A Comparative Study of Current and Voltage Transients on a Distribution Transformer Due To Capacitor Switching

Pawan Kumar Mehta*, Baidehi Nanda, Swayam Ranjan Halder**, Akhilesh Kumar**, Afsir Ahsan**, Santanu Das**, Poulomi Mitra****

*(Department of Electrical Engineering, St. Thomas' College of Engineering & Technology, Kolkata, India)
**(Department of Electrical Engineering, St. Thomas' College of Engineering & Technology, Kolkata, India)

ABSTRACT

A high voltage capacitor is relatively frequently switched during the periods of the system operations. The distribution transformers are subjected to many stresses during normal and abnormal operations. In this paper we simulate a portion of the distribution network of Durgapur Steel Plant using MATLAB 7.7 and observe the effects of capacitor switching events on transformer terminal at different instants. Simulations of capacitor switching transients show significant disturbances in HV transformers which illustrate cause of transformer failure due to matching of transient frequency to the natural frequency of transformer. This paper is intended to alert the industries from the impact of first transient phenomena on transformer which is the real cause of failure of transformer of above said network.

Keywords - **Feeders, MATLAB 7.7, Reactors, Switching, Transformers.**

I. INTRODUCTION

Transient phenomenon is a situation, where the power system is in a dynamic state with large disturbances caused by a fault, opening or closing of a capacitor or other kinds of perturbations[1,2]. It lasts in a power system for an extremely short period of time, ranging from a few microseconds to 1sec. The study and understanding of this phenomenon is of extreme importance because during this time period, the system suffers greatest stress from excessive over-currents or voltages which if severe, can cause extensive damage[3,4,5]. Switching transients are more common than any other form of transient . In this paper we try to observe,analyze and compare the effects of capacitor switching on the transformer terminals of a large power distribution network. The transformers are the most expensive equipments in the power system.Their protection therefore is a matter of utmost importance. Before proceeding to take protective measures ,it is necessary to have an idea about the frequency and the magnitude of the voltage and current which can occur due to switching. The switching overvoltage can be dangerous for the equipment if their peak value exceeds the rated switching impulse withstand voltage of the equipment. It is very important to know the level of dielectric stress that occurs during operation in the system in order to avoid insulation failures[6]. Besides that we must assess the low amplitude high oscillatory switching voltage and current, which can generate high over voltage at the windings of the transformer[7,8] when its natural frequency matches with transient frequency arise from the network[9,10,11]. Therefore, the main objective of this paper is to highlight the effect of low amplitude high oscillatory transient phenomena on transformer. To show the severity of this phenomena we capture voltage and current waveforms due to capacitor switching at 80 MVA 220/33kV Transformer (MX1), with variation of switching time instant from zero to 50 mili second.

The complete details of the distribution network, modeling technique and the single line diagram of the network are given in appendix –I, II and III respectively.

II. MATLAB WAVEFORM

When capacitor is connected to 33kV DSP MRS ASP O/D-LHS bus bar to compensate 35MVAR reactive power high oscillatory voltage & current waveforms are generated at the MX1 transform terminal.

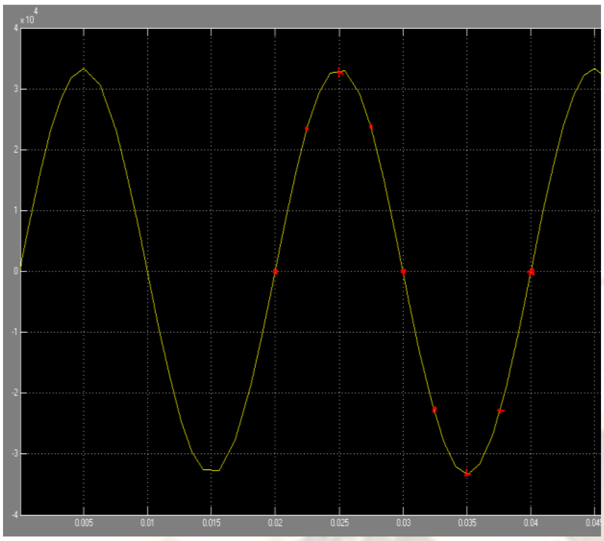


Fig.1.Fundamental Voltage (33kV) appearing at the MX1 transformer terminal (Red point indicates the instant of Switching).

