M L SULTAN TECHNIKON

AN INVESTIGATION INTO THE QUALITY OF SUPPLY

VOLTAGE DIP-PROOFING

A dissertation submitted to the Department of Power Engineering in candidacy for the partial fulfilment of the Masters Diploma in Technology, Electrical Engineering (Heavy Current).

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Preface

This dissertation was done as a partial fulfilment requirement for the Masters Diploma in Technology, Electrical Engineering (Heavy Current). This work has been carried out in conjunction with the supervision of the Head of Department of Power Engineering of ML Sultan Technikon, namely, Mr G F d' Almaine. The start of the Masters Diploma for the author was in January 1994.

The level of target reader for this dissertation is a fourth year candidate with a few years of general electrical industrial experience.

This topic being of a new field of study has been rather difficult in the collation of data. Therefore this dissertation is only as informative as far as the receipt of data at the time of this publication.

These studies represent original work by the author and have not been submitted in any form to any other tertiary institution. Where use has been made of the work of others it has been duly acknowledged in the text.

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Mr A. Crow : Durban Electricity, Quality of Supply

Mr G F d'Almaine : ML Sultan Technikon Department of Power Engineering

First Southern African Power Quality Conference : All Delegates

ESKOM, for literature

Switching Systems (Pty) Ltd

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ML Sultan Technikon Library, for literature

Abstract

With the ever increasing electrical demand on an electrical system, the quality of the supply will be tested more and more. And it is with this deteriorating quality that the topic of voltage dips and depressions has become a contentious issue amounts the industrial sector and supply authorities, hence the means to combat this issue in recent years.

This dissertation is aimed at the industrial electrical engineers that require a relatively comprehensive outline of the topic in question where problems associated within their own organisation can be related to this dissertation and provide with possible solution methods to solve their own issues.

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Part 1 GETTING STARTED

Terminology and Definitions

The following section contains terms that are used frequently in this dissertation and are defined in terms of the context for the purpose of the reader.

Voltage change (see Figure 2)
A variation of the r.m.s (or peak) value of the supply voltage between two adjacent levels, each of which is sustained for definite but unspecified times.

Magnitude of a Voltage change (see Figure 2)
The difference between the r.m.s (or peak) values of the voltage, before and after a voltage change.

Relative Voltage change (see Figure 2)
The ratio of the magnitude of a voltage change to a specific value of the voltage.

Duration of a Voltage change (see Figures 1 and 2)
Interval of time for the voltage to increase or decrease from the initial value to the final value.

Voltage change interval (see Figure 2)
Interval of time that elapses form the beginning of one voltage changes to the beginning of the next voltage change.

Voltage Fluctuation (see Figures 1 and 2)
A series of voltage or a cyclical variation of the voltage envelope.

Voltage Fluctuation Waveform (see Figures 1 and 2)
For a voltage fluctuation, the form of the envelope of the peak voltage as a function of time.

Sinusoidal Voltage Fluctuation (see Figure 1)
Voltage fluctuation of which the fluctuation waveform is sinusoidal.

Magnitude of a Voltage Fluctuation (see Figures 1 and 2)

During a voltage fluctuation, the difference between the maximum and minimum values of voltage.

Rate of occurrences of voltage changes

The number of voltage changes occurring per unit of time.

Point of Common Coupling (P.C.C) (see Figure 3)

The point of common coupling with the other consumers is the point in the public supply network, electrically nearest to the consumer in whose installation and appliance is, or is to be, connected, at which other consumers' installations are, or may be, connected.

NOTE: The P.C.C. may be at any point of the supply system but is usually considered to be the junction of Za and Zb.

Supply System Impedance (Za) (see Figure 3)

The system impedance up to the P.C.C with other consumers.

Service Connection Impedance (Zb) (see Figure 3)

The impedance of the connection from the P.C.C with other consumers up to the point on the users' side of the metering point.

House wiring Impedance (Zc) (see Figure 3)

The impedance of the house wiring between the metering point and the socket-outlet.

Appliance Impedance (Zd) (see Figure 3)

The appliance impedance is the sum of two impedances; the flexible cord impedance between the socket-outlet and the appliance, and the internal wiring impedance.

Reference impedance

A conventional impedance used to calculate or measure the disturbance caused by an appliance.

Extra High Voltage (EHV)

The set of nominal voltage levels that are used in power systems for bulk transmission of electricity in the range $220 \text{ kV} < U_n < 400 \text{ kV}$. [SABS 1019]

High Voltage (HV)

The set of nominal voltage levels that are used in power systems for the transmission of electricity in the range 44kV < Un < 220 kV. [SABS 1019]

Interruption

A phenomenon that occurs when one or more phases of a supply customer/group of customers are disconnected for a period exceeding 3 seconds. [NRS 047]

Forced interruption

An interruption that occurs when a component is taken out of service immediately, either automatically or as soon as switching operations can be performed, as a direct result of emergency conditions, or an interruption that is caused by improper operation of equipment or human error. [NRS 047]

Planned interruption

An interruption that occurs when a component is deliberately taken out of service (by the Utility or its Agent) at a selected time, usually for the purposes of construction, preventative maintenance or repair. [NRS 047]

Low Voltage (LV)

The set of nominal voltage levels that are used for the distribution of electricity and whose upper limit is generally accepted to be an a.c voltage of 1000 V (or a d.c voltage of 1500 V). [SABS 1019]

Medium Voltage (MV)

The set of nominal voltage levels that lie above low voltage and below high voltage in the range 1 kV < Un < 44 kV. [SABS 1019]

Standard Voltage

The phase voltage of 230 V measured between a phase conductor and neutral conductor, or a line voltage of $\sqrt{3}$ x 230 V measured between phase conductors.
[Electricity Act, 1987 (Act 41 of 1987), regulation R2265]

Utility (licensee)

A body, licensed by the National Electricity Regulator [NER], that generates, transmits or distributes electricity. Such a body might be the direct licensee, or an agent (sub-distributor) of the licensee. [NER 047]

Voltage Dip

A sudden reduction in the r.m.s voltage, for a period of between 20 ms and 3 s, 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 the declared voltage to when the voltage rises above 0,9 per unit of the declared voltage.

Voltage Flicker

The modulation of the amplitude of the supply voltage, perceived by the observer as a fluctuation of light intensity in electric lighting.

Voltage Harmonics

Sinusoidal components of the fundamental waveform (i.e. 50 Hz) that have a frequency that is an integral multiple of the fundamental frequency.

- Odd harmonics are defined as the 3rd (150 Hz), 5th (250 Hz),.........etc.
- Even harmonics are defined as the 2nd (100 Hz), 4th (200 Hz),........etc.
- Interharmonics are frequency components that are not an integral multiple of the fundamental frequency.

Total harmonic distortion (THD) is given by :

$$THD = \sqrt{\sum_{h=1}^{N} V_h^2}$$

where Vh is the per cent r.m.s value of the *h* th harmonic or interharmonic voltage component, and *N* is the highest harmonic considered in the calculation.

Voltage Regulation

The ability of the steady state-state r.m.s voltage to remain between the upper and lower limits.

Voltage Unbalance

Voltage unbalance arises in a polyphase system when the magnitude of the phase voltage or the relative phase displacements of the phases (or both) are not equal. The unbalanced voltages can be represented by the sum of three sets of symmetrical vectors, namely :

a) the positive sequence set, consisting of three vectors all equal in magnitude and symmetrically spaced, at 120 degree intervals, in time phase, their phase order being equal to the phase order of the system-generated voltages.

b) the negative sequence set, consisting of three vectors all equal in magnitude and symmetrically spaced, at 120 degree intervals, in time phase, their phase order being the reverse of the positive sequence phase order, and

c) the zero sequence set, consisting of three vectors, all equal in magnitude and phase.

Voltage unbalance (UB) is usually expressed as a percentage, given by :

$$UB = \frac{Vn}{Vp} \times 100$$

where

Vn is the negative sequence voltage, in volts; and
Vp is the positive sequence voltage, in volts.

Chapter 1 Introduction

This investigation has been of interest to the author for some time. The interest has stemmed from the visible, annoying and interruptible problems arising from the ever so slight drop in voltage causing the Television set to reset during that crucial moment of a thriller movie, the rebooting of ones computer and not having saved the information and most noticeable the dimming of the surrounding light sources.

Objective one of this investigating is to illustrate the existing typical Consumers network set-ups that one might expect in the market place which will enable one to assess the aspects of that Quality of Supply in the Consumers Plant.

The second objective is to highlight possible causes emanating from the assessed aspects of that Quality of Supply and in particular the aspect of voltage-dips.

The third objective is to provide parameters for solutions and design criteria for a Consumer to ensure a cost effective and acceptable standard of electricity supply, featuring on the aspect of Voltage-dip Proofing.

Finally this investigation can lead to a reference manual for Consumer's Plant Engineers and Technicians to enable quick solution to the parameters required in solving the issue of Voltage-dip Proofing.

This investigation is also based on the presumption that the reader has a fair knowledge of general electrical industrial experience.

Part 2 INVESTIGATION INTO QUALITY OF SUPPLY

Chapter 2 Introduction

2.1 Background

The use of more electricity on a given source will naturally lead to undesirable elements polluting the supply at the Point of Common Coupling. These elements are typically the following :-

- Variable Speed Drives
- Electric Arc Furnaces

Not only do internal elements pollute the supply but also external elements and events cause an unsatisfactory quality of supply. These external elements are typically the following :-

- Lightning
- Sugar cane fires
- Insulator pollution
- Wildlife, etc

These elements are usually the direct result of the use of overhead line based electrical system. It is not possible to design an overhead line to be completely immune to these elements and the ultimate level of immunity to these elements is determined by the trade-off against cost of construction.

2.2 Supply Authority

The Supply Authorities, whether Municipal or larger i.e. ESKOM, have in recent years started experiencing numerous supply-related complaints. This can be contributed to the increased use of sensitive electrical equipment by the Consumer, combined with the growth in availability of products that cause disturbance on the electrical supply network.

ESKOM has also recognised that Customers have different power quality needs and to this end ESKOM has developed an approach that provides three power quality options for Customers to choose from.

Firstly, Customers in general have the right to receive a power quality that falls within that of the National Quality Standards set by the National Electricity Regulator [NER]. The NER has adopted a minimum standard quality as specified in NRS 048. This minimum standard will be used by the NER as one of the main criteria when evaluating the performance of utilities for the purpose of license renewal. NRS 048 requires a utility to comply with this minimum standard for 95% of its customers. In general ESKOM will be liable for the improvement of the quality of supply, at ESKOM's cost, if such standard is not met. However where the cost of supplying a customer is not recovered through the tariff and the applicable monthly rental it may not be possible for ESKOM to comply with the minimum standard without cross-subsidisation from ESKOM's other customers. In general Customers will not incur additional costs to obtain a power quality that complies with this minimum standard.

Secondly, where Customers require a better power quality than specified in the NER, the Customer may choose the Network Specific Option. In terms of this option Eskom will investigate and determine the power quality that can be provided at the Customer's point of supply from the existing transmission or distribution system. Consequently certain costs will have to be recovered from the Customer.

In choosing the Network Specific Option, the Customer will be required to pay the following costs :-

- Once off payment to cover the cost of the investigation to determine and implement the power quality that can be provided from the existing system.
- Payment to cover the cost of the measuring device either in cash or a non-rebatable monthly rental over 5 years.
- A monthly payment in respect of the monthly costs of measurements, calculations, provision of information and investigations where required.

Thirdly, where Customers require a better power quality than specified in the Network Specific Option, the Customer may choose the Premium Power Option. All the costs incurred in providing premium power quality will be recovered from the individual Customer. Choosing the optimum power quality standard and thereby achieving a balance between the cost of supply and the cost of using the supply is a complex one. Utilities and their Customers need to work together to ensure that the power quality levels and the associated costs of supply are in the national interest.

Customers should in their own interest view the Supply Authority's Policy and measure the quality of supply at the terminals of their metering point. Secondly collaborate with the Supply Authority and measure the quality of supply at P.C.C. With this information on the table the Consumer can determine who is at fault. In other words is the problem :-

- in-house (Customer)
- load network related (Neighbouring Consumers)
- source network related (Supply Authority)

The polluting elements can now be addressed.

2.3 Statutory LV levels

The statutory limits for the supply voltage to residential customers have been summarized from the Government Notice No. R2665 of 16 November 1990 which replaces Regulation 1 of section 28 of the Electricity Act (No 41), 1987.
This stipulates that :

a) from 1 January 2004 all points of supply lower than 500V should conform to the standard voltage of 230V ± 6 % ;
b) existing systems can continue to provide supply at their declared voltage until 1 January 2004 with a voltage deviation of +6 % -10 % if the declared voltage is below 230V and +10% -6 % if the declared voltage is above 230V : these voltage deviation limits shall not be exceeded for any periods longer than 10 consecutive minutes ;
c) the National Electricity Regulator may, on application, permit other deviations from the stipulated supply voltage and frequency.

Chapter 3 Power System Analysis

3.1 Network

The South African Power network is characterised by a centrally located generation with long overhead transmission lines to the Consumer. The transmission and sub-transmission systems are subjected to the elements, i.e. lightning, cane fires and general pollution. The common occurrence of failure is insulation breakdown and flashover causing either line-to-ground or line-to-line faults, dependent on the line construction and voltage gradients.

The impact of Network expansion on dip performance can most definitely affect the end users from the early stages in the development of the network to when the system is overloaded. A utility therefore cannot easily contract to maintain the existing levels of supply quality in the case of developing networks.

Increasing the fault level at the HV infeed by increasing the transformer capacity at the EHV/HV substation tends to arrest the increase in the failure events in the short term. The closer a customer is to the EHV/HV substation, the more stable the process failure rate remains with time. This can be explained in terms of the voltage divider effect for the faults further down stream on the system, i.e. the impedance between the generator and that of the Customer tends to be smaller than the impedance from the customer to the fault.

An important consideration for the utility when contracting with customers to a guaranteed dip performance - particularly in the case of :

- new networks
- networks where every countermeasure has been exhausted in managing the line fault rates
- Customers remote from the EHV/HV busbar
- contracting including limits on small-magnitude dips

From a Customer point of view, it is clear that behind-the-meter mitigation options are important for ensuring that the plant is not affected by the potential increase in the number of small-magnitude voltage dips.

3.2 Supply Reliability

Depending on the location of a particular industrial plant in the utility network, a particular fault will give rise to either interruption or voltage dip events. The compatibility design of sensitive processes with utility networks requires the trade-off between voltage dip performance and supply reliability to be optimised. For example, two lines feeding a sensitive plant will give rise to more fault occurrences close to the plant. If the process is sensitive to these dips, the occurrence of fewer severe voltage dips and the corresponding increase in the number of short voltage interruptions when one line is energised, may be more acceptable to the Customer.

Network open points downstream from the HV busbar from which other Customers are supplied tend to result in an improvement of the dip distributions at this common busbar. This is related to the smaller fault current that flow when normally-open points created in the downstream network.

Opening a utility supply HV bus-bar in this manner has the effect of shielding the local network from the faults, which occur on the adjacent network. However, the reduced fault levels at the local HV busbar result in more severe dip magnitudes at this busbar due to faults on the local network. In order to justify such an action, the faults on the remote network must form a significant portion of the dips, which result in plant down-time. Other sensitive customers should also not be supplied from this network.

Network configuration options show a trend providing significant improvement for very sensitive plant and have limited effect on less sensitive plant.

Such studies should form part of a complete comparability design project which includes :-

- The relative losses associated with the downtime of the various processes in the plant
- The relative costs of behind-the-meter solutions
- The effects of network changes on other power quality parameters
- The effects of network changes on the Customers
- The effects of network changes on the operation of the network (including losses)

Refer to Annexure E - Appropriate Levels of Distribution Reliability.

3.3 Disturbances

The definition for an electromagnetic disturbance states "Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter. An electromagnetic disturbance may be electromagnetic noise, an unwanted signal or a change in the propagation medium itself". IEC 1000-2-1, 1990, Part 2, Section 1.3.3.

Voltage fluctuations are deviations in the voltage from the nominal value. These may be:-

- high (spikes, notches)
- short duration (dips, surges)
- long duration (continuous under- or over-voltage)

All these voltage fluctuations have various causes and effects as will be described in the following sections. Refer to Annexure F - Power System Disturbance Levels and Grading

3.4 System Concepts

Notch, Dip and Undervoltage Concepts

Short circuits or faults on the system and the switching on the system and the switching of large loads typically cause undervoltages. The closer to the source generation the fault is, the more severely are the entire system affected and the greater the effect the fault has on the Consumer. Conversely the closer to the load the fault is, the less the undervoltage condition has on other Consumers of the common supply.

Voltage notches are typically caused by converter equipment. The notch arises when one thyristor commutates the load current to another. Since this does not take place instantaneously, a momentary short circuit is applied between phases resulting in a voltage "dip". With normal capacitance in a system, the voltage will oscillate at the resonance frequency determined by the capacitance and the supply impedance. Voltage notches affect sensitive electronic equipment and undervoltage sensing equipment causing them to malfunction. Under resonant frequency conditions, capacitor equipment stands the good chance of been severely damaged or destroyed. The effects of voltage notching can be reduced by increasing the supply impedance, i.e. increasing the Consumers supply transformer impedance or by installing a choke in the supply to the converter equipment.

Spike, Surge and Overvoltage Concepts

Voltage spikes can be compared to frequency transients; their propagation through the system is governed by travelling wave computations. This means that the spike can be "reflected" from non ideal terminations of lines, etc. Simple calculations are not possible for spike propagation in supply systems and should be carried out using modeling techniques. These methods are beyond the scope of this investigation.

Spikes are caused either by both circuit breakers and isolation breakers opening or by closing. Opening a circuit device supplying an inductive circuit will cause the inductance to generate a "back e.m.f". The faster the current arc is extinguished, the higher the generated voltage will be. It is therefore noted that vacuum circuit breakers and contactors will cause higher spikes to be generated than SF6 or oil switchgear. An external element such as a lightning strike on a transmission line will cause a transient wave to travel in both directions on the line. Voltage spikes cause damage to insulation, particularly in motors, cables and transformers. Surge suppression units typically protect the affected equipment, i.e. surge arrestors, etc.

3.5 Frequency of Occurrence

Initial findings in South Africa indicate that 60 % of system network problems originate in the Consumer's premises (this figure is based on experience of ESKOM). There are many aspects to be taken into account for each individual situation by virtue of the weather conditions, customer equipment, geographic condition, etc. Quite often a Consumer generates their own power disturbances by operating disturbance-producing equipment near to sensitive equipment. Consumer can therefore record these events in a table format and assess the results with the Supply Authority to confirm the results for further analysis.

An example of the occurrence is tabled in Annexure F - Power System Disturbance Levels and Grading

Part 3 QUALITY OF SUPPLY

Chapter 4 Voltage Quality

4.1 Introduction

The quality of the voltage has influences on plant and equipment performance that has a direct effect on the Customer's overall business. Similarly, the Customer's plant and equipment can influence the Supply Authorities voltage quality.

This section is to illustrate the integrity of the voltage waveforms at the Customer's supply point, point of common coupling (PCC).

The following sub-sections contain the lists of voltage quality indicators.

These indicators are :-

- Harmonics
- Voltage unbalance
- Voltage spikes
- Voltage notches
- Flicker
- Voltage depressions or dips
- Frequency
- Voltage regulation

Note: The emphasis of this research project is on Voltage Dip-proofing, therefore the indicators will only be discussed in brief and further information may have to be sourced to substantiate the results highlighted in the following sub-sections.

4.2 Harmonics

Harmonics are generally integer multiples of the fundamental frequency (50 Hz). These are superimposed on the fundamental waveform causing distortion of the fundamental waveform. The harmonic components can themselves be subdivided into :

- odd harmonics 3, 5, 7, etc.
- even harmonics 2, 4, 6, etc.
- triplen harmonics 3, 6, 9, etc.

Voltage harmonics are the result of the flow of harmonic currents. A commonly used measurement is Total Harmonic Distortion (THD) which is the square root of the sum of the squares of all the existing harmonics, usually given in percent of the fundamental waveform.

$$THD = \sqrt{\sum V^2 n}$$

where Vn is the percent or per unit RMS value of the nth harmonic or interharmonic voltage components. The compatibility levels for harmonics on LV and MV networks are given in Table No. 1. The total harmonic distortion of the supply, including all harmonics up to the order 40, shall not exceed 8% (for LV and MV networks). It is intended that Customers supplied at HV will have compatibility levels written into contracts based on the recommended planning levels in NRS 048-4. These planning levels are provided in Table No. 2 for information only.

In assessing the compatibility levels the measurement undertaken shall be carried out in accordance with the IEC 1000-4-7. All phases of the supply shall be monitored. In the case of systems with solidly earthed transformer neutrals, the phase-to-earth voltages shall be measured. In the case of delta-connected systems or systems with impedance earthing or which are unearthed, the phase-to-phase voltages shall be monitored. The assessment period shall be at least seven (7) continuous days. On each phase of the supply voltage, the instrument samples and records each harmonic voltage at intervals of three (3) seconds or less. These samples are summated over each ten (10) minute period, to obtain ten minute root-mean-square values, over each period of twenty four (24) hours (0:00 to 24:00). For each harmonic and for the THD, for each twenty four (24) hour day, the highest ten (10) minute root-mean-square values that are not exceeded for 95% of the time are recorded for each phase. For each harmonic and for the THD, the highest of the values on each phase shall be retained as the assessed daily values.

The assessed levels, which are to be compared with the compatibility levels, are the highest of the assessed daily values over the full assessment period. The number of days during the assessment period that the THD levels exceeded the compatibility level given in Table No. 1, shall be recorded.

Under normal operating conditions, the assessed levels shall be less than the compatibility levels given in Table No. 1. The assessed levels that are to be compared with the compatibility levels are the highest or the retained assessed daily values over the full assessment period.

Note : The effect harmonics has on equipment and the solutions applicable will not be covered in this Research Project.

4.3 Voltage Unbalance

Voltage unbalance occurs when the voltage magnitude and/or the phase relationship of the three phases are different. Negative phase sequence is a mathematical method of unbalance description. Unbalance is then defined as the ratio of the negative phase sequence voltage to positive phase sequence voltage, expressed as a percentage.

As with most quality of supply indicators, voltage unbalance problems need to be individually evaluated. The true extent can only be determined by thorough investigation of a specific case. However, the steady state voltage unbalance shall not exceed 2% at any Transmission, Distribution or Reticulation voltage levels.

A close approximation of voltage unbalance produced by an unbalanced load, assuming a static network (positive, negative sequence impedance constant) with small source impedance, is given as :

$$Vub\ \% = \frac{\text{Unbalanced Load (MVA)}}{\text{Short Circuit Level (MVA)}} \times 100$$

Voltage unbalance can also be calculated by measuring the phase-to-phase voltage difference and equating as follows :

$$Vub\ \% = \frac{71}{Vave} \times (V\ high - 1/4\ V\ middle - 3/4\ V\ low)$$

Typical levels of voltage negative phase sequence on South African 132 kV network are between 0,5% - 1,5%.
Note: In the same manner as for the harmonics, the instrument samples values at three (3) second intervals or less, and calculates the ten (10) minute root-mean-square values.

The compatibility level for unbalance on three-phase networks is 2%. On networks where there is a predominance of single-phase or two-phase customers, the assessed unbalance may be up to 3%. The assessed voltage unbalance shall not exceed the compatibility level at any point of supply. The assessed level that is to be compared with the compatibility level is the highest of the daily values over the full assessed period.

4.4 Voltage Spikes

A voltage spike is a sudden severe rise in voltage, which has a short time duration (usually in the order of microseconds). Commonly caused by switching inductive loads on or off, i.e., motors, transformers, x-ray equipment and lighting ballasts. A more natural cause is a lightning strike on the system.

The extent of voltage spikes depends on the network configuration, size of equipment switched and various other factors that are unique to the case. Thus in order to determine the extent of the spike on the system, each case must be considered individually.
The effect of a spike on motor, cable and transformer insulation will result in possible damage and/or accelerated aging of the insulation. Commonly used solution for spikes in the system is the installation of quality transient suppressors that include surge arrestors.

4.5 Voltage Notches

A voltage notch is a specific type of voltage change of short duration where only a part of the fundamental frequency cycle changes. The duration is typically smaller than 2 ms. Commonly caused by the commutation in converter equipment and energizing a shunt capacitor bank. The extent of the notching will depend on the specific case information, namely, the supply impedance, the magnitude of current that is switched, capacitance present in the system circuit etc.

The effect that notching has on a capacitor bank and convertor controls is that damage will occur if resonance is set up in the particular capacitor circuit and malfunctioning of the convertor will be evident. Commonly used solutions for notching is the installation of quality transient suppressors. Secondly, to increase the fault level to reduce the effect of notching.

4.6 Flicker

Flicker is the subjective impression of fluctuating light intensity of incandescent lamps. Flicker is most noticeable in the 6 - 12 Hz range. Commonly caused by open-arc furnaces, mills, cyclo converter, welding machines and the repetitive starting/switching of large motors or loads.

The extent of the flicker depends on the system fault level at PCC as well as the fluctuating load short circuit rating. The ratio between these two quantities must be at least 40 to avoid excessive flicker levels at the PCC. The effect that flicker has on the human eye is subjective but one can notice the visual irritation of the flicker from an incandescent lamp. The common solution is to increase the fault level, or transfer large loads to their own circuits closer to the supply source. A more costly exercise is to install a static VAR compensator. This shall be discussed later in the next section.

The compatibility levels for LV and MV networks, are as follows :-

- Level for short-term flicker severity (P_{st}) is 1,0.
- Level for long-term flicker severity (P_{lt}) is 0,8.

Measurements undertaken to determine compliance shall be carried out by measuring ten (10) minute values of short-term flicker severity (P_{st}), using a UIE flickermeter that complies with the requirements of IEC 868. The assessment method is similar to the harmonic method as previously detailed.

Short-term flicker severity (P_{st}) shall be measured over a ten (10) minute period, and long-term flicker severity (P_{st}) shall be measured over a two (2) hour period. The assessed level which are to be compared with the compatibility level are the highest retained daily values over the full assessment period.

4.7 Voltage Dips and Depressions

A voltage dip is the occurrence where the voltage waveform is reduced in magnitude for a relatively long period. The magnitude of the dip may vary between 10 % and 90% of the fundamental and the time duration is typically from 20ms to a several seconds. Common causes of these "dips" are:

- transmission equipment failure
- power transfer swings from different networks
- network switching
- large customer load switching
- short circuit switching

The extent of the depressions depends on a specific case. An example is :

- The difference in power angles when a power swing occurs.
- The change in load current during the load switching.
- The fault impedance to earth during insulator flash overs, trees near to line, and cane fires.
- The severity of the short circuit caused by a lightning strike.

The effects that a depression/dip has on the system are highlighted briefly, and are expanded later in the next section;

- motor contactors drop out
- static converters malfunction
- variable speed drives control circuitry - untimely firing of thyristors
- PLC's maloperation
- Thyristors damage through commutation failure
- electronic equipment malfunction

The common solutions for depression/dip on the system are highlighted briefly, and are expanded later in the next section.

- restrict number of motor starts at a given time
- transfer large loads to their own circuits
- install faster protection to minimize depression duration
- install UPS to sensitive equipment

Voltage dips are characterised by the measurement of dip duration below the dip threshold, and by the dip magnitude. The duration of a dip is the time from the moment the root-mean-square voltage drops below 0,9 pu of the declared voltage to when it rises above 0,9 pu of the declared voltage. For clarification purposes, the magnitude of the dip is given by the maximum root-mean-square excursion from declared (in a percentage) and the duration of the dip is given by the maximum duration of the worst affected phase in each case.
Refer to Figure No. 4. Voltage dips can be represented graphically, in terms of duration and magnitude, on a graph known as a voltage dip window. Refer to Figure No. 5.

The compatibility levels for voltage dips are given in the form of a maximum number of dips per year for defined ranges of voltage dip duration and magnitude, designated as dipwindow categories, namely, “Z”, “T”, “S” and “X”. Refer to Table No. 3.

Utilities shall collect data on voltage dip occurrences as detailed in NRS 048-3, so that target values and standards can be evolved. All phases of the supply voltage shall be monitored. In the case of systems with solidly earthed transformer neutrals, the phase-to-neutral voltage shall be measured. In the case of delta-connected systems or systems with impedance earthing or which are unearthed, the phase-to-phase voltage shall be monitored. Metering class 0,1; 0,2; 0,5 and 1,0 voltage transformers can be used for the measurement. The measurement accuracy in the duration of the voltage dip shall be 10ms. The total accuracy in the minimum dip magnitude shall be ± 2,5% of the nominal voltage. The accuracy in the logged time of occurrence shall be ± 10 minutes.

Where an individual customer lodges a complaint that experiences dips in excess of the annual limits given in Table No. 3. The utility shall demonstrate compliance with the 95% assessment criteria for its area of supply, and the utility shall enter into discussion with the Customer to seek an optimal solution to that Customer's problem. The impact of any proposed solution shall be demonstrated to the NER.

For each category of the dip window, the assessed number for the monitored sites within an area of supply shall be the number for which 95% of the sites are below the assessed number. These assessed numbers shall be compared with the compatibility levels (limits for the number of dips) for each dip window category in Table No. 3.

4.8 Frequency

The standard frequency in South Africa shall be 50Hz, and the maximum deviation shall be:-

- for grid networks : ±2,5% at all times
- for islanded networks : ±5,0% at all times, and ±2,5% for 95% of a one-week period.

The frequency shall be monitored continuously. The frequency of the supply voltage shall be assessed at all points of generation. The assessed levels that are to be compared with the compatibility levels above shall be the instantaneous value of frequency.

4.9 Voltage Regulation

The ability of the steady-state root-mean-square voltage to remain between the upper and lower limits. The compatibility levels for voltage regulation are given below :-

Voltage level V	**Compatibility level** %
< 500	± 10
> 500	± 5

No two or more consecutive ten (10) minute values shall exceed the higher applicable compatibility level, and no two or more consecutive ten (10) minute values shall be less than the lower applicable compatibility level. The assessment period is a minimum of seven (7) days. Similarly, the lowest ten (10) minute root-mean-square values of the supply voltage within the voltage remains for 95% of the time are recorded for each phase and the lowest of these is retained as a daily value.

NB measurement shall be taken at the extremities of the feeders.

The assessed levels that are to be compared with the compatibility levels above shall be the highest and lowest daily values over the full assessed period.

4.10 Summary of Section

In conclusion on this section we can compare the different levels of the influencing factors on the Quality of Supply Standards compare against the International systems. Refer to Annexure G - Comparison of Levels.

Chapter 5 Customer Continuity of Supply

5.1 Indicators

The following indicators may/can be used to advise a Customer about an expected continuity of supply.

The following performance indicators are recommended for the use in determining the performance of the electrical network from the Customer's perspective.

1.) SAIDI System Average Interruption Duration Index
2.) SAIFI System Average Interruption Frequency Index
3.) CAIDI Customer Average Interruption Duration Index
4.) CAIFI Customer Average Interruption Frequency Index
5.) ASUI Average System Unavailability Index

Note : These indicators usually address interruptions over two minutes in duration.

These indicators should be stored on a monthly basis to illustrate the effect of seasonal weather trends, etc., on the availability of supply.

Definitions :

n	Total number of customers per group
a	Customers affected
i	Number of customer interruptions
d	Duration of interruption (hours)
t	Hours

SAIDI

The average interruption duration for customers served during a year.

$$\text{SAIDI} = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customers served}}$$

$$= \frac{\sum di}{\sum n} \quad = \text{(hours)}$$

SAIFI

The average number of interruptions per customer served during a year.

$$\text{SAIFI} = \frac{\text{Number of customer interruptions}}{\text{Total number of customers served}}$$

$$= \frac{\sum i}{\sum n}$$

CAIDI

The interruption duration for customers interrupted during a year.

$$\text{CAIDI} = \frac{\text{Sum of customer interruption durations}}{\text{Number of sustained interruptions}}$$

$$= \frac{\sum di}{\sum a} \quad = \text{(hours)}$$

CAIFI

The average number of interruptions experienced per customer affected (a customer must be counted only once, even if interrupted many times).

$$\text{CAIFI} = \frac{\text{Number of customer interruptions}}{\text{Number of customers affected}}$$

$$= \frac{\sum i}{\sum a}$$

ASUI

$$\text{ASUI} = \frac{\text{Customer hours lost}}{\text{Customer hours demanded}}$$

$$= \frac{\sum di}{\sum nt}$$

For examples;

Refer to Annexure H - Customer Continuity of Supply Examples

Part 4 VOLTAGE DIP PROOFING

Chapter 6 Voltage Dip Proofing - Issues

6.1 Introduction

The successful operation of industrial process is dependent on a steady power supply. The interruption of the supply voltage of even a short duration can lead to unnecessary down-time of the Plant unless adequate steps have been taken in the initial design of the electrical equipment.

The loss to a Plant when the process is halted can vary significantly depending on the type of Plant. Production can be affected when normal operation of the Plant cannot be restored in a reasonable time and the product has to be condemned. Furthermore, some Plants may require capital outlay in order to restore normal operation. At some Plants, the safety of personnel may be affected during the loss of operation. In almost all cases, corrective measures can be taken on the electrical and control equipment to prevent the loss of the process of a Plant during voltage dips.

6.2 Cause of Voltage Dips and Resulting Problems

Temporary Loss of Supply

The supply to a Plant can be temporarily disconnected for a short duration and the electrical Plant can be controlled to resume operation immediately after the supply recovers, maintaining operation of the process. Sources of this type of voltage dips are usually Automatic Recloser dead times and change-over from one supply to another supply source

Short Circuit Faults

The supply voltage to a Plant will dip when a short circuit occurs on the supply side or within the Plant distribution medium or low voltage system. The latter faults usually are of concern as the depth of the voltage dip can be 100% (zero volts). Also, the clearing times of faults on internal distribution systems are normally longer than for faults on the supply side.

Load Switching

Switching of a load onto the supply can result in a partial voltage dip. A severe problem may be experienced when large direct on line motors are being started. Switching could effect a Plant internally or externally to the supply system.

Network Switching

Switching on either the supply system or on the internal distribution network can result in various types of voltage dips. Paralleling two supplies running at different load angles will result in a fast transient change followed by a dynamic condition before settling at the new steady state load angle. The transient change-over is usually fast and it is unlikely to have an effect on the normal electrical supply of the Plant, unless the Plant is very sensitive to voltage dips such as may be the case for power electronic equipment.

Power Swings

When the supply network is weakened by the loss of transmission lines or after severe faults on the supply network, power swings between generating stations lasting several seconds can occur on the network. Resulting in voltage oscillations and thereby creating under and over-voltage conditions.

6.3 The Characteristics of Voltage Dips

Short Circuit followed by a Dynamic Condition

The terminal voltage of a Plant during a short circuit will depend on :-

- the impedance of the fault
- location of the fault

Terminal voltage, for faults of low impedance close to or at the Plant, will be close to zero. As the position of the fault moves away into a parallel supplied network, the supplied voltage during the fault will increase. Faults inside the distribution network of a Plant will always result in a low terminal voltage at the point of fault but may not necessary affect the entire Plant should the fault occur at a point where the impedance between the point of fault and the point of supply is high. Thus it is important to note that it is possible that only a part of a Plant may be subjected to a serious voltage dip. During a voltage dip a motor drive will lose speed and have to re-accelerate after the dip. On a weak system with large motors the inrush start-up currents will affect the terminal voltage as well as overload on the supply system. The current flow during that moment will depend on the load torque, stored inertia, of the drive and the duration of the fault. High inertia drives after a dip of short duration will typically draw a fraction of the starting current. As the duration increases, the start-up currents will approach full starting current and the duration of the re-acceleration currents will increase. Refer to Appendix I - Characteristic Voltage Dip under a Short Circuit Condition for a typical example of voltage and starting current curves during a fault condition with motor drives.

Far End of Line Tripping During Faults

When a fault occurs on one of several parallel feeders supplying a Plant, the time at which the fault clears on the plant side of the line, and on the far end of the line, could be different.

Back Generation of Motors

When the supply to a plant is disconnected, the motors will back-generate and the voltage will not instantaneously fall to zero. Motors with low inertia's and high load torque's can stall within 150 ms and the back EMF voltage will decay rapidly due to the rapid decay in shaft speed. On a Plant where one or more large motors with high inertia's operate, such as fans, the terminal voltage will decay as long as 1,5 seconds. This slow decay in voltage will reduce the deceleration of other small inertia and low torque motors connected to the same busbar.

Loss of Supply due to Arc Dead Time

Arc dead time for a three phase fault on a protective device such as an Auto-recloser is normally between three and five seconds. For a single phase trip, which is a partial loss of supply, the Arc dead time is as low as one second.

Supply Unbalance

The magnitude of unbalance in the three phase supply is as important as the magnitude of a voltage dip. The torque on a motor drive is dependent on the positive phase sequence component of the supply voltage. The presence of negative phase sequence components in the supply voltage will reduce the motor applied torque. It is thus important that any form of bus-bar voltage condition monitoring relay should not only sense the magnitude of the voltages, but also sense the negative phase sequence component. Such a relay will verify that the supply voltage is adequate to drive motors. A high negative phase sequence component can be present during the dead time of an Arc.

Power Swings

During a large power swing on the Network, the terminal voltage at a Plant can oscillate at a frequency between 0.1 and 2 Hz with minimum values as low as 65%. Such power swings normally last only for a few seconds but under severe weak interconnected network conditions, the oscillations may continue for several tens of seconds. The electrical equipment of an industrial plant, if correctly designed, can continue operation during such a voltage dip. This type of voltage dip is unlikely to occur on an industrial plant that is supplied from a strong network.

Switching of Loads

Voltage dips may result from a weak network when direct-on-line motors are started. The duration of these voltage dips is dependent on the starting time of the motors.

6.4 Effects of Voltage Dips

Plant Process

During a voltage dip the Plant process will approach a cut-off where the process must be disconnected in order to safeguard the equipment and production. It is vital to determine the initial moment of the voltage dip to the time when the process must be disconnected, before any dip-proofing techniques are used. It is also equally important for electrical equipment to restore the supply as soon as possible.

Control Circuits

A renowned problem with low voltage control circuits is the electo-mechanical control contactor which is sensitive to voltage dips. The electrical supply to the control circuit is normally taken directly from the associated busbar. Typically when the control voltage falls below the minimum magnitising nominal voltage of a contactor, e.g. 70%, the control contactor will open and the seal-in contactor to a motor will also open hereby stopping the process, etc. The use of Programmable Logic Controllers (PLC) in the modern Plant is very common in todays society. The suppliers of these sensitive control circuit devices insist that a stand-by supply supplies the PLC in question. Care in the design of this supply is important to ensure against voltage dips.

Variable Speed Drives (VSD)

Even the most sophisticated modern VSD of today is susceptible to voltage dips. The operation of firing circuits controlling power electronics such as thyristors cannot be maintained when the voltage falls to a low level and the drive must be stopped. Careful consideration should thus be given when selecting VSD's which will drive loads essential to maintain the Plant process.

Protection Relays

The correct settings for a protection relay is an important factor in the successful operation of a Plant during a voltage dip. The incomer, transformer, MV switchgear and motor protection relay settings must be correctly set in a coordinated manner. The following points are of importance :-

- The coordination of relay settings for the currents flow when the voltage recovers after a voltage dip.
- The settings on undervoltage relays and associated timers to ensure maximum Plant availability during a voltage dip without exceeding the capacity of the equipment.

Chapter 7 Voltage Dip Proofing - Solutions

7.1 Introduction

The devices available today to cope with the issues of Voltage Dip Solutions can be summed up into two areas, namely :-

- Static Devices
- Rotary Devices

These devices will be expanded upon in this section.
Although there are several more devices that will aid in the Voltage Dip Solutions the Author will only cover the well known devices that are currently employed in industry. These are in brief :-

Static Device :-	1)	Dip Proof Inverter
	2)	Contactor Slugging
	3)	Power Conditioner
	4)	SSD's
	5)	SVC's
Rotary Devices :-	6)	Written-Pole Motor
	7)	Statodyne
	8)	Dip-Doctor

7.2 Dip Proofing Inverter

The Dip-Proofing Inverter (DPI) is a device manufactured by " Switching Systems " for the use in control circuitry. The DPI is designed to maintain the control voltage on contactors and relays during a voltage dip, effectively maintaining connected supply to the Plant. The stored electrical and magnetic energy is allowed to flow, supporting the mechanical inertia of the Plant's equipment. As the dip recovers the Plant is still operating at near synchronous speed, the inrush currents will be small and the stress to the system kept to a minimum. In short the DPI provides a preventative solution to the Plant process. Refer to Annexure-J for the theory of operation of the DPI.

The DPI offers a low cost solution to production line stoppages caused by short power interruptions. The DPI is easy to incorporate during the manufacturing of new switchgear and equally as easy to be fitted to existing switchgear. The DPI is best used in continuous Plant process which is susceptible to short power interruptions, particularly when the restart of such process is complex and costly. The DPI can be applied effectively in the sectors of the mining, chemical, food, paper, cement, steel, glass and beverage industries. When compared to other product solutions such as UPS or DC contactors the DPI is up to five times more cost effective and offers a simple integration into an existing system.

7.3 Contactor Slugging

Contactors are a vital part in the control of large currents to equipment via smaller currents and voltage and to facilitate remote control. The voltage dip can cause the electrically held-in contactor to drop out. AC contactors are more susceptible to voltage dips than others, these contactors require the slugging. Firstly, the construction of a contactor consists of three basic parts :-

- control coil
- magnetic circuit
- spring loaded mechanism

The magnetic circuit consists of two parts, the armature which has the coil wound around it and is stationary and a yoke which is pushed away from the armature by springs and can move to close the magnetic circuit. The yoke is mechanically linked to a contact arrangement, typically three normally open power contacts and a series of normally open and closed auxiliary contacts. A current in the coil induces a magnetic field that flows through the armature, the yoke and two air gaps between the armature and the yoke. The field tries to reduce the air gap by producing a strong attractive force, if the force is stronger than the spring pressure that pushes the yoke away from the armature the yoke will move to close the air gap. The mechanical link will in turn operate the contact arrangement. A typical circuit arrangement is shown in Figure No. 6.

The reluctance of the magnetic circuit is much less with an air gap present than with the air gap closed. The current in the coil is therefore at first high and decreases when the contactor is closed. The relationship of inrush VA and holding VA is shown as follows :-

Comparison between pull-in and holding VA

Contactor size	Energising		Holding		Drop-off
	VA	pf	VA	pf	Voltage
Small (<50 A)	70	0.8	10	0.29	53%
Medium (50-200A)	350	0.5	45	0.24	68%
Large (>200A)	1750	0.5	125	0.25	65%

A contactor drops out when the field strength of the magnetic field becomes smaller then the spring pressure that tries to push the yoke away from the armature. This happens when the voltage falls to between 50% and 70% of the nominal voltage.

The term "contactor slugging" is the introduction of DC component to the AC contactor. A single diode and a capacitor across the coil terminals is used. The capacitor stores the energy and thus reduces the output voltage ripple. In the event of a voltage dip, all the energy stored in the capacitor is discharged through the coil. The current therefore still flows in the circuit. The time taken for the contactor to drop out is directly proportional to the amount of energy stored in the capacitor. Contactors are highly sensitive and will drop out on a voltage dip longer than 3ms, therefore an alternative supply must be connected within 3ms. To solve this problem one must look for an alternative to AC contactors or a system that is capable of restoring power within 3ms after a voltage dip.

7.4 Power Conditioner

A new range of power conditioning equipment for the improvement of quality of supply at the low to medium voltage levels has been introduced into the market by a well known manufacturer. The power conditioning system is based on standard IGBT industrial PWM power converter technology. Power Conditioners are designed to work in the following arrangements, namely :-

- shunt
- series
- shunt - series

If the aim is to protect the Customer from an inadequate supply voltage quality, the series connected Power Conditioner is the appropriate means of compensation. Conversely, if the aim is to reduce the Network pollution due to distorted load currents or sources of flicker, the shunt connection is more appropriate. The combined shunt - series connected Power Conditioner can provide both load protection and reduce pollution, thus providing greater flexibility. Features of the shunt connection Power Conditioner include the following :-

- Active harmonic filtering
- Reactive power compensation
- Dynamic load balancing
- Active power transfer

An application of the shunt connection Power Conditioner is an alternative to the conventional LC filters arrangement where unwanted reactive power injection of passive filters and possible interference with ripple control signals are transmitted across the power system. Features of the series connection Power Conditioner include the following :-

- series connected transformer (coupling transformer)
- compensation of transients
- compensation of voltage sags
- harmonic blocking

The series connection Power Conditioner compensates for a voltage dip of 50% and holds the load voltage to approximately 88% of the nominal voltage. The maximum level of compensation is a design parameter, set with the aim of maximizing the economics of the installation.

The shunt - series connection Power Conditioner incorporates both arrangements to maximize the benefit to the Customer.

An increasing number of applications demand what conventional equipment like passive filters do not offer. Here the Power Conditioner provides an effective solution. With the increasing power rating of PWM converters and the more powerful control hardware the application range of Power Conditioners will widen.

There are also strong links with GTO converter-based FACTS (Flexible AC Transmission System).

7.5 SSD

Superconducting Storage Device (SSD) uses a superconducting magnet composed of niobium-titanium wire as its energy source. The magnet is housed in a stainless steel cryostat, immersed in liquid helium, keeping it at 4.2K (-268.8 °C). The superconducting magnet is connected to the outside world via current leads combining copper and superconducting material. Cold helium gas is allowed to pass through these leads to minimise losses. This helium boil-off is contained within a closed loop refrigeration system maintaining the liquid helium levels in the cryostat. The cryostat consists of a vacuum insulated vessel with a thermal heat intercept shield cooled by a cryo-cooler, kept below 90K. The helium refrigeration system consists of a helium compressor and expansion engine/heat exchanger (Joule-Thompson) to obtain liquefaction. Refer to Figure 7 for a schematical of the refrigeration system. The refrigeration specifications are as follows :-

Electrical consumption	45 kVA
Refrigeration	25W @ 4.2K
Capacity	5 l/hour

Helium is initially compressed to approximately 250 kPa in the compressor module. This high pressure, room temperature helium gas stream then enters the heat exchangers in the liquefier cold box module. Cooling of the high pressure stream is in part provided by the low pressure boil-off gas returning from the cryostat back through the heat exchangers. Additional cooling is provided through two expansion engines through which a portion of the high pressure stream (about a quarter each) is expanded. This gas is cooled, lowered in pressure, and ejected to the low pressure stream. This process cools the gas to near liquid helium temperatures. The remaining gas in the high pressure stream flows through the Joule-Thompson valve where it is partially liquefied and lowered in pressure to approximately atmospheric pressure. The gas liquid mixture is then transferred to the cryostat via a remote delivery tube. Superconductivity Inc. developed the SSD with three different power electronic topologies to protect sensitive loads. They are the dc bus support unit, ac shunt connected with bus isolation and dip protector application. All topologies consist of the superconducting magnet which stores energy in its magnetic field (approximately 3 MJ - 1200A in 4.5H) and a dc to dc (current to voltage source) power conversion module.

The operation of the system is simple. In the standby mode, the current in the magnet circulates through the closed switch "S" (refer to Figure 8) of the voltage regulator, the magnet power supply and back to the magnet. The magnet power supply provides a small trickle charge (approximately 3 kW) to replace the losses in the non-superconducting parts of the circuit. When voltage drops on the dc side of the inverter during a dip or momentary outage, the switch "S" in the voltage regulator opens, and the current from the magnet flows to the capacitor bank and charges it back up to a pre-set level. When this level is reached, switch "S" closes again. The load will take energy out of the capacitor bank which will lower the voltage to the minimum set point at which the switch "S" opens again. This sequence repeats until normal utility supply is restored. In this fashion, energy is transferred from the magnet to the load, and the load does not see a power interruption. The magnet automatically recharges in a few minutes after the carryover.

The dc bus support SSD was developed to support the dc link of voltage source inverters against dips and momentary outages. Figure 8 shows the superconducting magnet's connection direct to the dc bus of a variable speed drive system with a multiple inverter loads off a common dc bus. This type of connection eliminates the need for additional power electronics to convert the dc energy into an 50 Hz ac system.

For those applications where a variable speed drive or in-line capacitors are not suitable, a second type of SSD was developed. This is a shunt connected system, suitable for protecting multiple and varied industrial loads, including large motors. This shunt connected topology is attractive because:-

- Large fluctuating loads can be part of the protected load.
- The efficiency of shunt connected "stand-by" equipment is inherently high.
- Simple power electronic equipment is placed in between the utility source and load (a solid state isolation switch instead of a full ac - dc conversion system of in-line configurations.)
- The shunt SSD has the potential to expand to electric grid stablisation (a static compensator with real energy available).

Refer to Figure 9 for a single line diagram of the shunt SSD system. The SSD's voltage regulator is connected to the capacitor banks of 2 six-pulse inverters. When a dip or momentary outage is detected on the utility line, the controller directs power to flow from the magnet to the capacitors of the inverters in a similar fashion as described earlier.

