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A Method for Measuring Transient Switching Overvoltage Case study: Electricity network of Imam Khomeini Airport City

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Abstract

Transient voltage increase in electricity networks is of great importance due to security of devices and insulation considerations. One of the factors which results in transient voltage increase is connection switching. This overvoltage cannot be measured and recorded via usual measurement devices. In this study, possibility of using power quality analyzer for recording and measuring transient overvoltages is studied. To this end, switching in a 20KV electricity network in Imam Khomeini airport city is simulated using EMTP-RV. Then, real switching is performed and overvoltage is measured by power analyzer. Then, these two methods are compared.

Keywords: Transient overvoltage, EMTP simulation, transient overvoltage measurement.

1. INTRODUCTION

Studying different types of overvoltages and their characteristics is of great importance. In general, overvoltages can be divided into two categories of wave overvoltages and switching overvoltages. Among characteristics of wave overvoltages, high gradient and short time can be mentioned; overvoltages caused by lightning are of this kind. Switching overvoltages are also caused by electrification or de-electrification of lines. In the first case, insulation is studied and in the second case, power switch design considerations are considered. When lines are electrified via power switches, damping overvoltages caused by line resistance with an amplitude proportional to the source type and load are created which are known as switching overvoltages. Origin of these transient overvoltages is mobile waves which move along the line with light speed and create reflective waves upon reaching two ends of the line which increase overvoltage after being combined with each other; line

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loss degrades mobile waves after several reflections [1].

Frequency components of the system voltage might be different before and after switching which is due to presence of mobile waves created after switching which are effective before damping. Thus, switching transients are usually complicated waves with a frequency higher than system frequency which are carried by system voltage with main freuquency [2].

In overvoltages cases because of switching, the overvoltage would be different depending on the type of devices and whether the load is either connected to or disconnected from the system. If switching is performed when no load is connected to the end of the line, the voltage is increased up to two times the peak value which might be even more considering impedance type of the source and load. In addition, if impedance of load or source are equal to wave impedance of the line, overvoltage would be minimum [3].

Previously, various methods were presented for measuring and representing transient phenomenon. In this study, possibility of using Power Quality Analyzer for measuring and monitoring transient overvoltage is studied. For this purpose, the medium voltage network of Imam Khomeini airport city is investigated. First, the network is implemented using EMTP-RV; switching conditions are simulated and voltage waveform caused by switching is extracted. Then real switching is applied and the resulting overvoltage and its waveform are measured by power analyzer. Finally, these two methods are compared.

2. SIMULATION USING EMTP-RV

2.1. Introducing EMTP

EMTP was proposed by Herman Dummel. In 1970, due to use of series capacitors in USA's network for controlling reactive power, axis of a turbine of one of the plants broke and resulted in resonance between electric and mechanical systems of the turbine. In this accident, subsynchronous frequency happened resulting in breakage of the turbine axis. Thus, it was decided to design a software which can analyze subsynchronous frequency. Since then, professor Dummel in Bonneville Power Administration started designing the software. Since the designed program responded well, it developed very fast. EMTP was first used in DOS environment without any graphical design, then EMTP-ATP was designed for Windows which is user friendly [5].

EMTP is used to study transient states of the network, solve equations in time domain and solve differential equations using fourth order Range-Kutta method and trapezoidal integration. In order to design electric power systems, engineers have studied networks extensively including analyzing failure in the network, load flow analysis, stability analysis and electromagnetic transient states analysis [6].

2.2. Network Characteristics

This study is conducted on electricity network of Imam Khomeini airport city. This network has a dedicated electricity network of 230/20 KV. Short current at the input of the station is 75 KA as announced

Table 1. ***Frequency of transient phenomena.***

Origin	Frequency Range
Ferroresonance	0.1 Hz to 1 kHz
Load rejection	0.1 Hz to 3 kHz
Fault clearing	50 Hz to 3 kHz
Line switching	50 Hz to 20 kHz
Transient recovery voltages	50 Hz to 100 kHz
Lightning overvoltages	10 kHz to 3 MHz
Disconnector switching in GIS	100 kHz to 50 MHz

by Tehran electricity company. This network has 20 KV distributed transmission lines including overhead lines and ground cables. In order to measure and study switching overvoltages, one of the reserve line is used. In this line, there is a 7 Km overhead line after the breaker on which switching is performed and there is a 2700m 240mm2 cable after that followed by a 1250m 120mm2 cable; measurement is performed in the bus connected to this cable.

