A PROJECT ABOUT VOLTAGE DIPS AND SHORT INTERRUPTIONS TO MEET CUSTOMERS' REQUIREMENTS

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SUMMARY

A project relating to voltage dips and short interruptions has been undertaken better to meet customers' requirements with respect to the quality of supply. The purpose of this project is three-fold. Firstly, the idea is better to identify the characteristics of dips and interruptions recorded in the system at the different voltage levels, the sensitivity of the customers' most current units of equipment and the desensitisation solutions that can be recommended. Secondly, to shed light on EDF's policy in the areas of standardisation and contractual character of quality. Thirdly, to produce information media (technical manuals) and study (software) tools relating to those voltage disturbances.

1.- CONTEXT

Customer satisfaction is one of EDF's major sources of concern. To this end, substantial efforts have been made over the past fifteen years to improve the quality of supply.

Initially, efforts have covered the structure of systems (creation of new HV/MV substations), their protection and operating conditions (re-meshing HV systems). The effects of these programmes has been substantially to reduce the number of long interruptions (longer than three minutes) suffered by customers, as well as the length of these interruptions.

In parallel, the emergence of new electricity applications has increased customer sensitivity to voltage dips and short interruptions (less than three minutes).

These phenomena which can disturb industrial processes and software applications are perceived by today's users as the most harmful disturbances.

A sample inquiry performed in 1994 has revealed a very high proportion of industrial customers' expectations on this point. Forty-four percent of them believe that voltage dips cause great disruptions in their activity, causing at least five production breakdowns per year, as well as equipment deterioration and loss of production.

These disturbances are of prime importance to a distributor seeking customer satisfaction.

Today, EDF is developing a more customised approach of quality, through the « Émeraude » contract [1] and its ancillary services. This contract, which is spreading to the largest industrial and tertiary customers, comprises a standard commitment by the distributor with regard to the number of short and long interruptions experienced by a customer.

Should contractual thresholds (defined on a nation-wide basis and approved by the public authorities) be overshot, EDF reimburses the customer on the basis of the suffered damage. Customers who so wish can also secure commitments relating to the number of voltage dips suffered by the installation by negotiating itemised thresholds.

However, no specific standard exists today regarding voltage dips and short interruptions, whether from the standpoint of immunity of equipment, electromagnetic compatibility or even measurement of disturbances.

In addition, in the context of opening of the electricity market, contractual commitments relating to voltage dips and short interruptions are of significant importance.

As a result, EDF's Research and Development Division has launched a project dealing with these disturbances with a three-fold aim :

- better to ascertain the characteristics of voltage dips and short interruptions recorded in the system at the different voltage levels, the degree of sensitivity of customers' most common units of equipment and the desensitisation solutions that can be recommended ;
- to shed light on EDF's policy in the field of standardisation and contractual commitment, especially to prepare the new developments of the « Émeraude » contract ;
- produce information media (technical manuals) and study (software) tools enabling EDF's commercial departments to meet customer expectations and answer their questions.

2.- BETTER KNOWLEDGE OF THE CONSEQUENCES OF VOLTAGE DIPS AND SHORT INTERRUPTIONS

2.1.- Disturbances observed at the different voltage levels

The readings taken in the French transmission and distribution systems (i.e. over 20.000 events) have provided a classification in terms of length and amplitude of the voltage dips and short interruptions observed. Tables 1 and 2 list the findings secured in HV and MV.

Table 1 : Distribution (as a %) of voltage dips and short interruptions in the HV system

duration (s) / resid. voltage (%)	> 0.05	> 0.20	> 0.40	> 0.60	> 1.00
< 80	17.2	6.5	2.5	1.8	0.9
< 75	10.8	4.1	1.4	1.0	0.6
< 70	7.7	3.0	1.1	0.8	0.5
< 50	3.3	1.1	0.6	0.4	0.3
< 30	2.5	0.7	0.4	0.3	0.3
short interruptions	2.0	2.0	1.9	1.8	1.8

Table 2 : Distribution (as a %) of voltage dips and short interruptions in the MV system

duration (s) / resid. voltage (%)	> 0.05	> 0.20	> 0.40	> 0.60	> 1.00
< 80	17.4	9.9	5.1	2.3	0.6
< 75	13.4	7.6	3.9	1.6	0.2
< 70	10.8	5.7	2.7	0.9	0.1
< 50	6.7	3.5	1.3	0.4	0.1
< 30	4.8	2.2	0.8	0.1	0.1
short interruptions	4.5	3.7	2.2	2.1	2.1

The method has then consisted of classifying readings in terms of the protection implemented to eliminate the fault.

