THE IMPORTANCE OF GRID IMPACT STUDIES FOR MUNICIPALITIES

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1. Introduction

With the relaxing of the licensing requirements for embedded generators (EGs) up to 100MW, for own use [1], municipalities throughout South Africa have been inundated with applications from clients wanting to install their own EG. This has resulted in many municipalities being overwhelmed since they are still in the process of setting up application and approval processes for EGs. Further to this, many municipalities do not have sufficient technical resources to adequately evaluate the impact these EGs will have on their network.

The NRS 097-2-3 [2] can be utilised to approve an EG to ensure it will have minimal impact on the network, however this is limited to low voltage (LV) connected customers, with EG up to 350kW. Since the limit is 100MW [1], and with most clients are wanting to install as large an EG system as possible, to maximise the financial benefits, this leaves a very large number of potential EGs, where the impact on the network, cannot be effectively analysed. Sustainable Energy Africa have setup a grid impact specification guide [3] to assist municipalities, as to what grid impact studies need to be conducted, in order to analyse the effects the EGs will have on their network.

The studies recommended in the guide [3] are drawn out of the regulatory requirements for embedded generators [4], various NRS guidelines and SANS standards.

Besides installing EG, many customers are also installing storage, in particular, battery energy storage systems (BESS). So further to the need to understand the impact EGs has on the networks, municipalities also need to understand the impacts storage will have on their networks and evaluate their compliance to the BESS grid code [5].

Grid impact studies are conducted from 2 different perspectives, i.e.

1. the customer evaluating the impact their EG will have on their point of connection (POC)
2. the municipality evaluating the collective impact the EGs will have on the larger network.

This paper will look into the different types of grid impact studies that need to be conducted (drawn from the requirements of the grid codes and guidelines), by whom the studies should be conducted, the data required to conduct the studies, the results that are produced from such studies and the interpretation of these results.

2. From Consumer to Prosumer

The relaxing of the licensing requirements for EGs [1] has led to the conversion of customers from consumers to prosumers. Prosumers are customers that both PROduce and conSUME electrical energy from the network. Figure 1 illustrates the concept of a prosumer and the net electrical energy at the point of connection (POC) or point of supply (POS).

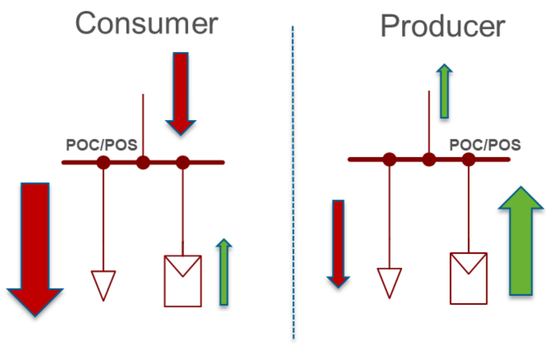

Figure 1: Concept of a customer that is both a producer and consumer (prosumer).

Many prosumers will install EG capacity that is typically less than or equal to their maximum demand (as a consumer). In such a case, simple arithmetic would then imply that this customer will, at best, not send any power back into the network (back feed) and consume all of their own production. However, the analysis of this type of customer, from a municipal perspective, is not as straight forward. In order to fully understand how this new customer will impact the network, it's important to analyse the customer's consumption and production over a period of time (day, month, year). Consider Figure 2, where a typical customer consumption and production profile are super-imposed on each other. The customer in this case has installed sufficient EG capacity, approximately 140kW to match the maximum load consumption (160kW) at approximately 7pm. However, the maximum EG production occurs at 12pm when the load consumption is significantly lower (60kW) thus resulting in excess power from the EG being fed back into the network. At this time in the day, the customer is a producer to the network. However, at 7pm, the production from the EG is almost 0, resulting in the customer consuming power from the network. So, in a day, this customer will be a producer to the network from 08:00 until 16:00 and a consumer for the remainder of the time.

