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Computer Aided-Program for Validation of HV Impulse Measuring Systems from Unit Step Response

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Abstract: - This paper presents the design and development of the computer algorithm based on LabVIEW for verification of high voltage measuring systems. This program was developed from the last version [1] by adding frequency domain consideration. Its algorithm consists of three parts. The first part is a program for calculating the parameters of unit step responses which are verified an ability of the measuring system by a comparison with the values given in IEC 60060-2. The second part is a program for computing frequency response of HV measuring system compared to magnitude of frequency contents of the standard waveforms by using FFT. The third part is a program for calculating the output voltage waveform by time convolutions between standard testing waveforms and unit step responses. The standard waveforms under investigation are full lightning impulse voltage waveforms, tail-chopped lightning impulse voltage waveforms, front-chopped lightning impulse voltage waveforms and steep-front voltage waveforms according to IEC standards 60060-2 [2] and 61211 [3]. This paper considers two measuring systems, with the resistive voltage divider and damped capacitive voltage divider for testings. The results show that the algorithms proposed in this paper is practicable, and should be a useful tool for impulse voltage measurements in a standard high voltage laboratory.

Key-Words: - computer aided-program, frequency domain, FFT, convolutions, impulse voltage measurements

1 Introduction

HV impulse measuring systems should be response with most of frequency contents of the measured impulse voltage waveform so the transfer functions of these measuring systems shall have frequency bands covering frequency of the measured voltage waveform. For verification of HV measuring system, the international standards such as IEC or IEEE/ANSI recommend that their parameters of unit step response shall agree with standard values. Moreover, CIGRE taskforce has mentioned that the convolution between an input, an output and an impulse response of the measuring system should be taken into account [4]. This paper is aimed to propose algorithms for the verification of impulse measuring systems with three analysis methods. The first one uses a comparison between unit step response parameters of the test measuring systems and these of given in IEC [2]. The second one uses comparison between bandwidths of frequency response of HV measuring systems and magnitude of frequency content of standard waveforms by using FFT. The third one uses an analysis on a correlation between input waveforms and output waveforms. Two different measuring systems are investigated with various input impulse voltage waveforms: full lightning, tail-chopped lightning, front-chopped lightning and steep-front surges. The methods for computing frequency response of a HV measuring system and FFT of the standard waveforms are explained. The comparison of the evaluation results using the standard unit step response tests and those from convolution method is discussed.

2 Impulse Voltage Measuring System

Basically, there are two major parts in an impulse voltage testing arrangement [4]. The first part is named as a voltage generating system consisting of an impulse voltage generator connected to a tested object via a lead cable. The other is named as an impulse voltage measuring system comprising an impulse voltage divider, a damped resister, a measuring cable, an attenuator and a digital oscilloscope. These are as shown in Fig. 1.

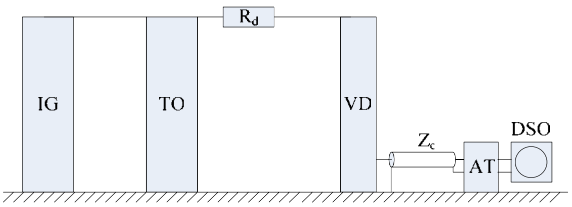


Fig 1. : Impulse voltage testing system[2,5]
(IG) Impulse voltage generator, (TO) Test object, (R_d) Damped resister, (VD) Impulse voltage divider, (Zc) Measuring cable, (DSO) Digital oscilloscope

According to IEC 60060-2, there are two important indicators, which are used to evaluate impulse measuring system characteristics [2]. These indicators are scale factors and the parameters of unit step response, experimental response time (T_N), partial response time (T_α), settling time (t_s), initial distortion time (T_0) and overshoot (β) as illustrated in Fig 2[2], [5]. For verification of the measuring system, unit step response parameters shall be in range, said in IEC standard [2], [3]

