Impact evaluation of conducted UWB transients on terminal loads in a network

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Abstract

In this paper, we consider a conducted UWB disturbance due to intentional electromagnetic interference (IEMI), and evaluate impact quantifiers at the loads of a network. Through FFT, we characterize the time-domain transient and apply a Baum-Liu-Tesche (BLT) approach. The EMI received at the loads, which can be inductive, capacitive or resistive, is calculated and via the inverse FFT, we get the load responses in time-domain. To perform an impact evaluation of the loads, five quantifiers, i.e., time-domain peak, total signal energy, peak signal power, peak time rate of change and peak time integral of the pulse, are employed. It is seen that the impact evaluation of different kinds of loads, in a particular network, should be based on different attributes depending upon the characteristics of the transient.

Keywords: conducted UWB transient, IEMI, galvanic network, impact evaluation.

1 Introduction

In modern society, the terminal loads connected to a power line network are not limited to simple electrical loads. With the development of smart grids and techniques of power line communication, more diverse loads, such as power line modems, smart meters, and other modern electronics, are also able to directly access to the power line network. This increases the vulnerability of the power line system when it is exposed to an electromagnetic disturbance.

Intentional electromagnetic interference (IEMI) is a particular high power EM threat to civilian society. In [1], the IEMI-cube is provided for evaluating IEMI vulnerability. Having a complete impact evaluation helps a lot to reinforce the robustness of the systems. To perform the evaluation, several metrics can be utilized. In [2], five common quantifiers, which differ in different aspects, such as the dielectric breakdown, heating effects, etc., are proposed. According to distinct characteristics of resistive, inductive and capacitive terminal loads, the situations of being affected by IEMI may differ a lot. The definitions of those five common and important criteria are given as follows:

- Time-domain peak, $\sup\limits_{0<t<\infty} \left| x(t) \right|$
- Total signal energy, $\int_0^\infty \left| x(t) \right|^2 dt$
- Peak signal power, $\sup\limits_{0<t<\infty} \left| x(t) \right|^2$
- Peak time rate of change, $\sup\limits_{0<t<\infty} \left| \frac{d}{dt} x(t) \right|$
- Peak time integral of the pulse, $\sup\limits_{0<t<\infty} \int_0^t x(t)\, dt$

In this paper, we consider a load, whose impedance varies from inductive to capacitive, placed in a multi-junction power line network. With an injected IEMI, we calculate the transient response of the targeted load, and obtain results in terms of five quantifiers.

2 Analytical Model

A network that consists of two junctions and four branches is studied in our work, as shown in Fig. 1. A conducted IEMI disturbance is injected into the network from the end of one branch and other branches have loads connected. For the sake of simplicity, we assume load 1 and load 2 are resistive, while load 3 varies in both amplitude and phase (of course any load arrangement can be made to better suit a specific situation). Regarding load 3 ($Z_3 = R \pm jX = |Z|\angle\varphi$), the ranges of amplitude (i.e., $|Z|$) and phase (i.e., φ) are given by 1 to 1000 Ω and -π/2 to π/2, respectively. Furthermore, we assume that branch lines are of the same length L and characteristic parameters Z_c. Parameters of the model are summarized in Table 1. Here, a double-exponential UWB transient is considered for the IEMI source, and expressed by

$$a(t) = A_0 \left(e^{-\alpha t} - e^{-\beta t} \right), \qquad (1)$$

where A_0 is the peak value, α and β relate to the full width at half maximum (FWHM) and rise-time, respectively (however any waveform could be used in the investigation).

In the calculation, the duration of the UWB transient is 10 ns and the rise-time is 0.1 ns. FFT is used to characterize the double exponential pulse in the frequency domain, and the number of sampling points for FFT is 1024.

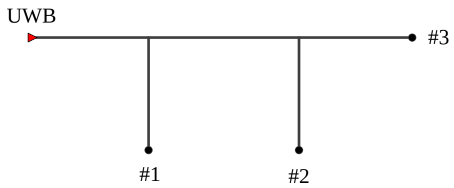

Figure 1. Example of a power line network.