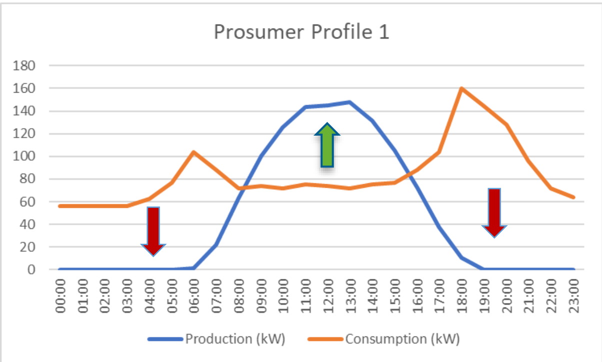

Figure 2: Prosumer with installed EG capacity approximately equal to maximum demand.

Next consider another customer that installs EG capacity of 400kW, that is significantly less than their maximum demand of 1000kW as shown in Figure 3. Also, the maximum production time coincides with maximum consumption time. The profile shows that there will certainly be no chance of back feed into the network. However, if there is one the thing the COVID pandemic has taught us is that there are no certainties in life. Consider the customers minimum load consumption of approximately 200kW. Assuming this customer is not present at their premises during the day (e.g., holiday) then the consumption would stay approximately equal to the minimum consumption value for that day. However, at midday this consumption is less than the installed capacity of 400kW, resulting in excess power being fed back into the network again. So, whilst the daily profile may not reveal this situation, a monthly or yearly profile certainly will.

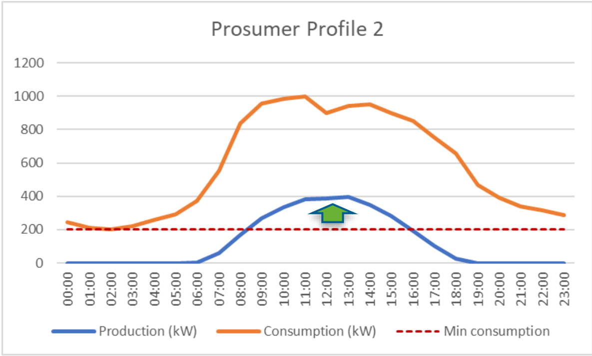

Figure 3: Prosumer with maximum production coinciding with maximum demand.

To further complicate matters the production of the EG may be both weather and seasonal dependent.

It is clear that with tens of thousands of potential prosumers in the municipal network, the impact of the EGs on the network can vary depending on several factors. Having little or no knowledge of the impact of EGs on the grid, will make planning, operating and protection of the power system near impossible. Therefore, grid impact studies are an important aspect for the municipalities to understand how the EGs are going to affect their electrical networks.

3. Who is responsible for grid impact studies?

Considering the reality of limited/scarce resources at municipalities, the additional requirement for municipalities to conduct grid impact studies, will be impossible. Furthermore, the execution of the grid impact study, needs to be done in such a manner as to provide meaningful results with limited information exchange between municipality and customer (prosumer).

This then begs the question, "Can the municipality ask the client to conduct a study of the impact the client's EG will have on the municipal network?". The answer is, "Yes, with limitations". If the municipality requested that each customer installing EG, analyse the effect they will have at their POC or POS on the network, then the municipality need only evaluate the results against required standards and codes, to determine if this is an acceptable impact or not.

4. Grid Impact Studies: Customer Level

Now that the nature of the prosumer electrical profiles is understood and that the prosumer can evaluate the impact they will have on the network, at their POC/POS, the next steps is to determine what data needs to be exchanged and also what studies need to be done.

4.1. Data to be exchanged

In order for the customer to evaluate the impact their EG will have at the POC/POS, the customer will need to know at least;

1) Fault level / Short circuit current (in MVA or kA)
2) Equivalent network impedance (X, R) from the customer POS/POC looking back into the municipal network.

Regarding the fault level, it is important that the municipality calculate this value based on fault levels from their HV infeed. Worst case impacts are noted when the fault level is low (weak) so, if possible, the fault level given to the customer should be the weakest fault level that the customer can expect at their POC, typically under contingency operation (e.g., loss of HV/MV transformer etc). The equipment fault current rating supplying the customer (or from upstream busbar rating) should not be provided as a fault level to the customer.

