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Evaluation of the Transient Overvoltage Stresses on 132 kV Power Transmission Network

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***Abstract*: -** Lightning over voltage has been a dilemma since the early days of electricity. Lightning mainly occurs on the Overhead Transmission Lines and overvoltage generated due to lightning travels along the line and ultimately reaches to the substation, where this overvoltage can damage the expensive equipment like Power Transformers, Circuit breakers, Isolators, Current Transformers etc. Power System networks in the urban areas mainly consist of Overhead Transmission Lines, High Voltage XLPE Power Cables and Gas Insulated Substations (GIS). The evaluation of the transient behavior of combined high voltage systems consisting of overhead lines, cables and GIS is an important task.

In this research work, the complete model has been developed by using PSCAD/EMTDC computer application. The modeling of each component has been done by using the manufacturer's datasheets/parameters. The transient over voltages have been observed at different points of the power system by injecting lightning current. Surge arrestors have been used to mitigate the over voltages in the system. The outcome of this research would be to improve the insulation coordination of the 132kV Power System in Pakistan.

Keywords: - *Gas Insulated Substations (GIS), Insulation Co-ordination, Lightning Over voltages, PSCAD/ EM TDC, Surge Arrestors.*

I. INTRODUCTION

In Pakistan Electrical energy consumption is increasing day by day. In order to reliable supply of energy to consumers, it is necessary to upgrade or relieve important nodes in the Power system.

Gas Insulated Substations (GIS) are replacing the conventional Air Insulated Substations all around the world due to their less maintenance and reliability [1]. Therefore, Lahore Electric Supply Company (LESCO) has decided to construct 132/11 KV GIS substations in Saggian, Lahore.

The Transient Overvoltage lasts for very short periods of time usually 10's of micro seconds to milliseconds but the system insulation is subjected to huge stress. The classification of transients proposed by IEC is as given in Table 1 below [2-3]:

TABLE 1 TYPES OF TRANSIENTS

Low-frequency oscillations	0.1 Hz - 3 kHz
Slow-front surges	50 / 60 Hz - 20 kHz;
Fast-front surges	10 kHz - 3 MHz;
Very fast-front surges	100 kHz - 50 MHz

The ideal way to study the transient behavior is to use the recording equipments in order to record and capture the transients. Alternately the simulations have been done by using electromagnetic transient program like PSCAD/EMTDC. In this research work, combined 132KV network in Saggian Lahore area has been modeled by using the Computer software PSCAD/EMTDC and the overvoltage stresses due to lightning on the network has been recorded.

Lightning current of standard wave shape i.e. 1.2/50µsec. having magnitude up to 100kA could be injected in the model to analyze the overvoltage developed in the system.

II. SYSTEM MODELING

The model used for this study consists of 132kV Transmission Line T1, XLPE Power cable (C1), 132kV GIS, Surge Generator, Surge impedances, Stray Capacitances and Surge Arrestors. Fig.1 given below shows the arrangement used for modeling the power system in PSCAD.

The different models of above network are as detailed below:

A. Surge Generator

The standard Lightning Impulse 1.2/50µsec has been modeled by adding two exponential functions as shown in (1), (2) & (3).