Simultaneously, the inverters are turned on, which converts this power into ac power for the loads and the bus isolation switch is opened to prevent back feeding of magnet power to the utility fault. When the utility line returns to normal, the load is first re-synchronised with the utility line before the bus isolation switch is closed.

Instead of the dc bus of a variable speed drive system or ac support system as shown above, an in-line UPS system can also be used. In this case, the batteries are replaced by or are supported by the superconducting magnet. Only minor changes in a standard commercial UPS system are required to make use of the superconducting magnet in either application.

A future advance to this system is the use of a dynamic compensator or power conditioning module (commonly referred to as the dip protector) fed off the magnet system. This device does not make use of a conventional bus isolation switch but consists of a series connected transformer with a electronic bypass switch. As soon as a dip is detected it opens the series connected transformer and compensates for the voltage component required to ensure a perfect load voltage i.e. boosting the voltage as required on a per phase basis. The system can thus be dimensioned to compensate only for the typical expected dip magnitude i.e. it does not have to be able to supply the full load. Refer to figure 10.

The SSD's are usually installed in mobile trailers or containers, which has a self contained heating, air conditioning and liquid cooling system. This facilitates quick "plug-in" solutions behind the customer meter panel. The SSD's energy storage capacity ranges from 1MJ to slightly over 3 MJ. The AC shunt connected system has a rating between 750 - 1400 kVA. The maximum load that can be protected for 1s is currently 1400kVA. Smaller loads can be protected for longer periods of time. The dip protector application is currently available to 1000kVA. Ride through is dependent on the amount of compensation required i.e. as the dip depth increases, ride through time decreases.

7.6 SVC's

A Static VAR Compensation (SVC) system is used to maintain an even voltage profile at load centers remote from the generation source. A SVC can have a large VAR rating and therefore to consider it as a fixed element can produce erroneous results in a transient stability study. Also a SVC may be installed to improve stability in which case good modeling is essential for both planning and operation. The model of the SVC is shown in Figure No.11.

The basic control circuit consists of two lead-lag and one lag transfer functionconnected in series. The differencial equations describing the action of the control circuit with reference to Figure No.11 is :-

$$pB_1 = [K(1+T_2p)(V_{SVset} - V'_{SV}) - B_1]/T_1 \qquad (1)$$

$$pB_2 = [(1+T_4p)B_1 - B_2]/T_3 \qquad (2)$$

$$pB_3 = [B_2 - B_3]/T_5 \qquad (3)$$

The initial VAR loading of the SVC is converted into a shunt susceptance (B_0) and added to the total susceptance at the SVC terminal busbar. During a system case study, the deviation from a fixed susceptance device is calculated (B_4) and a current equivalent to this deviation is injected into the network. A reduction in controlling voltage Vsv will cause the desired susceptance (B4) to increase. That is that the capacitance of the SVC will rise and the VAR output will increase.

The VAR output from the SVC into the network system is given by :-

$$S = Vi_{svc}$$

$$Q = |V|^2 (B_4 + B_0)$$

7.7 Written-Pole Motor

The written-pole machine is constructed with a continuous layer of "permanent" magnetic material on the surface of the rotor, refer to Figure No.12. The main windings of the stator are similar to those of conventional machines, but there is an additional concentrated winding around an "exciter pole". The magnetic layer can be magnetised (or "written") into any desired magnetic pole pattern by the exciter pole while the machine is operating. The machines are used as both generators and motors. As a generator the machine has constant frequency - variable characteristics. As a motor the pole writing allows superior starting characteristics to be achieved. This effectively allows the number of poles to be changed, continuously compensating for speed variations such that the rotor field frequency remains constant even as the rotor RPM varies up and down.

To achieve good efficiency, the ferrite magnet material used has unusual characteristics. Lower coercivity allows a thicker magnet layer to be used while still maintaining acceptable hysteresis loss levels. This improves both the input rating and voltage regulation of the machine when compared with a machine using more conventional magnetic materials. A machine built using this material would more likely demagnetise on starting or during overload. This would be a serious problem in conventional permanent magnetic machines. In the written-pole machine demagnetisation of the magnet layer provides starting torque. At operating speed the magnetic field is restored to proper levels by the exciter within one revolution of the rotor after an overload is removed. The resulting characteristics are two fold : a synchronous AC motor that has very low starting current, high torque, cool operation, ability to synchronise and run a very large inertia, and able to ride-through momentary interruptions because it can instantly restart without regard to the incoming line phase angle, and a true variable speed constant frequency generator that can supply exact controlled frequency and phase over a wide speed range, and full regulated voltage. The generator field can be positioned such that it is always synchronised to any other power source so that it can operate in parallel.

To simplify construction and achieve maximum "flywheel" stored energy, the machines are built inside-out. An annular rotor with its layer of magnetic material on its inner surface rotates around the internal stationary stator which contains the main windings and exciter pole.

Typical specification data for a written-pole motor generator system is as follows :-

SIZE	5-35 kVA
PF (Full Load)	±0.99
Ride through time	12 seconds
Inrush current	2 x Full Load
Efficiency	87 %
Response Time	4 ms
Functions	To provide dip ride through, power isolation, harmonic filtering
Cost	Approx. R3 500 per kVA

7.8 Statordyne

Based on the Synchronous motor-generator (SMG) concept, the key to the Statordyne innovation is its movable stator that allows the stator winding to change its relative magnetic field position from lagging to leading. When connected to the utility the Statordyne has three (3) modes of operation.

Normal motor operation in which the stator is in the motor position with the rotor's magnetic field lagging the stator's. The stator is free to move and adjust its position to any load or power change. This movement causes the SMG to act as a voltage stabiliser for the protected circuit and helps reduce any load current harmonics being reflected back to the utility source. The limited movement of the stator creates, in effect, an electrical "shock absorber" for the circuit being protected. In addition, the exciter field of the SMG can be adjusted to provide power factor correction.

Transition mode where the stator naturally senses any utility power interruption and immediately becomes a generator. As the stator moves towards the generator position the rotating magnetic field is maintained by simply shifting to the lead position. This eliminates the need for the collapse and rebuild of the fields as well as the internal "braking" effect that would be experienced with a normal synchronous motor. The result is much longer ride-through for brief power outages.

Generator mode in which the stator has shifted to the full generator position delivering power to the essential load. Long term operation in this mode requires mechanical power to the rotor from an alternative source, such as diesel or natural gas engine.

The Statordyne set can be configured as a complete no-break power protection system operating in parallel with the utility source as shown in Figure No. 13. Without the use of batteries the system becomes a very cost-effective power protection system with the addition of a simple hydraulic ride-through package and coupling to an engine for long-term power outage protection. The hydraulic system consists of a nitrogen pressurised fluid power package that drives the Statordyne at synchronous speed (1500rpm) until the engine takes over the load (about three (3) seconds). To ensure rapid and reliable starting, a hydraulic starter powered from the same hydraulic system is used. Once the engine assumes the load, the hydraulic system is repressurised in less than ten (10) minutes. The hydraulic package serves other functions. The ride-through motor provides "soft start" for the Statordyne and can be configured to permit total "black start" of the entire system in the event of the total power failure. For major disaster avoidance this feature permits power-up of the complete system without batteries.

During a utility power outage, transition to engine power, the statordyne is disconnected from the utility source. This prevents "utility backfeed" of Statordyne power in the standby mode. The system is capable of disconnecting from the utility source in one cycle and maintaining rated voltage to the load with maximum deviation of ±5% and a maximum frequency deviation of ±3% during the transition.

The "dynamic stator" Statordyne system is a power quality enhancement system in every operation mode. No current harmonics are produced, power factor is improved during normal operation, utility voltage is stabilised, and energy consumption is kept to an absolute minimum. The single unit Statordyne system has an overall operating efficiency of 96% during normal operation.

In conclusion the new generation rotating technology offers the Customer a choice of dip solution equipment without batteries and complex inverter equipment. The Written Pole motors specifically are attractive in weak supply applications or single phase applications where "soft starting" principles limit inrush currents added to the excellent dip ride through.

7.9 Dip-Doctor

To solve the issue of voltage dips on a global scale for connected loads has been very expensive exercise in the past. Secondly, the ratings of devices have been restricted to 5MVA due to the technology and restrictions on power electronics.

A novel concept was established in South Africa to utilise refurbished synchronous machines (from old power stations) and series reactors to provide large scale voltage support during voltage dips. This machine is called the Dip Doctor TM . Refer to figure No14.

Chapter 8 Voltage Dip Proofing - Dangers

8.1 Introduction

Reduction of the effect of most supply system voltage dips is not within the control of the Customer. The customer may take measures to reduce the consequences of faults within the Plant and even eliminate voltage dips for the majority of in-plant faults. Fast protection combined with earth-fault current limitation is the main line of attack. This section will discuss the approach and other measures that the Consumer can consider for reducing the effects of voltage dips, and adds a word of caution about the need for careful consideration of the consequences of voltage dip proofing major motor loads at the plant stage and, particularly, when retrofitting voltage dip proofing.

8.2 Dangers of Dip-proofing

While it is obvious that dip proofing is essential if plant disruption and loss of production for inevitable system voltage dips are to be avoided, the requirement does not only affect the plant control functions. Motors and their associated drives can be subjected to excessive current surges and transient shaft torques when the system voltage recovers following a voltage dip, so those drives that must remain connected during a voltage dip should be specified for this onerous duty at the design stage.

Winding forces and shaft torques

When the system voltage dips to a low value, the motor, though remaining galvanically connected to the supply busbar, can behave as if it is completely disconnected from the actual power source, refer to Figure No 15 and, depending on the severity and duration of the dip, will experience a drop in speed with a consequent shift in the relative phase angle of its internal EMF with respect to the supply, and an exponential decay of its internal voltage. A typical spiral response curve of internal voltage and angle with respect to the supply is shown in Figure No 16. If the impedance to the fault causing the system voltage dip is high compared with the motor locked rotor impedance, the motor internal EMF can decay slowly and shift progressively in phase. If the external fault is removed and full system voltage thereby restored while the internal voltage is still high and approaches 180°

out of phase with the system voltage, the "re-switching" motor re-acceleration current can approach 1.8pu of the normal DOL starting value. As the forces on the winding and the transient shaft torques are proportional to current squared (I^2), these can have values approaching 3.2pu of normal. Consequently, to dip proof a drive not designed for reswitching could ultimately result in severe damage. If the fault is close to the motor and the motor feeds appreciable short-circuit current to the fault, the demagnetising effect of the lagging stator current will reduce the internal EMF far more rapidly and the probability of high current reswitching surges is considerably reduced.

Tripping of supply transformers for post-dip re-acceleration

It is generally neither possible nor desirable to set the overcurrent back-up relays so that they will not operate for a post-dip re-acceleration current surge if the load consists predominantly of motors and they are all dip-proofed. In such a case dip-proofing would be in-effectual as the load would be lost when the back-up relays tripped.

8.3 Summary of Section

Dip-proofing should be applied only to vital drives and controls. These and their supplies must be designed to withstand the consequences of sudden restoration of voltage once a system fault is cleared, and the overcurrents resulting from post-dip reacceleration of such drives. Ideally a plant stability study should be made to establish that the plant will recover from severe dips. Retro-fitting dip proofing should only be undertaken when it has been established that the drives can withstand the possible high level currents and torques; and post-dip voltage depressions that could result.

Part 5 SURVEY ANALYSIS

Chapter 9 Survey

9.1 Introduction

The start to all investigations on power quality disturbances is at the capturing of valuable data of the system that can be interrogated by experienced personnel to determine the areas of power disturbance that will lead to further more specific issues relating to the power disturbance in specific.

The capture is done with the use of various sophisticated instrument recorders that can sample at very high rates. These instruments are very expensive and one would normally employ a specialist to perform the duties of this data capture and interpretation as an initial investigation. Should the results prove any doubt in the system then a full survey must be conducted to obtain the overall knowledge of the Plant or Process.

Finally, a survey after the implementation of any power disturbance mitigation devices has been installed to prove the integrity of the system and to prove that the exercise has been worthwhile.

9.2 Dip Window

Dip data in South Africa was historically presented in the form of a two-dimensional plot of dip depth (ordinate) and duration (abscissa) c.f Figure 17. A voltage dip is defined as "a sudden reduction in r.m.s voltage for a period of between 20ms and 3s of any or all three-phase voltages of a single-phase or a poly-phase supply. The duration of a voltage dip is the time measured from the r.m.s voltage drops below 0,9 p.u of the declared voltage to when this recovers above 0,9 p.u of the declared voltage. For classification purposes, the magnitude of the dip is given by the maximum r.m.s excursion from declared voltage and duration of the dip is given by the maximum duration of the worst affected phase in each case". Single phase, two phase and three phase dips are differentiated on the dip chart by the use of the different symbols to depict each type. Single-phase dips are represented by a small red circle, two phase dips by a blue square and three phase dips by a green diamond.

The historical dip presentation areas on the two dimensional chart were derived from observation of the clustering of the dips into four areas subsequently designated A, B, C and D. If an observer located at a given point in a power system (say a customer's 11kV bus) measures voltage dips over a long period of time, dips will be recorded originating from a fault locations in the interconnected network close to the observer as well as dips originating from faults located far from the observer. Due to the efforts of interconnection and multiple infeed in an interconnected network the depression of voltage at a given measurement location will be less for a distant fault than for a fault close to the observation point. Fault resistance is also a variable and the higher the fault resistance the shallower the dip for a fault at a given location. If the sensitivity to voltage dip measurement is high, voltage dips will be recorded for fault events occurring over a very large area of interconnected network. Measurements of the dips over a period of years in the Kwa-Zulu Natal area of South Africa resulted in observation of the above-mentioned four clusters. Figure 18 illustrates the measured voltage dip parameters and the two-dimensional dip classification chart, the so-called 'dip window". The dip window areas have been regarded as useful for purposes of severity classification and contractual monitoring. The clustering can be further analyzed for its origin in the performance of protection for faults in various locations relative to the dip measurement location.

Dips in **area A** are caused by faults remote from the dip measurement point which causes significant voltage depression at the fault location and are rapidly cleared by the correct operation of protection close to the fault. as a result of parallel infeed a relatively healthy voltage is maintained at the dip measurement point. Dips in **area C** are caused heavy faults on the local network close to the dip measurement location and which are cleared rapidly by the protection. Dips in **area B** are usually low level (e.g. high resistance) faults cleared slowly by protection such as back-up relays, or faults at a lower voltage level where protection times are longer. B area dips also result from the various customer dip generation mechanisms described in the annex A to this section. Dips in **area D** are usually heavy faults, or faults at the source end of a radial feed to the dip location, which are cleared slowly. D area dips are usually regarded as representing poor or incorrect protection operation. In the process of defining electricity supply industry standards for voltage dips for national application by South Africa's national Electricity Regulator (NER) it became apparent that the A, B, C and D paradigm was essentially too limited to be meaningful. The limitations were due to the nature of its origins, as described above, in that it only describes the stochastic occurrence of dips spread throughout a wide network when measured at a specific location. The impacts on customer's plant are largely ignored although the slanting of the lines between area A - B and B - C (see figure 18) were indeed an early attempt to introduce an element of customer impact into the diagram.

A major problem with the A, B, C and D areas is that the dips in areas A, B and D start at a drop in voltage greater than 10% of the declared voltage. This is a very sensitive measurement, which means that the extent of the network over which dips are seen from the measurement point is very great and the numbers of the dips recorded will be large. Further, a sag in voltage by 11% for 700ms, for example, is listed as a D dip and by implication is a very bad dip (dips closer to the origin are generally regarded as less severe than dips further away from the origin).

Shortcomings such as the above led the electricity supply industry to propose supplementing the A, B, C and D areas with an area for regulation and contract purposes designated "E". Area E is based on the EDF (Electricite" de France) contract area which lends it some international credibility. EDF is the only known utility outside RSA with an identified approach to contracting with customers for dip performance. In EDF's case they only contact with large customers for dip performance on a special tariff. Customers on this tariff are offered performance limits for dips over 30% depth and 600ms duration. Inspection of area E in Figure 19 shows that dips longer than 600ms are for the most part limited by the operation of protection systems. The 30% threshold has the effect of limiting sensitivity and thus only localized dips are included. 30% depth of dip also equates to definite negative impact on customers' plant. Both the time and depth limits define areas of practical management opportunities for utilities. South African electricity customers, like electricity users worldwide, suffer deleterious impacts from dips of duration shorter than 600ms and a strong call from them led to the proposal of areas E1, E2 and E3 as shown in figure 20. These areas all have a depth limit of 30% like area E but progressively shorter duration limits of 600ms, 400ms and 150ms. respectively. Annual maximum numbers if dips in each area E1, E2, E3 and E were proposed at various voltage levels. This proposal also proved to be unacceptable and in analyzing why all the above paradigms were problematical to customers and utilities, for one reason or another, it was realized that all the existing variations are predominantly based on observed performance of networks. The observations adequately describe the situation on large interconnected networks but do little to account for requisite management of those networks or the deleterious impacts on customer plant. The new approach taken in the final formulation of the standards for voltage dips, and which appears in NRS 048-2:1996, is to treat dips as an issue of Compatibility between customers and networks just as the other power quality phenomena such as harmonics and flicker are treated. The initial analysis involved plotting the sensitivities of dominant customer plant types on the two-dimensional dip chart as shown in Figure 21,

- A vertical line at 20ms blocks off phenomena below 1 cycle as such events are not generated on interconnected power systems and do not affect customers plant.
- A horizontal line at 20% marks the onset of problems with large variable speed drives.
- Customers motor control contactors drop out in the range 30% - 60% at durations of 20ms to 200ms.
- Contactors drop out in the range 30% - 40% at durations exceeding 200ms.
- At durations exceeding 200ms loss of real motive power can be a problem.

The elevation of the lower sensitivity limit from 10% to 20% has the added benefit of limiting the area of the interconnected network that will be monitored. This means that realistic management based on dip statistics is facilitated as all the figures relate to an essentially localized set of faults. When the concepts of segmenting areas for meaningful management of the utility network based on the localization of faults and the identification of protection times (see annex) are mapped onto the dip chart, the areas in Figure 22 are identified. If the customer sensitivity chart is plotted on top of the areas for utility management a close match is found. Thus the identified areas for declaring compatibility limits (annual numbers of dips per area) are meaningful to customers and utilities alike. The NER has specified numbers for limits (compatibility) and stretch targets for utilities were derived from historical data gathered in South Africa and represent the 90th and 10th percentiles respectively in the national performance levels of each voltage / network category. The character of the nearest network to which the customer is connected largely determines the dips experienced. In interpreting the voltage categories applicable to a particular customer it is important to identify the voltage and nature of the network to which the customer is connected rather than simply looking at the customer's supply voltage. To conclude, the rationale of treating voltage dips as an issue of compatibly in the analysis of power quality has gained acceptance amongst customers and utility personnel alike. Future experience gained in the implementation of the electricity supply industry national standards will be invaluable in determining the intrinsic value of the approach. The approach of setting stretch targets and performance limits for licensees goes some distance towards recognizing the needs of customers and the practical constraints of large interconnected networks.

Annex A :

Causes and Consequences of Voltage Dips :

Dips are primarily caused by the voltage depression due to abnormally large currents flowing through the power system impedance towards faults (c.f. Figure 23). Dips are also caused by customer's own reticulation network.

Utility Network dips :

Transient and indeed permanent faults are a normal phenomenon of all power systems with transient faults predominating in overhead line systems. One of the most common causes of electrical faults in overhead line systems is the breakdown of insulation by overvoltage due to direct or nearby lightning strikes. it is possible to design an overhead line to be completely immune to overvoltage caused by lightning and the ultimate level of immunity to these faults is determined by an essential trade off against cost of construction. Eskom follows and indeed, to an extent leads, international best practice in designing overhead lines for high lightning areas. Further causes of overhead line flashovers are insulator pollution, mechanical failure and accidental contact with conductors. Other network electrical faults causing voltage dips include failure of plant such as transformers, circuit-breakers, surge arresters and busbars.

Customer Initiated Dips :

Connection of large loads by customers can generate dips which not only affect their own plant but also may be transferred to adjacent installations. Motors draw large starting currents when accelerating from zero to full speed. Currents as large as six to ten times full load current are possible for direct on line started induction motors. These large currents cause a voltage drop across the source impedance (lines and transformers) which can last several seconds. Additionally, at the moment of switch on, the transient rush to magnetize the motor can cause an even greater volt drop for a short time. This cause of voltage dips is remedied conventionally by strengthening the supply system or employing softer starting techniques in the case of motors. Large heater loads can also draw large multiples of their rated current when switched on due to their low cold resistance. This current rapidly falls due to the positive coefficient of resistance as the heater temperatures rises. Magnetizing inrush when large transformers are energized can last for several hundred milliseconds. Operation of large loads such as arc furnaces can, in addition to causing flicker, cause voltage dips when for example, electrodes are lowered into the furnace on start up short circuit.

Number of Dips :

From a lightning exposure perspective the greater the length of lines in a system the greater the exposure to dips. This means that system reinforcement, which is usually beneficial from harmonic, fault level and security of supply considerations (availability) worsens the equipment failure due to the increased plant item count. Adding lines to the network may reduce the depth of a dip but will increase the number of dips due to the increased exposure to the causes of dips.

Depth :

Due to the nature of a utility system, there is always impedance between a fault and the source. This impedance impacts the depth of a dip. The depth of dip (% depression of voltage from nominal value) depends on the nature of the fault, the number of phases involved and the system, source impedance. In general, higher fault resistance, source impedance and a greater number of sources (or paths from source(s) to the affected plant) will reduce the depth of dip (less severe).

The other main determinant of depth of dips is system earthing. Earth-faults in solidly or effectively earthed systems are characterized by large fault currents and deep voltage dips. Unearthed or Peterson coil resonantly earthed systems have small fault currents and shallow dips. However once a power system has been designed and constructed changes to the earthing practice are not trivial. The depth of dip may well be reduced by system reinforcement, which however as mentioned above, increases the number of dips.

Duration :

The duration of a voltage dip depends on its cause and the nature of the affected plant. Dips caused by the failure of a power system plant are limited in duration by the operation of protective relays and the disconnection of the faulty plant by circuit breakers. EHV transmission systems are usually protected by "unit protection systems" which are designed for rapid and predictable operation times. It is a simple matter to differentiate between primary protection operations which are normal and back-up operations which may be considered abnormal and therefore not acceptable from a dip duration perspective. At lower system voltages the normal protection operation times are, in general longer. Below 132kV it is common to find non-unit protection schemes which depend on time differentiation to ensure selective isolation of faulty plant. In these cases normal protection tripping times are long, dependent on the nature of the fault and are largely unpredictable. The duration of a dip caused by a power system fault can be extended (see Figure 24) by the inrush currents to remagnetize iron circuits and re-accelerate motor loads. This is a problem particularly when large loads are fed by relatively weak sources and is common at lower supply voltages.

Phase shift :

Phase shift of the voltage presented to a customer can occur during a dip caused by a phase to phase fault. Phase shifts of up to 30 degrees have been measured in the Eskom system. A shift of as little as 5 degrees can cause commutation failure in line commutated controlled rectifers with consequent ruptures of SCR fuses.

Propagation :

Dips occurring in power systems manifest themselves differently at different locations. For example a theoretical 43% dip magnitude reduction takes place between the star (wye) connected primary (measured phase-to-earth) of a transformer compared with the delta secondary (measured phase-to-earth). In practice the reduction ranges from about 30% to 40%. On the same transformer, for a phase-to-earth fault on the primary network, the secondary network will have a dip on each of two phases (phase-to-phase) whilst a dip occurs only on the single primary faulted phase. Care should be taken in interpreting the effect of dips measured on the utility network on customer plant.

Chapter 10 Survey Measurement

10.1 The Measurement of Quality of Supply Parameters

The initiation of quality of supply investigation will normally be made by a customer who feels that their supply does not comply with minimum standards [3] in some way. If an investigation is carried out, the cost of the investigation will be borne by either the utility or the customer, depending on the outcome of the investigation [3]. Either way it should be possible to do all these measurements in an economical fashion, in order that extra expense is not imposed on the utility and/or the customer.

The first hurdle is to determine what the problem is, if there is indeed a problem, and whether it is caused by voltage dips, flicker, harmonics, sub-harmonics, or transients. Without prior knowledge of what is causing the problem, this could be a tedious task. Generally, this would involve the connection of various measurement instruments at the point of supply, to determine what the problem parameters are in the first place. The investigator would then have to proceed with the configuration of the various items of equipment necessary for the assessment of these elements. The shortcomings of this method is that it focuses on particular parameters, and does not give a complete overview of the system's operating characteristics at the point of measurement. The process is also time-consuming and requires much user input. If detailed information is required at a later stage (e.g. because of customer expansion), further investigations will have to be considered. The method requires in-depth post investigation analysis and report preparation for the customer, the utility, and NER as supervising body/mediator.

An easier, more practical and cost-effective approach may be to utilize an instrument that is capable of measuring all relevant QOS parameters. For economic reasons, this may only be possible for Category 1, Category 2 and Category 6 sites [4]. However, the benefits of using such a device for investigative work on the other categories of sites should also taken into account. The main advantages for this kind of work are :

- Where the customer has installed new plant equipment, it would allow both the customer and the utility to conduct thorough impact studies, to determine the effect of the new equipment on the supply network.
- When a new customer is added to an existing PCC, the utility can do intensive

commissioning studies to ensure that the addition will not adversely affect existing customers.

- In the case of a dispute between customers at a PCC, the device may be able to provide detailed information on such parameters as power swing and harmonic origin. [Note: This is only possible if the device is monitoring both voltage and current harmonics, with reference to phase and amplitude].
- It may be possible to record transient faults that occur, which can help the customer and utility to monitor their protection mechanisms, using the same device.

The device would then continuously record all parameters relevant to this configuration, for the required assessment periods. [Note: Assessment periods vary for the different measurements required, as detailed in NRS 048-2:1996, Part 2: Minimum Standards, Section 4, Requirements].

The device will flag all data which falls outside of these pre-set limits, time-stamp the data, and if possible, determine the place of origin of the problem. To be economically efficient as possible, the device would be able to monitor all QOS parameters to the specified standards, and with the required accuracy. A complete investigation should be performed for at least the minimum time required for the longest tests (usually 7 days).

To assist the investigator's work, at the end of the assessment period, the data should be immediately available in an assessment report format, as specified by the NRS 048-3:1996 Procedures for Measurement and Reporting, Annex D document. Time stamping the occurrence from all phenomena simultaneously will allow the user to accurately assess when the problems occur. This voltage quality data can be linked with other information data collected by the same device. This information can be, for example, frequency, power factor and current data, or could come from control relay outputs, which would give an indication of the timing characteristics of the operating system, or correlation of VAr and Flicker statistics. The data, analyzed simultaneously. can give an indication of the device(s) causing the pollution and the extent of the pollution. In the case of an unknown quantity having to be measured, the device should be able to provide sufficient computational capability to enable it to perform both FFT (Fast Fourier Transform) analysis, as well as DFT (Discrete Fourier Transform) analysis. This will enable the device to capture waveforms, automatically analyze the waveform components, and target the trouble components for monitoring purposes. These pre-requisites dictate a complex hardware design, and performance must be guaranteed under worst case conditions, when the device has to work. What is not always obvious is that measurement, triggering, analysis and communications should be mutually exclusive functions, and should not interfere with each other's functionality ! To ensure this will usually require the use of a multi-processor hardware platform, with dedicated processors controlling the :

- User interface (including analysis)
- Data Acquisition, and,
- Communications.

User Interface :

A built-in PC based user interface offers obvious advantages, especially if it takes on familiar form, such as graphical Windows TM environment. Requirements necessary to make this an effective option are :

- Isolation from the data acquisition process, for reliability and personnel safety
- Configuration flexibility. the device should be able to be configured for the most complex use, to simplified low-level operation. This can include user-configurable screen displays, function keys and data acquisition techniques.
- Suitable power outage ride-through capabilities, with full functionality - a period of twenty minutes should suffice. If power is still not restored, the device should back up the data and configuration, shut down, and re-boot on power return.
- Ability to upload new parameters remotely, or by Disk, to enable new specification updates to be implemented.

There is obviously no need for separate Laptop configuration or data manipulation, and off-site configurability, large data storage capabilities and on-site independent analysis are bonuses. Because of the pre-processing which can be carried out by the device, only the data that is relevant to the case study is presented at the end of the investigation. all the data can be stored for all parameters for future analysis purposes, and should be available for direct download in the National Database format.

Data Acquisition :

Data acquisition is the critical element in the equation, and requires a reliable and accurate design. If the acquisition is controlled by a separate industrial processor, the chances of lost data due to overloading are reduced to near zero. This gives the opportunity of totally gapless data acquisition, if required.

For reliability and accuracy of measurement, features should include:

- Linear frequency response over the whole range of possible measurement, to allow accurate phase and magnitudes of all channels to be monitored
- Isolation from the process of at least 2kVrms
- Consistent high sampling rates, in accordance with the sampling theorem, to allow the measurement of the high order harmonics and interharmonics.
- Sufficient accuracy to monitor all QOS parameters to relevant specifications (NRS/IEC/EN. etc.), at the most stringent levels - one device for all measurements.
- User configurable Binary inputs may be useful for connection of relay outputs to the device. This would allow device operation timing to be gathered with disturbance data.

The benefits of an accurate, reliable data acquisition module are obvious. It is sufficient to say that if a system's voltage and current information is accurately measured, any derived value may be calculated from them. As the nature of QOS monitoring has become a statistical task, this is extremely important.

Communications :

The QOS measurement device should possess the ability to download data, trigger alarms, and upload new parameter settings using various methods, for reliability and versatility. These could include such options as :

- Direct serial communications with a computer, with transfer speeds up to 115kb
- Modem communications for remote data and parameter transfer speeds up to 28.8kbaud (network infrastructure dependent)
- Configurable relay outputs for alarm purposes
- Other options such as X.25, LAN, etc. would be useful.

10.2 Selecting Quality of Supply Instrumentation

While the National Quality of Supply working group is finalizing the specification for Quality of Supply (QOS) monitoring instrumentation, the Electricity Supply Industry (ESI) are desperately seeking direction in the crucial decision of what instrument to select. The specification, when completed, will be general in nature and will specify technical aspects such as accuracy requirements, environmental capability, performance during loss of supply and immunity levels. Any instrument complying with these specifications and the other requirements of NRS048 will be acceptable for the enforcement of NRS048.

With no prescription on which instrument to use, the final decision will be in the hands of you, the user. This is a very healthy situation and will not only result in free market competition for cost effective solutions, but will also provide you with the opportunity to select an instrument best suited for your unique requirements.

ESI Categories:

Each category of the ESI has unique requirements for QOS instrumentation. No single category will be in the position to set the example, or attempt to enforce its preferences. It is essential for any decision maker on QOS instrumentation to know and understand the operation, limitations and potential of that electrical system.

Despite the above, there are certain generic guidelines which will support the decision maker in the selection of a QOS instrument. These guidelines will be discussed for each of the following categories:

- Primary Distributor (National/Regional Utility, Transmission)
- Secondary Distributor (Local Authority, Distribution)
- Large Industrial user
- Small Industrial user

Primary Distributor :

For large primary distributors the focus of a quality of supply monitoring system will be:

- Reporting to the NER
- Response to customer complaints and queries
- System monitoring for planning purposes
- Linking voltage dips to primary network faults

A large number of monitoring points will generally be distributed over a wide area and due to the volumes of instruments and data involved a number of people will be dedicated to QOS. Data will be stored in distributed QOS databases while selected data will be uploaded to a central database via a complex communications network. In general only voltage quality will be monitored because statistical and tariff metering information are provided on independent systems while the origin of QOS violations will be investigated using portable devices with current quality functionality, available in each of the areas. Resources will be available to manage the QOS system independently of other metering systems. Remote metering, full SCADA functionality and planning support systems are in place or being developed to support total information and system management. For this reason there is little incentive for primary distributors to utilize integrated systems and solutions to reduce the information burden.

Secondary Distributor :

Primary focus of a QOS system for secondary distributor will be the same as that of the primary distributor. Due to the reduced size of the system and in general incomplete system and information management tools, the following requirements should be added:

- Statistical metering functionality for system management and information purposes
- Current monitoring functionality for determining QOS violation contributions
- Single database functionality to reduce information management and maintenance requirements
- QOS information to be readily available.

Due to resource limitations, the secondary distributor will not always be in a position to dedicate a group of people to QOS. In most cases the staff in the metering or network environment will be given the task to manage QOS in addition to their present responsibilities. An integrated, configurable system will reduce the burden on secondary distributors and will offer the following advantages:

- Enhanced system information at no additional cost
- Reduced hardware and software maintenance requirements
- Configurability to cater for short, medium and long term requirements
- Flexible system to cater for all types of networks from EHV to LV.

Large Industry :

The QOS system requirements of a large industry is completely different from that of distributors, and industry should be careful not to follow blindly the example set by them. Industry is in general geographically centralized and resources cannot be dedicated to QOS. Their focus on QOS should be the following:

- Monitoring QOS received from the distributor
- Determining their contribution to QOS violations
- Monitoring internal voltage quality and the effect on sensitive plant
- Determing plant sensitivity levels
- Determining causes of voltage dips (distributor network vs. internal network faults)
- Monitoring current quality for the protection of rotating plant

To achieve these goals, a QOS monitoring system needs to monitor both the voltage and current quality. Unbalances in the voltage waveform are mostly amplified in the current waveform due to frequency dependent impendances and sources to load ratios. Voltage quality will not provide the industry with all the information required to properly manage and plan its system. Integrated solutions will offer the large industry many advantages, a few of which are listed below:

- Total system and information management
- Reduced hardware and software maintenance requirements
- Integration into existing or future SCADS systems using DDE or similar tools
- Reduced burden on staff
- A single system to perform check metering, energy management and QOS
- Configurability to cater for short, medium and long term requirements
- Refurbishment of outdated equipment at no additional cost
- Alarming and indication functionality if required
- Integrated, ready to use database functionality.

Small Industry :

The focus on the small industry will be as for large industry , but due to resources limitations the advantages of an integrated solution will be even greater. In most cases these plants have very little or no energy management systems in place. QOS now provides them with a complete energy management solution and instead of costing the industry money, can offer a substantial operational saving in the form of maximum demand and energy management functionality.

In addition to the above, integrated solutions offer remote alarming, indication and secure control functionality, the ideal system for industry where complex SCADA networks do not offer cost effective solutions. Small industry is the ideal place for the implementation of an integrated solution offering functionality far in excess of the QOS requirements. The full functionality offered can be summarized as follows:

- Voltage and current quality monitoring
- Maximum demand control
- Energy management functionality
- Tariff (check) metering
- Statistical metering and trending
- Integrated database
- Financial information on energy usage
- Remote alarming
- Remote indication
- Secure remote control
- Automatic control sequence

All functions are user defined for complete flexibility to meet current requirements, while information is available on either a dedicated master or in a client-server architecture. a typical system is demonstrated in Figure 24.

Conclusion :

Selecting the correct instrument for QOS monitoring is a complex task, requiring detailed knowledge of the plant or network it is intended for. Each plant or network will have unique requirements making it impossible to attempt national standardization. The decision should not be made in isolation but complete system and information management requirements should be taken into account. Whereas resources are available in dedicated QOS system could be the correct application, but integration into total management system will have to be established at additional expenses both at capital and operations level. Where resources are limited, lower level integration will offer advantages far in excess of QOS information. Total system and information management should be the key factor in the final decision of technology to be utilized.

10.3 Voltage Quality Recorder Check-List

Some guidelines and practical considerations when purchasing voltage quality instrumentation follow:

ONLY VOLTAGE NEEDS TO BE RECORDED!!!

All voltage distortions and deviations are a result of non-sinusoidal current. Therefore measuring current will only help to determine the cause of the voltage problem, but it cannot be used in any way to determine voltage quality.

WHICH PARAMETERS ?

The most important contributors to voltage related problems are voltage dips and voltage regulation. Other role-players are voltage imbalance, harmonics (THD), voltage spikes, surges and flicker. Some instruments can also record specialized parameters like voltage phase shift. Voltage phase shift usually has catastrophic impact on naturally commuted variable speed drives.

Currently available instruments mostly record some or all of the above parameters, but the way they present the captured information might require complex post processing to get the data into a usable format. A thorough assessment of parameters needed and their price impact must be made. For instance an instrument capable of capturing a fast waveform might use more expensive technology compared with a instrument capable of capturing only the amplitude of the same spike. The additional cost is not justified if only amplitude information is required. The addition of current readings to accompany voltage quality parameters must also be justified if the intent is to use the instrument as a voltage quality recorder and not as a fault diagnostic tool.

WHAT ELSE TO LOOK FOR ?

<u>Operator :</u>

The instrument must be simple to install and operate. Preferably, the instrument must also be able to supply real-time feedback to allow the operator to double-check the integrity of the installation. Use Windows based software: i.e. it is much more intuitive than DOS. The support for different hardware platforms is also better. Look for instruments that allow the distribution of configuration data between different instruments where applicable. It is very easy to miss a parameter if all instruments need to be configured individually. The capability to configure the instrument in your own office is an advantage.

Modem Support :

Telkom approved modem support has almost become a necessity for voltage quality instrumentation for it contributes big savings on logistical support cost. The control and integrity of recorded data are increased dramatically if the retrieval of data is automated.

Physical Requirements :

Size and portability is of concern for many a user of voltage quality instrumentation. The instrument must therefore be rugged, portable and immune to vibration and shock. The calibration status of the instrument must also be guaranteed if the instrument is subjected to rough handling.

"Ride through" capability :

The recording equipment needs to be able to "ride through" (function in the absence of auxiliary power) voltage dips with duration of 3 s or less. This requirement evolves from the classification of voltage dips by the NER. The scatter-plot used by them classifies dips shorter than 3 s into different categories.

Low Maintenance :

Hidden maintenance costs, like replacement of ride-through batteries, frequency of calibration and the replacement of batteries required to hold up memory and real-time clocks, must also be taken into consideration. Many instruments use rechargeable batteries for support during the absence of power. Ensure that suppliers have maintenance programs and that no additional maintenance is required if the replacement batteries operate outside their recommended operating temperature range, (e.g. in Street kiosks). Storage of energy in capacitors is highly recommended, as they require less maintenance than batteries.

Complete Package :

Many manufactures supply the software required to communicate with the instrument separately from the hardware. Some of the essential software options must even be purchased separately.

Retrieval of Captured Data :

Most of the instruments strongly rely on the use of Laptops to retrieve captured data from installed instruments. When used to analyze the captured data on the spot, a colour screen and a built-in pointing device is normally required. Modems can also be used to retrieve the data or else the instrument has the capability to be removed from the site to be downloaded in the office with the use of an ordinary PC.

Field Upgradeable :

Some instruments can be used as a platform on which to run different embedded applications. Field upgradeable instruments are very versatile. this feature also allows the instrument to keep track of new developments, thus extending the lifespan of the instrument.

Local Support and Repair :

With imported equipment a competent local agent is a necessity to repair and keep the client and product up to date. The down-time must be kept to a minimum when repairs are needed.

Conclusion :

The above mentioned guidelines can be used as criteria when considering available QOS products. Try to get a balance between the data required and the cost and versatility of the instrument. Refer to Appendix D - Voltage Quality Recorders.

Part 6 FINANCIAL CONSIDERATION

Chapter 11 Consideration to Finances

11.1 Introduction

Many industrial and commercial electric Customers now require a higher level of power quality due to increasing sensitivity of sophisticated process controls and the growing reliance on computers. These Customers are especially sensitive to momentary voltage dips by remote faults on the transmission system or on parallel feeder circuits.

Determining the optimum supply system and Customer electric system characteristics for these sensitive Customers requires an economic evaluation of different alternatives. Power quality can be improved through system-side solutions, Customer service entrance solutions, power conditioning for selected equipment within a facility, or improved specification and equipment design. All of these alternatives have costs and associated benefits.

The improved performance is then translated into economic benefits for Customers based on the expected costs of the different types of power quality variations (in this case, voltage dips of different severity). With the costs of the different technologies and the expected benefits, benefits/cost ratios can be calculated to compare the alternatives.

11.2 Economical Aspect to Distribution System Reliability

To maintain reliable service to Customers, the Utility has to have adequate redundancy in its own system to prevent a component outage becoming a service interruption to the Customers, causing loss of product, revenue to both Customer and Utility, service or benefits. To calculate the costs of reliability, the cost of the outage must be determined.

Reliability costs are used for rate reviews and requests for rate increases. The economic analysis of system reliability can also be a very useful planning tool in determining the capital expenditure to improve service reliability and providing the real value of additional (and incremental) investments into the system.

It is neither possible nor desirable to avoid all component failure or combinations of components to be 'appropriate' when the cost of avoiding additional interruptions exceeds the consequences of those interruptions to Customers. This then the appropriate level of reliability from the consumer perspective may be defined as that level of reliability when the sum of the supply costs of interruption which occur are at a minimum. FIGURE No 26 illustrates this theoretical concept. Note that the system's reliability and investment are not linearly related, and that the optimal (or appropriate) reliability level of the system corresponds to the optimal cost, i.e., the minimum total cost. However, it can be pointed out that the most improper parameter is perhaps not the actual level of reliability, though this cannot be ignored, but the incremental reliability cost. What is the increase in reliability per Rand invested ? Where should the next Rand be placed in the system to achieve the maximum reliability benefit ?

In general, other than for possible sectionalising or reconfiguration to minimise either the number of customers affected by an equipment failure or the interruption duration, the only operation option available to the Utility to enhance reliability is to minimise the duration of the interruption by the timely repair of the failed equipment(s).

Chapter 12 Case Study No. 1

12.1 Economic Evaluation Procedure for Assessing Power Quality Improvement Alternatives

The economic evaluation procedure is illustrated for a case study on the San Diego Gas & Electric Company system.

The Customer is especially sensitive to momentory voltage dips caused by remote faults on the transmission system. The options for improving power quality are evaluated at four (4) different levels, namely :-

1. Supply system modifications and equipment that affects multiple customers.
2. Service entrance technologies.
3. Power conditioning at equipment locations within a facility.
4. Equipment specifications and design.

The last alternative is ideal for long term solution but is often not practical when trying to improve the operation of an existing facility. The power quality improvement that can be obtained with each technology is evaluated using performance indices that address the power quality concerns affecting customer operation. In order to evaluate the economics of the different technologies for the improving power quality, the costs of the power quality variations must be determined. This may require expensive monitoring and understanding of the equipment sensitivity to different types of power quality variations. To accomplish this task, weighting factors are generated using the cost of a momentary interruption as the base. Usually, a momentary interruption will cause a disruption to any load or process that is not specifically protected with some type of energy storage device. After the weighting factors are applied to an event, the cost of the event are expressed in per unit of the cost of a momentary interruption. The *weighted* events can then be summed and the total is the total cost of all the events expressed in the number of equivalent momentary interruptions. Using this approach, the benefit of a power quality improvement technology can be estimated as the expected reduction in costs associated with voltage dips and interruptions at the facility. This value was compared with the cost of the technology (benefit/cost ratio) to determine recommendations for preferred power conditioning technologies.

The Example System

The Example system used for this evaluation involves a sensitive industrial Customer supplied from a 12kV sub-station. There are four (4) transformers (30MVA each) that supply the sub-station from the 69kV system. These transformers supply two separate 12kV buses with seven (7) feeders on each bus. The sub-station also includes 6MVAr capacitor banks on each bus which are switched on a time clock.

The evaluation focuses on the option for providing a premium power service to the Example Customer. Since the supply to the facility involves short underground circuits, the probability of actual interruptions to the facility is quite low. However, voltage dips are just as important as momentary interruptions for many industrial processes. Voltage dips at the Example Customer can be caused by faults on parallel feeder circuits as well as by faults on the transmission system. The Customer has experienced process interruptions due to voltage dip conditions. Refer to Figure No. 27 : Simplified single line diagram of Example System.

Characterising System Performance

The Example Customer is supplied by two (2) underground feeders. Some of the other feeders from the sub-station include overhead lines and auto-reclosing is employed for these feeders. The Example Customer should see very few actual interruptions due to the dedicated underground circuits. Therefore, the most important events are voltage dips caused by faults on parallel feeder circuits or by faults on the transmission system. The dip duration is determined by the length of time required for the protective devices to detect the fault and open. As soon as the fault section is cleared, voltage at the Example Customer returns to normal. Figure No. 28 :Voltage dip graph at Example Customer is a typical event with the duration of 150msec. The event could be caused by a fault on the parallel feeder circuit that is cleared quickly. Transmission faults will generally be cleared within about 100msec. Unfortunately, many types of industrial processes can be just as sensitive to voltage dips as they are to actual interruptions. With the interconnected nature of modern processes, an impact to any component in the process causes the entire process to shut down with significant economic impacts.

Characteristics of Equipment Sensitivity

When defining performance indices, it is important to understand the characteristics of disturbances that can cause customer equipment to mis-operate. Load susceptibility to RMS voltage variations is very dependent on the specific load type, control settings, and application. Consequently, it is often very difficult to distinguish which characteristics of a given RMS variation are likely to cause equipment to mis-operate. For the purpose of this example, equipment susceptibility to RMS variations is divided into three (3) categories :

- *Equipment sensitive to only the voltage during a RMS variation.* This group includes devices such as undervoltage relays, process controls, motor drive controls, and many types of automated machines. Devices in this group are sensitive to the minimum (or maximum) voltage magnitude experienced during a dip. The duration of the disturbance is usually of secondary importance for these devices.
- *Equipment sensitive to both the magnitude and duration of a RMS variation.* This group includes virtually all equipment that uses electronic power supplies. Such equipment mis-operates or fails when the power supplies output voltage drops below specified values. Thus, the important characteristic for this type of equipment is the duration that the RMS voltage is below a specified threshold at which the equipment trips.
- *Equipment sensitive to characteristics other than magnitude and duration.* Some devices are affected by other RMS variation characteristics such as the phase unbalance during the disturbance, the point-on-wave at which the variation is initiated, or any transient oscillations occurring during the disturbance. These characteristics are subtler than magnitude and duration, and their impacts are much more difficult to generalize. As a result, the RMS variation performance indices defined here focus on the more common magnitude and duration characteristics.

For most industrial customers with sensitive processes, the minimum magnitude during the RMS variation is the most important parameter to consider. These devices can generally be impacted by very short duration events and virtually all voltage dip conditions last at least four to five (4-5) cycles (unless a current limiting fuse clears the fault).

Performance Indices

Methods of characterizing RMS disturbances for calculation of performance indices were developed during the EPRI Distribution Power Quality project. Only the basic definitions for the indices of interest are provided. The most important parameter of a voltage dip in terms of its impact on sensitive industrial equipment is the minimum voltage magnitude.

Therefore, the most important index of voltage dip performance measures the frequency of occurrence of RMS variations below a specific threshold. Thresholds of 90%, 70%, 50%, and 10% are used for this analysis. In addition, it is important to understand if the dip occurred on all three phases or just one or two phases. Equipment like adjustable speed drives is typically less sensitive to voltage dips that do not affect all three phases. The performance can be calculated based on actual measured events or based on the concept of *aggregate events*. An aggregate event is the combination of multiple events that occur within a specified time window. It is useful to break the dip performance levels into different categories of duration to account for the possible impact of duration on the equipment sensitivity. Convenient breakpoints in the definitions for *instantaneous* (less than 30 cycles), *momentary* (30 cycles to 3 seconds), and *temporary* (3 seconds to 1 minute). By calculating the dip performance in each of these duration categories independently, the performance can be better matched with equipment sensitivity and the capability of different technologies to provide ride through support.

In this analysis, we focus primarily on the index $SAFAEFI_x$ (System Average RMS Aggregate Event Frequency Index) that specifies the expected number of aggregate events where the minimum voltage goes below some threshold x. This index is then divided into different categories that can result in different performance levels for different types of protection technologies.

Combining The Performance Indices with Equipment Susceptibility

The voltage dip compatibility chart presents the performance of the system as a series of constant supply dip performance contours (similar to a topographical contour map) that can be compared directly with a plot of equipment sensitivity. Figure 29 : Voltage dip performance contour plots with sensitive equipment, illustrates the performance contours with plots of equipment susceptibility superimposed. The chart permits the evaluation of the expected number of process disruptions directly. For instance, the sensitivity chart for the variable speed drive crosses the performance contour line representing 0.21 events per 30 days (10% of 2.1 events per 30 days). This means that the drive could be expected to experience 0.21 disruptions per month, or 2.52 disruptions per year. Note that this assumes a rectangular sensitivity characteristic rather than the characteristic shown but the calculation is approximately correct. The performance of the PLC is actually somewhat worse despite the fact that it has better long duration ride through capability.

Summary Of Performance Indices for The Example System

The voltage dip performance for the Example System is estimated based on detailed monitoring at the sub-station and the customer location that was in service for over one year. The performance is divided into a number of different categories that relate to the cause of the variation and the number of phases impacted. These different categories are necessary to evaluate different power quality improvement technologies and different locations for applying the technologies. Table No. 4 : Summary of performance statistics (18 months), summarizes the measured performance for the monitoring period.

