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A COMPUTATIONAL APPROACH TO SUBSIDIZE CONSUMERS REFUNDING ANALYSIS DUE TO SUPPLY DISTURBANCES AND EQUIPMENT DAMAGES

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ABSTRACT
This paper is aimed at presenting a computational methodology to assist decisions towards the analysis of the relationship between equipment damage and system disturbances. Such strategy consists on a first orientation to support studies, analysis and reports about the decision of refunding consumers in such a complex subject. The approach is based on a time domain modelling and computational implementation of different devices and power network elements into the ATP program to simulate the power system disturbances and the equipment performance. The main idea consists in establishing comparative terms between dielectric and thermal stresses with the corresponding withstand limits associated to individual equipment. In order to highlight the methodology, a typical TV set submitted to supply disturbances is used as a case study. The dielectric and thermal stresses are related to the occurrence of voltage swells, oscillatory transients and high-frequency impulse related to lightning strikes.

KEY WORDS
Equipment damage, repayment, dielectric and thermal stresses, household electronic device, and power quality

1. Introduction

In recent years, the electrical supply has presented no ideal characteristics that can compromise the normal operation of consumer devices. This situation may jeopardize the physical appliance integrity. This is especially true for new technology devices; which are generally more sensitive to the power quality [1].
On the other hand, the general population is quite well instructed about its consumer rights. This situation has provoked an appreciable growth of compensation demands for electrical equipment supposedly damaged because of a non ideal voltage supply from the utility. The question becomes more relevant if the involved financial resources that are usually under utilities responsibility are considered.
To better understand this matter it must be stressed that most power supply utilities do not have appropriate power quality instruments to record system events so as to present counter proofs. As a result, the majority of refunding demands succeed and the financial impact is very high to the supplier. In order no provide means for a more consistent analysis of electrical equipment compensation, the idea emerges of obtaining computational information to reproduce the non ideal voltage supply and apply it to distinct devices to estimate the dielectric and thermal stresses [2, 3, 4, 5, 6]. By plotting these data against the specific appliance thermal and dielectric withstand capability it will be possible to have first information about the correct relationship between disturbance and appliance damage possibility.
In order to illustrate the proposed approach, a typical residential device is considered. A TV set is submitted to different non ideal voltage conditions and the previously mentioned parameters are evaluated. The results are then compared to adopted withstand data sheet.

2. Methodology

In this work, the proposed methodology consists on comparison of the dielectric and thermal efforts that are submitted an equipment when operating with non ideal supply conditions with its respective withstand capability. The procedure aims to offer an alternative for the attainment of performance information that, based on technical data, may help for decisions of the repayment order consistence.
However, the apparent triviality of this procedure finds immense difficulties due to lack of disturbance measurements in distribution systems and the attainment of withstand capability of electrical equipment devices as well.
As alternative to round these problems, this proposal is based on studies in the computational scope, where equivalent models of electrical devices and distribution system elements are included for simulations and analysis.

The distinct stages of the proposed process are illustrated in the sequence. Although this methodology can be used for any equipment, to better illustrate the procedure, only a TV set will be considered for this paper.

2.1 TV Set Computational Modeling

The equivalent circuit of this device, which is based on a classical switched source, with diverse internal and stabilizing voltage circuits, had been extracted from manufacturer's catalogs, experimental surveys and others. After exhausting studies for the focused product, were defined simple arrangements, however good enough, to represent the device under ideal and non ideal conditions operation. This is the case of the Figures 1 and 2, which evidences the equivalent circuit used for computational representation of the television set and its respective model developed in the ATPDraw platform, respectively. These figures show the representation of the switched source typical components. Moreover, the internal circuits were modeled as constant power, fitting the physical principles that govern this kind of device operation.

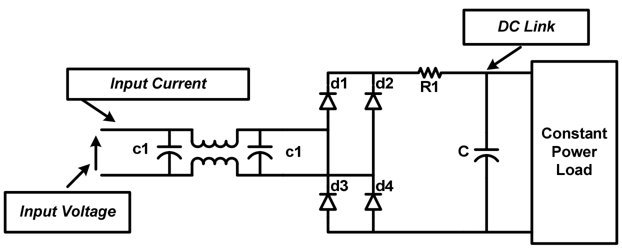

Fig. 1. Electrical equivalent circuit of the TV set.