2.3. Simulation

Transient phenomena in power system have different frequencies. Table 1 shows the frequency of transient phenomena [4].

Fig. 1 shows the network used for simulation in EMTP.

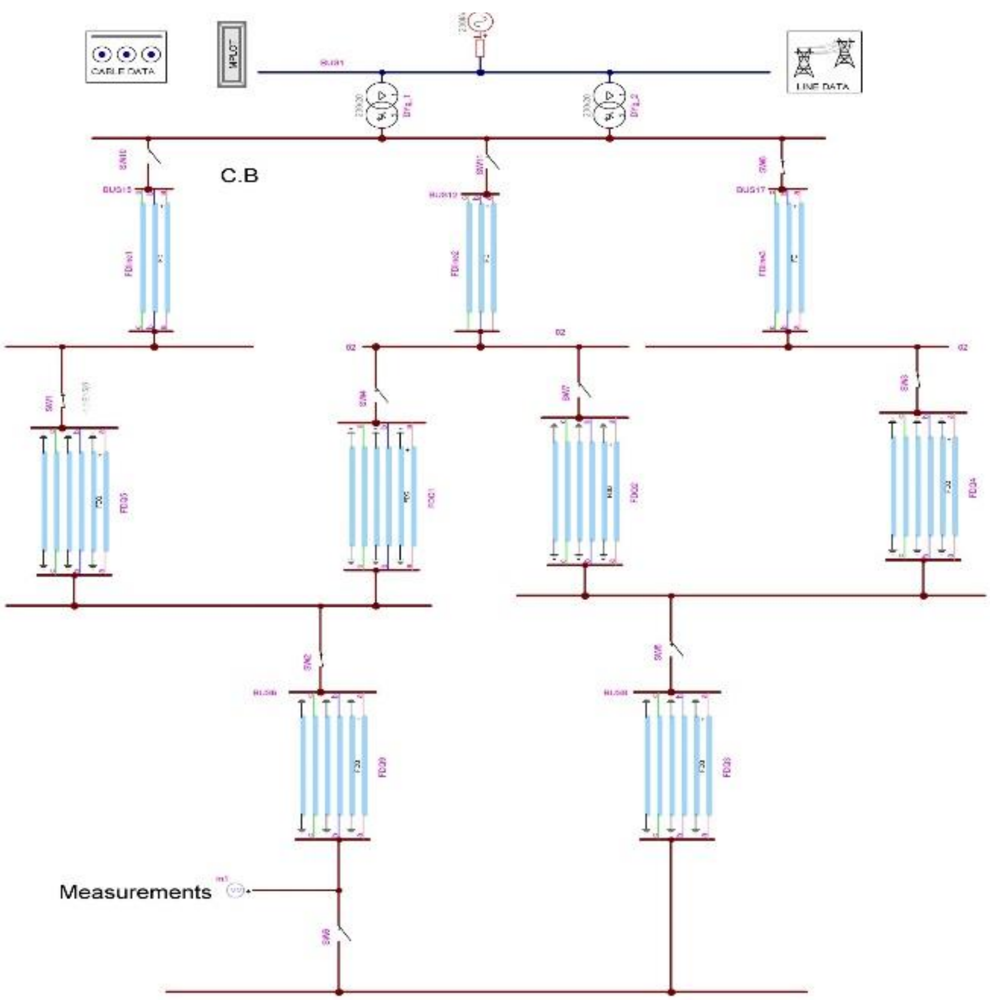

Fig. 1. Network simulated in EMTP, equivalent model of FD-Model cable.