By using the developed method [3] based on the BLT equation [4, 5], we subsequently calculate the voltage received at each load for different frequencies. Afterwards, the transient responses of the loads (in time domain) are obtained through the inverse FFT.

Table 1: Parameters in the model.

Parameter	Z_1	Z_2	$\|Z\|$	φ	Z_c
Value	100 Ω	100 Ω	1 ~ 1000 Ω	-π/2 ~ π/2	50 Ω
Parameter	A_0	α	β	**NFFT**	L
Value	1 kV	10^9	10^{10}	1024	3 m

3 Results and Analyses

Based on the analytical model established in Section 2, we can obtain numerical results for each load, with respect to the mentioned five quantifiers. Regarding load 3, results varying in the amplitude-phase plane, are shown in Fig. 2, and we can see that:

- From Fig. 2a) to 2d), in the region of low amplitudes (<= 400 Ω), there are two peaks occurring in each figure, at dominantly inductive and capacitive behaviour and around 50 Ω (which was seen to be, but not shown, a function of Z_c). It indicates that dominantly inductive or capacitive loads, with certain amplitudes, may suffer most from conducted UWB transients. However, in high amplitude region (> 400 Ω), with respect to amplitude or phase, the impacts of IEMI on five quantifiers are not significant.

- In Fig. 2e), for all phase values, the quantifier increases monotonically with amplitude, and the reason is that the transient voltage response of load 3 keeps positive in this case. Similarly to the first observation, when the amplitude is less than 200 Ω, especially around 50 Ω, the peak time integral of the pulse will faster achieve the highest value, when the load tends to be dominantly inductive or capacitive.

4 Conclusions

In this paper, we consider a specific multi-junction multi-branch power line network and investigate, with the aid of FFT and developed BLT method, the impact of IEMI on a targeted load in time domain.

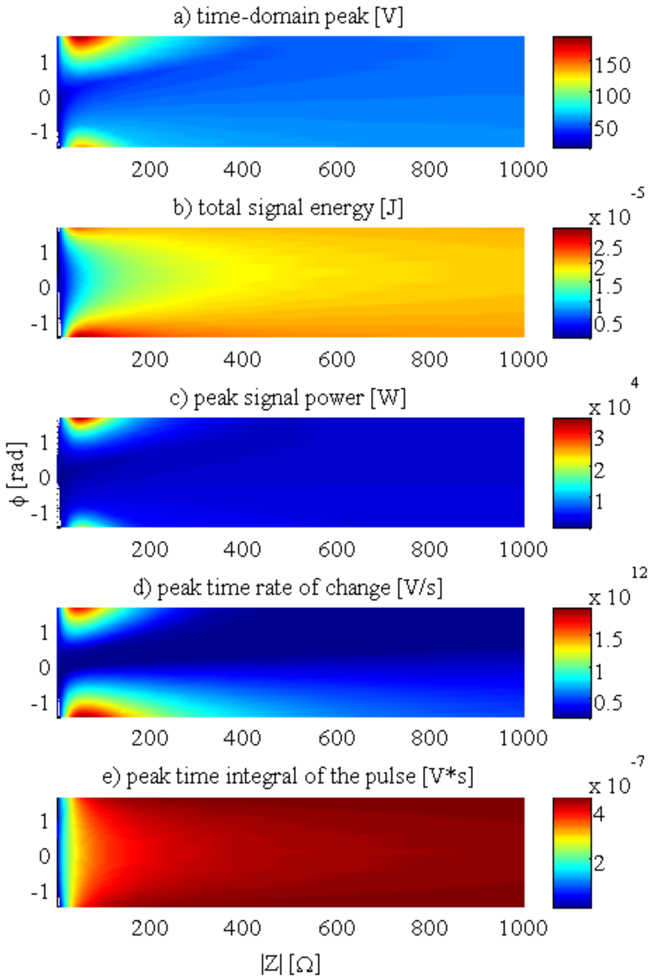

Figure 2. Calculation results of five quantifiers.

Results show that, in terms of the five common distinct evaluation quantifiers, a UWB source has a significant impact on a dominantly inductive or capacitive load with, here, a low amplitude (≈ 50 Ω). Thus, a system can be made less vulnerable by adapting the input impedance accordingly.

References

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