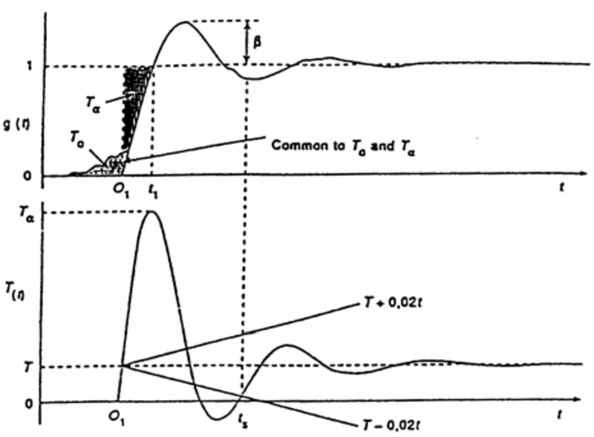


Fig 2. : The parameters of unit step response according to IEC [2, 5]

3 Calculations of Transfer Function and Output Waveforms of Measuring System from Unit Step Response

A voltage divider is constructed from passive components, and can be represented by a two-port network as shown in Fig. 3. The following parts are a mathematical analysis for such a network [4]-[6].

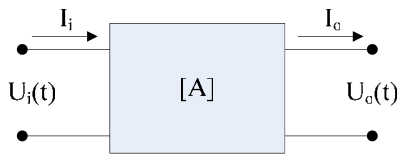


Fig. 3. A two-port network for a HV measuring system [4]

This network has relations between input and output waveforms in accordance with Equation 1[4].

$$\begin{bmatrix} U_i(s) \\ I_i(s) \end{bmatrix} = \begin{bmatrix} A_{11}(s) & A_{12}(s) \\ A_{21}(s) & A_{22}(s) \end{bmatrix} \begin{bmatrix} U_o(s) \\ I_o(s) \end{bmatrix} \qquad (1)$$

In case of a very low energy divider, $I_o = 0$, hence the transfer function is written as Equation 2.

$$H(s) = \frac{U_o(s)}{U_i(s)} = \frac{1}{A_{11}(s)} \qquad (2)$$

When the input voltage is a unit step, and a unit step response output is g(t). A transfer function of the measuring system is calculated by Laplace's transform or Fourier's transform of g'(t) from Equation 3.

$$H(s) = L[g'(t)] \qquad (3)$$

or $$H(f) = F[g'(t)]$$

$u_o(t)$ is calculated from $u_i(t)$ and g(t) by Duhamel's integration as shown in Equation 4.

$$u_o(t) = \frac{d}{dt}\int_0^t u_i(t) g(t-\tau)d\tau \qquad (4)$$

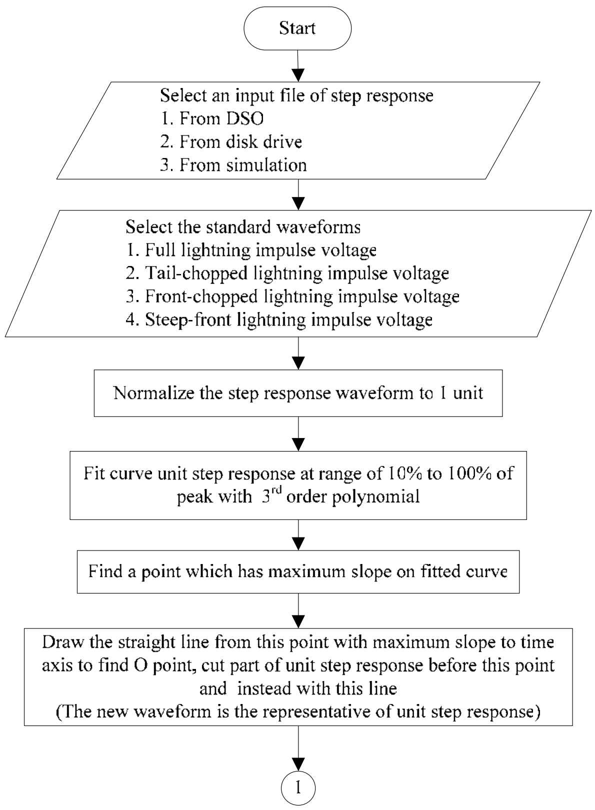
or $$= \int_0^t \frac{du_i(t)}{dt} g(t-\tau)d\tau$$

