Embedded Generator Grid Impact Study Guideline

Version 2.0

Developed under the ***Municipal Embedded Generation Support Programme***

Partners: SALGA, DMRE, GIZ, AMEU

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Document Control

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1.0	18/10/2022	Updated structure	GV Moodley (DIgSILENT Buyisa)
2.0	07/08/2023	Updated document to include distributor's studies required as per Distribution Codes.	GV Moodley (DIgSILENT Buyisa)

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Contents

1. Objective and References

This documents aims to provide a guideline to distribution network service providers (municipalities) and end clients, on assessing the impacts of embedded generation on the electrical network. The document draws on requirements from several NRS guidelines and South African grid codes to develop methodologies and assessments, in order to evaluate the impact of embedded generation. The document also provides a standardised reporting method to allow evaluation of results in an objective manner.

The following documents form the normative references for the methodologies and assessments presented in this guideline;

- Grid Connection Code For Renewable Power Plants (Rpps) Connected To The Electricity Transmission System (Ts) Or The Distribution System (Ds) In South Africa, Version 3.1 (RPP Grid Code)
- NRS 097-2-3 / NRS 097-2-1
- NRS 048-4
- Distribution Network Code, Version 6.2
- Distribution Information Exchange Code, Version 6.2

It must be noted that any updates or changes to the above-mentioned reference documents take precedence over any recommendations that may be contained in this document.

2. Definitions and Abbreviations

All definitions used within this document are in accordance with the definitions in the Distribution Code [2].

Embedded generator

A legal entity that operates one or more unit(s) that is connected to the *Distribution System*. Alternatively a legal entity that desires to connect one or more unit(s) to the *Distribution System*.

Point of connection (POC)

The electrical node on a distribution system where a customer’s assets are physically connected to the Distributor’s assets.

Abbreviation	Meaning
CT	Current transformer
EG	Embedded generator
NMD	Notified maximum demand.
OEM	Original equipment manufacturer
POC	Point of connection
RETEC	Renewable Energy Technical Evaluation Committee

SCADA	Supervisory Control and Data Acquisition
SLD	Single line drawing
VT	Voltage transformer

2.1 Supporting Documents

This guideline is to be used in conjunction with the following supporting documents

1. Grid Impact Data Requirements Rev1.0.xlsx
2. Grid Impact Evaluation Form Rev1.1.xlsx

3. Studies and Responsibilities

The following section explains the studies that are to be undertaken to evaluate the EG impact and the responsible party for the study.

3.1 Customer Classification

When traditional consumers connect embedded generators to their networks, they become prosumers i.e. ability to both produce and consume energy from the network. The energy produced by the EG is primarily for own use. There may be certain cases whereby the energy produced can be fed back into the network. However even though the EG may not feed energy back into the network, the impact the EG will have on the network, when operational, must be assessed. Figure 1 shows an overview of the studies that are undertaken and which party is typically responsible for the studies.

