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UNDERSTANDING PREMIUM POWER GRADES

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Summary: **Many sensitive industrial and some high-tech commercial customers require a premium grade of power. However, the term "premium power" often elicits unrealistic expectations from those customers. To accurately quantify premium power, utilities must define a baseline for grid power so that customers will have a clear idea of what is expected from "normal" grid power. This paper will provide in-depth analysis of the technical, economic, and regulatory issues that need to be resolved in order to make premium power services a viable option for energy providers of the 21st century. Power quality indices suitable for defining base-level power will be addressed, numerical values for these indices to define "basic power" will be quantified based on power quality benchmarking that has been conducted in several regions around the world, and the impact of local regulatory issues on offering premium power services will be analyzed. This paper will serve as a guideline for establishing premium power grades by energy service providers.**

1. INTRODUCTION

The energy services industry has, for the most part, delivered a "one-size-fits-all" grade of power reliability and quality. The power delivered to utility customers includes momentary voltage sags, which are acceptable to most residential and commercial customers. However these disturbances can be quite harmful to more sensitive industrial customers with automated process lines. For example, voltage sags down to 80% of nominal voltage for as little as one cycle can cause havoc in processing plants, resulting in hours of downtime. Therefore, the one-size-fits-all strategy of power providers is no longer viable. Many sensitive industrial and some high-tech commercial customers require a premium grade of power that can be achieved through a combination of custom power hardware currently developed by several vendors worldwide. To date, utility efforts to define options and apply this hardware for premium power have been sapped by unrealistic expectations.

Any effort to establish premium power options will require that each utility define a baseline for grid power so that customers will have a clear idea of what is expected from "normal" grid power. This baseline should be quantified region by region because of the variability between electric distribution and transmission systems, lightning flash densities, and soil resistance (among others), all of which will affect the baseline for grid power at a given location. Despite the difficulties inherent in this effort, defining a base level is essential to the customer's understanding of "normal" power.

Efforts by state regulatory agencies to arbitrarily define "normal" power do not differentiate between customer types, neglecting the industrial customer's higher need for premium power and elevating the need of the residential and commercial customer. To enable energy providers to profit from the delivery of premium power, regulatory agencies must allow service providers to define "normal" power and offer premium power services to customers who require such premium option.

2. QUALITY AND RELIABILITY OF POWER

The quality of power is often characterized by the availability of power. Traditional reliability indices that measure the performance of electric supply take into account the duration and the frequency of interruptions that impact the availability of power at a customer site. One of the indices that measure the availability of power is defined as ASAI, average service availability index. The ASAI represents the fraction of time (often in percentage) that a customer has power

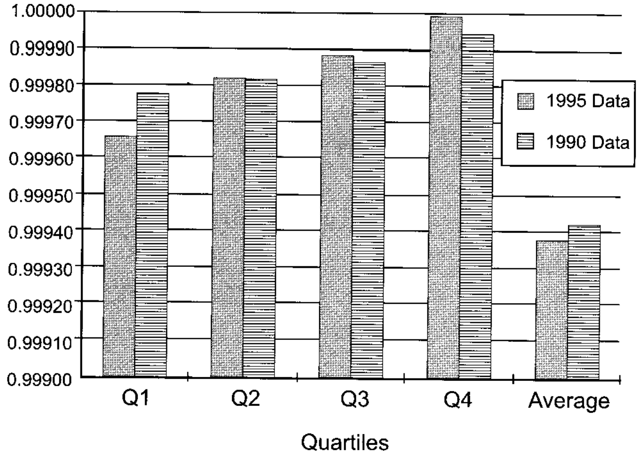

Figure 1. Results of Survey of Quality of Power as Measured by Availability [1]

provided during one year or the defined reporting period. For example, if a customer does not have power for a total of 2 hours in a given year (8760 hours), the ASAI index for that customer is calculated as ASAI =(8760-2)/8760 = 0.99977. Figure 1 shows the results of a survey conducted among North American utilities to quantify the reliability of grid power in terms of availability. The quartiles (Q) represent the distribution of the survey results among the respondents. As can be seen from the results, the 4th quartile (that is, the best-performing circuits) has a reliability that is approaching 1, or 100% availability. For most industrial customers, especially customers directly served by transmission lines, it is not uncommon to have a reliability of 100%, which means that the power is available for 8760 hours a year. In many cases, this results in industrial and large commercial customers expecting disturbance-free, 100% reliable power. When this expectation is not met, the customer perceives the power as a "poor quality."

