAGC Requirements for Renewable Power Plants [9]. As per the Grid Code, these plants are required to supply “rated power for power factors ranging between 0.95 lagging and 0.95 leading measured at the POC available from 20% to 100% of rated power”. In the case file they are set to operate at unity power factor, this parameter can be edited within the bounds set out by the Grid Code if any voltage issues are experienced due to the PV generation. The actual output of each PV plant is chosen based on the study requirements.

TABLE III. DETAILS OF EXISTING PV INSTALLATIONS

Name	**Connection Voltage**	**Rating**
Single Axis PV	11 kV	558 kWp
Dual Axis PV	400 V	203 kWp
Rooftop PV	400 V	250 kWp

F. Demand

There are approximately 50 buildings on the site supplied from approximately 34 substations i.e. some buildings have dedicated transformers that supply their load whereas others are supplied via LV from other buildings. Some buildings also have multiple supplies for their various loads. Due to location of metering at the "sending end" LV supplied buildings are represented as loads on the busbars that supply them.

The entity makes use of an online metering platform to monitor electricity consumption. It contains half hourly load data for each building. Thus load data could easily be downloaded and used, without need for coincidence factor calculations. However, the meters used do not have any redundancy thus if data is corrupt there is no alternate source. The loads in the power system simulation model are based on the loads recorded at the time that coincides with peak consumption from the local electricity supplier. A few buildings’ meters had erroneous data for this particular time, thus assumptions had to be made to ensure overall load matched what was measured at the main substation at that time.

IV. DISCUSSION

The site visits to collect data for the various network components proved successful for transformers and shunt capacitors as the nameplates contain substantial detail. Some information could not be found on the nameplates; therefore, assumptions were made in order to estimate the required parameters. These assumptions have been clearly documented such that if more accurate information becomes available, the model can easily be updated.

The data on the PV installations was available as these were commissioned recently. For now, the installations have been modelled using the in-built DIgSILENT PV system. However, the data required to represent these plants in more detail in order to assess their Grid Code compliance in terms of fault ride through and frequency response, when required, is available.

The availability of metering data online made it simple to model the loads on the premises without having to calculate coincidence factors. However, the accuracy of the meter data in some instances presented a challenge.

The loads and the output of the PV plants in the case file are based on a snapshot of the network (peak consumption from the local electricity supplier as observed in 2016). It is possible to change these to time variant profiles in order to analyse the impact of varying load and generation conditions on the network performance.

The two components that presented the biggest challenge were the local electricity supply and the underground cables. It was not possible to obtain actual minimum and maximum fault level values together with related X/R ratios from the electricity supplier. A conservative assumption was made based on circuit breaker ratings.

The cables have been represented using typical cable parameters as contained in the DIgSILENT global library as there was no data available on site. The cable distances used in the case file are based largely on information obtained from records kept by the entity, with some assumptions also being made based on GIS data.

The case file needs to be validated to confirm that the results it gives match the reality on the ground. Thereafter, this case file can be used to conduct load flow and fault level analysis studies for the existing network, as well as to determine the steady-state impact of integrating additional embedded generation in the network. The case file can also be used as a tool to create a network development plan focused on grid investments in the short to medium term.

A configuration management process is required to ensure the case file is correctly stored, maintained and updated. Should additional information become available to improve on the assumptions, the case file can then be updated accordingly.

TABLE IV. summarises the studies that the developed case file can be used for once verification is complete. Should other studies be required, it is recommended that the suitability of the case file for such be assessed based on the assumptions highlighted in this paper.

TABLE IV. SUMMARY OF STUDIES THAT DIGSILENT MODEL CAN BE USED FOR

Study	**Comment**
System healthy load flow analysis	Model can be used to determine steady state voltages and thermal loadings
Contingency studies	
Fault level analysis	Results are preliminary as fault contribution from the grid has not been confirmed
Network optimisation (Voltage profile, losses, normally open points)	Based on voltages and thermal loadings, network normally open points can be modified to reduce losses and/or improve voltage profiles

V. CONCLUSIONS

A DIgSILENT case file to represent a commercial entity's reticulation network has been developed. Site visits were conducted to acquire the necessary data and where data was not available, some assumptions and calculations were made.

Any other commercial, industrial or even residential entity wishing to simulate the impacts of distributed energy resources behind the meter on their network can utilise the methodology outlined in this paper if network data is not readily available to build a simulation model in any simulation package.

This work is ongoing, the next step is to use the model to conduct load flow studies on the network, and also to augment the model so that protection studies and dynamic studies can be conducted for the grid.

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