Regarding the equivalent network impedance from the POC into the municipal network, ideally this should also be calculated and provided to the customer. NRS 097-2-1, Annex C [2] provides some guidance for typical network impedance for LV connect customers, however for MV connected customers it is recommended to calculate this impedance, since the transformers and cabling will impact the equivalent network impedance.

With this information the customer is able to create a Thevenin equivalent representation of the municipal network at the POC/POS, and in turn study the impact that their EG will have on the POC/POS.

If, however the municipality requires that the customer also evaluate the impact the EG will have on the feeder supplying the POC/POS, then this information also needs to be provided. Typically, the following information can be supplied, i.e.

i. Fault level at the infeed to the feeder
ii. Equivalent network impedance (X, R) from the feeder infeed looking back into the municipal network.
iii. Feeder cable(s) used and lengths
iv. Typical feeder maximum and minimum loading including power factor

Optionally, if the municipality requires the customer to check impact on the feeder protection, then the information about the protection relay, settings, CT or VT ratios etc, should also be provided.

4.2. Low Voltage (LV) connected prosumers and EG < 350kW

As per NRS 097-2-3, LV customers are all customers that are connected to the interconnected power system with the POS or POC nominal voltage < 1000V. Further to this, if the prosumer installed EG capacity is <350kW, then the simplified methodology of evaluation, as per NRS 097-2-3 can be utilised to evaluate the application. The analysis of this type of customer is outside the scope of this paper.

4.3. MV connected prosumers or > 350kW

The focus of this paper is on the grid impact studies that need to be conducted by the customers that satisfy the criteria of installing EGs > 350kW (for own use) and/or are also medium voltage (MV) connected.

The customers that fall into this classification need to produce a grid impact study report, with supporting documentation, as part of their EG application approval process. The grid impact study should cover the following aspects;

4.3.1. Load vs production profile (with BESS)

One of the most important aspects in evaluating the impact of the EG on the grid is to understand the load vs production profiles of the customer. The customer should produce a detailed analysis of the expected EG production vs a typical consumption profile, over a specific period of time, preferably a daily profile shown over a typical week of operation. These profiles should be for the total load and production. Utilising the profiles or statistical analysis methods, the customer should also declare their maximum and minimum, load and generation (production) values, for the site. Utilising this information, at least 4 scenarios will need to be studied by the customer i.e.

- High generation, High Load (HGHL)
- High generation, Low Load (HGLL)
- Low generation, High Load (LGHL)
- Low generation, Low Load (LGLL)

Should the customer also install storage, e.g., BESS, then the study scenarios will increase since the following scenarios also need to be considered, with each scenario above i.e.;

- BESS charging
- BESS discharging

The control of BESS can be quite complex, based on time of day and also the load or production on the customer site. So, each possible operating scenario of the BESS, needs to be added to the scenarios identified, so that the full operating range of the production and BESS can be studied. A typical BESS time of use chart is shown in Figure 4.

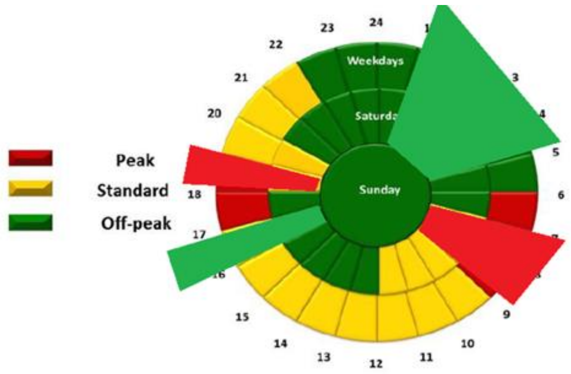

Figure 4: Typical BESS time of use chart.

4.3.2. Load Flow

Once all the scenarios have been identified, a load flow study for each scenario needs to be conducted. The purpose of load flow studies is to analyse the voltage variation at POC/POS and loading (thermal) of the network.