12.2 Expected Performance for Evaluation Of Power Improvement Alternatives

The performance estimates in Table No. 4 are based on a specific monitoring period. These can be used as the basis for estimating longer term performance levels that can be expected at the customer facility. In developing these estimates, the performance during the monitoring periods should be qualified based on any unusual factors (major storms, etc) and the level of fault activity during the monitoring period. The expected performance estimates are developed in three different categories:

1. Distribution faults causing an interruption - fault on dedicated circuits to the facility
2. Distribution faults on parallel feeder circuits (dips at the customer)
3. Transmission faults (dips at the customer)

A given technology for improving voltage dip performance could have significantly different levels of effectiveness for events in these different categories. Duration of the event could also be important but virtually all of the events encountered at this facility are either instantaneous events (less than 30 cycles) or momentary events (30 cycles-3 seconds). The technologies being considered have similar performance characteristics for events of these durations. The other factor that is important is the number of phases affected during the voltage dip. This is provided as a further level of differentiation in the following summary table. Table No. 5 gives the results from the monitoring period for both the East bus and the West bus and then gives an assumed value that will be used for the economic analysis. These assumed values are appropriate for evaluation of customers supplied with a dedicated underground feeder from either the East bus or the West bus. Some engineering judgment and knowledge of the system was involved in extrapolating from the monitoring results to the assumed values.

12.3 Power Quality Improvement Technologies

A variety of different options for power quality improvement were considered, ranging from power conditioning at sensitive loads to energy storage technologies on the distribution system. The most important categories for the power quality improvement options are discussed briefly here.

End Use Equipment Power Conditioning

The manufacturing process used by this customer involves electronic production equipment (with associated power supplies), variable speed motor drives, and process controllers (PLCs). Other supporting loads include HVAC, lightning, etc. A site survey was performed to determine the critical equipment affecting the production process and the sensitivity of the loads to voltage dips. It was determined that control panels with PLCs and adjustable speed drives were also the most sensitive to voltage dips based on observations during the monitoring period. Options for providing ride through support at these individual control cabinets include:

- Constant voltage transformers/magnetic synthesizers
- Motor/Generator sets
- Uninterruptible power supplies

The costs for power conditioning at the end use equipment depends on the technology selected and the kVA of equipment that must be protected. Controls can be protected with constant voltage transformers to prevent the shut down of the whole process due to the sensitivity of the controls. The estimated requirements for this level of protection was as follows:

- *Estimated Number of Equipment Required : 45*
- *Estimated Size of each equipment : 500VA*
- *Estimated Installed Cost : $50,000*

With this option, interruptions to the process can still occur if a dip causes a larger drive or other equipment in the process to trip. It is estimated that the entire process should be able to ride through voltage dips down to 70% of nominal with protection of the controls.

Another option is to identify a broader range of sensitive equipment that can cause the process to trip. Examples include ASDs, sensitive electronic equipment, computers, etc. In this facility, adjustable speed drives were the most important type of equipment in this category. By protecting the drives, the overall process ride through capability can be improved to 50% of nominal (at 50% voltage, a wider variety of loads and contactors will trip). Protection can be provided with a magnetic synthesizer or UPS systems. Estimated costs for these options are dependent on the kVA of load to be protected:

- *Loads to be protected:*

  1-25 kVA

  4-8 kVA

  1-10 kVA

  6-1 kVA

  14-2kVA

  - *Estimated Installed Cost for Magnetic Synthesizer option : $55,000*
  - *Estimated Installed Cost for UPS option : $110,000*

12.4 Technologies for Service Entrance Application

For plants that have critical loads making up a large portion of the total plant load or when it is possible to segregate the loads in the plant so that all the critical loads can be supplied from the common service, service entrance protection may be appropriate. This takes advantage of the economies of scale associated with protection of larger loads. The most obvious choice for protection at the service entrance is still UPS systems. They can be obtained with individual unit sizes up to 1000kVa and they can be paralleled to obtain much larger installations. Although conventional UPS systems (static or rotary) are applicable for protecting large loads at the service entrance, many other options are available. They may have significant advantages in terms of lower operating costs, improved efficiency, and reduced maintenance. Some of these options are listed in Table No. 6 along with estimated costs for large installations. Note that these estimated costs are rough engineering estimates and depend on many factors specific to individual installations and individual manufacturer designs.

For the example facility, virtually all events are of short duration. This makes options like the motor/generator with flywheel storage or other alternative configurations with alternative energy storage technologies (superconducting magnets, fast discharge batteries, etc.) possible candidates. The static switch alternative involves fast switching to a backup supply. If the backup feeder comes from the same point on the transmission system, this alternative does not provide any protection for transmission fault conditions.

12.5 Technologies for Supply System Application

A number of different supply-side options are considered here for improving the voltage dip and interruption performance at customer facilities over a portion of the distribution system. The first and most obvious solution is to eliminate faults on the power system. Of course, it's not feasible to completely eliminate faults. Measures that help include the following :

- washing insulators that are prone to build-up of salt and dirt that could cause a flashover during heavy fog conditions
- use of arresters on transmission towers if there happens to be any lines that experience faults due to lightning
- tree trimming on overhead distribution circuits
- converting overhead lines to underground

Basically, the example has already implemented every type of fault reduction program that is feasible. There is a fairly aggressive insulator washing program because dirty insulators and heavy fog conditions represent one of the most important causes of faults on the transmission system in the supply area. Problems due to insulator flashovers during heavy fog have been dramatically reduced in the last two years. Lightning is not a significant problem in the supply area. The customer has been steadily converting circuits to underground for the past ten years. The example has one of the highest percentages of underground circuits of virtually any power system in USA. These measures that are already in place are the main reason that the expected performance at the example customer is significantly better than the national average, even without any additional power conditioning equipment. However, there is still room to improve the performance if the measures can be economically justified. Table 6 lists some new technologies that can be applied at the distribution system level. They are only likely to be economical from the improved performance. Feeder reactors limit the exposure to faults on parallel feeders. However, they do not provide any benefit for transmission system faults. As with a 480 volt switch, a primary static switch requires an independent backup supply. If the backup supply comes from the same point on the transmission system, there is no benefit for transmission system faults. New electronic voltage regulation (dynamic voltage restorer, series voltage regulator) technologies are available for distribution system application. The costs depend on the amount of voltage support that is needed and the rating of the loads that are to be protected. It is also possible to apply energy storage technologies at the distribution level with appropriate power electronics. These technologies are potentially suitable but are further from commercialization and are not included in this example economic evaluation.

12.6 Expected Performance Improvement for Different Technologies

Weighting Factors for Different Power Quality Variations

The actual financial impacts of the different types of disturbances are often not known or may be confidential for a customer operation. However, it is clear that power interruptions are generally more severe than momentary voltage dips. It is often possible for a customer to estimate the economic impacts for a power interruption because all unprotected equipment will trip and the impact to the process can be determined. Different costs will be associated with less severe voltage dips because not all unprotected equipment will trip (some equipment can ride through the voltage dips) and not all processes will be interrupted. The procedure developed here uses the concept of weighting factors for different power quality variations.

The weighting factors are developed using the cost of a momentary interruption as the base. Usually, a momentary interruption will cause a disruption to any load or process that is not specifically protected with some type of energy storage technology. Voltage dips and other power quality variations will always have an impact that is some portion of this total shutdown. These base costs associated with a momentary interruption will be designated as C_i. At the example customer, we assume that a momentary interruption causes a shutdown of all the production lines. If a voltage dip to 40% causes 80% of the economic impact that a momentary interruption causes, then the weighting factor for a 40% dip would be 0.8. Similarly, if a dip to 75% only results in 10% of the costs that an interruption causes, then the weighting factor is 0.1.

After the weighting factors are applied to an event, the costs of the event are expressed in per unit of the cost of a momentary interruption. The *weighted* events can then be summed and the total is the total cost of all the events expressed in the number of equivalent momentary interruptions. Weighting factors for different categories of voltage dips will be different from customer to customer. Therefore, the evaluation tool (spreadsheets) should allow weighting factors to be easily changed in order to evaluate the impact on the estimated value associated with different types of power quality improvement technologies. The value is measured as the estimated customer costs that can be avoided with the technology. This value can then be compared with the costs of the technology (benefit/cost ratio) to determine recommendations for preferred power conditioning technologies.

The weighting factors used for the example facility were developed based on a number of assumptions. First of all, it is assumed that the facility loads are sensitive to the minimum voltage magnitude during a disturbance. Duration may also be important but the voltage dips experienced at this facility are consistently in the range of 5 cycles -30 cycles and the impacts should be similar in this range. Therefore, duration was not considered in the weighting factors for this analysis.

The customer has indicated that some loads may be impacted by disturbances that result in a voltage below 90% for as short as a few cycles. Therefore, all voltage dips where the voltage goes below 90% should at least be considered. Based on the results of numerous case studies at individual industrial facilities, most sensitive equipment can ride through short duration dips down to about 70%. Since only a small percentage of the equipment is sensitive to voltage dips in the 70-90% range, a weighting of 0.1 is used for dips where the minimum voltage is in this range.

A much higher percentage of loads are affected by voltage dips that go below 70%. A weighting of 0.4 is proposed for dips where the voltage is in the range of 50%-70%. Motors with inertia can ride through these voltage dips and electronic equipment with power supplies may not be impacted in some cases. Almost all loads that are not protected will be impacted for voltage dips below 50%. Even motor contactors are dropping out at these voltage magnitudes. A weighting of 0.8 is proposed for dips 50% that are not actual interruptions.

A summary of the proposed weighting factors is provided below :

Category of Events	Weighting for Economic Analysis
Interruption	1.0
Dip below 50%	0.8
Dip between 50% and 70%	0.4
Dip between 70% and 90%	0.1

This table forms the basis for evaluating the expected incremental improvement of that can be achieved with different supply side and service entrance options.

12.7 Evaluating the Performance Improvements for Each Technology

Each individual technology needs to be evaluated in terms of the performance that can be achieved with the technology. This was the reason for dividing the expected dip performance estimates into different categories in Table 5. The ability of a particular technology for performance enhancement can be evaluated separately in each of these categories and then the total impact of the technology determined. In Table No. 7, these performance estimates are provided again along with the weightings that apply to each category. The table also shows that there are expected to be 27 events per year that could affect the plant. The table also shows the impact of applying the weighting factors to the results. The 27 expected events per year will have an equivalent economic impact at the customer of 5.4 interruptions (with the assumed weighting factors). The performance improvements associated with a particular technology application can then be estimated in each category separately and the total improvement in expected performance determined.

The expected costs per year at the customer without any additional power quality enhancement is 5.4 times the cost of a single momentary interruption. For instance, if one momentary interruption costs $100,000, then the total costs due to these disturbance is $540,000.

In evaluating the different protection options, a cost saving is derived based on the reduced number of events that would caused a disruption. The performance without any additional protection is an equivalent of 5.4 interruptions per year. The cost saving is determined by the expected number of equivalent interruptions with a particular improvement technology in place. For instance, a UPS protecting the whole facility would result in virtually 100% performance improvement, or a savings of $540,000 per year if each interruption cost $100,000. Other power conditioning technologies may only provide ride through support for a portion of the events and the cost savings is something less than the total $540,000. The cost savings expected can then be compared with the installed and operating costs of the improvement technology to arrive at a benefit to cost ratio.

Let's use the application of a primary static switch as an example. A static switch can provide fast switching between a primary supply and a backup supply in the event of a voltage dip or interruption. The advantage of the primary side application is that the amount of load that can be protected is much larger than for a secondary side static switch (on the order of 10MW). This is an important advantage for the example facility because the sensitive loads are spread across a number of step-down transformers. The static switch is only as good as the backup supply. The backup feeders in this case are supplied from the other bus at the same substation. Both buses are supplied from the same point on the transmission system. This means that a static switch will not provide any benefit for transmission fault events. The performance improvement comes from faults on parallel feeders (100% improvement) and faults on the same feeder (100% improvement). The overall performance improvement results in a cost saving of 2.2 times the cost of an interruption using the weightings and the base expected performance estimates. The evaluation is summarized in spreadsheet form in Table No. 8.

12.8 Economic Evaluation of Alternatives

Table No. 9 compares the different alternatives considered. A number of important assumptions have to be made to make these comparisons :

- The costs of a momentary interruption at the customer is assumed in order to illustrate the procedure ($100,000). This number must be developed in cooperation with the customer.
- The weightings used for the costs of power quality variations (dips of different severities) are also assumed.
- The supply side alternatives are based on providing protection for one of the major services to the facility (approximately 10 MVA).
- The amortization period for the initial costs of each technology is assumed to be 5 years with an interest rate of 10%
- The annual operating costs for each technology are estimated and are not based on any detailed performance information. These annual operating costs include losses associated with the power conditioning technology, maintenance (e.g. batteries or synchronous machines), cost of the space for the technology, spare parts, etc.

Note that the comparisons are designed to illustrate the procedure rather than to be representative of any actual costs associated with the different power conditioning technologies. These costs should be generated based on discussions with manufacturers involving the specific requirements of individual applications.

It is clear from the analysis in this particular case that protection of control cabinets with constant voltage transformers has the largest benefit/cost ratio. This will almost always be the case-control circuits should never determine the sensitivity of an overall process. Even after this measure, other power conditioning technologies could be justified based on the incremental improvement in the operation of the plant. Even though it does not provide protection for transmission faults, the static switch could be attractive due to the low cost (the backup feeder already exists). The M/G with flywheel technology could also be attractive because virtually all of the events are of short duration.

12.9 Summary of Section

The economic evaluation procedure described provides a systematic method for evaluating a range of alternatives that could be used to improve the power quality supplied to customers. The technologies can be applied at the end use equipment, at the customer service entrance, or on the utility supply system. The economic justification for distribution system technologies will usually involve a large customer or multiple customers.

The procedure is based on characterizing the expected number of power quality variations in a number of different categories. The impacts of variations in each category are characterized by a weighting factor that expresses the economic costs associated with the variation in per unit of the costs associated with an interruption. The total impacts to a customer are determined by summing the costs associated with the events in each category (number of expected events times the weighting factor).
The different technologies are then evaluated by estimating the improved performance that can be expected after the technology has been applied. The cost savings are calculated for each technology along with the costs of applying the technology. The benefit/cost ratio is calculated as a means of comparing the different technologies.

For a South African example, refer to Appendix L : The Effects of QOS on SAPPI's Southern African Mills.

Part 7 DESIGN CRITERIA

Chapter 13 Design

13.1 Introduction

The motivation to all design criteria would be to investigate the profitability of the Plant should the likelihood of a voltage dip interfere with the operation of that Plant, resulting in a costly exercise to reinstate the power and operation condition to normal. Secondly, where the cost of human lives plays an important part in the statis of the Plant, i.e., medical fields, air-traffic controlling, etc. And where inconvenience to the Public can cause for unhappy situations like the banking institutes data processing failure, road-traffic controlling, etc. These are some of few motivational points for the initial consideration for design of voltage dip-proofing of a specific Plant.

13.2 Reliability

Experience indicates that most distribution systems service interruptions are the result of damage from natural elements, such as lightning, wind, rain, ice and animals. Other interruptions are attributable to defective materials, equipment failures, and human actions such as vehicles hitting poles, cranes contacting overhead lines, felling of trees, cane fires, vandalism, and excavation equipment damaging buried cable or apparatus. The co-ordination of preventive maintenance scheduling with reliability analysis can be very effective. Most Utilities design their system to a specific level, e.g., single contingency, so that, due to existing sufficient redundancy and switching alternatives, the failure of a single component will not cause any customer outage. Therefore, contingency analysis helps to determine the weakest spots of the distribution system. The special form of contingency analysis in which the probability of a given contingency is clearly and precisely expressed is known as the risk analysis. The risk analysis is performed only for important segments of the system and/or Customer. The resultant information is used in determining whether to build the system to a specific contingency level or to risk a service interruption. Figure No. 30 : Reliability planning procedure, shows the flow chart of a reliability planning procedure.

13.3 Fundamental Approach

Dip Versus Dip and Outage Solution

The following key points are required to be assessed when considering the implementation of dip-proofing of a Plant :

- Choice depends on the Site specific to QOS and the Plant response to the dip ride-through with the economic aspect taken into account.
- Energy storage devices cover the dip and start-up time in relation to a rotary device such as a diesel generator.
- Minimise the running time of the dip-proofing devise to save on the running costs.

Distributed and Integrated Solutions

The advantage to using distributed and integrated solutions in the overall Plant solution is primarily the following :

- The technical elegance of the solution.
- Minimum equipment burden
- Potential lowest cost
- No waste of clean up power

However, the disadvantage to the above issues are :

- Requires an in-depth knowledge of the Plant
- Piecemeal results
- Higher risk
- Higher count of small items of equipment
- Lower efficiency
- Standby generation integration more difficult

Total Plant Solution

The advantage to using a total Plant solution is the following :

- Minimum intrusion
- Clear responsibility
- Utility friendly
- Higher efficiency
- Standby generation integration

However, the disadvantage to the above issues are :

- High cost
- Indiscriminate clean-up of all power
- Large equipment unfamiliar to factory engineering staff

Load Characteristic

The following fundamental characteristics for load consideration must be taken into account :

- Load
  - average or continuos
  - peak
- Voltage and Current
  - harmonics
  - other distortions
  - rates of change
  - regulation requirements

Process Characteristics

The following fundamental characteristics for process consideration must be taken into account :

- Dip sensitivity
  - electrical
  - product
- Nature of the process
  - continuous or batch
  - catch up time
- Product sensitivity parameters
  - quality or reject
  - export vs local

  market impact

Supply Characteristics

The following fundamental characteristics for supply consideration must be taken into account :

- Voltage
    - level
    - distortion
- Fault level
- Dip characteristics
- Outage

13.4 Planning Solutions to Voltage Dip Problems

Each Plant will have its own Unique Solution

It is not possible to find a solution which would be suitable to all industrial, mining and manufacturing plants. The supply systems and processes are not identical and the solution best suited for a plant must be available before the best counter measure to voltage dips can be selected.

Understand the Process of the Plant

The processes on the plant must be fully known. The important parts are the essential processes and the systems/subsystems critical to voltage dips.

Known Types of Dips to be expected

Voltage dips due to short circuits can occur on any electrical system; but voltage dips due to temporary disconnection of supply to a plant is unusual but can occur in some cases. An electrical system where there is a change from one supply to another, where the supply will be disconnected, must be identified.

A plant with a high "plant inertia's" can be designed to ride trough the dead time of line ARC.

Dropout of Contactors vs Holding Closed

The problem of LV contactors dropping out during a voltage dip can be solved in two basic ways namely:

- secure the supply to hold the contactor closed during a voltage dip
- trip the contactors in a controlled manner when a voltage dip is detected and then reclose the contactors after voltage restoration

Advantages of Holding Contactors Closed

The advantages of holding contactors closed during a voltage dip are as follows:

- minimum disturbance to the plant process-

The disturbance to the plant processes are minimized. This is essential to plant processes having system/s or sub-system/s with low "plant inertia's".

- multiple voltage dips-

By holding the contactors closed, the disturbance to the plant process are minimized and the recovery of the process after voltage recovery is relatively quick. This increases the possibility of plant being able to ride through multiple voltage dips without any stoppage.

- solution could be simple-

In general, the implementation could be very simple depending on the configuration of the plant.

- low capital outlay-

The capital outlay required to implement this type of counter measure generally will be relatively low.

Disadvantages of Holding Contactors Closed

The disadvantage of holding the contactors closed during a voltage dip are as follows:

- restarting currents of motors-

The restarting currents drawn by motors could become high if the duration of the fault is long. Power supply equipment such as the supply transformer may be overloaded. However, this depends on the ratio of the supply equipment rating and the size of the total amount of rotating machines on the plant and is not necessarily a problem in all cases.

Advantage of Tripping and Reclosing Contactors

The advantages of tripping and reclosing the contactors during a voltage dip are as follows:

- control of the restarting currents drawn by motors-

On a plant with a weak supply and large rotating machines, starting the motor sequentially can control the restarting current.

Disadvantages of Tripping and Reclosing Contactors

The disadvantages of tripping and reclosing the contactors during a voltage dip are as follows:

- disturbance to process-

Once the induction motor has been disconnected from the supply, reclosing can only be carried out safely once the flux in the motor has decayed below approximately 36% of its nominal value. This decay time is the motor open circuit time constant and can be as high as 1.5 seconds for large low voltage motors. Motors with high inertia loads will decelerate and their restarting times will be long. The motors are then restarted in sequential groups preventing overloading of the supply equipment. The disturbance to the processes on the plant is thus very high when compared to the method of holding the contactors closed. This method is difficult to apply when dealing with systems with low "plant inertia's" and/or when multiple voltage dips occur.

- tripping contactors before drop-off-

Where the motors are controlled by a complex process control system, contactors must be opened in a controlled manner such that they can be reclosed. This must be done to ensure that the control system has continuos control over the plant. The dropout time of the contactors could be very fast and they are likely to open due to the voltage dip before a controlled shutdown can be performed.

- complex control system-

Tripping and reclosing of contactors requires a complicated control system to perform this function satisfactorily.

- high capital outlay-

The capital outlay on an automatic reclosing system could become relatively high. The engineering time to implement such a system is also high.

<u>Methods of Holding Closed</u>

There are many ways to secure LV contactor control supply or holding the contactor closed during a voltage dip. An appropriate solution would depend on the number of contactors to be held closed and the types of voltage dips expected. Some of the options are discussed below:

Capacitor per Contactor

The supply to the contactor can be rectified and energy stored in a capacitor to slug the dropout time of the contactor. The contactor must be changed to then have a DC-operated coil. This solution would be expensive and result in the following problems:

- The contactor will be slow to open when tripped. This problem can be overcome by placing additional auxiliary contacts in the control circuit.
- The reliability of DC operated control coils is not as good as AC operated coils.
- The capacitor will be carrying high ripple currents and is likely to fail. Failure of capacitors can result in major contamination of the panels unless the capacitors are well enclosed.

Slugging of Contactor

The mechanical mechanism of the contactor can be arranged in such a manner that dampers slug the opening action of the contacts. The problems associated with this type of solution are:

- Mechanical system becomes complicated and would either be expensive or unreliable.
- The contactor will be slow to open when tripped. This problem can be overcome by complex mechanical interlocks which will increase cost and may introduce reliability problems.

Large Centralized Ups

Most Uninterrupable Power Supplies (UPS) have passive filters on their output circuits and cannot supply loads which have a low power factor. Unless some other form of load is placed in parallel on the UPS output to improve the overall power factor, the output filter and inverter cannot function correctly when supplying highly inductive control circuit loads.

It would not be advisable to connect sensitive computer/control equipment and LV contactor control supply to the same UPS output as high switching surges can be generated when switching the highly inductive loads.

Latched Contactors

Mechanically latched contactors can be used to control small LV drives. The contactors would obviously not open during a loss of control supply but serious problems may arise when a complete loss of supply occurs as it would not be possible to open (unlatch) the contactor.

DC Supply Contactors

The contactors can be held closed by DC supply from a battery. Unless a battery already exists on the plant, the maintenance on the battery will be high. Also the load drawn by DC contactors are high and the size of the batteries will have to be significant. A further problem is the reliability of DC operated contactors. However, a combination of latched contactors controlled by a battery supplied Dc system is expensive but an attractive solution.

MG Sets

An AC Motor driven AC Generator set (MG) with a large fly wheel can be used to secure the control supply. The disadvantage is the frequent maintenance required on the mechanical rotating system.

Dip Proofing Inverter (DPI)

An off line UPS referred to as a DPI is a feasible solution to secure the control supply to contactors. The DPI should be designed such that if it fails:

- the possibility of losing the output should be minimized
- self monitoring circuits shall, where possible, give a failure alarm.

Methods of Reclosing Contactors

An automatic contactor reclosing control system must have the following minimum features:

Intelligent Control

The control system must be intelligent and equipment such as a PLC can be utilized.

Pre-Memory of Running Motors

The reclosing system must monitor, on a continuous basis, the motors which are running on the plant as only the motors which were running prior to the voltage dip must be reclosed when the voltage recovers.

Controlled Opening of Contactors

The contactors must be opened in a controlled manner shortly after the voltage dip occurs. Unless the contactors are opened in a controlled manner, control is lost and the reclosing may not be successful. A further problem is that the contactors can start to chatter during partial voltage loss. This chattering can lead to failure of the main contacts of the contactor and contactors should thus be opened shortly after the initiation of the voltage dip.

Sequential Restarting

Due to the relatively long outage of the motors after tripping, the restarting currents may be higher and will last longer than the re-starting / re-accelerating currents when holding the contactors closed. The motors must then be started sequentially in groups to prevent thermal overloading of the supply system equipment and in accordance with plant operating and interlocking requirements.

Reducing Fault Clearing Times

The reducing of the fault clearing time on the supply system as well as on the plant internal distribution system can make a remarkable difference on the ability of the plant to continue normal operation after a voltage dip. As an example, installing instantaneous overcurrent relays on the internal distribution feeders can shorten fault durations and the motors will then be in a better position to recover to nominal speed after a voltage dip if the contactors are held closed during the dip.

Modifications to "Plant Inertia"

On a plant where a system or sub-system has a short process inertia constant, a possible solution is to increase the "plant inertia" by modifying the plant. As an example, a gravity fed conservator tank can be installed on a lubrication oil feeding system. This type of solution could become very costly unless it is identified during the initial design phase of the plant.

Conclusion

Once the process of the plant, condition of power supply to the plant and the types of voltage dips expected is known, a solution can be engineered. The following papers have some further ideas and give detail insight into possible solutions.

13.5 Cost of Mitigation

Economics

The following fundamental characteristics for economic consideration must be taken into account :

- Capital
- Finance
- Operations and maintenance
- Other

Mitigating Equipment

A wide variety of products are available that can help mitigate power line disturbances. Much care should be taken to properly select effective mitigating equipment. Improper application of these products is a common cause of power quality problems. Before selecting a product, the Customer should have a good understanding of the cause of the problem, as well as the characteristics of the available equipment. Mitigating equipment that was once effective may fail to protect sensitive equipment after a change in load has occurred. When selecting equipment that has an operational heat loss, as indicated by an efficiency of less than 100%, provision should be made for adequate air conditioning if the equipment is to be located in a computer room.

The Figure No. 30 shows the relative costs of various types of equipment. These amounts are based on the USA market and may be quite different for our own market.

In Appendix M- a tabular format of characteristics of mitigating equipment and selecting mitigating equipment is provided for the consideration of the design to the solution of power quality.

Part 8 CONCLUSION

As one can conclude form this investigation, Voltage Dip-proofing and associated Power Disturbances are not as predictable as one might predict. The variable events that make up an electrical system is complex with failures, faults and interruptions occurring on a frequent basis and predicting the reliability of the electrical system can be quite frustrating.

However, should one be persistent enough and follow the guidelines outlined in this investigation, from the regulations to data capture and interpretation to mitigation techniques and finally resolving of the issue in question, whether it be a Voltage Dip-proofing issue or another Power Disturbance matter, the general method of applying this investigation to ones own Plant is still applicable.

Finally, the Power Disturbance issue can become a costly exercise from the point of installing mitigating equipment. So it is advisable to employ experienced personnel to perform the Power Disturbance survey and act accordingly on the recommendations. With the aid of this investigation one will observe any discrepancies in any recommendations presented.

Reference List

[1] NRS 047 : 1996, *Electricity Supply - Quality of Service for application* by the National Electricity Regulator.

[2] NRS 048-1 : 1996, *Electrical Supply - Quality of Supply. Part 1 : Overview of implementation of Standards and Procedures.*

[3] NRS 048-2 : 1996, *Electrical Supply - Quality of Supply. Part 2 : Minimum Standards.*

[4] NRS 048-3 : 1996, *Electrical Supply - Quality of Supply. Part 1 : Procedures for Measurement and Recording.*

[5] IEC 555-3, *Disturbances in Supply System caused by Household Appliances and similar Electrical Equipment. Part 1 – Definitions and Part 3 - Voltage Fluctuations.*

[6] ESKOM - *Power Quality Reference Guide, Revision 1*, March 1994.

[7] First South African Power Quality Conference, Various Papers and Manuals, May 1997.

[8] Electron Journal : October 1994, July 1996, August 1997.

[9] Dr G.P Chhalotra, *Electrical Engineers Economics*, 1st Edition, 1979, *Knanna Publishers, Dehli-6.*

[10] George J. Anders, *Probability Concepts in Electrical Power Systems*, 1990, *A Wiley-Interscience Publication.*

[11] J. Arrillaga & C.P Arnold, *Computer Analysis of Power Systems.*

[12] Turan Goren, *Electrical Power Distribution System Engineering*, Mc Graw-Hill International Editions.

[13] Internet, http://www.eskom.co.za and http://www.durban.gov.za

Table No. 1

Compatibility levels (LV and MV)

Odd harmonics (non-multiple of 3)		Odd harmonics (multiple of 3)		Even harmonics	
Order	%	Order	%	Order	%
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.3	6	0.5
13	3	21	0.2	8	0.5
17	2	>21	0.2	10	0.5
19	1.5			12	0.2
23	1.5			>12	0.2
25	1.5				
>25	0.2+ 1.3x25/h				

THD : 8%

Table No. 2

Recommended planning levels (HV and EHV)

Odd harmonics (non-multiple of 3)		Odd harmonics (multiple of 3)		Even harmonics	
Order	%	Order	%	Order	%
5	2	3	2	2	1.5
7	2	9	1	4	1
11	1.5	15	0.3	6	0.5
13	1.5	21	0.2	8	0.4
17	1	>21	0.2	10	0.4
19	1			12	0.2
23	0.7			>12	0.2
25	0.7				
>25	0.2+ 0.5x25/h				

THD : 3%

Table No. 3

Limits for voltage dips per year

Network voltage range	Number of voltage dips per year				
	Dip window category				
	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
>132kV to 765kV	5	6	11	45	88

TABLE No. 4
SUMMARY OF PERFORMANCE STATISTICS (18 MONTHS)

East Bus
1 Minute aggregate voltage sag summary performance statistic

	SARAEFI		Transmission System Faults			East Bus Distribution System Faults			Events per month by duration of the worst measured event within the aggregate event		
Minimum Sag Voltage (%)	Average Aggregate Events/Month	Fault on Customer Feeder	SLGF	Two Phase Fault	Three Phase Fault	SLGF	Two Phase Fault	Three Phase Fault	Instantaneous (< 30 cycles)	Momentary (30 cycles to 3 seconds)	Tempory (> 3 seconds)
70-90	1.53		0.28	0.87	0.31	0.00	0.07	0.00	1.49	0.03	0.00
50-70	0.21		0.07	0.07	0.03	0.00	0.03	0.00	0.21	0.00	0.00
10-50	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<10	0.04	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.03

West Bus
1 Minute aggregate voltage sag summary performance statistic

	SARAEFI		Transmission System Faults			West Bus Distribution System Faults			Events per month by duration of the worst measured event within the aggregate event		
Minimum Sag Voltage (%)	Average Aggregate Events/Month	Fault on Customer Feeder	SLGF	Two Phase Fault	Three Phase Fault	SLGF	Two Phase Fault	Three Phase Fault	Instantaneous (< 30 cycles)	Momentary (30 cycles to 3 seconds)	Tempory (> 3 seconds)
70-90	1.67		0.28	0.87	0.31	0.14	0.03	0.03	1.63	0.03	0.00
50-70	0.38		0.07	0.07	0.03	0.00	0.14	0.07	0.38	0.00	0.00
10-50	0.17		0.00	0.00	0.00	0.00	0.07	0.10	0.17	0.00	0.00
<10	0.03		0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00

TABLE No. 5
ESTIMATE OF EXPECTED PERFORMANCE WITH A DEDICATED UNDERGROUND FEEDER

		Minimum voltage at Customer				
Category of Disturbance	Data	<10%	10%-50%	50%-70%	70%-90%	**Total**
	East Bus Data	0.4				0.4
Interruptions	West Bus Data	0.0				0.0
(Customer Feeder)	**Assumed Data for Analysis**	**0.5**				**0.5**
	East Bus Data	0.0	0.0	0.4	0.8	1.2
Sags due to Faults on Parallel Feeders	West Bus Data	0.0	0.8	1.7	2.1	4.6
SLGF or Two Phase Faults	**Assumed Data for Analysis**	**0.0**	**0.5**	**1.0**	**2.0**	**3.5**
	East Bus Data	0.0	0.0	0.0	0.0	0.0
Sags due to Faults on Parallel Feeders	West Bus Data	0.0	1.3	0.8	0.4	2.5
Three Phase Faults	**Assumed Data for Analysis**	**0.0**	**0.5**	**0.5**	**1.0**	**2.0**
Sags due to Transmission Faults	East or West Bus Data	0.0	0.0	1.7	13.8	15.5
SLGF or Two Phase Faults	**Assumed Data for Analysis**	**0.0**	**0.0**	**2.0**	**14.0**	**16.0**
Sags due to Transmission Faults	East or West Bus Data	0.4	0.0	0.4	3.8	4.6
Three Phase Faults	**Assumed Data for Analysis**	**0.0**	**0.5**	**0.5**	**4.0**	**5.0**

TABLE No. 6
SERVICE ENTRANCE TECHNOLOGIES FOR POWER QUALITY IMPROVEMENT

Service Entrance Technologies

Power Conditioning Technology	Typical Cost ($/kVA)	Annual Operating Costs (% of Total Cost)	Comments
UPS	700	25	full protection
Sunchronous M/G with Fly-wheel	500	25	2 second ride through
Energy Storage Technology	800	15	shorter ride through than UPS
Secondary Static Switch	100	5	requires independent supply
Feeder Reactors		2	prevent sags due to parallel faults
Primary Static Switch	60	5	requires independent supply
Electronic Voltage Regulation Technology	200	10	shorter ride through than UPS

TABLE No. 7
SUMMARY OF EXPECTED PERFORMANCE LEVELS AND WEIGHTING FACTORS FOR ECONOMIC IMPACT

Type of Condition Affecting Customer	Weighting	Base Performance (events/year)
Interruption due to flt on Customer ckt	1.0	0.50
Interruption due to other faults (e.g. sub-station)	1.0	0.00
Sag due to 1 or 2 phs faults on par. fdr ckt (<50%)	0.8	0.50
Sag due to 1 or 2 phs faults on par. fdr ckt (50-70%)	0.4	1.00
Sag due to 1 or 2 phs faults on par. fdr ckt (70-90%)	0.1	2.00
Sag due to 3 phs faults on par. fdr ckt (<50%)	0.8	0.50
Sag due to 3 phs faults on par. fdr ckt (50-70%)	0.4	0.50
Sag due to 3 phs faults on par. fdr ckt (70-90%)	0.1	1.00
Sag due to transmission 1 or 2 phs flt (<50%)	0.8	0.00
Sag due to transmission 1 or 2 phs flt (50-70%)	0.4	2.00
Sag due to transmission 1 or 2 phs flt (70-90%)	0.1	14.00
Sag due to transmission 3 phs flt (<50%)	0.8	0.50
Sag due to transmission 3 phs flt (50-70%)	0.4	0.50
Sag due to transmission 3 phs flt (70-90%)	0.1	4.00
TOTAL EVENTS AFFECTING PLANT		27.00
Total Events Weighted for Severity		5.40

TABLE No. 8
PERFORMANCE IMPROVEMENT OF THE EVALUATION FOR PRIMARY STATIC SWITCH

Evaluation of improved performance from primary static switch

Type of condition affecting plant	Weighting	Base Performance	Expected reduction	Improved Performance
Interruption due to flt on Customer ckt	1.0	0.50	100%	0.00
Interruption due to other faults (e.g. sub-station)	1.0	0.00	100%	0.00
Sag due to 1 or 2 phs faults on par. fdr ckt (<50%)	0.8	0.50	100%	0.00
Sag due to 1 or 2 phs faults on par. fdr ckt (50-70%)	0.4	1.00	100%	0.00
Sag due to 1 or 2 phs faults on par. fdr ckt (70-90%)	0.1	2.00	100%	0.00
Sag due to 3 phs faults on par. fdr ckt (<50%)	0.8	0.50	100%	0.00
Sag due to 3 phs faults on par. fdr ckt (50-70%)	0.4	0.50	100%	0.00
Sag due to 3 phs faults on par. fdr ckt (70-90%)	0.1	1.00	100%	0.00
Sag due to transmission 1 or 2 phs flt (<50%)	0.8	0.00	0%	0.00
Sag due to transmission 1 or 2 phs flt (50-70%)	0.4	2.00	0%	2.00
Sag due to transmission 1 or 2 phs flt (70-90%)	0.1	14.00	0%	14.00
Sag due to transmission 3 phs flt (<50%)	0.8	0.50	0%	0.50
Sag due to transmission 3 phs flt (50-70%)	0.4	0.50	0%	0.50
Sag due to transmission 3 phs flt (70-90%)	0.1	4.00	0%	4.00
TOTAL EVENTS AFFECTING PLANT		27.00		21.00
Total Events Weighted for Severity		5.40		3.20
Cost Saving =	**2.2**	times the momentary interruption cost for the plant (Ci)		

TABLE No. 9
ECONOMIC COMPARISON OF THE POWER QUALITY IMPROVEMENT ALTERNATIVES

Power Conditioning Technology	Expected Saving (Ci)	Expected Saving ($)	Cost for Solution ($/kVA)	Size Required (kVA)	Total Solution Cost ($)	Annual Operating Costs (% of Total Cost)	Total Annual Cost ($)	Benefit/Cost Ratio
Feeder Reactors	1.7	170 000			1 000 000	2%	294 000	0.6
Primary Static Switch	2.2	220 000	60	10000	600 000	5%	189 000	1.17
Electronic Voltage Regulation Technology	4.1	410 000	200	10000	2 000 000	10%	728 000	0.56
UPS	5.4	540 000	800	2000	1 600 000	25%	822 000	0.66
Sunchronous M/G with Fly-wheel	5.15	515 000	400	2000	800 000	25%	411 000	1.25
Energy Storage Technology	5.15	515 000	800	2000	1 600 000	15%	662 000	0.78
Secondary Static Switch	2.2	220 000	100	2000	200 000	5%	63 000	3.51
Protect controls with CVT's	3.26	326 000			50 000	5%	16 000	20.78
Protect controls and selected drives	3.9	390 000			150 000	8%	52 000	7.56

Assumed cost per Interruption (Ci) $100,000

Total load for Facility to be Protected (kVA) 10000
Assumed Portion of Plant Load that requires Protection (%) 20% (Production Line is 2000 kVA)

Number of years to amortize Investment 5
Assumed interest Rate for Capital 10%

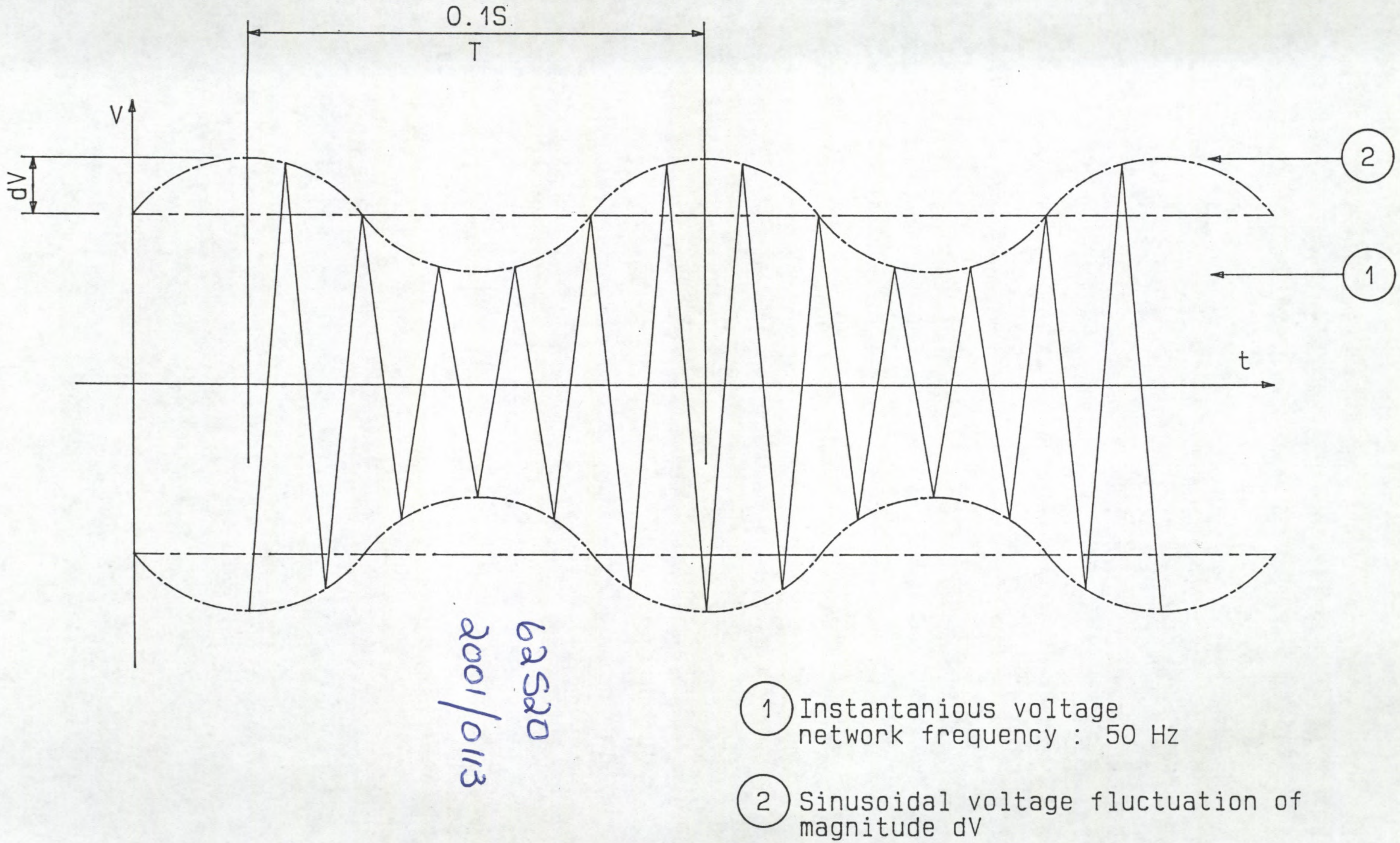
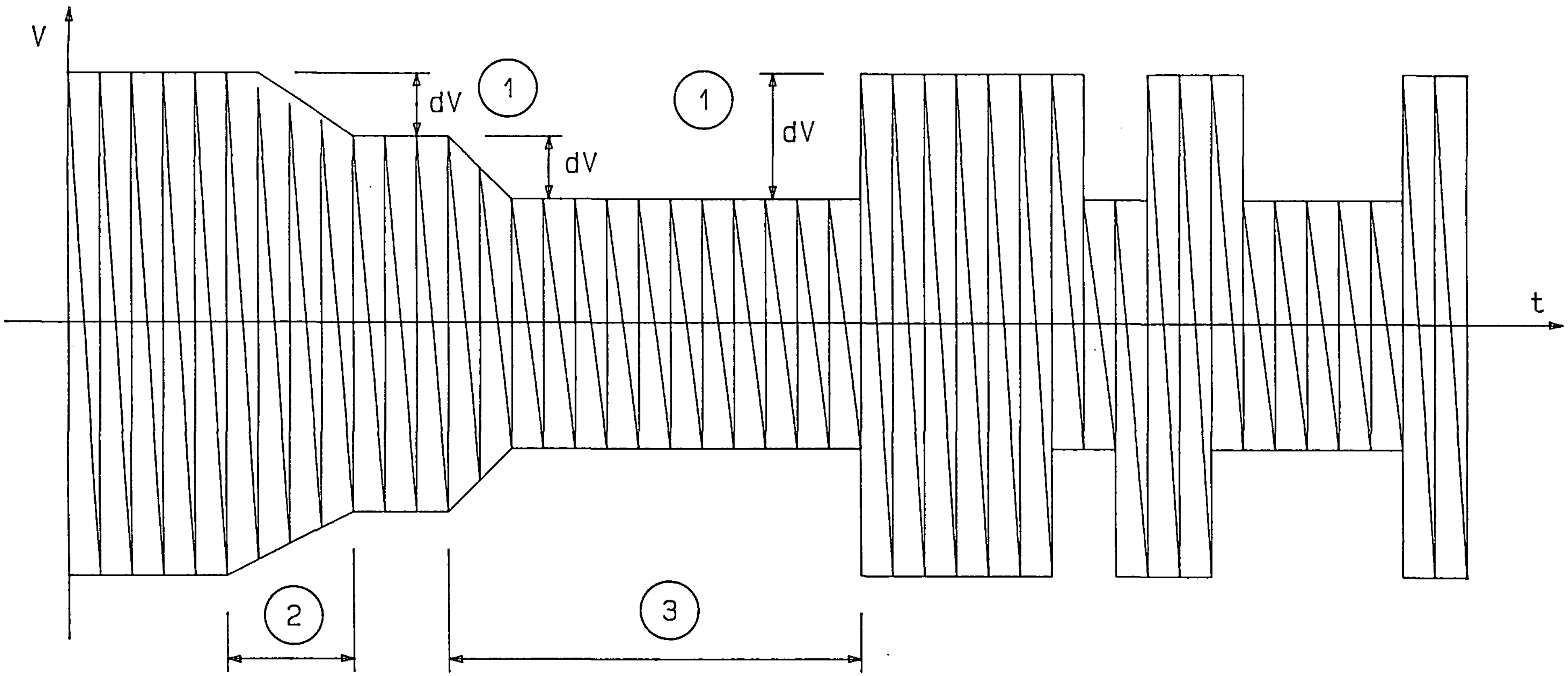


FIG 1 - Sinusoidal voltage fluctuation of 10 Hz frequency



(1) = voltage change of magnitude dV
(Note: Seven voltage changes are shown on the diagram)