3. THE NEED FOR DIFFERENT GRADES OF POWER

Let us consider an industrial customer, say a paper mill, that receives power at the transmission level and the availability of that power is 100%. However, from time to time, the customer experiences momentary disturbances that cause voltage on one or more phases to drop below 90% of nominal. Figure 2 shows the voltage waveform typically associated with this class of voltage disturbance, commonly known as a voltage sag or voltage dip. Typically for transmission faults, these voltage disturbances last for fractions of seconds (» 1/10 second), which represents the total fault-clearing time for transmission faults. However, these momentary events can cause a complete plant-wide process shutdown, which may take hours to recover.

A survey conducted by South African Group SAPPI [2], which operates eight pulp and paper operations in South Africa, estimates 891 minutes of time lost in 1996 as a result of voltage dips, resulting in a total turnover loss of approximately $2 million for that year. A recent article 'Split second power dip wrecks havoc' in The Straits Times of Singapore illustrates the wide range of impact of Voltage Dips. *IT LASTED a mere 0.3 seconds. But the effects of last Friday's power dip on some petrochemical and wafer-fabrication plants lasted for hours if not days. Production was set back, hundreds of thousands of dollars were lost and hundreds of workers were mobilized to work over the weekend to start up the plants again. The dip also played havoc with computer screens and ATM machines. But the worst hit was Jurong Island, Singapore's petrochemical-manufacturing hub where several plants were shut down at Merbau, Chawan, Sakara and Seraya. Fifteen out of 20 petrochemical plants on Jurong Island and three wafer-fabrication plants at Woodlands contacted by The Straits Times reported varying degrees of damage ... from delays in production to huge losses.* [The Straits Times, Singapore, March 2000]

Clearly, while the availability of power may have been 100%, the quality of the power resulted in significant losses

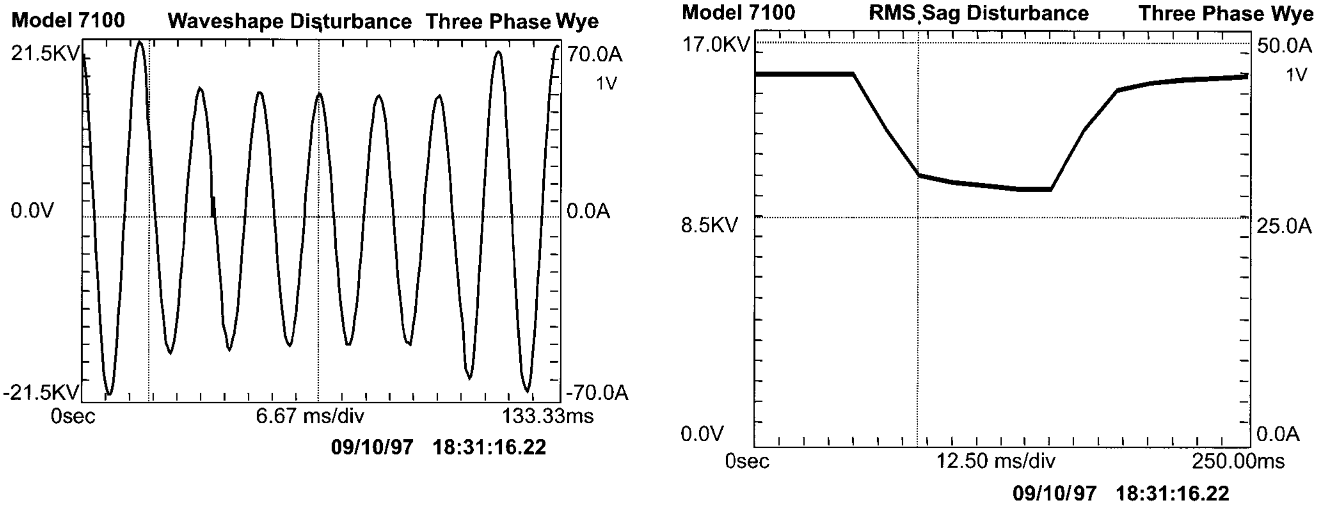

Figure 2. Characteristics of a Voltage Sag

to the industry. The customer expectation, which was based on traditional reliability measures, was met by the utility. However, reliability alone was not sufficient to meet the requirements of the process to operate properly in its electrical environment. Clearly, the customer was significantly affected by voltage dip, and this is true for a very small but very important segment of industrial customers that rely on sensitive machines and controls in their production line that require 100% quality power 100% of the time.

