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Switching Surge Design of 1200kV UHVAC Transmission Line

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Abstract*: With the increase in operating voltage of transmission system to transport large amounts of power to meet increased demand switching surges became governing factor in the insulation design of EHV and UHV systems. Insulation failure probability under switching surges that is switching surge flashover rate (SSFOR) is the main concern in the switching surge design of transmission lines. In this paper, SSFOR of 1200kV UHVAC transmission line under switching surges which are generated during energization of no-load transmission line is estimated.

Keywords*: Electrical stress, Insulation strength, SSFOR, Switching Overvoltage, UHVAC Transmission line.

I. INTRODUCTION

Electrical energy is the important input for the growth of an economy of any country. As the Indian economy is growing at rapidly increasing pace, sufficient electricity is required to maintain its growth. In India, coal sources are available in the Eastern region while hydro potential is available in the Northern and the North-Eastern region whereas major load centers are in the Western and Northern region. To transfer bulk power from Eastern to Western region and to address the right of way (ROW) issue, high capacity East-West transmission lines consisting of 765kV and 1200kV are planned. Wardha being the gateway for power transfer towards Northern and Western region, up to Wardha 765kV transmission lines are planned from Eastern region and beyond Wardha, i.e., from Wardha to Aurangabad (405km) hybrid 1200 kV and 765 kV transmission lines are planned [1]. For operating voltages beyond 345kV, the magnitude of switching overvoltages (SOVs) is more as compared to lightning overvoltages [2]. Thus, in UHVAC transmission lines SOVs decide the insulation level which greatly influences the cost of transmission lines. Hence, an accurate estimation of SOVs are important for insulation design of UHVAC transmission lines. The most significant switching overvoltages are the overvoltages produced on transmission line when it is energizing under no load condition [3] and such overvoltages are called as line energization overvoltages which are considered in this work. The switching surge design of transmission lines uses the concepts of electrical stress and insulation strength. Here electrical stress is the stress experienced by the line when line energization overvoltages are subjected to it. Insulation strength is the electrical insulation strength of tower. From these two concepts of electrical stress and insulation strength the SSFOR of 1200kV transmission line under no load energization is estimated.

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II. OVERVIEW OF THE UHVAC SYSTEM

The complete work is carried out on world's first 1200kV UHVAC transmission line which is under construction between Wardha–Aurangabad and its length is about 405km [4-6]. The schematic diagram of this UHVAC transmission system is shown in Fig. 1.

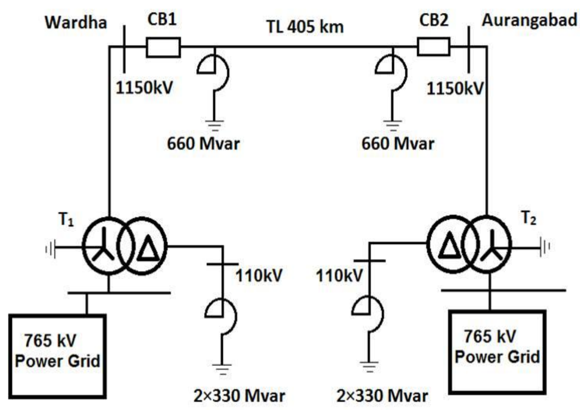

Fig. 1. Schematic Daigram of 1200kV UHVAC Transmission line

III. MODELLING APPROACH AND PARAMETERS SETTING

The UHVAC transmission system is modelled in PSCAD [7] and procedure for modelling of all components is as follows:

A. Transmission Lines

In PSCAD these are modelled as frequency phase dependent. Nominal and Maximum voltages of the transmission line and it's constants are given in Table 1 [8]. The base voltage and base MVA for these voltages and constants are 1200 kV and 100 MVA respectively. The assumed soil resistivity is 100Ω-m [8]. Conductor and tower specifications for a 1200 kV transmission line are given in Table 2 [9] and Tower structure is shown in Fig. 2.

Table- I: Parameters of 1200kV Transmission Line [8]

Parameter	Value
Nominal Voltage	1150 kV
Maximum Voltage	1200 kV
Resistance/km	4.338 x10^{-7}p.u.
Reactance/km	1.772 x10^{-5}p.u.
Susceptance/km	6.447 x10^{-2}p.u.
Surge Impedance Loading (SIL)	6030 MW
Surge Impedance	239

Table- II: Conductor and tower specifications of 1200 kV UHVAC transmission line [9]

Parameter	Value
Conductor Radius(r)	2.315 cm
Conductor Diameter(D)	4.63 cm
Height of the Conductor above ground at mid-span (H_m)	24.3m
Height of the Conductor above ground near the tower (H)	37m
Spacing between phases (S)	24m
Bundle Radius(R)	0.6m
No. of sub-conductors in the bundle (N)	8 Nos.
Spacing between the sub-conductor(B)	0.46 m