2.1. CURRENT WAVEFORMS

The current waveforms are shown for a complete cycle(from 0.02 second to 0.04 second as indicated by red points in the above figure) for different instant of switching.

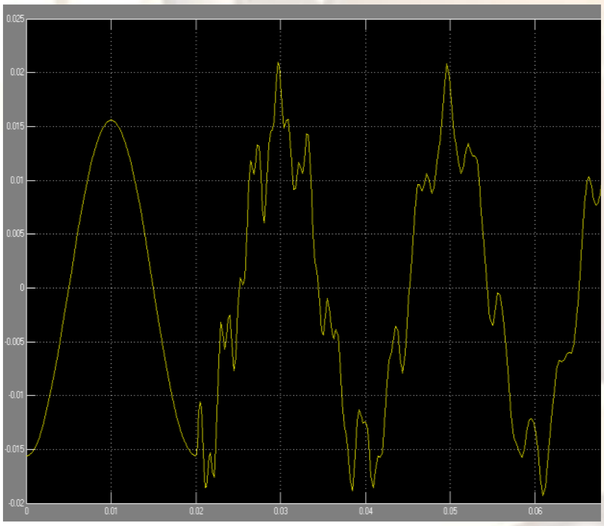


Fig. 2.Current at MX1 transformer terminal. Switching time=0.02 second.

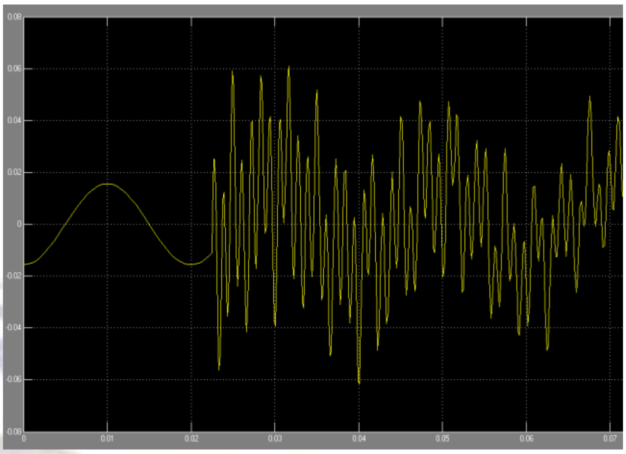


Fig. 3.Current at MX1 transformer terminal. Switching time=0.0225 second.

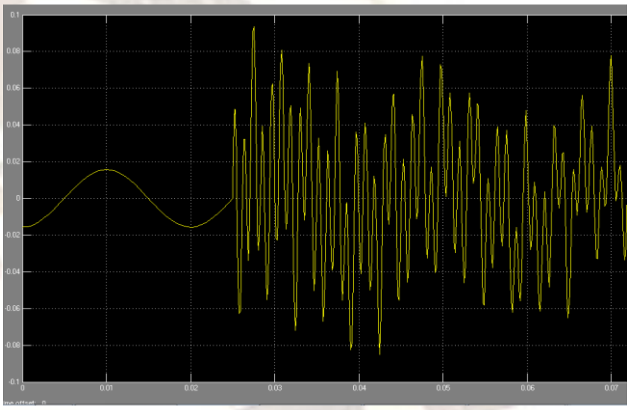


Fig. 4.Current at MX1 transformer terminal. Switching time=0.025 second.

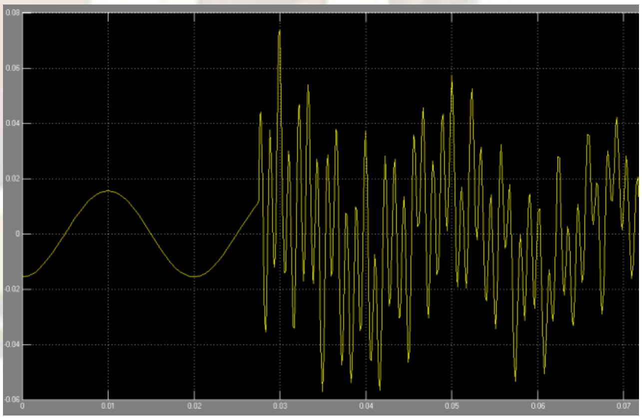


Fig. 5.Current at MX1 transformer terminal. Switching time=0.0275 second.