4.3.3. Short Circuit Current

All generation sources will contribute to the short circuit current (fault current) in a network. Some EGs contribute more than others e.g., a synchronous generator can contribute up to 6 times its rated current whereas most PV inverters will contribute up to 1.2 times their rated current. What's important to note is that this contribution is at the terminals of the EG however the contribution of all the EGs on site needs to be reported at the POC/POS.

If analysis is to be done using static short circuit calculation methods, then it is recommended that the IEC60909:2016 edition be used. This methodology allows for the specification of the contribution at inverter level, and calculates a more acceptable result, when compared to previous versions, since it accounts for the contribution of inverter-based technology. Alternately a dynamic study can be done to evaluate the short circuit current from the inverters, however this will require detailed modelling of the dynamic controllers of the inverters.

4.3.4. Rapid Voltage Change (RVC)

A rapid voltage change study is the analysis of the instantaneous (step) change in voltage before and after an event. In the case of grid impact studies, the event considered would be the trip/loss of all the EGs on a customer's site, simultaneously.

RVC studies are done by performing two load flows i.e., one before the trip and one after the trip. For the analysis after the trip, no tap changer or other network controller action should be considered. The results should be reported as a ΔU/UN, in %. RVC studies must be conducted for all scenarios identified in 4.3.1 and should be compared to a scenario with no EG on site.

4.3.5. Network (Feeder) Losses

If the customer was provided information about the feeder, then the customer is also able to evaluate the impact on feeder losses, for the different operating scenarios. This can also be compared to the scenario with no EG installed on the customer site.

4.3.6. Protection Assessment

The customer must firstly clearly indicate suitable protection onsite to ensure that any faults on their site is cleared before affecting the municipal protection. With the installation of EG, this may require a review of the protection settings on the client's side and they should clearly show updated settings in the report.

If the customer was provided information about the feeder protection, then the customer will be able to evaluate the impact the EG will have on the feeder current, under normal operation. Since EG will decrease the current drawn on a feeder, this will lead to a larger discrimination between the relay pickup current and feeder current, when considering the various operating conditions with the EG active.

4.3.7. Power Quality

Where the total installed EG capacity exceeds 5MW, power quality assessment is required as per the Renewable Power Plant (RPP) gride code [4]. Assessment requires that a class A power quality meter is installed at the POC/POS and measurements are taken (up to the 50^{th} order harmonic), for a minimum period of 10 days. The municipality would be required to provide the customer with apportioned harmonic limits at their POC/POS, in order for the customer to check if the harmonics are acceptable (within limits).

4.4. Producers

Unlike prosumers, who produce electricity (energy) primarily for own use, producers (often referred to as renewable power plants, RPPs) produce electricity (energy) for sale to the grid (third party). The bulk of the energy produced by the EG, is delivered to the grid. As such, there are further requirements to the grid impact studies identified in Section 4.3, for producers.

Producers will need to be evaluated using the full scope of the RPP grid code [4]. As such, they will need to prove;

I. <u>Controllability:</u> There is sufficient communication to the EG site, in order to control the production as per the requirements of the RPP grid code [4].

II. <u>Capability:</u> the EG site has sufficient capability (reactive power, active power, reactive current support) in order to support the grid as and when called upon.

Not only will the compliance to the code need to be done by means of studies, the EG will also need to be physically tested to demonstrate compliance. These test results need to be backed up by supporting documentation, all cross-reference to the RPP grid code [4].

The evaluation of grid code compliance by producers is handled by Renewable Energy Technical Evaluation Committee (RETEC) which falls under NERSA.

Typical studies undertaken in the grid code compliance study are;

- Reactive and voltage capability assessment
- Voltage Ride Through (Low / High)
- Frequency Assessment
- Phase jump evaluation
- Short Circuit current evaluation
- Transient stability (synchronous machines)

The details of this evaluation process falls outside the scope of this paper.

5. Evaluation of Grid Impact Study Results (Customer level)

Once the studies have been completed, the results need to be evaluated. This section provides a guide on how to evaluate the results of grid impact studies.

