A COMPUTATIONAL APPROACH FOR CONSUMERS REFUNDING ANALYSIS ASSOCIATED TO VOLTAGE DISTURBANCES AND EQUIPMENT DAMAGES

Carlos Eduardo Tavares, José Carlos de Oliveira, Marcus Vinícius Borges Mendonça,
Antônio Carlos Delaiba, Rildo Marley Tavares da Silva*
Federal University of Uberlândia, *CEB distribution
Av. João Naves de Ávila, 2121 – Campus Santa Mônica, Bloco 3N, CEP: 38.402-902, Uberlândia, MG - Brazil,
cetavares@eel.ufu.br, jcoliveira@ufu.br, borgesmarcus@yahoo.com.br, delaiba@ufu.br, rildo@ceb.com.br

***Abstract* – This paper is aimed at presenting a computational methodology to assist in the establishment of electro-electronic device performance indicators towards the analysis of consumers refunding. The strategy is based on the calculation of appliance dielectric and thermal stresses with different power 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 modeling and computational implementation of different electronic devices and power network elements into the ATP program to simulate the power system disturbances and the equipment performance. In this work, a typical TV device is taken to illustrate the proposed methodology. The dielectric and thermal stresses here considered are related with the occurrence of voltage swells, oscillatory transients and high-frequency impulse related to lightning strikes.**

***Keywords* – Equipment damage, dielectric and thermal stresses, household electronic device, power quality, repayment.**

I. 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 and these concerns are especially true for new technology devices. These are generally more sensitive to power quality deviation [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 when one considers the amount of financial resources involved in the matter.

To better understand this problem 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, arises the idea of obtaining computational information to reproduce the disturbed voltage supply and apply it to distinct devices to estimate the dielectric and thermal stresses [2, 3, 4, 5, 6]. The approach is based on the relationship between the disturbed voltage and current impacts upon the device and the appliance thermal and dielectric withstand capability.

In order to illustrate the proposed approach, a typical residential device is considered, i.e. a TV set. The equipment is submitted to different non ideal voltage conditions and the previously mentioned parameters are evaluated in accordance with the methodology proposed and implemented in the ATP simulator.

II. DEVICE AND DISTURBANCE MODEL

To achieve the above goal, a few steps are to be followed, initiating from obtaining specific equipment equivalent circuit and making possible the generation of distinct supply voltage disturbances. Following this procedure, by implementing these into a time domain platform it will be possible to have a tool to investigate the device behavior submitted to voltage disturbances. In this way, this section focuses the strategy to model the appliances and the non-ideal supply conditions. Although the methodology can be applied to any equipment, to better illustrate the procedure, the following description focuses the application to a TV set.

A. TV set computational modeling

The first step consists in obtaining the equivalent circuit for the chosen appliance. Focusing the TV set, the input unit is given by the classical switched source, followed by several other internal circuits. The general data to achieve the circuit to model the appliance can be extracted from manufacturer's catalogs, experimental surveys and other sources. Although the great complexity associated to the equivalent model, it should be pointed out that, for the present analysis, the major concerns are the equipment input units. In this way, Figure 1 shows the final circuit chosen to be implemented into the ATPDraw platform. This figure highlights the mentioned power source and other internal circuits are simplified throughout a constant power model. This approach aims at including the effect of the stabilizing circuits always presented in such type of equipment [7].

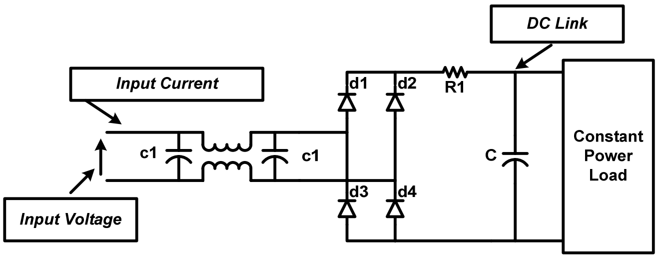

Fig. 1. Electrical equivalent circuit of the TV set.