4 Program Developments

The developed program based on the LabVIEW [6] can be summarized as a flow chart shown in Fig. 4. The program is consists of three parts. The first part for a calculation of unit step response parameters receives a step response waveform from a digital oscilloscope, disk drives or waveform simulations computed on base of RLC circuit from Equation 5.[7]

$$g(t) = 1 - e^{-\frac{t}{T}}\left(\frac{1}{\omega T}\sin\omega t + \cos\omega t\right) \qquad (5)$$

The results of unit step response parameters are T_N, T(t), T_α, T_o, t_s, and β as shown in Fig. 5. The second part for frequency domain displays the comparison of the transfer function of the measuring system and normalized magnitude of frequency contents of the standard waveforms by using FFT. Additionally, this part shows the comparison of cut off frequency of magnitude of transfer function of a measuring system and f1% of magnitude of frequency contents of a selected standard waveform. f1% is frequency, of which magnitude is 1% of DC component of the selected standard waveform. The third part for an output waveform calculation displays the comparison of a standard waveform and a calculated waveform from the convolution method according to Equation 4. The standard waveforms can be selected from a list consisting of full lightning impulse voltage waveforms, tail-chopped lightning impulse voltage waveforms with a selected chopping time, front-chopped lightning impulse voltage waveforms with a selected chopping time and steep-front voltage waveforms with a selected chopping time. Moreover, this part shows the comparison of time parameters, peak voltages and relative slopes between the standard waveforms and the calculated waveform, as shown in Fig. 5.