5.1. Low Voltage LV connected prosumers < 350kW

Since this evaluation is done against the NRS 097-2-3 guideline, the client should submit as part of their approval process, the NRS 097-2 certification of the inverter. A useful evaluation tool can be found at https://www.sseg.org.za/sseg-assessment-spreadsheet/ to asses such applications and is outside the scope of this paper.

5.2. MV connected prosumers and > 350kW

When assessing the grid impact study report, the following criteria can be used to determine if the impact is acceptable or not.

5.2.1. Load vs Production profile (with BESS)

It is very important to understand how the customer will typically operate their EG (and BESS) against their load consumption therefore the municipality must check that all conceivable operating scenarios have been considered. The municipality should also check if the declared maximum and minimum loading and production, correlates with other sources of data e.g., billing data and ensure that the customer has provided sufficient evidence to back up their determination of the operating scenarios.

5.2.2. Load Flow

Since load flow focuses on voltage and loading, check that there are no conditions that cause the POC/POS voltage to go outside of acceptable NRS levels. Also check that there is no overloading on the municipal cables/lines. If permitted, check the expected back feed under excess production scenarios. Where no back feed is permitted into the network, the municipality should check that the customer has effectively blocked the power at the POC/POS and also supply proof of power blocking scheme/relays used.

For a more detailed evaluation of the results there are three broad operating modes to consider i.e.

<u>**When the customer is a consumer**</u>: In these cases, the customer will be consuming active power from the network and at all times should ensure that the power factor is maintained within supply agreement terms. In cases where blocking (no back feed permitted), the active power can be approximately zero whilst the reactive power can still be considerably high, resulting in a very poor power factor at the POC/POS. In all cases the customer needs to ensure that the reactive power demands are catered for and the power factor is maintained as per supply agreement.

<u>**When the customer is a producer**</u>: In such scenarios, excess generation is exported to the grid therefore it is important that full control can be maintained over the EG. Control of power factor at the POC/POS becomes essential as it is a requirement as per the RPP grid code [4]. The power factor limits that need to be achieved are dependent on the total installed capacity of the EGs on site.

<u>**When customer has BESS only operation**</u>: When the customer has their onsite BESS operating only, then the requirements at the POC need to be evaluated against the BESS grid code [5]. Whilst it is highly unlikely that excess energy will be exported into the grid when the customer is operating their BESS, the charging of the BESS should be carefully looked at as this increases the load consumption of the customer, especially when

the EG is not able to charge the BESS e.g., cloudy day or EG offline (low generation scenarios). Control of power factor at the POC/POS also becomes essential as it is a requirement as per the BESF grid code [5]. The power factor limits that need to be achieved are dependent on the maximum amount of storage capacity of the BESS.

5.2.3. Short Circuit Current

The contribution of the customer EG to the short circuit current (fault current) needs to be compared to the total contribution from the network to the POC/POS. Whilst it is not expected for inverter based EGs to make a significant contribution to the POC/POS, where existing fault levels are close to equipment ratings, then the contribution from EGs needs to be carefully looked at.

5.2.4. Rapid Voltage Change

The results of the RVC studies should be compared to the limits as specified in the NRS 048-4, Table A5. It is recommended that half the NRS limits be used as the threshold for comparing the RVC results.

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.

If the RVC results are found to be greater than half the NRS048-4 limits, then analysis of the RVC without the EG should also be considered. If the RVC results without EG is also greater than half the limits, then this indicates a weak network connection for the customer. Check to see if the EG improves the RVC results.

If the RVC results are found to be unacceptable (greater than the full limits) then it is recommended that the EG is not approved. Network strengthening or reduction in EG size needs to be considered in such cases.

5.2.5. Network (Feeder) losses

Feeder losses are evaluated to assist with future planning of network upgrades, should significant penetration of EGs on a feeder increase the losses to unacceptable levels

5.2.6. Protection Assessment

Protection assessment is important to determine if adjustment to the feeder settings is required. Also, the client is to ensure that their protection is co-ordinated with the municipal settings, after the installation of EG on the customers site to prevent nuisance tripping.