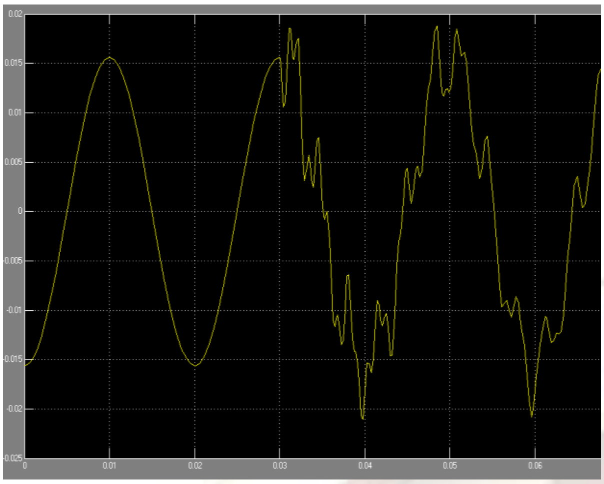


Fig. 6.Current at MX1 transformer terminal. Switching time=0.03 second.

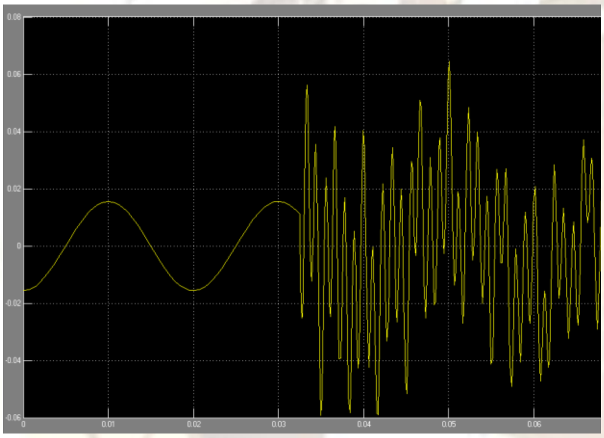


Fig. 7.Current at MX1 transformer terminal. Switching time=0.0325second.

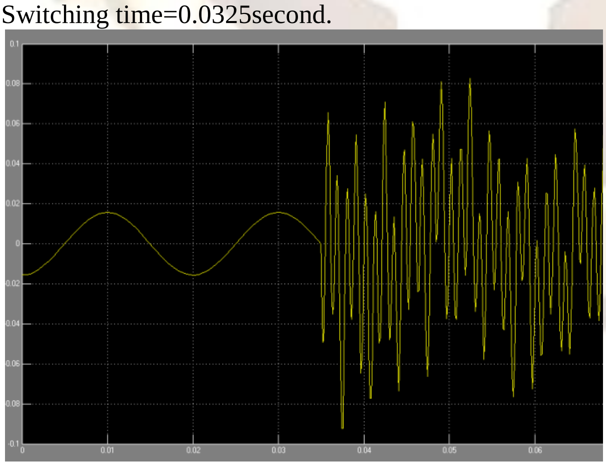


Fig. 8.Current at MX1 transformer terminal. Switching time=0.035second.

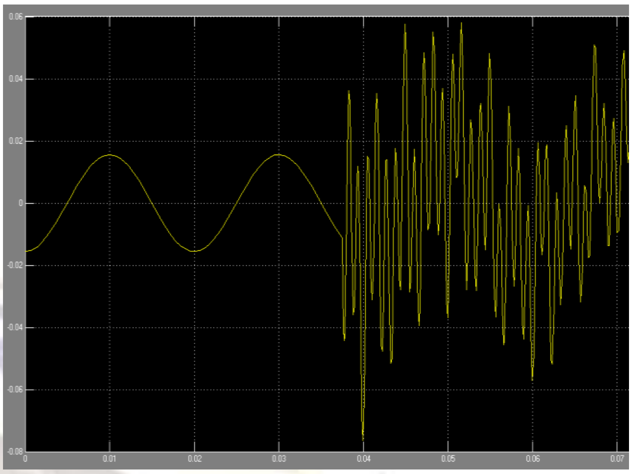


Fig. 9.Current at MX1 transformer terminal. Switching time=0.0375second.