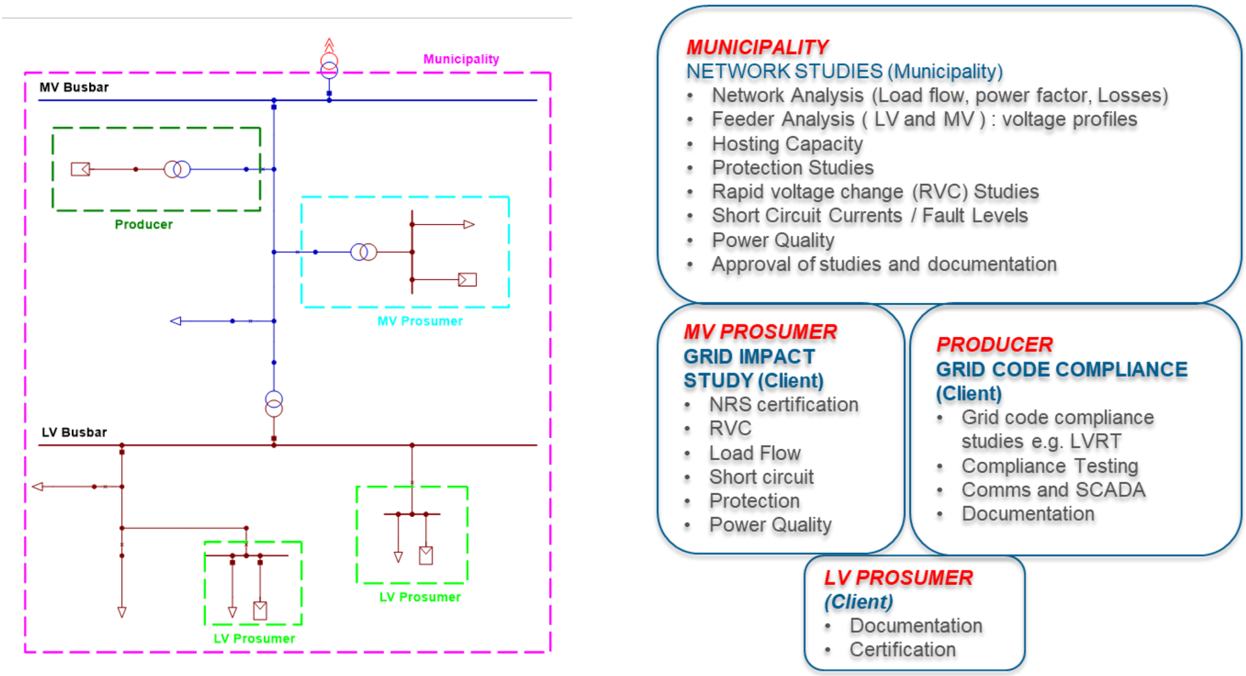

Figure 1: Studies and responsibilities

3.1.1 LV Prosumer (< 1000kVA)[1]

These customers have a LV connection to the distribution (municipal) network and typically install EG for own use. Evaluation should be done as prescribed in the NRS097-2-3 (Simplified Connection Criteria). This evaluation typically does not involve any network studies. A detailed description thereof is outside the scope of this guideline.

3.1.2 LV Prosumer (> 1000 kVA) or MV Prosumer

Such customers install EG primarily for own use. Grid impact studies will be applicable to these types of customers. Studies can be done by either the distributor or the client. This evaluation falls within the scope of this guideline and is conducted to check the impact of the EG at the POC.

3.1.3 MV Producers

These customers install EG primarily for supply of energy to the distribution network. Such customers must be evaluated against the RPP grid code and the full grid code compliance process must be evaluated i.e.,

a) Grid code compliance studies (includes steady state and dynamic LVRT, HVRT, phase jump studies etc)
b) Testing of the plant's capability and controllability
c) Submission of all supporting documents

Grid code compliance should be conducted in collaboration with RETEC. This evaluation is outside the scope of this guideline.

3.2 Point of Evaluation

It is very important to establish the reference point for evaluating the impact the EG will have on the distribution network, for all studies considered. All necessary technical requirements, will then be evaluated at this point. The RPP grid code [1] is evaluated at the point of connection (POC) between the RPP network and the distribution network.

This guideline, unless otherwise stated, will utilise the POC between the EG network and the distribution network, as the point of assessment for grid impact studies.

3.3 Storage Systems and Synchronous Generation

The analysis of storage systems, in particular battery storage systems and synchronous backup generation are excluded from this version of the guideline. It must be noted that that evaluation of battery storage systems must be done as per the requirements of the latest version of the "GRID CONNECTION CODE FOR BATTERY ENERGY STORAGE FACILITIES (BESF) CONNECTED TO THE ELECTRICITY TRANSMISSION SYSTEM (TS) OR THE DISTRIBUTION SYSTEM (DS) IN SOUTH AFRICA". Besides the studies listed in this guideline consideration must be given for both charging and discharging of battery storage systems as well as their intended time of day usage.

Regarding synchronous backup generation, where instances occur during the operation of the generators that result in the generators being grid tied e.g. load transfer to/from the generators, then these scenarios need to be considered in the dynamic studies of the generators.

[1] Some distributors reserve the right to have grid impact studies performed for installations > 350kVA

4. Data Exchange

This section specifies the minimum set of data to be exchanged for the grid impact studies to be completed.

The requirements of the data to be exchanges is governed by the distribution code, info exchange and any contradictions in requirements, the distribution code information exchange will take precedence. This document stipulates the minimum set of data that should be exchange between the different parties however each party has the right to request additional data as stipulated by the distribution code.

4.1 Customer conducted Grid Impact Studies

The document ***Grid Impact Data Requirements Rev1.0.xlsx***. should be used as a supporting document for this section. The distributor should complete the worksheet **Distributor Info**.

Where the EG applicant is requested to conduct the grid impact study, the following data should be provided by the distributor to the applicant;

i. The minimum and maximum short circuit current / fault level (kA / kVA) at the POC
ii. The equivalent network impedance (X and R) from the POC, looking back into the distributor network
iii. Typical operating voltage.