The « signature » of a voltage dip must be identified in line with the type of this protection. Approximately 20 profiles have thus been identified. This procedure therefore identifies the origin of voltage dips. An initial distribution has been drawn up for HV and MV systems (see table 3).

Table 3 : Distribution of voltage dips as a function of the type of protection cycle implemented

protection cycle	HV distribution	MV distribution
fast EHV protection	22%	9%
1st stage HV protection	48%	21%
2nd stage HV protection	6%	9%
HV re-closing	1%	
HV interruption	2%	2%
fast re-closing of feeder		6%
slow re-closing of feeder		3%
fast-slow re-closing of feeder		1%
fast re-closing of neighbouring feeder		2%
slow re-closing of neighbouring feeder		1%
fast-slow re-closing of neighbouring feeder		3%
fast r. neighbouring feeder or 1st stage HV	3%	18%
slow r. neighbouring feeder or 1st stage HV	1%	10%
unknown	16%	14%

This procedure has been validated on the grounds of data collected by EDF's operational divisions.

2.3.- Sensitivity of equipment

A set of tests has been carried out regarding the different types of industrial equipment (motors with their supply, variable speed drives, air conditioning, heat pump, etc.) and tertiary equipment (office science, cold storage, lighting, etc.). The sensitivity thresholds of these units of equipment have thus been established.

Some examples of thresholds are given in figure 1, which outlines the sensitivity area of equipment in a depth / duration plane (equipment is disturbed below and to the right of the threshold).

The sensitivity threshold varies from one unit of equipment to the next. Schematically, time-wise, the threshold is between 100 and 300 milliseconds and amplitude-wise, between 50 and 70% of rated voltage. The behaviour of equipment beyond this limit also varies : either the equipment starts up automatically at the end of the disturbance without change to its operating mode, or it stops and must be re-initiated to start-up again.

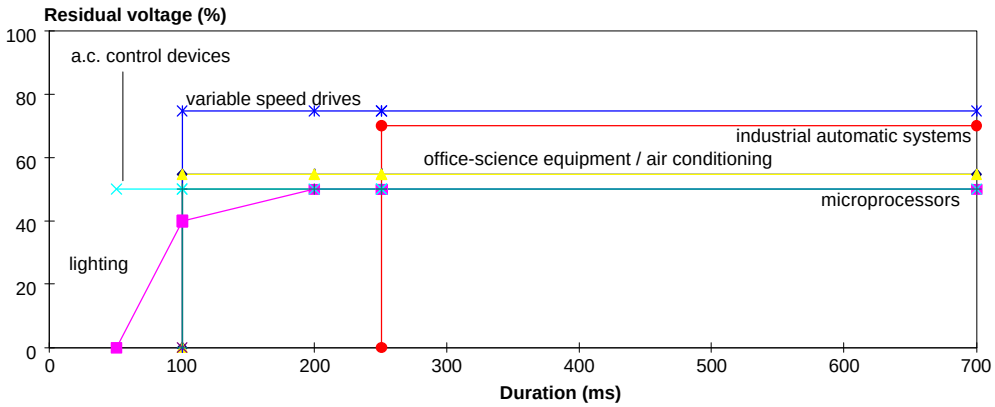

Figure 1 : Sensitivity threshold of some units of equipment to voltage dips

2.4.- Prejudice linked to short interruptions

A sample inquiry carried out over the last few years has provided an estimate of the financial prejudice linked to short interruptions (see table 4).

Table 4 : Estimate of the financial prejudice linked to short interruptions in the industrial sector

amount of prejudice	proportion of incidents that have had financial consequences
less than 10.000 FRF	30%
between 10.000 and 50.000 FRF	35%
between 50.000 and 100.000 FRF	18%
over 100.000 FRF	17%

It should be observed that all processes are not affected in the same fashion. The most sensitive areas are among others non-stop processes, the rubber industry and electronic manufacturing.

2.5.- Desensitisation solutions

Collaboration with equipment manufacturers has allowed the numerous desensitisation solutions proposed today to be identified (see § 4.2).

