Comparative Analysis of Energization of 765kV Shunt Compensated Transmission Line With and Without Control Switching

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Abstract— **In this paper analysis of overvoltages due to switching operations in 765kV transmission system has been done. Here energization of transmission line has been considered with & without controlled switching for both with and without trapped charges in the line respectively has been analyzed. Study represents the over voltages and inrush current during line charging to check suitability of the breaker with appropriate representation of transmission line, circuit breaker, surge arrester and all other equipment of the substation. PSCAD / EMTDC tool is used to perform simulation and analyze results.**

Keywords-Controlled switching, Energization, Switching overvoltage, Trapped charges, Transmission line.

I. INTRODUCTION

The switching transient originate from energization of transmission line, cable or capacitor bank, sudden shutting of load, short circuit, fault clearing and resonance phenomenon like ferroresonance [1]. These switching overvoltages can be reduced by line energization through pre-insertion resistor, point on wave switching and limiting overvoltage by using surge arrester [1]. The switching transient analysis is primarily importance in insulation co-ordination for EHV lines and helps to reduce the damage to the equipments [2]. Switching overvoltages have different magnitude for different line lengths for the same voltage level. The three phase circuit breaker opening and closing produces significant transient overvoltages depending on voltage waveform. These are more specifically in transmission line switching.

The objective of this paper is to investigate voltage stress due to various conditions of switching for line energization with and without trapped charges of transmission line. This paper represents analysis of 765kV line with conductor configuration AAAC QUAD BERSIMIS. PSCAD/EMTDC modeling guidelines for representation of the substation equipment is shown in [3]. Modeling guidelines for the switching transients is shown in [4]. The standard insulation levels for voltage ranges from 1kV to 800kV are shown in [2].

II. SYSTEM REQUIREMENT AND MODELLING OF EQUIPMENTS

1) Source

Source models are represented with the information such that magnitude of AC line to line r.m.s voltage value, voltage ramp up time, fundamental frequency, phase shift. Based on the fault levels during strong & weak source conditions, the source has been represented with voltage behind source impedance with parallel RL in series with resistive. For external inputs, connect with slider for convenient runtime manual adjustment or use control system output for dynamic adjustment [3].

2) Transformer

Transformer is represented by classical modeling approach. The classical model approach requires its MVA rating, winding HV and LV voltage levels, tap change range and normal setting, leakage reactance between windings, knee point of transformer core saturation characteristic in per unit of rate flux or voltage, and estimated saturated air core reactance [3].

3) Transmission line

Transmission line is represented by PI model which is accurate for the short and medium length of line with in the substation, where its propagation travel time is less than one time step. Model is represented with impedance/admittance data in R, X_L, and X_C in p.u or in ohms or R, X, B in p.u or ohms, line rated frequency and line length. However, transmission lines where line lengths are high are represented as distributed parameters model with frequency dependent phase model with its tower geometry [3].

4) Circuit breaker

The circuit breaker operated according to its logic given for switch on and off with respect to time. Other parameters of circuit breaker determined are protection delay or clearing times, reclosing sequence, pole closing resister etc. [3].

5) Surge arrester

It plays vital role to determination of economic insulation level of surge arrester is modeled with voltage rating of arrester, energy absorption capability and V-I characteristics according to its various classes [3].

6) Modeling in case of transient behavior

Each equipment used in the substation for example current transformer, capacitor voltage transformer disconnector, circuit breaker are modeled by line to ground capacitance because effect of capacitance of the system is predominant in switching analysis. This capacitance values to ground are according to different voltage levels. Capacitor in case of circuit breaker is represented by capacitors on both side of the breaker [4]. These capacitances to ground capacitance value of switching transient for different elements are given below.

TABLE I

CAPACITANCE TO GROUND VALUES FOR VARIOUS SUBSTATION EQUIPMENTS

Equipment	Phase to Ground Capacitance
Isolator	160pF
Circuit Breaker	300pF
Bus Support Insulator	150pF
Capacitor Voltage Transformer	8000pF
Current Transformer	1200pF

III. DISCRIPTION OF WORK

Switching overvoltage of 765kV AAAC QUAD BERSIMIS conductor configuration transmission line of 369km has been performed to determine line energizing transients with and without trapped charge carriers with the following cases figure for this network is shown in figure 1.

1) Line Energization Without Trapped Charges

The Line charging analysis was performed to determine the capability of line breaker to handle the inrush current during line switching. Line energization with weak source i.e., minimum fault MVA at source results highest over voltages at 765 kV Phase and Phase-Phase voltages at line.

In this case, breaker logic is given such that it initially opens and closed at voltage peak.

