SKA1 POWER QUALITY STANDARD

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LIST OF ABBREVIATIONS

A	Ampere
CBEMA	Computer Business Equipment Manufacturers Association
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESKOM	South African Electricity Supply Utility
HV/MV/LV	High/Medium/Low Voltage
INFRA SA	SKA1_Mid Infrastructure and Power
ITIC	Information Technology Industry Council
KAPB	Karoo Array Processor Building
KHz	KiloHertz
kV	KiloVolt
kW	KiloWatt
LV	Low Voltage
MCB	Miniature Circuit Breaker
MCCB	Moulded Case Circuit Breaker
MHz	MegaHertz
MVA	MegaVolt Ampere
Mvar	MegaVolt Ampere Reactive
NRS	National Rationalized Specification
PEN	Protective Earth and Neutral
PMCS	Power Management and Control System
PVC	Polyvinyl Chloride
p.u.	Per unit
RAM	Reliability Availability Maintainability
RFI	Radio Frequency Interference
r.m.s.	Root Mean Square
SANS	South African National Standard
SKAO	Square Kilometre Array Office
UPS	Uninterruptable Power Supply
W	Watt

1 Introduction

1.1 Purpose of the Document

The purpose of this document is to specify the various quality of supply parameters applicable to the SKA Observatory. The parameters defined in this document will be applicable to all entities or elements responsible for both the provision of power to the observatory as well as the users or consumers of this power. This document should therefore be used as an input to the design of the power system as well as the design of all consumer loads that will be connected to the SKA power system.

It must be noted that this document is not applicable to central on-site power stations. The power quality parameters for on-site power stations will be specified in a separate document which will most likely comprise of more stringent requirements.

1.2 Scope of the Document

This report defines two sets of criteria relating to power quality. The first set of requirements is allocated to the power supplier i.e. the power system responsible for the delivery of power to the observatory and defines the various power quality parameters applicable to this system. The second set of criteria relates to the actual consumers of power and defines the applicable parameters of the loads being connected to the SKA power system.

It is important to note that, even though the first set of requirements are allocated to the power supplier, consumers of power still have to ensure that their equipment can operate satisfactorily on the resulting power supply. That is, their equipment must operate satisfactorily if the power supplier meets their requirements. The concept of equipment immunity, compatibility levels and assessed levels will also be discussed in this document.

The following criteria are applicable to the supplier of power to the observatory:

- Frequency
- Magnitude of Supply Voltages
- Voltage Unbalance
- Voltage Harmonics
- Dips, Swells and Transients
- Power Interruptions

The following criteria are applicable to the users or consumers of power:

- Power Factor
- Voltage Flicker
- Current Harmonics
- Current Unbalance

This document also highlights certain boundaries of responsibility relating to the protection of equipment against the harmful effects of unwanted system transients, over voltages and voltage unbalance.

2 References

2.1 Applicable Documents

The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, the applicable documents shall take precedence.

[AD 1] IEC 610000-4-3:2009, *Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power Quality Measurement methods*

[AD 2] IEC 610000-2-2:2002, *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

[AD 3] BS EB 50160:2010, *Voltage Characteristics of Electricity Supplied by Public Electricity Networks*

[AD 4] IEC 61000-3-6 Ed.2: *Electromagnetic compatibility (EMC) - Part 3-6: Assessment of harmonic emission limits for the connection of distorting installations to MV, HV and EHV power systems*

[AD 5] IEC 61000-3-7 Ed.2: *Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating load installations to MV, HV and EHV power systems*

2.2 Reference Documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, this document shall take precedence.

[RD 1] NRS-048-1:1996, *Electricity Supply – Quality of Supply*[1]– Part 1: Minimum Standards

[RD 2] NRS-048-2:2003, Electricity Supply – Quality of Supply[1]– Part 2: Voltage Characteristics, compatibility levels, limits and assessment methods

[RD 3] IEEE 519:1992, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

[RD 4] NRS-048-4:1999, Electricity Supply – Quality of Supply[1] – Part 4: Application Guidelines for Utilities

[1] NRS-048 is the power quality standard used in South Africa and is largely based on IEC 61000.