In addition, innovative solutions have been assessed as part of a study of applications of MV and LV power electronics. The most promising devices are :

- the series compensator which offsets voltage dips ;
- the parallel compensator, associated with an energy storage system, which offsets voltage dips and interruptions ;
- the short-circuit current limiting device which reduces the amplitude of voltage dips ;
- the static switch which allows switchover from one source of supply to another without causing a disruption to the user.

Today, these innovative devices can be competitive alternatives to the conventional devices. They open up many opportunities in a competitive area, i.e. :

- to meet targeted quality needs at customers' premises ;
- to provide a service consolidating the supplier/customers relation ;
- to supplement supply contracts with more efficient and versatile solutions which meet EDF's and customer's reciprocal commitments.

3.- PROPOSALS FOR MEASUREMENTS AND STANDARDIZATION

3.1.- Guidelines for standardisation

Existing standardisation documents relating to the definition and measurement of voltage dips and short interruptions, as well as to the immunity of equipment to those disturbances, have initially been listed. This analysis has revealed the existence of inconsistencies between the different definitions and the lack of an explicit measurement method, despite the existence of indicative specifications covering immunity testing of equipment.

Definitions - From this observation, and the information gathered as part of the studies described in section 2, new standard definitions of the voltage dip and the interruption can be proposed.

"For a single-phase voltage of period T, a voltage dip occurs when the RMS value computed over a time window (whose duration is a multiple of T/2) is lower than 90% of declared voltage. It begins at the beginning of the first window and ends at the end of the last window for which the previous condition is verified.

In a polyphase system, a voltage dip occurs when at least one voltage (phase to phase or phase to neutral) experiences a voltage dip. It starts when the dip appears in the first affected voltage and ends when the dip disappears in the last affected voltage."

"For a single-phase voltage of period T, an interruption is a special voltage dip for which for which the RMS voltage value over a time window is equal to zero.

In a polyphase system, an interruption begins when the interruption occurs simultaneously in all voltages and ends with the disappearance of the interruption in at least one voltage.

Remark : For measurement purposes, it is considered that the interruption begins when the RMS voltage value is lower than 10% of declared voltage. "

Disturbances are defined as a reduction of the RMS voltage value with reference to a theoretical measurement method of the RMS value (over a time window whose duration is a multiple of *T*/2). They are defined for single-phase and polyphase systems. Time and amplitude limits should be specified in contractual commitments as they are linked to the characteristics of the power system. Both definitions have been submitted to working group 1 of IEC committee 77.

In parallel, the concept of voltage dip at *x*% is introduced :

"For a single-phase voltage of period T, a voltage dip occurs when the RMS value computed over a time window (whose duration is a multiple of T/2) is lower than x% of declared voltage. It starts at the beginning of the first window and ends at the end of the last window for which the previous condition is verified.

In a polyphase system, a voltage dip at x% occurs when at least one voltage (between phases or between phase and neutral) experiences a voltage dip at x%. It starts when the voltage dip at x% appears in the first affected voltage and ends when the voltage dip at x% disappears in the last affected voltage."

This concept is used to define the way to count voltage dips. It has been proposed to working group 9 of IEC

committee 77 dealing with the standardisation of measurement methods.

Measurement method - It would be desirable to standardise the computation method of voltage amplitude, fault detection and counting voltage dips (see § 3.2). Event grouping methods could be proposed for information.

Immunity - The proposed guidelines basically cover the definition of immunity tests. The test basis defined in the IEC standard 61000-4-11 [2] can be supplemented as follows :

- by specifying that it corresponds to single-phase dips for single-phase equipment and to three-phase dips for three-phase equipment ;
- by introducing the concept of benchmark area to assess equipment sensitivity, i.e., a « duration, amplitude » couple beyond which the unit of equipment is always sensitive.

In terms of standardisation, there is no strict specification relating to sensitivity levels of equipment. Nevertheless, customers today have a preference for units of equipment that are more immune to voltage dips.

In contradiction, manufacturers are not very keen on having much stricter immunity levels for their equipment. The introduction of the concept of benchmark area mentioned above is therefore a proper compromise to meet customer expectations without imposing over strict standards.

It is also difficult to define stricter immunity levels for tertiary and household appliances. However, an increase in sensitivity may be observed in the domestic sector over the next few years owing to the development of appliances fitted with an electronic programmer, which is relatively sensitive and necessitates outside intervention to be started up again.