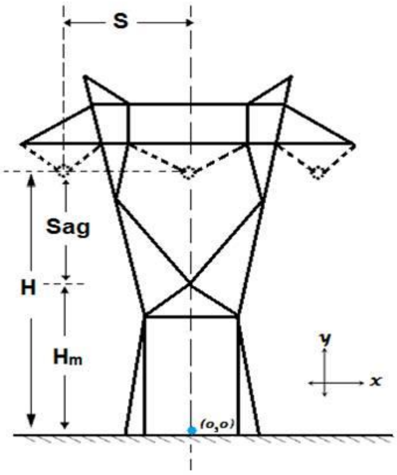

Fig. 2. Tower structure of 1200kV transmission line

B. Transformers

For the considered 1200kV transmission line shown in Fig. 1, T1 & T2 are UHV auto transformers. Their power and voltage ratings are 333/333/111 MVA, and 1150/765/110 kV respectively. Transformers % impedance are IV-LV 20%, HV-LV 40%, and HV-IV 18% [8].

C. Circuit Breaker (CB)

In Indian power system CBs are equipped with closing resistors but with no opening resistors. The closing resistor of these CBs is 600Ω with 10ms insertion time [8].

D. Shunt Reactors

To absorb line charging MVAR in system, it consists of 660 MVAR line reactor at both ends of the line. In addition to these, two more 660 MVAR reactors are connected at Wardha and Aurangabad buses [5]. In PSCAD, these are modelled as simple lumped inductances.

IV. ESTIMATION OF SSFOR

The objective here is to determine the probability that the electrical stress along the line exceeds the line insulation strength which is called as SSFOR.

Electrical stress experienced by the line is obtained any transient programme such as PSCAD. The electrical stress is characterized by statistical distributions of line energization overvoltages which is obtained by non-simultaneous closing of three poles of circuit breaker [10]. In this non-simultaneous closing, the closing time of one pole is varied uniformly from 0 to 20ms.The closing times other two poles follow normal distribution with a standard deviation of 1 ms over a range of ±3ms [11]. With this randomness total 526 switching operations are made on the 1200kV transmission line and peak values of SOVs are recorded in each case and their bar chart is shown in Fig. 3. A typical line energization overvoltage waveform at receiving end is shown in Fig. 4.

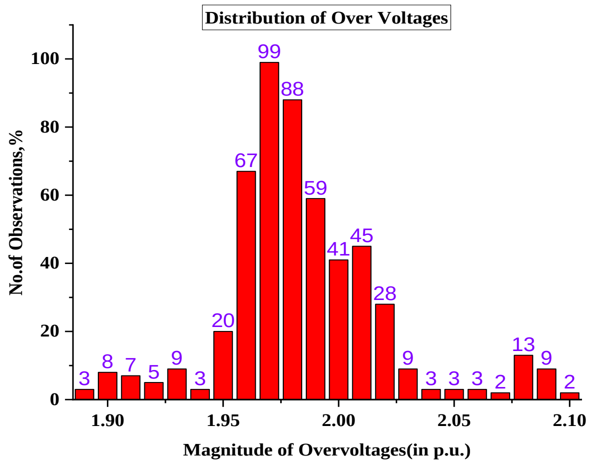

Fig. 3. Bar chart of switching overvoltages

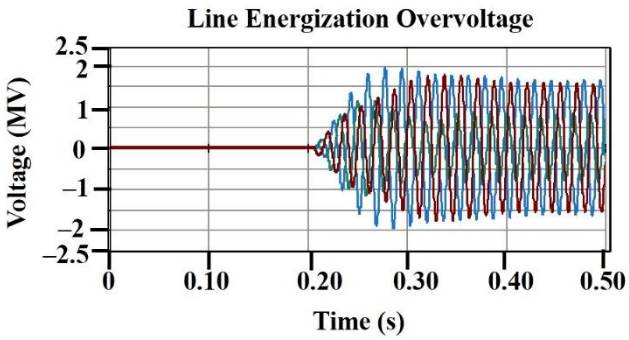

Fig. 4. Typical Line Energization Overvoltage at the Receiving end

The electrical insulation strength of tower or transmission line can be represented by a cumulative Gaussian distribution [12-15] which is characterized by mean denoted as Critical Flashover voltage (CFO) and a standard deviation which is 5% of CFO [16]. Literature gives various methods [17-23] to calculate CFO. In this work, we used the CFO proposed CRIEPI [22] and is given by equation (1) .

$$CFO = K_a K 1080 \ln(0.46d + 1) \quad (1)$$

where, K_a is the altitude correction factor, K is the gap factor, and d is the gap length in meters.