(2) = duration of the voltage change

(3) = voltage change interval

FIG 2 - Illustration of peak voltage changes

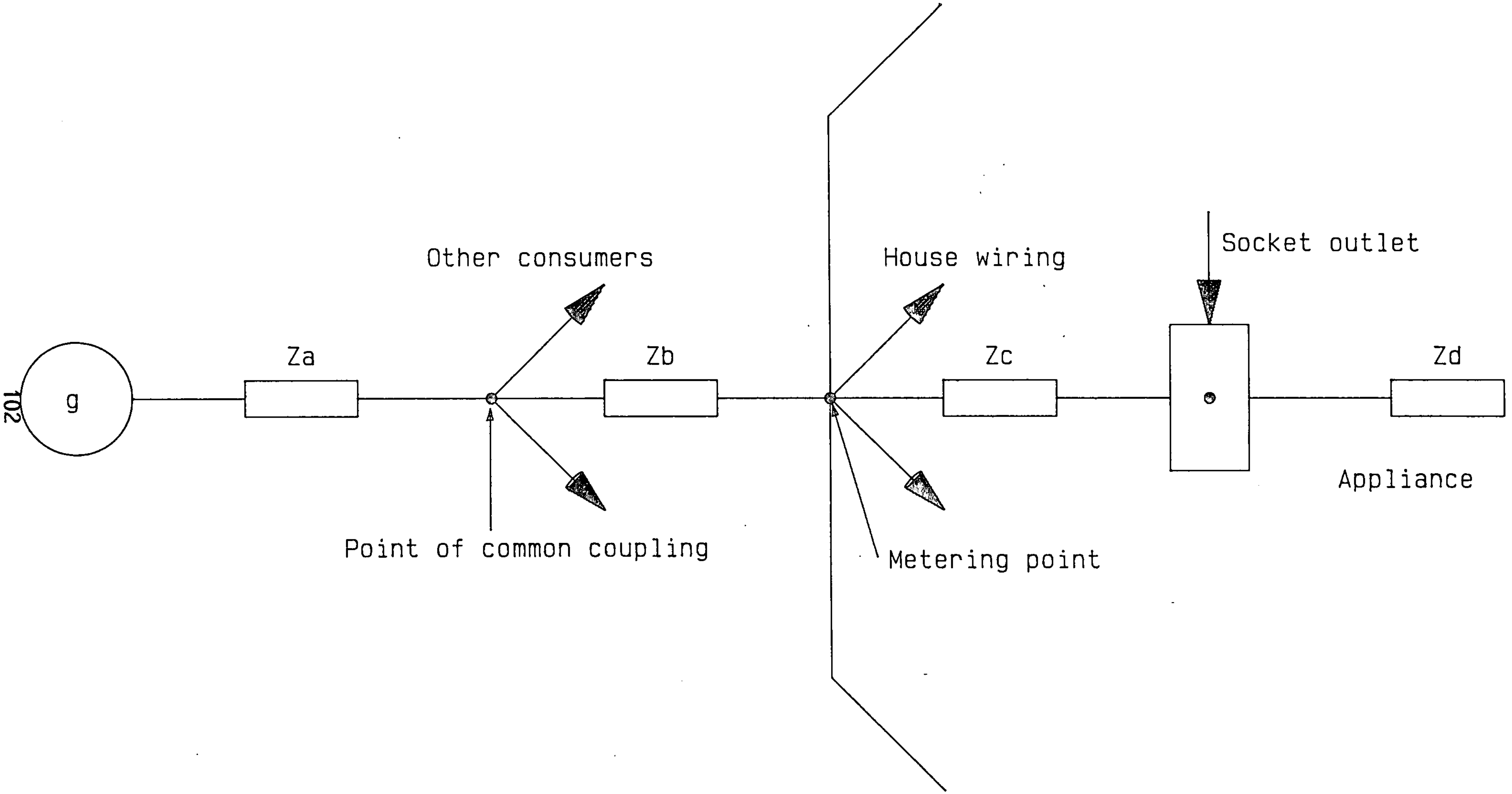
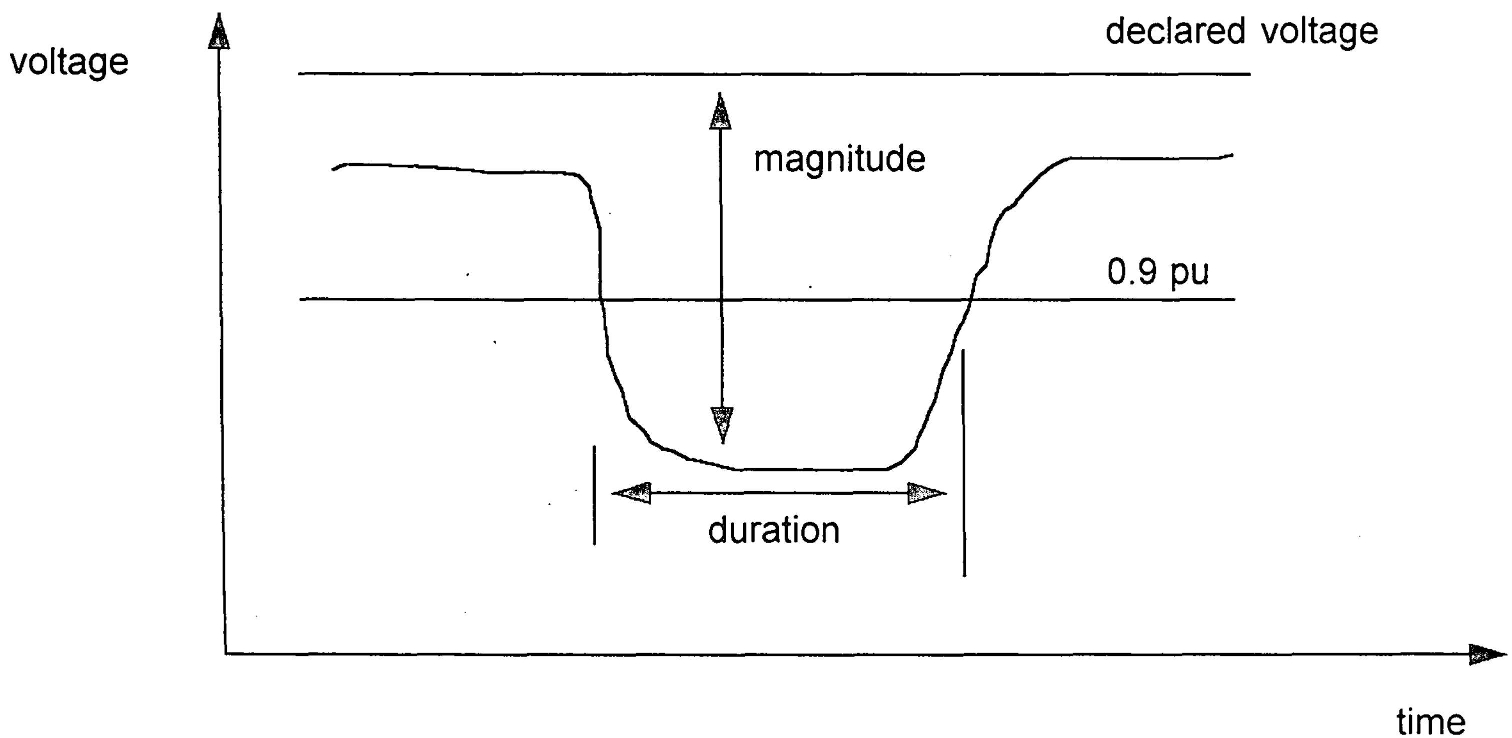


FIG 3 - Impedances diagram

VOLTAGE DIPS

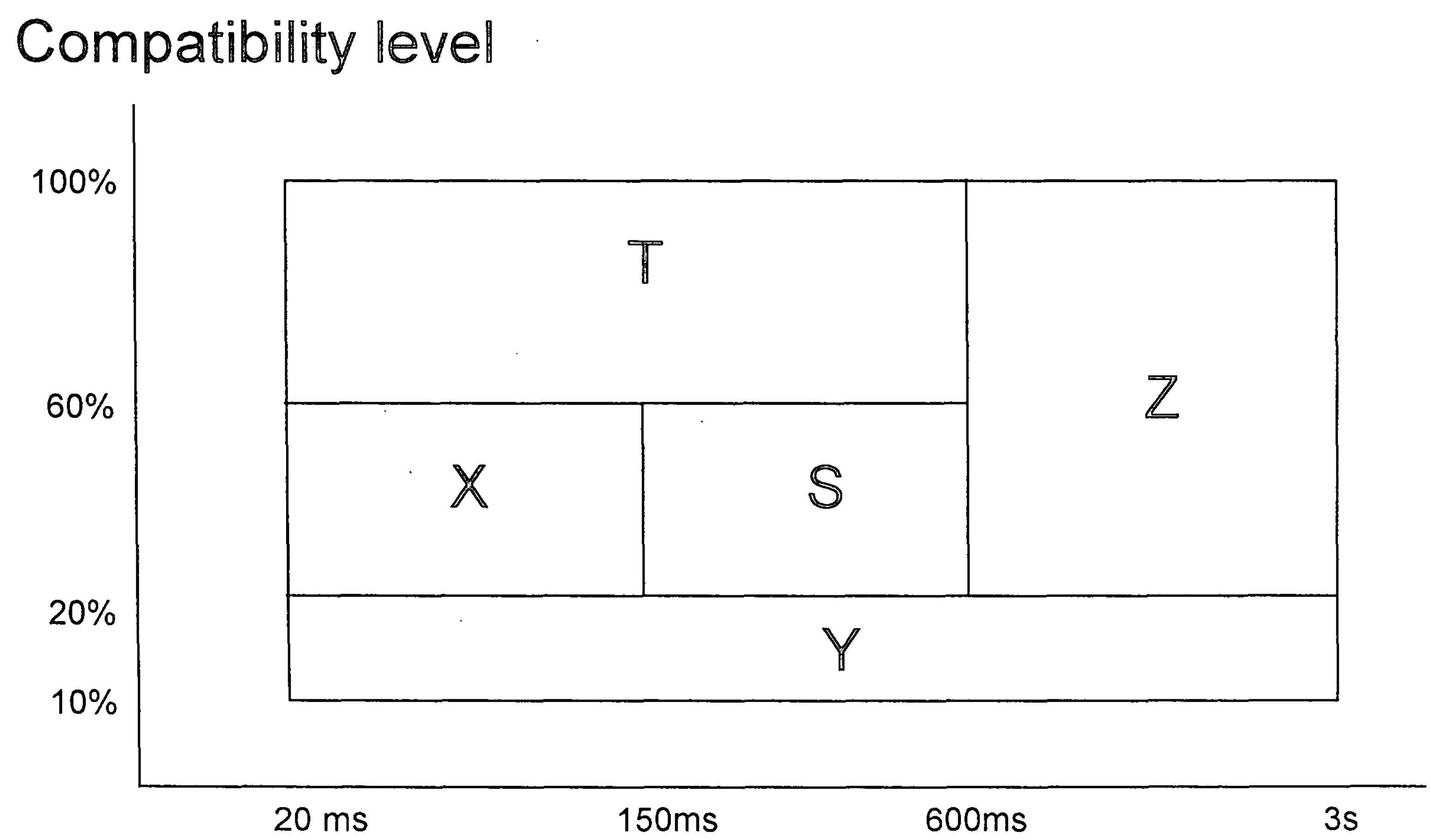
FIGURE No. 4

Characteristics



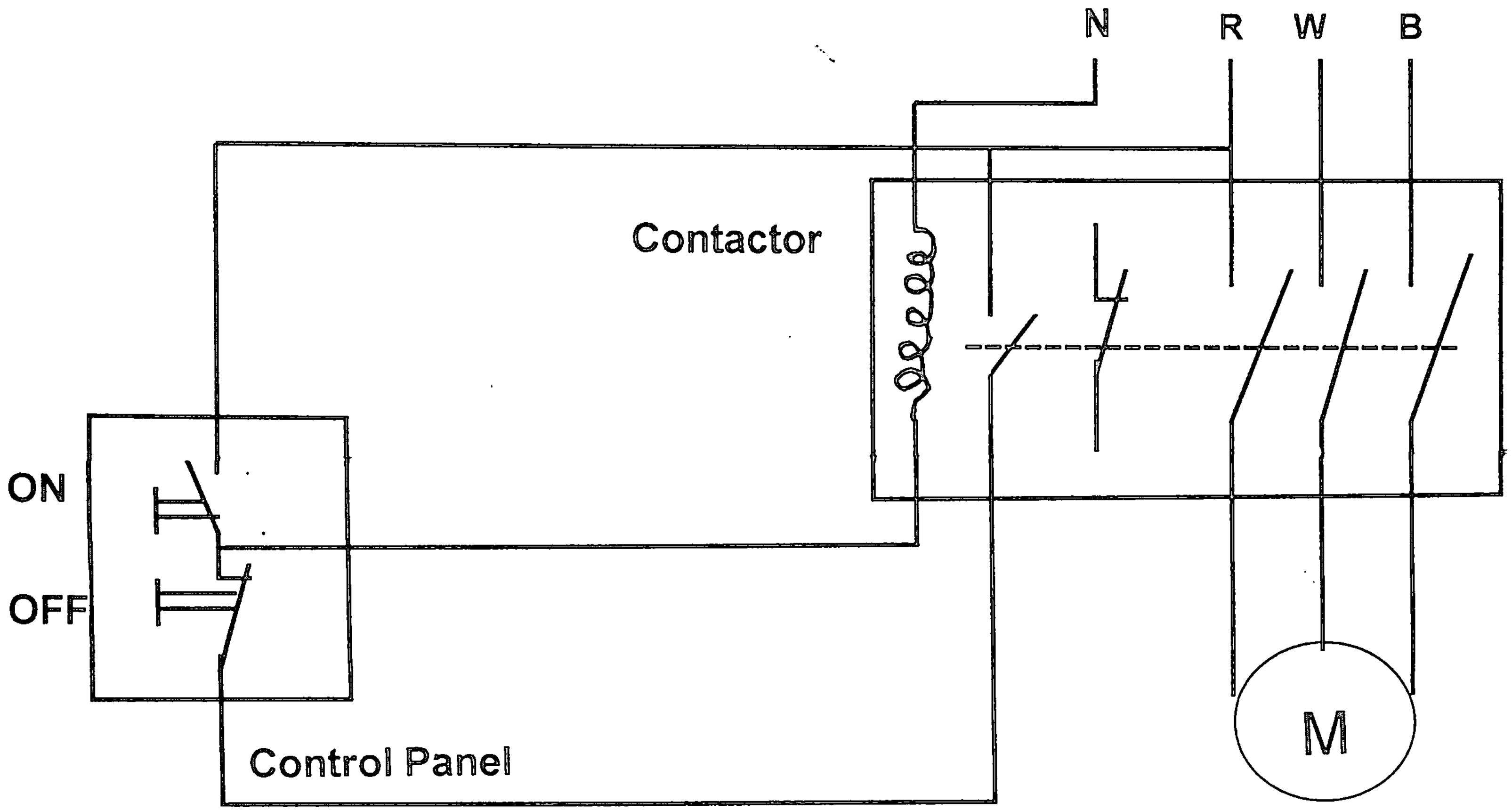
VOLTAGE DIPS

FIGURE No. 5



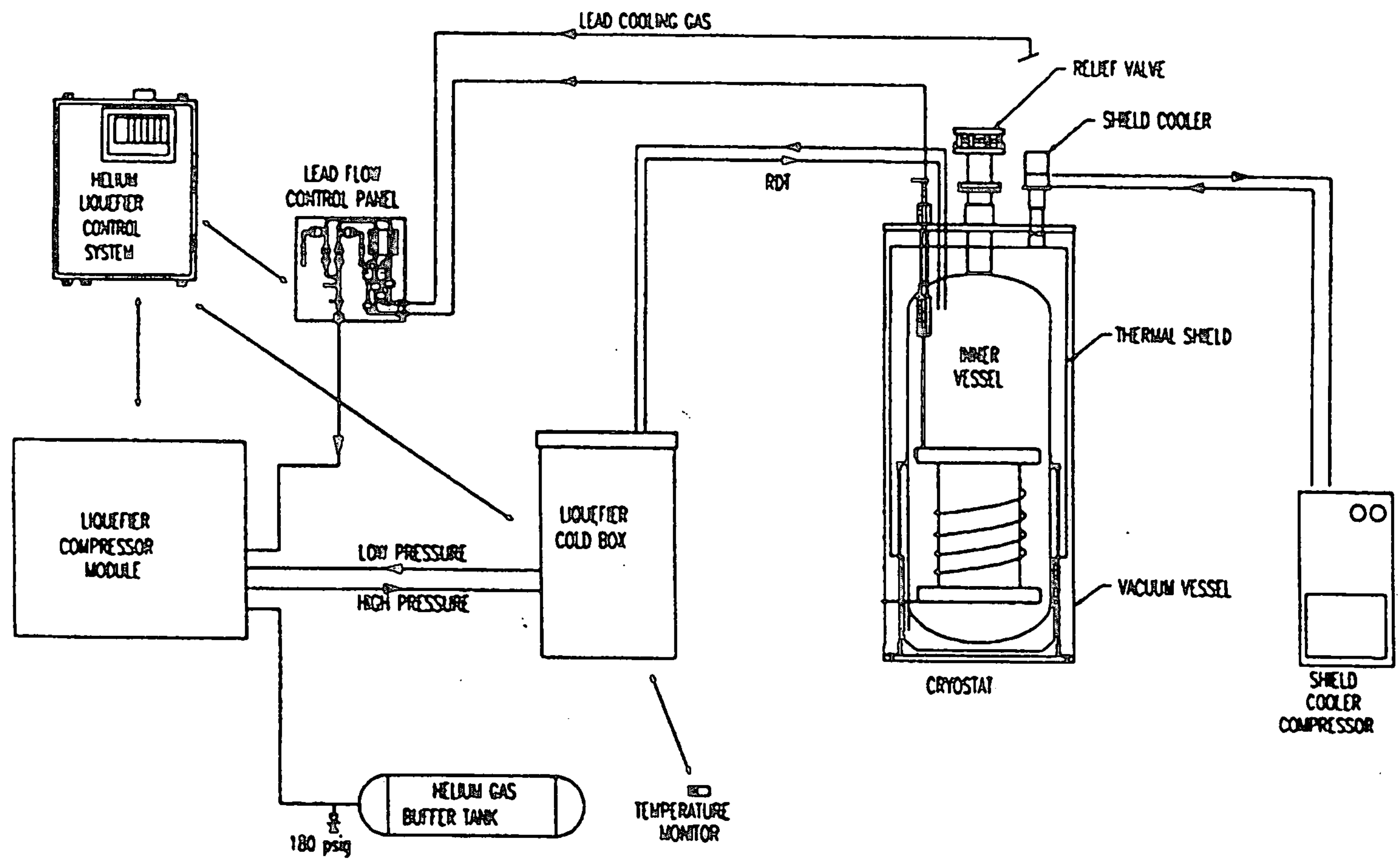
TYPICAL CONNECTION DIAGRAM OF A CONTACTOR

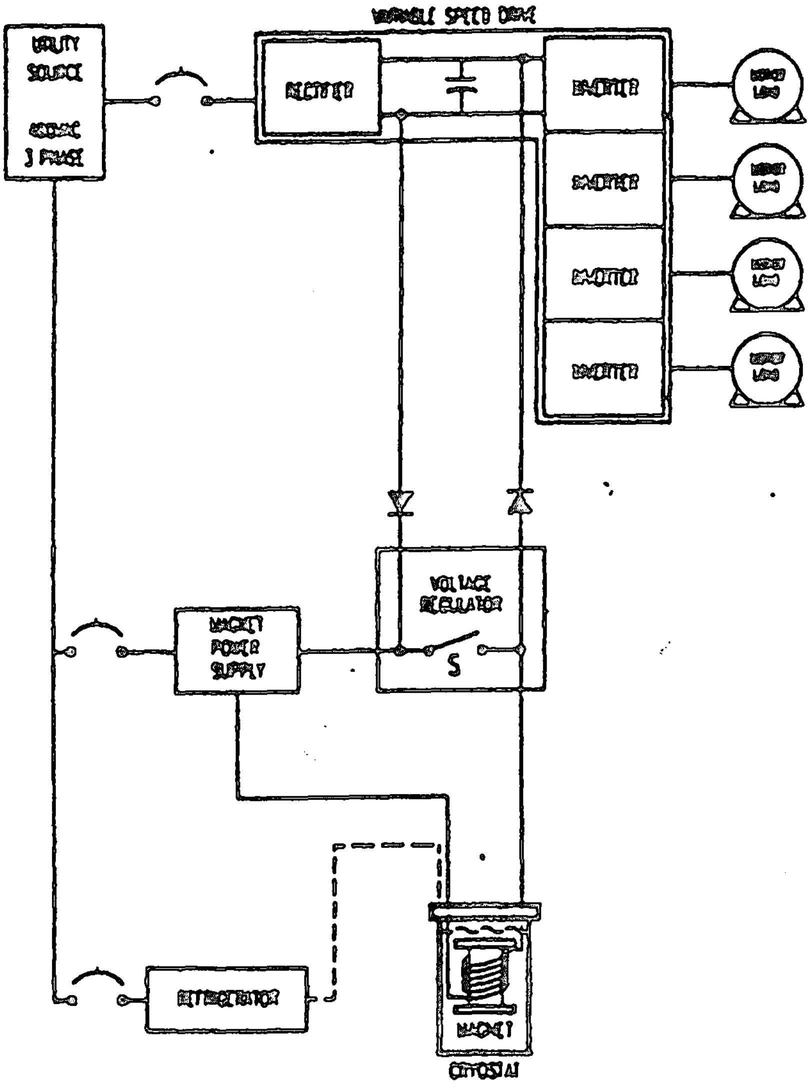
FIGURE NO. 6



SSD: REFRIGERATION LAYOUT

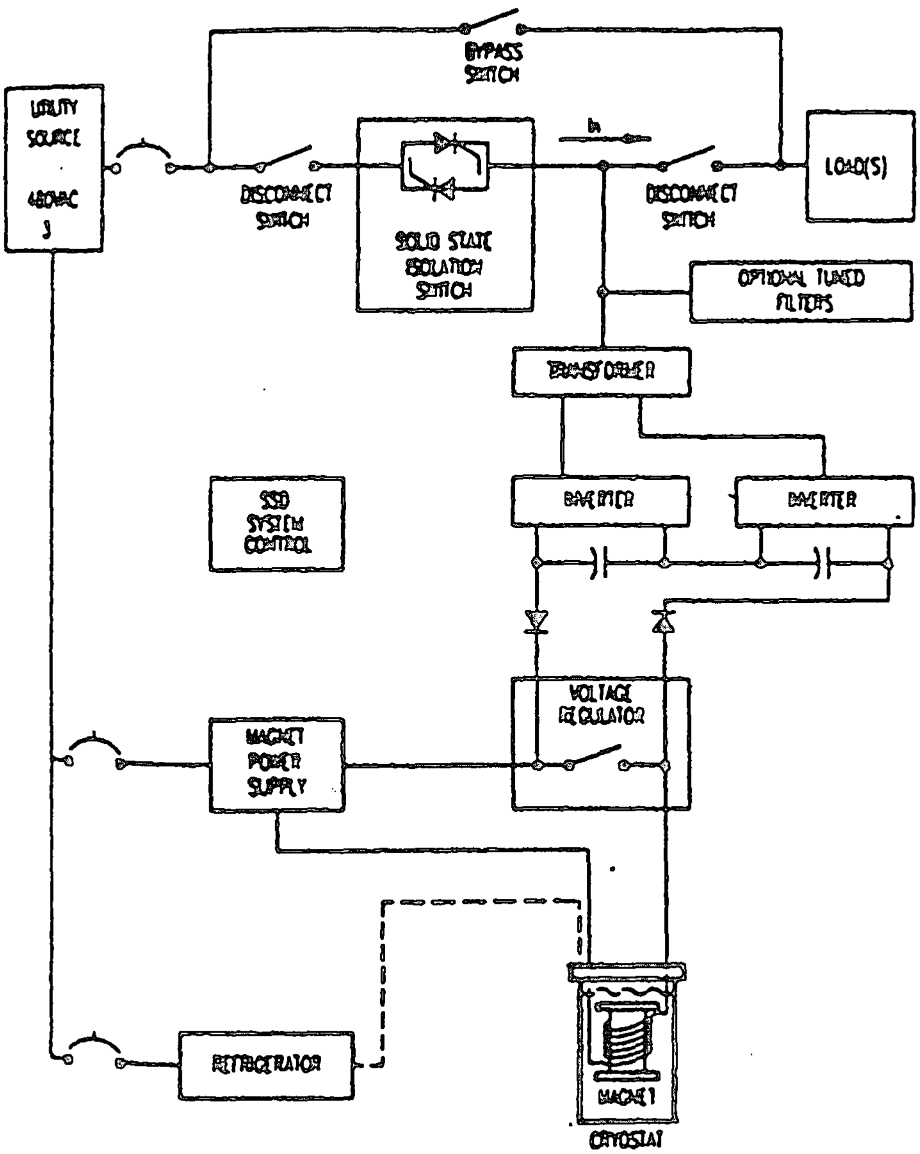
FIGURE NO. 7





SSD: DC BUS APPLICATION

FIGURE NO. 8

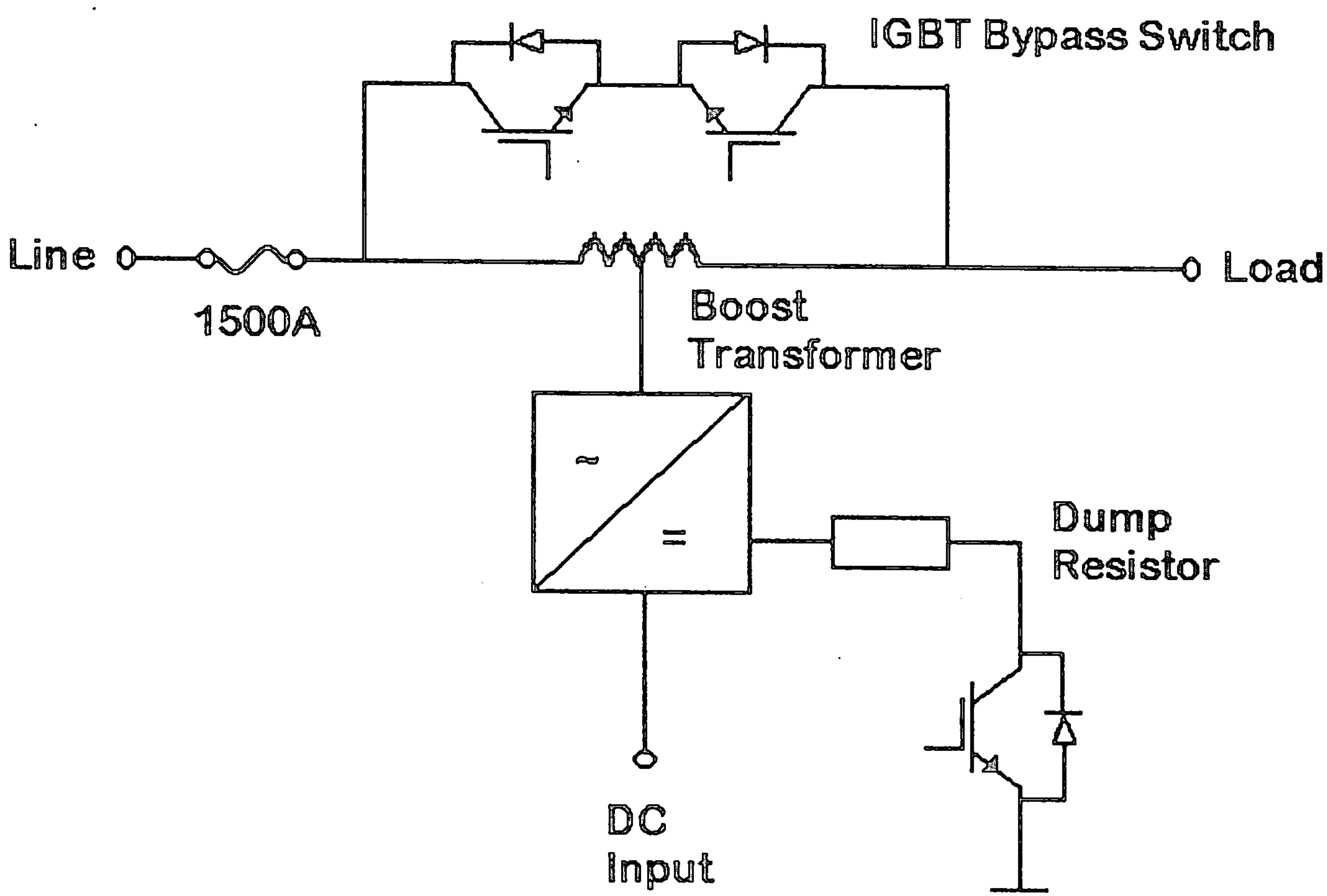


SSD: SHUNT APPLICATION

FIGURE NO. 9

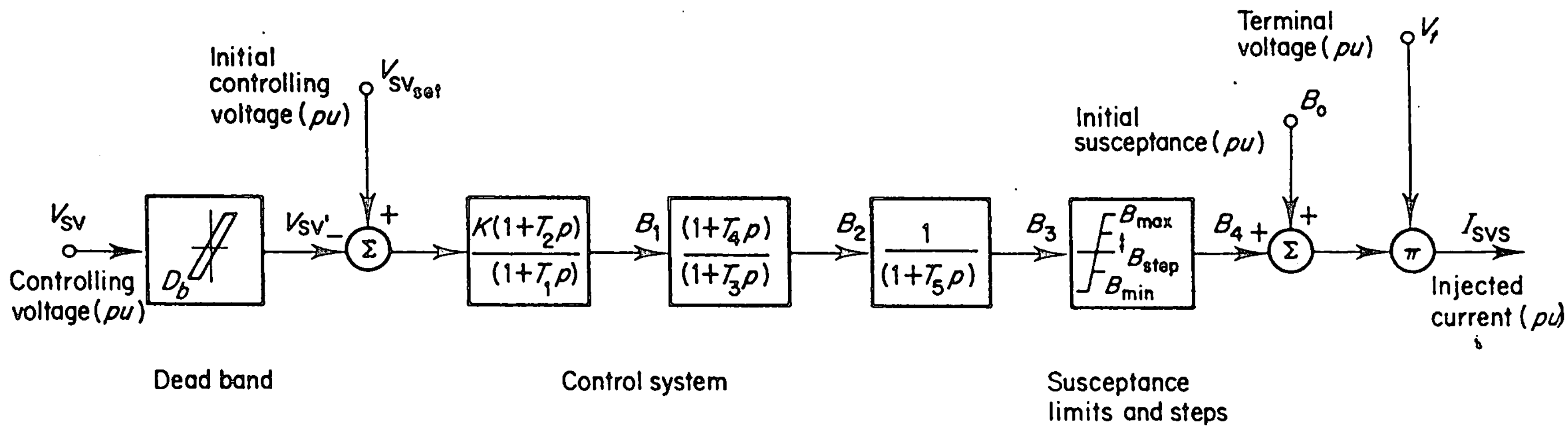
SSD: DIP PROTECTOR

FIGURE NO. 10



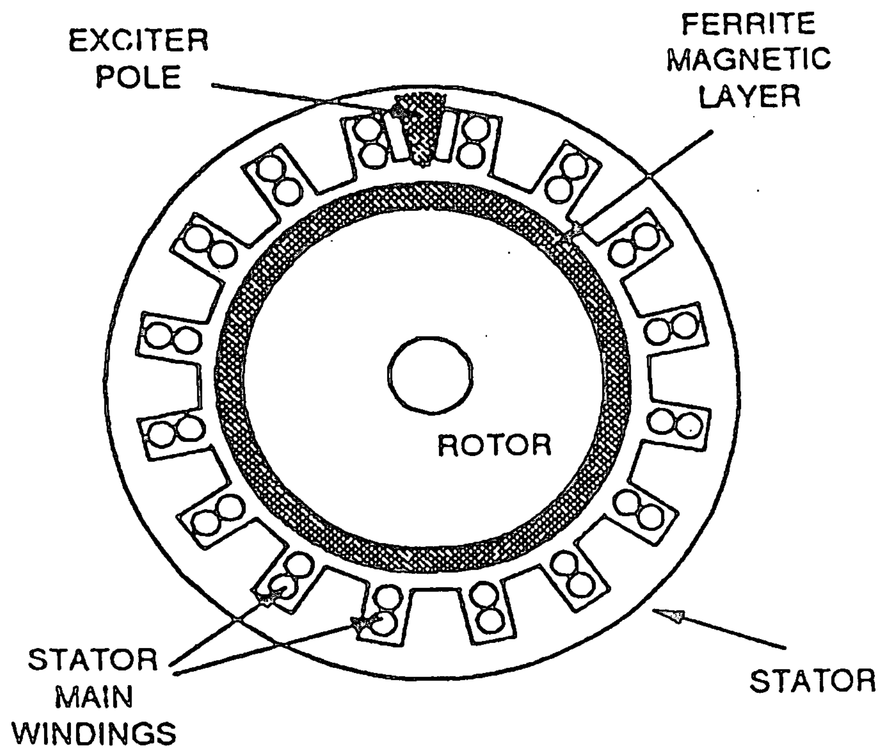
SVS: SYSTEM MODEL

FIGURE NO. 11



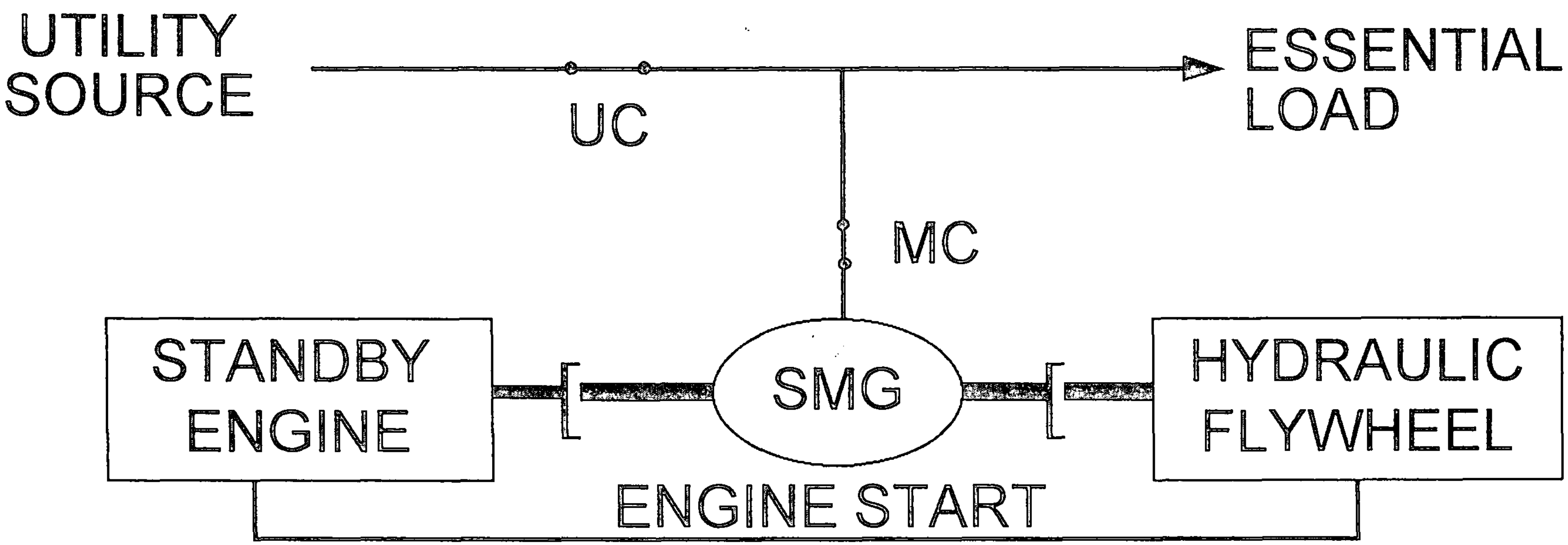
"WRITTEN-POLE" MOTOR:CONSTRUCTION

FIGURE NO.12

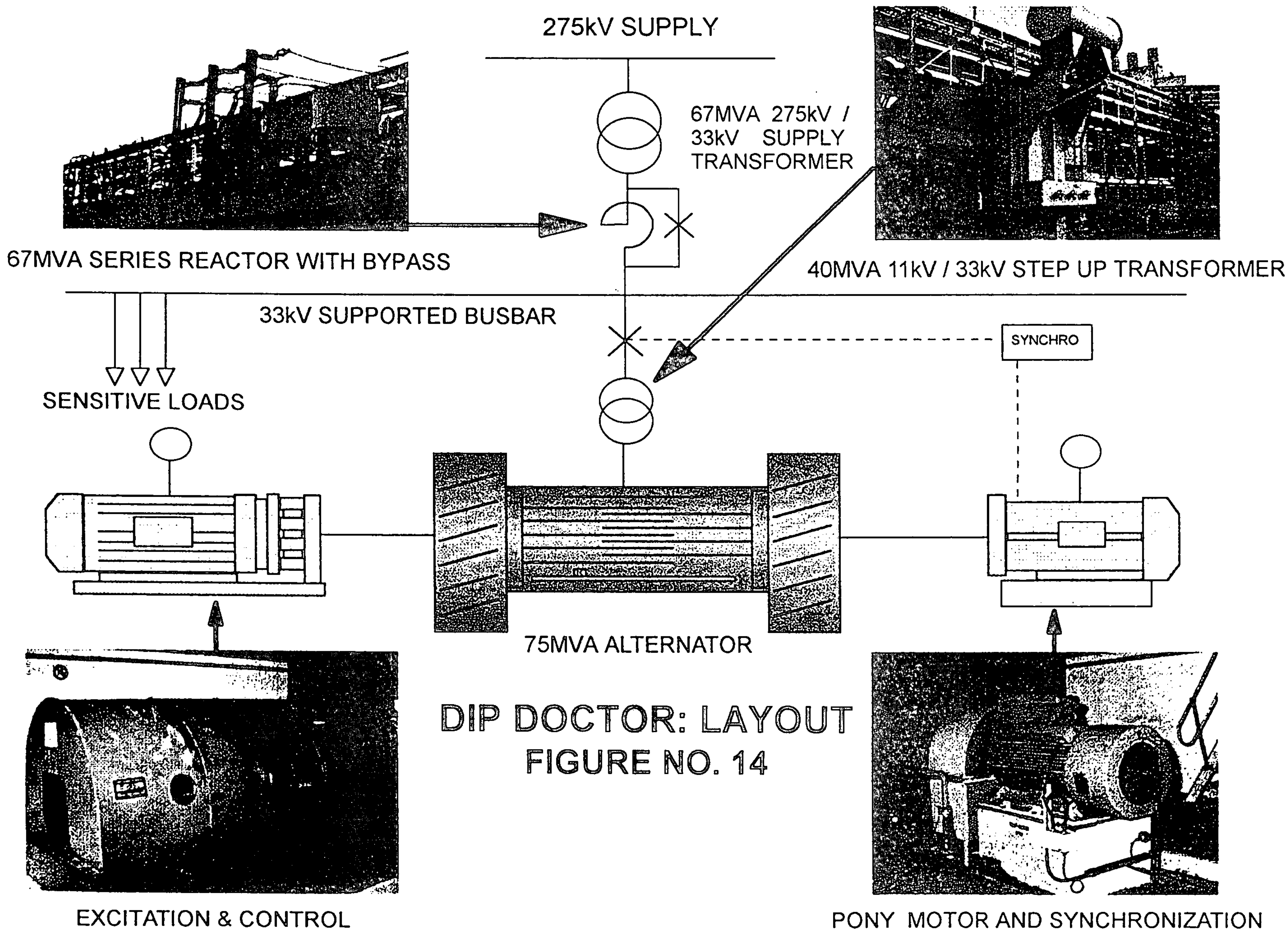


STATORDYNE: SCHEMATIC

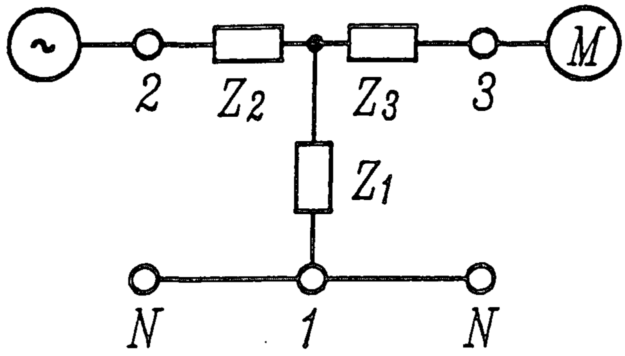
FIGURE NO. 13

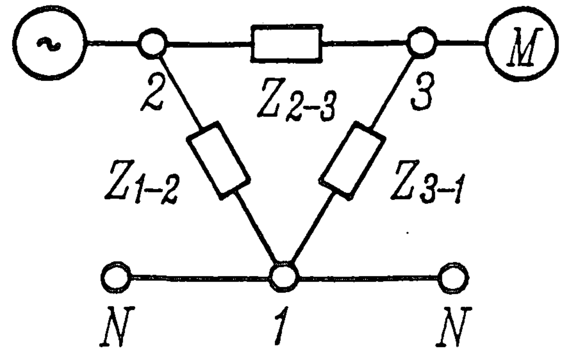


SCHEMATIC LAYOUT OF EXISTING DIPDOCTOR AT RICHARDS BAY MINERALS



DIP DOCTOR: LAYOUT
FIGURE NO. 14





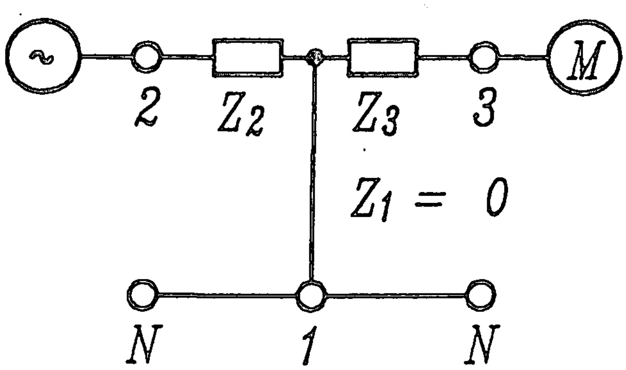
TRANSFORM STAR TO EQUIVALENT DELTA

AS $Z_1 \rightarrow 0$

$$Z_{1-2} = \frac{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}{Z_3} \qquad Z_{1-2} \rightarrow \frac{Z_2 Z_3}{Z_3} \rightarrow Z_2$$

$$Z_{2-3} = \frac{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}{Z_1} \qquad Z_{2-3} \rightarrow \frac{Z_2 Z_3}{Z_1} \rightarrow \infty$$

$$Z_{3-1} = \frac{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}{Z_2} \qquad Z_{3-1} \rightarrow \frac{Z_2 Z_3}{Z_2} \rightarrow Z_3$$



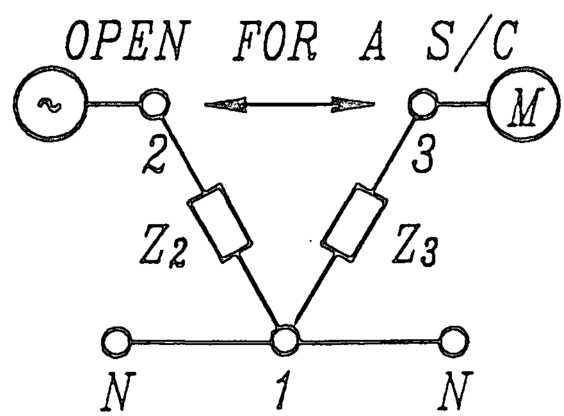
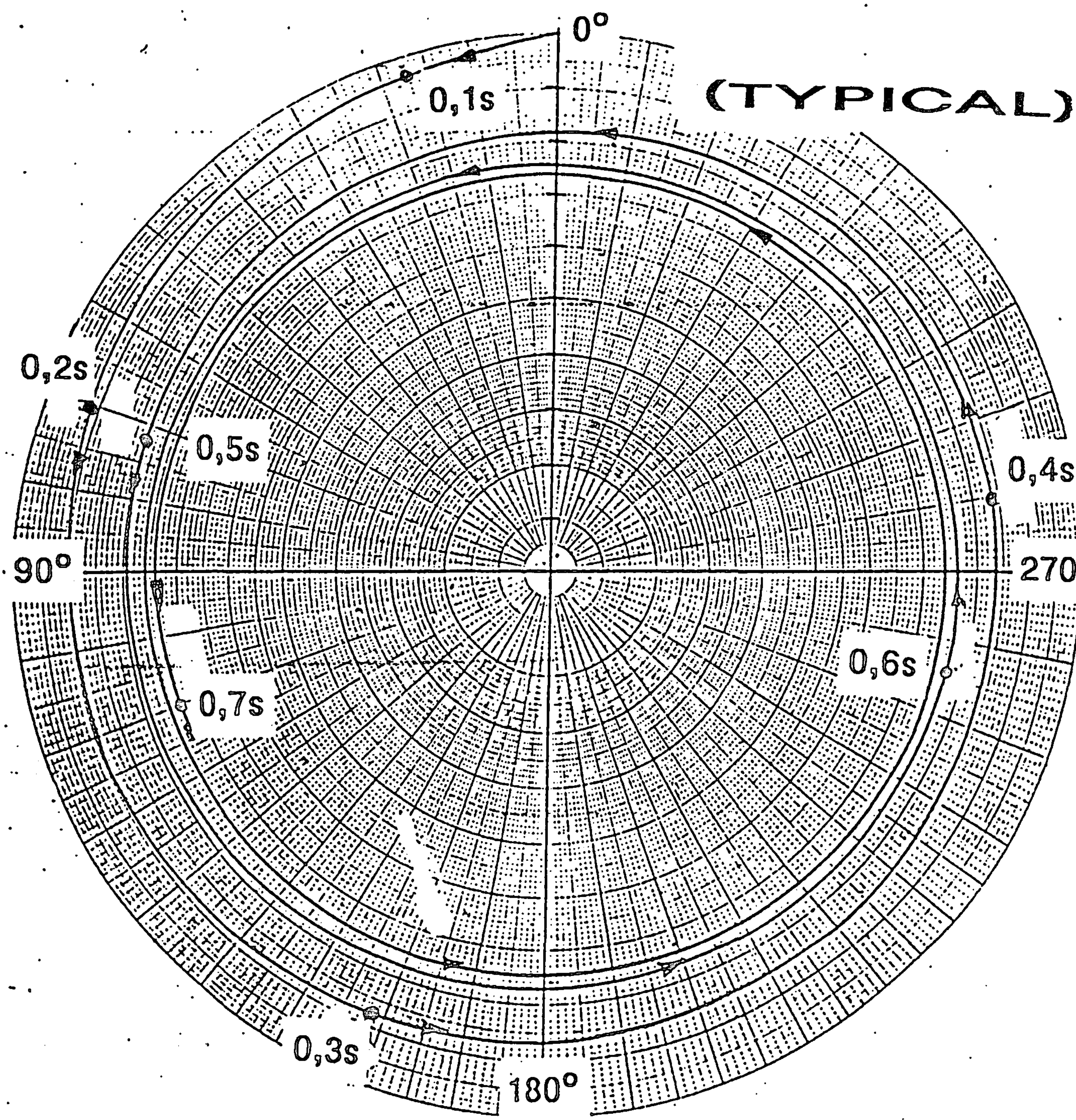