2) Line Energization With Trapped Charges

The principle of the energization with trapped charges phenomenon is based on energizing occurs at an instant with a large difference between (instantaneous) supply voltage and line voltage; a large traveling wave will be injected onto the line. When this wave reaches the open, far end of the line, it will be reflected and a high overvoltage will be initiated.

At reclosing operations of shunt compensated lines (shunt reactor connected on the line side of the circuit breaker), the voltage on the line will be a gradually damped sinusoidal oscillation, with a frequency determined by the line capacitance and the inductance of the shunt reactor. The frequency will generally be lower than the frequency of the supply voltage. As a result, there will be an amplitude modulated voltage oscillation across the open circuit breaker, with the actual shape determined by the degree of compensation of the line.

For shunt compensated lines, Line energization with trapped charges scenario consists of 100 statistical runs, over 360 degrees. The three poles of the line switch close with a random separation, within a cycle.

In this case breaker is initially close, then open and after some time again closed for 100 statistical runs as specified above. The line voltage at opening instant was at a peak value (Positive peak). The breaker reclosed at bus voltage peak with polarity opposite to line voltage (negative peak). This results in highest overvoltage magnitude.

3) Line Energization With Controlled Switching: Without Trapped & With Trapped Charge Carriers

Analysis of line energization with & without trapped charge carriers will determine the suitability of the line breaker & requirement of pre-insertion resistor or zero crossing breakers (controlled switching relay) and also will determine the suitability of arrester. By considering the disadvantages of pre-insertion resistors, controlled switching has been proposed in this paper. In order to limit the over voltages during line closing/re-closing, point ON wave switching was simulated for 765kV line to determine switching over voltages limits are not violated by using controlled switching or point ON wave switching. The point ON wave switching measures voltage at two ends of the breaker of each phase and defines internally a differences in voltage at both sides of the breaker. The breaker is closed when the difference in voltage is observed as minimum or ideally zero.

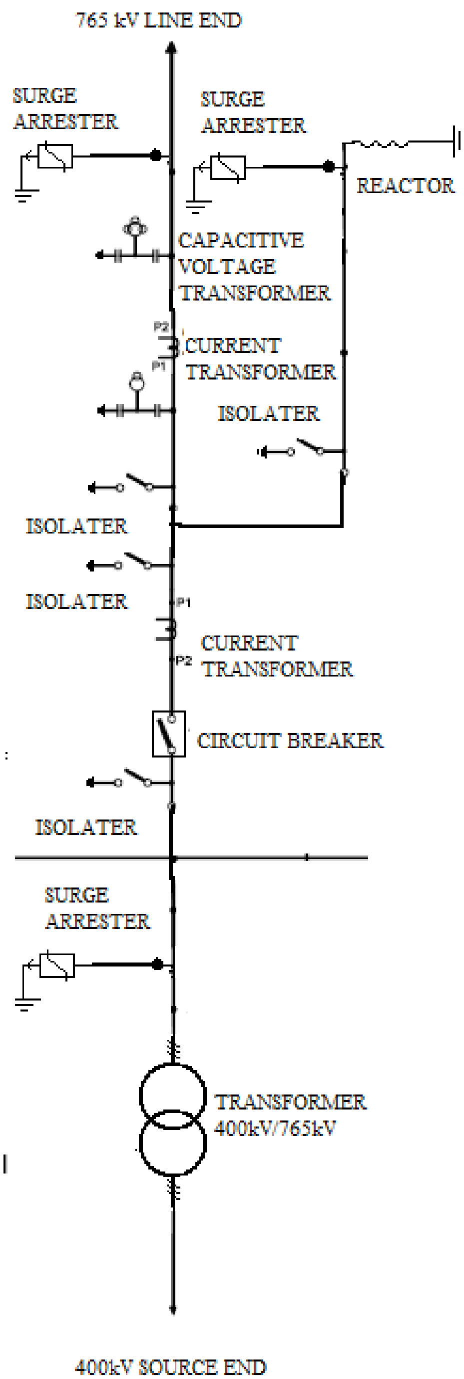

Figure 1. 765kV transmission network

IV. SIMULATION RESULTS

Simulation results are for line energized with and without trapped charges and also switching methodology of controlled switching for reduction of switching overvoltages has shown below figures. Results 1 and 2 shown below are indicated with waveforms of charging current, phase to phase voltage, phase to earth voltage, sending end voltages and receiving end voltages without or with trapped charges respectively. Figure 12 indicate the controlled switching methodology to reduce the switching overvoltages.