For the considered 1200kV line, gap length d is 8.3 meters [24] and gap factors is 1.26 [25]. Using these values, the calculated CFO is 2.183p.u. and standard deviation is 0.1091 p.u.

SSFOR is estimated for the transmission line consisting of One Tower and transmission line consisting of n Towers

A. Transmission line consisting of one tower

In this case, the SSFOR is estimated as follows: Consider any overvoltage sample above the mean which influences the stress [16] from statistical distribution of line energization overvoltages. Calculate reduced variate using equation corresponding to the sample. Calculate probability of flashover corresponding to reduced variate from the Cumulative Normal Distribution Table and repeat the procedure for all samples.

B. Transmission line consisting of n Tower

In this case, the generated over voltages are applied to all the n towers simultaneously. The probability of flashover for a given over voltage changes to equation

$$P(FO(V)) = 1 - q^n = 1 - (1-p)^n (2)$$

Where

p is the flashover probability for a single tower insulation
q is the probability of no flashover and equal to (1-p)
n is the number of towers

V. RESULTS

First consider the transmission line consists of one tower, in that consider an overvoltage of 1.97pu. The probability that this occurs is 18.82% or 0. 1882.The reduced variate Z for this over voltage is -1.95.

The flashover probability P(FO(V)) for this reduced variate is 0. 0256.The flashover probability for this voltage is simply the probability of occurrence of 0.1882 times the flashover probability given this voltage, or 0. 00482.The same procedure is repeated for all overvoltages and the results are given in Table 3.

Finally, the estimated SSFOR for this case is 7.34×10^{-5}.

Table- III: SSFOR values of a single tower 1200kV transmission line

Overvoltage in p.u(V)	Reduced Variate(Z)	P(V)	P(FO(V))	SSFOR
1.97	-1.95	0.1882	0.0256	0.00482
1.98	-1.86	0.1673	0.0314	0.00526
1.99	-1.77	0.1122	0.0384	0.00430
2.00	-1.68	0.0780	.0465	0.00362
2.01	-1.59	0.0856	0.0559	0.00478
2.02	-1.50	0.0532	0.0668	0.00356
2.03	-1.40	0.0171	0.0808	0.00138
2.04	-1.31	0.0057	0.0951	0.00054
2.05	-1.22	0.0057	0.1112	0.00063
2.06	-1.13	0.0057	0.1292	0.00074
2.07	-1.04	0.0038	0.1492	0.00057
2.08	-0.95	0.0247	0.1711	0.00423
2.09	-0.86	0.0171	0.1949	0.00333
2.1	-0.76	0.0038	0.2236	0.00085
Total SSFOR				0.03862

Next consider the transmission line consists of n towers, using Eq. 2, the calculation of the SSFOR proceeds as before and the results are shown in Table 4 for a 1000-tower line. The considered 1200kV transmission line consists of 1000 towers. Finally, the estimated SSFOR for this case is 1.46×10^{-3}, which is within the limits given by IEC i.e.,1×10^{-3} [3].

One order of magnitude of SSFOR makes difference so the estimated SSFOR is considered as within the range.

Table- IV: SSFOR values of 1000 tower 1200kV transmission line

Overvoltage in p.u(V)	Reduced Variate(Z)	P(V)	P(FO(V)) $=1-(1-p)^n$	SSFOR
1.97	-1.95	0.1882	1.00000	0.1882
1.98	-1.86	0.1673	1.00000	0.1673
1.99	-1.77	0.1122	1.00000	0.1122
2.00	-1.68	0.0780	1.00000	0.0780
2.01	-1.59	0.0856	1.00000	0.0856
2.02	-1.50	0.0532	1.00000	0.0532
2.03	-1.40	0.0171	1.00000	0.0171
2.04	-1.31	0.0057	1.00000	0.0057
2.05	-1.22	0.0057	1.00000	0.0057
2.06	-1.13	0.0057	1.00000	0.0057
2.07	-1.04	0.0038	1.00000	0.0038
2.08	-0.95	0.0247	1.00000	0.0247
2.09	-0.86	0.0171	1.00000	0.0171
2.1	-0.76	0.0038	1.00000	0.0038
Total SSFOR				0.7681

VI. CONCLUSION

Statistical distribution of no-load line energization overvoltages is obtained for 1200kV UHVAC transmission line and it's insulation strength is also calculated. The SSFOR of 1200kV UHVAC transmission line under no-load line energization is estimated for the given gap length which is within the limits given by IEC.

