THE EVOLUTION OF REGULATORY POWER QUALITY STANDARDS IN SOUTH AFRICA (1996 TO 2006)

Robert KOCH
Eskom – South Africa
robert.koch@eskom.co.za

Anthony DOLD
eThekweni Electricity (WG Chair) – South Africa
doldaj@elec.durban.gov.ca

Paul JOHNSON
Eskom (PIESA) – South Africa
paul.johnson@eskom.co.za

Richard McCURRACH
Eskom (ESLC) – South Africa
mccurrr@eskom.co.za

Tshilidzi THENGA
National Energy Regulator of South Africa
tshilidzi.thenga@nersa.co.ca

Paper prepared on behalf of the NRS 048 working group[1]

ABSTRACT

The South African power quality standard (NRS 048-2) was first adopted as a basic licence condition by the South African National Electricity Regulator in 1996. This paper discusses the evolution of this standard and related parts of the NRS 048 series of standards over the past 10 years. It highlights key considerations such as: the need for a well-defined regulatory framework (based on input from all stakeholders), quality management based on both minimum standards and continuous quality improvements, consideration of the application conditions of standards, the probabilistic nature of power quality phenomena, and appropriate measurement and assessment criteria.

INTRODUCTION

The first regulatory power quality standard (NRS 048-2 Edition 1) was introduced in South Africa as a license condition by the National Electricity Regulator - NER (now the National Energy Regulator of South Africa - NERSA) in 1996. Since then several changes to the standard have been effected. The latest edition (NRS 048-2 Edition 3) is currently being finalised for publication in early 2007. The changes to the standard were motivated by: (i) a change in the regulatory framework for power quality management; (ii) experience in the implementation of the standard; and (iii) recent developments in international standardisation bodies such as the IEC and technical bodies such as CIGRE and the IEEE.

REGULATORY FRAMEWORK

The development of NRS 048 Edition 1 was based on a general premise that all power quality parameters required defined minimum standards. Where such minimum standards could be derived from international standards such as the IEC 61000 series, these were applied (for example, the requirements for LV harmonics, flicker, and unbalance in IEC 61000-2-2). Where such standards did not exist, or were considered inappropriate for South African conditions, local data was used to inform decisions on what minimum standards should be set (for example voltage dips and interruptions).

Post-implementation experience with the application of Edition 1 highlighted a need for a better-defined regulatory framework for power quality management before specific standards are enforced. For example, "*minimum standards*" need to ensure that: (i) customer connections requirements do not result in unreasonably stringent limits on customer installation emission levels and the types of loads that can be started; (ii) that funding mechanisms exist to meet these minimum standards in networks where historical industry investment criteria have not been linked to such minimum standards; (iii) that performance assessment criteria suitability take into account both the probabilistic nature of power quality phenomena and the conditions under which such minimum standards are applicable; and (iv) that these standards adequately meet customer requirements. Such minimum standards on the other hand, may discourage a culture of "*continuous improvement*". For example, the network-specific nature of voltage dips meant that the minimum standards for dips in NRS 048-2 Ed.1 were easily met in some areas of the country – resulting in some customers complaining that distribution companies were not prepared to further improve dip performance if it already met these minimum standards. On the other hand, distribution companies were under pressure in networks not meeting the minimum requirements, to improve voltage dip performance for voltage dip types that customers accepted did not impact them at all.

1. At the time that this paper was prepared the members were: A Dold (Chairperson), S Adams, D Bhana, W Breed, B Chatterton, G de Beer, S Delport, G Dindi, H Geldenhuys, A Hepburn, P Jaeger, A Kachelhoffer, M Kneen, R Koch, P Mabuza, J Maree, C Mamone, R McCurrach, H Mostert, M Mncube, M Ngcamu, T Nortjie, A Sayed, V Shikoana, M Shozi, I Sigwebela, T Thenga, S Zuma.

In order to address these concerns the NER developed (through extensive stakeholder consultation) a framework for power quality management in 2003 [1]. The framework is documented in the NER Power Quality Directive of 2003 [2]. The framework addresses: (i) the application of power quality standards; (ii) customer interaction requirements; and (iii) power quality performance reporting to NERSA. As a result, significant changes were made to NRS 048-2, resulting in Edition 2 and more recently Edition 3.