3 General Requirements

3.1 Introduction

The provision of a reliable, high quality power supply will be critical to the safe, economical and reliable operation of the SKA Observatory. The ideal power system would comprise of perfectly sinusoidal voltage and current waveforms of stable magnitude at a constant frequency without any interruptions, distortions and disturbances. Unfortunately, in reality, this scenario is not possible due to a number of factors. These factors include power system impedances caused by items such as cables and transformers as well as transients, outages and external influences such as the effects of faults within the supply authority networks as well as pollution caused by other users. The way in which the various elements making up the SKA Observatory use electricity will also affect the quality and reliability of the power system and therefore also needs to be properly designed.

Figure 1 below, shows the relationship between compatibility levels and assessed levels. Essentially, the assessed level is compared with a compatibility level (described as allowable limits in this document) which is the required minimum standard. The SKA Observatory will typically be designed using planning levels below the compatibility or allowable levels described in this document.

Typically, the assessment method for each parameter allows for the extreme 5% of measured values to be discounted when calculating the assessed level.

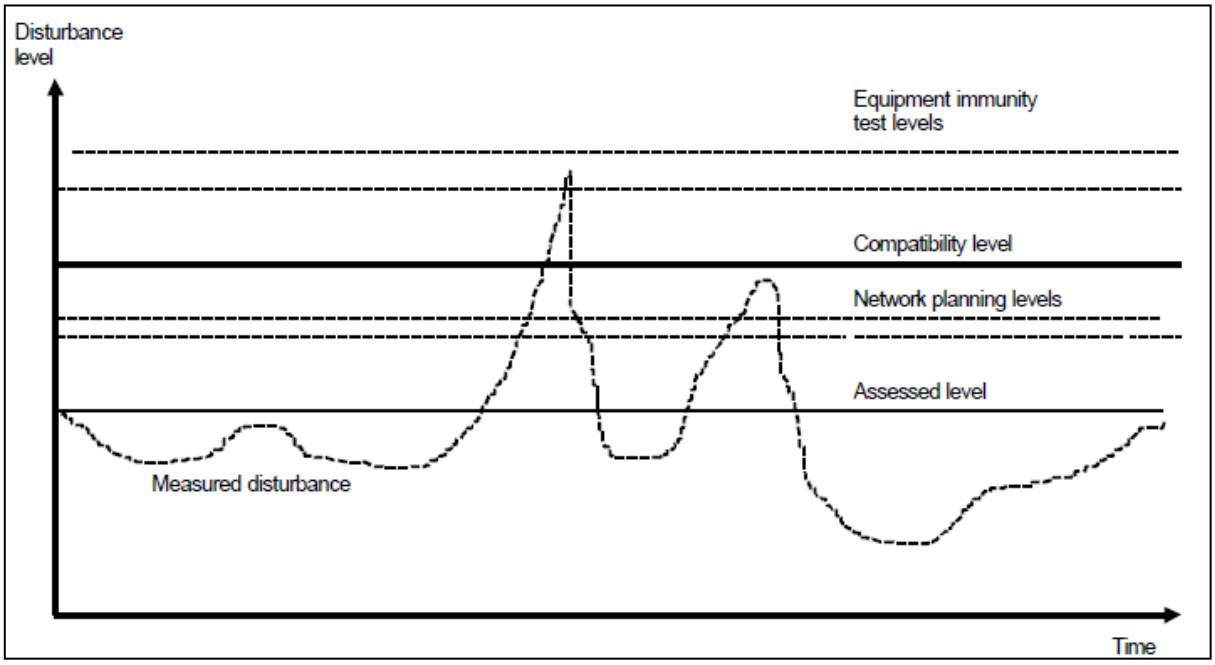


Figure 1: Relationship between compatibility levels and assessed levels

This standard relates to the steady state or normally expected conditions of the power system rather than abnormal or extreme events or multiple contingencies.