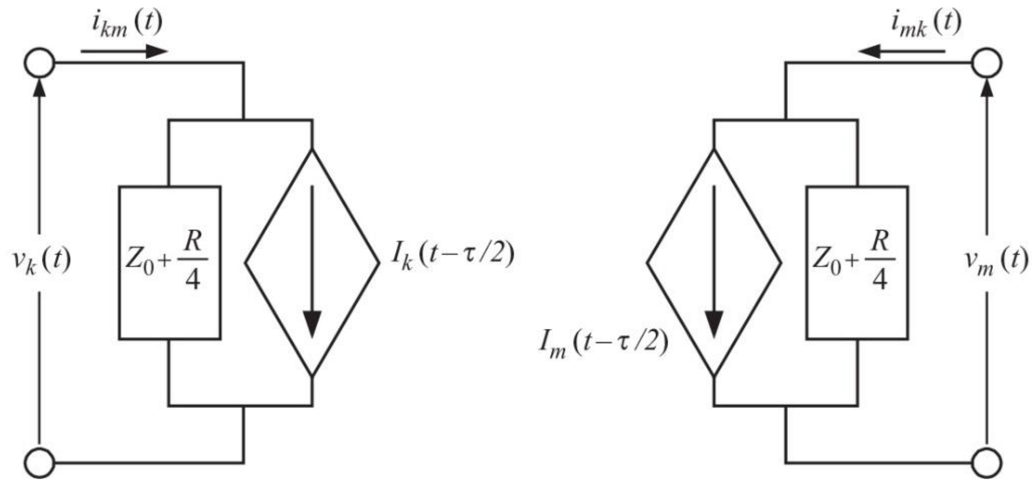

Fig. 2. Equivalent Model of FD-Model Cable.

Network parameters and transformers before switching point are introduced according to the information received from Tehran regional electricity company and the manufacturer factory. In order to simulate other elements, their transient model is required. Further, for simplification, power switches are considered to be ideal.

In the simulation, Frequency-Dependent (FD) model of cables and overhead lines is used. Fig. 2 shows equivalent circuit of FD model [7]. In general, FD-model has parameters which depend on frequency of the cable and they are obtained using propagation and admittance matrices of the cable. Comparing different cable models show that using the frequency domain increases the results accuracy. In FD-model, all calculations are performed in frequency domain and the results are converted to time domain using Fourier transform or Z-transform [8].

According to [7], parameters required by EMTP for simulating the cable are as follows:

- *DC resistance of conductors:*

Resistance of conductors used in the cable is obtained as,

$$R = l\frac{\rho}{A} \quad (1)$$

where, R is resistance (ohm), l is length (meter), p is resistivity, and A is cross section of the conductor. Table 2 shows resistivity of different conductors.

- *Relative permittivity of Insulators*:

Relative permittivity of material can be obtained from information of the manufacturer factory. Table 3 shows the relative permittivity of different insulators.

Table 2. ***Resistivity of conductors.***

Material	Copper	Aluminum	Lead	Steel
ρ[Ωm]	1.72E-8	2.83E-8	22E-8	18E-8

Table 3. ***Relative permittivity of insulators.***

Material	XLPE	Mass-impregnated	Fluid-filled
Permittivity	2.3	4.2	3.5

- *Relative permeability of semiconductors*

Modelling semiconductor layer of cables cannot be usually done in EMTP, but as shown in [9] and [10], in transient mode, these layers affect waveform, thus they should be considered in calculations.

Semiconductor layer can be considered in simulations by changing parameters of the insulator and assuming the capacitor between conductor and cover to be fixed [9]:

- Thickness of semiconductor layer is added to thickness of insulator.
- Relative permeability is modified as,

$$\varepsilon' = \varepsilon \frac{\ln\left(\frac{r_2}{r_1}\right)}{\ln\left(\frac{b}{a}\right)} \quad (2)$$

where, r_1 is external diameter of the conductor, r_2 is internal diameter of the cover, *a* is internal diameter of the insulator and *b* is external diameter of the insulator.

- *Distance between Cables:*

Horizontal and vertical distance between cable of each phase can be calculated considering Fig. 3.

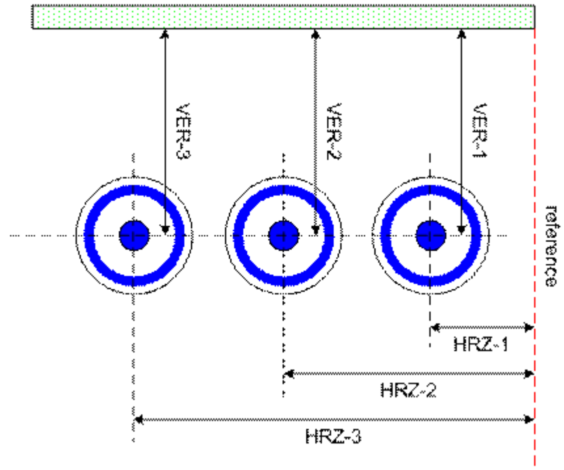

Fig. 3. Deployment of cables in the underground cable.

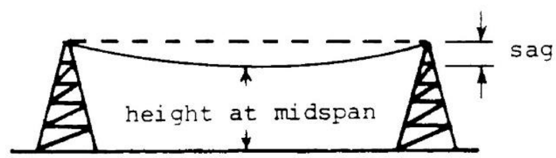

Fig. 4. Height at midspan.