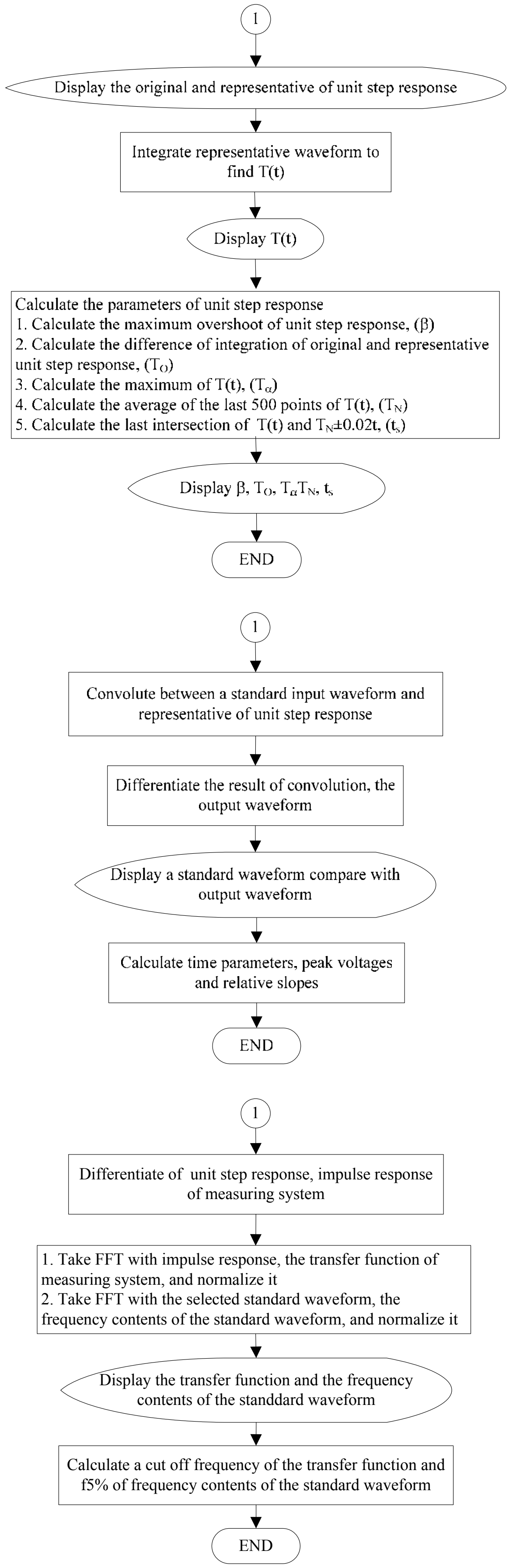


Fig. 4. Flow chart of the developed program

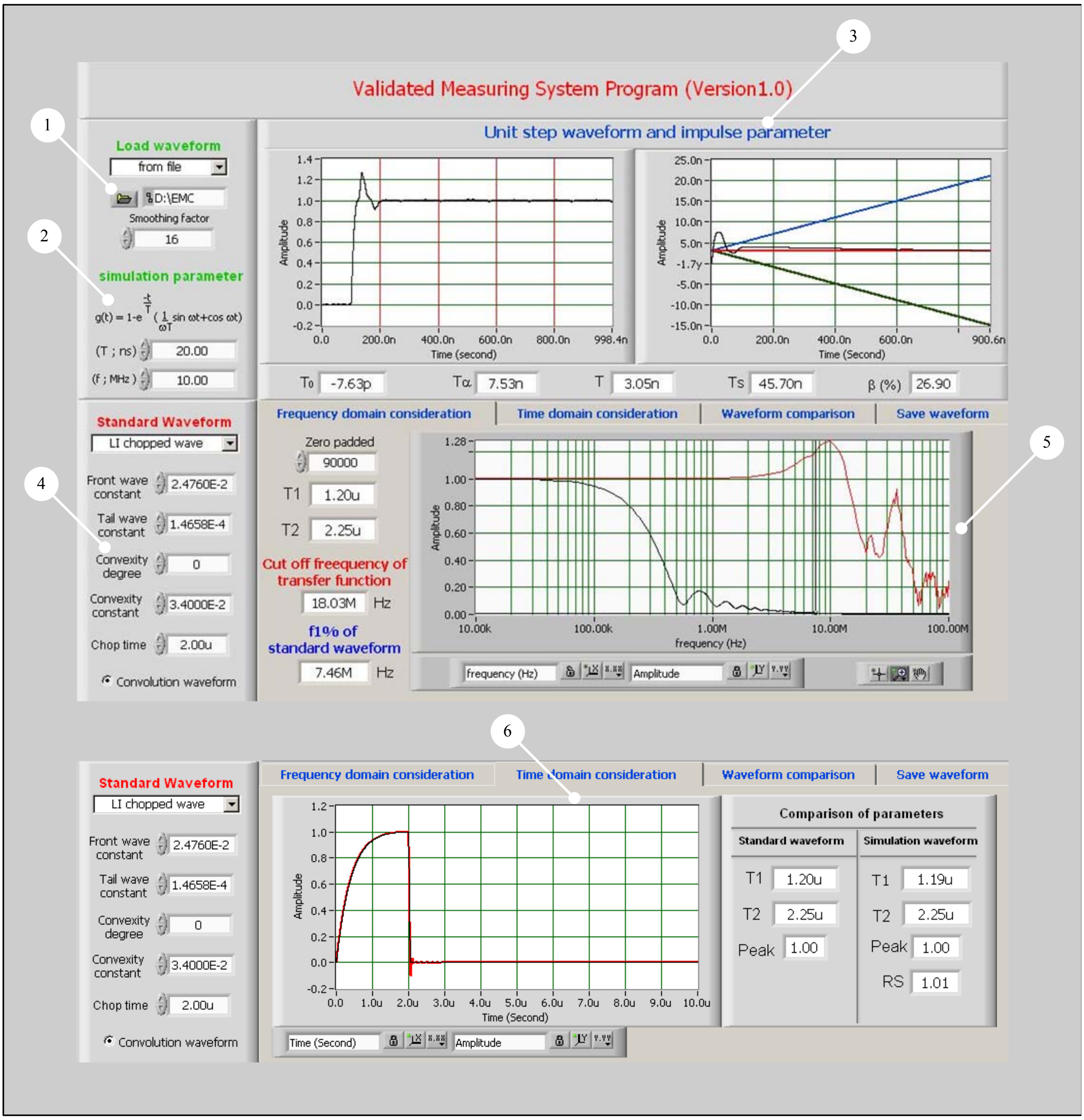


Fig. 5. A panel of the developed program

1) Part for selecting file source
2) Part for parameters of simulated unit step response
3) Part for displaying unit step response waveform, integral of unit step response waveform and unit step response parameters
4) Part for the selecting standard waveforms
5) Part for displaying magnitude of a transfer function of a measuring system and its cut off frequency, and frequency contents of a selected standard waveform and its f1% frequency
6) Part for displaying a result waveform from Duhamel' integration and an input selected standard waveform, and time parameters, peak voltage and relative slope

5 Example Test

In this paper, the program is employed to calculate the unit step response parameters and to verify two measuring systems, a resistive voltage divider 7kΩ 300 kV[8] and damping capacitive voltage divider 2nF, 200 kV. The unit step response of the measuring systems, and the results of the unit step response parameters are shown in Fig. 6 and Table 1.

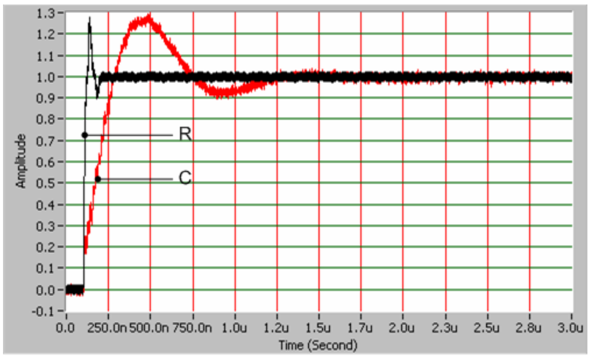


Fig. 6. Unit step response of impulse voltage dividers under investigations
R : from resistive voltage divider, C : from damped capacitive voltage divider

Table 1 Parameter of unit step response of impulse voltage dividers

Parameters	R	C
T_N	3.05 ns	85.67 ns
T_α	7.53 ns	91.42 ns
t_s	-7.63 ps	-2.67 ns
β	26.90	29.44