NRS 048-2 DEVELOPMENTS

Clarification regarding the application of NRS 048-2 was addressed by distinguishing more clearly between those network conditions under which the standards apply (defined as "*normal conditions*"), and do not apply.

An important change made in aligning Edition 2 with the new regulatory framework was to replace specified minimum standards for voltage dips and interruptions with "characteristic levels" of performance in South Africa. This is because the new framework recognises: (i) the vast differences in performance in various parts of the country (given different network types and environmental conditions), (ii) the need for a licensee to "continuously improve" performance - even in areas with relatively good performance, and (iii) the need for customers to be aware of the potential impacts of voltage dips and interruptions when designing new plant. It is a further requirement for licensees to provide site specific dip performance information to new customers (these general characteristic levels serve as an indication of the relative performance of the site against national dip statistics). A new characterisation of voltage dips was also defined in order to differentiate the responsibilities of customers to protect their installations against less severe (and more frequent) dips that arise due to faults at locations more remote from the customer supply point (particularly Y dips), and licensees to take actions to minimise / improve more severe dips due to faults more local to a particular customer [1]. A more detailed discussion on the nature of the required interaction between a customer and a licensee is given in [3].

Table 1. Voltage dip characterisation (NRS 048-2 Ed.2)

<table>
<tr><th rowspan="2">Dip depth
ΔU
(% of U_d)</th><th colspan="3">Duration</th></tr>
<tr><th>20 < t ≤ 150 ms</th><th>150 < t ≤ 600 Ms</th><th>0,6 < t ≤ 3 s</th></tr>
<tr><td>10 < ΔU ≤ 15</td><td colspan="3"></td></tr>
<tr><td>15 < ΔU ≤ 20</td><td colspan="2">Y</td><td rowspan="2">Z1</td></tr>
<tr><td>20 < ΔU ≤ 30</td><td></td><td rowspan="3">S</td></tr>
<tr><td>30 < ΔU ≤ 40</td><td>X1</td><td rowspan="3">Z2</td></tr>
<tr><td>40 < ΔU ≤ 60</td><td>X2</td></tr>
<tr><td>60 < ΔU ≤ 100</td><td colspan="2">T</td></tr>
</table>

Table 2. Characteristic voltage dip performance for 50th percentile and (95th percentile) of sites in South Africa.

Network voltage range ($U_{nominal}$)	Number of voltage dips per year					
	Dip window category					
	X1	X2	T	S	Z1	Z2
6,6 kV to ≤ 44 kV (note)	13 (85)	12 (210)	10 (115)	13 (400)	11 (450)	10 (450)
6,6 kV to ≤ 44 kV	7 (20)	7 (30)	7 (110)	6 (30)	3 (20)	4 (45)
> 44 kV to ≤ 220 kV	13 (35)	10 (35)	5 (25)	7 (40)	4 (40)	2 (10)
220 kV to ≤ 765 kV	8 (30)	9 (30)	3 (20)	2 (20)	1 (10)	1 (5)
Note: Extensively overhead networks						

Table 3 (Edition 3) shows characteristic values for the number of sustained interruptions per annum experienced by up to 50 % (and up to 95 %) of LV and MV customers, and characteristic values for the duration of individual sustained interruptions for up to 50 % (and up to 95 %) of interruptions experienced by LV and MV customers.

Table 3. Characteristic interruption performance: number per MV or LV customer, and duration per interruption.

Network Category (MV)	Unplanned		Planned	
	Number Per year	Duration (hours)	Number	Duration (hours)
> 80% cable	3 (6)	3,5 (18)	< 1 (3)	4 (9)
> 80% line (overhead)	18 (75)	2,5 (12)	4 (11)	3 (14)
Numbers indicate are for 50th percentile and (95th percentile).				

Interruption performance of South African overhead line networks is dominated by the performance of MV networks supplying mainly rural customers, which have historically been designed for lowest capital cost and no specific reliability criteria. Since 2006 NERSA has for a 3-year period introduced economic incentives to improve SAIDI, currently at 48 hrs, by a targeted 20% (and future incentives may focus on additional indices). This is expected to result in reduced values in Table 3 in future editions of the standard.

Edition 3 has further clarified EHV and HV minimum standards for harmonics, flicker and unbalance. Where, in the absence of international recommendations, earlier editions referred to recommended "planning levels" in IEC 61000-3-6/7 at EHV and HV, Edition 3 has incorporated as minimum standards the recommendations made by CIGRE/CIRED JWG C4.07 in 2004 [4].