REFERENCES

1. S.Jha, Y.K. Sehgal, Subir Sen, "Development of 1200kV Transmission System in India", International Conference on Development of 1200 kV National Test Station, 2010, New Delhi.
2. CIGRE Working Group 13.02, "Switching Overvoltages in EHV and UHV Systems with Special Reference to Closing and Reclosing Transmission Lines," Electra N°30, pp. 70-122, 1973.
3. Insulation Coordination—Part 2: Application Guide, IEC 60071-2, 1996.
4. CIGRE Technical Brochure 542, June2013, "Insulation Coordination for UHV AC Systems" CIGRE WG C4.306.
5. I.S.Jha ,Y.K. Sehgal, Subir Sen "Development of 1200kV Transmission System in India", International Conference on Development of 1200 kV National Test Station, 2010, New Delhi.
6. V. Ramakrishna ,R.N. Nayak, M.C. Bhatnagar, B.N.DeBhowmick, R.K. Tyagi "1200 kV Transmission Network and Development Status of 1200 kV Technology in India",CIGRE session,2010,Paris,paper A3-105.
7. PSCAD® Software. Rep. ver. 4.2.1, Apr. 2010.
8. R.N. Nayak, M.C. Bhatnagar, B.N.De.Bhowmick, R.K.Tyagi, "1200 kV Transmission system and status of Development of Substation Equipment/Transmission Line Material in India" Second International Symposium on Standards for Ultra High Voltage Transmission, 2009, New Delhi.
9. Rajesh Kumar, Anish Anand and Rajiv Gandhi, "Optimization of design of 1200 kV transmission line", International Conference on Development of 1200 kV National Test Station, 2010, New Delhi.
10. J. A. Martinez, R. Natarajan, and E. Camm, "Comparison of Statistical Switching Results using Gaussian, Uniform and Systematic Switching Approaches," in Proc. IEEE Power Eng. Soc. SummerMeeting, Seattle, WA, USA, 2000, vol. 2, pp. 884–889.
11. Patricia Mestas, Maria Cristina Tavares, Relevant Parameters in a Statistical Analysis— Application to Transmission-line Energization, IEEE Trans. Power Deliv. 29(6) (2014) 2605–2613.
12. G.Carrara,L.Marzio, "Discharge probability under dielectric stress," Annexe to the report of CIGRE Study Committee No.8,1968.
13. M.Kawai, "Flashover probability of switching surges for air gaps," IEEE Paper 31 PP67-106, presented at Winter Power Meeting, January 1967.
14. Project EHV Staff, EHV Transmission Line Reference Book, New York: Edison Electric Institute,1968, pp.235-237.
15. T. Suzuki, I. Kishijima, Y. Ohuch, and K. Anjo, "Parallel multigap flashover probability," IEEE Trans. Power Apparatus and Systems, vol.

PAS-88, pp. 1814-1823, December 1969.
16. Insulation Coordination for Power Systems, Andrew R. Hileman, published by Marcel Dekker Inc., June 1999.
17. L. Paris, "Influence of air gap characteristics on line-to-ground switching surge strength," IEEE Trans. Power App. Syst., vol. 86, no. 8, pp. 936–947, Aug. 1967.
18. R.Cortina, E.Garbagnati, A.Pigini, G.Sartorio, L.Thione.: 'Switching impulse strength of phase-to-phase UHV insulation', IEEE Trans., 1985, PAS-104, (11), pp. 3161-3168
19. IEEE COMMITTEE REPORT," Recommendations for Safety in Live Line Maintenance", IEEE Trans. Power App. Syst., vol. PAS-92, pp. 346–352, February1968.
20. IEEE Towers, Poles and Conductors Subcommittee of the IEEE Transmission and Distribution Committee" Live-Line Maintenance Methods" ", IEEE Trans. Power App. Syst., vol. PAS-92, pp. 1642–1648, September/October1973.
21. G. Gallet, G. Leroy, R. Lacey, and I. Kromer, "General expression for positive switching impulse strength valid up to extra-long air gaps," IEEE Trans. Power App. Syst., vol. 94, no. 6, pp. 1989–1993, Nov. 1975.
22. I. Kishizima, K. Matsumoto, and Y. Watanabe, "New facilities for phase-to-phase switching impulse tests and some test results," IEEE Trans. Power App. Syst., vol. PAS-103, no. 6, pp. 1211–1216, Jun. 1984.
23. ANSI/IEEE Std 516-1987" IEEE Guide for Maintenance Methods on Energized Power-Lines"1987
24. V. Ramakrishna ,R.N. Nayak, M.C. Bhatnagar, B.N.DeBhowmick, R.K. Tyagi "1200 kV Transmission Network and Development Status of 1200 kV Technology in India",CIGRE session,2010,Paris,paper A3-105.
25. Yang Li, Jinliang He, Jun Yuan, Chen Li, Jun Hu, and Rong Zeng, "Failure Risk of UHV AC Transmission Line Considering the Statistical Characteristics of Switching Overvoltage Waveshape," IEEE Trans. on Power Delivery, Vol. 28, No. 3, pp. 1731–1739, July 2013.

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