With the consideration on the basis of IEC standards [3], the four parameters shown in Table I are used in calculations to indicate whether each divider is capable of measuring the input impulse waveforms correctly. From this consideration the measuring system is in accordance with IEC standard 60060-2 but not in accordance with IEC 61211. To verify the validity of this measuring system under investigations by this program, various input waveforms, which are full lightning impulse voltage (LI), tail-chopped lightning impulse voltage at 2 µs (LITC), front-chopped lightning impulse voltage at 0.5 µs (LIFC) and steep-front impulse voltage with 100 ns chopping time (SF) are employed with an amplitude of one unit.

With frequency domain consideration, the cut off frequency of this measuring system, resistive voltage divider and damped capacitive divider, are 18.3 MHz 2.25 MHz respectively and f1% of the standard waveform, LI, LITC, LIFC and SF, having time parameters following by above, are 220 kHz, 7.46 MHz, 15.27 MHz and 43.92 MHz respectively. From these results show that cut off frequency of resistive voltage divider is above f1% of all standard waveforms except of SF waveform and cut off frequency of damped capacitive divider is just only above f1% of LI waveform.

In order to apply a convolution technique for predicting the capability of the dividers of the impulse voltage measurements by this program, the four input waveforms (LI, LITC, LIFC and SF) are substituted as $u_i(t)$ in Equation 4. From the method of derivative of convolution, the results of output waveforms are calculated. The output waveform parameters, which are peak voltage (V_p), front time (T_1), tail time (T_2) and relative slope (RS) are determined and compared with those of the input waveform so that the evaluation of each divider for different input voltages can be indicated. The parameters for such input voltages are shown in Tables 2, 3, 4 and 5.

