Study of Transient Phenomena with Feature Selective Validation Method

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Abstract— In recent years, computational electromagnetism has had a great development thanks to the computational systems speed increase and their cost reduction. With those improvements the mathematical algorithms are able to work properly with more practical EMC issues. The problem that arises many times is to become confident with the results, in other words, to be able to quantitatively validate the results of the numerical simulation. In this paper we present a method to evaluate the difference between results obtained by visual expert opinion and those obtained from the FSV method.

1. INTRODUCTION

In recent years, computational electromagnetism has had a great development thanks to the computational systems speed increase and their cost reduction. These improvements have allowed us to analyze more complex systems and their EMC behavior.

One of the most interesting signals from the viewpoint of electromagnetic compatibility is impulsive noise, also known as transient phenomenon. Transient interference could be described as a signal that varies between two consecutive steady states during a short period of time compared to the time scale of interest. In other words, there must be a "momentary" change of the magnitude seen for a very short time in the sense that this short interval of time should be much less than one cycle of the signal affected [1].

The particular feature of them makes it difficult to analyze the effect of it in the different systems. For this reason, the numerical methods are a useful tool to analyze the effect of the transient signals in other systems [2, 3]. However, this new tool requires to ensure the quality of the results, in other words, to make a correct validation of the results.

The validation method most widely used today because of its versatility and simplicity in the field of EMC, is the Feature Select Validation method (FSV) [4, 5]. FSV, which is now an IEEE standard [6], has the advantage of analyzing the two major aspects that are considered in any validation, the magnitude levels and the shape of the graphs.

Despite all the benefits offered by the FSV in the validation processes, it has been observed in previous studies that there are some problems when trying to use this method in transient signals [7, 8]. To overcome these drawbacks, and to make a correct validation of transient signals, an original solution was proposed [8]: to mimic what an expert does when he analyzes a transient, dividing the signal in three different regions (pre-event, event, post-event) and assigning a specific weight to each of them. But not all transients are equal, so the main problem that arises in this new technique is the assignment of weights and the assessment of the size of each event for different types of transients.

This paper presents the analysis of three types of FSV methods to analyze some of the most representative transients in the EMC area. Specifically, eight transients were evaluated using the traditional FSV, the Weighted-FSV and the Manual-Weighted-FSV. All these methods were compared with expert opinion to help us make a more objective evaluation of each method.

2. FSV AND TRANSIENT PHONEMENA

The FSV method is based on the decomposition of the results into two groups; the first one discusses the difference in amplitude (Amplitude Difference Measure, ADM) and the second one the difference between the characteristics of the signal (Feature Difference Measure, FDM). The combination of these two indicators (ADM and FDM) is a measurement of the overall difference (Global Difference Measure, GDM).

All indicators ADM, FDM and GDM have the ability to be configured to perform a point-to-point analysis. The advantage of relying on point-to-point data is to know which areas of the data sets have the major differences. A subscript "i" is added to consider this point-by-point feature (ADMi, FDMi and GDMi). All of the indicators are calculated accordingly to the following equations ([6]):

$$ADM(n) = \frac{\alpha}{\beta} + ODM \cdot e^{ODM} \tag{1}$$

where:

$ODM = \frac{x}{\delta}$.

$x = (|DC_1(n)| + |DC_2(n)|)$.

$\delta = \frac{1}{N} \sum_{i=1}^{N} (|DC_1(i)| + |DC_2(n)|)$.

DC-data is the "very low" component of the original data.

Lo-data is the low-frequency component of the original data.

Hi-data is the hi-frequency component of the original data.

$$FDM(n) = 2(|FDM_1 + FDM_2 + FDM_3|) \tag{2}$$

where

$$FDM_1(n) = \frac{(|Lo'_1(n)| - |Lo'_2(n)|}{\frac{2}{N} \sum_{i=1}^{N} |(|Lo'_1(i)| + |Lo'_2(n)||}.$$

$$FDM_2(n) = \frac{(|Hi'_1(n)| - |Hi'_2(n)|}{\frac{6}{N} \sum_{i=1}^{N} |(|Hi'_1(i)| + |Hi'_2(n)||}.$$

$$FDM_3(n) = \frac{(|Hi''_1(n)| - Hi''_2(n)|}{\frac{7.2}{N} \sum_{i=1}^{N} |(|Hi''_1(i)| + |Hi''_2(i)|)|}.$$

$$GDMi(n) = \sqrt{ADM(n^2) + FDM(n)^2} \tag{3}$$

Another way to qualitatively analyse the FSV indicators is represented by a probability density function. This indicator is useful for a rapid and comprehensive analysis of the results. Histograms are sorted according to the quality of the results in excellent, very good, good, fair, poor and very poor.