5.2.7. Evaluation by certification

Besides the study results that need to be considered, the following items must also be checked by the municipality;

i. NRS 097-2 certification for equipment (inverters)
ii. EG complies with the required normal operating voltage and frequency ranges as specified in the RPP grid code [4]
iii. Anti-islanding functionality is enabled. In the case of inverters this is a built-in function. In the case of other EGs e.g., synchronous machines, a separate protection relay may need to be installed.
iv. The EG is fitted with mandatory over and under frequency capabilities as required by the RPP grid code [4]
v. Two series isolation devices as per NRS 097-2

Where requested by the municipality, the following items should also be checked

vi. Suitable communication interface in order to connect to municipality control centre [6].

5.3. Producers

For producers, the grid code compliance assessment and testing, is typically done by consultants and RETEC. However, RETEC may request that the municipality review the grid code compliance report and witness the testing, in order to provide approval for the RPP. The review and approval of grid code compliance is outside the scope of this paper.

6. Grid Impact Studies (Network Studies): Municipal level

Grid impact studies consider the singular impact on the network. It now becomes important for municipalities to consider all the installed (and planned) EGs and what cumulative impact this will have on the network. Not only will this assist municipalities with the planning and operation of the network, it will also assist with determining what are maximum levels of EGs that can be accommodated in present networks, without the need for further network strengthening.

6.1. Who is responsible for network studies?

Requesting customers to perform network studies is not feasible because;

i. The first customer connecting to the grid will utilise available capacity with minimal impact however as more customers apply for connection to the feeder, the hosting capacity will eventually be exceeded. As such, customers connecting later on will incur the cost of a network study with no guarantee that they will be permitted to connect to the feeder.

ii. Not cost effective as each customer must perform a network/feeder impact study (considering others EGs), adding to the cost of their installation.

iii. The municipality needs to share other customer information such as;
- Size of EG
- Type of EG e.g., PV, gas turbine, wind etc
- Load and production profiles

Sharing of information can become a sensitive matter since the POPI Act is currently in effect in South Africa.

Therefore, the responsibility of conducting network studies must be that of the municipality.

6.2. Network Model

In order to conduct network studies, the municipality will require a suitable simulation analysis tool. There are several commercially available simulation software available that can be utilised for this purposed with a useful comparison provided at https://www.sseg.org.za/power-systems-simulations-comparison/ . However, this is just a tool and the integrity of the results produced by this tool is dependent on the data that is put into the tool. The simple rule when working with simulation packages is;

Garbage in = Garbage out

Therefore, it is important that concerted effort be placed on creating accurate models of the network using the following data;

- Latest single line drawings or operational diagrams
- Accurate cable / overhead line, lengths and conductor types
- Updated network loading information
- Correct transformer impedances and tap ranges
- Accurate fault levels from main HV infeed(s) (Eskom in-feeds)
- Accurate equivalent network impedances looking back into the larger power system at the main HV in-feeds.

The level of detail of the simulation models is also very important. Typically, HV and MV networks are modelled in the simulation tools. Due to the size of LV networks, often evaluation at this level is done using simplified analytical methods and not necessarily requiring a simulation tool. The total LV load can be modelled as lumped loads at the MV/LV transformers in simulation packages.

Since the EG approvals are becoming a daily occurrence, the need to keep the simulation models constantly updated is also very important. The use of a centralised database to capture information and then feed this information into analytical tools is a recommended and efficient practice. Many municipalities capture network and customer information in Geographic Information System (GIS) based databases. The ability to export this data from GIS systems and import into power system simulation tools, allows for quick modelling of the network.

Having an accurate model of the municipal network will create confidence in the results that are produced.

6.3. Typical Network Studies

The following list of studies are typically done in order to assess the cumulative effect of all EGs in the network.

6.3.1. Hosting capacity

Hosting capacity is generally defined as the amount of new generation or consumption that can be connected to the grid without violation of system constraints and without any network expansion.

Alternately, the hosting capacity can also be defined as the amount of new generation or consumption where the performance index reaches its limit (This index can correlate with voltage violation, loading violation, protection setup etc).