Before a customer's requirements can be met, very critical and often omitted information must be disclosed: the expected quality of the power[1] that is normally delivered by the energy service provider. How many sags, as shown in Figure 2, can be expected in a given year, and what can be expected from a utility supply? The answer to that question requires defining grades of power in terms of its quality, just like gasoline levels are defined in the U.S. by octane grades such as "87 Regular," "89 Premium," and "93 Super Premium." Defining such grades would allow customers to choose what grades of power they would require and the cost implications for obtaining that grade versus the normal or basic grade. Defining a basic grade of power that takes into account these momentary voltage variations will allow utilities to manage end-user's expectations of grid power and provide an economic justification for investing into premium power or purchasing machines and equipment that can tolerate the expected electrical environment.

4. REQUIREMENT FOR NEW INDICES FOR DEFINING POWER GRADES

In 1996, EPRI completed the Reliability Benchmarking Methodology (RBM) project [3], which provided a set of power quality indices to allow power quality to be described in a consistent manner from one utility to another and one system to another. Just as SAIFI, SAIDI, and CAIDI have served as a common means of relating interruption performance, the RBM power quality indices provide the tools to quantify distribution system power quality in terms of the various quality disturbances that affect sensitive end-use equipment.

The most basic RBM index for voltage sag performance is the System Average RMS (Variation) Frequency Index$_{\text{Voltage}}$ or SARFI$_X$. The SARFI$_X$ concept is the basis for most of the other RBM indices as well.

SARFI$_X$ represents the average number of specified short-duration RMS variations that occurred over the monitoring period per customer served from the assessed system. For SARFI$_X$, the specified disturbances are those RMS variations with a voltage magnitude less than x for voltage drops or a magnitude greater than x for voltage increases. SARFI$_X$ is defined by the following equation.

$$SARFI_x = \frac{\sum N_i}{N_T}$$

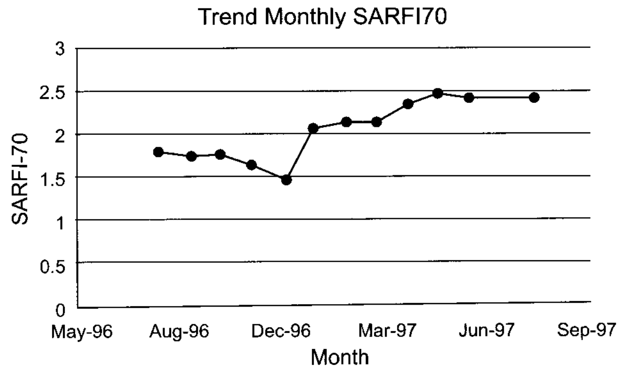

Figure 3. Trend of Monthly SARFI$_{70}$ Values Showing the Variation in Voltage Sag Performance over a Period of Time

where:

X — RMS voltage threshold. Any positive value is possible. However, some of the more common values include 140, 120, 110, 90, 80, 70, 50, and 10.

N_i — number of customers experiencing voltage deviations with magnitudes above X% for X>100 or below X% for X<100 due to measured event i.

N_T — total number of customers served from the section of the system to be assessed.

SARFI$_X$ is calculated in a similar manner as the System Average Interruption Frequency Index (SAIFI) value, which many utilities have calculated for years. The two indices are, however, quite different. SARFI$_X$ assesses system performance with regard to short-duration RMS variations, whereas SAIFI assesses only sustained interruptions. SARFI$_X$ can be used to assess the frequency of occurrence of sags, swells, and short-duration interruptions. Furthermore, the inclusion of the index threshold value, x, provides a means for assessing sags and swells of varying magnitudes. For example, SARFI$_{70}$ represents the average number of sags with a retained voltage less than 70% experienced by the average customer served from the assessed system.