This efficient and rapid method of analysis is ideal for most signals, but as mentioned above, some studies showed that the use of FSV for transient analysis is inadequate. For this reason, a variation of the method was created, **Weighted-FSV** [8]. This method divides the signal in three different sectors or regions and assigns a fixed weight to each of them. The first region (pre-event) is defined from $t = 0$ to the time the signal amplitude reached 5% of peak value. The pre-event represents 5% of the total weight on the transient analysis.

The second region (the event) is defined as the transition itself, ranging from the end of the pre-event up to a point that contains 65% of the signal energy (the largest region is chosen when the two sets of data match each other). Since this region is the most important of the entire disturbance, it is assigned a weight of 70% of the total.

Finally, the third region, the post-event, is defined from the end of the event to the end of the signal. Usually, this is the region of longer duration, but it is not the most important, for this reason a weight of 25% is assigned. However, despite this method has proven to be a good alternative for transient analysis, it has not been tested against a wide variety of them.

3. ANALYSIS OF THE TRANSIENTS

In this section we have analyzed eight typical EMC transients (Table 1). Figure 1 shows two short and very similar transients. In Figure 2, the transients analyzed have a longer settlement time and a larger ripple in each area of the event. The transients in Figures 3, 4 and 5 are more complex, with settlement times longer and with more ripples throughout the signal. Figure 6 shows two transients (Modulated Gaussian pulse) with equal amplitude but different modulation frequencies. Figure 7 shows two transient phenomena without pre-event and lengthy settlement times. In the last figure (Figure 8), shows two completely different transient signals.

The transients were carefully chosen and have a unique feature that will help us better understand the interpretation of the FSV, the "Weight-FSV" (W-FSV) and the "Dynamic-Region-FSV" (D-FSV). In the D-FSV method the weights are assigned in each zone manually, depending on the length and breadth that has the transient in that area in particular.

Finally, the results are compared with those obtained from a survey based on Likert scale questions [9], carried out with a sample of 18 experts in the area, who evaluated the transient based on previous studies [5]. To ease the comparison between the different methods and expert opinion, the mean square difference (see equation 4) is calculated for each indicator and each expert D-FSV method.

$$Diff(GDm_{expert}, GDMi_{FSV}) = \sqrt{\left(\frac{\sum_{i=1}^{n}(GDM_{expert(i)} - GDMi_{FSV(i)})^2}{n}\right)} \tag{4}$$

where: "i" is an element in the set of subjective values of the GDM indicator (from excellent to very poor).

4. DISCUSSION

Table 1 shows, as expected, that the worst results compared with the expert opinion are found in the FSV method. In the specific case of the transient signals, the FSV method has two problems. The first one is found in the ODM indicator (see Equation (1)), as it is severely affected by the offset levels. The reason can be found in the smaller offset in the signals when the value of "δ" decreases and the ODM grows. This error directly affects to the ADM indicator and, through it, to the GDM indicator. This is an important drawback for transients because most of them have offset

Table 1: Different type of transients analyzed.

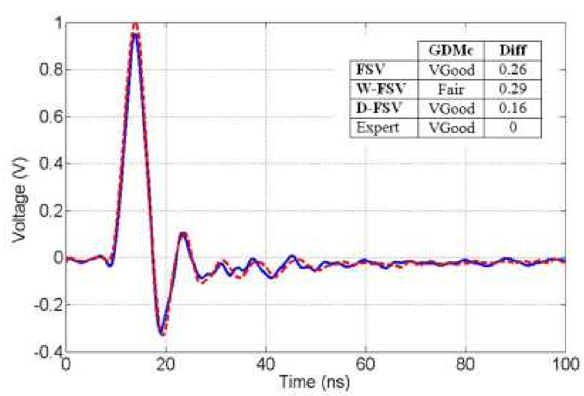

Figure 1: Weights used in D-FSV: pre=2%; event=95%; Post=3%.