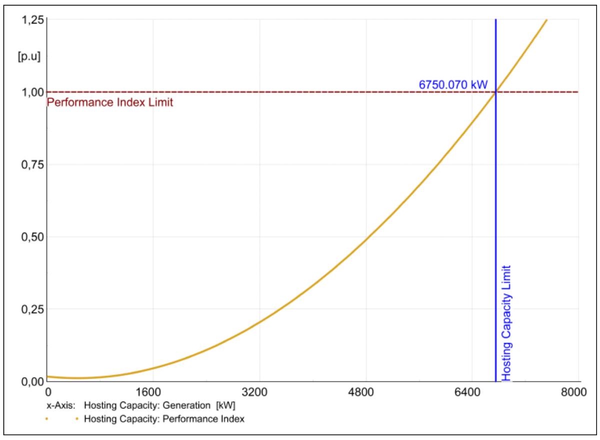

Figure 5: Hosting capacity study result

Hosting capacity is very important as it provides a tangible limit to the amount of EG capacity that can be accommodated on a feeder, Should the total capacity of EGs applied for on a feeder be nearing this limit, then the municipality can warn potential customers that their application to connect EG may be delayed, until the network is upgrade to accommodate more EGs. Hosting capacity studies are crucial for municipalities that are encouraging customers to supply excess production to the grid with a typical result of a hosting capacity study shown in Figure 5.

6.3.2. Load flow

With load flow studies the voltage of the entire network, as well as specific feeders, needs to be analysed. Not only must voltage drops on feeder be considered, voltage rise must also be studied, especially when the network load is low and the EGs outputs are high e.g. mid-summer holidays. A feeder voltage profile is shown in Figure 6 where the voltage rise at a customer with EG can be seen.

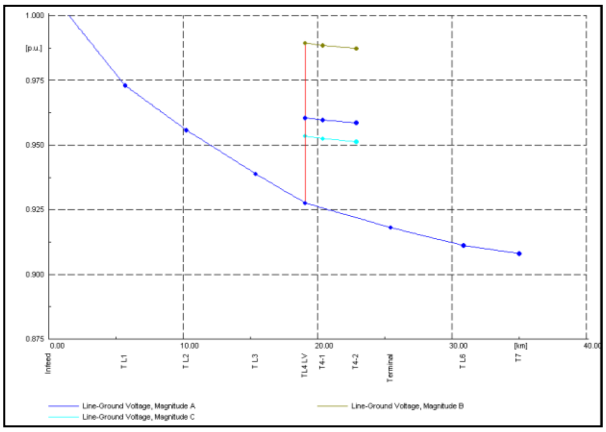

Figure 6: Feeder voltage profile with voltage rise due to EG shown

The impact on transformer taps changers, for the different operating scenarios, must be carefully analysed. With large voltage fluctuations, this may lead to increased tap changer operation, thus decreasing the expected life span of the transformer tap changer.

Maximum and minimum loading of equipment needs to be analysed, to determine planned network upgrades. With increasing EG penetration in networks, this helps to de-load some of the network equipment, which could assist with delays in network upgrades.

6.3.3. Losses

Since network losses need to be accounted for in the tariff, the impact of EGs on the network losses needs to be analysed.

6.3.4. Protection co-ordination studies

With increasing penetration of EGs in the networks, the probability of reverse power flow through MV/LV and also HV/MV transformers, increases. The impact of this reverse power flow on the protection settings must be regularly reviewed.

Furthermore, where directional settings on protection is utilised, this could be affected by reverse power flow.

Co-ordination of all the relays in the system should be considered with a time overcurrent plot of a typical feeder protection shown in Figure 7.

