SOURCE SELECTION TECHNIQUES FOR EMP DIRECT DRIVE SIMULATION

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ABSTRACT

An important element in the development of a direct drive system for the simulation of electromagnetic pulse (EMP) effects on a system, and subsequent evaluation of hardening elements, is the selection of a suitable source waveform. Due to the magnitude of the signals involved, direct drive waveform choice is often limited to relatively simple types such as a double exponential or damped sine wave. Therefore, a suitable selection criteria or technique is needed to aid in the development of a direct drive system. This paper studies the suitability of a set of waveform norm attributes as a direct drive source selection technique. Experimental data are analyzed and the sensitivity of the waveform norm is presented.

INTRODUCTION

Theoretical development of the multi-port injection simulation technique [1,2] proved that the simulation would be exact if the proper multi-source excitation was applied at the terminals of the cable. A more compact approximate simulation technique was developed that reduced the number of sources needed for an N conductor cable from 2N to 2. Experiments were performed to demonstrate the accuracy of the approximate Thevenin equivalent source injection technique. Judgement of the accuracy of the approximate technique was based on overlays of the injection cable response with radiating EMP simulator data [2]. It was deemed desirable to have a more concise method of determining the quality of an injection simulation. Therefore, the concept of waveform norm attributes is investigated here as a method of estimating the accuracy of a simulation. An IBM PC based software package was developed that will compute the norm attributes of digitized data. Results of using the norm attributes as a criteria for judging injection simulation quality are discussed in the following section.

INJECTION SOURCE SENSITIVITY STUDY USING NORM ATTRIBUTES

The approximate Thevenin source injection technique is described in

references [1] and [2]. Experimental investigation of the adequacy of the technique is presented in [2], [3] and [4]. The experiment involved simulation of the cable response due to the Army's AESOP simulator with an approximate equivalent source injection technique. An overview of the experiment is given later in this paper. In the injection test portion of the experiment, two different source waveforms were used. The effect of the waveform differences on the quality of the simulation was analyzed via norm attributes. The purpose of this effort is to determine the suitability of the norm attribute computations as a basis for judging the adequacy of a synthesized injection source. As will be seen, the norms provide a simplified look at a waveform. The question to be addressed is their suitability for specifying and accepting injection sources.

The approach used to study this question is to analyze the results of the cable experiments described in the reference papers with the norm attributes. The cable experiments were performed with two different drive waveforms, one giving good simulation results based on a visual comparison of the data and one providing a poorer simulation. The ability of the norm computations to predict the quality of the simulation from the source waveform norms will be used as the criteria for estimating the suitability of the norms in selecting the proper drive waveform.

The use of norm attributes to analyze EMP waveforms was first proposed by Baum [5]. The specific set of norm attributes studied here are defined as [6]:

$$\text{Peak Absolute Amplitude } |f(t)|_{\max} \quad (1)$$

$$\text{Peak Absolute Derivative } \left| \frac{df(t)}{dt} \right|_{\max} \quad (2)$$

$$\text{Peak Absolute Impulse } \left| \int_0^t f(x) dx \right|_{\max} \quad (3)$$

$$\text{Rectified Impulse } \int_0^t |f(x)| dx \quad (4)$$

$$\text{Root Action Integral } \sqrt{\int_0^t [f(x)]^2 dx} \quad (5)$$

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An IBM PC software package [7] was written to allow computation of the norms using the digitized data from the cable experiment described in the next section. This will be followed by the actual results of the norm attribute comparisons.

INJECTION CORRELATION EXPERIMENT

Tests were conducted to evaluate the actual responses of the internal wires at the ends of a complex multiconductor cable due to free field (distributed) and direct drive excitation. Two different waveforms were used in the direct excitation mode.

The cable used in both experiments was a multiconductor cable with a braided metallic shield. The interior bundle is comprised of 25 individual wires. Pairs 14-15 and 20-21 are twisted together and covered with another shield. Pairs 16-17, 18-19, 22-23 and 24-25 are twisted together without additional shielding. The cross-section of the cable is given in Figure 1. It was determined that the cross section was fundamentally constant over the length of the cable. The cable has an outer jacket of polyethylene for environmental protection.

The EMP coupling to the interior bundle of wires is predominantly caused by electrical current flowing on the cable shield. The complex transfer impedance of the sheath and the sheath current gives rise to a longitudinal electric field just inside the cable shield. Additional coupling to the interior bundle is caused by the external electric field penetrating the cable shield.

