System Performance (Quality of supply, load shedding challenges)

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1) INTRODUCTION

Power System Performance is influenced by many factors. This report is a simplified look at the impact of protection equipment and protection settings on the performance of Power Systems and areas where this may be mitigated and/or improved. This paper is of an academic nature and does not quantify the results before and after intervention.

When looking at System Performance, various indices are calculated to determine the status of the overall performance of a power system and will allow the Engineer to perform a comparative analysis across the network.

Most Metro's are a result of the combining of various cities. Each city had their own standards and way of doing things, so with the combining of these cities into one large Metro a mosaic of networks and methodologies is the order of the day.

Rationalising of the various standards is key to the future success of the Metro, as well as the ongoing improvement in the operation of the power system. A key factor behind this is the optimising of the network connectivity as well as the protection settings. A single model of the power system enables the Metro owner to better understand the power system interaction under normal and abnormal circumstances.

By addressing these issues, a step in the improvement of the overall system performance can be achieved.

2) PERFORMANCE

a) Indices

The most commonly used reliability indices are SAIFI, SAIDI, CAIDI and RSLI. These indices provide information of the frequency and duration of system faults as experienced by the connected customer base.

The average interruption duration represents the average number of hours each customer is without electricity due to a network supply interruption.

The **SAIDI** index represents the system average interruption duration based on the total number of connected customers, while **CAIDI** represents the customer average interruption duration based on the number of customers interrupted.

SAIDI is a measure of how many interruption hours per customer served a system (feeder, substation supply area or region) may experience during a supply period of a year.

SAIDI can be calculated as follows:

$$SAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of customers } served}$$

$$= \frac{\sum_{\text{Inter}=0}^{\text{Tot No. of Int for Reporting Period}} \left(\text{Restore time per interruption} \times \text{Number of Interrupted Customers per interruption}\right)}{\text{Total Number of Customer Served}}$$

$$= \frac{\sum_{i=0}^{\text{Int Tot}} r_i N_i}{N_T}$$

Equation 1 - SAIDI equation

A utility is expected to reduce SAIDI (the average number of hours each customer is without power per annum) through regulation by NERSA. A reduction in SAIDI is achieved by reducing the number of customers interrupted due to equipment faults or planned maintenance and also by reducing power restoration times to customers. SAIDI is influenced by the network configuration.

The Customer Average Interruption Duration Index (CAIDI) represents the time required to restore the electricity supply to the interrupted customers. It is a response time indicator of the average interruption duration in hours to those customers interrupted. However because CAIDI is a value per customer it does not reflect the magnitude (or extent) of the interruption event. CAIDI can be calculated as:

$$CAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Number of customers interrupted}}$$

$$= \frac{\sum_{\text{Inter}=0}^{\text{Tot No.of Int for Reporting Period}} (\text{Restore time per interruption} \times \text{Number of Interrupted Customers per interruption})}{\sum \text{Number of Interrupted Customers per interruption}}$$

$$\frac{\sum_{i=0}^{\text{Int Tot}} \mathrm{r_i} N_i}{\sum_{i=0}^{\text{Int Tot}} N_i}$$

Equation 2 - CAIDI equation

The system average interruption frequency is provided by the System Average Interruption Frequency Index (**SAIFI**), indicating how often the average customer experiences a sustained interruption over a predefined period. The SAIFI can be calculated as:

$$SAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}}$$

$$= \frac{\sum_{\text{Inter}=0}^{\text{Tot No.of Int for Reporting Period}} (\text{Number of Interrupted Customers per interruption})}{\text{Total Number of Customer served}}$$

$$= \frac{\sum_{i=0}^{\text{Int Tot}} N_i}{N_T}$$

Equation 3 - SAIFI equation

From the above equations it can be noted that the CAIDI can also be calculated from the ratio of the SAIDI and SAIFI:

$$CAIDI = \frac{\text{SAIDI}}{\text{SAIFI}}$$

$$= \frac{\sum_{i=0}^{\text{Int Tot}} \mathrm{r_i} N_i}{N_T} \times \frac{N_T}{\sum_{i=0}^{\text{Int Tot}} N_i}$$

$$= \frac{\sum_{i=0}^{\text{Int Tot}} \mathrm{r_i} N_i}{\sum_{i=0}^{\text{Int Tot}} N_i}$$

Equation 4 - CAIDI alternative equation

The Reticulation Supply Loss Index (is equivalent to the Average System Interruption Duration index, ASIDI) supply an indication of the average MVA lost due to interruptions during a period (month or annual) due to interruptions.