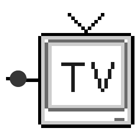

Fig. 2. Representative ATP model for TV set.

2.2 Disturbance computational modeling

As the ATP used in the investigations (ATPLauncher version 1.11 and ATPDraw version 4.0p2) do not have in its library the disturbance sources to represent the network's phenomena, generally associated with the repayment order, it was necessary to elaborate some specific models. Thus proceeding and inserting such models in the selected computational base, the reproduction of the typical phenomena associates to the subject power quality became then possible. In this way, beyond the use of sources and conventional devices, the models had been configured with the TAC's functions and, later, inserted in the ATPDraw modules. Figure 3 presents the resultant models of this process, which had been implemented in the computational base through specific cards. Due to space limitation is not possible to detail each one of them, however, the Figure 3 shows these models which allows applying: voltage distortions, voltage fluctuation, voltage interruption, voltage dip, voltage swell, oscillatory voltage transients and high-frequency impulses. These disturbances can be applied to any point of the network system and the program propagates it until the point of connection of the equipment under analysis.

Fig. 3. ATP models to represent the electrical disturbances.

3. Dielectric and Thermal Stress Calculation

The proposed methodology is based on two indicators associated with equipment operation. One to express the imposed dielectric requirements and other to relate the thermal conditions of the equipment when submitted to voltage supply disturbances. Obeying such strategy, the mechanisms to determinate these pointers are presented in the sequence.

3.1 Dielectric Stress

It is known that dielectric stress is directly dependent on the reached levels and duration of the stages that constitute any disturbance occurred on the voltage supply. In this way, the adopted procedure consists in purchase discrete data in the period of the phenomena e calculate, for each instant of time, an indicator that represents the cumulative voltage effect. In accord with this goal, (1) can be taken as producing a similar physical meaning to RMS value computation. However, there is a great difference in relation to the conventional way, since this would demand an interval of corresponding integration to a complete period of the 60 Hz sine wave. In accordance with the proposal contained in (1), the time interval is increasing, initiating from the disturbance instant, suffering increments defined by a step (Δt) chosen. Moreover, to avoid errors in the transitory phenomena studies is considered as starting point for the calculations the instant where the voltage reaches its maximum value.

$$V_k = \sqrt{\frac{\sum_{i=1}^{n} V_i^2}{n}} \tag{1}$$

Where:

V_k - Dielectric stress for any instant of time;
V_i - Instantaneous voltage value for any instant of time;
n - Sample numbers.

3.2 Thermal Stress

Equation (2) is used to calculate the thermal stress. It allows for referring the current waveforms in thermal impacts on household electronic devices.

$$I_k = \sqrt{\frac{\sum_{i=1}^{n} I_i^2}{n}} \qquad (2)$$

Where:

I_k - Thermal stress for any instant of time;

I_i - Instantaneous current value for any instant of time;

n - Sample numbers.

4. Equipment Withstand Capability Features

Although the recognition of the existence of procedures to obtain factory equipment approval, these are not enough to derive reliable withstand capability curves. This leads to the necessity of finding these limits for specific products throughout experimental tests which must reach equipment physical withstand capability. The difficulties associated to this challenge include the large number of similar products owing to distinct manufacturers, the absence of standards to be followed, the ageing effect, etc. Due to the mentioned difficulties, the use of alternatives such as the ITIC curve [7] of the Information Tecnology Industry Council provides means for a first orientation towards equipment voltage limits. This well known curve establishes the bordering region for the minimum and maximum levels of physical and operational tolerance for computers. However, these limits can not be applied to general products and the lack of withstand dielectric and thermal information is still a great problem in this area.
Due to the above considerations, the approach considered in this paper is based on the following possibilities of equipment voltage limits:

- ITIC limits [7];
- TV set susceptibility limits suggested by reference [5]. The withstand voltage values were obtained from experimental tests using distinct voltage swell at fundamental frequency;
- TV set tolerance curve given by reference [6]. This was obtained throughout experimental tests comprising impulse voltage and voltage swell on household electronic devices in accordance with IEC 61000-4-5 and IEC 61000-4-11 standards.