7-Km Overhead line is an unbundled double-circuit line without guarding wire and ACSR conductors are installed on telescope towers. In order to simulate overhead line, FD model is used and in addition to electric parameters, physical characteristics of the transmission line and conductor are required:

- External diameter of the conductors
- Horizontal distance of conductors from reference point
- Height of tower conductors from ground (VH_{Tower}).

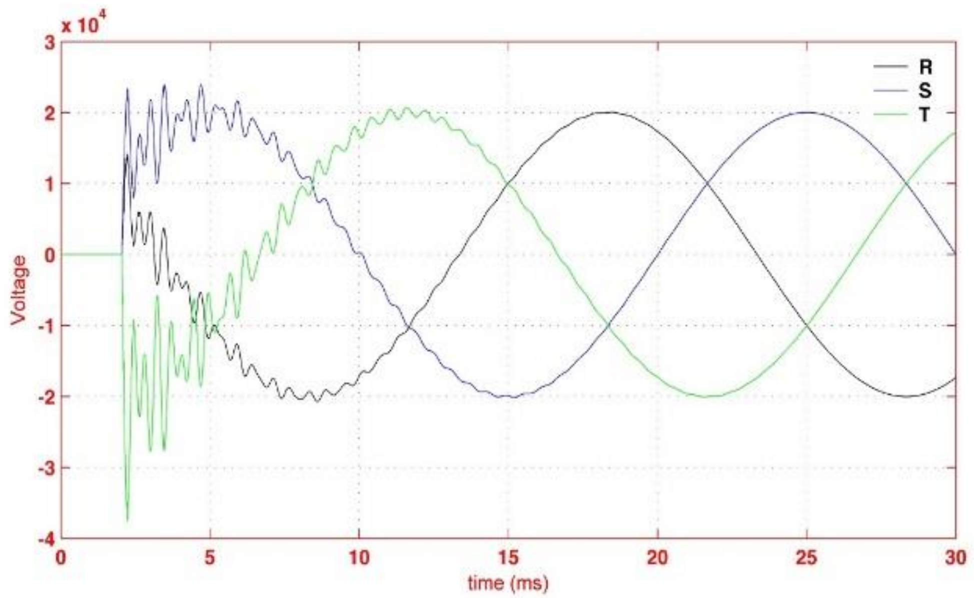

Fig. 5. Simulation results.

- Height of conductor at midspan (Height at midspan)

Fig. 4 shows the Height at midspan.

2.4. Simulation Results

Fig. 5 shows the simulation results. It can be seen that at switching instant, a transient wave is created which is carried by the main wave and damps after about one cycle and the voltage waveform becomes a sinusoid waveform, again. It can be seen that transient voltage amplitude increases to 1.5 p.u.

3. MEASUREMENT USING POWER ANALYZER

3.1. Previous Studies

In previous studies [11-13], capacitive sensors and dividers and oscilloscopes are used to measure and monitor the transient voltage. Fig. 6 shows the corresponding equivalent circuit [11].

3.2. Introducing Power Analyzer

In this study, HIOKI Power Analyzer is used. These devices are used for accurate analysis of electric conditions and parameters like voltage, current, harmonic, and power. And they can sample voltage at a frequency of 2GHz. In addition, the software can be used to analyze and plot diagram of different parameters. Fig. 7 shows an example of power analyzer device.

3.3. Methodology

Measuring voltage in MV and HV networks is performed by Potential Transformers (PT). PT is a high accuracy transformer which its secondary is LV and can be connected to measurement devices and protection relays.