Similarly to the CAIDI, a customer frequency index called the Customer Average Interruption Frequency Index (**CAIFI**) provides the average frequency of sustained interruptions for those customers experiencing sustained interruptions.

$$CAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Interrupted}}$$

$$= \frac{\sum_{i=0}^{\text{Int Tot}} N_i}{CN}$$

Equation 5 - CAIFI equation

The most commonly used performance indices used by electrical utilities are the CAIDI, SAIDI, SAIFI and CAIFI. These indices are customer orientated indices to evaluate the utility’s service reliability.

b) Factors impacting the performance

Most Metro’s have a diverse mixture of networks, the characteristics and performance of which are influenced by a range of factors including the customer population, load density and environmental factors i.e. Vegetation (presence of forestry), the terrain’s geographic (presence of rivers, dams, mountains) and weather conditions (i.e. rainfall, wind and lightning).

All of these factors can influence both the network design and performance:

- Factors such as overhead line or underground cables determine the degree of exposure to the elements.
- A high load density will tend to result in short MV feeders as is the case in urban networks.
- In low load density and rural areas tend to have comparatively long overhead MV feeders. The number of faults increasing with increased feeder length, resulting in reduced performance of rural networks if compared to urban networks.
- Very hilly terrain and poor access will increase the outage duration times.
- Networks in dense vegetation or high lightning incidence areas will experience more faults when compared to networks in low density vegetation/lightning areas.
- The presence of forestry, rivers, and dams, environmentally sensitive areas etc. influence the layout of the network which in turn affects network performance e.g. the ability to build inter-connectors between feeders will influence outage restoration times.

c) Impact of Line Length

Feeder length plays an important role in determining the probability of failure of a feeder. The overall influence of backbone/total length on the customer interruption indices is a function of network configuration / topology, failure rate of equipment and restoration / isolation of faulty components in the network. The operating and maintenance of long feeders will hamper the optimal operation and restoration of supply and results in an increase in O&M costs.

Minimizing the exposure of a medium voltage feeder (reducing the length of the feeder) will result in fewer faults on the feeder and hence fewer interruptions or outages. This also affects the SAIDI of the line. There is a relationship between the number of medium voltage feeders at a prescribed length and the number of substations required to support these feeders. Feeder length is typically reduced via feeder splitting and additional MV sources.

d) Impact of Re-closers, Sectionalises and Fuses

The installation of an additional recloser on an MV system can be used to reduce the MV-line exposure. On an MV line without any reclosers, the installation of a recloser may improve the network performance by up to 50%. Note that the addition of additional two re-closers on this line will not yield an improvement of 100%.

Similar to reclosers, fuses are also used to isolate faulted MV equipment (i.e. MV/LV transformer) thereby reducing the MV-line fault exposure.

The customer numbers and the length of line are important considerations during the installation of a recloser and must be planned to correctly to protect the overall customer base from the total exposed MV line length. For rural towns, large customers and bulk supplies, these must preferably not be supplied from the MV-line backbone but via dedicated supplies.

The installation of reclosers or fault path indicators on tee-offs with relatively short line length or for tee-offs for which faults impact relatively few customers may still be justified in cases of poor performing lines or limited access.

The successful isolation of faults is very dependent on protection co-ordination between the series connected feeder breaker and recloser. The addition of too many devices requires a longer clearing time subjecting the primary equipment to undue fault currents and system to longer duration voltage dips.

e) Impact of Lightning

The impact of lightning is a major fault contributor. The lightning ground flash density provides a good insight into the regional distribution of lightning. See Figure 1 below.

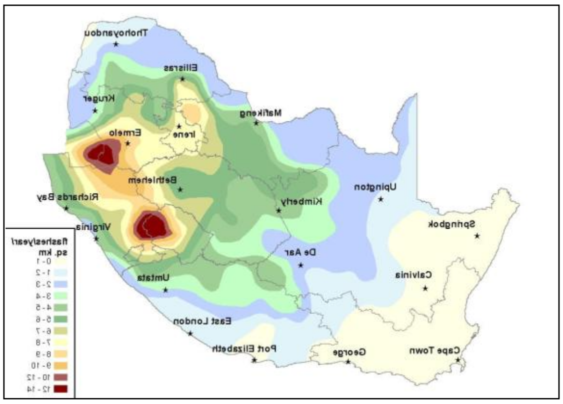

Figure 1: Lightning ground flash density map

f) Impact of Vegetation

Vegetation management is also a major cause of line outages as well as the single biggest maintenance budget line item for most utilities. For the purposes of this study vegetation a vegetation map for South Africa based on data published by the CSIR was used to classify all blocks.