A) Result 1: Energization without trapped charges:

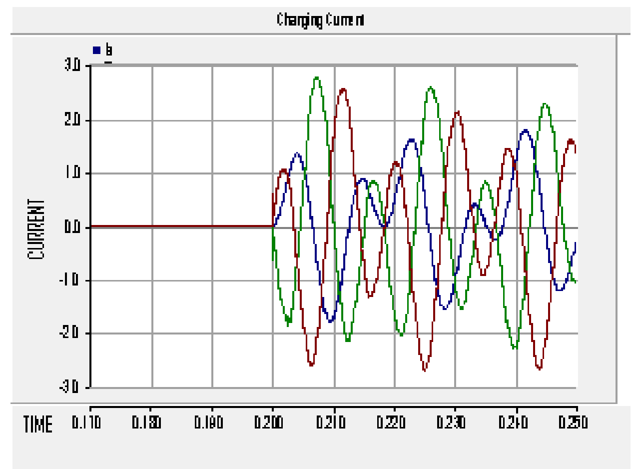

Figure 2. Charging current without trapped charges

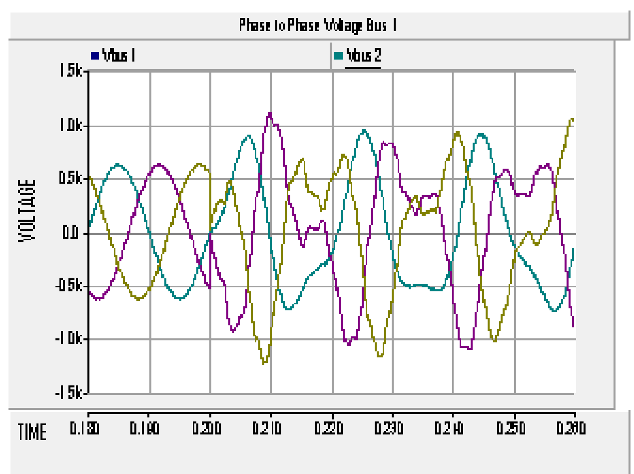

Figure 3. Phase to phase voltage without trapped charges

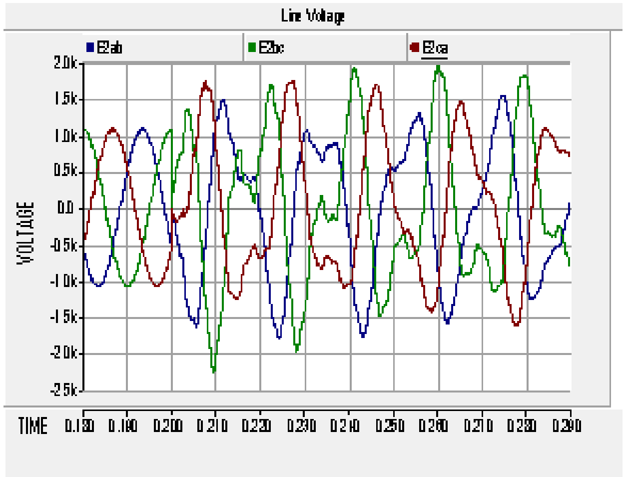

Figure 4. Line voltage without trapped charges

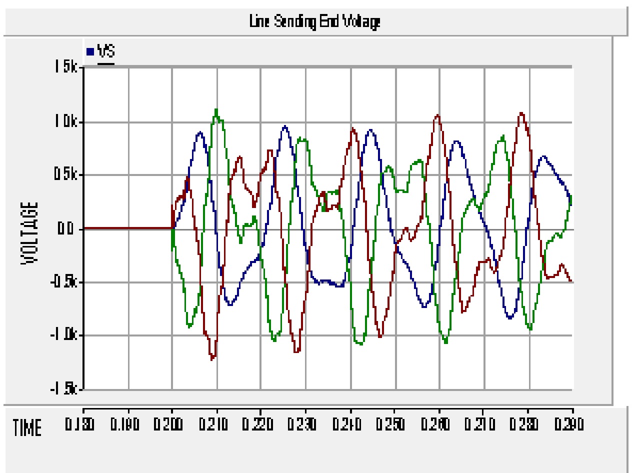

Figure 5. Sending end voltage without trapped charges

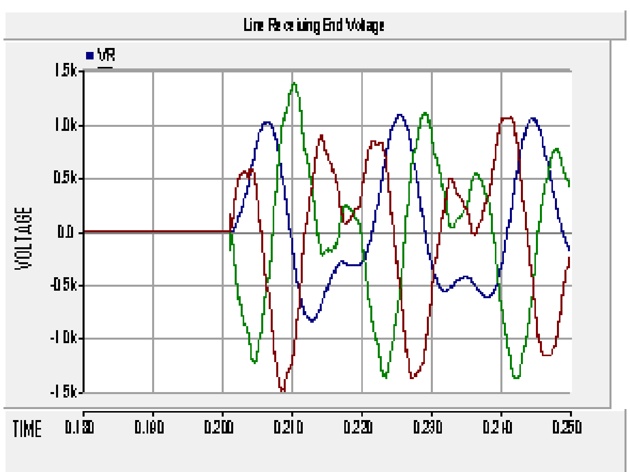

Figure 6. Receiving end voltage without trapped charges

B) Result 2: Energization with trapped charges

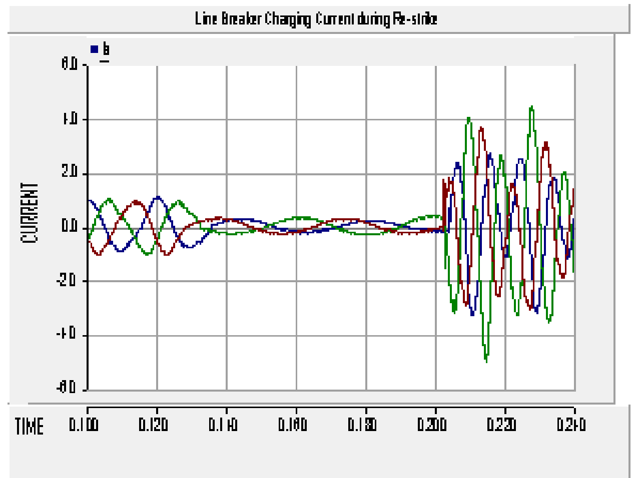

Figure 7. Charging current with trapped charges

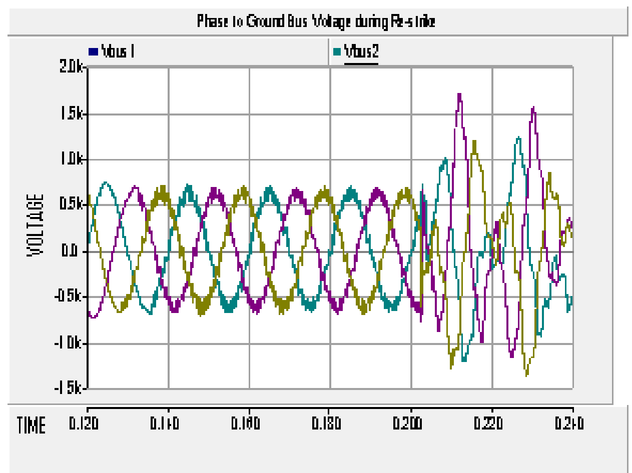

Figure 8. Phase to phase voltage with trapped charges

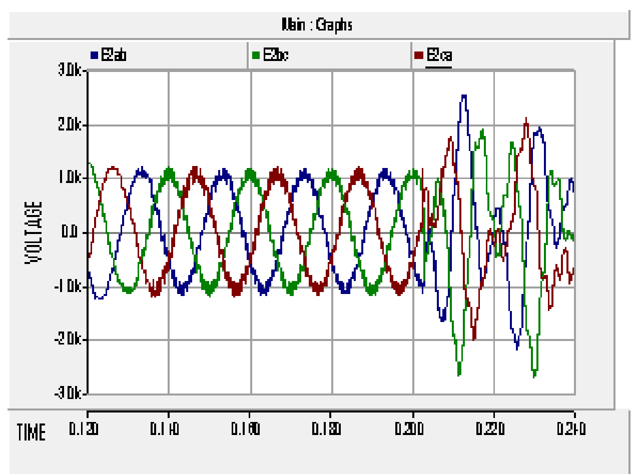

Figure 9. Line voltage with trapped charges

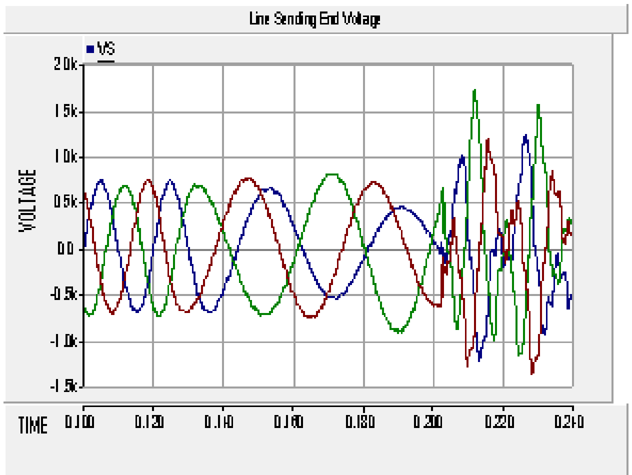

Figure 10. Sending end voltage with trapped charges

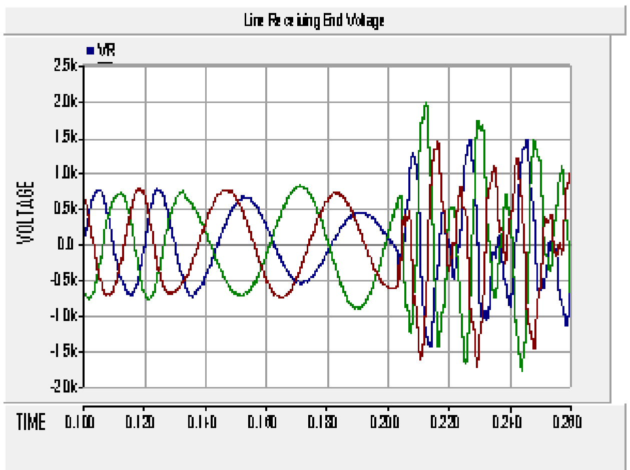

Figure 11. Receiving end voltage with trapped charges

C) Result 3: controlled Switching methodology

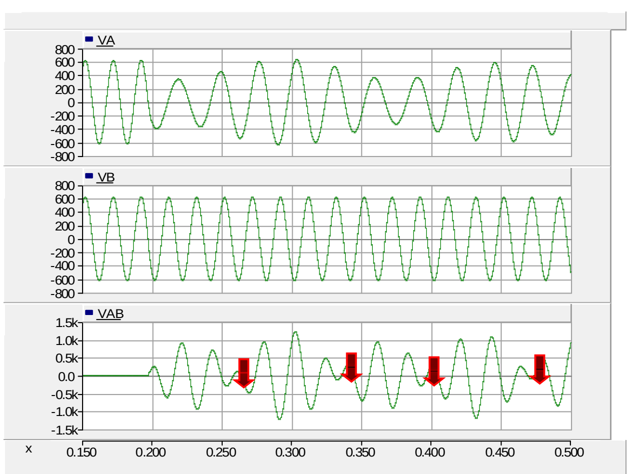

Figure 12. Controlled switching methodology

V. COMPARISION TABLES