Note that the number of customers used to define SARFI$_X$ is nothing more than a weighting factor used to aggregate voltage sag measurements recorded at specific monitoring sites into a system performance metric. For example, consider the calculation of SARFI$_X$ for a single customer site. For each sag recorded, N$_i$, the number of customers experiencing the sag, would be one because SARFI$_X$ is being calculated for only the single customer. N$_T$, the total number of customers served from the system, is also one. Thus, the SARFI$_X$ equation reduces to a count of the number of sags that have a magnitude to below the specified RMS voltage threshold. Figure 3 shows the number of voltage sags below 70% of nominal in any phase at a given site using the SARFI$_{70}$ index. In this case, the SARFI index is nothing but a counter that counts the number of voltage sags below the specified threshold, which is 70% in this case.

Using a similar concept, indices that track the performance of the quality of the supply with respect to industry stan-

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1) In this paper, "power" is used synonymous to "voltage," even though "voltage" is the more technically correct term.

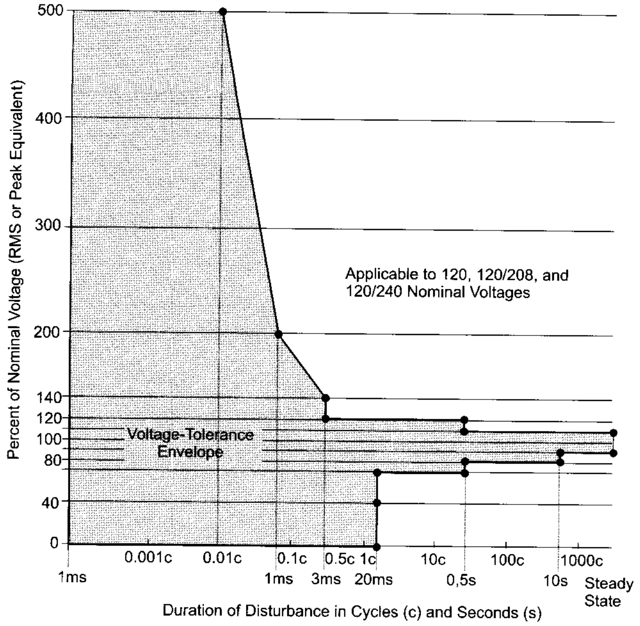

Figure 4. ITIC Curve Curve Defining Voltage Sag Ride-Through Design Goals for Manufacturers of Information Technology Equipment (Applies to Single-phase 120/240-Volt Equipment)

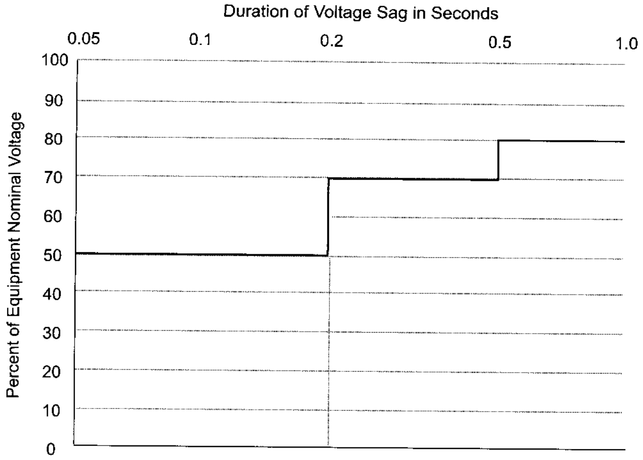

Figure 5. SEMI F-47 Standard Curve Required Semiconductor Equipment Voltage Sag Ride-Through Capability Curve

dards for voltage sag ride-through for equipment can also be established. For example, the ITIC (Information Technology Industry Council) curve, formerly known as the CBEMA (Computer Business Manufacturers Association) curve, defines the expected performance of equipment over a voltage-time profile, as shown in Figure 4. A recent development in the semiconductor industry was establishing a voltage sag ride-through standard for tools that are used in a semiconductor processing plants. This curve, commonly known as the SEMI F-42 curve, [4] defines the expected performance of a semiconductor processing tool, such as an etcher or vapor deposition tool, when subjected to voltage sags. Based on this curve, as shown in Figure 5, semiconductor production equipment should be able to tolerate voltage sags up to 50% of nominal. A $\mathrm{SARFI}_{\mathrm{ITIC}}$ or a $\mathrm{SRFI}_{\mathrm{SEMI}}$ index could track the performance of the supply voltage by quantifying the number of times a voltage disturbance falls outside the envelope defined by the curve. Customers can use such indices to track the quality of supply. Based on pre-negotiated contracts with the energy provider or a third-party entity, customers can then enter into a premium power contract that specifies the maximum number of events that may fall outside the ITIC or the SEMI curve.