4 Power Quality of Supply Parameters

4.1 Frequency

4.1.1 Frequency Limits

The nominal frequency of the supply voltage to the SKA Observatory shall be 50Hz.

The frequency of the supply is controlled by the SKA Observatories own generating plant (if applicable) or in the case of a grid tied supply, by the supply authority i.e. ESKOM in South Africa.

The normal operating frequency band is shown in Table 1:

Table 1: Supply Voltage operating Frequency band

Network Type	Allowable Frequency Band
Grid	± 2% (49Hz – 51 Hz)
SKA Observatory running on own generating plant	± 2% (49Hz – 51 Hz)

4.1.2 Measurement Method

The measurement method shall be as per IEC 61000-4-30 for Class A measurements.

4.1.3 Assessed Level

All the values over a period of one year shall be recorded. The frequency deviation for 99.5% of one year should be retained and fall within the allowable frequency range given in Table 1.

4.2 Magnitude of Supply Voltage

4.2.1 Voltage Limits

Voltage variation management will be implemented by the power system supplier/designer to maintain voltage levels at the user's terminals within acceptable limits during all likely loading scenarios.

All loads supplied at low voltage will be supplied at 400V phase to phase and 230V phase to neutral. It is not envisaged that any power consumers within the SKA Observatory will take power at medium voltage but applicable voltage limits for medium voltage have been included for sake of completeness.

The various power users will also have a responsibility to ensure the satisfactory operation of the power system by ensuring loads are balanced between all three phases as much as possible.

Table 2 below, defines the maximum deviation from declared voltages:

Table 2: Maximum Deviation from declared voltages

Network Type	Allowable Voltage
< 500V	± 10% (360V – 440V for 400V)
≥ 500V	± 5%

The voltage levels defined in Table 2 refer to allowable voltage deviations at the customer or power users point of supply. The power users are responsible for voltage drop management within their own power distribution network or power circuits, which could be up to 5% (depending on design). Therefore, users may see -15% at their outlet terminals if not properly managed.

4.2.2 Measurement Method

The measurement method shall be as per IEC 61000-4-30 for Class A measurements.

4.2.3 Assessed Level

95% of the 10 minute mean r.m.s. values over each one week period should be within the parameters stated in Table 2.

4.3 Voltage Unbalance

4.3.1 Voltage Unbalance Limits

In simple terms, voltage unbalance is defined as a difference in magnitudes of the phase voltages of a three phase system. Voltage unbalance can also refer to a situation where the phase displacement of the three phases is not equal.

The following expression can be used to define voltage unbalance when simultaneous measurements or readings of the three r.m.s. line to line voltages are know:

$$UB = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}} \times 100 \qquad \text{where} \qquad \beta = \frac{V_{12}^4 + V_{23}^4 + V_{31}^4}{\left(V_{12}^2 + V_{23}^2 + V_{31}^2\right)^2}$$

V_{12} Represents line to line voltage between phase 1 & 2.

Excessive voltage unbalance in supply voltages may cause overheating of three phase induction motors and therefore needs to be monitored and guarded against.

Table 3 below, defines the maximum allowable voltage unbalance for all voltage ranges:

Table 3: Maximum Allowable Voltage Unbalance

Network Type	Allowable Voltage Unbalance
< 500V	3%
≥ 500V	2%

4.3.2 Measurement Method

The measurement method shall be as per IEC 61000-4-30 for Class A measurements.

4.3.3 Assessed Level

95% of the 10 minute mean r.m.s. values over each one week period should be within the parameters stated in Table 3.

4.4 Voltage Harmonics at Consumer LV Connection Points

4.4.1 Voltage Harmonic Limits

Harmonic distortion is created when a non-linear load is connected to the power system. This non-linear load causes harmonic distortion in the current drawn by the load, which in turn distorts the supply voltage, resulting in harmonics. The adverse effects of harmonics include an increase in system losses which could result in overheating of cables, transformers and motors etc. Harmonics may also interfere with the operation of sensitive electronic devices.