Should the distributor also require the applicant to evaluate the singular *impact that the EG will have on the feeder* connected to the POC, then the following information should also be provided, *at the feeder infeed point*;

i. Short circuit current / Fault level (kA / kVA)
ii. Equivalent network impedance looking back into the distributor (municipal) network, at the feeder infeed point.
iii. Feeder cables and lengths. Preferably a SLD or drawing of the feeder
iv. Feeder loading

Regarding the feeder loading, the distributor need only provide cumulative values of the feeder loading and other EG on the feeder. Ideally provide the maximum and minimum loading of the feeder NOT taking the existing SSEG into account. For example assume the maximum feeder load is 1 800 kVA and minimum load is 1 200 kVA. The total other EG on the feeder is 700 kVA (0.7 MVA). Then, the distributor may provide the following information;

- Maximum feeder load = 1 800 kVA excl EG
- Minimum feeder load = 1 200 kVA excl EG
- Total other EG installed on feeder = 0.7MVA

If measurements of the feeder loading are available, then the distributor can provide the maximum and minimum feeder loading only, and clearly state that the values provided take into account the other EG installed on the feeder already.

Where evaluation of the **protection co-ordination** between feeder protection and customer protection is required, then the distributor should also provide the following information;

i. The type of protection functionality utilised e.g. 50/51 or relay model used and active functions.
ii. Protection settings e.g. Standard inverse, time multiplier = 0.2, current pickup = 0.8
iii. CT/VT ratios.

4.2 Distributor conducted grid impact studies

In order for the distributor to execute the grid impact studies, it is recommended that the customer complete the Worksheet **Customer Info** in the Excel file titled **Grid Impact Data Requirement Rev 1.0.xlsx**

The applicant should supply all supporting documentation, referenced to the relevant sections in the completed Excel file, for easy access by the distributor.

4.3 Power Quality Assessment

Where the total installed EG is greater than 5 MVA, then a separate power quality assessment at the POC needs to be undertaken. The distributor would need to provide

- the apportioned current harmonic limits
- flicker limits
- voltage unbalance limits
- network impedance sweeps at the POC looking back into the distributor network

to the applicant, in order to complete the assessment.

The evaluation procedure to be used should be as per Appendix 13 of the RPP grid code.

5. Grid Impact Studies

The studies that need to be completed are explained in this section. Studies are separated into required studies and optional studies. Where the distributor requests the applicant to conduct the studies, the distributor must clearly state the optional studies that are to be completed by the client.

5.1 Required Studies

These studies must be completed for all grid impact studies.

5.1.1 Assessment of production and consumption data

A detailed analysis of the consumption and production data is required to establish the different operating scenarios the EG may operate under. In order to do this the following is recommended for consumption measurements;

a) Measurement of the site consumption should be undertaken at the POC. Preferably recording the kW and kVAr at the POC.
b) Where kW/ kVAr is measured, then the minimum resolution should be 30 minutes between data samples
c) If energy kWh is measured then the minimum resolution should be 30 minute between data recordings
d) The minimum period of measurement should be at least 1 week, however recordings over a month or a year are preferable.

If the EG is not installed, then the simulated EG production should also be provided. The simulated EG production should consider any seasonal change in production.

The raw data should be processed (e.g. using histograms) in order to remove erroneous data due to;

a) Outages or load shedding
b) Missing data

Where an EG is installed, the measured EG production, separated from the consumption, should be provided.

The data should be clearly labelled including units and preferably in Excel format.

Once the data has been processed, further analysis using pivot tables are required in order to establish the;

a) Maximum and minimum site load consumption (no EG considered). Both the active and corresponding reactive power must be determined, at the same time stamp. If only active power is available, a suitable assumption based on the nature of the customer's consumption needs to be made about the power factor.
b) Maximum and minimum EG production (kW)

If the minimum generation was not calculated, the following criteria can be used to determine minimum generation

i. For category A plants, 20% of maximum generation
ii. For category B and C plants, 5% of maximum generation

This aligns with the grid code requirements of minimum active generation where the reactive power must still be controlled.