$$f(t)=g_1(t)+g_2(t) \qquad (1)$$

Where

$$g_1(t)=1-e^{-At} \qquad (2)$$

$$g_2(t)=e^{-Bt}-1 \qquad (3)$$

So, (1) can be rewritten as

$$f(t)=e^{-Bt}-e^{-At}$$

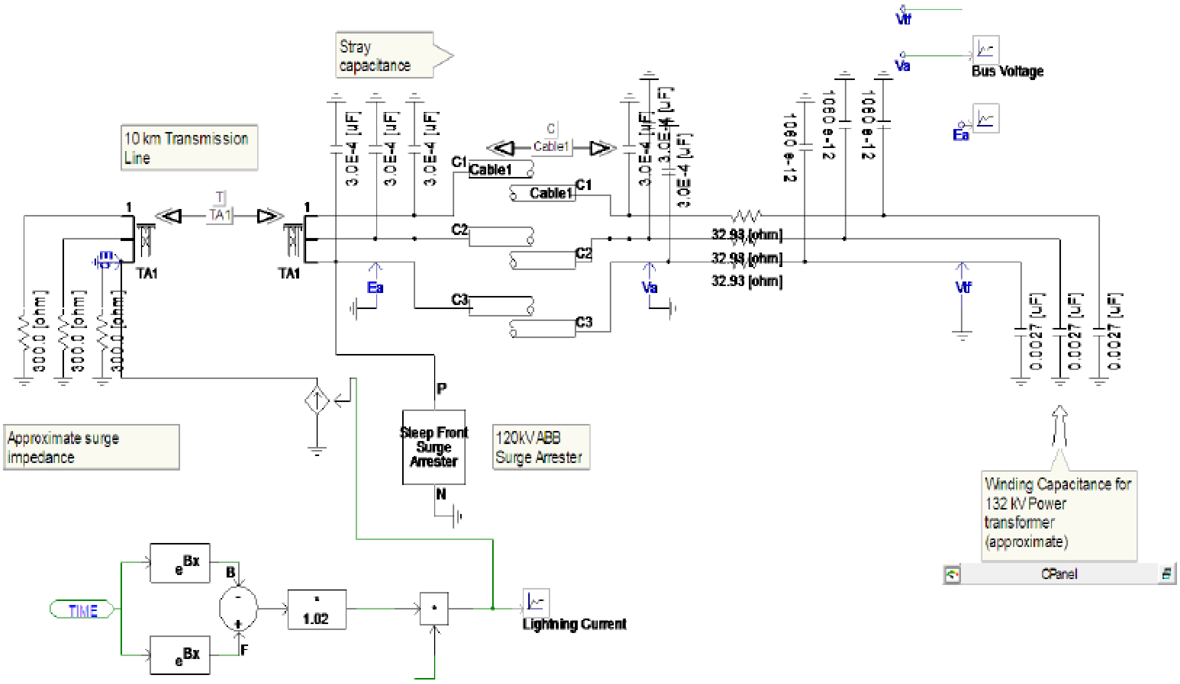

Fig.1 Simulation model

The exponential constants A & B depend upon the required wave shape to be generated. These can be calculated by empirical formulas. For standard lightning impulse 1.2/50µsec, the calculated constants used for simulation are

$$A=-\frac{\ln(\frac{1}{e})}{\frac{t_{front}}{5}}=4166000$$

$$B=-\frac{\ln(0.5)}{\frac{t_{\frac{1}{2}}}{5}}=13862000$$

B. Transmission Line

Transmission lines in power systems are non linear in nature, mainly due to the frequency dependency of conductors [4]. The ability to represent these systems precisely and efficiently plays an essential part in the electromagnetic transient simulation of power systems as a whole.

The 132kV Transmission Line parameters used for modeling are given below in Table 2.

TABLE 2 TRANSMISSION LINE PARAMETERS

Conductor Name	ACSR Rail
Conductor Dia	29.61mm
Conductor DC Resistance	0,06Ω/m
Sag for all conductors	7m
No. of Sub Conductors in bundle	1
Height of lowest conductor	14m
Ground Wire Diameter	9mm
No. of ground wires	1
Height of ground wire	24.5m
Tower/ Pole	SPA
Height of Pole	24.5m
Ground Resistivity	100Ωm

C. XLPE Power Cable

The ABB make 1000mm2 145kV XLPE Power Cable has been modeled in PSCAD [5]. The main parameters of XLPE cable are given in Table 3.