Consumers connecting loads at LV connection points should design their equipment to tolerate the compatibility levels in Table 1 of IEC61000-3-6.

4.4.2 Measurement Method

The measurement method shall be as per IEC 61000-4-30 for Class A measurements.

4.4.3 Assessed Level

95% of the 10 minute mean r.m.s values of each harmonic voltage shall be less than or equal to the limits.

4.5 Dips, Swells and Transients

4.5.1 Dips, Swells and Transient Limits

For the purposes of this report, the definition of a voltage dip will be the same as that given in NRS048-2. NRS048-2 describes a voltage dip as the following:

"A sudden reduction in the r.m.s. voltage, for a period of between 20ms and 3s, of any or all of the phase voltages of a single-phase or a polyphase supply. The duration of a voltage dip is the time measured from the moment the r.m.s. voltage drops below 0.9 per unit of declared voltage to when the voltage rises above 0.9 per unit of declared voltage"

Voltage dips are usually experienced when a fault occurs on the distribution system to which a customer or load is connected. The voltage levels that are reached during a dip depend on the nature of the fault, the system generation sources, impedance to the point of fault and also where the fault occurred in relation to the load connection point.

It is not possible to stipulate and specific limits or values that need to be complied with when it comes to voltage dips. For purposes of this standard, the phenomenon of dips is merely described so that it can be brought to the attention of the designers of the loads that will be connected to the SKA Observatory power system. The designers of the loads should therefore make an assessment of the impact a voltage dip would have on the operation and performance of their equipment so that necessary mitigation measures can be put in place to limit permanent damage or poor performance.

A voltage swell is essentially the opposite of a voltage dip and is defined be IEEE 1159 as the increase of the r.m.s. voltage level to between 110% - 180% of nominal, at the power frequency for duration of between ½ cycle to one minute.

Voltage swells can be caused by the tripping of large loads or due to problems with transformer tap changers for example.

Once again, it would be difficult to define the allowable limits of a voltage swell as it is an event that cannot be controlled as it is defined by power system parameters and location of the load on the power system. The intention is therefore to make load designers aware of the possibility that a voltage swell may occur on the power system so the potential impact on equipment can be assessed and mitigation measures put in place to protect the equipment to ensure satisfactory operation if necessary.

Voltage transients on a power system can be caused by lightning, system faults or by switching. The power system for the SKA Observatory will be designed using best engineering practices to try and minimise the impact of lightning strikes and voltage transients on the power system and customer loads. Although every effort will be made by the power system designer to protect equipment and customers or loads against the harmful effects of voltage transients, the load designer should still install protective devices to further minimise these effects.

In the absence of accurate historical data on the performance of the power system or the nature of the power quality disturbances that are most prevalent at a particular SKA Facility, the load designers are encouraged to make use of the CBEMA/ITIC curves when designing their systems. Load designers in South Africa who are not familiar with the CBEMA/ITIC curves can make reference to item 4.2.9. NRS-048-2 [RD2] for details of voltage dip characterisation which could be used to assist with dip immunity designs.

4.6 Power Interruptions

4.6.1 General

The availability of supply is defined as the time that a supply is made available to customers or loads and includes any form of power interruptions.

The reliability of the power supply will vary and depends on the physical configuration of the power system. For example, in South Africa, equipment housed inside the KAPB will have a higher power reliability than equipment installed at the far end of one of the spiral arms.

4.6.2 Planned Interruptions

Planned interruptions of the electricity supply may occur due to maintenance activities, power system upgrades or due to other factors such as RFI measurement campaigns etc. The power system operator will provide suitable notice to the telescope operators of telescope manager prior to carrying out any activities which will affect the continuity of the power system supply.