Concerning thermal withstand capability levels the corresponding curve was derived from manufacturer's rectifying bridge datasheets as defined by the switched source used to feed the internal TV circuits. However, it must be emphasized that this limit can be exchanged by another more fragile component such as the protection fuse or the rectifier smoothing capacitor.

5. Studied Cases

To illustrate the use of the approach and to evaluate the consistency of the methodology, a number of studies were carried out. From these, a summary is described in this paper. Table I shows the non-ideal supply voltage conditions chosen to be discussed.

Table 1
Studied Cases

Case	Event	Characteristics
1	Impulsive high-frequency transients	Standard impulse of 1,2x50 μs, showing peak value of 2kV and 4kV.
2	Oscillatory transient	Oscillatory voltage with 740V of peak value, 1 kHz, with duration of ¼ cycle.
3	Voltage swell	200% of voltage swell upon the rated value with a duration of 100ms

6. Results

Using the ATP computational base in which the TV set and other equipment have been inserted, as well as the libraries to reproduce the above disturbances, the investigations were carried out. Although a large number of information is available, for this paper purposes the following results are given:

- Equipment input voltage and current waveforms;
- Dielectric and thermal withstand capability and corresponding efforts associated to the specific voltage disturbance.

6.1 Case 1 – Impulse High Frequency Transients

The waveforms due to the incidence of an impulse voltage of 4 kV are illustrated in Figures 4 and 5. The associated dielectric and thermal performance are given in Figures 6 and 7.

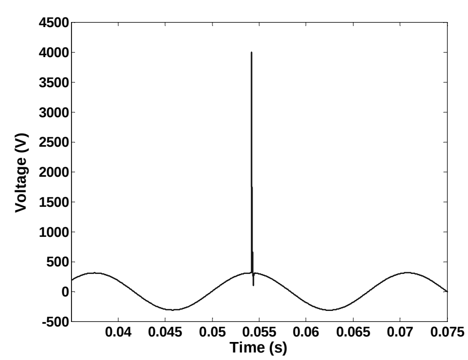

Fig. 4. Voltage supply with 4kV high-frequency impulse.

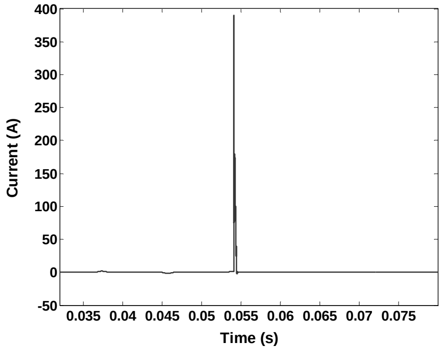

Fig. 5. Input current for 4kV high-frequency impulse.

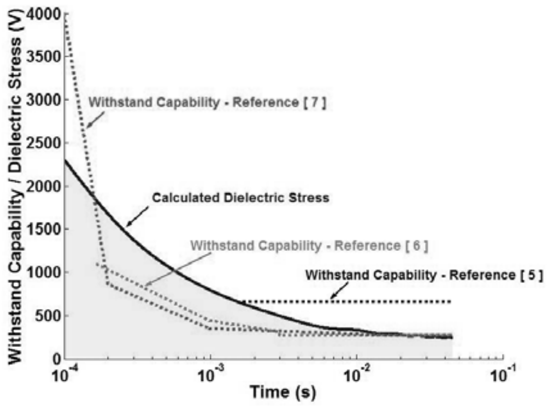

Fig. 6. Dielectric withstands capability versus calculated dielectric stress for 4kV high-frequency impulse.