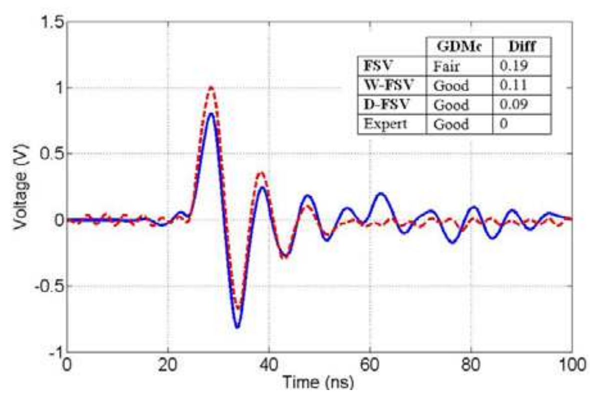

Figure 2: Weights used in D-FSV: pre=5%; event=70%; Post=25%.

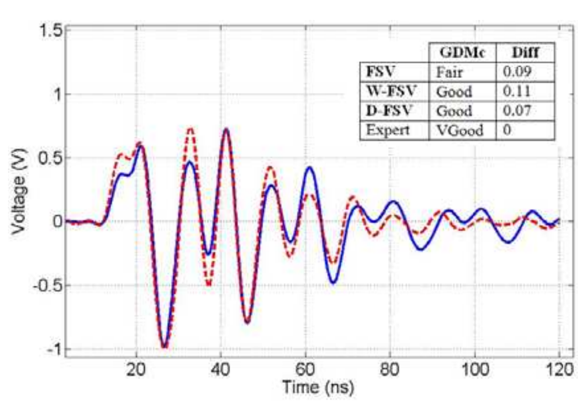

Figure 3: Weights used in D-FSV: pre=5%; event=85%; Post=10%.

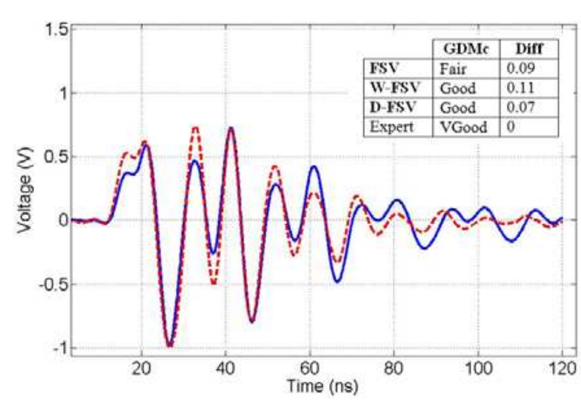

Figure 4: Weights used in D-FSV: pre=5%; event=80%; Post=15%.

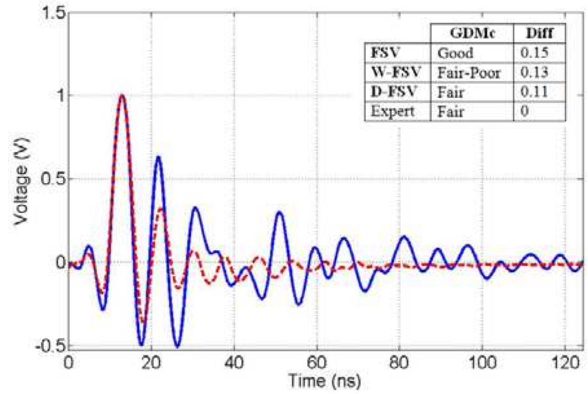

Figure 5: Weights used in D-FSV: pre=5%; event=70%; Post=25%.

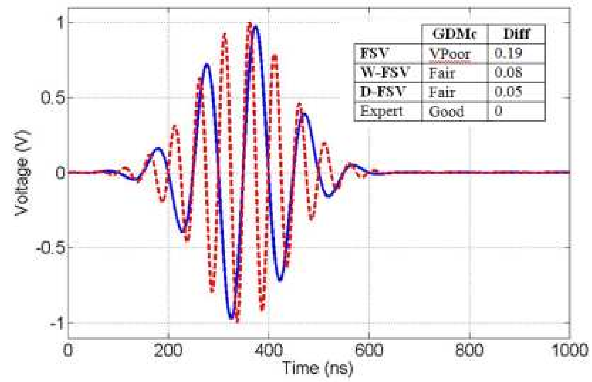

Figure 6: Weights used in D-FSV: pre=5%; event=85%; Post=10%.