5.1.2 Load Flows Studies

Utilising the processed data in 5.1.1, the following study scenarios should be setup for load flow analysis;

a) Zero generation, (maximum) high load: (ZGHL)
b) Zero generation, (minimum) Low load: (ZGLL)
c) (Minimum) Low generation, (maximum) High load: (LGHL)
d) (Minimum) Low generation, (minimum) Low load: (LGLL)
e) (Maximum) High generation, (maximum) High load: (HGHL)
f) (Maximum) High generation, (minimum) Low load: (HGLL)

For all scenarios, the following control conditions of the EG must also be studied;

i. The EG operating at unity power factor (at its terminals).
ii. The EG operating in power factor control mode, controlling the power factor at the POC.

All studies must take into account the reactive power limits of the EG in order to be deemed valid. Where reactive power limits are reached, this must be clearly indicated in the results.

Where **power blocking** is installed or required by the distributor, then the studies must not consider any power export to the grid. If only active power is blocked, the impact on power factor must be clearly reported.

If the **feeder** analysis is required, then the six study scenarios listed above for the EG need to be considered with;

- Maximum and minimum feeder loading
- Maximum and minimum feeder EG production

For all studies, the following parameters should be recorded/saved;

i. voltages at the POC
ii. equipment loading on the feeder
iii. active and reactive power at the POC (client side)
iv. power factor at the POC (client side).

5.1.3 Short Circuit Current Contribution

For a fault at the POC, the short circuit current contribution of the EG to the POC, needs to be evaluated.

If static analysis methods are used to calculate the short circuit current contribution, it is recommended that the IEC60909:2016 method be used. EG equipment manufacturers specify the short circuit current contribution from tests and this contribution can be entered into the calculation. The maximum short circuit current contribution should be calculated from the EG at both the terminals of the EG and the POC.

5.1.4 Rapid Voltage Change

Rapid voltage change, is a study of the instantaneous step change in voltage before and after a switching or disconnection/ connection event in the system. To study the rapid voltage change, the following methodology can be followed;

1. Execute an AC load flow calculation considering all tap changers, shunt tapping and other control actions in the network.
2. Save the voltage results at the POC.
3. Fix all the transformer and shunt tap positions.
4. Disconnect the total installed EG. Regardless of how unlikely this may seem, this is the worst case consideration.
5. Execute an AC load flow study, however do not consider any shunt or transformer tap changer action. The tap positions should stay locked as per 3 above.
6. Record the results of the voltage at the POC.
7. The % step change should be calculated as per the formula

$$\Delta U/U_N$$
$$\%$$

5.2 Optional Studies

5.2.1 Feeder Losses

If the distributor provided the feeder information, then the losses for the different operating scenarios should also be evaluated.

5.2.2 Protection Co-Ordination

Some EG applicants may review and update their protection relay settings on site, after the installation of EG. It is important that the co-ordination between the customer relay and the feeder relay is evaluated to ensure that the customer relay operates first, for any faults within the customer network.

5.3 Power Quality Assessment

Where the total installed EG is greater than 5MVA in capacity, it is recommended that a separate power quality evaluation is performed at the POC. The recommended method for evaluation is as per the RPP grid code, Appendix 13.

For sites with total installation of EG < 5MVA, the individual inverters used on site must not exceed the limit specified in Appendix 13 A13.4.3.1 of the RPP grid code [1]. NRS 097-2-1 certified conformance is adequate evidence of power quality compliance for systems < 5MVA.

5.4 Deliverables of Grid Impact Studies

Whilst the grid impact study report is an integral part of the approval process, it is recommended that all supporting documents is also provided to the evaluator. A list of deliverables is provided

- Report
    - Clearly indicating study results, assumptions and findings

    - Summary of key information e.g. anti-islanding, protection, 2-breaker configuration, confirmation of mechanical chop over if EG runs in island mode, protection (anti-islanding, over-frequency, voltage range)
- Supporting documents (NRS certificate and test document, SLD of site showing protection, power blocking, SCADA, series protection switch, location of EG, location of CTS, VT, metering)
- Simulation model (if simulation software utilised for the studies)
- Copy of Application form
- Completed Grid Impact Data Requirements Rev1.0.xlsx document
- Completed Grid Impact Evaluation Form Rev1.1.xlsx document

6. Assessment of Grid Impact Study Report

6.1 Evaluation criteria

Since the assessment is performed at the POC, the criteria used to evaluate the results must take into account the operation of the EG. When the EG is operating as;

Consumer: The criteria used to evaluate the impact will be as per the supply agreements e.g. allowed voltage ranges, NMD, minimum power factor etc.

Producer: The criteria used will be as per the requirements of the RPP grid code [1]. The supply agreement should also be taken into account.