5. DEFINING BASIC POWER GRADE

After defining indices that track the number of voltage sags based on either a predefined level such as $\mathrm{SARFI}_{\mathrm{X}}$ or based on industry indices such as $\mathrm{SARFI}_{\mathrm{ITIC}}$ or $\mathrm{SARFI}_{\mathrm{SEMI}}$, the next question is: What is the level of these indices that a customer can expect from a "typical" utility service? This would represent the basic level of power that is expected from the grid. However, because of the variation of grid power from site to site, it is difficult if not impossible to define a level that will fit all possible combinations of geographical location and electrical system characteristics. For example, weather-related events are a major cause of voltage sags, and the number of voltage sags to some extent depends on the exposure of the distribution and transmission lines to lightning events. Lightning flash density becomes a variable that affects voltage sag rate. Expecting the same sag rate at two different locations with a large difference in flash density rate is not feasible. The most definitive approach to define the expected quality of power as defined by the voltage sag indices is to conduct benchmarking of power quality indices over a considerable period of time by statistically choosing monitoring sites that represent the system under consideration. The process of benchmarking power quality requires an effort to understand the existing levels of service quality provided to consumers and to determine the levels of quality that can be reasonably expected.

Several power quality benchmarking projects have been conducted across the world. The data from these efforts provide an indication of base-level power in terms of expected number of voltage sags at a given site. In 1989, EPRI began an extensive assessment of the quality of service provided on distribution systems across the United States. This effort, known as the EPRI Distribution Power Quality (DPQ) Project, was completed in 1995, and the results were made available to EPRI member utilities in 1996. The report of the DPQ [5] summarizes the power quality data recorded on 24 utility systems from across the country. Measurement data was collected from 276 locations on 100 distribution system feeders over a 27-month period, resulting in a measurement database of over 30 gigabytes of power quality data, which provides a good basis for defining the expected number of voltage sags that a customer will experience. Using a probability distribution, the basic level of power with regards to voltage sags can be defined as the CP50 and CP95[2] percen-

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[2] This is the expected number of events per site per year that will be exceeded at only 5% of the sites

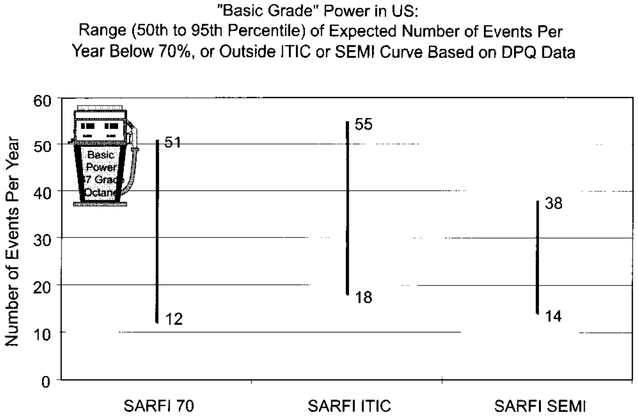

Figure 6. Basic Power (87 Grade Octane) Based on DPQ Results for US Distribution Circuits

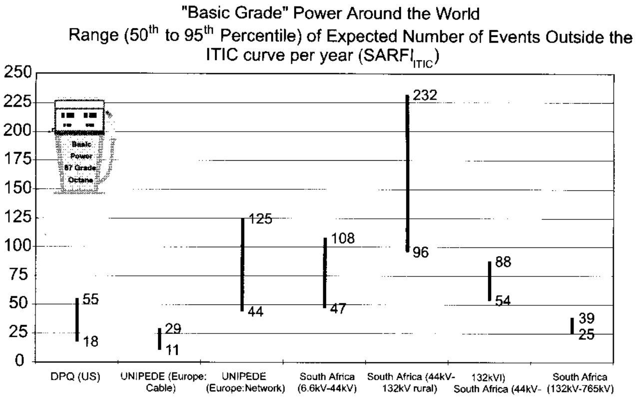

Figure 7. Basic Power (87 Grade Octane) Based on ESKOM Results for South African Circuits

tiles of the measured data from the DPQ project. Using this criterion, the "basic" level of power quality that on average a customer will receive can be quantified as shown in Figure 6. Based on this, an average site is expected to experience voltage sags that will fall below 70% of nominal voltage 12 to 55 times a year, or fall outside the SEMI F47 curve envelope 14 to 38 times a year.

