CIGRE/CIRED/UIE JWG C4.110, VOLTAGE DIP IMMUNITY OF EQUIPMENT IN INSTALLATIONS, SCOPE AND STATUS OF THE WORK

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ABSTRACT

This paper presents the status of the work in C4.110, a joint working group by CIGRE, CIRED and UIE. The scope of the working group is to gather technical knowledge on the immunity of equipment, installations and processes against voltage dips, and to use this knowledge in the further development of methods and standards. The activities of the working group are divided in seven "chapters", where the work has started in three chapters: "equipment and process performance", "voltage dip characteristics" and "economics and probabilities".

INTRODUCTION

A joint working group on voltage dip immunity of equipment is supported by CIGRE, CIRED, and UIE. The scope of the working group is to gather technical knowledge on the immunity of equipment and processes against voltage dips and to use this knowledge in the further development of methods and standards.

The working group was formed during the autumn of 2005 and started its activities early 2006. Two meetings were held during 2006 and one in January 2007. Further meetings are scheduled for May and October 2007. The group currently consists of 20 regular members and 15 corresponding members. The members have the following background: 12 network operators; 10 academics and consultants; 6 industrial customers; 4 equipment manufacturers; and 3 persons with extensive experience on immunity testing of equipment. For more information, the reader is referred to the working-group website [1].

SCOPE OF THE WORKING GROUP

The results of the work will be delivered in the form of a technical report, in January 2009. This report will provide guidelines for power companies dealing with customers, equipment manufacturers and other interested parties, and give recommendations for future IEC standardization. To organize the work on this difficult but interesting subject, it was decided to split up the activities into a number of "chapters" that should later correspond to the chapters in the working-group report.

1. Introduction.
2. Voltage dip characteristics
3. Equipment and process performance.
4. Characteristics for testing.
5. Economics and probabilities.
6. Equipment and process dip immunity objectives.
7. Conclusions.

The activities (chapters) are shown in a systematic and chronological way in **Figure 1**.

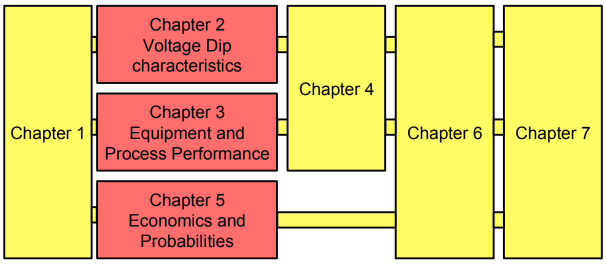

Figure 1 – *Activities within the working group organised in the form of chapters.*

Work has started on three of the five main chapters. Chapter 2 will summarize the existing knowledge on the characteristics of individual voltage dips, with emphasis on those characteristics that may possibly be relevant for the performance of equipment and processes. Chapter 3 will summarize the knowledge within the working group on the performance of equipment and processes during voltage dips. Chapter 5 will evaluate the economic tradeoffs that must be made whenever voltage dip immunity levels are selected, first considering available voltage dip statistics (on their number and characteristics), then considering economic impact of dips with various characteristics, and finally considering the economic cost of making equipment immune to dips with various characteristics. The activities (especially) in this chapter will be coordinated with the work in group C4.107 [2].

At a later stage, in Chapter 4, the results from Chapter 3 will be used to narrow down the information from Chapter 2 towards those characteristics that are identified as the most relevant for the assessment of equipment and process sensitivity to voltage dips. The results from Chapter 4 will, together with the results from Chapter 5, provide the input for Chapter 6.

VOLTAGE DIP CHARACTERISTICS

The main aim of this chapter is a detailed description of voltage dips. Particular attention will be given to a potential impact of various voltage dip events on customers' equipment and processes - any dip characteristic that may potentially influence the equipment will be included in this chapter.

The characterisation and analysis of various types of voltage dip events, as well as the further assessment of their impact on equipment/process sensitivity, is a complex, time consuming and cumbersome process. This is a simple consequence of the large number of characteristics, parameters and factors that may have an influence on the ultimate response of a specific piece of equipment, or process, to voltage dip events.

Although the voltage during a dip will be the dominant cause of changes in the equipment behaviour, the equipment may also be influenced by the voltage before and after the actual dip. Accordingly, three categories of voltage characteristics will be considered:
a) *Pre-dip characteristics*, related to the voltage magnitude and waveform before the actual dip.
b) *During-dip characteristics*, related to the voltage magnitude and waveform during the actual dip, including the starting and ending periods of the actual dip.
c) *Post-dip characteristics*, related to the voltage magnitude and waveform after the actual dip.

The most common pre-dip characteristics are related to voltage magnitude variations, voltage waveform distortion and three-phase unbalance, present immediately before the occurrence of a voltage dip. In most of the practical cases, the voltage before the dip is in a quasi-stationary state, so that characteristics over relatively long periods may be used.