The assessment of the results of a grid impact study along with supporting documentation, should be done utilising the Excel file named "***Grid Impact Evaluation Form Rev1.0.xlsx***".

6.2 Assessment of Study Results

The following notes are provided as additional considerations when evaluating the results.

For all data processing and studies, the applicant is to clearly state the methodology and assumptions used.

6.2.1 Classification of EG category

The RPP grid code categories are determined by the rated power of the RPP. The rated power is defined in the RPP grid code as "*The highest active power measured at the POC, which the RPP is designed to continuously supply*."

Considering EGs are installed primarily for own use, the highest active power that can be delivered at the POC may vary, as it is a function of the consumption on the EG site. So this maximum power is not necessarily continuous. For example, a total EG installation is 6 000kW and under certain operating conditions may supply a maximum of 500kW to the grid, for a short period of time. If the RPP grid code definition is utilised, then the EG will be classified as a category A plant. However this 500kW is not continuous maximum power and can only be delivered for short period of time.

For the purposes of this guideline, the maximum installed capacity of the EG will be utilised to determine the category of the EG. In the case of this example, the EG will be classified as category B. All requirements of the RPP Grid code for category B plants will therefor be applicable to the EG.

Where the results indicate that the EG is supplying power to the network, the evaluation of the EG's ability to control the power factor at the POC is required. Depending on the category of the EG, the following power factors is required, when export maximum power to the network;

- Category A3: 0.95 leading and lagging,
- Category B: 0.975 leading and lagging
- Category C: 0.95 leading and lagging

6.2.2 Production vs consumption

The client should provide a detailed analysis of the load/consumption measurements, at the POC. The raw data can be provided along with the processed data, clearly indicating how the maximum and minimum consumption (load) was determined.

Often clients may measure the energy at the POC (kWh). It can be assumed that the measured value for that hour, is the peak kW recorded for the hour (assuming hourly interval reporting).

If the EG is still to be installed, the applicant is to provide a simulated production data. Preferably the simulated production should take into account seasonal variations of the EG as well.

The maximum load consumption and EG productions as well as the minimum load consumption and EG production, independent of each other, should be clearly stated in the report.

6.2.3 Load Flow

The results of a minimum of 6 study scenarios identified in 5.1.2 must be presented in tabular format. The following results must be checked;

From NRS 048-2: [2]

a) The magnitude of supply voltage shall be within ±10% for voltage levels <500 V and ±5% for voltage levels >500 V.
b) The compatibility level for voltage unbalance on LV, MV and HV three-phase networks is 2%. On LV networks, a compatibility level of 3% may be applied.

The NRS 097-2-3 states the following as technical limits that constrain embedded generation:

c) The maximum change in LV voltage caused by embedded generation may not exceed 3%.
d) The thermal ratings of the installed equipment such as feeder cables may not be exceeded.
e) Where thermal loading of equipment on the client side is noted, the client should provide necessary plan to upgrade in order to reduce/limit network failure.

Results considering different feeder loading scenarios and other EG should also be presented.

The results for operating the EG at unity power factor and power factor control mode are to be presented.

Ensure that the reactive power limits are implemented in the models and taken into consideration, in the study calculations.

6.2.4 Rapid Voltage Change

The NRS 048-4 [3] Table A5 specifies "Compatibility levels are not defined for rapid voltage changes (these are largely addressed by flicker requirements). Table A.5 provides indicative planning levels for rapid voltage changes as a percentage of nominal voltage (i.e., ΔU/UN, in %) under normal operating conditions. These limits depend on the number of changes in a given period of time (r).

[2] Note that requirements may be amended by mutual agreement (and specified in the connection agreement). For example, voltage of ±7.5% is often considered acceptable above 500 V.

Table A.5 — Indicative planning levels for rapid voltage changes as a function of the frequency of repetition

1	2	3
Repetition rate of changes in a period of time r	**Rapid voltage change as a percentage of nominal voltage** $\Delta U/U_N$ %	
	MV	HV/EHV
$r \leq 1$ per day	6	3-5
$1 < r \leq 4$ per day	5	3-4
$r \leq 1$ per hour	4	3
$1 < r \leq 10$ per hour	3	2,5

NOTE 1 At HV/EHV, the permissible voltage change has a wide range due to the significant range of voltage levels covered (e.g. >35 kV to 500 kV).

NOTE 2 Higher values may be permitted under abnormal system conditions.