Table 3 XLPE power cable parameters

Diameter of Conductor	37.9mm
Insulation Thickness	15mm
Diameter over Insulation	71.3mm
Cross-section of screen	95mm^2
Outer Diameter of Cable	81.2mm

The cross section of XLPE Cable modeled in PSCAD is shown in Fig.2 below:

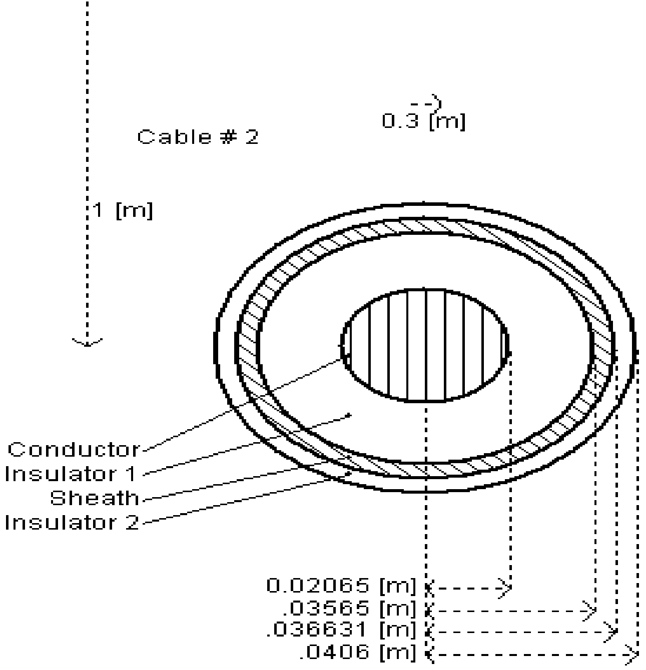

Fig.2 XLPE cable in PSCAD

The different radii shown in above figure are calculated by using following equations:

$$r_1 = \frac{diameter\ of\ Cond.}{2} + semiconductor\ screen\ thickness \tag{4}$$

$$r_2 = \frac{diameter\ over\ insulation}{2} \tag{5}$$

$$r_3 = \sqrt{\frac{A_{scr}}{\pi} + (radius\ over\ insulation)^2} \tag{6}$$

$$r_4 = \frac{Outer\ diameter\ of\ cable}{2} \tag{7}$$

By using the parameters of 1000mm^2 Power Cable, the values of radii are given below:

r_1 = 20.65mm
r_2 = 35.65mm
r_3 = 36.31mm
r_4 = 40.6mm

The per-unit length capacitance and inductance of the cables can be calculated as follows:

$$C = \frac{\varepsilon_r}{1.8\ln(\frac{r_2}{r_1})} \tag{8}$$

$$= \frac{2.5}{1.8\ln(\frac{35.65}{20.65})}$$

$$= 0.255\,\mu F\ /\ km$$

$$L = 0.5\pi\mu_r\mu_o \ln(\frac{radius\ over\ insulation}{radius\ of\ inner\ conductor}) \tag{9}$$

$$= 109.21\,nH\ /\ m$$

The Characteristic impedance of XLPE Cable is

$$Z_o = \sqrt{\frac{L}{C}} \tag{10}$$

$$= 20.71\ \Omega$$

D. Surge Arrestor

The surge arrester model available in the PSCAD Master Library is for switching over voltages. For fast front transients, i.e., due to lightning, the surge arrester (behavior) representation is significantly different. The voltage across the arrester increases as the time to crest of the arrester current decreases and the arrester voltage reaches its peak before the arrester current reaches its peak [6].

The model proposed by IEEE Working Group shown in Fig.3 for protective devices has been used for lightning over voltages investigation [3], [7].

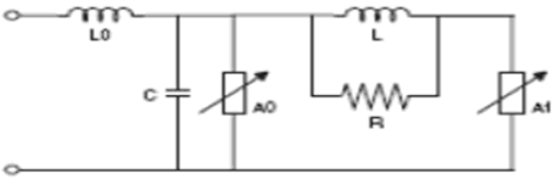

Fig.3 Surge arrestor model

A_0 & A_1	Non-linear resistors; each comprised of the surge arrester model used for switching surge transients.
L_0	The inductor L_0 represents the inductance associated with magnetic fields in the neighborhood of the arrester.
L & R	R & L are used to form R-L filter, which has very little impedance, but is significant for fast front surges.
C	The terminal-to-terminal capacitance of the arrester.