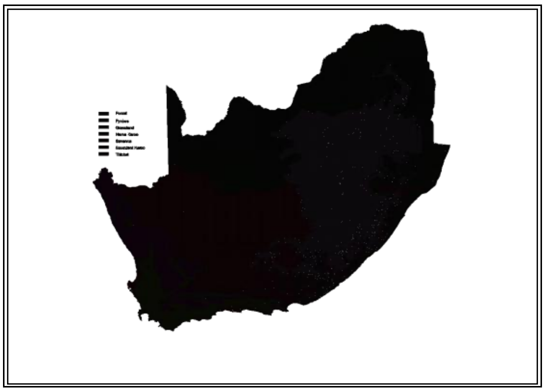

Figure 2: Biome map based on CSIR vegetation type data

There are 68 types of vegetation indicated, starting with “coastal forest” and ending with “sand plain fynbos”. For each vegetation type a biome classification (“fynbos”, “forest”, grassland etc.) is also indicated.

g) Impact of Corrosive Pollution

Corrosive pollution is the destructive reaction of material (e.g. copper, steel, aluminium) with its environment. This erosion of the material could manifests as rust and other forms of corrosion or polluting deposits. In electrical systems corrosive pollution can cause flashovers and one of the ways to counter its effects is to design networks that use components designed for corrosive environments such as for example silicone coated insulators as opposed to uncoated porcelain insulators. Flashovers are typically associated with network interruptions and also influence equipment life expectancy.

3) PROTECTION EQUIPMENT & SETTINGS

a) General

To analyse and understand Power System Performance and the impact protection systems have on system performance, a power system network model is required to be built and studies performed. This model must incorporate a wide range of power system parameters in order to perform such a study.

b) Modelling

The basic requirements for a power system model is to build a comprehensive network model for the whole utility and the more detail you have, the better - although after a fashion the returns do not justify the effort.

A typical model will include the Sub Transmission and Distribution Systems and normally focus on the HV and MV systems, but if data is available or can be captured, the LV as well. The studies are usually limited to the calculation of protection settings for current and time graded over-current and earth-fault protection only but unit protection such as Solkor is normally excluded as the normal assumption is that this protection will operated before the backup protection.

c) Analysis

The existing protection settings are evaluated via the co-ordination study. Where the coordination was acceptable the settings were not changed. Where incorrect co-ordination is found, the relevant settings are adjusted, based on an agreed philosophy, to ensure acceptable co-ordination margins. Where correct grading was not possible, these instances are highlighted for further evaluation.

For instances where the existing or proposed settings might pose a problem under N-1 conditions, the instances are highlighted for further evaluation.

Problem areas such as CT saturation are also identified during the study. The importance of this is that a saturated CT does not result in a protection trip (with old technology relays).

Grading curves are generated for all substations, indicating grading margins, system fault levels and the applicable transformer/cable damaged curves.

By analysing the impact of tripping times and calculating the relevant indices as a result of the trips, the power system engineer can identify the priority areas which require attention.

d) Results

The outcome of the grading studies looks something like this:

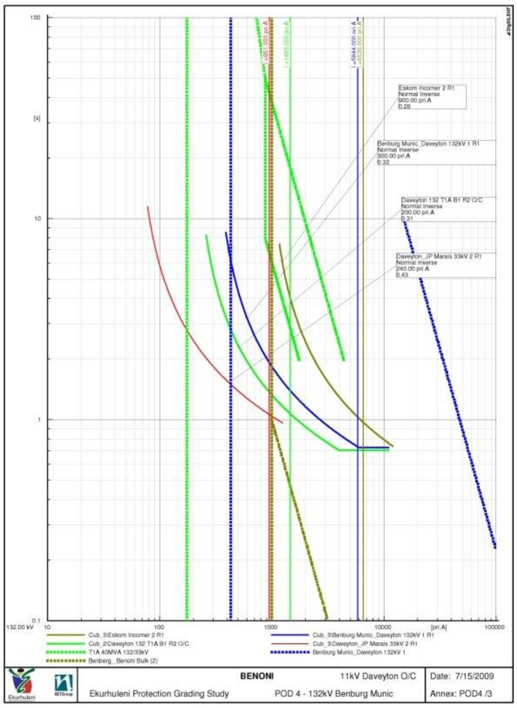

Figure 3 – Sample Grading Curve

Whereas previously, the curves would've criss-crossed each over for systems with incorrect grading margins (depending on scales etc), the result is now a neat and uniform set of curves. This then implies that correct tripping will occur for a fault on the power system. It needs to be stated that the settings calculated are only for a particular network configuration - one setting for all configurations do not exist.

