



Statistical Analysis of Switching Overvoltages in a 1200 kV Wardha-Aurangabad UHVAC Transmission Line

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Abstract: The rapid increase in transmission Analysis by means of simulation studies is essential for providing useful information to researchers regarding switching transients in transmission systems. This paper investigates the overvoltages due to different types of switching in 1200kV transmission line. The PSCAD/EMTDC is used to perform the simulation. The overvoltages due to the line energization, re-energization, single line to ground fault initiation and fault clearing events are considered. For statistical switching operations various randomnesses are considered. In series of simulations, the maximum overvoltage is determined in each case and statistical analysis is made on the simulated results. Using statistical analysis, mean value, standard deviation and 2% overvoltage values are estimated and finally probability density function is drawn for each case.

Keywords: Switching overvoltages, ultra high voltage (UHV) AC transmission line, statistical switching, 2% overvoltage, probability density function.

I. Introduction

For high capacity power transfer, with lesser right of way (ROW) and reduced transmission losses between the generation pockets in the Eastern parts to the demand pockets in the West and Northern parts of India, a 765 kV Ultra High Voltage (UHV) AC system up to Wardha and then a hybrid 765 kV and 1200 kV line between Wardha-Aurangabad (405km) is planned.

With increasing operating voltage of transmission systems, switching surge overvoltages decide the insulation design and not the lightning overvoltages [1]. So, an exact estimate of the switching overvoltages (SOVs) for various operating conditions is one of the crucial factors in UHV transmission system design. Such studies are normally performed with particular interest in avoiding breakdown, or minimizing transient stress on the insulation systems as well as the transmission equipment. In general, characterisation of overvoltage stress may be performed by the following means [2]:

- The maximum peak value
- A statistical overvoltage of the peak values
- A statistical overvoltage value generated by particular events with a peak value that has a 2% probability of being exceeded.

From the literature [3-5] it has been found that the evaluation of switching overvoltages is an important task for planning and design of power systems, as it has a direct bearing on insulation characteristics and coordination, cost and reliability of particular projects. Also, accurate simulation by means of electromagnetic transient program is the most convenient way to undertake such studies.

Switching surge overvoltages generally arise from line closing, line reclosing (with trapped charge), fault initiation and clearing, load rejection, line dropping, switching transformers at no load, switching reactor loaded transformer, switching of ehv reactors, switching of capacitor banks [6]. However, the overvoltages produced during the switching of reactors and transformers may readily be limited by surge diverters and are therefore not considered here. Of the other switching operations, line closing and reclosing generally produce the larger overvoltages if restrike-free breakers are used. When the overvoltages due to line energization or re-energization are controlled to values below 2p.u., fault initiation and fault clearing overvoltages require careful examination if they are not controlled to the same degree [1], consequently this paper focuses on these four events.

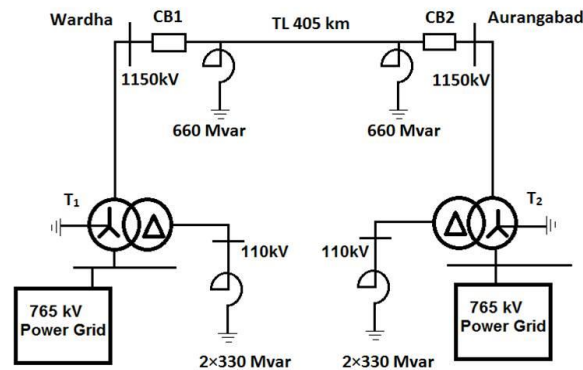
This paper presents a statistical analysis of overvoltages produced in a 1200 kV transmission line due to the above four events. The power system network model in PSCAD/EMTDC will be presented in Section 2. The characteristics of switching overvoltage presented in Section 3. The simulation approaches and results obtained are discussed in Section 4 followed by conclusions in the Section 5.

II. Description of the UHV System

Entire simulations and investigations correspond to the Wardha–Aurangabad UHVAC transmission system, which is the first 1200kV UHVAC double-circuit transmission system in India connecting the Eastern to the Western part of the country.

The simplified figure of the studied UHVAC transmission system is shown in Fig.1. The system voltage is rated at 1200kV with a base value of 1200kV. The modelling procedure for all equipment is as follows:

Figure1 Schematic Diagram of Wardha-Aurangabad UHV System.



A. Overhead Transmission Lines: In PSCAD [7], these are modelled as un-transposed frequency phase dependent with the following information; transmission line conductor diameter, spacing between phases, no. of sub-conductors in a bundle, bundle conductor type, radius of the bundle, sub-conductor spacing, conductor height above ground at tower, conductor height above ground at mid span, height of shield wire at the tower and ground resistivity. This information regarding the transmission line has to be given at the tower [7].