The RLC elements of model are determined by the following formulae [7]:

$$L = \frac{15d}{n} \ \mu H$$

$$R = \frac{65d}{n} n\Omega$$

Where:
d = is the estimated height of the arrester in meter
n = number of parallel columns of metal oxide in the arrester

$$L_o = \frac{0.2d}{n} \ \mu H$$

$$C = \frac{100n}{d} \ pF$$

The basic performance data of ABB make Surge Arrestor is as given below in Table 4 [6]:

Table 4 Surge arrestor parameters

Make & Type	ABB EXLIM-Q-E
Max. System Voltage	Um = 145Kv
Rated Voltage	Ur = 120Kv
Max. Cont. Operating Voltage	Uc = 92kV
TOV Capability For 1 Sec.	139kV
TOV Capability For 10 Sec.	132kV
Max. Residual Voltage with 8/20µsec Current Wave of:	
a) 5kA	295KV
b) 10kA	311KV
c) 20kA	342KV
d) 40Ka	382KV
Creepage Distance	5302mm
Height of Housing	1969mm

For 145kV ABB make EXLIM Q-E Surge arrestor the above mentioned RLC parameters are calculated as:
d = 1.969m
n = 1
L = 29.535 µH
R = 127.985 Ω
L_O = 0.3938 µH
C = 50.8 Pf

E. 132kV Gas Insulated Substation

The 132kV Gas Insulated Substation (GIS) has been modeled in PSCAD by representing the phase conductors by cables as shown in Fig.1 above. The characteristic impedance of GIS bus-bar can be calculated by using the capacitance and propagation velocity [8]. The equivalent capacitance of conductors of bus-bar placed in the GIS tube is C = 106.8pF/m. The velocity of propagation in GIS is 0.95Co = 285×10^6. The Characteristic impedance is calculated using (11);

$$Z = \frac{1}{vc} \qquad (11)$$

$$Z = 32.93\Omega$$

III. SIMULATION RESULTS

The lightning surge of 1.2 / 50µs, 20kA as shown in Fig. 4 has been injected to the 132kV Transmission Line.

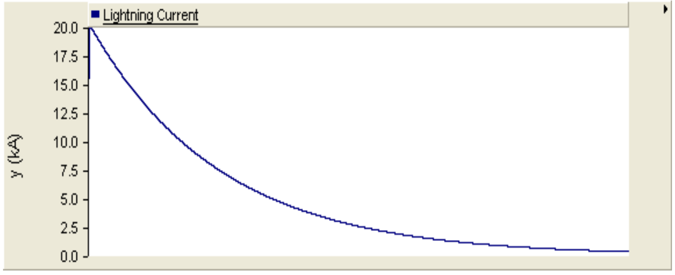

Fig.4 1.2 / 50µs standard lightning current wave

The overvoltage developed at the point of impact on the Transmission Line has been shown in Fig.5. Theoretically these can be calculated by using the lightning current (I_0) and Surge Impedance of the Transmission Line (Z_0) indicated in (12). For 20kA Lightning Current, the overvoltage calculated is:

$$V_o = \frac{1}{2} I_o Z_o \qquad (12)$$

$$= \frac{1}{2} \text{ X } 20 \text{ X } 300$$

$$= 3000kV$$

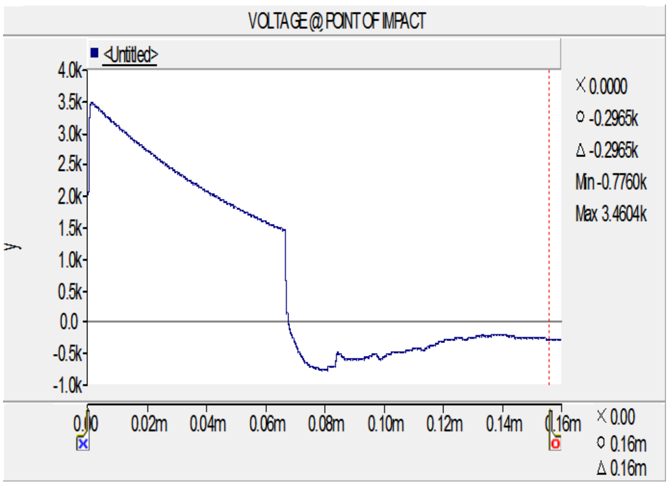

Fig.5 Overvoltage developed at transmission line

These voltages travel along the transmission line. When they reach at the junction point of the transmission line and the XLPE cable, some part of them is transmitted to XLPE cable where as some part is reflected back to the transmission line.

The overvoltage transmitted to the XLPE Cable is shown in Fig.6. 2443KV has been transmitted to XLPE Cable.

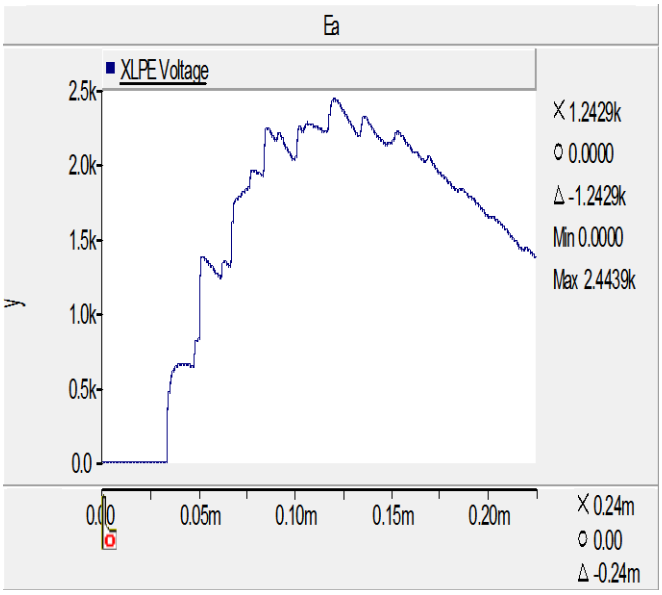

Fig.6 Over voltages transmitted to XLPE cable

These over voltages travel along the GIS conductors; these are well above the BIL requirement as per IEC and WAPDA standards i.e. 650kV. After the GIS enclosure these overvoltage reaches to the Power Transformer.

The overvoltage reached at the terminals of the 132kV Power Transformer is shown in Fig.7.

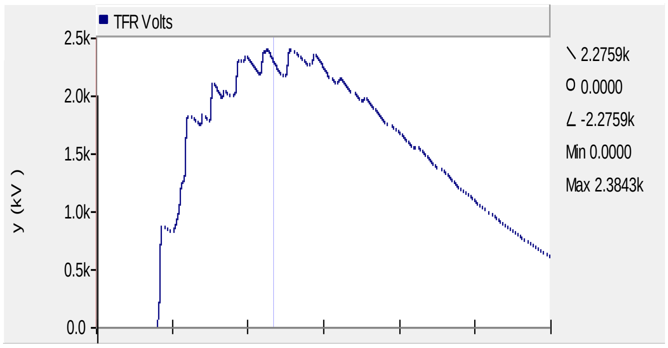

Fig.7 Voltage @ HV side of 132kV power transformer

By placing a Surge Arrestor at the interconnection point of Overhead Transmission Line and XLPE Cable as shown in Fig.1, the voltage entering to the XLPE Cable and onward equipment can be reduced. The voltage entering to the XLPE Cable, after passing through the surge arrester is shown in Fig.8.