Once the equivalent circuit has been established, it is necessary to implement it in the selected computational platform, namely, the ATP simulator. Using the ATP Draw facilities, the equipment model was set up and the final product is represent by the icon shown in Fig. 2. It must be stressed that this model allows for studying the TV behavior under steady state and transient conditions.

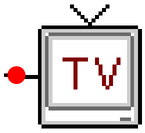

Fig. 2. Representative ATP model for TV set.

B. Disturbance computational modeling

As the ATP used in the investigations (ATPLauncher version 1.11 and ATPDraw version 4.0p2) do not provide the whole set of disturbance sources to represent network non-ideal operating conditions, these had to be developed and inserted into the program. The availability of such facilities is quite relevant to the matter of repayment analysis as it allows for reproducing real site phenomena impacting on the devices. Figure 3 presents the final type of disturbances which were developed and implement throughout the TAC´s functions. Therefore, the program can now easily handle voltage disturbances related to: harmonic distortions, voltage fluctuation and flicker, interruption, sag, swell, oscillatory transients and high-frequency impulses. These disturbances can be applied to any point at the network system and the program will propagate the phenomena until the busbar where the equipment under analysis is plugged.

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

III. 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 indicators are presented in the sequence.

A. Dielectric stress

Having in mind that the dielectric stress is directly dependent on the applied voltage level and duration, the adopted procedure uses the discrete data, as given by each ATP integration step, and calculates the voltage stress indicator as given by (1). It can be seen that the cumulative variable is found at each time interval and has a similar meaning to the true RMS voltage value. However, the calculation does not provide, as usual, a final RMS value for a given full period of the fundamental frequency, but a type of instantaneous pattern. In accordance with the proposal contained in (1), the reference time is taken at the moment the disturbance impacts the device.

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

Where:

V_k - Dielectric stress for any instant of time;

V_i - Instantaneous voltage value for any instant of time;

n - Sample numbers.

B. Thermal stress

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

$$I_k = \sqrt{\frac{\sum_{i=1}^{n} I_i^2}{n}} \tag{2}$$

Where:

I_k - Thermal stress for any instant of time

I_i - Instantaneous current value for any instant of time

n - Sample numbers.

IV. 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 [8] 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, it must be recognized that 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 allows for the following possibilities of equipment voltage limits:

- ITIC limits [8];
- TV set voltage susceptibility limits obtained from experimental tests using distinct voltage swell at fundamental frequency [5];
- TV set withstand tolerance limits obtained throughout experimental tests comprising impulse and voltage swell in accordance with IEC 61000-4-5 and IEC 61000-4-11 standards [6].

Concerning thermal withstand capability limit, the corresponding curve was derived from manufacturer's rectifying bridge datasheets as defined by the switched source used to feed the internal TV circuits.

V. STUDIED CASES

To illustrate approach applicability 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 selected non-ideal supply voltage conditions to be discussed.

TABLE I
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

The mainly characteristics of these cases were based on information given in [5,6,9].

VI. RESULTS

Using the ATP computational base in which the TV set and other equipment have been inserted, as well as the facilities to reproduce the system disturbances, the investigations were carried out. Although a large number of information can be extract for both equipment and system, for this paper purposes only the following results are given:

- Investigated appliance input voltage and current waveforms;
- Dielectric and thermal withstand capability, as well as the corresponding efforts associated to the specified voltage disturbance.

A. 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.

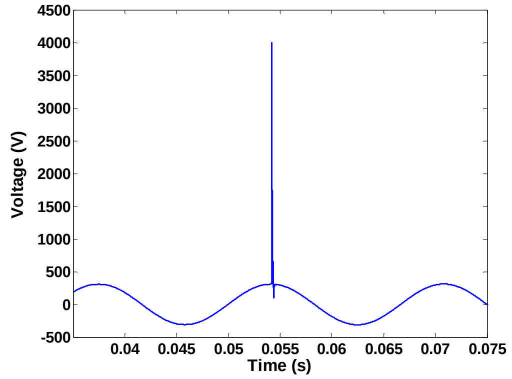

Fig. 4. Voltage supply with 4kV impulse at the TV input.