The fundamental specifications of the considered system is given in Table 1 [4], on a base kV of 1200 kV and a base MVA of 100 MVA with an assumed soil resistivity of 100Ω-m. Data for 1200 kV single circuit overhead transmission line is shown in Table 2. V-insulator string configuration is used for most suspension towers as shown in Fig. 2 [5].

Table 1. Transmission Line Parameters [4]

Parameter	Value
Maximum Voltage	1200 kV
Nominal Voltage	1150 kV
Resistance/km	4.338×10^{-7} p.u.
Reactance/km	1.772×10^{-5} p.u.
Susceptance/km	6.447×10^{-2} p.u.
Surge Impedance Loading (SIL)	6030 MW
Surge Impedance	239

B. Transformers: In PSCAD, transformer model is represented by the following information: MVA rating, winding voltage ratings, winding configuration and leakage reactance between windings [3].

For considered system as shown in Fig. 1, T₁ and T₂ represent UHV auto-transformers, rated at 333/333/111 MVA, with voltage rated at 1150/765/110 kV, and a short-circuit impedance of HV-IV 18%, HV-LV 40%, IV-LV 20%. The transformers are modelled as an inductance [6].

C. Circuit Breaker (CB): It is modelled as a non-ideal switch with inner resistors where CBs have closing resistors of 600Ω with an insertion time of 10ms [4] with no opening resistors.

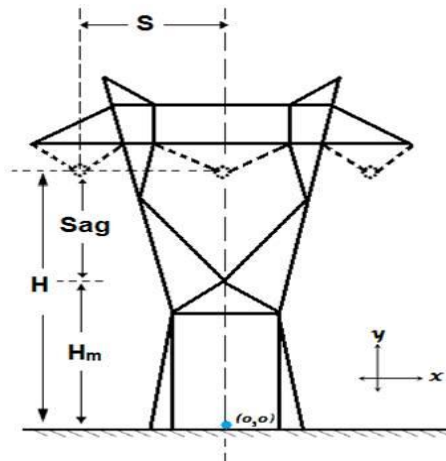
D. Shunt Reactors: The shunt reactors in the studied 1200 kV system are modelled as a simple lumped inductance and are line connected [7].

E. Operating Condition: The bus voltages at Wardha and Aurangabad are 1150kV.

Table 2. Conductor Specifications

Description	Notation	Value	Units
No. of sub-conductors in a bundle	N	8	Nos.
Radius of the Bundle	R	0.6	m
Sub-conductor spacing	B	0.46	m
Diameter of Conductor	D	4.63	cm
Radius of Conductor	R	2.315	cm
Conductor Height above ground at tower	H	37	m
Conductor Height above ground at mid span	H _m	24.3	m
Phase Spacing	S	24	m
Bundle conductor type	Bersimis/Moose		

Figure2 Single Circuit UHV Tower Configuration.



III.Characteristics of Switching Overvoltages

This work considers the following four cases as they determine the SOV level of the UHVAC transmission line and the corresponding typical waveforms are shown in Fig. 3.

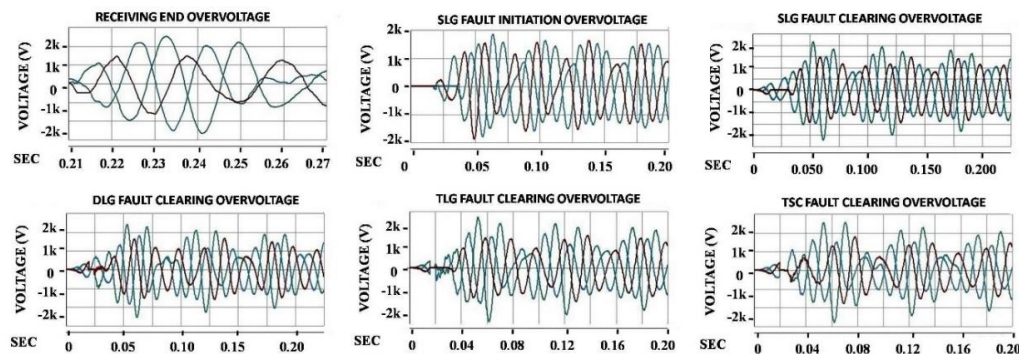
A.Line Energization:Line energization overvoltages are the most frequent overvoltages among all types of overvoltages that appear on the line as the CB switches from open to close.

B. Line Re- energization:The initial conditions of the transmission line have trapped charge that may stimulate higher overvoltage.