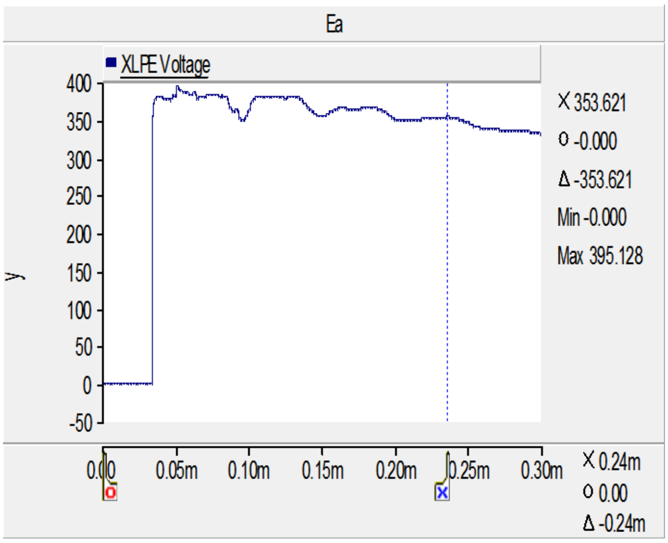

Fig.8 Overvoltage transmitted to XLPE cable after passing through surge arrester

The overvoltage developed at the HV terminals of Power Transformer is shown in Fig.9.

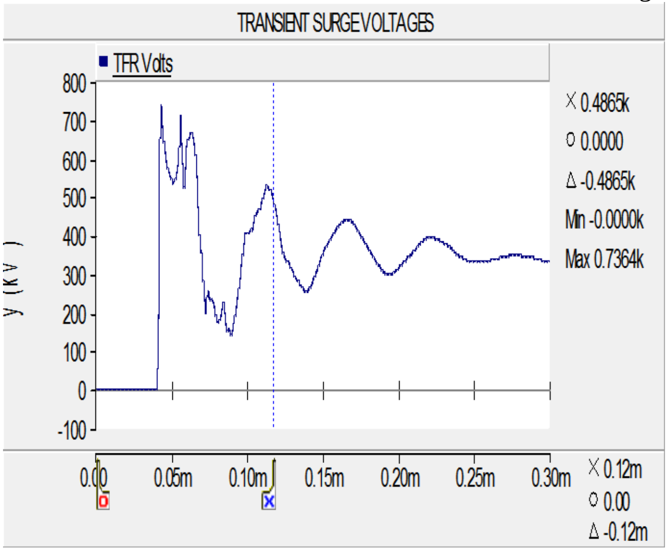

Fig.9 Voltage @ HV side of 132kV power transformer

The over voltages developed due to different values of lightning currents at different points of the model without Surge Arrester are summarized in Table 5.

TABLE 5 Voltages before application of surge arrester

Lightning Current Magnitude (kA)	**Voltage at 132kV T/L (kV)**	**Voltage at XLPE Cable (kV)**	**Voltage at HV side of Power Transformer. (kV)**
5	865	611	596
10	1730	1222	1192
15	2595	1833	1788
18	3114	2199	2145
20	3460	2433	2384

TABLE 6 Voltages after application of surge arrester

Lightning Current Magnitude (kA)	**Voltage at 132kV T/L (kV)**	**Voltage at XLPE Cable (kV)**	**Voltage at HV side of Power Transformer. (kV)**
5	865	363	447
10	1730	382	623
15	2595	388	678
18	3114	392	700
20	3460	395	736

IV. CONCLUSIONS

The complete 132kV power system has been successfully modeled in PSCAD. The lightning surges of different values have been injected and have found that lightning surge of value greater than 10kA is dangerous for power transformer and substation equipment as shown in Tables 5 & 6. Moreover, the insulation coordination can also be improved by installing Surge Arrestors at entry point of the substation.

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