Table 4. Example of individual voltage harmonics.

Odd harmonics						Even harmonics	
Non-multiples of 3			Multiples of 3 (See NOTE)				
H	Magnitude %		*h*	Magnitude %		*h*	Magnitude %
	LV MV	HV EHV		LV MV	HV EHV		
5	6	3	3	5	2.5	2	2
7	5	2,5	9	1,5	-	4	1
11	3,5	1,7	15	0,5	-	6	0,5
13	3	1,7	21	0,3	-	8	0,5

For THD the minimum requirements are 8% for MV and LV networks, and 4% for HV and EHV networks.

For LV and MV networks, the minimum standard for long-term flicker severity (Plt) was increased to 1,0 in Edition 2, based on several years of experience at various sites in South Africa where Pst levels of 1.25 resulted in no complaints from residential customer. No minimum standards are defined for HV and EHV networks, as the reduction of flicker from HV to LV can be significant. Industrial customers were specifically concerned about the "low" planning levels of Pst (0.8) and Plt (0.9), as these resulted in strict emission limits imposed by licensees. (Some EHV sites operate at Pst = 1.8 without complaints).

The minimum standard for (negative sequence) voltage unbalance on EHV systems in Edition 3 is 1.5% and that on HV, MV, and LV three-phase systems 2 % (based on recent CIGRE/CIRED recommendations [4]). On networks with a predominance of single-phase or two-phase customers, a compatibility level of 3 % may be applied. On MV and HV networks where there is a predominance of single-phase or two-phase customers, 3 % is applicable, as long as 2 % is not exceeded for more than 80 % of the time and three-phase customers are informed when connected. A network with a predominance of single-phase or two-phase customers is interpreted as a network where the size (maximum demand in MVA) of customers connected between phases or between phase and ground represent more than 60 % of the maximum load (maximum demand in MVA) on the feeder under consideration, and the single-phase load represents more than 60 % of the energy (kWh) supplied for the 12 month period.

For voltage magnitude, ±10% is specified for LV (as per IEC 60038) and ±5% at other voltage levels (unless otherwise contracted). These permitted variations are based on standard voltage (230V phase-neutral at LV) and the declared voltage in other cases.

COMPLIANCE ASSESSMENT

NRS048-2 was developed as a self-contained document, and in addition to the minimum standards and characteristic values, measurement and assessment methods are specified.

The probabilistic nature of power quality phenomena and the changing nature of loads and emissions from customer installations, make it impossible to ensure 100% compliance at all times at every site on the system. However, an important clarification made in Edition 2 is that the minimum standards apply at <u>every</u> customer supply point. (Edition 1 suggested compliance for "95% of sites", making it difficult for a specific customer to evaluate a licensee's compliance). Sites not complying with the minimum requirements must be addressed by the licensee.

IEC 61000-4-40 Class A measurement methods are specified for site-specific compliance assessment. A separate set of "Class B" methods have been developed in national standard SANS 1816 for use in surveys and annual reporting of system performance to NERSA (Class B methods in IEC 61000-4-30 were not considered suitable for adoption). Compliance assessment is based on the 95th percentile of the 10-minute Class A measurement values over a period of a week (as is the requirement in EN 50160). In the case of voltage regulation, an additional criterion has been introduced – i.e. that no more than two consecutive 10-minute values exceed the minimum requirements at any time. This criterion is significantly stricter than the 95%-weekly criterion.

System indices based on a "high percentage" of sites meeting the power quality objectives have been proposed by CIGRE/CIRED [4]. These apply to *system indices* used for reporting overall *system performance*. As NRS 048-2 addresses site (customer) and not system power quality performance, such system indices (95% of measured sites) are specified in NRS 048-4 (for the purpose of annual reporting of compliance *at a system level* to NERSA). NRS 048-4 provides guidance on the selection of measurements sites (a summary is provided in the annex to this paper).

OVERVIEW OF ASSOCIATED STANDARDS

The above discussion has focussed on NRS 048-2, which is a basic NERSA license condition. The following standards either support NRS 048-2 or other aspects of the power quality management framework, or have been replaced:

- <u>NRS 048-1 (definitions)</u> - *repealed*: Definitions are now included in NRS 048-2 for ease of reference by customers
- <u>NRS 048-3 (performance reporting formats)</u>- *repealed*: Changes are made annually by NERSA to these formats.
- <u>NRS 048-4 (licensee application guidelines)</u>: *A new Edition 2* addresses: (i) licensee responsibilities; (ii) customer interaction requirements (power quality contracting and continuous improvement); (iii) monitoring requirements - including site selection for permanent monitoring; and (iv)

guidelines for calculating customer emission limits and indicative planning levels based on [5].