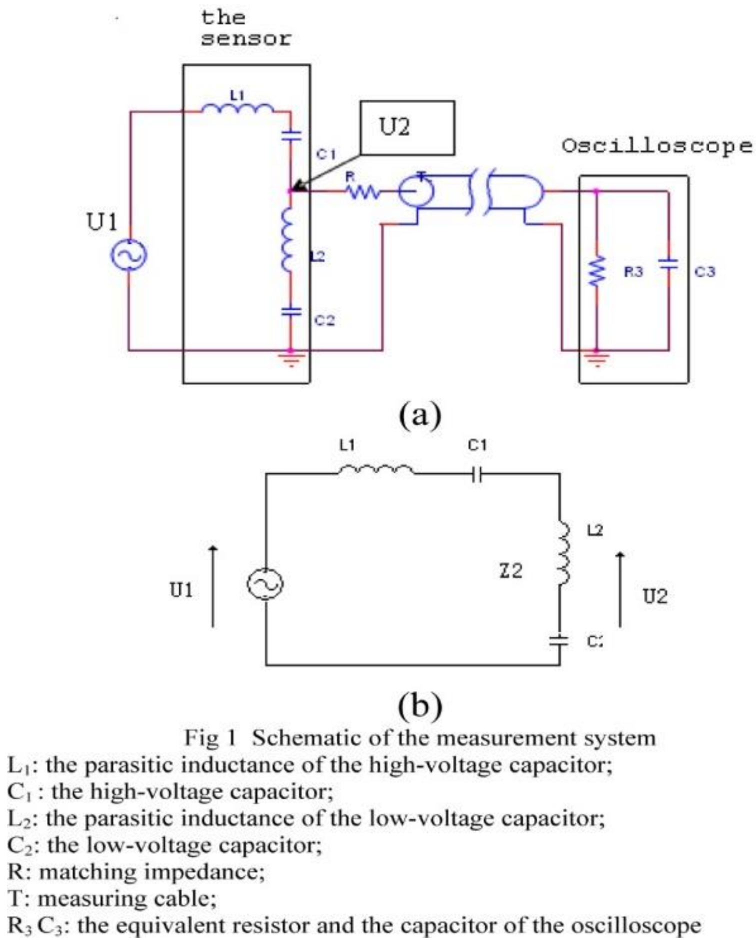

Fig. 6. Diagram of a transient overvoltage measurement system [11].

Fig. 7. A sample power analyzer device.

PT performance in transient state and switching frequencies is like capacitor; thus, PT can be used instead of capacitive divider. Since Power Analyzer devices can operate at voltages under 1000v, secondary of PT can be connected to Power Analyzer device.

Thus, switching is applied to one of the MV reserve lines of Imam Khomeini airport city and measurement is done using Power Analyzer connected to PT. Fig. 8 shows the measurement results by Power Analyzer device and Fig. 9 shows the results extracted from analysis software. It can be seen that a transient wave (created after switching) is damped after one cycle. Further, overvoltage is about 1.5 p.u.

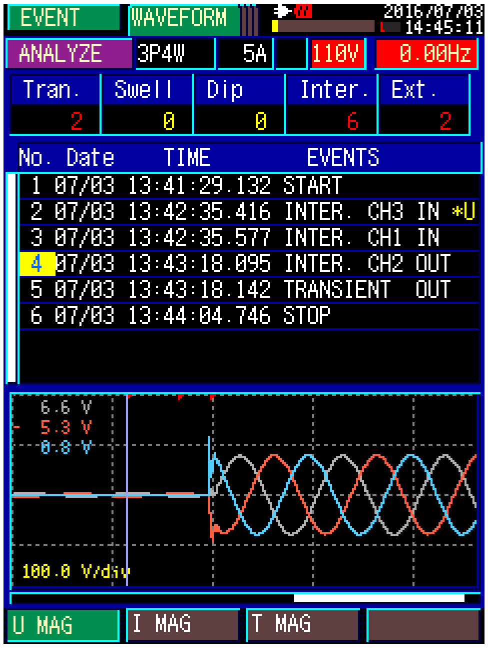

Fig. 8. Measurement by Power Analyzer Device.

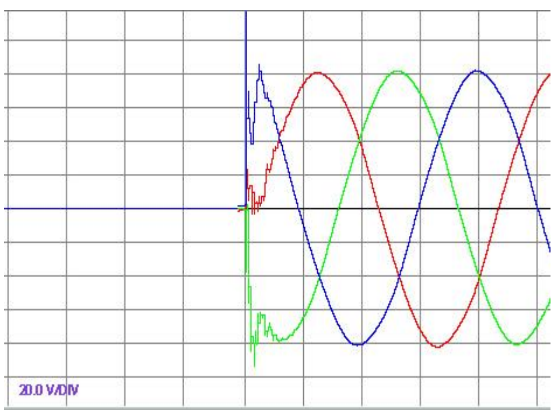

Fig. 9. Waveform extracted from analysis software.

4. CONCLUSION

Comparing the results obtained from the simulation and the measurement validate our proposed method. Therefore, this approach can be used to measure the transient overvoltage accurately. It should be noted that we have to consider the frequency of transient phenomena written in Table 1, and a Power Analyzer should be able to operate at frequency of the phenomena of interest.

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