C. Single-line-to-ground (SLG) Fault Initiation: During a SLG fault when the CBs at the two terminals of the faulted phase are inoperative, the transient occurs on the healthy phases.

D. Fault clearing: Fault clearing overvoltages are the most severe overvoltages compared to all other overvoltages. These overvoltages may appear either on faulted lines or on adjacent lines, usually the worst case is on adjacent lines. Single line-to-ground (SLG), double line-to-ground (DLG), three-phase line-to-ground (TLG) and three-phase short-circuit (TSC), fault clearing overvoltages are considered.

Figure 3 Maximum Overvoltages in all the Cases



IV. Simulation and Results

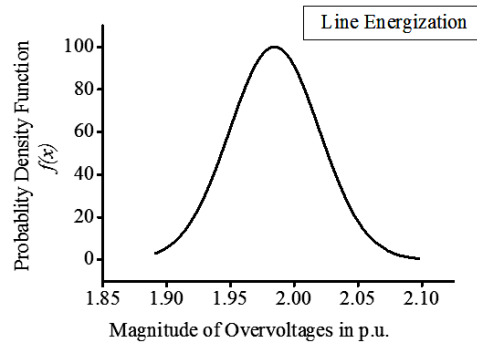
In this work, a single - circuit 1200 kV UHV system is considered as shown in Fig. 1, which is under construction in India. Electromagnetic transient analysis software PSCAD/EMTDC [7] is used for the simulation.

To derive the SOV probabilistic distribution the randomness of several factors is considered.

A. Line Energization: In the line energization case, the randomness of instant of closing time of three phases is considered. Hence, three-phase circuit breakers close non-simultaneously, the closing times of the three phases are described by $T_0 + \Delta T$, T_0 follows the uniform distribution on 50 Hz sine period and all times follow independent Gaussian distribution with standard deviation of 1 ms up to 3 standard deviations [12]. The behaviour of overvoltages due to switching is strongly dependent on the pole closing span of the circuit breaker and also the closing angle of the power frequency voltage [13].

Using the above procedure 526 line energization operations were performed. The maximum overvoltage is recorded in each case. The overvoltages at the receiving end varied from 1.8911 p.u. to 2.0975 p.u. The statistical calculations were carried out on these 526 cases and the mean value, standard deviation and 2% overvoltage in p.u. were calculated as 1.9846, 0.0353 and 2.0552 respectively. Finally, the SOV probability density function $f(x)$ is drawn as shown in Fig. 4.

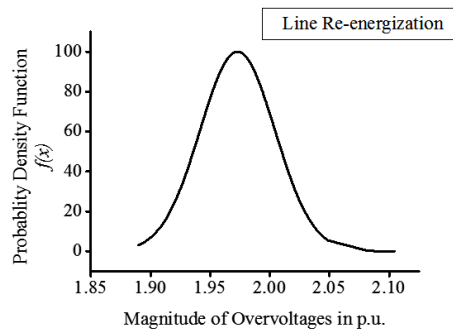
Figure 4 SOV Probability density function for Line Energization



B. Line Re- energization: In the line re-energization case also the randomness of instant of closing time of three phases is considered with a trapped charge of 1 p.u.

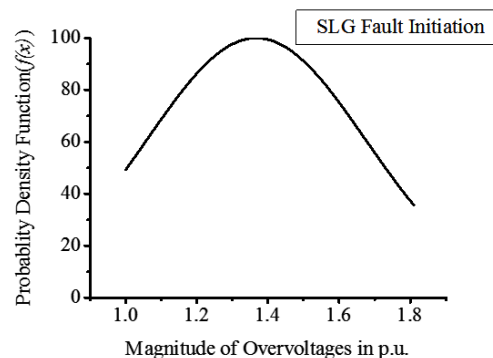
Following the same procedure as in the case of line energization 526 line re-energization operations were performed. The maximum overvoltage is recorded in each case. The overvoltages at the receiving end varied from 1.8900 p.u. to 2.1046 p.u. The statistical calculations were carried out on these 526 cases and the mean value, standard deviation and 2% overvoltage in p.u. were calculated as 1.9729, 0.0314 and 2.0357 respectively. Finally the SOV probability density function $f(x)$ is drawn as shown in Fig. 5. Usually, line re-energization overvoltages are smaller than the line energization overvoltages [1].