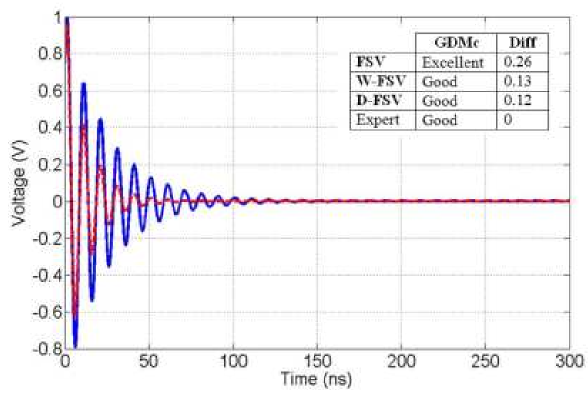

Figure 7: Weights used in D-FSV: pre=0%; event=80%; Post=20%.

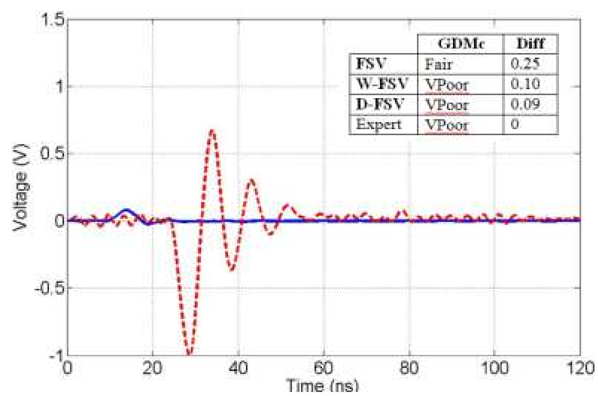

Figure 8: Weights used in D-FSV: pre=5%; event=80%; Post=15%.

levels close to zero. The second problem with FSV is, as stated above, that it gives equal weight to the three regions of the transient. This produces a grossly overestimating in the pre-event and the post event, skewing the final assessment away from the expert opinion.

The previous problems related with the FSV method were corrected with the W-FSV method. The ODM indicator deviations are solved by applying a large enough offset level to both signals to ensure an objective interpretation. On the other hand, the division of the transitional phenomenon into regions makes the results closer to the expert opinion in most of the cases.

However, this method still has some drawbacks. The main problem in W-FSV is that the weight remains fixed in all the proposed regions, regardless of the type of transient. Some good examples of this problem could be seen in the previous figures, where the importance of each event varies depending on the extent and duration of the event. An additional problem with this technique is that the possibility that the pre-event could be zero (Figure 7) or that the post-event could be extremely long (Figure 1) are not taken into account, making the results drift away from the assessments made by experts.

Finally, the results obtained by the method D-FSV presented in this paper, show an improvement over the W-FSV. The main reason for this improvement is that the weight assigned to each region of the event is selected manually in terms of magnitude and duration (Figures 1, 4, 6 and 7).

An important feature of this method is the procedure used to select the regions in the transient event. It was noted that if the power method (70% of total energy) is used to divide the event and post-event regions in the transient with very long or very short time of settlements (Figures 1, 4 and 6), some errors still appears in the interpretation of the transient. This division creates very short event and very long post-event regions in the transient, having a direct effect on the results of FSV. To solve this problem we use an approach based in the classical control theory [10] to divide the transient in the regions of interest. The theory defines the post-event region when the signal level decreases to 5% of the maximum. Conducting a study with the experts, the best value obtained for most of the transients was when the signal reached 10% of maximum.

5. CONCLUSIONS

This paper has addressed some problems related to validation of transient signals using different variants of the FSV method. The principal conclusion of this work is that, to use the FSV as a validation method for transient signals, it is not only necessary to divide each region of the transient carefully, but that a specific weighting for each region must also be carried out. The results obtained in this test show that it is necessary to assign weights to each region depending on both, its duration and amplitude.

Our results suggest that it is necessary to continue investigating ways of improving the analysis of transients in time domain through the FSV.

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