Post-dip characteristics are strongly influenced by the recovery of the system and the load after the dip. Examples at different time scales include higher current taken by induction-motor load; high in-rush current for electronic equipment; recharging of capacitor banks; and harmonic distortion due to transformer saturation upon voltage recovery.

During-dip characteristics include, among others, dip type, dip shape, dip magnitude, dip duration, points on wave of dip initiation and ending, and during-dip phase shift.

Based on the two most common ways for description and representation of voltage dips (i.e., "rms voltage versus time" data/plot, and "instantaneous voltage versus time" data/waveform), during-dip characteristics are divided in three groups:

- Characteristics that can be obtained from the rms voltage versus time data. Examples are residual voltage and duration.
- Characteristics that can be directly obtained from the instantaneous voltage versus time data (the "voltage waveform"). Examples are phase-shift and point-on-wave characteristics.
- Derived dip characteristics, for example harmonics and symmetrical components, which require further processing of the waveform data.

The distinction is to a large extend historical, but nonetheless important, as it will be strongly linked to the possibilities of obtaining statistical information from existing databases. The difference between the first two and the third group is that the derived dip characteristics cannot be obtained from pure visual inspection of the instantaneous voltage waveform or the rms voltage plot.

Within this chapter a distinction will be made between "*simple dip events*" (one voltage drop and one voltage recovery) and "*composite dip events*", e.g., multistage dips caused by developing faults, dip-sequences due to automatic reclosing operations, and simultaneous occurrence of combinations of dips, interruptions and swells. These composite dips usually represent a series of individual dip events occurring either in different phases or at different but nearby moments in time. Although composite, they should be treated as one inclusive event, as the impact of a series of events on equipment/process performance may be very different from the impact of each individual event in the established series.

The correlations between dip characteristics and their origins and causes will be provided, as well as a review of existing methods for classification and representation of individual dip events and system dip performance. Statistical information on dip characteristics will be obtained from data provided by a number of network operators.

Finally, a "check-list" of relevant dip characteristics will be provided for the benefit of all parties interested in the presented analysis. Such a checklist may be used for fast and transparent assessment of equipment and process sensitivity to voltage dips, e.g., during all stages of equipment and process design.

EQUIPMENT AND PROCESS PERFORMANCE

In order to harden processes against voltage dips, a good understanding of the process under consideration is of extreme importance. Processes can be divided into two big groups. Some processes are perfectly capable to operate without supply voltage for a small period of time (e.g. chemical plants). Some processes on the other hand are interrupted at the occurrence of a voltage interruption or a voltage dip (e.g. extrusion, steel and paper mills). For these processes, the knowledge of the individual equipment behaviour under dip conditions is required to take the correct measures to harden the process.

Therefore, this chapter starts with a review of equipment behaviour as obtained from different sources. The impact of a voltage dip on direct on line induction motors, synchronous generators, transformers, adjustable speed drives, contactors, PLC's, PC's, large rectifier units and lighting systems is discussed.

For each type of equipment, different hardware components, different topologies and control algorithms are implemented by different manufacturers. The discussion of equipment performance is therefore kept rather generic. For direct on line induction motors and synchronous generators, their behaviour and impact on the supply system during and after the dip is discussed. For contactors and equipment containing power electronics, best case and worst-case rectangular voltage tolerance curves are presented, based on the current technology of tested pieces of equipment.

The equipment parameters and tripping mechanisms responsible for the high sensitivity of the equipment are discussed with great care. Knowledge of these parameters often indicates what type of mitigation technique is best suited to immunize the equipment. For example, the dip behaviour of a contactor with ac control voltage depends on the point on wave of dip initiation. If a dc control voltage is used, flux is constant and the voltage tolerance curve changes drastically. As an example, **Figure 2** shows the current state of the art of ac contactors with ac control coils. Worst case, best case and most likely voltage tolerance curves are presented. For single-phase equipment, the ITIC curve [4] is plotted as a reference. It can be seen in this example that not all contactors satisfy the ITIC curve.

To harden processes with sensitive equipment, voltage tolerance curves for the specific type of equipment are required. For each type of equipment, a checklist of relevant dip characteristics (introduced in chapter 2) will be provided. This checklist may be used for fast and transparent assessment of equipment sensitivity during all stages of equipment and process design. In chapter 4, "characteristics for testing", different methods to determine the actual tolerance curves of a specific piece of equipment will be discussed. Time consuming testing procedures of equipment and the use of simulation software to gather information are discussed.