Table 2 Parameters of output waveforms; input waveforms are full lightning impulse voltage (LI)

Parameters	Input	R	C
T_1	1.20 µs	1.21 µs	0.987 µs
T_2	50.00 µs	50.02 µs	50.24 µs
V_p	1.00	1.00	1.00
RS	1.00	0.99	1.24

Table 3 Parameters of output waveforms; input waveforms are tail chopped lightning impulse voltage (LITC)

Parameters	Input	R	C
T_1	1.20 µs	1.19 µs	0.962 µs
T_2	2.24 µs	2.25 µs	2.17 µs
V_p	1.00	1.00	0.99
RS	1.00	1.00	1.24

Table 4 Parameters of output waveforms; input waveforms are front chopped lightning impulse voltage (LIFC)

Parameters	Input	R	C
T_1	0.525 µs	0.522 µs	0.407 µs
T_2	0.585 µs	0.588 µs	0.571 µs
V_p	1.00	1.00	0.97
RS	1.00	1.00	1.25

Table 5 Parameters of output waveforms; input waveforms are steep-front impulse voltage (LIFC)

Parameters	Input	R	C
T_1	99.53 ns	93.52 ns	84.84 ns
T_2	119.80 ns	121.20 ns	287 ns
V_p	1.0	0.98	0.33
RS	1.0	1.05	0.38

The indicator for evaluating whether the divider are suitable to measure the specified input voltage waveforms is the correlation in values of V_p, T_1, T_2 and RS between the input waveforms and the output waveforms calculated from the convolution method. The results from frequency domain and time domain considerations show that the resistive voltage divider can be employed to measure all waveforms correctly except the steep-front impulse voltage waveform and the damped capacitive voltage divider can not use to measured all waveforms correctly. It should be noted that there are some cases that the measuring system can be used in impulse voltage measurements according to IEC standard consideration based on unit step tests but cannot be practicable when taking correlation between the inputs and outputs in frequency domain and in time domain into account.

6 Conclusion

The computer algorithm based on the LabVIEW for evaluating the validation of high voltage dividers in impulse voltage measuring system has been presented. In frequency domain, the cut off frequency of the transfer function and f1% In time domain, the convolution between a unit step response and standard waveforms has been calculated. Two types of high voltage dividers, a resistive divider and a damped capacitive divider, have been investigated for the verification of the calculation. The results have shown that the algorithm developed in this paper is able to analyze whether the impulse voltage measuring system under consideration is compatible with the input transient waveforms.

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References:

[1] P. Yutthagowith, N. Pattanadech, A. Kunakorn, and S. Phoomvuthisarn, Computer Aided-Program for Validation of Measuring System from Unit Step Response by Time Convolution Method, *TENCON 2005*, November 2005.

[2] *High-Voltage Test Technique Part 2 : Measuring System*, IEC Standard 60060-2, 1994.

[3] *Insulators of Ceramic Material or Glass for Overhead Lines with a Nominal Voltage greater than 1000 V : Puncture test*, IEC Standard 61211, 2004.

[4] CIGRE TASK FORCE 33.03.06, Response parameters for characterizing high-voltage impulse measuring system, *ELECTRA*, no. 161, pp.120-129, Aug 1995.

[5] E. Kuffel , W. S. Zaengl and J. Kuffel, *High-Voltage Engineering Fundamentals,*2nd ed., pp 129 – 146, Pergamon Press, 2000

[6] J. Travis, *LabVIEW for Everyone*, 2nd ed., Prentice Hall PTR, 2002

[7] S. Sato, T. Harada, T. Wakimoto and M. Saeki, A New Numerical Convolution Method for Impulse Response Analysis, *Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES,* Volume 1, 6-10 Oct. 2002, pp. 444 – 447.

[8] A. Rimsrimarat and K. Petcharat, *Design and Construction of 300 kV Referent Impulse Voltage Divider*, Technical report, Department of Electrical Engineering, Chulalongkorn University, 1999 (in Thai).