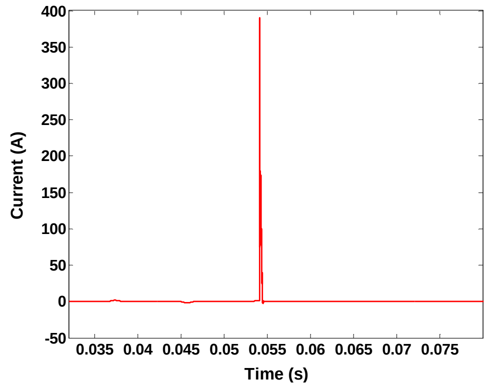

Fig. 5. TV input current related to the 4kV impulse.

The associated dielectric and thermal performance are shown in Figures 6 and 7. As already mentioned, both the disturbance impact and the equipment withstand capability are given.

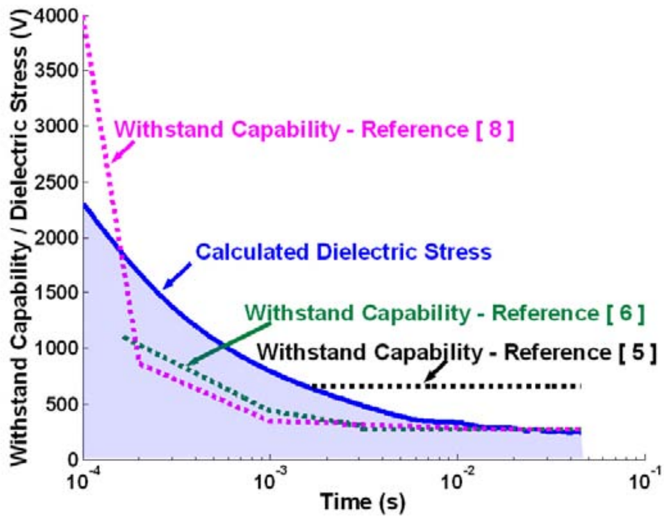

Fig. 6. Dielectric withstands capability versus calculated dielectric stress related to the 4kV impulse voltage.

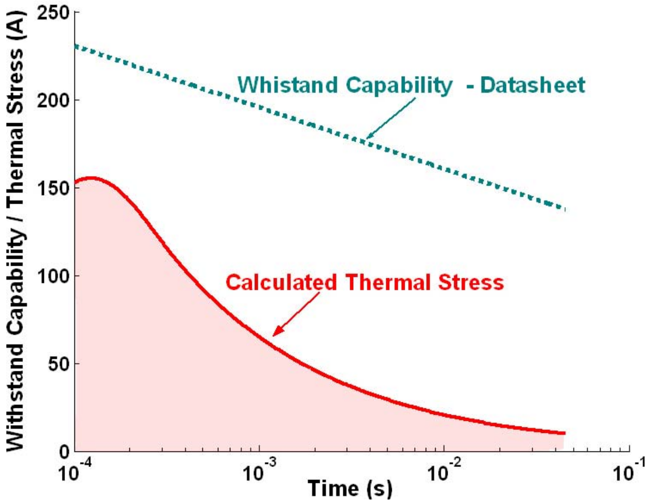

Fig. 7. Thermal withstands capability versus calculated thermal stress associated to the 4kV impulse voltage.

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. The figures also show that the thermal limit has not been reached. The results are in agreement with the terms stated in reference [6] which inform that 4 out of 7 equipments (TV sets) 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. With this disturbance, the voltage limits are marginally achieved, i.e. the probability of damaging the TV will be small, as it should be expected. Again, this conclusion is in accordance with references [5] and [6].

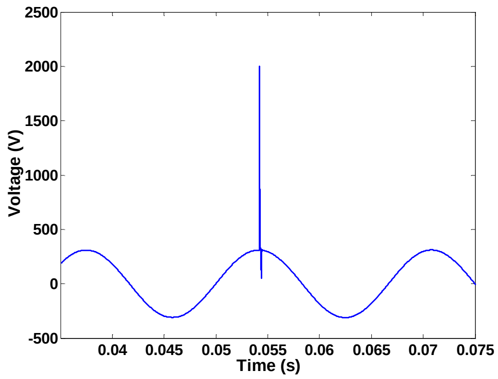

Fig. 8. TV input voltage supply with 2kV impulse.