Figure 1: Cable Cross Section

A test program was conducted to obtain current and voltage data on the cable as it is electrically excited by an incident electromagnetic pulse. The same set of measurement was then made utilizing the equivalent source injection system to drive the cable. A test was conducted using a radiating EMP simulator. The 25 conductor shielded cable was deployed at a distance of 100 meters from the simulator. The cable was 220 meters long and the ends of the cable were terminated to grounded shielded enclosures as shown in Figure 2.

Figure 2: Radiating Simulator Cables Response Experiment

Measurements performed included the open circuit voltages and short circuit currents of the internal wires. The open circuit voltages were nearly equal. The cable was then tested using the approximate Thevenin equivalent drive [1] shown in Figure 3. The voltage sources at each end were adjusted as close as possible to the radiating simulated induced voltage. Sources were placed at each end of the cable. The short circuit currents were measured.

Figure 3: Direct Drive Test Setup

A representative wire current comparison is presented in Figure 4. The injection response is seen to be similar in all respects to the radiating simulator wire current. Similar results were obtained for the other wires in the cable. In order to quantitatively evaluate the accuracy of the injection simulation, the standard set of waveform norms (equations 1-5) were computed for each measured wire response.

The norm values for all measured wire currents are included in the histogram of Figure 5. A negative value means that the drive value was lower than the radiating simulator value. The percent deviations are seen to be typically less than 50% for most of the norms. This is considered to be good agreement.

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Figure 4: AESOP vs. Direct Drive 1

Figure 5: Drive 1 Response Norms

In order to study the sensitivity of the injection technique to source waveform characteristics, a second drive waveform was used. The two different drive waveforms are compared to the radiating simulator waveform (the open circuit bundle voltage) in Figure 6. A represen-

Figure 6: AESOP Open Circuit Bundle Voltage and Direct Drive Source Waveforms

tative wire current is compared to the AESOP response in Figure 7. The norm attributes of the drive waveforms were computed and normalized to the AESOP values and are presented in Figure 8. The biggest difference in the drives was found to be their peak impulse norm (20% verses -24%). The other norms were within 10% for the two different drive waveforms.

Figure 7: AESOP vs. Direct Drive 2 Wire Response

Norm	Drive 1	Drive 2
PAA	0%	0%
PAD	80%	77%
PAI	20%	-24%
RI	31%	40%
RAI	9%	20%

Figure 8: Normalized Direct Drive Source Waveform Norms

Again, we looked at the short circuit current data induced by the drive 2 waveform. Waveform norm attributes were computed for each of these current measurements and the results are presented in Figure 9.

Figure 9: Normalized Direct Drive 2 Response Norms

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It can be seen that while the drive 2 source waveform norms (Figure 8) were close to the drive 1 norms, the drive 2 waveform created much larger errors in the internal current responses of the cable. Therefore, it was concluded that the standard set of waveform norms does not possess the sensitivity needed to be used in this application as a direct drive source selection techniques when applied only to the source waveform.

Voltage Integral Norm Attributes

The short circuit current in the cable bundle is proportional to the integral of the open circuit voltage [8]. Therefore each of the waveforms, AESOP open circuit voltage and both direct drive waveforms, were integrated numerically. Again waveform norms were calculated for the voltage integral waveforms. Comparisons were made against the AESOP (freefield induced) signals for both direct drive response waveforms. These results, shown in Figure 10 indicates that a maximum difference of 30% between the AESOP and good direct drive waveform norms. However, for the bad direct drive waveform a difference of over 200% was observed for the peak impulse, rectified impulse and root action waveform norm values.

<u>Norm</u>	<u>Drive 1</u>	<u>Drive 2</u>
PAA	-10%	24%
PAD	17%	6%
PAI	-30%	219%
RI	-30%	219%
RAI	-23%	200%

Figure 10: Normalized Voltage Integral Waveform Norms

The reason for the large errors in the integrated drive 2 waveform can be seen in Figure 6. The drive 2 source damps down much quicker than either the AESOP or drive 1 waveforms. Therefore, the integral of the drive 2 waveform reaches a much larger value than the other waveforms. This effect is evident in the wire current for the drive 2 excitation shown in Figure 7.

This technique yields the required sensitivity for waveform norm analysis to evaluate the direct drive voltage sources.

CONCLUSION

The goal of this study was to identify a quantitative method to evaluate the relative merit of a direct drive waveform or technique. In the past qualitative visual comparisons were the primary evaluation criteria. In the study we have shown that waveform norm analysis applied to good and bad direct drive source waveforms does not provide the necessary quantitative selection criteria. However, when one applies an appropriate system response function to the waveforms

(integration of the open circuit voltage in this case) prior to calculation of waveform norms, quantitative comparisons confirm visual observation.

The use of norm attributes as a method for selecting drive sources can be an effective technique if some analysis is applied to the source waveforms.

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