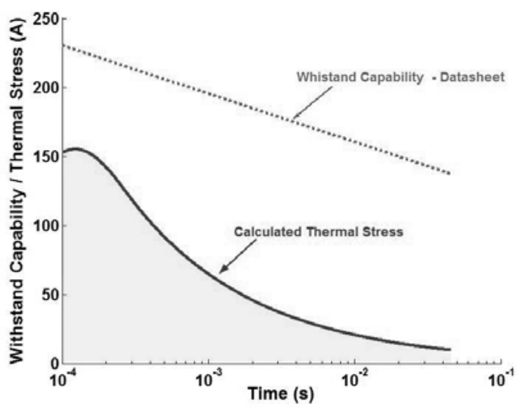

Fig. 7. Thermal withstands capability versus calculated thermal stress for 4kV high-frequency impulse.

The results are clearly enough to highlight that the applied impulse will not be tolerated by the equipment. This violation occurred for the dielectric withstand capability whist the thermal limit has not been reached. This is in agreement with the terms stated in reference [6] which inform that 4 out of 7 equipments were damaged by applying the specified voltage.

By changing the impulse to a lower peak value of 2 kV, the new results are given in Figures 8, 9, 10 and 11. Under this disturbance it is shown that the voltage limits are marginally achieved, i.e. the probability of damaging the TV will be lower, as it should be expected. Again, this conclusion is in accordance with references [5] and [6].

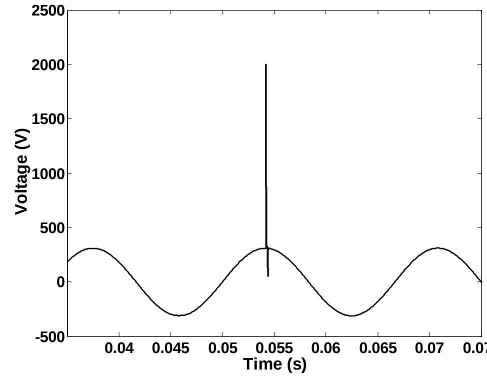

Fig. 8. Voltage supply with 2kV high-frequency impulse.

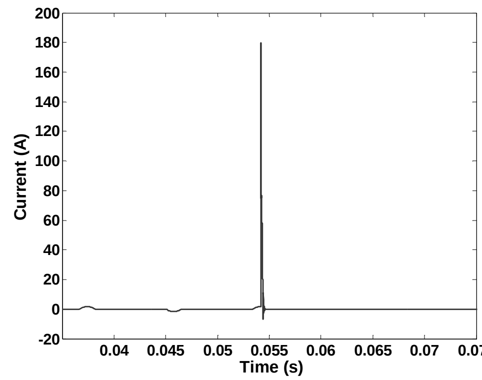

Fig. 9. Input current for 2kV high-frequency impulse.

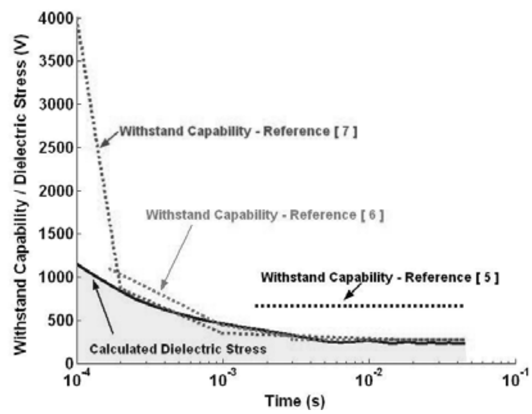

Fig. 10. Dielectric withstands capability versus calculated dielectric stress for 2kV high-frequency impulse.

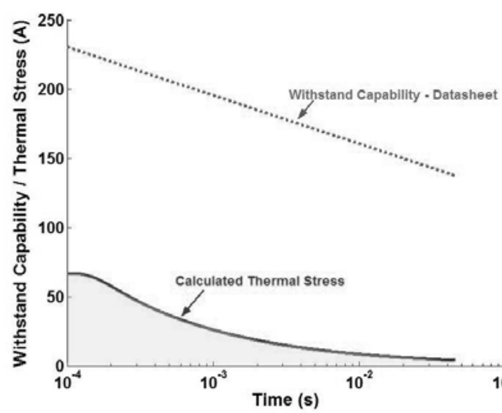

Fig. 11. Thermal withstands capability versus calculated thermal stress for 2kV high-frequency impulse.