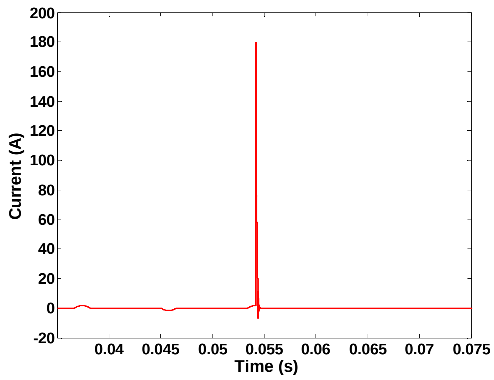

Fig. 9. TV input current with 2kV impulse voltage.

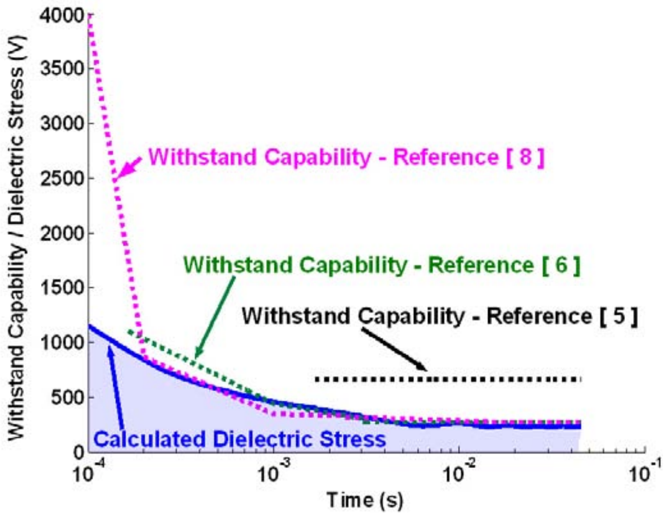

Fig. 10. Dielectric withstands capability versus calculated dielectric stress with 2kV impulse voltage.

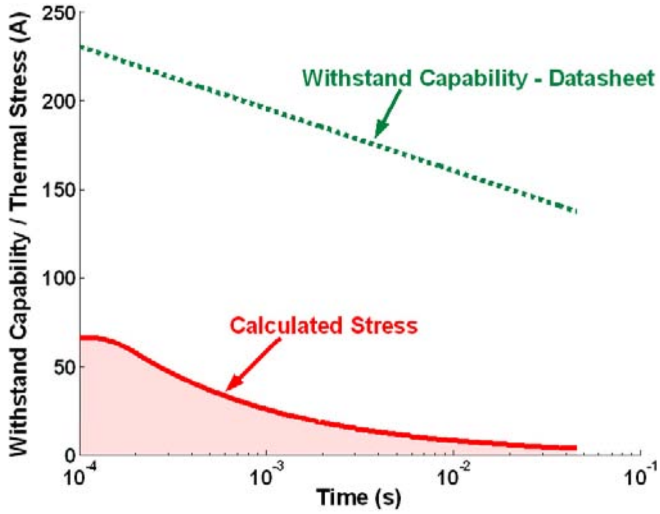

Fig. 11. Thermal withstands capability versus calculated thermal stress with 2kV impulse voltage.

B. Case 2 – Oscillatory transients

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

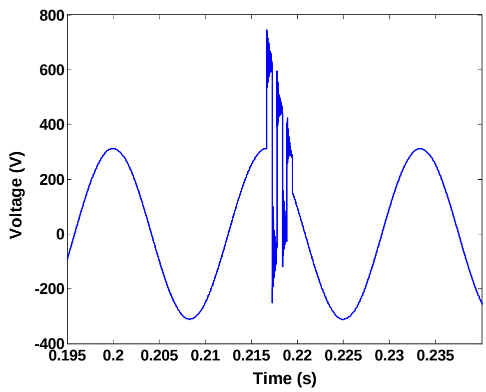

Fig. 12. Oscillatory transient voltage.