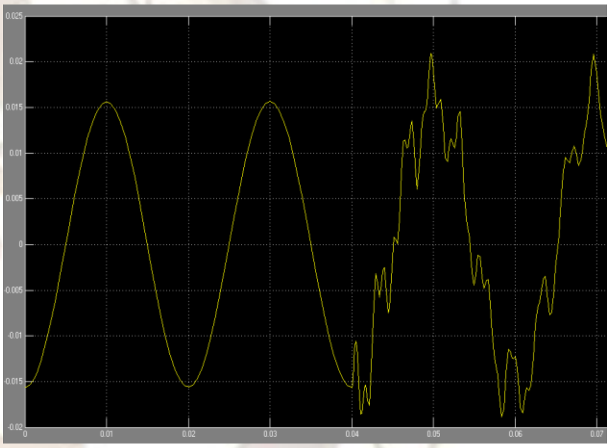


Fig. 10.Current at MX1 transformer terminal. Switching time=0.04second.

2.2. VOLTAGE WAVEFORM

The voltage waveforms are shown for a complete cycle(from 0.02 second to 0.04 second) for different instant of switching.

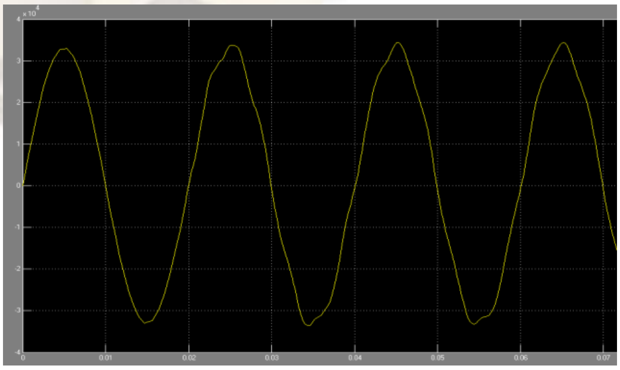


Fig.11.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.02)

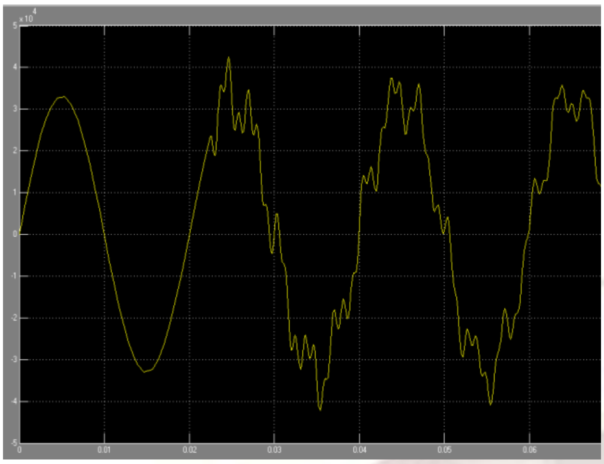


Fig.12.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.0225)

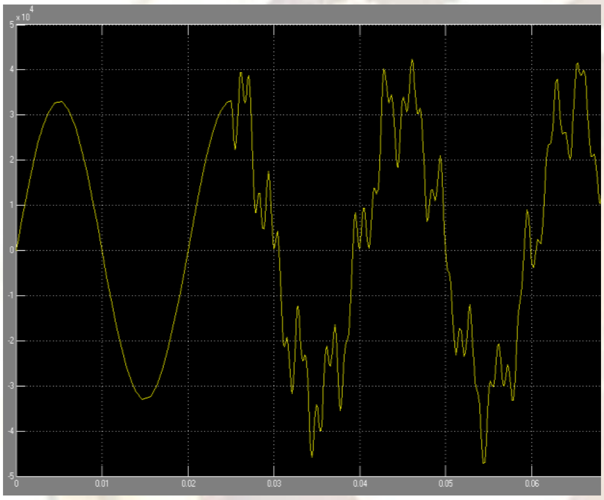


Fig.13.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.025)