6.2 Case 2 – Oscillatory transients

By replacing the impulse transients by the oscillatory one, the corresponding input voltage and current are illustrated in figures 12 and 13.

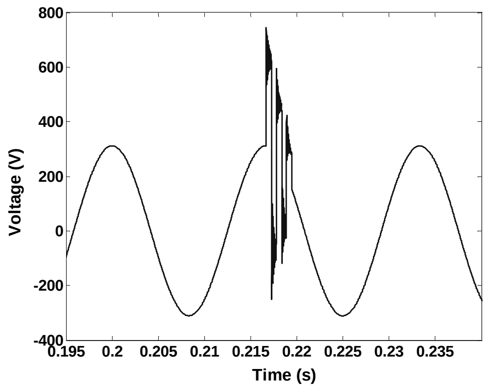

Fig. 12. Oscillatory transient voltage.

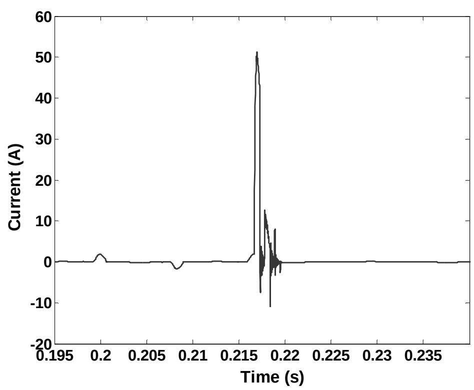

Fig. 13. Input current for oscillatory transient voltage.

Once again, by superimposing the withstand voltage and current limits to the disturbed voltage effect upon the equipment, Figures 14 and 15, it can be seen the thermal limit curve is far away from the current effort.

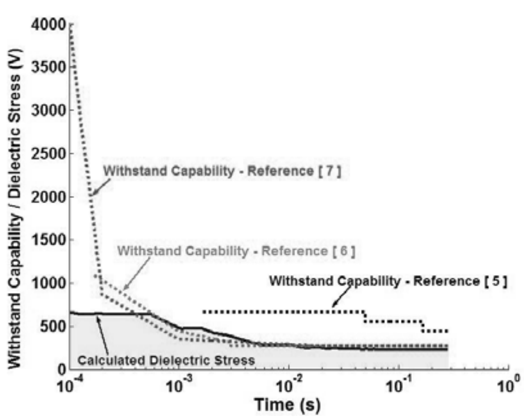

Fig. 14. Dielectric withstands capability versus calculated dielectric stress for oscillatory transient voltage.

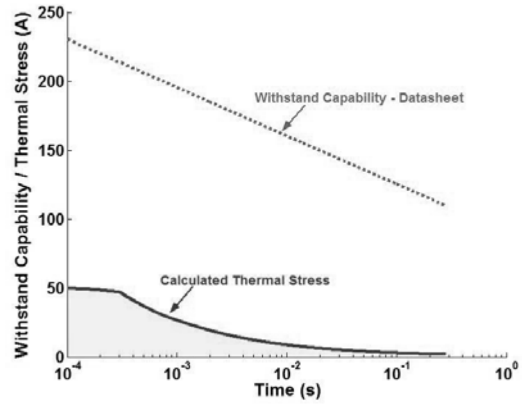

Fig. 15. Thermal withstands capability versus calculated thermal stress for oscillatory transient voltage.

6.3 Case 3 – Voltage Swells

The disturbance here considered is a common type of phenomenon to occur in distribution network. However, the use of a voltage swell leading to a final value of 660 V is a hypothetical and critical situation.

The voltage and current waveforms are given in Figures 16 and 17. Complementarily, the comparison between the withstand capability to the system efforts are illustrated by Figures 18 and 19. They show that the dielectric limits were violated considering any criterion of limit. This is in accordance with references [5] and [6] which states that TV set equipments were damaged during experimental tests with the same conditions here established.