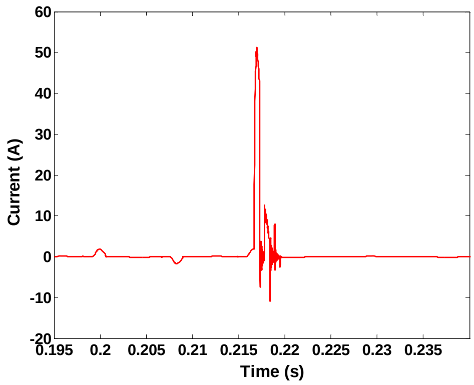

Fig. 13. Input current due to the oscillatory transient voltage.

Once again, by superimposing the withstand voltage and current limits to the disturbed voltage effect at the equipment input, Figures 14 and 15 evidence that the dielectric stress may be the reason for an eventual TV damage whilst the thermal limit curve will easily tolerate the current effort.

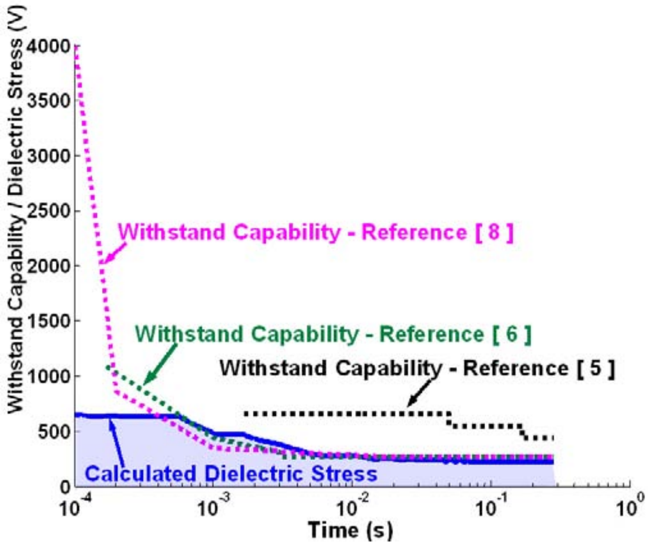

Fig. 14. Dielectric withstands capability versus calculated dielectric stress associated to the oscillatory transient voltage.

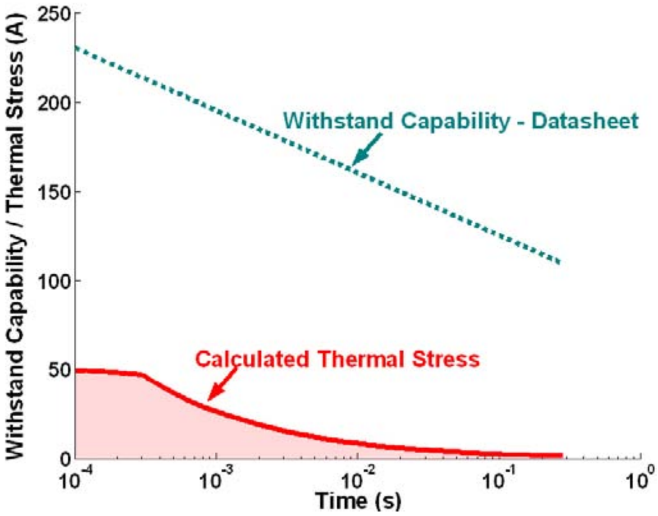

Fig. 15. Thermal withstands capability versus calculated thermal stress related to the oscillatory transient voltage.

C. Case 3 – Voltage swell

The disturbance here considered is a common phenomenon that occurs in any distribution network. Typically, values around 173% of the rated voltage are the highest levels. However, aiming at producing an over voltage corresponding to that utilized in [5], the voltage swell disturbance here adopted lead to a final value of 660 V. This is equivalent to 300% of the rated voltage, i.e. 200% of over voltage.