4.6.3 Unplanned Interruptions

Unplanned outages are outages which are unforeseen and cannot be predicted. Customers or load designers must be aware that the power supply to their equipment can be disrupted at any time and therefore need to have suitable measures put in place to ensure satisfactory system operation should an item of equipment trip unexpectedly i.e. the installation of a static UPS might be required to shut certain systems down in a controlled manner or to maintain communication for a certain period of time.

Unplanned outages can be broadly broken down into two main categories, namely:

4.6.3.1 Involuntary Customer Load Reduction

This scenario could occur when power supply capacity on site is constrained. This could include a major power transformer failure or capacity constraints from the supplier. During these events, it might be necessary to implement a load shedding scenario whereby certain loads or sections of the network need to be tripped. The severity or magnitude of the load curtailment programme will be dependent upon the nature of the interruption or event which prompted the load curtailment programme in the first place.

4.6.3.2 Power Distribution System Trip

A sudden and unforeseen trip of the power distribution system could occur due to a large number of reasons. The majority of power system trips are however due to equipment failure and environmental influences i.e. lightning, severe weather etc. Once again, the customer or load needs to be aware that they can be tripped at any time without any prior notice or warning.

5 Power Quality of Supply Parameters – Consumer Requirements

5.1 Power Factor

The power factor of all loads connected to the Infrastructure power system shall be **0.8 or better at the point of connection.**

5.2 Voltage Flicker

5.2.1 Voltage Fluctuations or Flicker

Voltage fluctuations or flicker are mainly caused by rapid and repetitive switching or variation of customer loads. The effect of these load variations are exacerbated in weak electrical networks comprising low fault levels, as is the case with SKA.

Customers equipment must be designed to prevent causing disturbances which may impact other customers connected to the SKA network. It is however advisable that Customers ensure their equipment has built in immunity to deal with these voltage fluctuations should they appear.

The allowable limits shall be as per IEC 61000-2-2 and are listed as follows:

Short-term: $P_{st} = 1$;
Long-term: $P_{lt} = 0.8$

5.2.2 Measurement Method

The measurement method for P_{st} (short-term severity) can be found by measurement with a flickermeter over a 10-minute period.

The long-term severity, denoted by P_{lt}, is calculated for a two-hour period. It is derived as follows from the values of P_{st} for 12 consecutive 10-minute periods.

$$\mathrm{Plt} = \sqrt[3]{\frac{1}{12}\sum_{i=1}^{12} Psti^3}$$

Where P_{sti} (i = 1, 2 .....12) are 12 consecutive values of P_{st}

5.2.3 Assessed Level

The highest of the 95% weekly Plt values over the full measurement period must be compared with the levels defined in 5.2.1.

5.3 Harmonics

Consumers connecting equipment to the network must not cause the harmonic voltage distortion to exceed the apportioned limits in the MV network. Stage 1 or Stage 2 assessment must be undertaken in accordance with IEC61000-3-6.

The maximum short circuit current and system capacity required for this calculation can be obtained from the power system designer when required.

Similarly, apportioned limits will be provided to the consumer based on the principles in this standard and the actual parameters at the connection point.

5.3.1 Measurement Method

The measurement method shall be as per IEC61000-4-30 for Class A measurements

5.3.2 Assessed Level

95% of the 10 minute mean r.m.s values for each harmonic voltage shall be less than or equal to the limits.

5.4 Voltage Unbalance

All three phase loads connected to the power distribution system shall be as balanced as possible across all three of the phases so as not to cause a voltage unbalance at the point of supply greater than 3%.

6 Consumer Protection Requirements

All loads or consumers of power must take responsibility for protecting their own equipment as far as possible against any undesirable events that could occur on the SKA power system.

The consumer will need to identify which equipment in their system would be affected by at least the following events and put the necessary protection systems in place in order to prevent damaging their equipment:

- Unplanned outages or tripping out of consumers without any prior notice;
- Voltage Unbalance (this event could affect the performance and lifespan of motors for example);
- Failure of one or more phases of a three phase system;
- Under Voltages;
- Over Voltages;
- Transients or surges
- Voltage Dips