ILLUSTRATION OF HOW SHORT-CIRCUIT BETWEEN MOTOR & GENERATOR HAS SAME EFFECT AS OPENING THE CIRCUIT

FIGURE NO.15

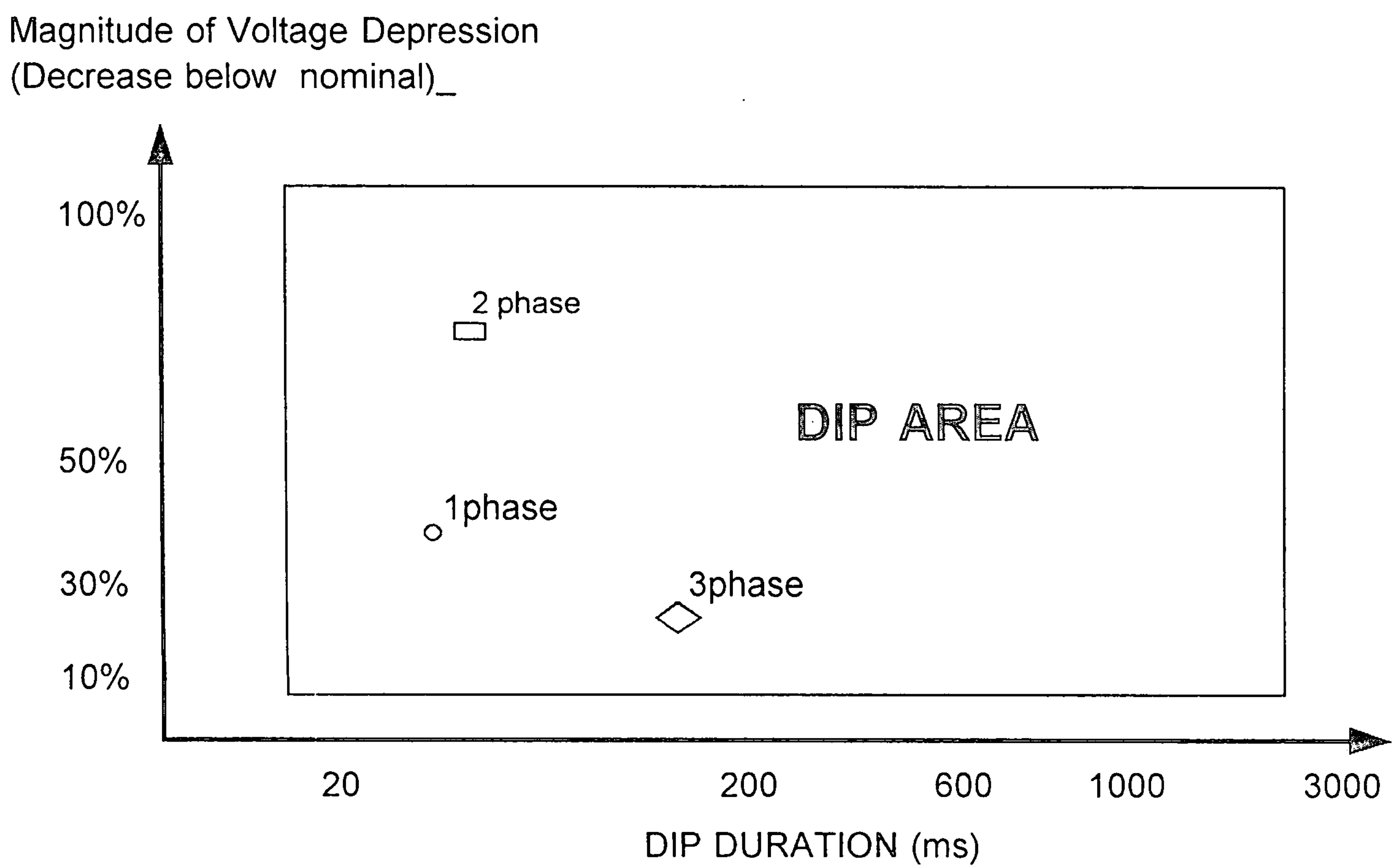


VARIATION OF MOTOR EMF & ANGLE WRT SUPPLY DURING DIP OR DISCONNECTION

FIGURE NO. 16

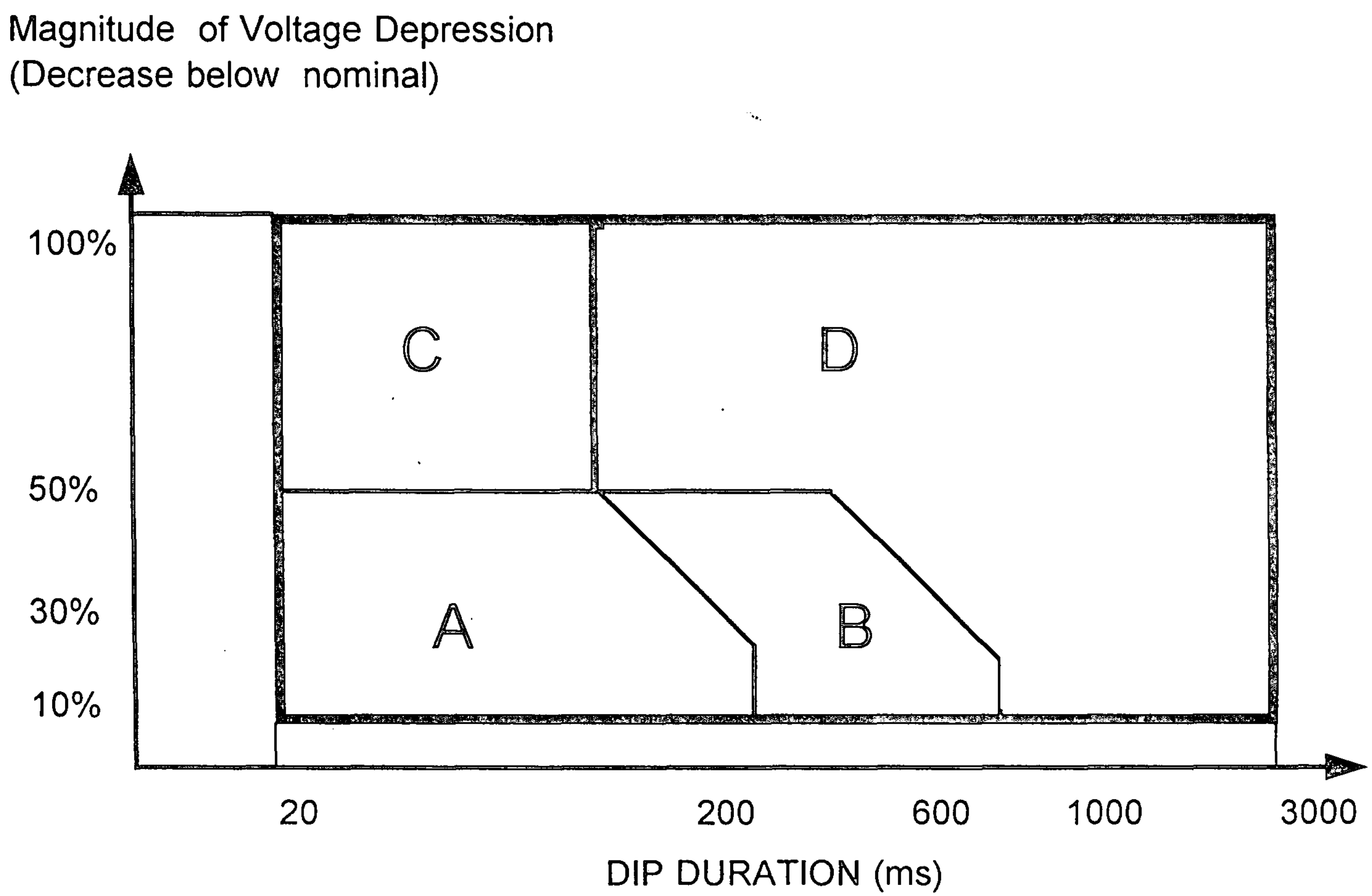
DIP AREA

FIGURE NO. 17



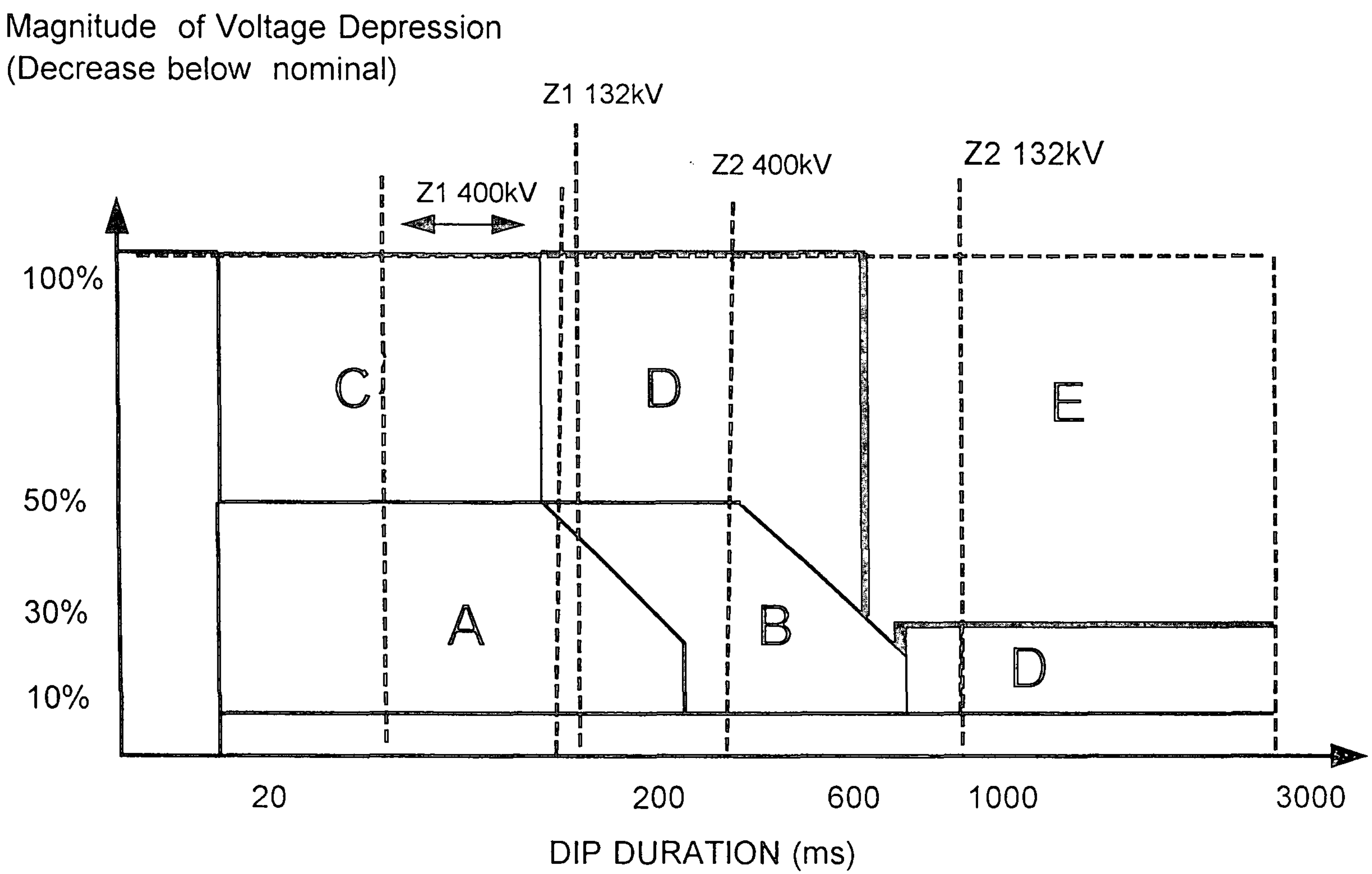
DIP WINDOW : 1

FIGURE NO. 18



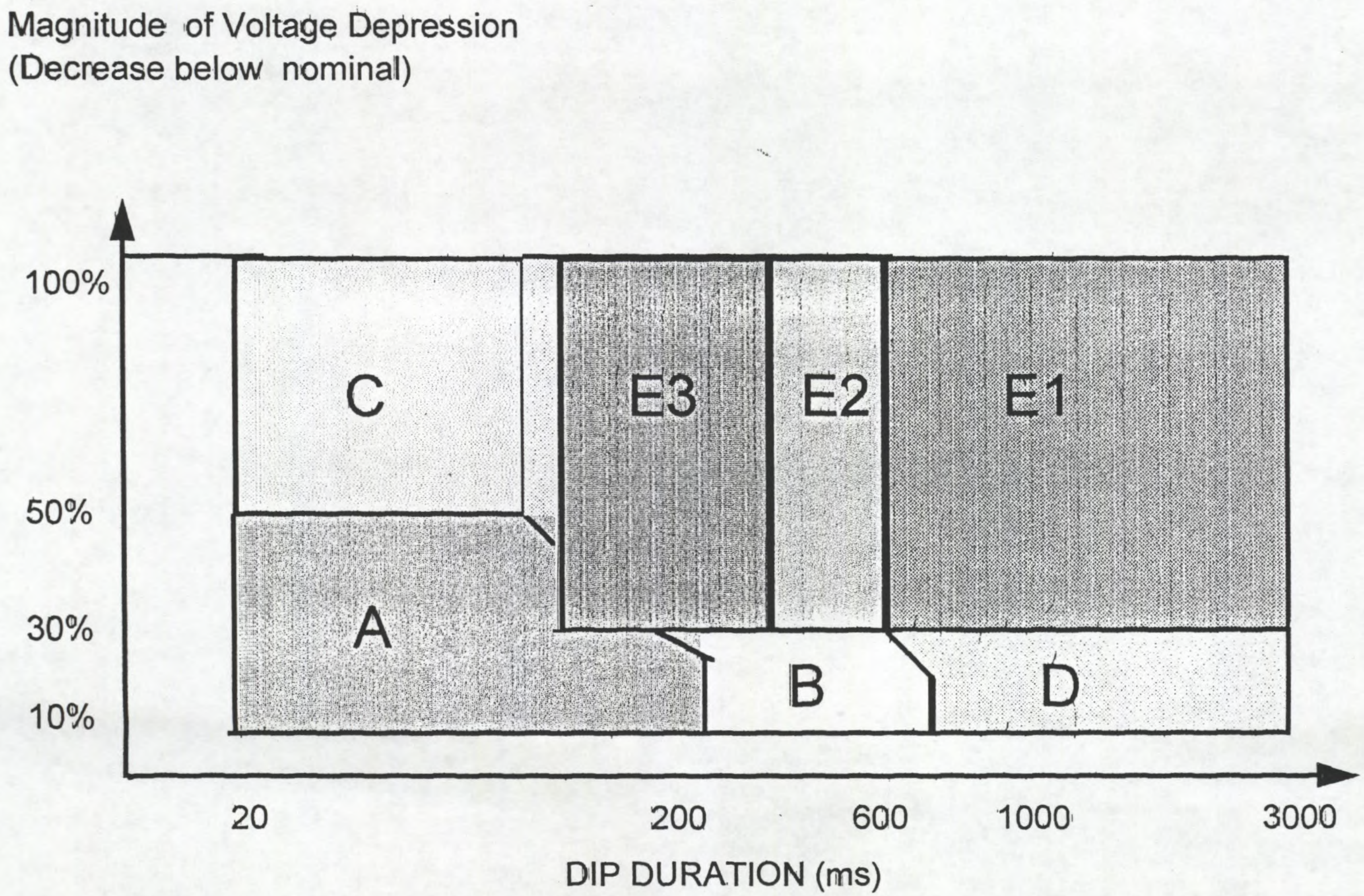
DIP WINDOW : 2

FIGURE NO. 19



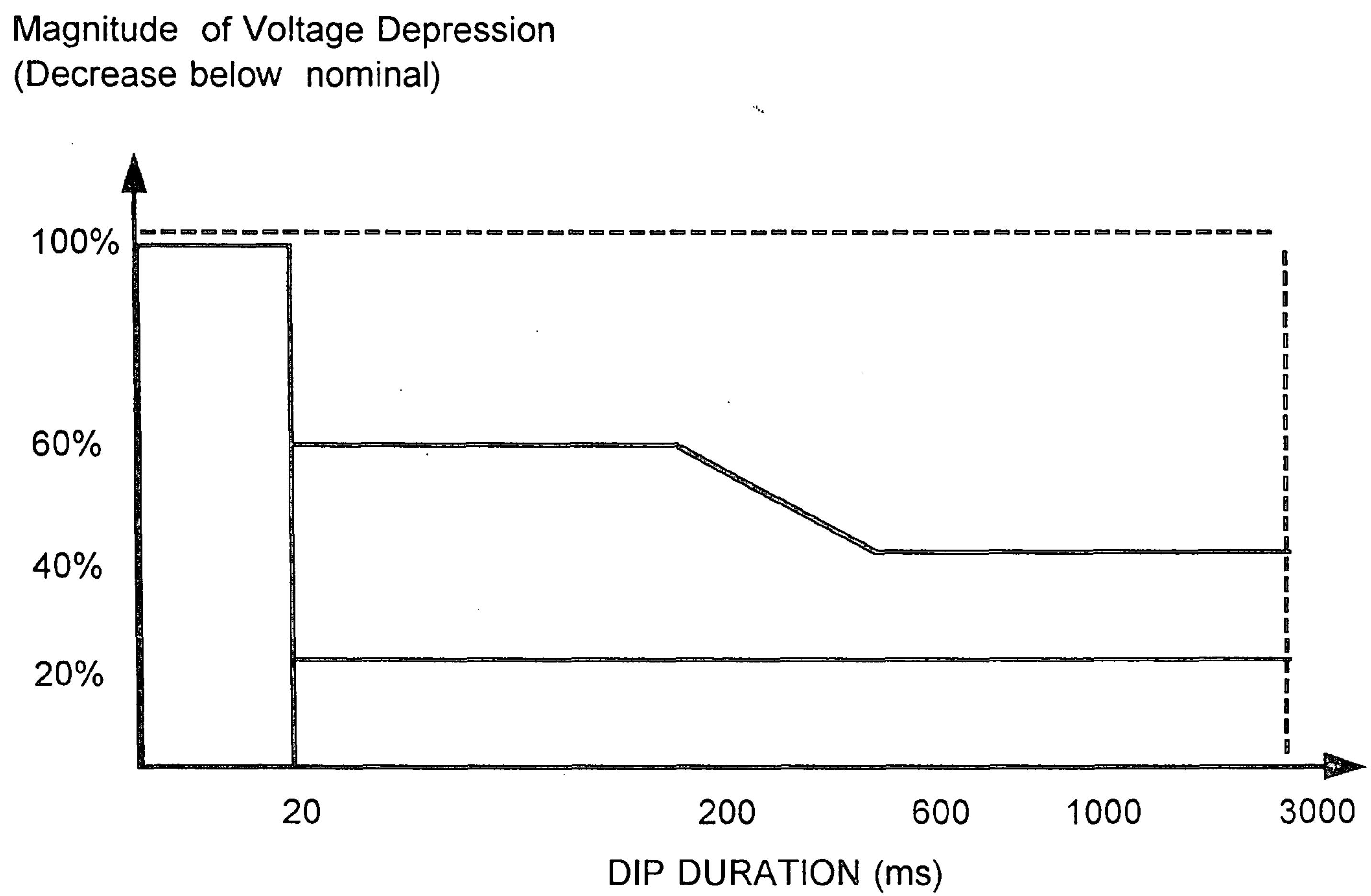
DIP WINDOW : 3

FIGURE NO. 20



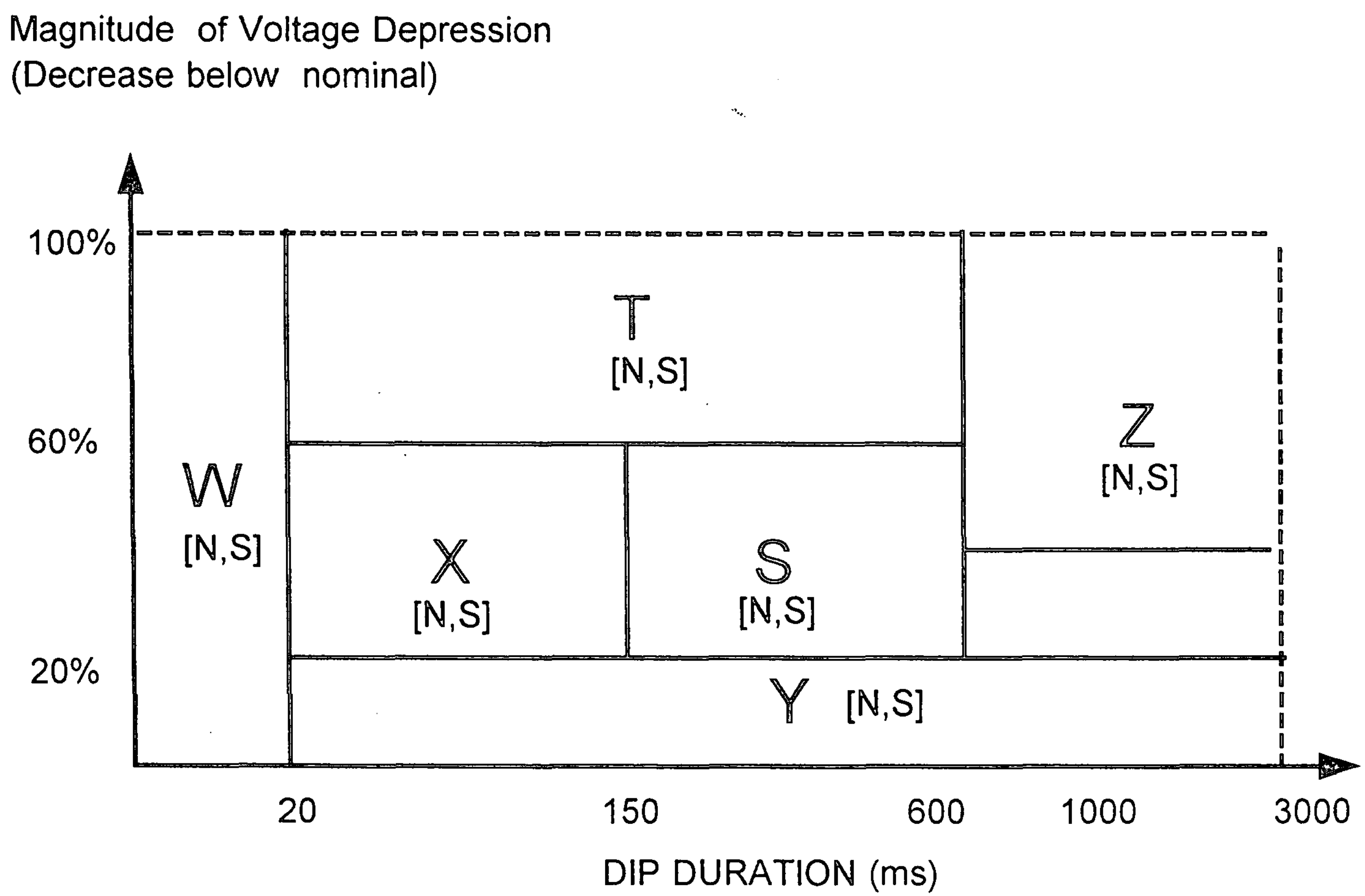
CUSTOMER SENSITIVITY

FIGURE NO. 21



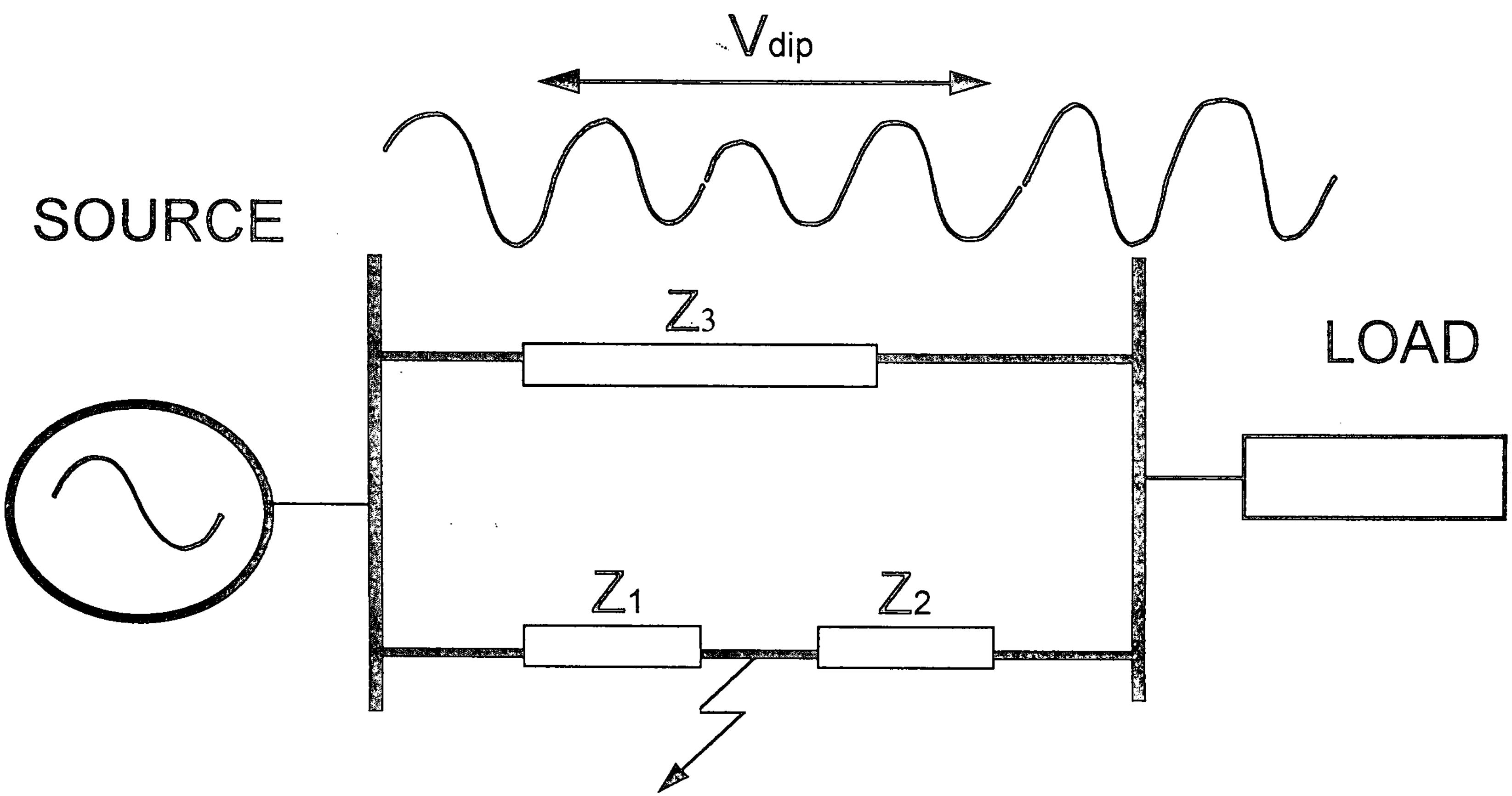
DIP AREAS FOR NETWORK VOLTAGES 6,6-765 kV

FIGURE NO. 22



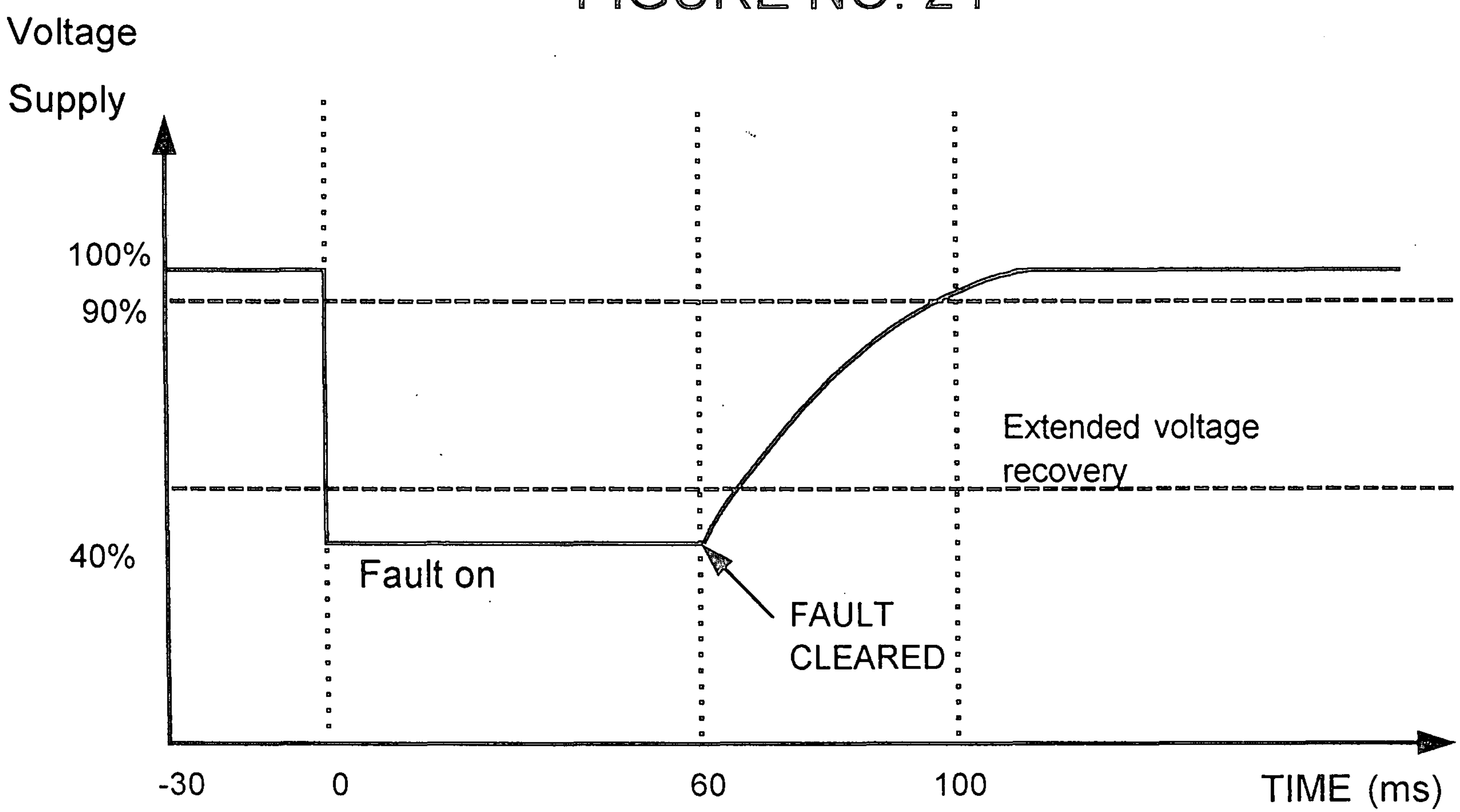
POWER SYSTEM IMPEDANCE TOWARDS FAULTS

FIGURE NO. 23



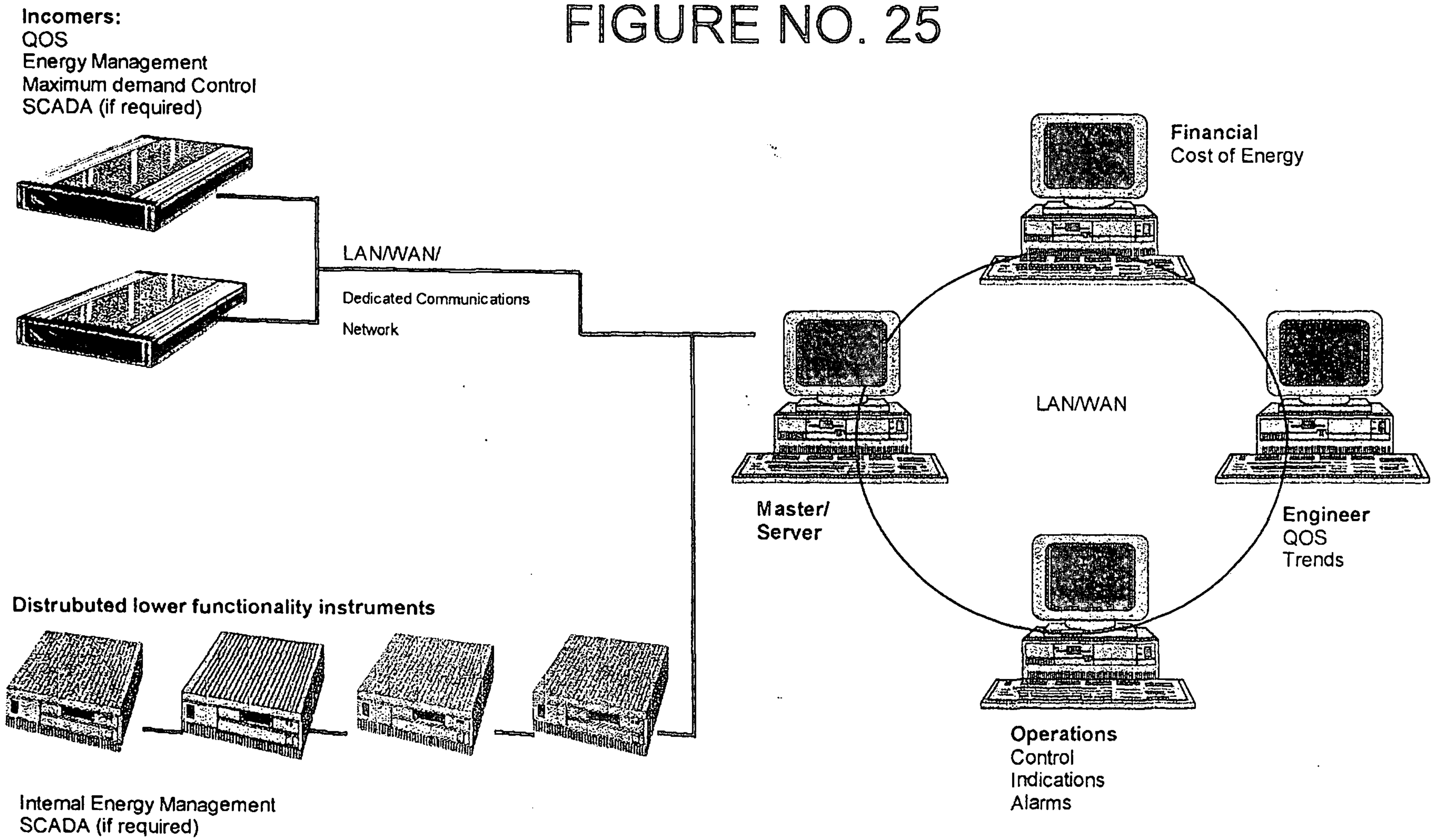
POWER SYSTEM INRUSH CURRENT

FIGURE NO. 24



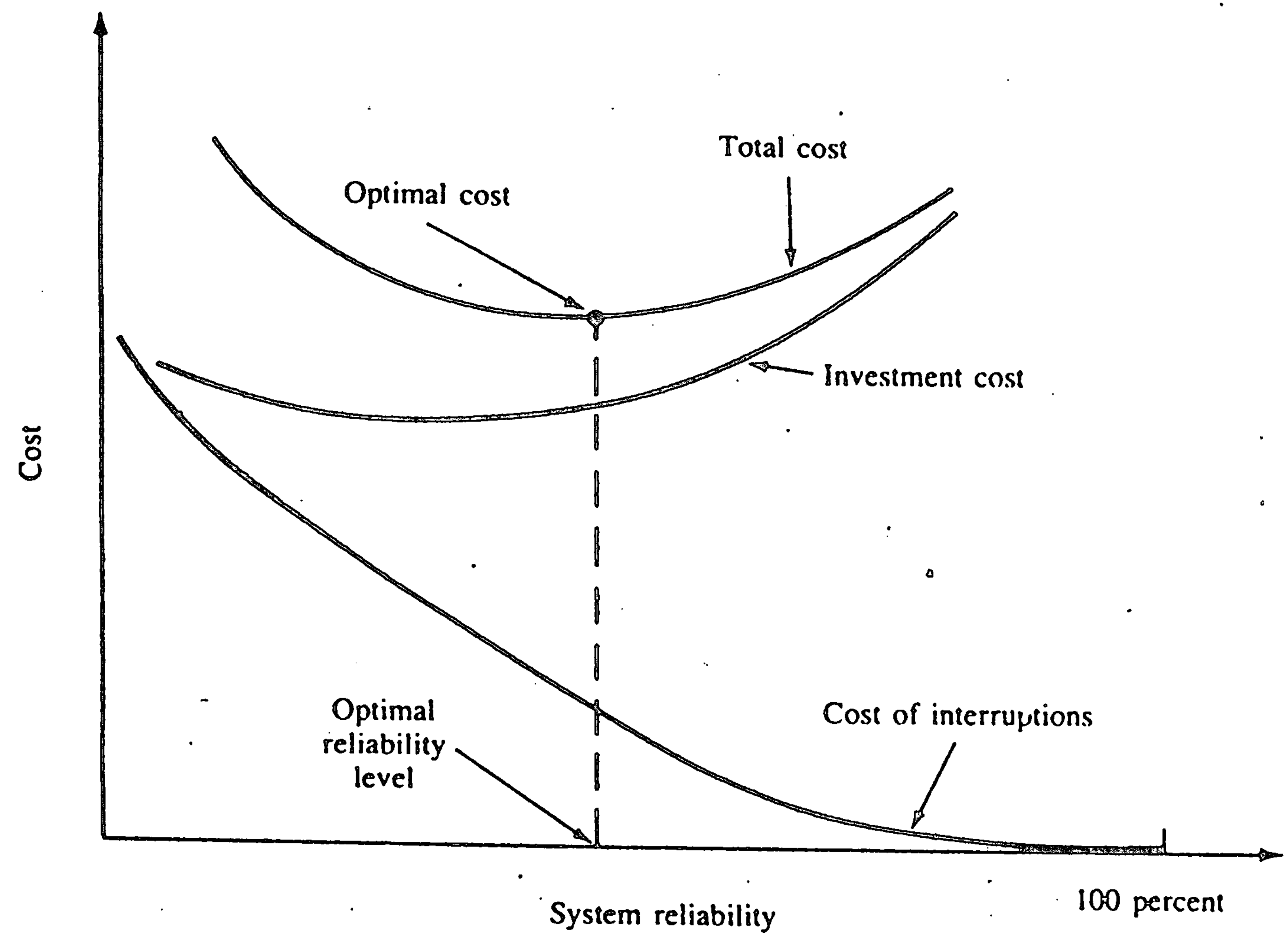
TYPICAL QOS ENERGY MANAGEMENT SYSTEM

FIGURE NO. 25



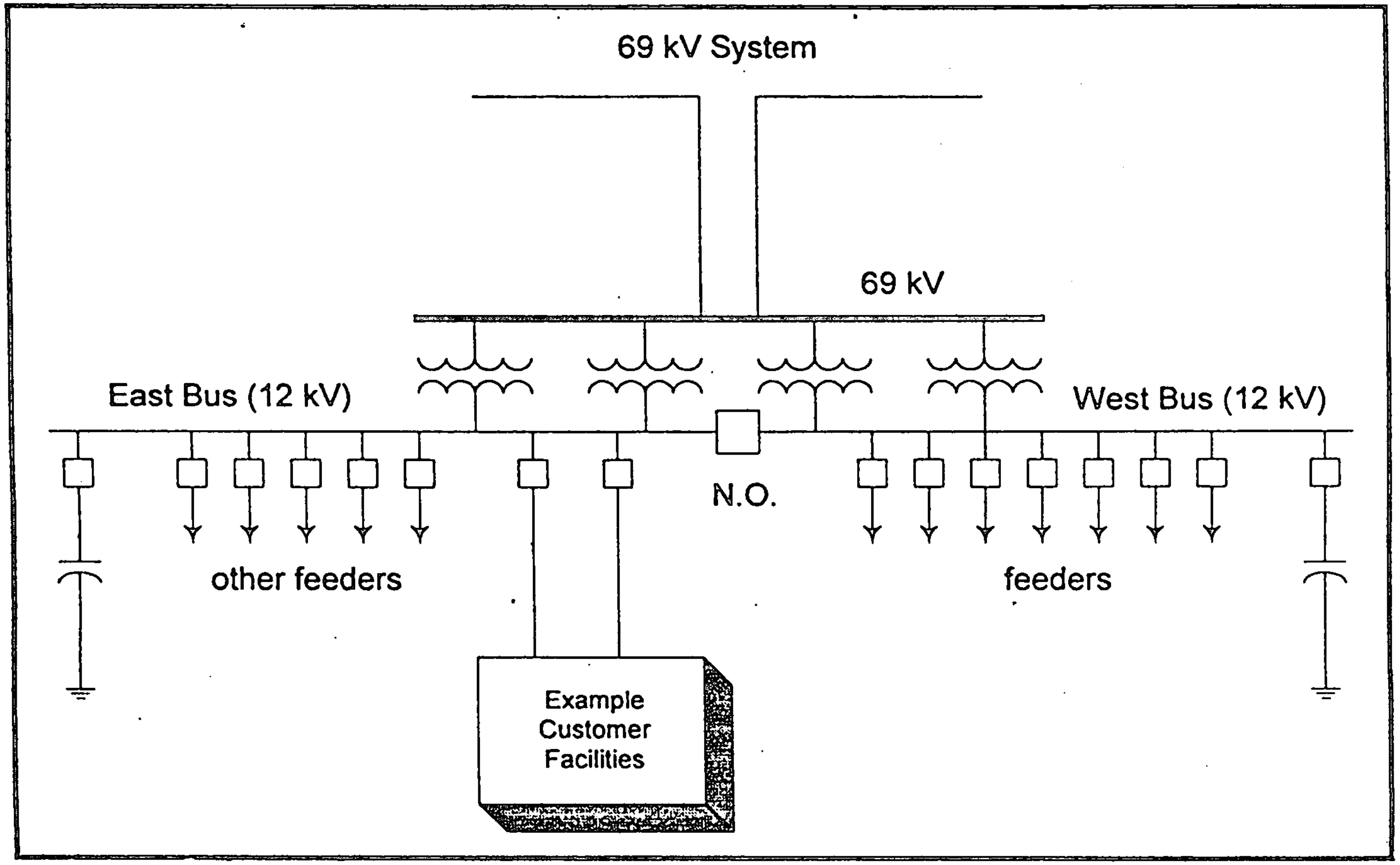
COST vs SYSTEM RELIABILITY

FIGURE NO. 26



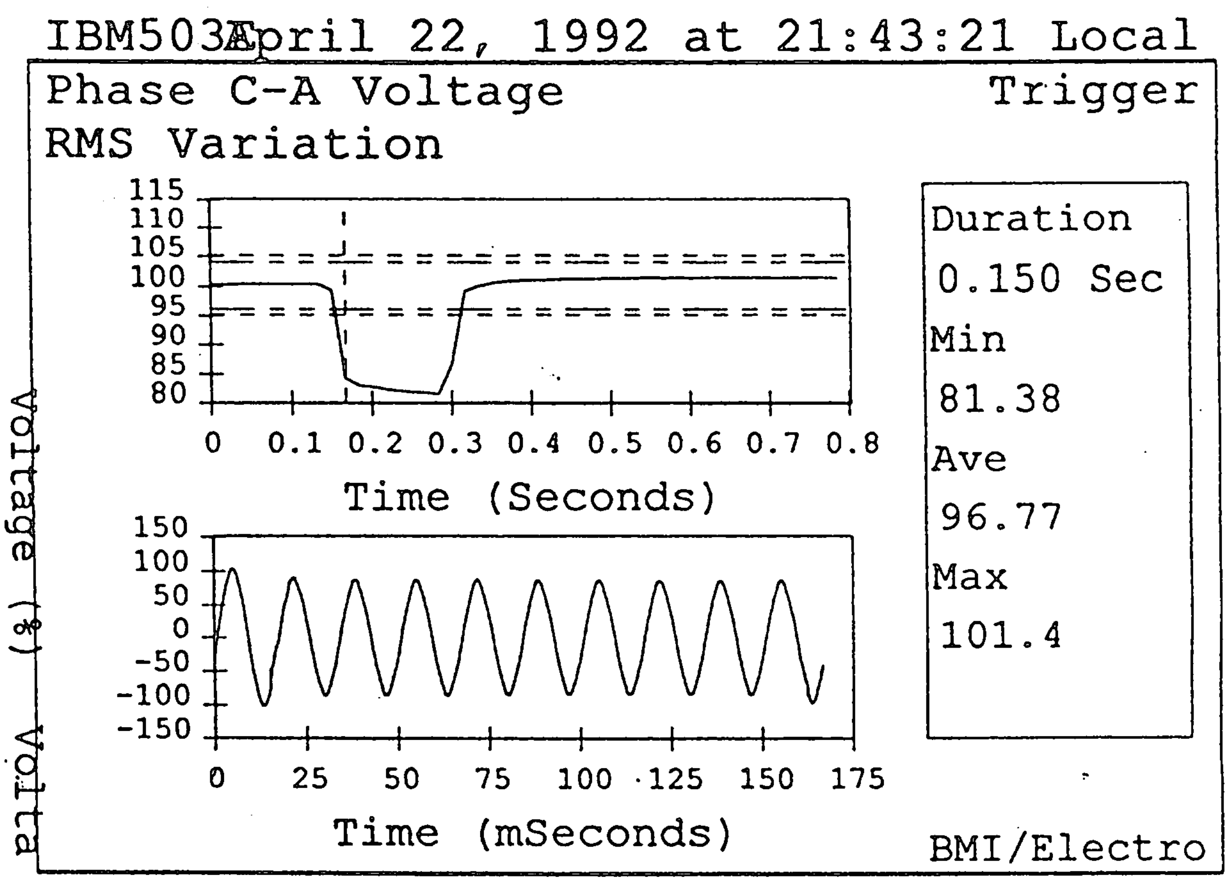
SIMPLIFIED SINGLE LINE DIAGRAM OF EXAMPLE SYSTEM

FIGURE NO. 27



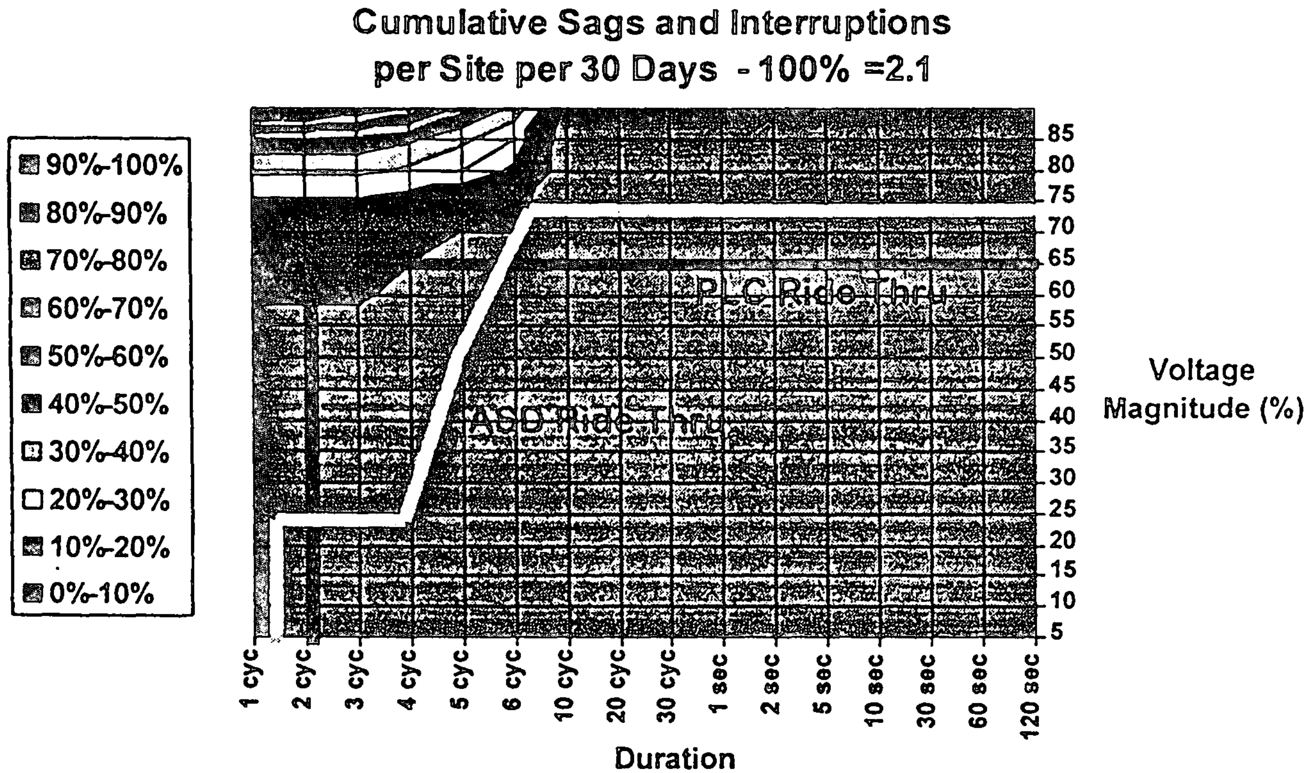
VOLTAGE SAG GRAPH OF EXAMPLE CUSTOMER

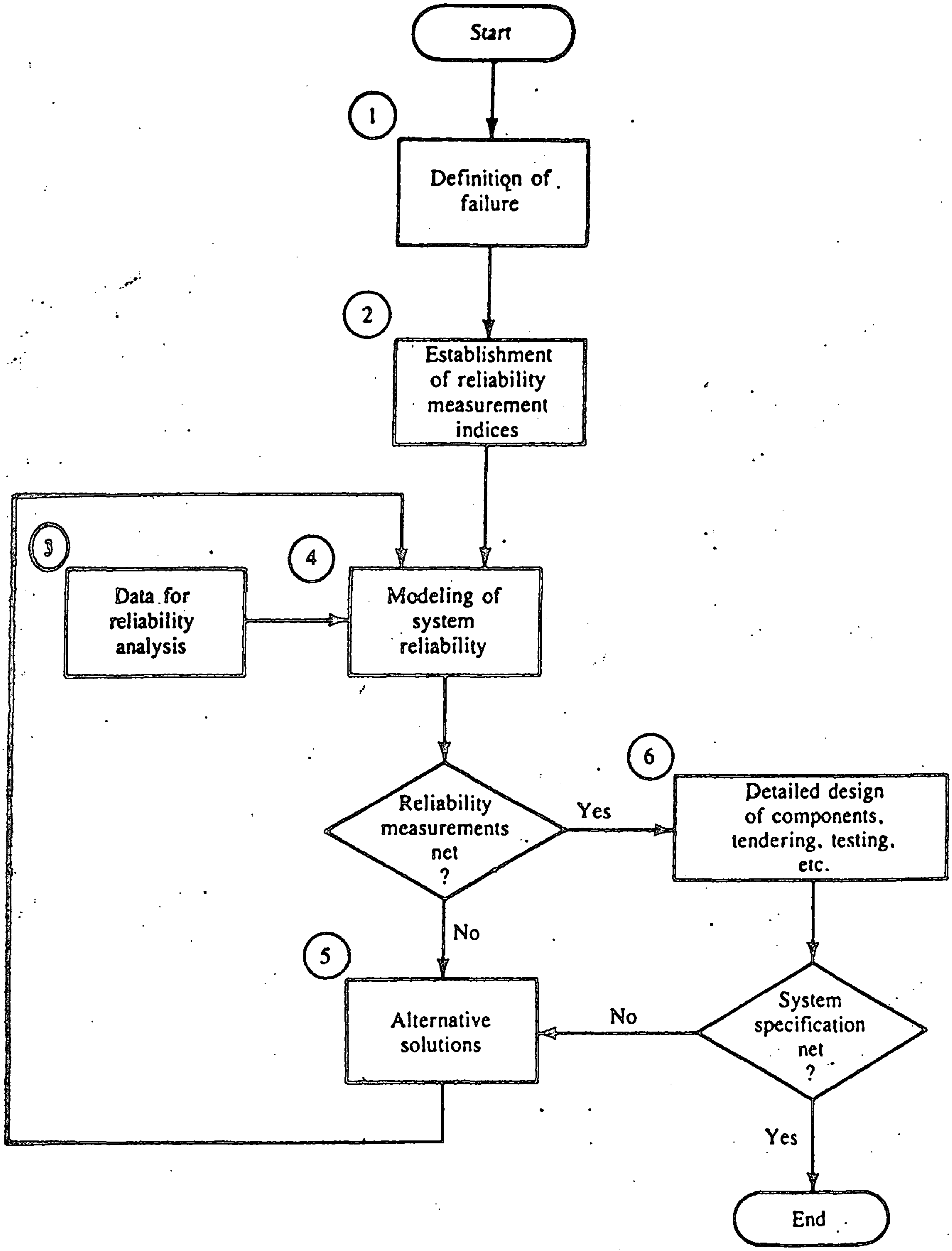
FIGURE NO. 28



VOLTAGE SAG PERFORMANCE CONTOUR PLOTS WITH SENSITIVE EQUIPMENT

FIGURE NO. 29



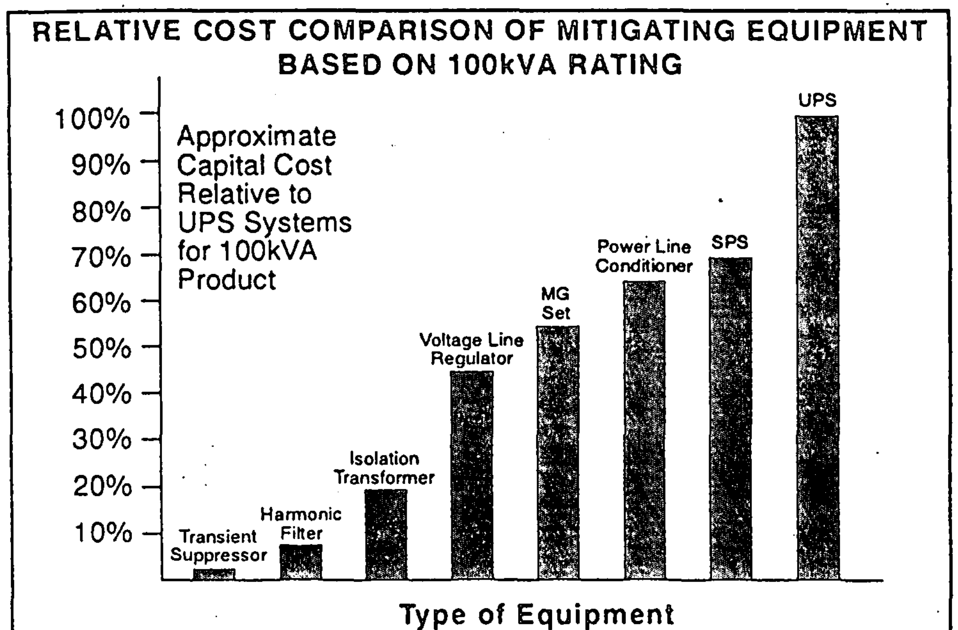


A RELIABILITY PLANNING PROCEDURE

FIGURE NO. 30

RELATIVE COST COMPARISON OF MITIGATING EQUIPMENT BASED ON 100kVA RATING

FIGURE NO. 31



* *Cost increases with kVA rating. Typical maximum relative costs are shown for equipment rated at 100kVA*

APPENDIX

A

CORRESPONDANCE

RESEARCH PROJECT

L G LANGE
STUDENT No. 942425

PROJECT

Research and preparation of material on the Electrical Quality of Supply : Voltage Dip-Proofing. This will cover the power system analysis, voltage quality, disturbances, solutions and a survey of large companies in the Greater Durban Area. The emphasis being placed on voltage dip-proofing.