Figure 5 SOV Probability density function for Line Re-energization



C. Single-line-to-ground (SLG) Fault Initiation: In the single-line-to-ground (SLG) fault initiation case the randomness of the faulted phase, fault time and fault location is considered. The statistical distributions of single line-to-ground fault initiation over voltages were derived from the results of 504 ($3 \times 21 \times 8$) cases. The maximum overvoltage is recorded in each case. The overvoltage values varied from 1.0001 p.u. to 1.8099 p.u. The statistical calculations such as mean value, standard deviation and 2% overvoltage in p.u. for 504 cases were calculated as 1.367, 0.3082 and 1.9834 respectively. Finally, the SOV probability density function $f(x)$ is drawn as shown in Fig. 6.

Figure 6 SOV Probability density function for SLG Fault Initiation



D. Fault clearing: In fault clearing cases to deduce the probabilistic distribution of SOV, the randomness of faulted phase, fault timing and fault location are considered for SLG and DLG faults; the randomness of fault timing and fault location are considered for TLG and TSC.

The statistical distributions for SLG and DLG fault clearing overvoltages were derived from the results of 504 ($3 \times 21 \times 8$) simulations. Similarly, the statistical distributions of TLG and TSC fault clearing overvoltages were derived from the results of 168 (21×8) simulations. The maximum overvoltage is recorded in each case.

The minimum and maximum overvoltages in above four cases are given in Table 3. The statistical calculations are made on each of these 504 cases for SLG and DLG, 168 cases for TLG and TSC, and calculated Mean value, standard deviation and 2% overvoltage for the above four cases are given in Table 4 and the SOV probability density function $f(x)$ is drawn for all the four cases as shown in Fig. 7, 8 and 9.

Table 3. Minimum and Maximum Overvoltages

CASE	SLG	DLG	TLG	TSC
Minimum Overvoltage in p.u.	1.1036	1.1034	1.0036	1.0861
Maximum Overvoltage in p.u.	2.8634	2.9863	2.7114	2.0443

Table 4. Statistical Information of Overvoltages

CASE	SLG	DLG	TLG	TSC
Mean of Overvoltages in p.u.	1.9839	1.8959	1.8131	1.5915
Standard Deviation of Overvoltages in p.u.	0.3117	0.3642	0.5135	0.2608
2% Overvoltage in p.u.	2.6079	2.6243	2.8401	2.1131

Figure 7 SOV Probability density function for SLG & DLG Fault Clearing Overvoltage

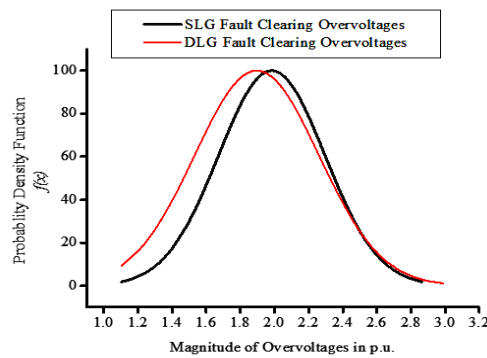


Figure 8 SOV Probability density function for TLG Fault Clearing Overvoltages

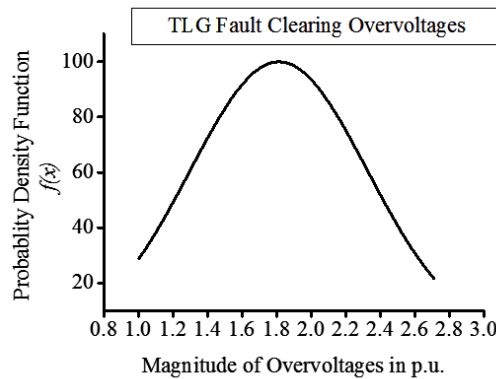
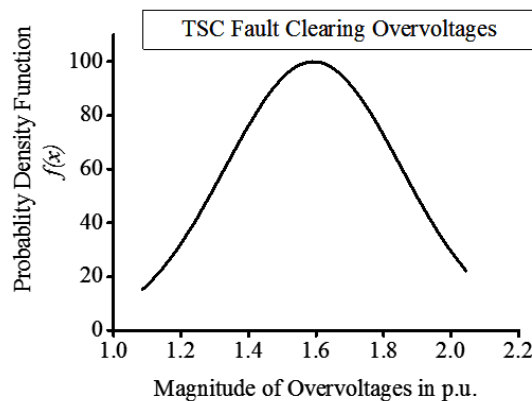


Figure 9 SOV Probability density function for TSC Fault Clearing Overvoltages



V. Conclusion

A statistical analysis has been carried out for the switching overvoltages of a 1200kV transmission line. From the above analysis it can be concluded that, the line energization statistical overvoltage (2% overvoltage) is greater compared to re-energization statistical overvoltage. Further, the statistical overvoltage increases from SLG fault clearing to TLG fault clearing.

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