With correct tripping of the network, only the relevant portion of the faulty network is isolated which then affects a reduced number of customers. For example, a fault should be cleared by the protective device as close to the fault as possible. Should this not be the case, then the next level of protection operated but the impact is greater as there are more customers affected. The more customers affected, the higher the SAIFI values.

Note that tripping times only reduces the duration of the fault and the overall stress on the primary equipment. There are no calculations for the time taken to return to service.

The next crucial step is to return the affected feeder back to service as quickly as possible. In the radial networks this is usually not possible as there is a single point of supply. All that can be done to minimise the impact of the outage is to isolate the faulted equipment as quickly as possible and return the supply to the remaining customers. In networks that are interconnected, but separated by a normally-open point, the supply can usually be returned a lot faster after some switching. Naturally, the quickest return to service method is where auto-reclosing is possible and this depending on whether the equipment is damaged or not.

The impact of outages then is to affect the SAIDI values. Thus, the longer the outages are, the higher the index will be and the worse the performance of the supply.

Typical results from various studies conducted have identified a number of issues that need to be addressed:

i) Over-current setting and earth-fault settings to be changed required ensuring correct grading.
ii) There are low ratio 5A current transformers that will saturate under fault conditions.
iii) There are some grading problems that cannot be resolved by altering the settings alone, and will require some network configuration to achieve.
iv) There are Eskom settings which need to be raised and high-set elements to be disabled in order for the new settings to be effective.

e) Improving Performance

A lot can be done from a protection perspective to improve overall power system performance. From applying correctly calculated protection settings, to unit protection in order to improve fault detection and selection.

With a power system model, one can also predict the impact a fault can have on a section of network and determine the relevant indices based on an average number of faults/km. This allows the power system engineer to determine the best place to start with the preventative actions.

In addition, reducing outage times involves a number of decisive actions, some concepts of which are listed below:

Early recognition of the escalating events

Obtaining data from an outage management system, a global view and real-time tracking of the current day's outage events is possible. For live systems, details of each event, how many customers are affected, event duration, whether a crew has been dispatched, and projected restoration time. With this information available, the control room operators have a clear view of the emerging picture of outage activity as a basis for deciding how to respond.

Effective communications

A set of automated alerts through the paging system that triggers conference calls with the appropriate level of management as the size of outages increased and events became more widespread.

Better up-front decision-making

Early decision-making about whether to mobilize resources is critical to quick resolution of outages. Should we bring in additional crews and supervisors? Should we have tree crews on stand-by? Should we decentralize dispatching to the local area work centres? These are all tough decisions with resource and financial implications. Once a crew works an extended workday, it is not available for work the following day and schedules are disrupted. When making decisions in isolation, supervisors tended to hesitate, not wanting to do the wrong thing and hoping the situation would stay under control. With the right people on the early conference call, better decisions could be made.

Better coordination of field work.

Outage minutes grow when a crew is dispatched to a site but, when it arrives, find that it is not able to perform the task on hand. To improve reconnaissance and problem diagnosis ahead of the arrival of a field crew, field supervisors should have the same information the dispatcher is sees. With work underway at one site, the supervisor can move to the next site and do an early assessment. In a mid-sized storm, it is essential to work events in parallel and get the right materials and people on site so the crews can be fully productive.

4) CONCLUSIONS

Everything that has been stated above is not new or foreign to the power system engineer. Essentially, your protection system and associated protection settings form an integral part of the power system performance.

With the amalgamation of the various networks, opportunities exist to optimise the supply side of the both from system strengthening perspective as well as from the protection side.

By measuring outage events and calculating the various SAIDI, SAIFI, CAIDI, CAIFI indices, the power system engineer can identify the priority areas to focus on. These issues include, amongst other things, verifying that the protection setting is correct and suitable for the specific application, as well as whether the protective device is suitable for the duty at hand.

Experience from other utilities has shown that, while there is an improvement in the SAIDI, an unexpected outcome was that CAIDI actually increased. This is because the CAIDI measure improves when many customers go off line for a short period of time. The bigger events had provided a damper on the effects of smaller, longer outages. The reduction in the impact of the mass outage while a very good thing, it meant that CAIDI performance became more vulnerable to how well the company responded to the remaining outages, highlighting an important customer service issue.

5) REFERENCES

CSIR – Vegetation map

South Africa Weather Service – Lightning Flash density map

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