TITLE

AN INVESTIGATION INTO THE ELECTRICAL QUALITY OF SUPPLY : VOLTAGE DIP-PROOFING

PREAMBLE

A consumer of electricity may assume that the supply of electricity is perfect in all respects at any time. Nevertheless due to unforeseen interferences and disturbances the supply may be interrupted for a mere micro second to an entire power outage. This causing major interference with production thereby leading to a financial loss.

AIM

The main aim of this research project is to provide electrical plant engineers with a source of practical ideas/solutions applicable to their plant needs.

SCOPE

The following will give an outline of the material intended but need not be exactly in accordance with the end result. The research project in itself will in itself broaden the understanding of the researcher and hence improve the presentation.

1. INTRODUCTION

   The introduction of this research project will briefly cover the availability/continuity of supply. An understanding of the requirements of a Supply Authority.

2. POWER SYSTEM ANALYSIS

   This will investigate the requirements of a consumer's power system together with the supplied suppliers power system thereby determining the stability of the supply of electricity.

3. VOLTAGE QUALITY

This will investigate the quality of the following:-

3.1 Frequency
3.2 Magnitude (dips, surges)
3.3 Waveforms (harmonics)
3.4 Symmetry (Neg. and Zero phase seq)

4. VOLTAGE DIP-PROOFING

The main reference of this research project will to provide an understanding of present problems and solutions employed in voltage dip-proofing under individual consumer's conditions. The research project will also cover the different types of disturbances through to the practical solutions including the new development in SSD's (Superconducting Energy Storage Systems).

5. SURVEY

A survey of the larger companies in the Greater Durban Area together with the existing statistical data obtainable from Eskom and Durban Corporation.

6. SOLUTIONS

This will conclude the investigations with possible and existing solutions, costs and savings to the consumer of electricity.

SUPERVISION AND EXAMINER

1.	SUPERVISOR	:	D P Serfontein, Eng.Tech, M Dip Tech.
2.	MODERATOR	:	G F d'Almaine, M Dip Tech (MSAIETE), HOD Power Engineering (ML Sultan Technikon).
3.	EXAMINER	:	P Cowan, PrEng MSc (Elec MSAIEE) of Rainbow Technologies - Specialist Design and Consulting Electrical Engineers.

DURATION

It is expected to present the above with material as the project progresses to check on suitability, to act as editors and give a report back on directions.

Investigation	180
Survey	180
Collation of data	50
Presentation	30
Binding	20
TOTAL TIME	460 hrs

RESOURCES

The preparation will be done on a computer with Windows as the word processor, spell checker and thesaurus.

The source of data and information will be different reference libraries having a varied source of technical literature.

Test instruments are available. The hire/rental shall be considered if and when practical involvement is required to gain data information for the research project.

At present no funding is projected but if funds are required, BOSCH & ASSOCIATES, CONSULTING ENGINEERS will be approached to make funds available. As this firm is sponsoring this project, copyright shall remain with this company.

PRESENTATION

A presentation to a recognized institute will be favourable. Dates and venues will be advised depending on success on the research project.

OWNERSHIP

Sufficient copies of the research project as required by the M.L. SULTAN TECHNIKON and its project authorities will be provided for academic purposes, but the project itself will not become the property of the M.L. SULTAN TECHNIKON.

The TECHNIKON will not be allowed to reproduce the material for gain or any other purposes than to meet the approval of the examination for the qualification offered. The research project material will remain the property of BOSCH & ASSOCIATES SA (PTY) LTD.

SIGNED BY: ______________________ DATED : ______________

APPENDIX

B

PROGRESS REPORTS

established 1951

cbm

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consulting engineers

Chew Bowen and Marais cc
Reg. No. CK 87/24050/23
12 Charles Strachan Road
P.O. Box 30123
Mayville 4058
Durban
Tel: (031) 2618254
Fax: (031) 2616389
Email : cbmdbn@iafrica.com

3 November 1997

dissertation
\progl6\LL

Electrical Department :
Power Engineering
ML Sultan Technikon
PO Box 1334
DURBAN
4000

Attention : Mr Fred d'Almaine

Dear Sir

SUBJECT : **MASTER DIPLOMA IN TECHNOLOGY**
PROGRESS REPORT No. 6 & DISSERTATION (DRAFT COPY)

Enclosed please find Progress Report No.6 and the Draft Copy of the Dissertation for your remarks and/or approval.

I would appreciate it if your remarks to the Dissertation be made available for collection by mid-December 1997, for corrections over the Holidays and to be returned to your office as the Final Copy of the Dissertation in the New Year.

Please note that the Dissertation is bound double sided for Draft presentation purposes and will in the Final format be single sided.

Should you have any queries at all please do not hesitate to contact myself at the following :-

Telephone : 031-2618254 (work)
Telephone : 031-444854 (home)
E-mail : langelg@dbn.lia.net

Yours faithfully

L.G Lange
Student No. 942425

encl. Progress Report No. 6
Draft Copy of Dissertation

Master Diploma in Technology

Electrical Engineering (Heavy Current)

Progress Report No. 6

Topic : An Investigation into the Electrical Quality of Supply - Voltage Dip Proofing

By

L. G Lange

Student No. 942425

M. L SULTAN TECHNIKON

Introduction

The purpose of this report is to advise as to the progress that has been made on the Research Project.

Background

The **new** anticipated date for the Draft Copy is **31 October 1997.**

The Draft Copy is handed in on **3 November 1997.**

Research Project

This Research Project is an investigation into the Electrical Quality of Supply, covering the aspects of a supply to a Customer with the emphasis on Voltage Dip-proofing.

General

Since the last Progress Report (No 5) the investigation has consisted of typing out and preparation of the remaining chapters and preparing of the Appendix.

E-mail address is : **langelg@dbn.lia.net**

Progress

A huge effort was made during the month of October to complete the dissertation to a First Draft Copy which is therefore to be handed in by the end of October 1997.

No problems have interfered with this progress.

Progress to Date to First Draft Copy

		Progress	Hours
1.0	Introduction to the investigation	6%	24
2.0	<u>Investigation</u>		
	2.1 Introduction	4%	16
	2.2 Power System Analysis	10%	40
	2.3 Quality of Supply	12%	48
	2.4 Voltage Dip Proofing	15%	60
	2.5 Survey	15%	60
	2.6 Financial Aspects	15%	60
	2.7 Design Criteria	10%	40
	2.8 Conclusion	3%	12
3.0	Bibliography	2%	8
4.0	Appendices	10%	40
	Power Quality Conference	6%	24
	Progress to Date	**108%**	**432**
	Total to First Draft Copy	**108%**	**432**
	Total to Completion	**110%**	**440**
	Minimum Hours Required for Dissertation	**100%**	**400**

APPENDIX

C

VOLTAGE DIP REPORTS

Provograph Voltage Dip Recorder (c)1995 CT-Lab: Dip Report

```
   Datafile: G:\PROV\DATA\DBNSOUTH\DBNS11.PRO
 Instrument: ProvoGraph 1.6dp
erialnumber: PRO0150
nstallation:        Feeder: TX1A or TX2B
                  Operator: D.A. CROW
                    Client: DBN SOUTH
              Point Number:
              Transf Ratio: 275 : 132
             Transf TapPos: AROUND 7
  Nominal V: 63.6 V
Threshold V: 57.2 V
             9.9% below nominal
 Start Time: 1995/09/15 14h40:54.00
   End Time: 1995/10/10 07h42:14.00
```

ip Statistics for all recorded dips:

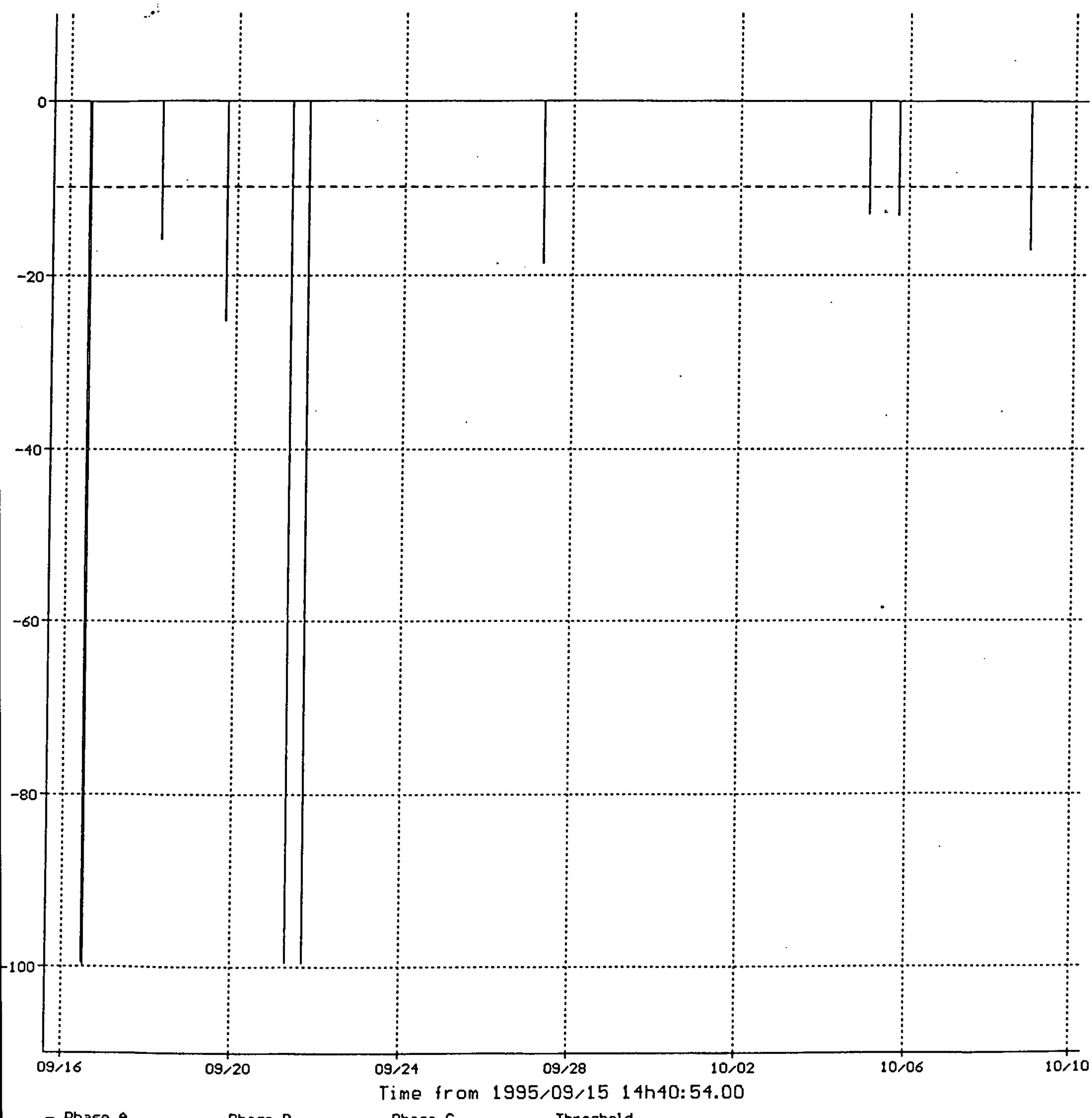
ıase	A	B	C	2ph	3ph	All
ısignificant	0	0	0	0	0	0
.ass A	2	2	2	0	0	6
.ass B	0	0	0	0	0	0
.ass C	0	0	0	0	0	0
.ass D	0	0	0	0	5	5
ım. Outages	0	0	0	0	0	0
ıtages	0	0	0	0	0	0
ıtal Dips	2	2	2	0	5	11

.ronological list of recorded dips:

#	Start Date	Start Time	Phases	Durat	%Dev	Dip Class
1	1995/09/16	11h21:41.59	ABC	2.31	99.6	Class D
2	1995/09/16	12h11:59.76	ABC	0.19	100.0	Class D
3	1995/09/16	12h12:00.02	ABC	0.10	99.6	Class D
4	1995/09/18	05h19:53.54	C	0.10	16.1	Class A
5	1995/09/19	17h59:48.03	B	0.05	25.5	Class A
6	1995/09/21	07h43:15.32	ABC	2.33	99.3	Class D
7	1995/09/21	16h56:36.39	ABC	0.26	99.6	Class D
8	1995/09/27	07h22:04.37	A	0.08	18.8	Class A
9	1995/10/05	01h52:01.52	C	0.08	13.1	Class A
0	1995/10/05	19h05:59.73	A	0.04	13.2	Class A
1	1995/10/08	23h25:30.18	B	0.07	17.4	Class A

rovograph Voltage Dip Recorder (c)1995 CT-Lab: Dip Graph

```
    Datafile: G:\PROV\DATA\DBNSOUTH\DBNS11.PRO
  Instrument: ProvoGraph 1.6dp
erialnumber: PRO0150
nstallation:          Feeder: TX1A or TX2B
                    Operator: D.A. CROW
                      Client: DBN SOUTH
                Point Number:
                Transf Ratio: 275 : 132
               Transf TapPos: AROUND 7
   Nominal V: 63.6 V
 Threshold V: 57.2 V
               9.9% below nominal
  Start Time: 1995/09/15 14h40:54.00
    End Time: 1995/10/10 07h42:14.00
```

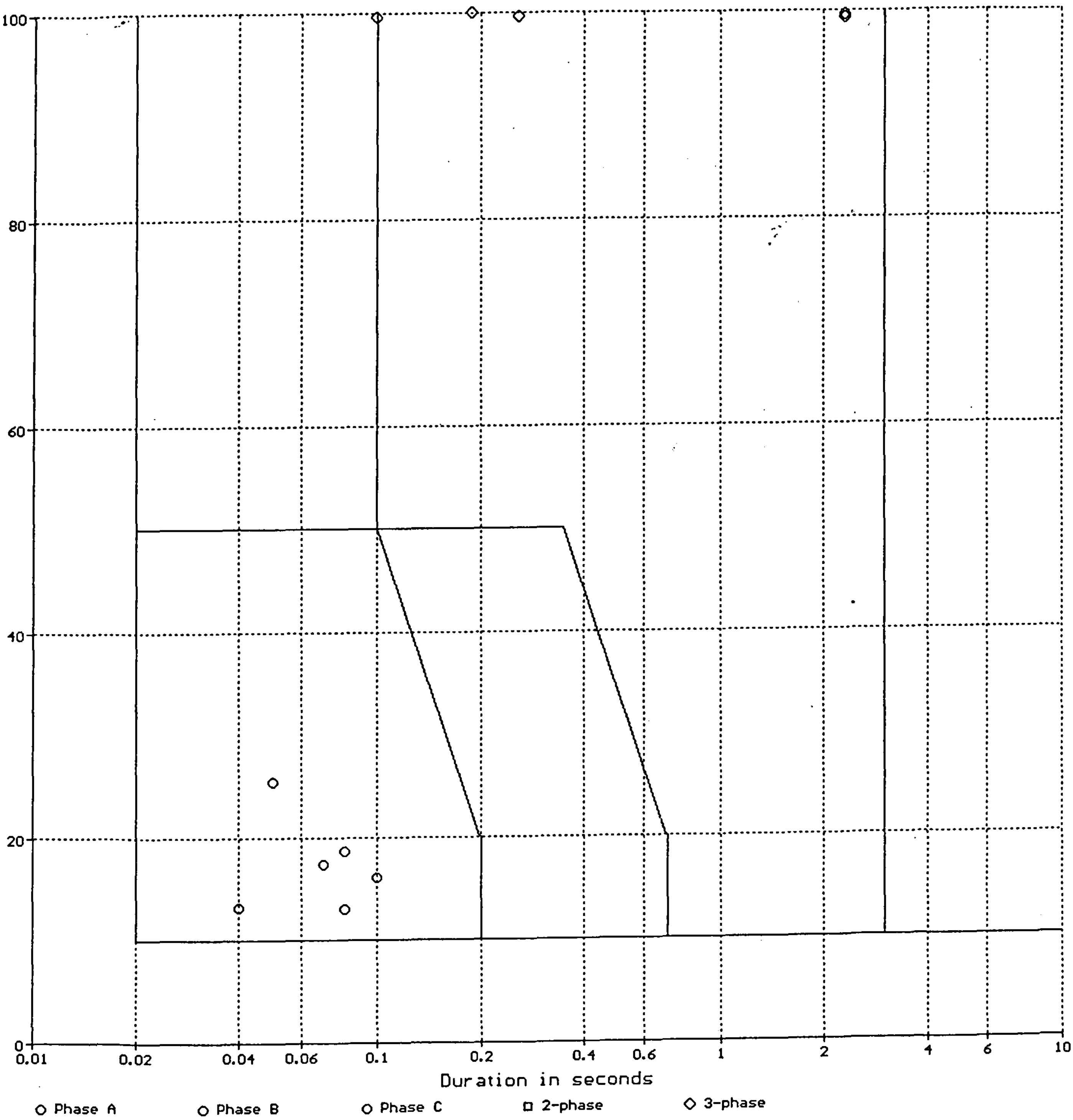


Provograph Voltage Dip Recorder (c)1995 CT-Lab: Dip Scatterplot

Datafile: G:\PROV\DATA\DBNSOUTH\DBNS11.PRO
Instrument: ProvoGraph 1.6dp
Serialnumber: PR00150
Installation: Feeder: TX1A or TX2B
Operator: D.A. CROW
Client: DBN SOUTH
Point Number:
Transf Ratio: 275 : 132
Transf TapPos: AROUND 7
Nominal V: 63.6 V
Threshold V: 57.2 V
9.9% below nominal
Start Time: 1995/09/15 14h40:54.00
End Time: 1995/10/10 07h42:14.00

Dip Statistics for all recorded dips:

Phase	A	B	C	2ph	3ph	All
Insignificant	0	0	0	0	0	0
Class A	2	2	2	0	0	6
Class B	0	0	0	0	0	0
Class C	0	0	0	0	0	0
Class D	0	0	0	0	5	5
Mom. Outages	0	0	0	0	0	0
Outages	0	0	0	0	0	0
Total Dips	2	2	2	0	5	11

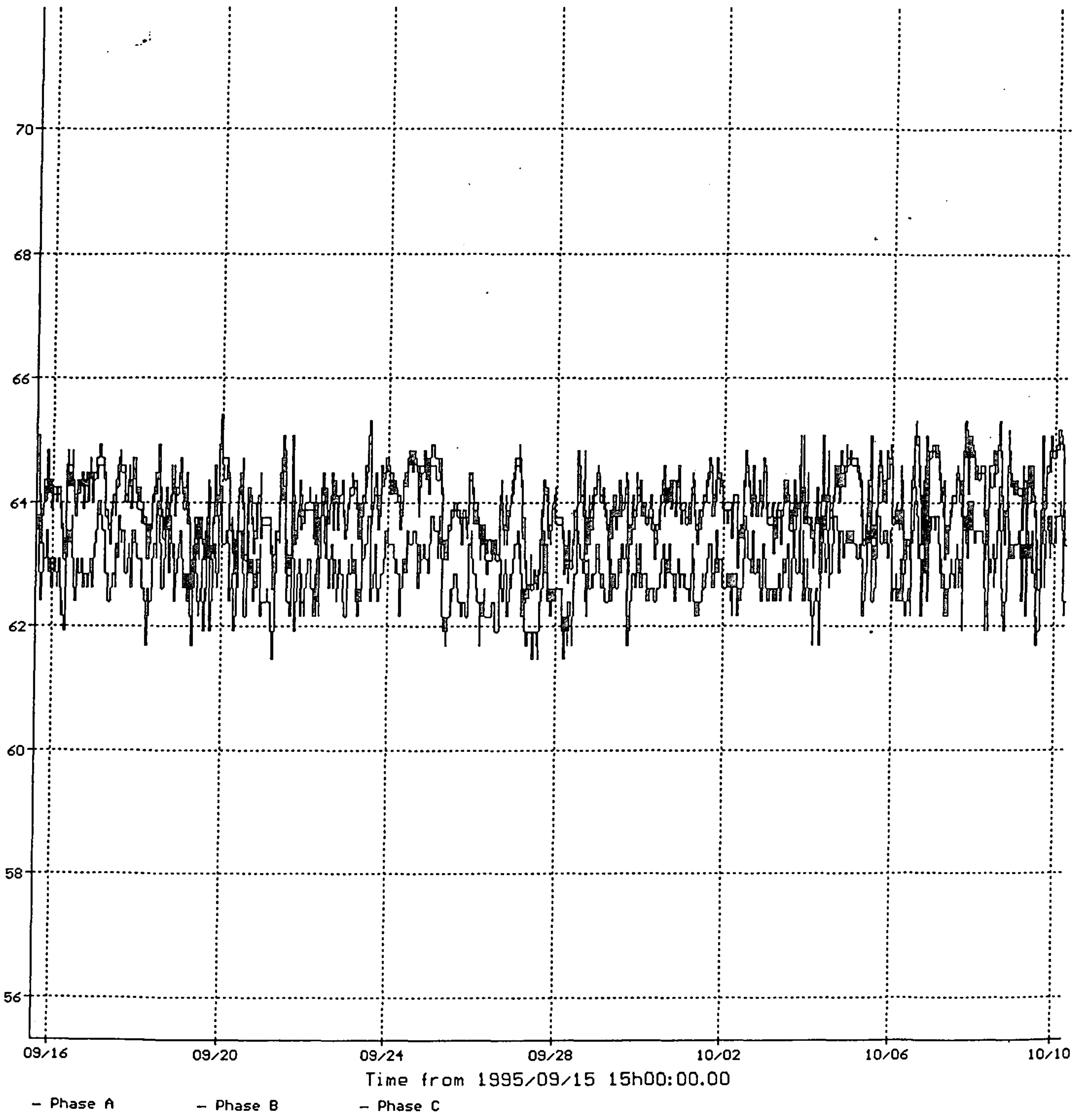


'ovograph Voltage Dip Recorder (c)1995 CT-Lab: Profile Graph

Datafile: G:\PROV\DATA\DBNSOUTH\DBNS11.PRO
Instrument: ProvoGraph 1.6dp
'rialnumber: PRO0150
stallation: Feeder: TX1A or TX2B
Operator: D.A. CROW
Client: DBN SOUTH
Point Number:
Transf Ratio: 275 : 132
Transf TapPos: AROUND 7
ample Ival: 00h30:00
Start Time: 1995/09/15 15h00:00.00
End Time: 1995/10/10 07h30:00.00

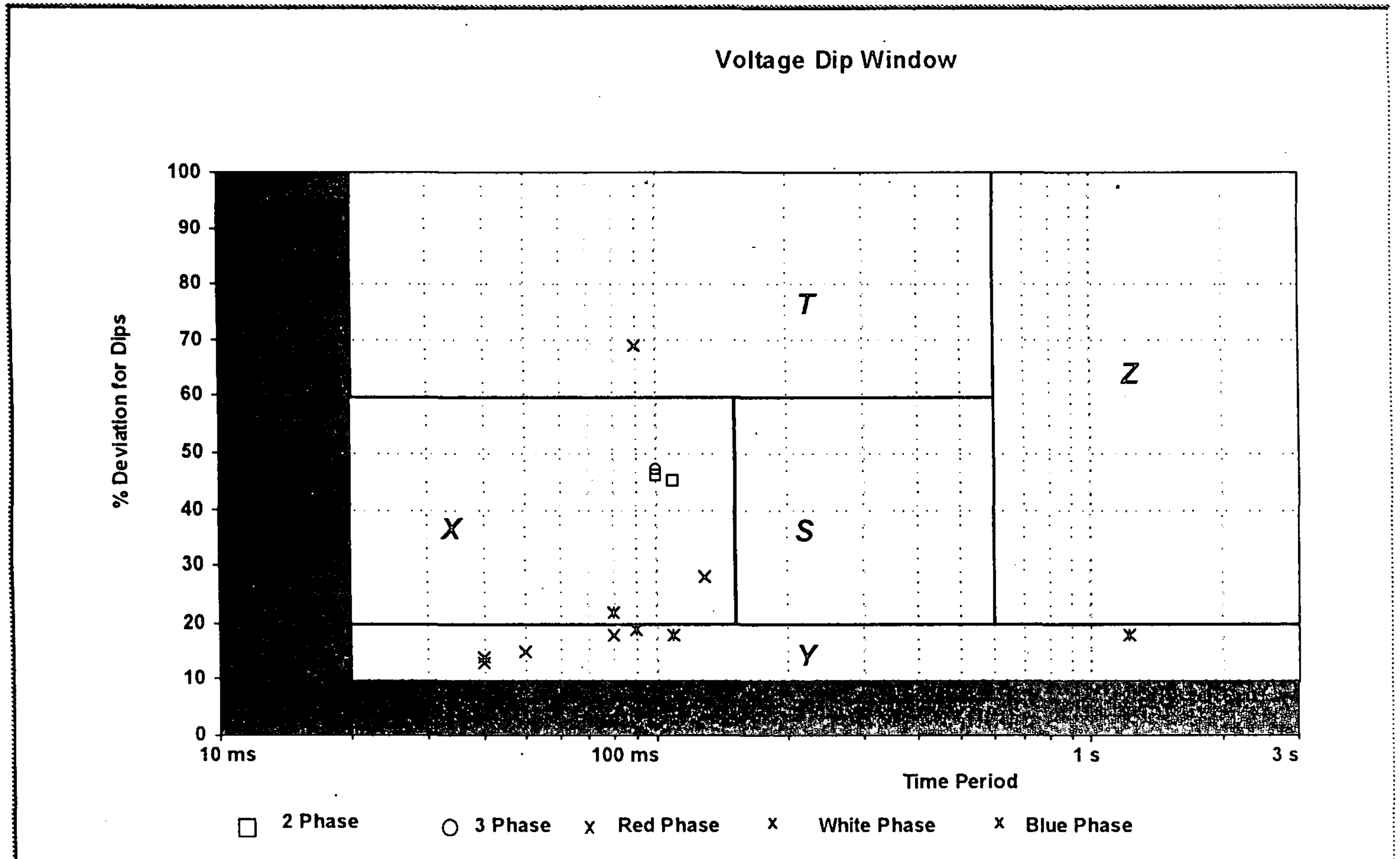
Statistics for all samples:

Phase	A	B	C	ABC
Average	62.9	64.0	64.0	63.6
Std Deviation	0.5	0.5	0.5	0.7
Minimum	61.4	62.4	62.4	61.4
Maximum	64.5	65.4	65.3	65.4



Voltage Dip Window: Records for the Selected Period: 97-02-01 To 97-02-28

For Durban_South



Category	*All Categories*
Supply Voltage	*All Voltages*
Phases	*All Phases*
Circuit Name	*All Circuits*
Responsibility	*All Parties*

Substation Only

Causes

All Causes

APPENDIX

D

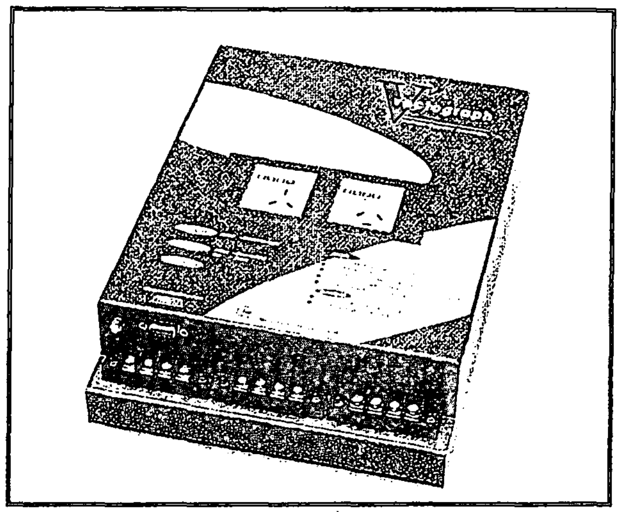
VOLTAGE QUALITY RECORDERS

Vectograph

Voltage Quality Recorder

Eight Quality of Supply recorders in one instrument

- True RMS Dip & Surge Recorder
- Spike Recorder
- Profile Recorder
- Unbalance Recorder
- THD Recorder
- Regulation Recorder
- Vector Recorder
- Panel Meter & Oscilloscope



Features

- True 3-phase operation (3 or 4 wire)
- Stand-alone and non-volatile
- 10 second dip/outage ride-through capability
- Rugged aluminium housing
- Field upgradable embedded software
- AC or DC auxiliary supply
- 0.2% accuracy
- External time synchronization inputs
- Fully software configurable

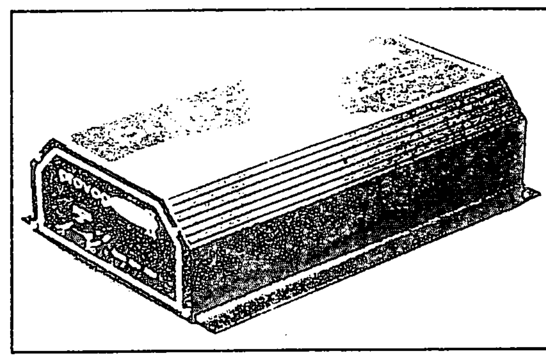
Communication & Reports

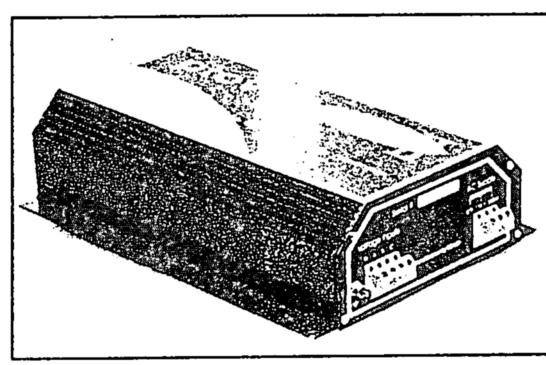
- Windows communication and report generation software included
- Interfaces with PC/Modem through RS232 port
- Instrument management through included Windows software
- RS485 networking support
- Modem and automatic dial-up support
- Automatic report generation

provog

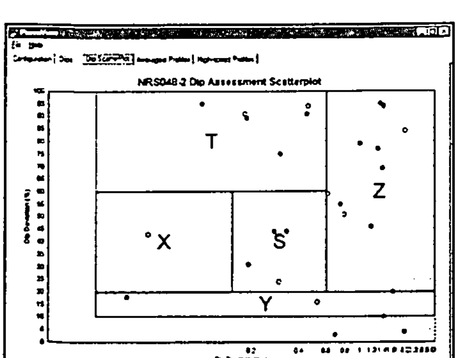
voltage dip and profile recorder

- NRS048 Category 3, 4 and 5 compliant
- Rugged, stand-alone instrument
- Single or Three Phase Operation (star or delta connection)
- High accuracy (0,5% of full scale)
- High resolution (200mV on reading every 10ms)
- Large Storage Capacity (30+ days)
- Battery backed ride through capability (5s in abscence of power)
- Records manually triggered high-speed profiles (up to 80s profile at 10ms time resolution)
- Field upgradeable embedded code
- Automated Data Retrieval Software
- Powerful Graphical Presentation and Report Generation Software

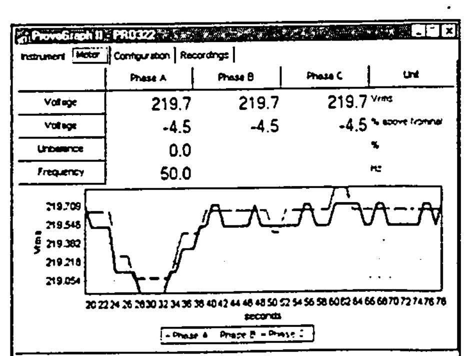




NRS Scatterplot



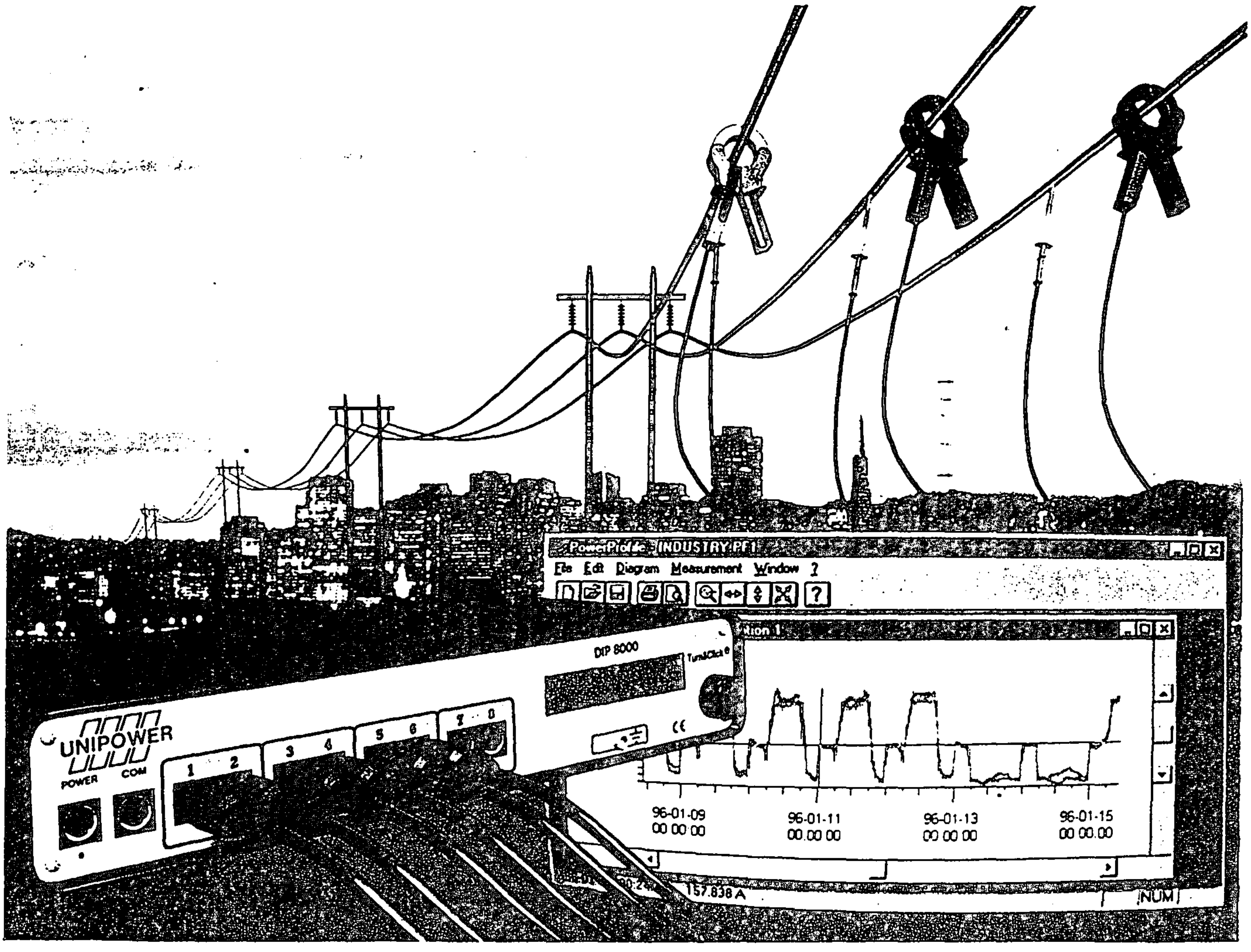
Instantaneous Display Window with Short-Profile



Designed and Manufactured by CT LAB, South Africa

UNIPOWER Power Network Analyzer

Dip 8000 - Your eye into the power network



DIP 8000 making things easier for you when...

- Checking voltage quality
- Performing load analysis
- Analyzing reactive power
- Discovering phase unbalances
- Analyzing harmonics
- Looking for vagabond currents
- Analyzing in-rush currents
- Measuring temperature
- Measuring general purpose signals, for example 4-20 mA
- Registering pulses from kWh-meters or other general pulse transducers

DIP 8000 is designed for power distributors, utilities, industries, consultants, hospitals and for many other users. DIP 8000 is easy to use and it is equipped with our new user-interface Turn&Click®. It also has fast configuration and auto identification of transducers for a quick measure start. The DIP 8000 is designed for field use and personal safety. It is portable and equipped with an internal battery allowing measurements for up to 250 hours.

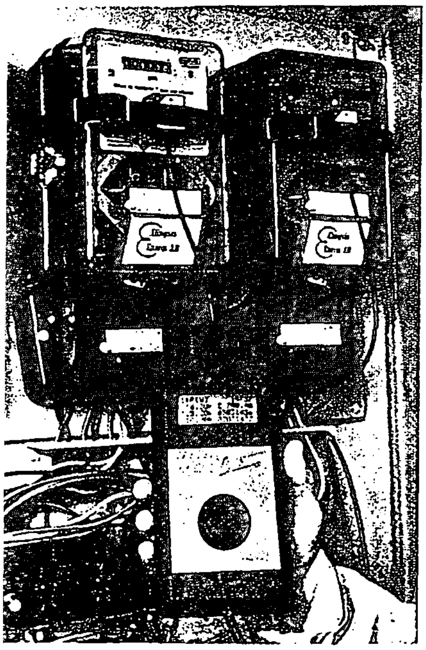
Dip 3000

s both a real time multimeter and a ogger with high memory capacity.

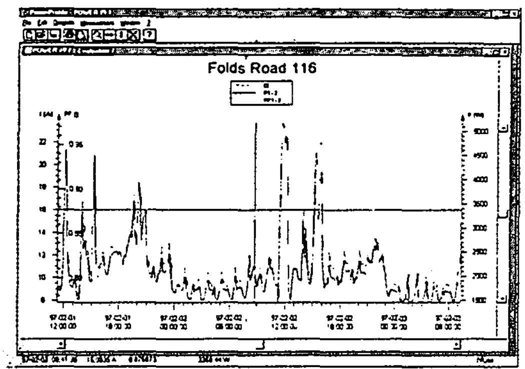
)IP 3000 is a multimeter for power ıetwork applications. It shows all /alues on its display and. at the ;ame time, stores values in its nemory. To make the system easy o use we have equipped it with our ıser interface Turn&Click®. Forget about complicated keypads, Turn&Click® consists of only one button! Do not worry that your DIP 3000 will become old and out of date, thanks to software updates via your PC new applications can be added easily. Latest software modules can, for instance. be downloaded from our Internet homepage: http://www.unipower.se !

DIP 3000 is delivered as a complete measurement system with transducers, software and accessories in a robust carrying case.

Troubleshooting an industrial plant. Three phase currents and their harmonics are studied. It is important to measure and record during a full load cycle in order to achieve comprehensive analysis results.



Three-phase demand analysis with DIP 3000. One optical transducer measures active power and another optical transducer measures reactive power. DIP 3000 calculates the power factor and shows all measured values in the display.



Evaluate your measurements using PowerProfile, an easy to use Windows software package included with the DIP 3000. Analysis reports can be printed directly from PowerProfile screens or pasted into text documents.

DIP3000 - Technical specification

Analogue inputs	3 individually programmable general purpose inputs.
Level	2.5V
Input impedance	10 MΩ.
Dynamics	48 dB. (56 dB).
Digital inputs	3 general purpose inputs.
Digital outputs	3 general purpose outputs.
Accuracy	±0.5 % exkl. transducers.
Communications	Asynchronous serial communications RS-232. 19 200 bps. 57 600 bps.
Memory	128kB.
Display	LCD. 4x16 characters.
Turn&Click®	Unique user interface for operating and configuring the system. Consists of one button that can be turned and pressed.
Power Supply	12V DC 400 mA and internal battery. Battery capacity 1 hour.
Weight	450g.
Size (WxDxH)	100 x 195 x 50 mm.
Operational temperature	-10° to +55° C.
Humidity	10% - 90% non condensing.
EMC	Complies with EN 50 081-1.2: EN 50 082-1.2.
Personal safety	Complies with EN 61 010-1.

Measure Capabilities

Voltage	0-275V AC/DC TRMS.
Current	Measure range depends on used current clamp. Typically 0-100A. 0-500A or 0-1000A TRMS.
Power and Power Factor	Single Phase kW, kVAr, kVA and PF when analogue inputs are used. Three phase kW, kVAr and PF when counting pulses from kWh- and kVArh meters.
Harmonics	Voltage and current harmonics up to 25th at 50 or 60 Hz fundamental. THD calculated according to American and European definition.
General Purpose Transducers	Measurements via general purpose transducers with current signal output (0-20mA or 4-20mA).
Digital Pulses	1, 2 or 3 channels for counting pulses. Specially designed to count pulses from kWh-, kVArh-, gas-, watermeters etc.

Accessories

Current Transducers	A wide range of clamp-on ammeters for AC or DC are available.
General Purpose Adapter	measurements can easily be adapted. Adapter for 0-20mA and 4-20mA general purpose transducer signals.
Optical sensor	Registering kW, kWh, kVAr and kVArh from a kWh- or kVArh meter.

QUALIMETRE OSCILLOSTORE P512

Measuring, recording and fault-monitoring device for the analysis of 50 Hz power supply systems

19" rack-mounted unit for stationary use

Permitting the setting up of power system monitoring installations through the integration of a personal computer and the OSCOP® Q system program (MS-Windows user interface)

Decentralized data acquisition - centralized evaluation

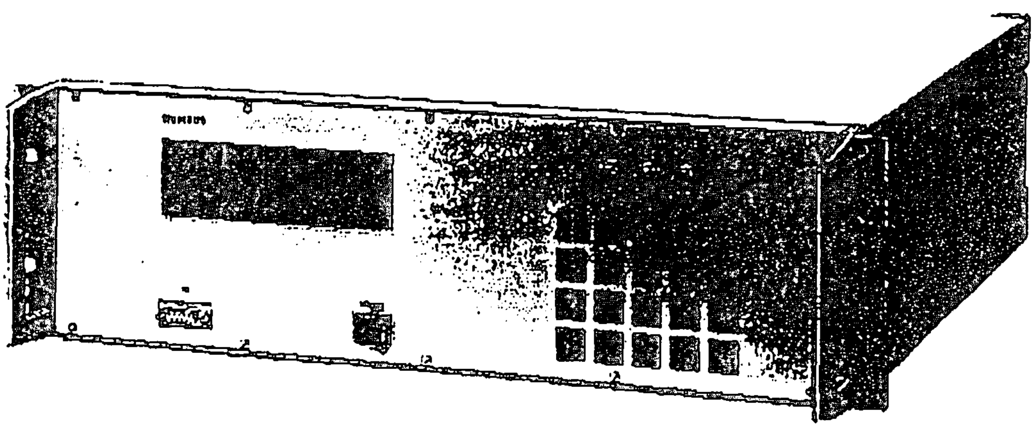
Suitable for analyzing 1, 3 or 4-wire systems

Recording of voltages, currents, frequency, mains symmetry, active and reactive power as well as voltage drops

Recording of individual harmonics in the range up to the 50th order, of the distortion factor and of ripple control signals with different frequencies

Simultaneous, parallel acquisition of all power system quantities with continuous and/or fault-triggered recording

4 voltage, 4 current channels and 4 binary inputs with integrated signal conditioners, interference-free as per IEC 255.4 app. E. class III and DIN VDE 0435, sect. 303, class III



4 relay outputs for signalling the operating status of the equipment

Operation and display on the device

A built-in accumulator compensates for mains failures

Data transfer via RS232 interface with cable or leased-line modem as well as via public or private telephone networks with integrated modem (option)

APPENDIX

E

APPROPRIATE LEVELS OF DISTRIBUTION RELIABILITY

GENERIC NETWORK LAYOUT RELIABILITY

Purpose

The purpose of this study is to determine the relationship in reliability and availability between various substation configurations. As a further indication, a high level cost estimate for each option has also been calculated.

Introduction

As a result of the Power Distribution Policy which states that a customer is entitled to a non firm supply reliability, studies for various options of substation layout were conducted.

Methodology

The following methodology was followed whilst conducting the studies for the 8 different options.

1. Determine reliability block diagram from the single line diagram
2. Calculate the system reliability for each option after one year.
3. Calculate the high level cost estimate.
4. Calculate availability
5. Tabulate the results

Definitions

RBD	Reliability block diagram
Reliability	Is the expectation that the system will function for 1 year without failure
Failure Rate (λ)	Number of failures per unit time/ number of components exposed to failure.
Series System	Components are said to be in series if they must all work for the system to work
Parallel System	Components are said to be in parallel if only one needs to be working for the system to be working.
MTBF	Mean Time Between Failures
MDT	Mean Down Time
Availability	Availability can be interpreted as the expected fraction of time a system would be available for operation.

Assumptions

1. The maximum demand can be supplied by any one of the installed bays (both transformer and line bays).
2. The equipment is identical for all the options.
3. The following failure rates, MTBF, MDT and maintenance times for the equipment were used.
4. The study is based on a line length of 1 km.

Table 1

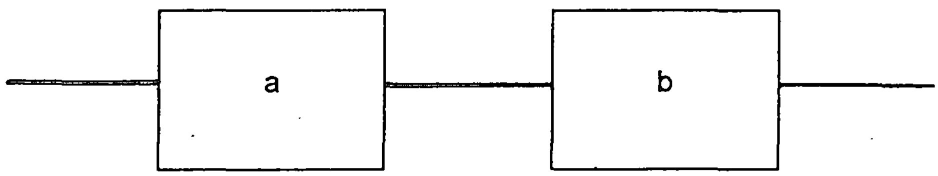
Equipment	failure Rate per hour x !0 -6	MTBF Hours	MDT Hours	maintenance hrs per year
Breaker	0.76104	1314000	12	8
Transformer	1.14155	876000	24	8
Line	22.83100	43800	6	
Busbar	5.70780	175200	4	3

5. Life cycle costs not taken into account.
6. Auxiliary equipment such as protection, Cts or VTs have not been considered.
7. The underlying reliability function is an exponential function. Hence, $R=e^{\lambda t}$
8. Unless otherwise negotiated with the customer, where supply interruptions are caused by maintenance, all equipment will be serviced in one session in order to minimize the outage time.
9. The following outage hours per year due to maintenance for each option was used.

Option	Hours per year
A	12
B	12
C	12
D	8
E	8
F	8
G	8
H	2

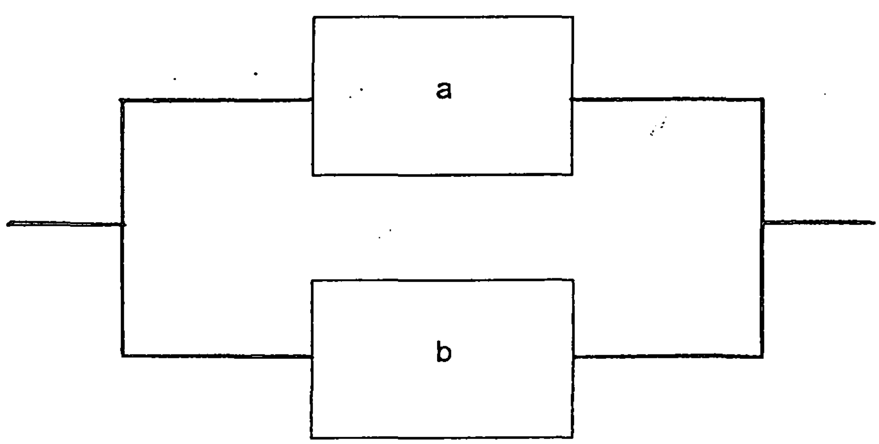
Formulae

For a series system.