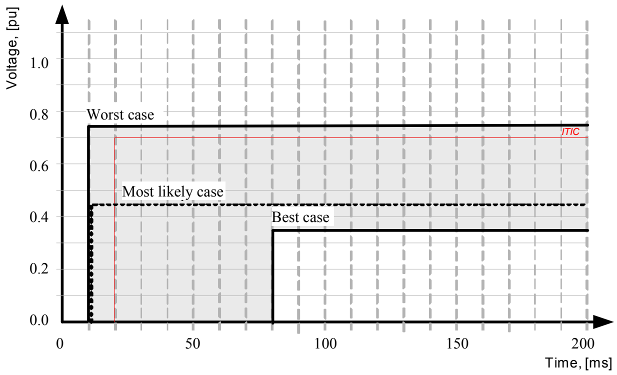

Figure 2 – *Voltage tolerance curves for ac contactors with ac control coil, worst, best and most likely case.*

The second part of the chapter discusses process behaviour. For typical processes, the *process immunity time* (critical time) is given. The process immunity time is defined as the total time that equipment within the process can be isolated from the power supply, including the time to restore, without unacceptable adverse impact on the process. For example, for a motor load "isolated" means the deceleration during a voltage dip, and the "restore" time is the time to re-accelerate the motor after the voltage has recovered.

Knowledge of the process immunity time is required to select the correct hardening technique. For a process with a time constant of several seconds, the voltage dip sensitive equipment may be stopped in a controlled manner at voltage dip detection and restarted as soon as the voltage has recovered without noticeable impact on the process. Another example is the coordinated re-start of direct on line induction motors after a voltage dip in order to avoid a voltage collapse due to the high currents during reacceleration. If the impact of each motor on the process is known, the most critical ones can be started first.

Finally, the chapter will propose a flowchart that can be used for the systematic detection of critical processes and the critical pieces of equipment within these processes. For typical processes, values for the process immunity time will be presented as a guideline when determining process sensitivity.

ECONOMICS AND PROBABILITY

Whereas chapters 2 and 3 address individual dips and individual installations; chapter 5 takes a more global look at dips and installations. A number of questions are asked to support the setting of immunity requirements in standards such as IEC 61000-4-11 [5] and IEC 61000-4-34 [6].

Among others, the following information is needed to set immunity requirements:

- The frequency of occurrence of voltage dips with different dip characteristics, for customers all over the world.
- Equipment mal-function, damage and process interruptions due to voltage dips with different characteristics, and the economic consequences of these.
- Costs of voltage-dip immunity requirements, including mitigation measures in installations, mitigation measures in the grid, costs of immunity testing and immunity requirements, and adverse side effects of mitigation measures.

The working group is aware of the huge complexity of the economics of voltage dips, and is also aware that it will not be possible to get all this data within their three-year mandate. However, available information will be gathered and best guesses will be given from this information.

In order to get the expected performance of already existing and new equipment it is essential to know the voltage-dip performance of the supply at the equipment terminals. The performance is presented by using graphs with remaining voltage and duration; an example is shown in **Figure 3**. This allows us to compare the performance with requirements set by SEMI [3], ITIC [4] or IEC [5][6] and with tolerance curves as in **Figure 2**. To obtain a complete picture of the supply performance it is essential to consider the three-phase character of the system and to include that most dips are associated with unbalanced voltages. One way of considering this in the statistics is by presenting different curves, as in Figure 3, for different types of unbalanced dips.

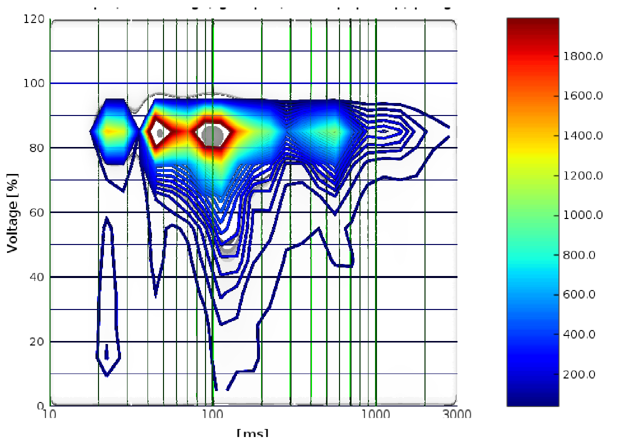

Figure 3 - *Example of presentation of voltage-dip performance of a system. (The vertical column on the right represents the number of dips recorded during the study.)*

Measurement sites will be chosen as close as possible to the equipment terminals. Some data comes from permanent installed equipment at MV busbars, since this is the location that utilities most commonly use for power-quality monitoring. This data may be adjusted based on known transforms between the MV system and the equipment terminals, to obtain a reasonable approximation of dips at the equipment terminals.

All voltage measurements, including voltage dips, are made between pairs of conductors (although voltage dips are sometimes labelled with a single conductor name). To properly understand the voltage dip statistics, it is important to understand on which pair of conductors a voltage measurement was made. For example, on some common European MV networks, voltage is often recorded only between phase conductors since not very fast potential increases to earth are not transferred to the secondary side (primary is not grounded). In contrast, in low-voltage networks with neutral, measurements are often carried out between phase conductors and neutral.

CONCLUSIONS

This paper presents the scope and the status of the activities within the working group. As the activities are ongoing this paper should not be referred to as the opinion of the working group. Instead it only presents the current status of the discussions as interpreted by a limited number of working-group members.

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