3.2.-Measurement method of voltage dips

Typically, a measurement method of voltage dips comprises several modules (see figure 2) :

◊ voltage amplitude computation ;
◊ voltage dip detection ;
◊ counting of dips and interruptions.

Different methods have been identified for each stage. The study has then consisted of :

◊ assessing the differences between the various methods ;

◊ linking the findings secured to equipment sensitivity by performing immunity tests of equipment in operation at domestic, tertiary and industrial customers' premises ;

◊ drawing a comparison between these methods and those in place in measurement devices (existing or in development) and with the methods recommended by standardisation organisations ;

◊ identifying the effect of each measurement method on the number of events overshooting contractual thresholds.

The studies resulted in the following observations :

- The index adopted for the computation of voltage amplitude is the RMS value. It should be computed with a time resolution of a half-period between two passages through zero. The degree of accuracy relating to the length of the disturbance is thus sufficient, this length being of the order of a hundred milliseconds. The computation is performed without harmonic filtering.
- Detection of a fault is performed by comparison with a set threshold.
- The counting method of voltage dips and interruptions consists of comparing RMS voltage value of each phase with the threshold value. It is nevertheless necessary to draw a distinction between voltage dips and interruptions upstream of the process. The concept of « voltage dip at *x*% » provides a relatively accurate representation of equipment sensitivity, as in general, a time and amplitude threshold beyond which an appliance is always sensitive can be defined. It applies identically to both a single-phase and a polyphase system, for phase to neutral or phase to phase voltages.
- The only characterisation method of the three phase fault and the equivalent single-phase event that can be adopted is the duration envelope and the minimum amplitude, knowing that none of the methods represents the sensitivity of equipment and should therefore not be recommended for counting events.
- Possible grouping methods are as follows :

  1. Two successive voltage dips are grouped when the interval between them is lower than 100 ms. The equivalent duration is equal to the sum of durations of each voltage dip.
  2. Two successive interruptions are grouped. Appliances are generally sensitive from the initial interruption. The equivalent duration is equal to the sum of durations of each interruption.
  3. Dip - interruption sequences, without restoring voltage, are equivalent to an interruption irrespective of the length of the interruption. When the appliance is not sensitive to the interruption, it does become so due to the sequence. The equivalent duration is equal to the sum of durations of each disturbance.

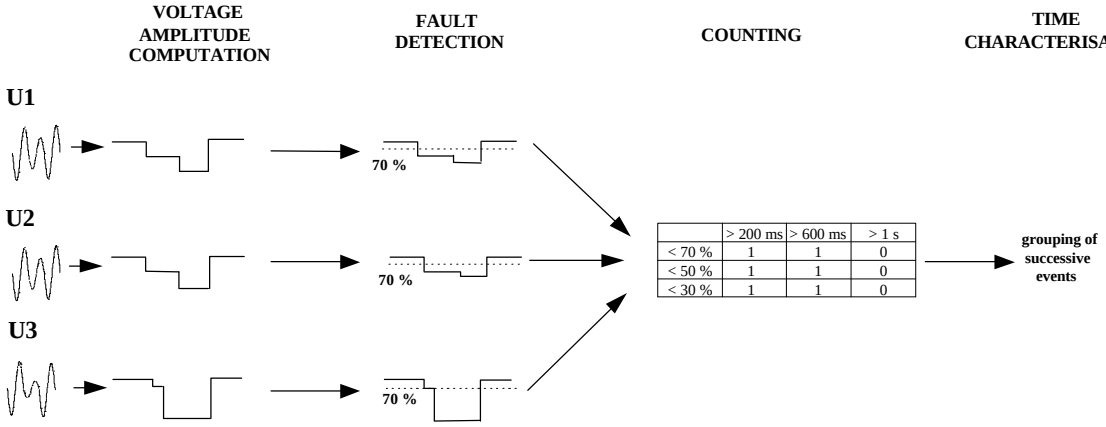

Figure 2 : Principle of a voltage dip measurement method

4.- INFORMATION AND STUDY TOOLS

4.1.- Information guidelines relating to voltage dips and short interruptions

Information guidelines relating to voltage dips and short interruptions have been drafted. This document is divided into two parts :

- a general presentation (of roughly ten pages) of the problem of voltage dips : What is a voltage dip ? Why are there voltage dips in the system ? What are the effects on equipment ? What are the solutions in the system ? What are the solutions at customers' premises ?
- more technical fact sheets on the following themes : structure of the system at the different voltage levels, the HV and MV protection plan, the effect of voltage dips and short interruptions at HV and MV customers' premises, sensitivity of industrial and tertiary units of equipment, actions implemented to limit the generation of voltage dips and short interruptions in the distributor's system, solutions to limit voltage drops induced by a customer's installation, solutions at the customer's premises to forestall voltage dips and short interruptions.