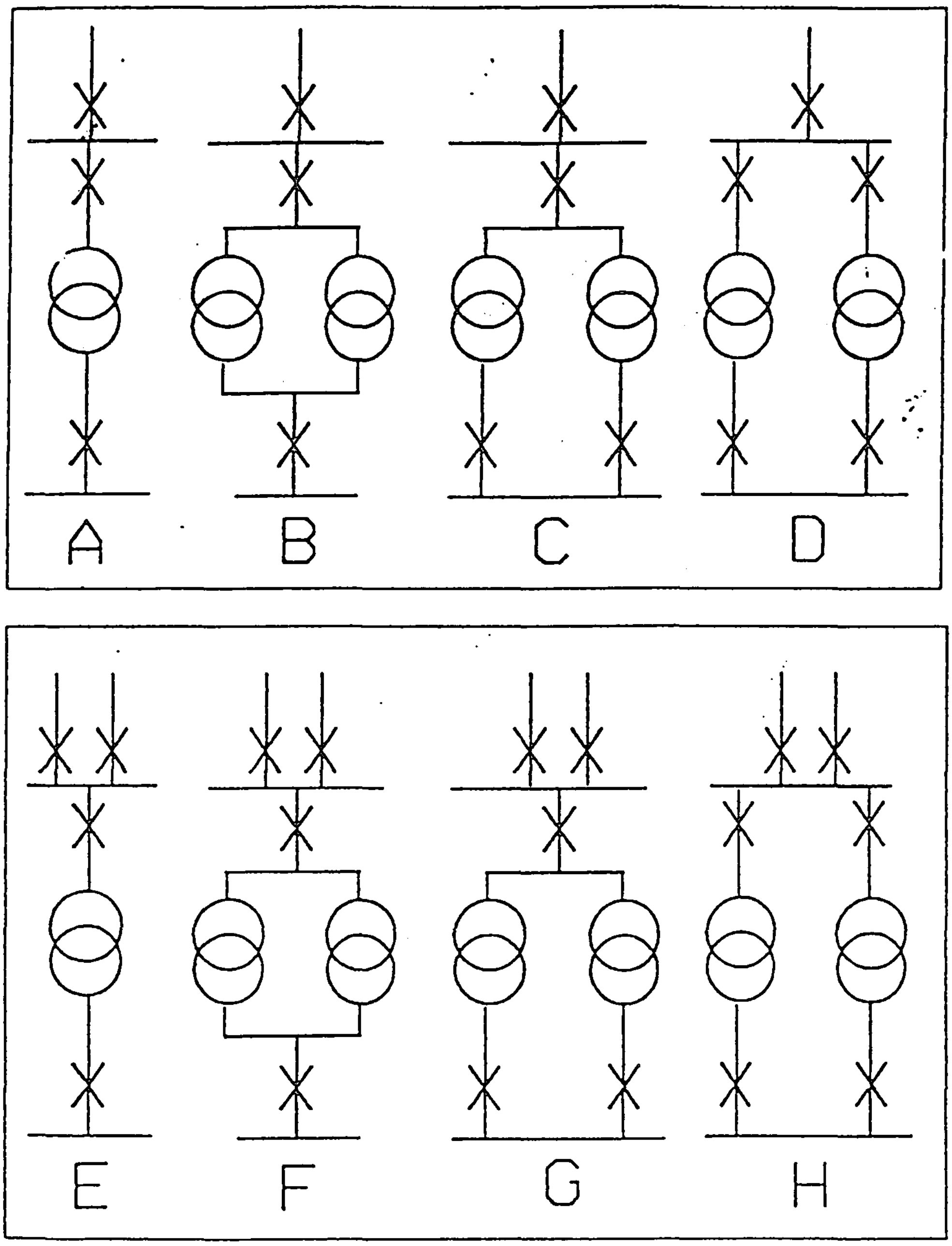
The reliability is given by $R_{sys}+R_a x R_b$

For a parallel system.

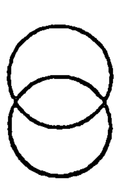


The reliability is given by $R_{sys}=(R_a+R_b)-(R_a x R_b)$

Options



where



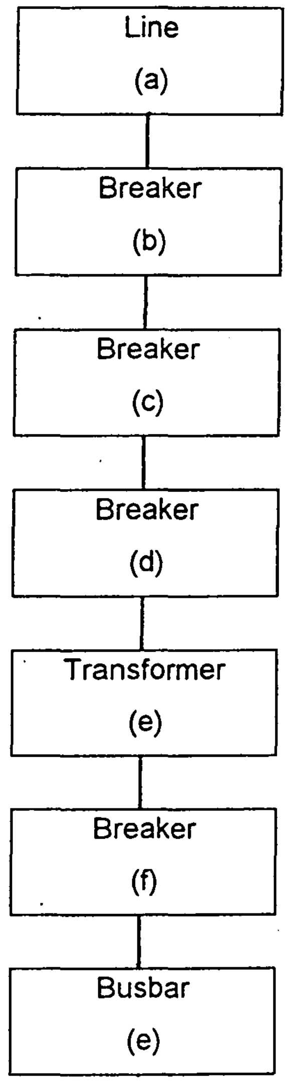
Transformer

Breaker

Calculations

The following is an example of the calculations used to determine the reliability for each of the above options.

Option A RBD



$R_{sys(t)} = R_a \times R_b \times R_c \times R_d \times R_e \times R_f \times R_g$

$R_{sys(t)} = e^{-t(\lambda a+\lambda b+\lambda c+\lambda d+\lambda e+\lambda f+\lambda g)}$

$R_{sys(8760)} = e^{-8760 \times 0.000038}$

$R_{a(8760)} = 0.718923$

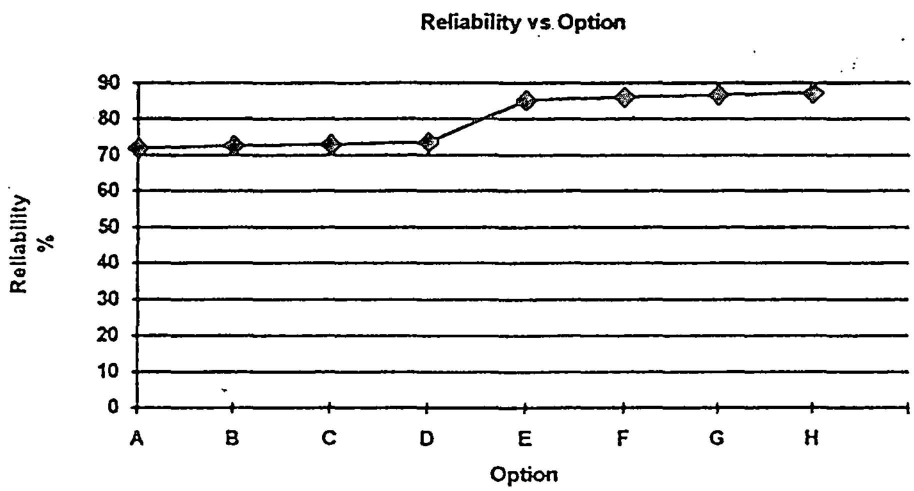
The availability for each of the options was calculated by making use of a computer program called Uniram.

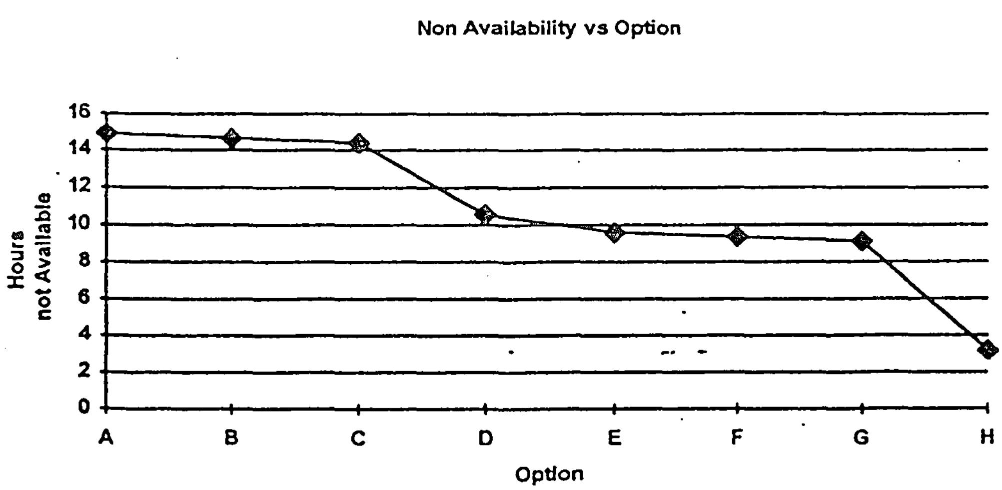
Results

Table 2

Option	Percentage System Availability	Hours not available per year	Percentage System Reliability (t=1 year)	Per unit cost with Option A as base
A	99.97	14.88	71.89	1.00
B	99.97	14.64	72.61	1.64
C	99.97	14.40	73.08	1.67
D	99.97	10.56	73.55	1.82
E	99.98	9.60	85.32	1.17
F	99.99	9.36	86.16	1.82
G	99.99	9.12	86.73	1.84
H	99.99	3.20	87.28	1.99

Graphs





Discussion of results

With option A as the base, the improvement in reliability of 21.41% (Option A to Option H) is achieved at twice the cost whilst only improving the availability by 11.69 hours.

Table 2 clearly shows that (a) by making use of double lines (Option A vs. Option E) the greatest improvement in reliability (18.68%) for the smallest increase in cost. (17%) is achieved and (b) the use of double transformers has an improvement in reliability of 1% (Option A vs. option B) while having an increase in cost of 64%.

These results should be seen as relative to the listed options and should only be used as a guide to show reliability principles.

Example

Outages of a transmission circuit may be caused by :

a) equipment breakdown due to high winds

b) flashovers due to lightning, or

c) protection malfunction

Suppose that each one of these three classes of outages occurs according to independent Poisson processes with mean rates of 0.1,5 and 1 per year, respectively. Moreover, the duration of an outage for the respective classes follows an exponential distribution with mean durations of 240,0.02 and 1 hour respectively.

a) If the power supplied through this line is required for 5 days without any interruptions, what is the probability that there will be no outage during this time ?

b) What is the availability of this circuit and what is its frequency failure ?

c) Suppose that the circuit is in operation now : What is the probability that it is in a failed state exactly 1 day from now ?

d) What is the expected downtime of this circuit in a year ?

Solution

a) The combined occurrences of all outages follow a Poisson process with a mean rate

A = 0.1 + 5 + 1 + 6.1

The probability of no outage over a 5 day period is, therefore,

$$P(N = O) = \frac{(6.1 \times 5/365)^0 e^{-6.1 \times 5/365}}{0!} = 0.9198$$

b) To obtain the availability of the circuit, the departure rate from state F is required. Since the repair times are exponentially distributed, the departures from state F form a Poisson process with the mean rate

$$\mu = 8760\left(\frac{1}{240} + \frac{1}{0.02} + \frac{1}{1}\right) = 446796.5 \text{ per year}$$

The availability, or the probability of residing in state S in the long run, is obtained

$$\text{from } A(\infty) = \frac{pi}{\lambda + pi}$$

$$A(\infty) = \frac{446796.5}{6.1 + 443796.5}$$

The frequency of failure is obtained from

$f = \lambda$ ps

f = 6.1 x 0.999986 = 6.08 per year

c) If the circuit is operating now, the probability of an outage 1 day from now is given by the unavailability :

$$1 - A(1/365) = \frac{6.1}{6.1 = 446796.5} (1 - e^{-6.1 - 446796.5}) = 1.36 \times 10^{-5}$$

d) The mean duration of an outage is obtained from

$T_F = P_F/f = 8760 \times (1 - 1.999986)/6.08 = 0.0202$ hr

Concluding Remarks

The reliability of the power system has been defined as the probability of providing the users with continuos service of satisfactory quality. The quality constraint refers to the requirement that the frequency and the voltage of the power supply would remain within prescribed tolerances.

APPENDIX

F

POWER SYSTEM DISTURBANCE LEVELS AND GRADING

Power System Typical Levels

The following levels are typical for a Supply Authority distribution system. Note that the percentages are with reference to the nominal voltage.

	MAGNITUDE	DURATION
Notches	- (5-25) %	100-3000μS
Spikes	+ (50-300) %	10-3000μS
Dips	- (10-80) %	10mS-1S
Surges	+ (10-40) %	10mS-1S
Under-voltages	- (5) %	>1S
Over-voltages	+ (5) %	>1S

Power System Disturbance Grading

A. Transients

- duration : < 0.5 cycles
- coupling mechanism : conductive, electromagnetic

A.1 Impulses

- spikes
- notches

A.2 Oscillations

- Frequency oscillations

B. Momentary Problems

- duration : 0.5 - 120 cycles
- coupling mechanism : conductive

B.1 Dips

- Dip in supply

B.2 Surges

- overvoltage

B.3 Voltage Flicker

- Repetitive sags or surges in the voltage

C. Steady State Problems

C.1 Voltage Deviation

- duration : >120 cycles (>2.4 S)
- coupling mechanism : conductive
- undervoltage
- overvoltage

C.2 Brown-outs

- voltage reduction : 3 - 5 % fluctuation

C.3 Power Interruption

- duration of momentary interruptions : 2 minutes
- duration of sustained interruption : > 2 minutes
- coupling mechanism : conductive

C.4 Voltage Phase unbalance

- duration : >120 cycles
- coupling mechanism ; conductive, electromagnetic

C.5 Harmonic Distortion

- duration : continuous
- coupling mechanism : conductive, electromagnetic

C.6 Frequency Deviation

- duration : continuous
- coupling mechanism : conductive

C.7 Electrical Noise

- duration : continuous
- coupling mechanism : conductive, electromagnetic, common impedance

A typical table is exampled as follows : -

DISTURBANCES TO POWER SYSTEM

Supply to	Operator
Period	From 1 January to 31 January
Operator	L. Lange

DISTURBANCE	OCCURRENCE	PERCENT
Oscillatory transients	63	49
Voltage spikes	51	40
Undervoltage (dips)	14	11
Overvoltage (surges)	0	0
Outages	1	1
		100 %

From the above values further presentation type graphical layouts can be derived for better understanding, i.e. bargraph, pie-graph, etc.

The collation of the data for insertion into the above table will be addressed later in the section of measurement.

APPENDIX

G

COMPARISON OF LEVELS

COMPARISON OF LEVELS (LV)

	IEC	CENELEC	EDF	ESKOM	NER
Regulation	10%	10%	7%	10%	10%
Unbalance	2%	2% (3%)	2%	2%	2%(3%)
Harmonics	IEC	IEC	IEC	EPCC	IEC
Inter-harm	(0.2%)	-	-	EPCC	(0.5%)
THD	8%	8%	8%	6%	8%
Flicker Pst	1	-	1	1	1
Flicker Plt	0.8	1.0	0.8	0.8	0.8
Dips	-	10-1000	-	-	XYZ
Interruptions	-	10-50	8	-	2-60
Frequency	2%	1% , +4/-6	1%	2.5%	2.5%

COMPARISON OF ESKOM LEVELS

	LV	MV	HV
Regulation	—	—	—
Unbalance	—	—	—
Harmonics	↑ ↓	↑ ↓	↑ ↓
(Inter-harmonics)	↓	↓	↓
THD	↑	↑	↑ —
Flicker	—	—	↑
Interruptions	★	★	★
Voltage dips	★	★	★
Frequency	—	—	—

COMPARISON OF ESKOM LEVELS

	LV	MV	HV
Regulation	—	—	—
Unbalance	—	—	—
Harmonics	↑↓	↑↓	↑↓
(Inter-harmonics)	↓	↓	↓
THD	↑	↑	↑ —
Flicker	—	—	↑
Interruptions	★	★	★
Voltage dips	★	★	★
Frequency	—	—	—

COMPARISON OF ESKOM LEVELS

	LV	MV	HV
Regulation	—	—	—
Unbalance	—	—	—
Harmonics	↑ ↓	↑ ↓	↑ ↓
(Inter-harmonics)	↓	↓	↓
THD	↑	↑	↑ —
Flicker	—	—	↑ (circled)
Interruptions	★	★	★
Voltage dips	★	★	★
Frequency	—	—	—

COMPARISON OF ESKOM LEVELS

	LV	MV	HV
Regulation	—	—	—
Unbalance	—	—	—
Harmonics	↑ ↓	↑ ↓	↑ ↓
(Inter-harmonics)	↓	↓	↓
THD	↑	↑	↑ —
Flicker	—	—	↑
Interruptions	★	★	★
Voltage dips	★	★	★
Frequency	—	—	—

APPENDIX

H

CUSTOMER CONTINUITY OF SUPPLY EXAMPLES

Customer Continuity of Supply Examples

Table No. 1 - Customer Load Information

Customer Group	No. of Customers (n)	Load (kW)
1	200	3000
2	150	1500
3	100	1000
4	250	2000
5	300	4500
TOTAL	1000	12000

Table No. 2 - Interruptions for one Year

Interruption	Customer group affected	Customer affected (a)	No. of Customers interrupted (i)	Load interrupted (kW)	Duration (hours) (d)	Customer hours (di)	Energy not supplied (kWh)
1	3	100	100	1000	5	500	5000
	1	200	200	3000	2	400	6000
2	4	250	250	2000	3	750	6000
3	1	--	200	3000	2	400	6000
	3	--	100	1000	1	100	1000
4	2	150	150	1500	4	600	6000
	1	--	200	3000	2	400	6000
TOTAL		700	1200	14500	19	3150	36000

Examples calculated from tables 1 and 2 :-

$$SAIDI = \frac{\sum di}{\sum n} = \frac{3150}{1000} = 3.15\ h$$

$$SAIFI = \frac{\sum i}{\sum n} = \frac{1200}{1000} = 1.2\ \text{interruptions/customer}$$

$$CAIDI = \frac{\sum di}{\sum i} = \frac{3150}{1200} = 2.63\text{h/customer interruption}$$

$$CAIFI = \frac{\sum i}{\sum a} = \frac{1200}{700} = 1.71\ \text{interr./customer affected}$$

$$ASUI = \frac{\sum di}{\sum nt} = \frac{3150}{1000 \times 8760} = 0.0003$$

This extract was taken out of the ESKOM Guideline reference DTG 0068, REV 0.

APPENDIX

I

CHARACTERISTIC VOLTAGE DIP UNDER A SHORT CIRCUIT CONDITION

Characteristic Voltage Dip under a Short Circuit Condition

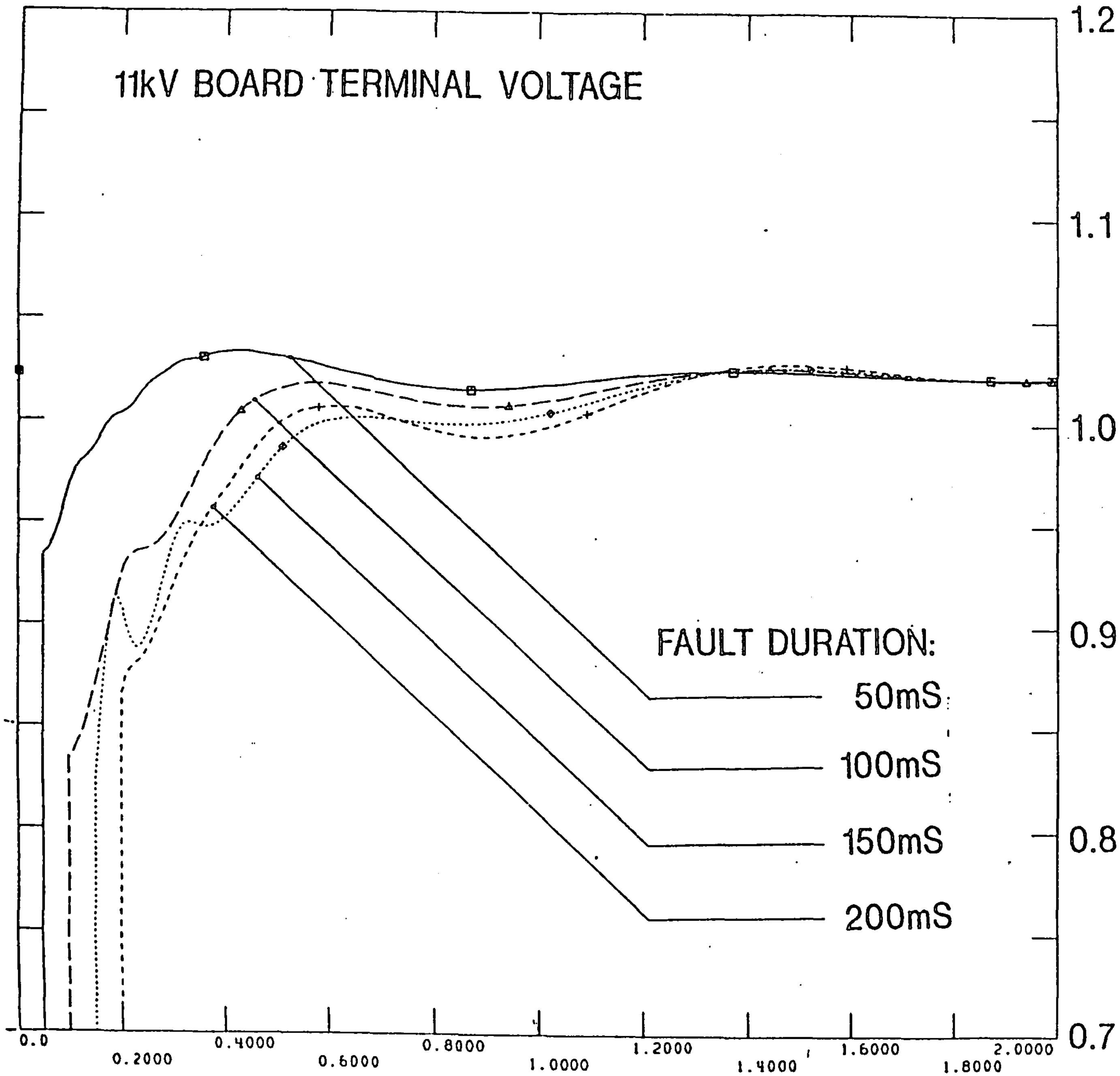
During a fault, induction motor drives will lose speed and have to re-accelerate after the fault has cleared. On a relatively weak supply with large induction motors, the current, may affect the terminal voltage as well as overload the supply system. The current drawn by the motor during such a condition will depend on the load torque, the inertia of the drive, and the duration of the fault. High inertia drives (H>6) after a fault of short duration (<100ms) will typically draw a fraction of a starting current. As the fault duration increases, the current drawn by the motors will approach full starting current and the duration of the re-acceleration current will increase.

Examples of voltage curves and starting currents are shown in Figure 1 to 6 for the system shown in Figure 7. The voltage during the fault may not necessary remain the same as the impedance of the fault may vary.

This extract was taken out of the Paper presented by G.J Coetzee, ESKOM

FIGURE 1:

180



11kV BOARD TERMINAL VOLTAGE
FAULT DURATION:
50mS
100mS
150mS
200mS
1.2
1.1
1.0
0.9
0.8
0.7
VOLTAGE (pu)
0.0
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
1.4000
1.6000
1.8000
2.0000

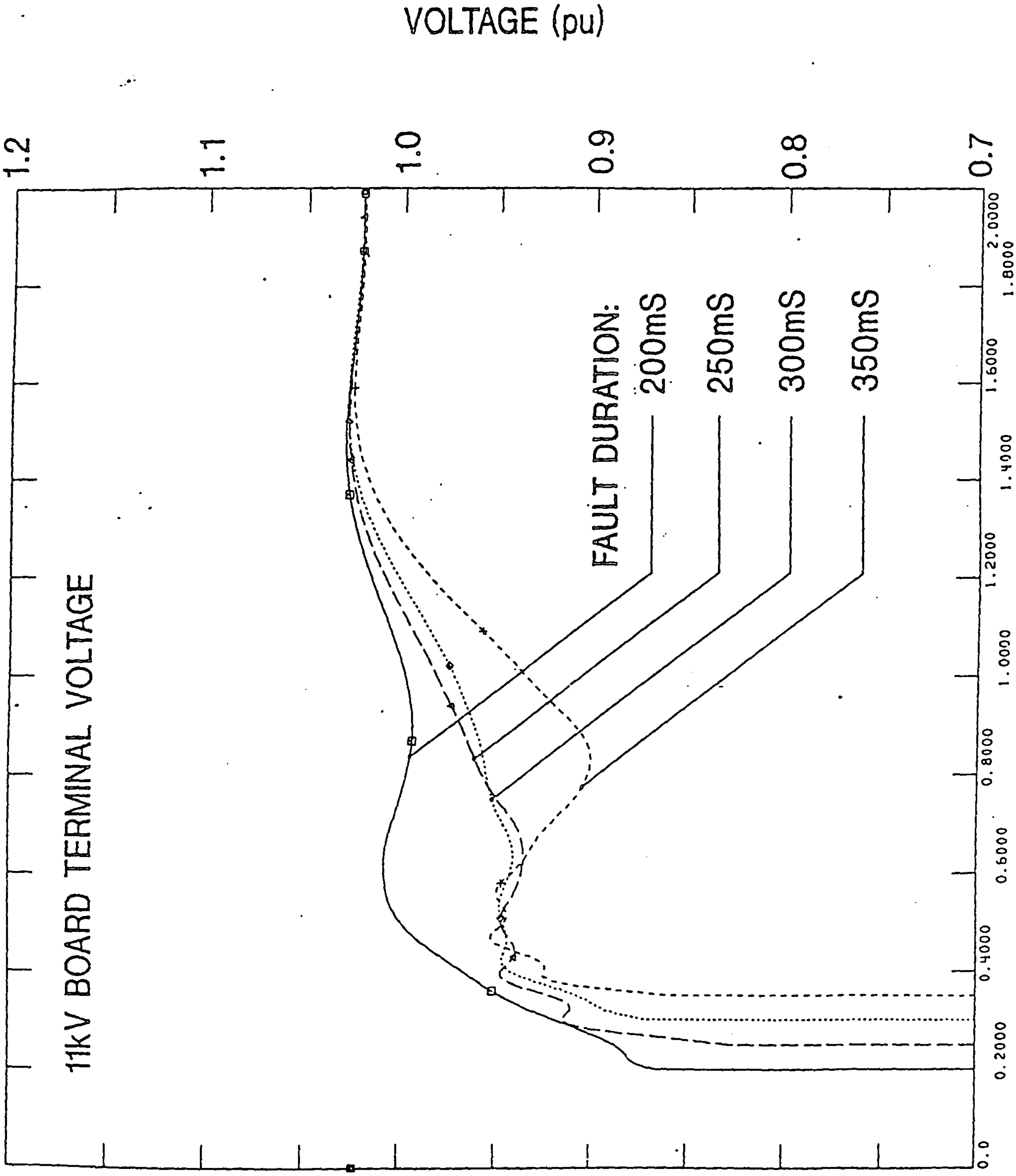
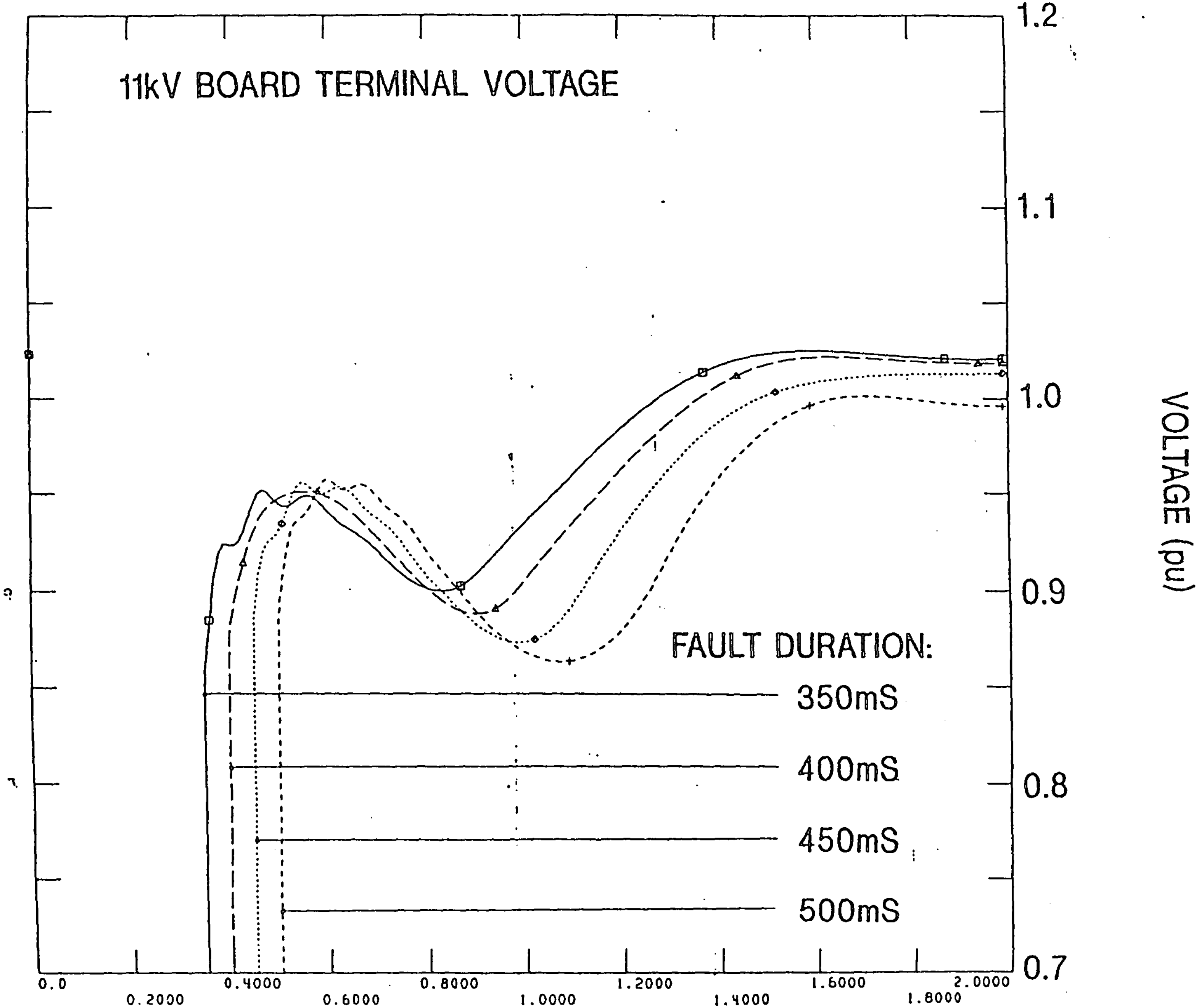

11kV BOARD TERMINAL VOLTAGE
VOLTAGE (pu)
1.2
1.1
1.0
0.9
0.8
0.7
FAULT DURATION:
200mS
250mS
300mS
350mS
0.0
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
1.4000
1.6000
1.8000
2.0000

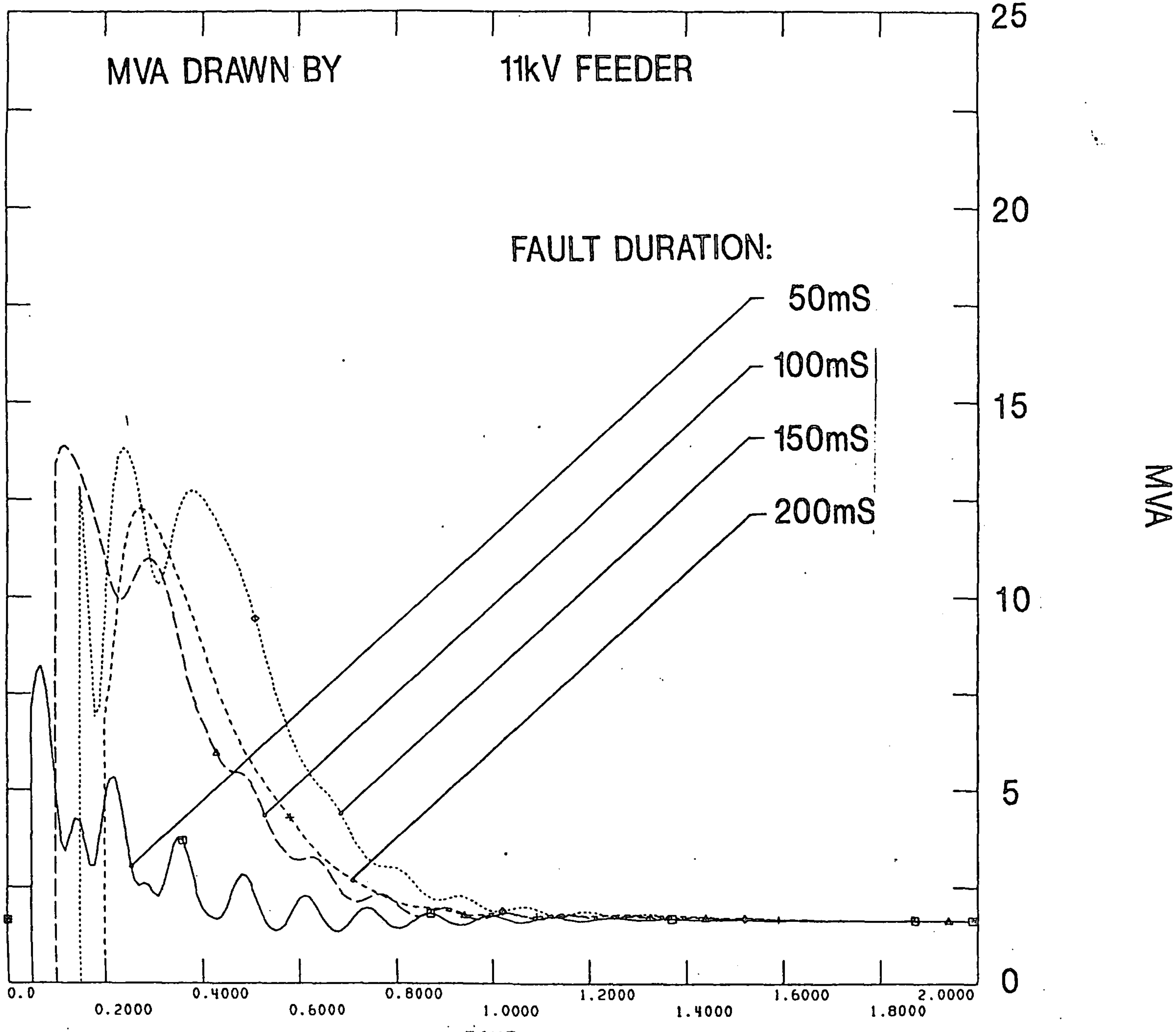
FIGURE 2:



11kV BOARD TERMINAL VOLTAGE
FAULT DURATION:
350mS
400mS
450mS
500mS
1.2
1.1
1.0
0.9
0.8
0.7
VOLTAGE (pu)
0.0
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
1.4000
1.6000
1.8000
2.0000

FIGURE 3:

FIGURE 4:



MVA DRAWN BY 11kV FEEDER
FAULT DURATION:
50mS
100mS
150mS
200mS
MVA
0
5
10
15
20
25
0.0
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
1.4000
1.6000
1.8000
2.0000

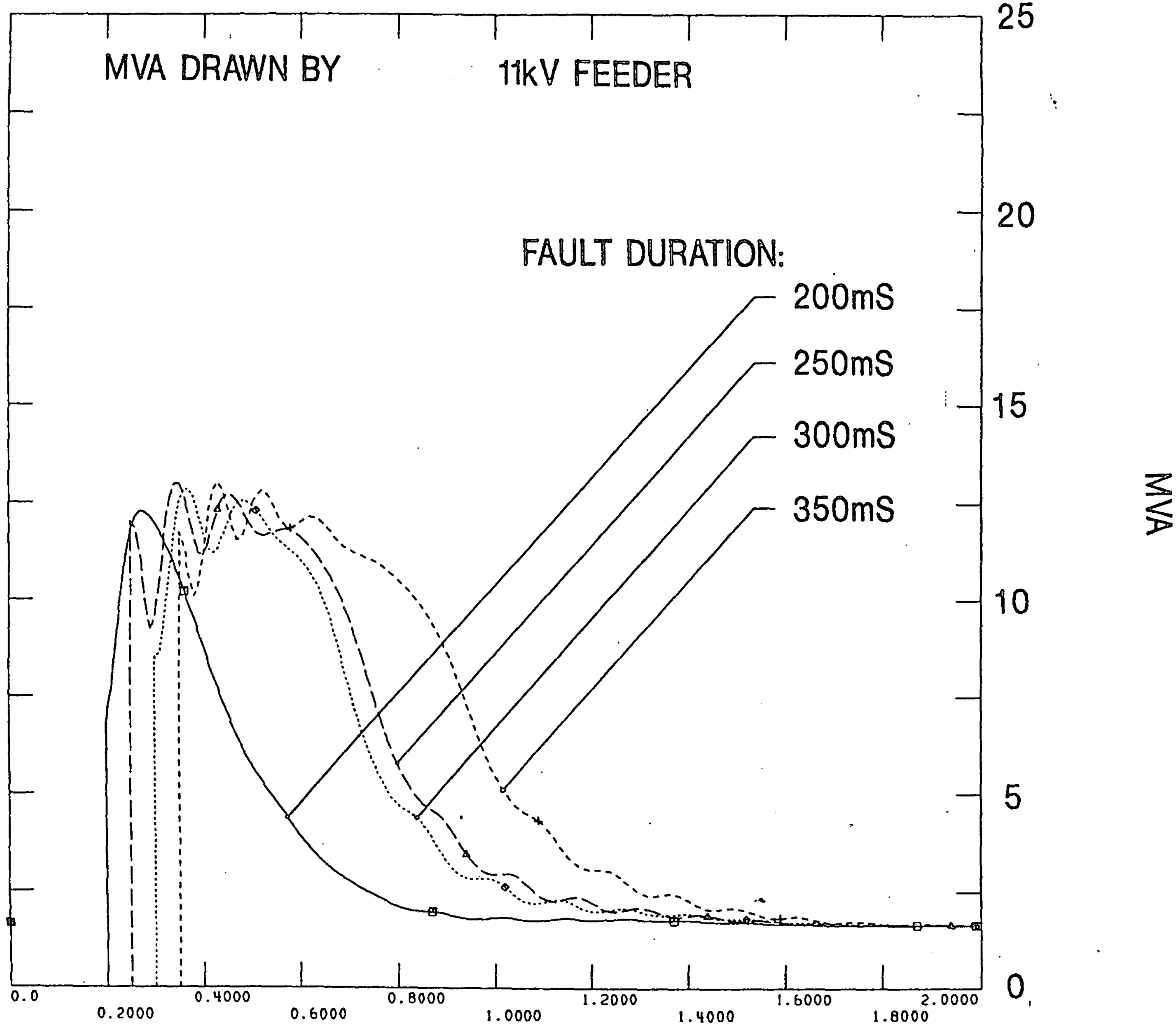

MVA DRAWN BY 11kV FEEDER
FAULT DURATION:
200mS
250mS
300mS
350mS
MVA
0
5
10
15
20
25
0.0
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
1.4000
1.6000
1.8000
2.0000

FIGURE 5:

184

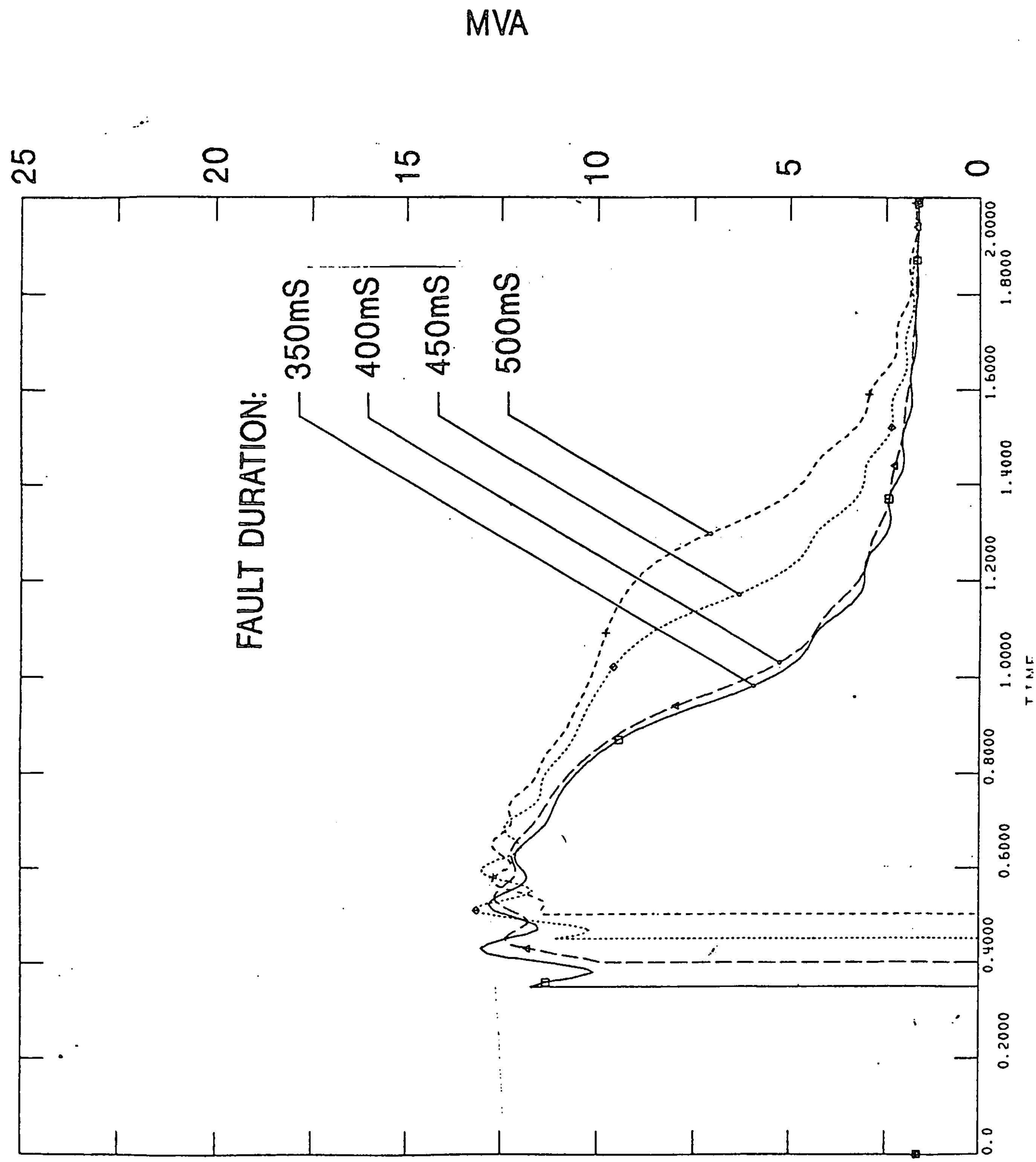
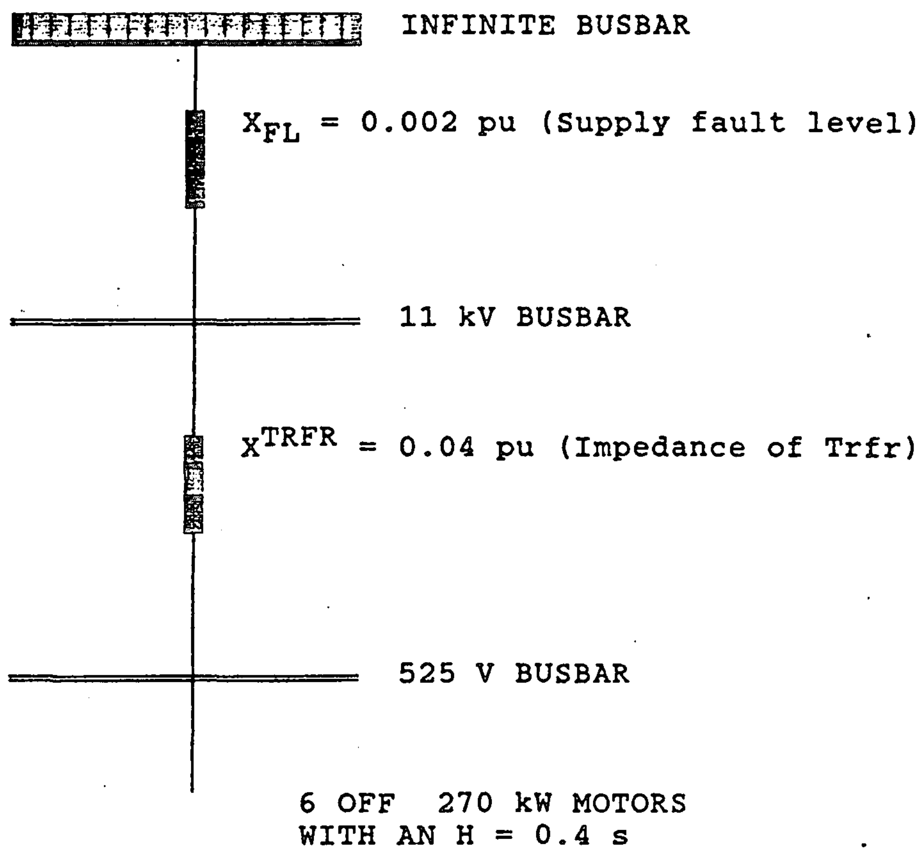

MVA
25
20
15
10
5
0
FAULT DURATION:
350mS
400mS
450mS
500mS
0.0
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
1.4000
1.6000
1.8000
2.0000

FIGURE 6:



ALL IMPENDACES ARE AT 525 V AND 6 x 270 kVA BASE

FIGURE 7: NETWORK DETAILS OF THE CASE STUDY

APPENDIX

J

DIP PROOFING INVERTER : THEORY

Dip-Proofing Inverter (DPI) : Theory

The DPI is an "off-line" device as shown the block diagram in figure 1.

The system consists of a static switch in line with the load, and an inverter parallel to it. Capacitors are used for energy storage. In this configuration the inverter only operates during voltage dips. The incoming sine wave is continuously monitored and should it deviate from the normal value by a pre-determined percentage, the static switch is switched off and the inverter is switched on. The static switch also prevents power flow back into the supply.

The voltage supplied by the DPI is in synchronous with the supply voltage and is a stepped square wave, as can be seen in figure 2. This wave shape has various advantages, firstly the RMS and peak value is the same as that of a sine wave, it can therefore be used with transformers and coils where RMS is important and with electronic relays using capacitor input filters where peak voltage is required. it can supply and inductive load without being distorted and the RMS voltage can be regulated. Last but not least, the electronic components needed to create this wave shape are relatively simple and less prone to failure. The only disadvantage is a higher harmonic content with an associated higher loss in the load. This is irrelevant as the DPI only operates during a voltage dip.

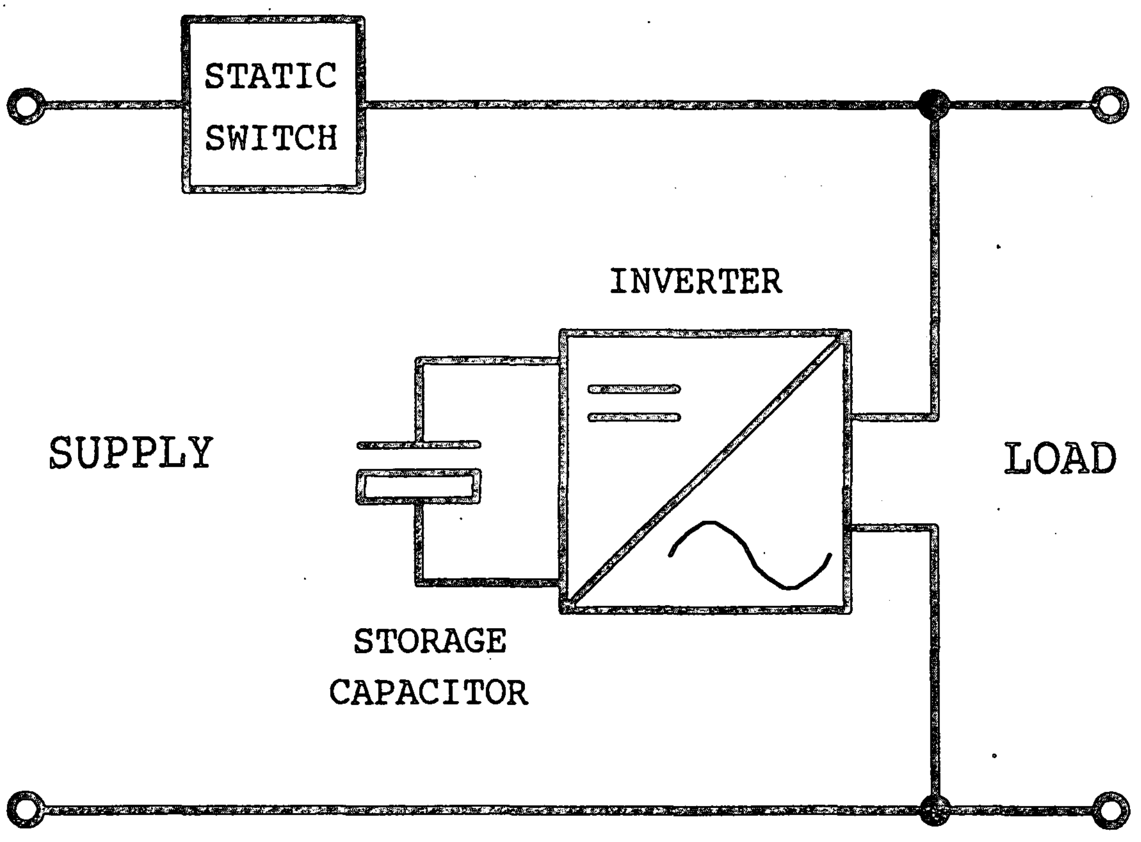
The theory of operation as shown in figure 4 shows a typical interruption in the supply caused by a short circuit in the Plant. The length of the voltage dip is determined by how long it takes the protection equipment toclear the fault. Motors would hardly notice a 50ms interruption, but the contactors would all drop out. Figure 6 magnifies the point of failure. As can be seen, the voltage must drop below 65% of the nominal in this case and must persist for longer than 500ms. The static switch is then switched off and the inverter switched on. Power is then supplied by the capacitors via the inverter.

