A simulation method for lightning surge response of switching power

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Abstract. In order to meet the need of protection design for lightning surge, a prediction method of lightning electromagnetic pulse (LEMP) response which is based on system identification is presented. Experiments of switching power’s surge injection were conducted, and the input and output data were sampled, de-noised and de-trended. In addition, the model of energy coupling transfer function was obtained by system identification method. Simulation results show that the system identification method can predict the surge response of linear circuit well. The method proposed in the paper provided a convenient and effective technology for simulation of lightning effect.

1. Introduction
Surge poses an important LEMP (lightning electromagnetic pulse) effect on electric devices. According to the accident statistic data, 70% surge interferences come from power lines [1-2]. Effect of lightning is mainly presented in surge injection to power circuit. In order to promote the LEMP immunity of electric devices, it is very important to research on the lightning surge energy coupling to power.

LEMP energy coupling is the key for system level effect simulation. It can be divided into mechanism analysis method and data statistic method. Computation in the mechanism analysis method is complex, while data statistic method obtains energy coupling model from input and output data of a black box. Data statistic method includes many realized methods such as probability statistic method, spectrum estimating method, system identification method. As a comparatively mature method, system identification has been widely used in linear system modelling. The principle is to take the energy coupling way as a black box. Model parameters can be identified from experimental data in order to get energy transfer function model.

2. System identification
L. A. Zadeh defined the identification as follows: Identification is to choose a model equal to real system from a set of models based on input and output data. Identification contains experiment design, model structure identification, parameter identification, model verification [3]. Figure 1 shows a system identification procedure.

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Model structure identification includes model class choice and model structure parameter confirmation. MATLAB system identification tool-box has provided several models such as ARX model, ARMAX model, BJ model, etc [4]. Function of ARX model can be expressed as follows:

\[ A(q)y(t) = q^{-nk} B(q)u(t) + e(t) \]  
\[ A(q) = 1 + a_1 q^{-1} + a_2 q^{-2} + \ldots + a_{na} q^{-na} \]  
\[ B(q) = b_1 + b_2 q^{-1} + \ldots + b_{nb} q^{-nb+1} \]  

In equations (1)-(3), \( na \) and \( nb \) are the polynomial orders, \( nk \) is the pure delay time, \( e(t) \) is the zero mean noise.

The estimating criterion for unknown system includes residual error quadrum sum criterion, check criterion, final error prediction criterion and AIC (Akaika Information Criterion) [4]. AIC is a model order confirmation criterion which has an objective standard. Its order confirmation criterion is as follows:

\[ AIC(n_\theta) = N \ln \sigma_e + 2n_\theta \]  

\( n_\theta \): Number of \( n \) order known parameters.  
\( \hat{\theta} \): Maximum likelihood estimating value.  
\( L(\hat{\theta}, n) \): Likelihood estimating function which reflects the accuracy. Akaika proved that \( \hat{n} \) is a system order when \( AIC(n_\theta) \) is the minimum.
3. Experiment design
Lightning surge injection test has been designed according to GB/T 17626.5-1999 (surge immunity test) [5]. Surge generator is a LSG-8015 made by Shanghai SANKI. Oscilloscope used in experiments is a Tektronix TDS7404B whose maximum sampling rate is 20 GSa/s (testing band width 4 GHz). EUT (Equipment under test, EUT) is a regulated power supply. The testing equipments for lightning surge injection are showed in figure 2.

Injection and response waveforms of EUT are collected by a digital oscilloscope. Three grades of surge peak voltages (600V, 700V, 800V) are chosen in order to avoid EUT works in the nonlinear region. Figure 3 shows the injection surge waveforms and EUT response voltage waveforms.

4. Data pre-process
Since noise burried in experimental data can affect the accuracy of model identification, it must be reduced before modelling. Wavelet can analyse signal in time domain, frequency domain and separate accident component and noise. Donoho-Johnstone shrinking de-noising method is used by db series of
wavelet function decomposition [7-8]. It has been concluded from repeated tries that db3 wavelet function for surge signal and db9 for response signal can get a better result.

Identification demands that the mean value of data is zero and the statistic speciality has no relationship with start time. So data smoothing is mandatory to remove the tendency. In order to reduce the model order and increase the model accuracy, only middle frequency component switch has been excited thoroughly. Figure 4 is the waveforms after pre-processing. The peak and accident part of signals has been reserved well.

![Figure 4. Waveform after pre-processing.](image)

5. Modelling
In fact, a majority of systems are essentially non-linear. Linear model is only proximate in some characteristics. The energy between power circuit and lightning surge is assumed to be linear. Surge voltage is taken as the input signal of a black box. Response voltage is the output signal of a black box. Model is identified via ARX model based on the least square method. Experimental data of 800V surge is used for identification. Data of 600V and 700V are used to verify the model.

5.1 Model identification
The order of model should be chosen as low as possible if the accuracy is satisfied. Program is written with MATLAB. Polynomial model can be identified as follows:

\[
A(q) = 1 - 1.809q^{-1} + 1.816q^{-2} - 1.483q^{-3} + 0.8928q^{-4} - 0.0911q^{-5}
\]

\[
B(q) = 0.009799q^{-5} - 0.0067q^{-6}
\]

Loss coefficient is 0.577032. Akaike final predictive error is 0.644352. Transfer function can be written as equation (7) if noise item \(e(t)\) is ignored.

\[
H(q) = \frac{B(q)}{A(q)}
\] (7)

Figure 5 is a comparison of the model output and the real output with 800V surge injection data. The GOF (Goodness of Fit, GOF) is 90.12%.
5.2 Model verifying

Model verification is necessary to system identification. In order to verify the generalization ability of model, estimating result is compared with the real output with a series of surge injection levels. It can be seen from figure 6 and figure 7 that the simulating results approximately match to the real output waveforms. The change trend is same. But the end part of waveforms is different.

Figure 5. Comparison of model output and real output.

Figure 6. Model output compares with real output of 600V surge injection.
6. Conclusion

Modelling for lightning surge coupling based on system identification has been researched in this paper. It proves that the system identification is an efficient modelling and forecasting method for lightning surge simulation.

This modelling method is applicable to the linear system. When the surge level is high, the EUT may work in a nonlinear area where the coupling will be more complex. So a further study such as neural network will be needed to get nonlinear model.

Acknowledgements

This project has been supported by Natural Science Foundation of China (50877079) and National Key Lab Foundation (9140C87030211JB34).

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