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 withstand criterion. 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.

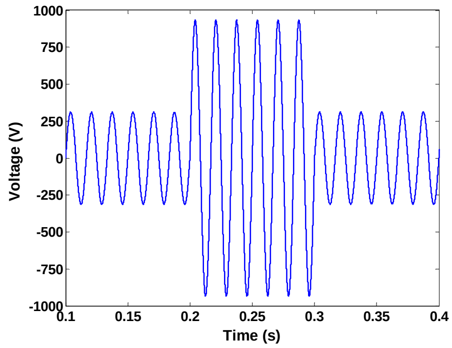

Fig. 16. Voltage supply with 200% of voltage swell with a duration of 100ms.

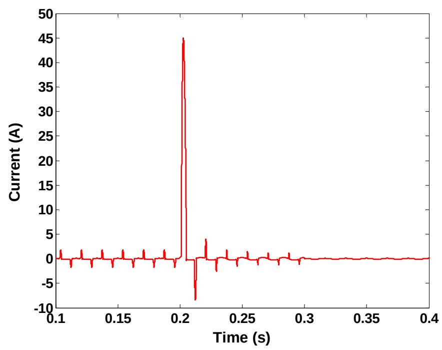

Fig. 17. Input current for 200% of voltage swell with a duration of 100ms.

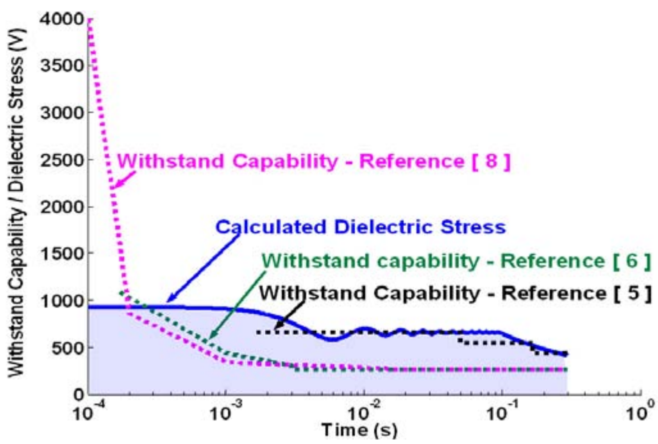

Fig. 18. Dielectric withstands capability versus calculated dielectric stress for 200% of voltage swell with a duration of 100ms.

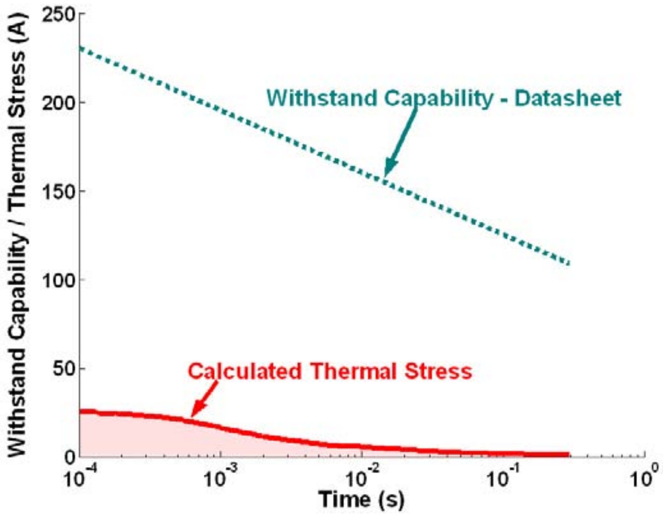

Fig. 19. Thermal withstands capability versus calculated thermal stress for for 200% of voltage swell with a duration of 100ms.

VII. 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 the found efforts to the equipment withstand curves it was possible to verify the possibility of causing equipment damage throughout the curves violation limits.

Using published information related to real tests in laboratory involving TV set operation with voltage disturbance conditions, as describe by the specified references, it has been shown that the proposed method is promising in handling the focused mater, i.e. the establishment of an approach to cope with consumer refunding technical analysis.

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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