The study is done considering a worst-case event of a trip of the total EG on site. Such events are assumed to occur less than 1 times per day therefore the maximum allowable step voltage change limit should be 6 %. Considering that there may be other EG on the feeder that could also possibly trip, **half this limit** i.e., 3 % should be use as the limit for the RVC evaluation.

The RVC should also be evaluated with no EG present on the site.

If it is found that the RVC for cases both with and without EG are > 3%, then check the results to see if the EG improved the RVC (made it less) when in service as compared to when there is no EG in operation.

6.2.5 Feeder Losses

Feeder losses are reported more for information rather than for evaluating the EG for connection to the network or not.

6.2.6 Protection co-ordination

Where clients have updated their onsite protection settings, the following should be evaluated

i. There is sufficient grading margin between the feeder protection and the client's protection
ii. Where reverse power into the distributor network is noted and the injected power is greater than the feeder load, this may result in a reverse power flow through the feeder protection. If there is directionality protection active on the feeder protection, this may be activated hence should be checked.
iii. The difference between the feeder loading current and pickup current, for the different scenarios, should also be checked.

6.3 Assessment of mandatory grid code requirements

The grid code specifies several requirements that are to be considered as mandatory when evaluating the impact and compliance of the EG. The following requirements are extracted from the RPP grid code [1] and should be checked by the distributor

If the EG has NRS 097-1 certification:

i. Most of the requirements of the grid code will already be checked and tested. The NRS 097-2 test certificate and test report should be supplied with the grid impact study report.

ii. The NRS-097-2 certification does not take the following into account and the distributor should ensure that the installers adjust on site.
   a. The NRS 097-2 test is conducted for the EG to trip if the frequency exceeds 52 Hz for longer than 4 seconds. To be compliant with the RPP grid code clause 6.1 (3) [1] , it is recommended that the installer adjust the over-frequency limit to trip the inverters if the frequency exceeds 51.5 Hz for longer than 4 seconds.
   b. The reconnection time after disconnection of the EG should be > 60 s to makes it compliant to the RPP grid code clause 5.1.1 (1) [1] .

Where the EG is not tested to NRS 097-2 certification, the following test results of the EG must be presented:

Voltage Assessment:

- Ensure that the voltage range of operation is as per Section 5.1 of the RPP grid code [1] .

Frequency Assessment:

- Frequency range of operation is as per section 5.1 of the RPP grid code
- The EG is fitted with over frequency power reduction functionality as per Section 6 of the grid code [1].

Anti-Islanding:

- The unit is fitted with anti-islanding capability. Where no such capability is on the EG, proof of an external protection relay needs to be supplied as part of the grid impact study report.

Safety Disconnection:

- The EG should be connected through 2 series disconnectors to the POC and distribution network. These disconnecting devices can be within the EG or external to the EG.

6.4 Communication

Embedded generators or generator systems larger than 100 kVA may have additional requirements, for example, they must be able to receive communication signals for ceasing generation/disconnection from the utility supply, if the utility requires such. Communication facilities shall be provided to utility at no charge for integration with SCADA or other systems when required. Refer to Annex G (G.1) of NRS 097-2-1:2017 for further details.

7. Distributor Network Impact Studies

The studies recommended in this section are as guided by the Distribution Network Code. It is important that all distributors be familiar with all the requirements of the code and ensure compliance to the entire code thereof.

As a guide, Section 4 (9) of the Distribution Network code stipulates the studies that distributors need to complete and is extracted below.

9) The Distributor shall conduct Distribution System Impact Assessment studies to evaluate the impact of additional loads or embedded generator or major modification to the Distribution System. The assessment conducted shall include the following where relevant:

(a) Voltage impact studies

(b) Impact on network loading

(c) Fault currents

(d) Coordination of protection systems

(e) Impact on the system's quality of supply

(f) Strengthening of the system

Further to the studies above, it is also recommended that the distributors also conduct hosting capacity studies. Such studies will enable the distributor to assess the total amount of EG that can be connected to the network, without the need to upgrade the network.

8. References

[1] SA Grid Code Secretariat, "Grid Connection Code for Renewable Power Plants (RPPs) Connected to the Electricity Transmission System (TS) or Distribution System(DS) in South Africa. Version 3.1," NERSA, Johannesburg, January 2022.

[2] RSA Grid Code Secretariat, "Distribution Code Glossary, Version 6.2, January 2022," NERSA, Pretoria, 2022.

[3] NRS, "NRS048-4 Electricity Supply - Quality of Supply," ESLC NRS, South Africa, 2009.