12.000 copies of this commercial document have been printed. It will be used by EDF's commercial departments to inform industrial and tertiary customers as to the problems involved with voltage dips and short interruptions as well as in relation to the solutions they can implement to prevent them.

4.2.- General guidelines for the desensitisation of electrical installations to voltage dips and short interruptions

These guidelines have been drafted in collaboration with compensation device manufacturers and a few engineering companies. This document is as follows :

- a main part lists the basic information relating to the problem of desensitisation to voltage dips and short interruptions : description of a desensitisation approach, approach to a pre-diagnosis, presentation of desensitisation solutions, examples of desensitisation of existing or future industrial or tertiary equipment.
- this main section is supported by technical annexes broaching the following subjects : principle of desensitisation, total desensitisation using energy storage solutions (inverter (or UPS), rotating generating set, batteries, etc.), specific desensitisation solutions for industrial equipment, case studies.

500 copies of this technical document have been printed. Its purpose is to provide technical information to be able to identify existing or future problems linked to voltage dips and short interruptions and desensitisation solutions proposed today by manufacturers. Its priority is to assist persons in charge of diagnoses, especially as part of the implementation of the « Émeraude » contract, to be able to meet industrial and tertiary customers' requirements.

4.3.- Software for the pre-determination of voltage dips

A prototype software has been developed for the pre-determination of the number of voltage dips and short interruptions that may occur in a tree-like MV distribution system.

Input data used in the software are the type and the characteristics of the elements of the power system (that can be taken from EDF's system databases), the faults suffered by the system and the protection relays installed. Default values are proposed for each parameter.

The findings provided by the software are tables giving in synthetic form the number of interruptions by category of length, and the number of voltage dips by categories of length and depth. These tables are presented for a given node of the MV system, for a feeder, a sub-feeder, or even a group of feeders.

This software should allow the number of foreseeable interruptions and voltage dips at any point of the system to be calculated, the consequences of the connection of a new customer or of the development of the system to be predicted, and an operational diagram to be optimised. This tool is presently undergoing testing.

5.- CONCLUSION

A project relating to voltage dips and short interruptions was conducted between 1996 and 1998 better to meet customer requirements regarding the quality of supply. The main technical teachings of this project are as follows :

- design of a measurement method of voltage dips and short interruptions, based on the computation of the RMS value of voltage and consisting of counting voltage dips by applying a threshold to the RMS value of each phase ;
- drawing up standardisation proposals in terms of definition, measurement method and immunity of equipment to voltage dips and short interruptions ;
- determination of the sensitivity threshold of a few units of industrial and tertiary equipment to specify guidelines that can be followed in terms of contracts between EDF and a customer ;
- drafting of information guidelines to inform customers as to the problems involved with voltage dips and short interruptions and to assist the technical divisions in a pre-diagnosis to remedy a customer's disturbance problem ;
- development of software tools to characterise and pre-empt voltage dips and short interruptions in the MV system ;
- identification of innovative solutions in terms of desensitisation to voltage dips.

On the basis of these findings, EDF today can :

- experiment the pre-determination software of voltage dips and short interruptions in the MV systems ;
- at the level of the various standardisation organisations, in particular the IEC (SC77 - WG1 and WG-9, SC77A - WG8), propose the guidelines chosen for the definition and the measurement of disturbances, as well as for the immunity of equipment ;
- follow up with more efficiency the studies started in the field of desensitisation to disturbances and specify the present offer in terms of new compensation devices of voltage dips and short interruptions. The potential market must be identified for these appliances at customers' premises and in the system, and they must be tested in pilot sites. EDF is envisaging proposing these appliances to customers to enhance their distributor/customer relation and developing a « quality » approach in the form of a whole range of services.

6.- REFERENCES

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[2] Technical report CEI 61000-4-11
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