A) This table indicates rated value of voltages and current and also limited value of switching over voltage values above this vale voltage or current become violated.

TABLE II

RATED VALUES FOR 765KV NETWORK AS PER CEA MANUAL

Phase to earth voltages		**Phase to phase voltages**		**Limits of surge over voltages**		**Rated short circuit current**	**Rate of change of current**
kV peak	**p.u**	**kV peak**	**p.u**	**kV peak**	**p.u**	**kA**	**A/µs**
1131	1	653	1	1240	1.9	40	17.76

B) This table indicates that comparison of values with and without controlled switching and values with bold indicate witch are violated values.

TABLE III

COMPARISON OF CASES WITH AND WITHOUT CONTROLLED SWITCHING

Case	**Phase to earth voltage**		**Phase to phase voltage**	
	kV peak	**p.u**	**kV peak**	**p.u**
Without Controlled Switching				
Without trapped charges	1254	**1.92**	2240	1.98
with trapped charges	1715	**2.62**	2972	2.62
With Controlled Switching				
Without trapped charges	872	1.33	1381	1.22
with trapped charges	953	1.46	1532	1.35

C) This table indicates the value of charging current and rate of rise of inrush current which calculate by formula given below:

$$di_i/dt = 2´ *f_{i*}i_{ipeak} \quad (1)$$

where,

$f_{i=}$ frequency of inrush cyrrent

$i_{ipeak=}$peak magnitude of inrush current

TABLE IV

CHARGING CURRENTS AND CHARGING CURRENT FREQUENCIES FOR BOTH CASES

Case	Rate of change of current (A/µs)	Inrush current frequency (kHz)
Energization without trapped charges	2.44	140
Energization with trapped charges	6.07	206

VI. CONCLUSION

Switching overvoltages originated from different switching conditions of line energization with & without control switching comparative analysis has been investigated. The 765kV shunt compensated line overvoltages also analyzed with & without trapped charge carriers in the line using PSCAD/EMTDC. The observation tables indicates that line energized with trapped charges overvoltages are very high than the line energized without trapped charges, however the rate of change of inrush current flowing through the breaker has been within limits. The basic insulation levels (BIL) of 765kV are violated as per [2] without control switching. However by control switching of the transmission line, the BIL are within limits.

VII. ACKNOWLEDGMENT

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VIII. REFERENCES

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