A timer, adjusted in increments of 10ms and a maximum of 2.52s starts timing the inverter out. When the supply voltage is restored within the set time, the inverter frequency is increased by up to 8% until the input voltage and the inverter voltage is synchronised. At this point the inverter is switched off and the static switch reconnects the supply. The output voltage can be seen in figure 5.

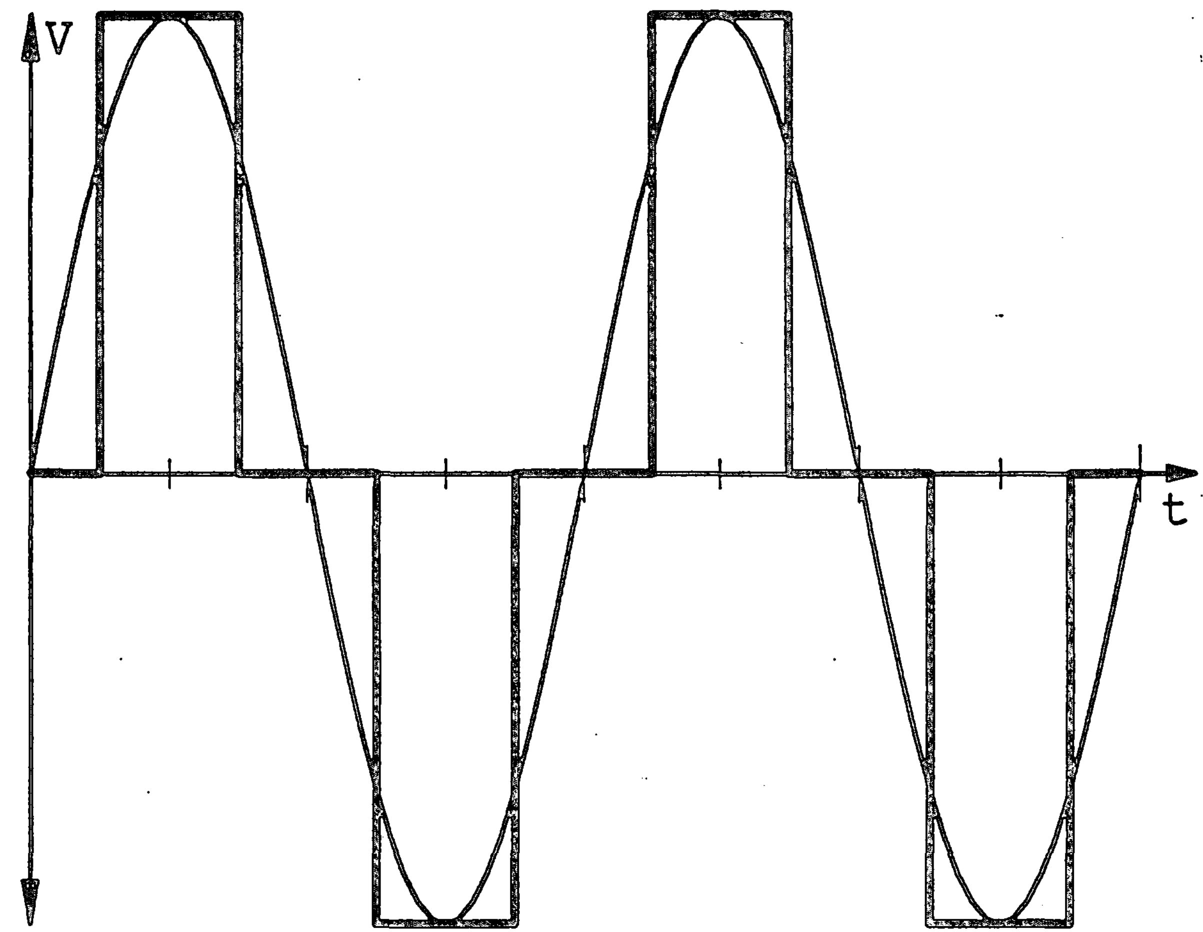
The capacitors are re-charged in 800ms or less, depending on the load. After this the DPI is ready to compensate for the next voltage dip.

A range of peripheral equipment is available to support the DPI, namely, test units, by-pass switches (figure 7) and line filters.

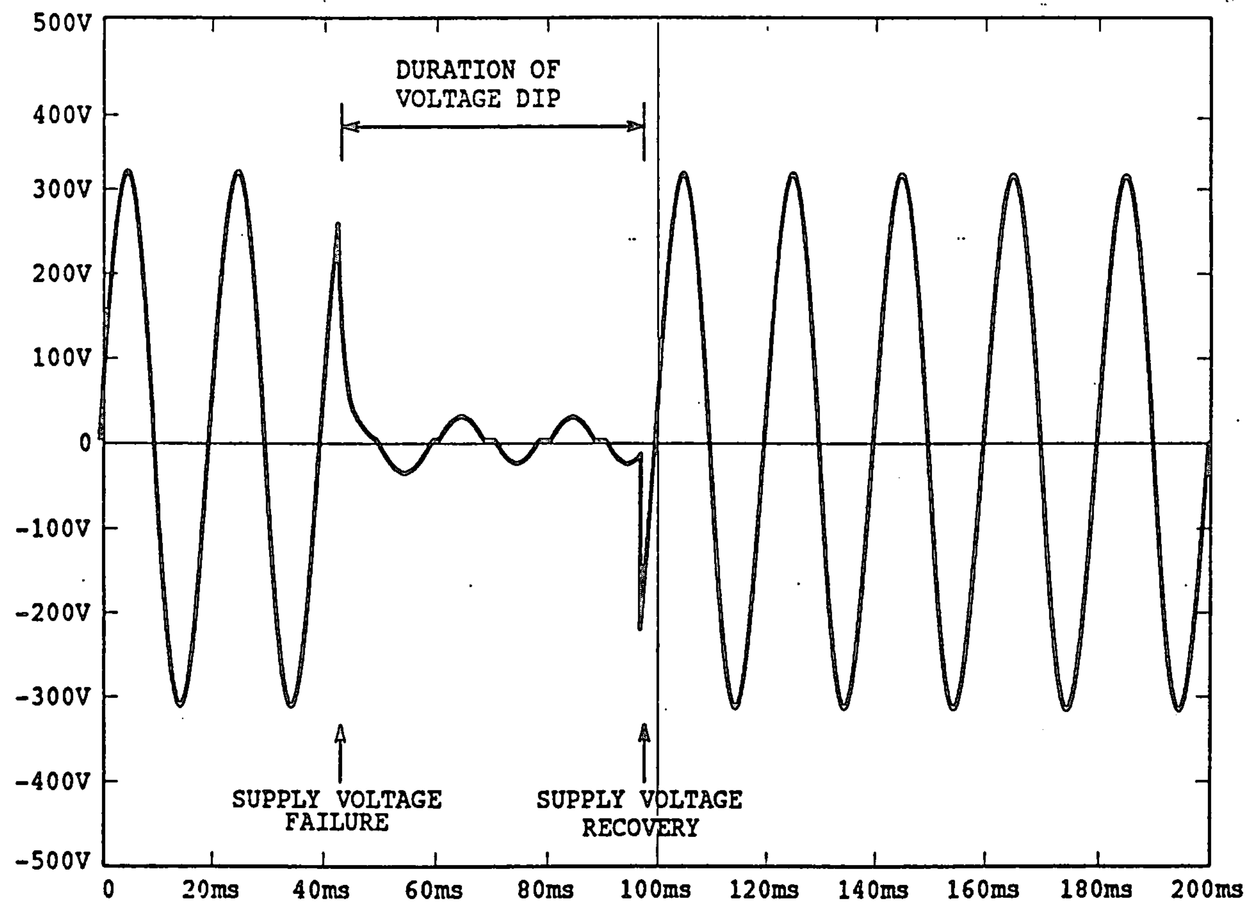
This extract was taken out of the Paper by F.V Fischer of Switching Systems.



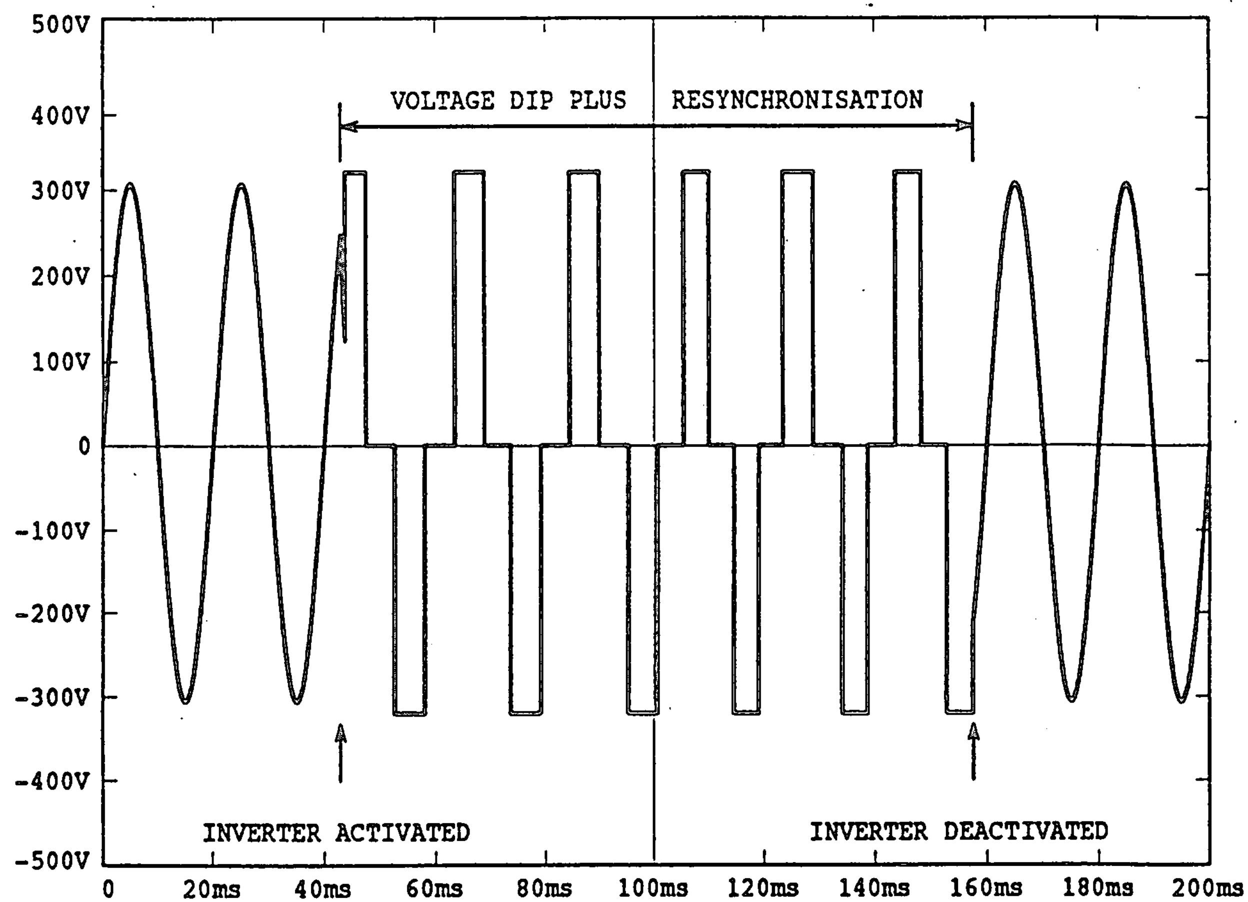
DPI BLOCK DIAGRAM Fig 1



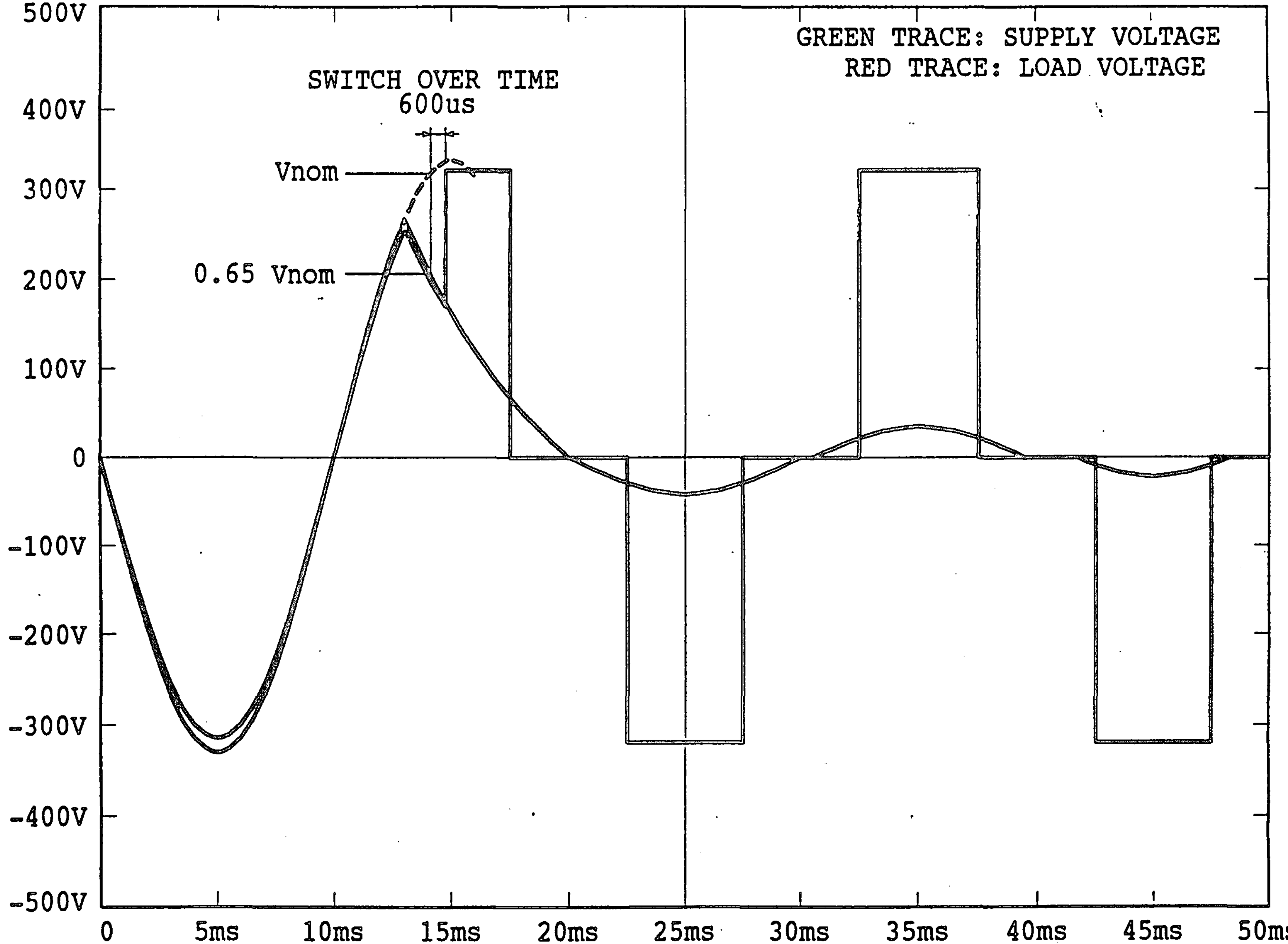
DPI WAVEFORM COMPARISON   Fig 2



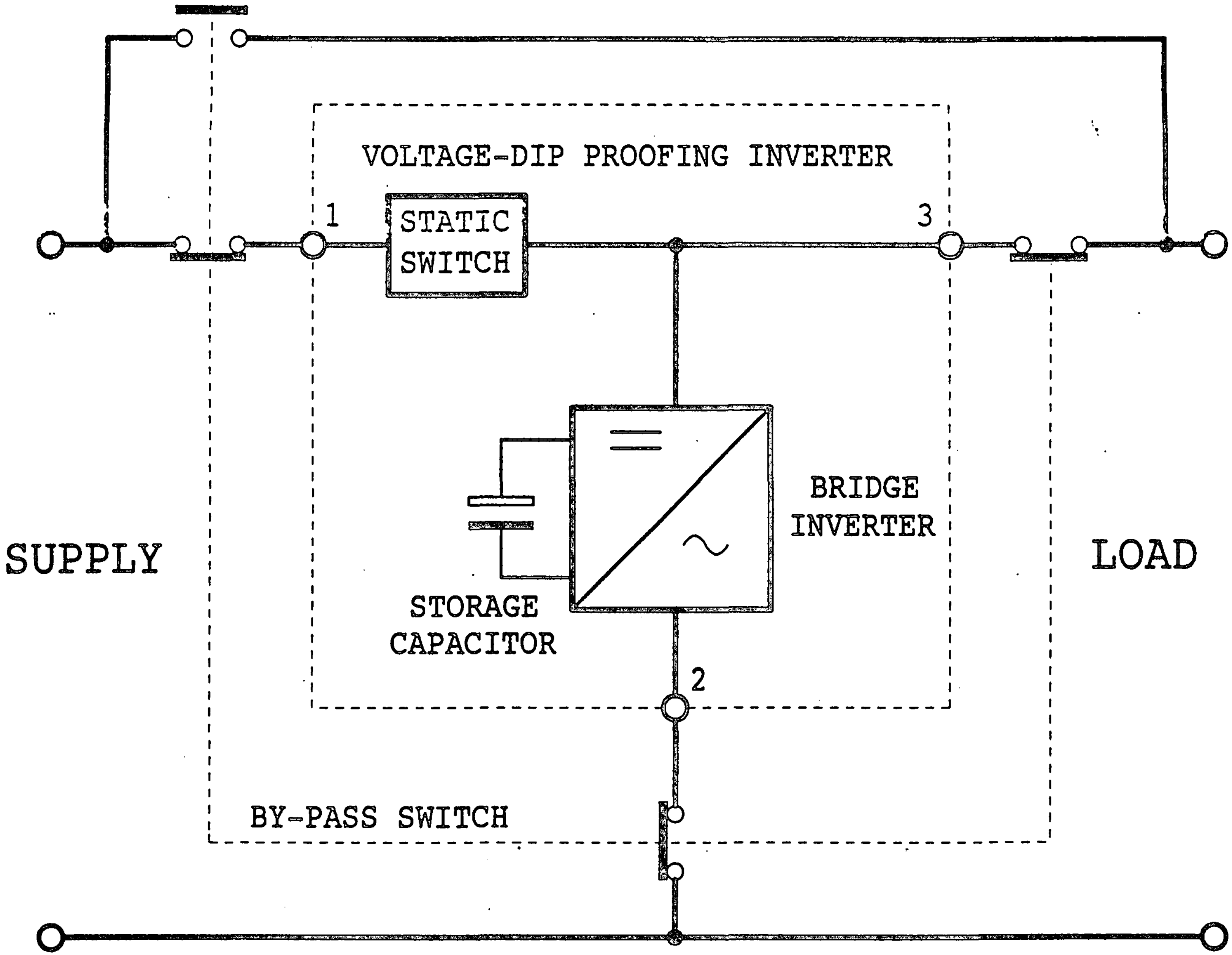
SUPPLY VOLTAGE WAVEFORM Fig 4



LOAD VOLTAGE WAVEFORM   Fig 5



SUPPLY AND LOAD WAVEFORMS AT SWITCHOVER Fig 6



BY-PASS SWITCH Fig 7

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VOLTAGE - DIP PROOFING INVERTERS AND ACCESSORIES

Valid from 1st October 1994 to 31st March 1995
All prices are EXCLUDING VAT

STOCK #	TYPE	DESCRIPTION	PRICE
060	DPS040-110V	Dip Proofing Relay	R 680.00
062	DPS150-110V	Dip Proofing Relay	R 680.00
063	DPS700-110V	Dip Proofing Relay	R 790.00
066	DPS020-220V	Dip Proofing Relay	R 680.00
067	DPS070-220V	Dip Proofing Relay	R 680.00
068	DPS300-220V	Dip Proofing Relay	R 790.00
130	DPI 4000ST	4kVA inverter 220V metal box	R 11 900.00
157	DPI4k22A5/6	4kVA Inverter 220V aluminium box	R 9 250.00
161	DPI1k22A5/6	1kVA Inverter 220V aluminium box	R 4 750.00
159	DPI0.5k22A5/6	500VA Inverter 220V aluminium box	R 3 900.00
173	DPI0.25k22A5/6	250VA Inverter 220V aluminium box	R 2 600.00
156	DPI3k11A5/6	3kVA Inverter 110V aluminium box	R 10 100.00
162	DPI1k11A5/6	1kVA Inverter 110V aluminium box	R 5 600.00
158	DPI0,5k11A5/6	500VA Inverter 110V aluminium box	R 4 200.00
172	DPI0.25k11A5/6	250VA Inverter 110V aluminium box	R 2 950.00
174	DPI0.1k38A5/6	110VA Inverter 380V aluminium box	R 2 500.00
163	DPIBPSW	By - Pass Switch Housed 40A	R 580.00
131	DPI4k22TST	Test Unit 220V 4kVA	R 15 000.00
175	DPI0.5k22TST	Test Unit 220V 500VA	R 12 000.00
135	DPI 4000LF	Line Filter 220V 4kVA	R 2 650.00
138	DPI 3000LF	Line Filter 110V 3kVA INV	R 2 650.00

APPENDIX

K

VOLTAGE DIP SOLUTION : COMMISSIONING OF 132kV DIP DOCTOR

VOLTAGE DIP SOLUTIONS: COMMISSIONING OF 132kV DIP DOCTOR

Lightning and storm related faults on the Eskom transmission network caused over 100 voltage dips per annum at a large industrial site in Mpumalanga Province. Nearly 50% of these annual voltage dips resulted in production losses.

Various strategies have been implemented to reduce production loss which include: slugging of motor contactors, UPS's on control equipment, lightning activity early warning (LPATS) and subsequent islanding onto own generation.

However, due to the continued loss of production, a review of dip proofing requirements was undertaken. A 132kV modified series reactor, utilizing Raiqott's Dip Doctor tm topology and control system was decided on as the most appropriate and cost effective device. The patented Dip Doctor tm utilizes the inherent reaction of synchronous machines to terminal voltage fluctuations (i.e. an instantaneous supply of reactive power to counteract voltage fluctuations), coupled with increased source impedance (the series reactor) to give a greater support to busbar voltage during dip conditions.

In this way, and by varying the series reactor impedance, the load busbar undervoltage during dips can be restored by as much as 70% (i.e. a 50% dip can be reduced to a 15% dip allowing sensitive load processes to remain operating).

Test Procedure

A total of four 132kV faults were placed on the network, the first two with the Dip Doctor tm in service and the last two without. Each sequence of two faults consisted of a phase-earth fault followed by a phase-phase fault.

The average fault clearance period was selected as 160 ms (i.e. the dip duration).

A number of measurements were conducted at various points, with the two most relevant from a voltage dip point of view being the "Eskom" and 'Supported" 132kV voltages.

The "Eskom" 132kV voltage was recorded at the incoming supply busbars, while the "Supported" 132kV voltage was recorded downstream of the Dip Doctor tm.

Results

The recorded results with and without the Dip Doctor tm are given in the table below.

	132kV VOLTAGE DIP MAGNITUDE (%)	
Measured	∅ - Earth dip with (without)	∅ - ∅ dip with (without)
Eskom 132kV Supported 132 kV	29 (19) 7 (19)	23/30 (20/26) 9/10 (20/26)
Dip Reduction	76% (63%)	66% (62%)

The busbar voltage is supported by more than 69% with the Dip Doctor tm in service (i.e. voltage dip magnitudes are reduced by more than 60%).

The waveform recordings of the voltages and 132kV current are shown in Fig 1. Note the "constant" voltage support from the generators witnessed by the constant load current during the voltage dip.

Discussion of Results

The voltage support factor is slightly better than that predicted due to the small decay of synchronous machine reactive power over the 160 ms period. The predicted decay over the period was 7% of initial output, compared with the measured 4%. The discrepancy is due to the difficulty in obtaining accurate machine data (i.e. time constraints).

This proven performance will reduce production loss by more than 80% compared with previously.

This meets the motivation and design criteria on which to the justification for the Dip Doctor tm was based (in this case with a payback on Capex of less than a year).

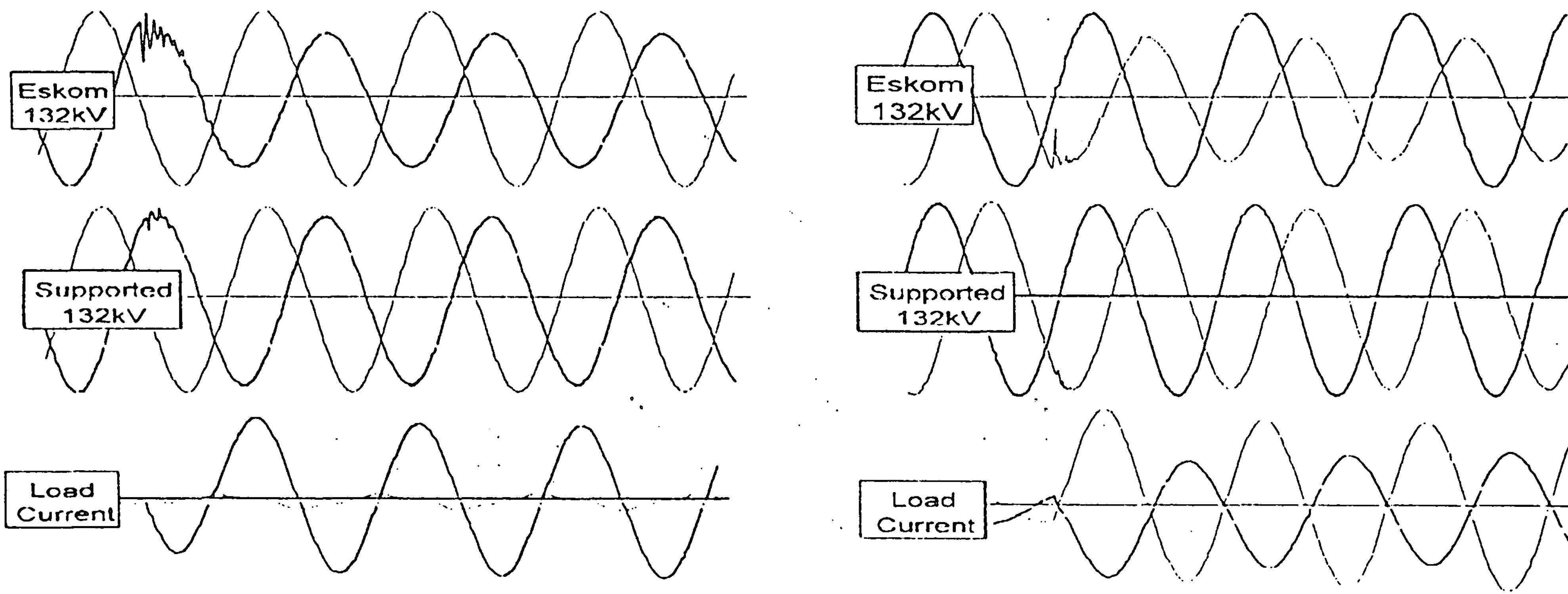
Conclusions

The concept of globally supporting busbar voltage dips has proven successful as a cost effective means of reducing production loss. This is now the second local Dip Doctor tm implementation with results as good, or better, than the first.

In conclusion, the Dip Doctor tm has excellent benefits where total load support is required and more installations are presently planned for other industries adversely affected by voltage dips.

WAVEFORM RECORDINGS: VOLTAGES AND 132kV CURRENT

FIGURE 1



APPENDIX

L

THE EFFECTS OF QOS ON SAPPI's SOUTHERN AFRICAN MILLS

THE EFFECTS OF QUALITY OF SUPPLY ON SAPPI'S SOUTHERN AFRICAN MILLS

MILL	LOCATION	PRODUCTS	CAPACITY TONS/ANNUM
Ngodwana	Mpumalanga	Liner Board	220 000
		News Print	140 000
		Bleached soft wood market pulp	210 000
Tugela	Kwa Zulu-Natal	Linerboard, fluting, sack/bag kraft, packaging paper	310 000
Cape Kraft	Western Cape	Waste based linerboard, fluting & ceiling board	55 000
Enstra	Gauteng	Uncoated woodfree printing & writing paper	125 000
Saiccor	Kwa Zulu-Natal	Dissolving pulp	600 000
Stanger	Kwa Zulu-Natal	Coated printing, label & specialty label paper	60 000
		Tissue paper	30 000
Adamas	Eastern Cape	Uncoated specialty, packaging & industrial paper	35 000
Usutu	Swaziland	Unbleached softwood kraft market pulp	220 000

Table 1 - Mills in the Sappi Southern Africa Group

3.0 Sources of Electrical Power at the Various Mills

The pulping process generates surplus energy in the chemical recovery section in the form of organic material released from the wood, which is burned in a chemical recovery furnace. High pressure steam so generated is used in the pulp and paper making processes as well as for the generation of electrical power. Steam is generally raised at the highest pressure possible and reduced through a turbine to produce power and steam for the process at a range of lower pressures.

THE EFFECTS OF QUALITY OF SUPPLY ON SAPPI'S SOUTHERN AFRICAN MILLS

In integrated mills, i.e. mills which have pulp plants and paper machines, the steam from chemical recovery is insufficient to meet the total requirements and has to be supplemented with steam coming from coal and wood waste fired boilers. This allows for further electricity generation. The balance of the power requirements are sourced from outside.

The power sources and usage at the Sappi Southern Africa mills, is given in Table 2.

MILL	MILL MAX. DEMAND (MVA)	OWN GENERATION (MVA)	SOURCED FROM OUTSIDE		
			SUPPLIER	NOTIFIED MAX. DEMAND (MVA)	USAGE/ ANNUM (GWh)
Ngodwana	110	117	Eskom	110	174
Tugela	56	20	Eskom	45	323
Cape Kraft	5,4	-	Eskom	7	36
Enstra	47	-	Eskom	62	226
Saiccor	70	31	Eskom	54	270
Stanger	18	-	Stanger Borough/ Eskom	20	143
Adamas	4,2	-	Port Elizabeth Municipality/ Eskom	5	34
Usutu	21	16	SEB (Swaziland Electricity Board)/ Eskom	7	23

Table 2 - Power Sources at Group Mills.

Eskom is the major bulk generator of electrical power in Southern Africa and is the only source of outside supplied power either direct to the mills or via intermediaries such as municipalities and Swaziland Electricity Board.

At source the power generated is of a high quality. The quality at the consumer end varies substantially depending on a number of factors, including distance away from the power stations, atmospheric conditions and the effects from other consumers, such as traction, large pumping schemes, etc.

4.0 Quality of Supply (QoS)

In recent years the plant and equipment installed in the mills have become more vulnerable to variations in the electrical power supplied to such equipment. Most of the mills have employed Eskom or electrical power consultants to study the quality of supplies to their plants. Sappi has installed quality of supply monitoring equipment on various of the mills and the supply authorities have installed similar equipment on their networks in the vicinity of the mills. In one case a neighbouring industry has installed the necessary equipment. Monitoring takes place on an ongoing basis and serves to confirm the origins of production losses due to power supply problems.

Up to now dip monitoring was done in accordance with the A,B,C and D dip window as specified in the Eskom quality of supply specification. The S,T,X,Y and Z window will in future be used, now that it is defined in the NRS 048 specifications of the NER.

A number of the Sappi mills have negotiated, or are in the process of negotiating the inclusion of quality of supply standards in the power supply agreements with their power supplier.

Table 3 give a summary of QoS monitoring at the various mills, and details of the quality of supply provisions in power supply contracts.

MILL	DIP MONITORING		QoS STANDARDS IN CONTRACTS		
	MILL	SUPPLIER	QoS PROVISION	DIP STANDARD	OUTAGE STANDARD
Ngodwana	Y	Y	Max. No. of Dips per annum + other QoS provisions	Class A≤ 50 Class B≤ 12 Class C≤ 3 Class D≤ 3 p.a.	≤ 4 p.a. ≤ 60 min p.a.
Tugela	Y	Y	*	*	*
Cape Kraft	Y	N	N	N	N
Enstra	Y	Y	N	N	N
Saiccor	Y	Y	Max No. of Dips per annum + * other QoS provisions	Class B - D ≤ 13 p.a.	N
Stanger	Y	Y	N	N	N
Adamas	N	#	N	N	N
Usutu	Y	Y	N	N	N

Y = Yes N = No/Not included # = Being done by other user
* = Being negotiated.

Table 3 - Dip monitoring and details of quality of supply provisions in power supply contracts.

5.0 Financial Losses Due to Power Dips and Outages

Power dips and power outages result from various occurrences which affect the power supply systems. There are generally line faults, switching faults, veld and cane fires and lightning. Power dips in the B, C and D windows and outages result in boiler and furnace trips, paper breaks on paper machines and blockages in the pulp processes and consequently production losses are incurred.

A summary of the cost of power supplied by outside sources to the various mills and the direct losses that resulted from dips and outages during 1996 is given in Table 4.

MILL	COST OF POWER FROM OUTSIDE SOURCES (R MILLION)	TIME LOST AS A RESULT OF DIPS AND OUTAGES (MINUTES)	TURN-OVER LOSSES (R MILLION)
Ngodwana	16,4	434	0,76
Tugela	35,0	1789	2,95
Cape Kraft	3,9	80	0,18
Enstra	25,0	412	0,53
Saiccor	29,6	1620	4,30
Stanger	16,2	361	0,34
Adamas	4,9	1392	0,45
Usutu	6,3	1045	0,73
TOTAL	137,3	-	10,24

Table 4 - Cost of power supplied by outside sources and financial losses during 1996 as a result of dips and outages.

6.0 Past Strategies for Dip-Proofing.

Sappi has taken the view that investment in protection against quality of supply shortcomings, like any other investment, must provide an adequate return on investment. The strategy at most of the mills has been to identify the plant that suffers the highest cost of dips and, where the expenditure is justified, to implement "dip-proofing".

6.1 *Critical / high risk plant.*

The first step in the strategy was to identify "critical" or high risk plant where the cost associated with power dips was out of all proportion to the expenditure needed to secure the power supply. This plant would justify providing separate secure supplies and generally would have a few distinguishing features:

- Other production plant cannot run without this plant.
- Outages / trips lead to long recovery times.
- Outages can result in major plant damage.

As the technologies used in production plant becomes more advanced and depends to a greater extent on software that needs to be rebooted in the event of an outage, more and more equipment begins to fall into the high risk category. A historical look at this category for pulp and paper mills would look something like:

DECADE	TYPE OF PLANT
1970s	Boiler plant, Bleach plants
1980s	Boiler plant, Bleach plants, some instrumentation
1990s	Boiler plant, Bleach plants, most instrumentation, PLCs, DCSs, manufacturing computer systems, Variable speed drives, Networks.

Table 5 - Historical look at critical plant.

The solution implemented of course depends on the size of the secure supply required and the level of security required. Table 6 gives some examples of solutions:

SOLUTION	TYPE OF PLANT	LEVEL OF SECURITY
• Self generation • Auto islanding • Reactive isolation.	Boiler plant, Bleach plants, Variable speed drives	≥ 10 MW, ≥ 1 HR 50% DIP REDUCTION
• Super Conducting Storage Device.	Variable speed drives	≥ 500 kW, 1-5 SEC 100% DIP PROTECTION
• U.P.S.s	Instrumentation MCC control circuit, DCSs, PLCs, Computers, Lighting.	≤ 100 kW, ≤ 15 MIN 100% DIP PROTECTION

Table 6 - Strategies for dip-proofing high-risk plant.

The table below gives an indication of the techniques as they are applied in Sappi Southern Africa.

TECHNOLOGY MILL	SELF-GEN	AUTO-ISLAND	REACT-ISOL	S.S.D.	U.P.S.
ADAMAS					X
CAPE KRAFT					X
ENSTRA					X
NGODWANA	X	X	X		X
SAICCOR	X	X			X
STANGER				X	X
TUGELA	X	X	X		X
USUTU	X	(X)	(X)		X

Table 7 - Techniques for dip-proofing in Sappi Southern Africa.

6.2 *Production / medium risk plant.*

The second step in Sappi's dip proofing strategy was to identify production plant that suffered extended production or quality losses due to power dips. In this case there was generally insufficient justification to provide a totally secure supply as the risk / power consumption ratio was too small. The strategy was then to reduce the sensitivity of the plant to dips.

When analysing the dips into the different categories A,B,C & D as defined by Eskom, it was found that about 80% of all dips typically fall into categories A. It was possible therefore at minimal cost, to ensure that all production equipment could ride through dips that fall into this category.

The methods of doing this are given in table 8.

SOLUTION	TYPE OF EQUIPMENT	LEVEL OF SECURITY
U.P.S.s	Control circuits of L.V. motor control circuits.	100% DIP PROTECTION $\geq$ 0.5s
Under Voltage Trip relays	M.V. motors	$\geq$60% DIP PROTECTION, $\geq$ 0.5s
Increased control voltages	D.C. drives	$\geq$50% DIP PROTECTION
C.V.T.s, M.G. sets	Instrumentation, PLCs, and other fast re-starting equipment	$\leq$ 100 kW $\geq$ 15 MIN 100% DIP PROTECTION
Flying re-start	Pumps, Conveyors and other supply equipment.	Protection against short outages where there are buffer capacities.

Table 8 - Strategies for dip-proofing "medium-risk" plant

6.3. *General services / low risk plant*

This final category is plant that falls into the following classification.

- Standby plant.
- Production plant with large buffers and excess capacities.
- General services (e.g. domestic water supplies).

For this plant the only precautions taken were to protect against voltage transients (e.g. surge protection etc.) and to ensure that there was sufficient operator attention to re-start equipment when required.

7. Costs of Dip-Proofing at Sappi Mills.

The investment in dip-proofing in the Sappi mills over the past two decades is difficult to quantity, however, an estimate has been done of the cost to install such equipment at today's prices at one of the mills (namely Ngodwana mill). The table below covers the main categories of equipment installed to protect against dips and does not include engineering hours or other techniques such DC coils on contactors, under-voltage relays etc.

Note: The generation at Ngodwana was not justified solely on dip-proofing thus a nominal 10% of the cost has been allocated to dip-proofing.

TECHNOLOGIES	DATE	COSTS
Self generation /Auto-islanding	1984	R 6.5 m (10% x R 65 m)
Reactive isolation	1994 to 1996	R 2.1 m
Un interuptable Power Supplies	1986 to 1995	R 2 m
Total		R 10.6 m
Estimated savings		R 4.7 m p.a.
Estimated R.O.I.		44%

Table 9 - Capital costs of dip-proofing Ngodwana mill (Estimated 1997 Rands).

8. Future Strategies.

The process to date has been to a large extent reactive, following repeated losses due to dips and outages, and not one that has been 100 % effective. However, major reductions in the losses due to voltage dips have been made. Unfortunately, the point is rapidly being reached where all the financially justifiable dip-proofing solutions on existing plant have been implemented and any further expenditure will fall into the following categories:

- New plant
- Upgrading / replacing existing technologies
- Agreements with suppliers to improve quality of supply

Agreements with suppliers is receiving much attention, and it is hoped to have QoS agreements between suppliers and all the mills by year end. A few of the features being negotiated in these agreements are:-:

- Supply quality standards expected from the supplier.
- Consumption quality standards expected from the consumer.
- Actions to be taken in the event of deviations from the standards.

9. Conclusion.

The Sappi S.A. pulp and paper mills have, over the past 3 decades made significant investments into technologies to reduce the effects of poor power quality. Current losses being incurred however remain very significant, and require continued attention.

Sappi, is a company committed to world class performance, and operates in global markets. It expects world class performance from all of its suppliers. This will require enhanced levels of co-operation between the suppliers and the mills to continue to improve the quality of power supplied to the mills..

APPENDIX

M

CHARACTERISTICS OF MITIGATION EQUIPMENT AND SELECTION OF MITIGATING EQUIPMENT TO ALLEVIATE POWER DISTURBANCES

CHARACTERISTICS OF MITIGATION EQUIPMENT

TYPICAL CHARACT.	LINE CLAMP	LINEAR PASSIVE FILTER	ISOLATION TRANSFORMER	FERRORESONANT POWER CONDITIONER	TAP-SWITCHING CONDITIONER	SIMPLE - STATIC SPS	CONT. STATIC UPS	ROTARY UPS	MOTOR GEN.
Noise Attenuation	None: diverts excess energy	Yes: filters out given % voltage level	Non-shielded: no attenuation for normal mode noise Shielded:provides noise attenuation	Good	Good	Good:if line filter present, otherwise, none	Good	Good	Good
Regulation	None	None	None	Good	Good	None	Good	Good	Good
Isolation	None	None	Good	Good	Good :if isolation trans-former used None: if auto-transformer used	None	Good	Good	Good
Ride through Power failure Protection	None	None	None	3 to 8 msec	None	5 min -1 hr depending on battery size	5.min -1 hr depending on battery size	5.min -1 hr depending on battery size	100-500ms
Reliability	Questionable if energy rating is exceeded	Good	Good	Good	Limited	Good	Good	Good	Good
Efficiency (at full load)	Not Applicable	99-99.5%	95-98%	78-90%	98%	85-90%	75-95%	85-90%	85-90%

CHARACTERISTICS OF MITIGATION EQUIPMENT
(continued)

TYPICAL CHARACT.	LINE CLAMP	LINEAR PASSIVE FILTER	ISOLATION TRANSFORMER	FERRORESONANT POWER CONDITIONER	TAP-SWITCHING CONDITIONER	SIMPLE - STATIC SPS	CONT. STATIC UPS	ROTARY UPS	MOTOR GEN.
Maintenance	Short Lifetime	Low	Low	∘ Periodic inspection of capasitors: input & output current check ∘ Buldge may indicate a leak of electrolyte	∘ Annual inspection of components replacement of failed electronic parts	∘ Reg battery inspection ∘ Replacement of failed electronic parts	∘ Annual battery inspection ∘ Annual testing UPS & inspection components		
Typical Reaction Time	5 nanoseconds	0	Not Applicable	80 msec	12-20 ms	4-10ms	0 ms on-line	0 ms on-line	0 ms on-line

CHARACTERISTICS OF MITIGATION EQUIPMENT (continued)

TYPICAL CHARACT.	LINE CLAMP	LINEAR PASSIVE FILTER	ISOLATION TRANSFORMER	FERRORESONANT POWER CONDITIONER	TAP-SWITCHING CONDITIONER	SIMPLE - STATIC SPS	CONT. STATIC UPS	ROTARY UPS	MOTOR GEN.
Desirable features	∘ Adequate Joule rating ∘ Ability to divert common mode as well as transverse mode impulses ∘ Diagnostics to indicate failure ∘ Diagnostics to show conditions such as open safety ground	∘ Adequate current rating ∘ Adequate peak voltage rating	∘ Size at least 140% nominal current requirements for loads with switching power supplies ∘ Ensure good quality assurance procedures were followed when manufactured ∘ Application of resin to the core and windings should be done under vacuum to ensure even coating	∘ Neutralizing winding present to minimize harmonics ∘ Ensure device will not have to operate less than 80% of full load ∘ Ensure overload capability satisfactory ∘ Service and parts available	∘ Shielding present for added protection from noise ∘ Zero current crossing design preferable to zero voltage crossing design ∘ Service and parts availability	∘ Filter used in normal mode operation ∘ Short switching time	∘ Service and parts availability ∘ Diagnostics to show fault conditions for large remote systems	∘ Service and parts availability ∘ High efficiency ∘ Low starting inrush current ∘ Frequency regulation 50Hz output ∘ Diagnostics to show fault conditions for large remote systems	• Service and parts availability

SELECTION OF MITIGATING EQUIPMENT TO ALLEVIATE POWER DISTURBANCES

VOLTAGE DISTURBANCE	TRANSIENTS			MOMENTARY PROBLEMS			LONG TERM (STEADY STATE) PROBLEMS								
Mitigating Equipment	Impulses		Oscillations	Sags	Swells (surges)	Voltage Flicker	Voltage Fluctuations		Power Interruption	Voltage Phase Imbalance	Harmonic Distortion	Frequency Deviation	Electrical Common Mode	Noise Traverse Mode	Tingle Voltage
	Spikes	Notches					overvolt-age	brown out							
Individual Branch Circuit	L	L	L		-	-	-	-	-	-	L	-	L	L	-
Lightning Arrestors	G	G	G	-	-	-	-	-	-	-	-	-	-	-	-
Line Clamp	G	-	G	-	L	-	-	-	-	-	-	-	L	L	-
Linear (Passive Filter)	L	L	L	-	L	-	-	-	-	-	Special designs only	-	L	L	-
Hybrid Filter	G	G	G	-	L	-	-	-	-	-	Special designs only	-	L	L	-
Tingle Voltage Filter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	G
Isolation Transformer	Common Mode: G Normal Mode: L	Common Mode: G Normal Mode: L	G L	-	-	-	-	-	-	-	L Good designs can reduce higher order harmonics. Poor designs may create harmonics		Non-shield 10-100 kHz ------------ Shield G	Non-shield No. ---------- Shielded. Maybe for low level	-

Legend :

G	=	good attenuation if properly applied
L	=	limited attenuation
-	=	no attenuation
(1)	=	See ride-through capabilities
(2)	=	attenuation capabilities for these applications can be improved by using a ferroresonant SPS

VOLTAGE DISTURBANCE	TRANSIENTS			MOMENTARY PROBLEMS			LONG TERM (STEADY STATE) PROBLEMS								
Mitigating Equipment	Impulses		Oscillations	Sags	Swells (surges)	Voltage Flicker	Voltage Fluctuations		Power Interruption	Voltage Phase Imbalance	Harmonic Distortion	Frequency Deviation	Electrical Common Mode	Noise Traverse Mode	Tingle Voltage
	Spikes	Notches					overvolt-age	brown out							
Ferroresonant Power Conditioner	G	G	G	G	G	G	G	G	Only for duration of 1 cycle or less	G	Older designs with square wave outputs generate harmonics. Products with neutraliz-ing windings can attenuate harmonics	-	L	G	-
Tap-switching Power Conditioner	G	L	L (Common mode only)	G	G	G	G	G	-	G	No : voltage zero-crossing types actually generate harmonics	-	Yes: if isolation trans-former used.	G	-

Legend :

G	=	good attenuation if properly applied
L	=	limited attenuation
-	=	no attenuation
(1)	=	See ride-through capabilities
(2)	=	attenuation capabilities for these applications can be improved by using a ferroresonant SPS

VOLTAGE DISTURBANCE	TRANSIENTS			MOMENTARY PROBLEMS			LONG TERM (STEADY STATE) PROBLEMS								
Mitigating Equipment	Impulses		Oscillations	Sags	Swells (surges)	Voltage Flicker	Voltage Fluctuations		Power Interruption	Voltage Phase Imbalance	Harmonic Distortion	Frequency Deviation	Electrical Common Mode	Noise Traverse Mode	Tingle Voltage
	Spikes	Notches					overvolt-age	brown out							
Motor Generator	G	G	G	G	G	G	G	G	L Depends on rotational inertia of flywheel	G	G	L A motor generator does compen-sate transient frequency deviations due to its inertia, but will not compen-sate long term frequency deviations.	G	G	-
Simple Static SPS	L	L	L	L	-(2)	L	-(2)	L(2)	G	-	-	-	-	-	-
Continuous Static UPS	G	G	G	G	G	G	G	G	G	G	G	G	L	G	-
Rotary UPS	G	G	G	G	G	G	G	G	G	G	G	G	L	G	-

Legend :

G	=	good attenuation if properly applied
L	=	limited attenuation
-	=	no attenuation
(1)	=	See ride-through capabilities
(2)	=	attenuation capabilities for these applications can be improved by using a ferroresonant SPS