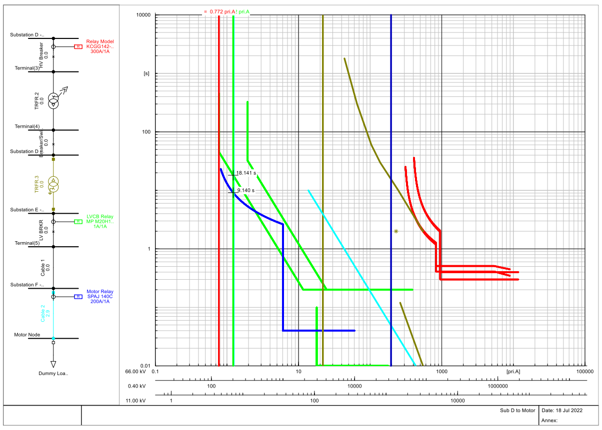

Figure 7: Time overcurrent plot with all feeder protection shown.

6.3.5. Power factor studies at main intakes

Whilst most EGs are installed at LV or MV level, the cumulative effect of active power produced by all EGs will be seen at the main HV in-feeds to the municipality. In particular, the power factor at the HV in-feeds could be seriously affected, when considering that most EGs, if permitted, will produce only active power, thus relying on the network to supply the reactive power. The effect at the HV in-feeds is that the active power demand decreases and the reactive power demand stays the same, resulting in poor power factor at the HV metering points. This could lead to penalties from Eskom for poor power factor regulation. Table 1 illustrates how a network with very good power factor can quickly become poor, as the EG output of active power only, increases.

Table 1: Increase in EG active power production and the impact on the network power factor.

EG	P	Q	S	pf
kW	kW	kVAr	kVA	
	90	**10**	90.6	0.994
10	80	10	80.6	0.992
20	70	10	70.7	0.990
30	60	10	60.8	0.986
40	50	10	51.0	0.981
50	40	10	41.2	0.970
60	30	10	31.6	0.949
70	20	10	22.4	0.894
80	10	10	14.1	0.707
90	0	10	10.0	0.000

6.3.6. RVC studies

Whist the customers will quantify the RVC impact at their POC/POS, the impact of this RVC needs to also take into account other customers that are connected to the point of common coupling (PCC). Where customers are known to have sensitive equipment, the RVC impact of large EGs on the network, need to be carefully analysed.

6.3.7. Short circuit current contribution

The contribution of short circuit current, of all EGs in the network, to the total short circuit current, is very important as it is required to determine the necessary protection settings as well as determine which equipment are at risk i.e., where high fault currents will exceed design capacity.

6.3.8. Power Quality

Whilst PQ analysis is required for EG > 5MW, the cumulative impact of all the EGs on the power quality needs to evaluated. This will help to determine the THD at various substations in the municipality and if possible mitigation (filters) is required on the municipal side. The synthesised inverter sinusoidal current waveform and the impact on the network voltage are shown in Figure 8.

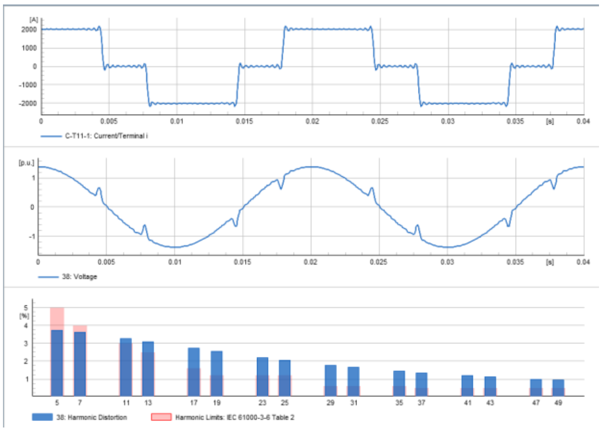

Figure 8: Typical power quality results.

7. Conclusions

Due to the variable nature of the customers load and EG production, the impact on the municipal network can be varied. Grid impact studies provide an assessment of the impact the customer will have, at their POC/POS. These studies can be undertaken by the customer with minimal information provided from the municipality.

Further to the grid impact studies undertaken by each customer, the municipality must undertake network studies to analyse the cumulative effect of all the EGs in the network. Network studies will also assist the municipality to determine the limits of acceptable EG penetration in their network.

Without the results of grid and network studies, the planning, operation and protection the municipal grid will become an extremely difficult task. Therefore, grid and network studies play an essential and vital role in managing the municipal network of the future.

8. References

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