□ NRS 048-5 (power quality instrument specifications) – *repealed*: IEC 61000-4-30 Class A measurement methods have been adopted in South African national standards and specific Class B methods and instrument specifications have been defined in a new standard SANS 1816.

□ NRS 048-6 (MV interruption reporting): *A new first edition* addresses MV interruption measurement, system indices (e.g. SAIFI, SAIDI), and reporting requirements.

□ NRS 048-7 (customer application guidelines): *A new first edition* is under development to address customer responsibilities and mitigation guidelines.

□ NRS 048-8 (EHV and HV interruption reporting): *A new first edition* addresses EHV and HV interruption measurement, system indices, and reporting requirements (based on CIGRE recommendations in [4]).

Initiatives are also underway to implement a regional power quality standard for Southern Africa. Such as standard (PIESA 048), which is based on NRS 048-2, is currently at an advanced stage of review by participating countries.

CONCLUSIONS

A well-defined regulatory framework for power quality management is necessary when power quality standards are developed. In order to meet customer requirements, this framework must balance the role of *minimum standards* and *continuous improvement mechanisms* (through economic incentives or other mechanisms). The principle of applying "*minimum standards*" needs to take into consideration: (i) performance assessment criteria that suitably take into account both the probabilistic nature of power quality phenomena and the conditions under which such minimum standards are applicable; (ii) the impact on customers of stricter emission limits in connection requirements; (iii) funding mechanisms for meeting minimum standards in networks where industry investment criteria have not been linked to such minimum standards in the past.

REFERENCES

[1] R Koch, P Balgobind, E Tshwele, "New Developments In The Management Of Power Quality And Performance In A Regulatory Environment", IEEE Africon Conference, South Africa, 2002.

[2] NER Power Quality Directive, 2003, www.nersa.org.za

[3] R Koch, P Balgobind, P Johnson, I Sigwebela, R McCurrach, D Bhana, J Wilson, "Power Quality Management in a Regulated Environment: The South African Experience", *CIGRE Session, France*, 2004.

[4] CIGRE/CIRED JWG C4.07, *Power Quality Indices and Objectives,* CIGRE Technical Broshure TB261, 2004.

[5] G. Beaulieu, R. Koch, M. Halpin, L. Berthet, "Recommended Methods of Determining Power Quality Emission Limits for Installations Connected to EHV, HV, MV and LV Power Systems ", *CIRED 2007, Vienna, Austria,* 2007.

Acknowledgments

The authors wish to acknowledge: (i) the team work shown and contributions provided by the various stakeholders represented on the NRS 048 working group and NER Power Quality Advisory Committee; (ii) the executive oversight of the set of NRS standards by the ESLC and in particular Vinod Singh, Technology Standardisation Manager (NRS).

Annex A - Measurement sites defined in NRS 048-4.

Site Description	Number of sites to be monitored	Instrument connection
EHV customer supply points or interfaces with other licensees (i.e. the boundary of physical ownership of the assets is at EHV)	All	EHV points of supply
EHV to HV substations supplying end customers or other licensees at HV.	At least one point of supply at each substation (normally the highest HV supply voltage where several points of supply exist in the substation)	HV busbar
Customers with PCC at HV (including supply interfaces with other licensees but excluding traction supplies)	50% of such HV PCC's.	HV PCC, supply point, or MV supply point
HV/HV substations	50% of such substations	Either of HV busbars
HV/MV substations where customers are supplied at MV.	20% of HV/MV substations OR 50% of HV/MV substations where the load supplied is predominantly taken (at the MV side) by commercial or industrial customers served by the licensee	MV busbar at a substation supplying MV networks supplying predominantly commercial or industrial customers
Interfaces between licensees at MV	50% of sites where Licensees are supplying more than one end customer (e.g. excluding water pump installations)	MV metering point
Rural customers with PCC at MV	0.1% of PCC's supplying customers with PCC at MV.	MV or LV metering point
LV customers	0.005% (1 in 20000) sites	Preferably toward the end of the LV feeder