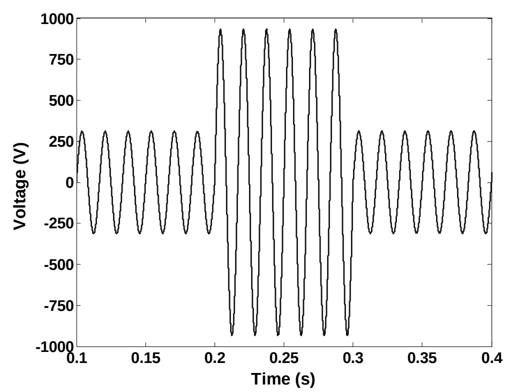

Fig. 16. Voltage supply with 200% of voltage swell upon the rated value with a duration of 100ms.

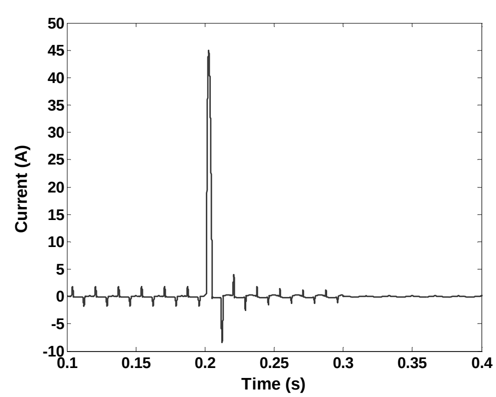

Fig. 17. Input current for 200% of voltage swell upon the rated value with a duration of 100ms.

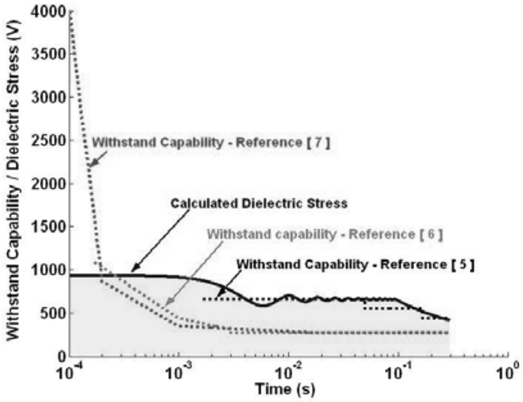

Fig. 18. Dielectric withstands capability versus calculated dielectric stress for 200% of voltage swell upon the rated value with a duration of 100ms.

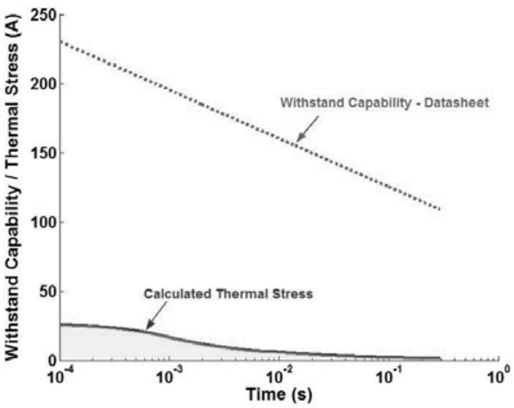

Fig. 19. Thermal withstands capability versus calculated thermal stress for for 200% of voltage swell upon the rated value with a duration of 100ms.

7. Conclusion

This paper has summarized an approach to assist technical reports in response to consumer demands towards refunding of damaged equipment due to supply voltage disturbances.

The methodology and the computational simulator were based on comprehensive appliance models and common disturbances often found in distribution networks. The ATP software was used for this work. This choice was made so as to achieve a reliable and low cost platform to perform the studies.

By applying typical voltage disturbances it has been shown that the equipment and system models allow for obtaining the device disturbed input voltage and current. These are then converted into dielectric and thermal efforts. By comparing these to the equipment withstand curves it was possible to check if the limits were violated or no. The results given in this paper have illustrated the use of this strategy and the methodology to produce the required relationship between the abnormal voltage or current and the possibility of equipment damage.

Using published information related to real tests in laboratory it was possible to obtain a first view of the approach adequacy for the type of analysis here focused.

Although the results were quite encouraging it must stated they are initial and much deeper investigation are to be carried out until a final and reliable procedure is achieved.

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