Similar benchmarking efforts were undertaken in 1985 by the Distribution Study Committee of UNIPEDE to improve the knowledge of the rates of occurrence and severity of voltage dips and short interruptions in public electricity supply networks. This group arranged a coordinated series of measurements in nine countries (Austria, France, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom, and Germany), which provide statistical information based on over 80 system-years of monitoring experience covering a wide range of environmental and geographical conditions [6]. The measurements were performed at 85 sites on medium-voltage networks. Of these, 33 sites were cable systems and 52 sites were mixed overhead-cable systems.

Similar system-wide PQ monitoring conducted in South Africa by the local utility ESKOM led to regulatory agencies to create a minimum power quality standard for different classes of service voltage as defined in NRS 048 [7]. The standard specifies the number of voltage dips based on bins that are defined by the magnitude and duration of voltage dips. The results of the UNIPEDE and the ESKOM benchmarking can be extrapolated to determine the number of times an event will fall outside the 70% nominal range which is similar to the ITIC curve envelope [8]. The results of such analysis are shown in Figure 7. Figure 7 provides a range of expected number events based on the CP50 and CP95 values for the UNIPEDE and the ESKOM data.

6. CALCULATION OF DPQ RESULTS IN THE SOUTH AFRICAN NRS 048-2 FORMAT

The ESKOM model attempts to divide the voltage dip-duration window into S, T, W, X, Y, and Z bins, as shown in Figure 8 for the purposes of defining quality-of-service standards. The derivation of these limits takes into account utility controllability and customer sensitivity. Figure 8 is based on calculating voltage dip magnitude, which is the remaining voltage during a sag. For example a sag down to 70% of nominal is classified as a 30% dip.

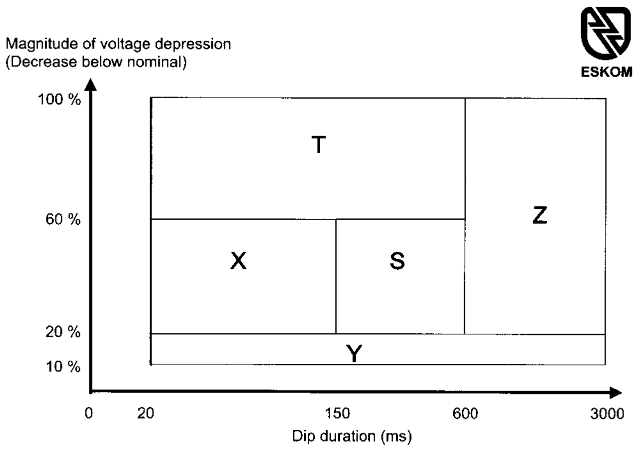

Figure 8. NRS 048 Dip-Duration Bins S, T, X, Y, & Z

Presentation of the DPQ results in the ESKOM format requires modification to the ESKOM table to convert the time scale for each category of dip from 50 Hz to 60 Hz.

The DPQ project used weighted and un-weighted values to present the results. The weighted values were an attempt to statistically represent under-represented feeders in the entire set. Table 1 and Table 2 shows the DPQ weighted result in ESKOM Bin format for CP95 that is the maximum allowable number of dips (Table 1) and CP50, which is the target value (Table 2), defined in NRS 048.

7. CALCULATION OF DPQ RESULTS IN THE UNIPEDE DISDIP FORMAT

Presentation of the DPQ results in the UNIPEDE DISDIP Survey format is helpful to compare the results. Two modifications to the DISDIP table were necessary. The first was to convert the time scale for each category of dip from 50 Hz to 60 Hz. The second was to change from sag depth to sag level. Table 3 shows the results for UNIPEDE mixed cable/overhead network and the DPQ weighted results.

Table 1. DPQ Results in ESKOM NRS –048 Format (Maximum Allowed, CP95)

Network voltage range	NRS 048 Dip window category				
(see Note 1)	Z	T	S	X	Y
6.6kV to ≤ 44kV	20	30	30	100	150
6.6kV to ≤ 44kV Rural	49	54	69	215	314
> 44kV to ≤ 132kV	16	25	25	80	120
220kV to ≤ 765kV	5	6	11	45	88
DPQ < 34.5kV, CP95	**9.5**	**16.3**	**13.8**	**38.8**	**77.9**

Table 2. DPQ Results in ESKOM NRS –048 Format (Target Level, CP50)

Network voltage range	NRS 048 Dip window category				
	Z	T	S	X	Y
6.6kV to ≤ 44kV	10	8	10	50	75
6.6kV to ≤ 44kV Rural	20	15	25	100	150
> 44kV to ≤ 132kV	5	10	10	50	80
220kV to ≤ 765kV	2	3	3	33	59
DPQ < 34.5kV, CP50	**5.2**	**13.8**	**5.3**	**3.1**	**26.1**

Table 3. UNIPEDE DISDIP for mixed cable/overhead network and DPQ Results (CP 95) in parenthesis

Depth	10ms – 100ms	100ms – 500ms	500ms – 1sec	1sec – 3sec	3sec – 20sec	20sec – 60sec
10-30%	61 (87)	68 (46)	12 (7)	6 (3)	1 (1)	0 (1)
30-60%	8 (24)	38 (14)	4 (2)	1 (2)	0 (1)	0 (0)
60-90%	2 (10)	20 (7)	4 (2)	2 (3)	1 (2)	0 (0)
100% (Interruption)	0 (0)	18 (4)	26 (3)	5 (5)	4 (5)	9 (5)

8. IMPACT OF REGULATION

The definition of "Basic Power Grade" as presented in this paper is based on voltage sags, which is of importance to a very few percentage of the total utility customer base. Residential customers, most commercial customers, and even some industrial customers could not care less about voltage sags. To them, quality of power is adequately defined by availability. From a regulatory perspective, there is no need for regulating the quality of power in terms of voltage sags. Voltage sag impacts only a very select group of customers, mainly industrial processes that rely on sophisticated machines and controls and operate on a 7/24 schedule. For this select group of customers, defining the basic power in terms of voltage sags allows them to differentiate a higher "premium" grade of power that could be achieved through a combination of custom power devices and upgrades to utility system with regards to improving voltage sag performance. Such traditional utility side measures could include tree trimming, line shielding, improving pole grounding, installing arrestors in critical portions of the circuits, and other means that are above and beyond what is required in order to maintain the traditional reliability of the system.

It is not economically and socially justifiable to improve utility line performance to reduce voltage sags just for a select group of customers when the cost of doing such improvements will invariably be borne by all customers, a majority of whom is not impacted by voltage sags. This is a key issue that regulators have to understand and allow the utility company (that is, the wires company) to work either with the customer or with the customer's energy service provider (that is, a retail energy service company) in order to define the grade of power that is required by that specific customer and offer options on how to achieve those grades and the price premium that the customer has to pay for the enhanced grade of power.

Too often in the past, utilities would get involved in premium power offering as a way of a demonstration project where the "true cost" of such an offering is never borne by the affected customer. This fosters unrealistic expectations by the customers, hampers the growth of premium power service offerings in general, and hampers the market for custom power devices in specific. Managing customer expectations by defining a basic level of power quality and allowing utilities to work with customers on a one-to-one basis to offer premium power are necessary for premium power to ever become a reality in the real marketplace.

9. CONCLUSIONS

Any effort to establish premium power options will require that each utility define a baseline for grid power so that customers will have a clear idea of what is expected from "normal" grid power. This baseline should be quantified region by region because of the variability between electric distribution and transmission systems, lightning flash densities, and soil resistance (among others), all of which will affect the baseline for grid power at a given location. Despite the difficulties inherent in this effort, defining a base level is essential to the customer's understanding of "normal" power. Grades of power will become meaningful only when a "Basic Level" is first defined. This will allow utilities to work with customers who require a premium grade power and are willing to pay for the premium.

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