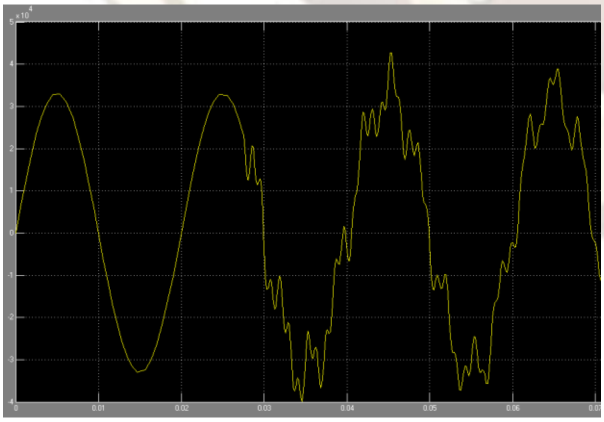


Fig.14.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.0275)

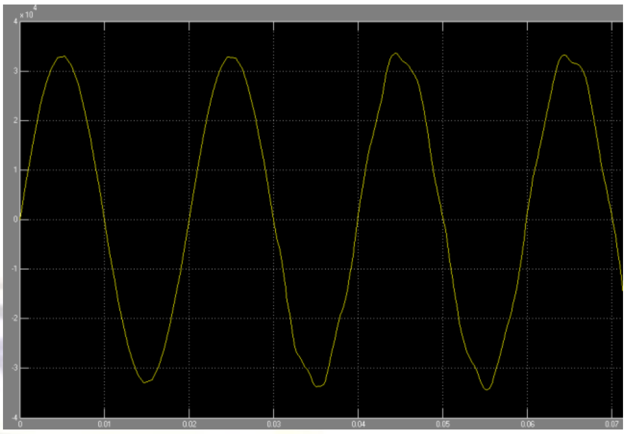


Fig.15.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.03)

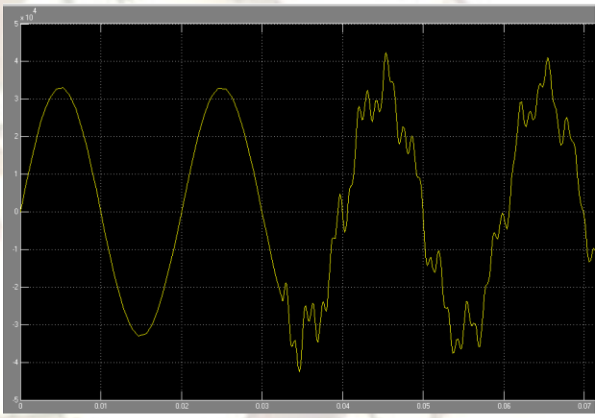


Fig.16.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.0325)

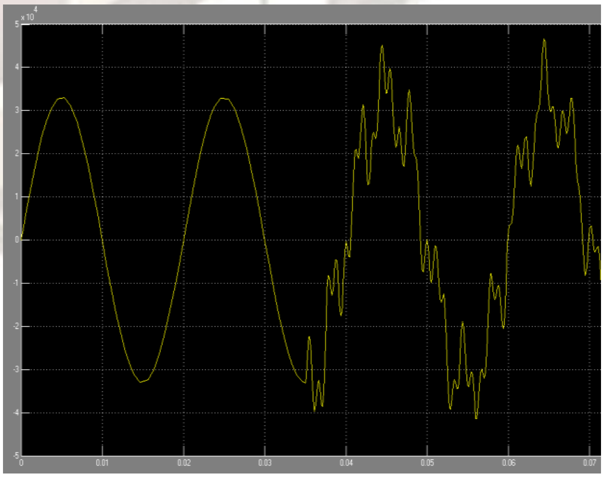


Fig.17.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.035)

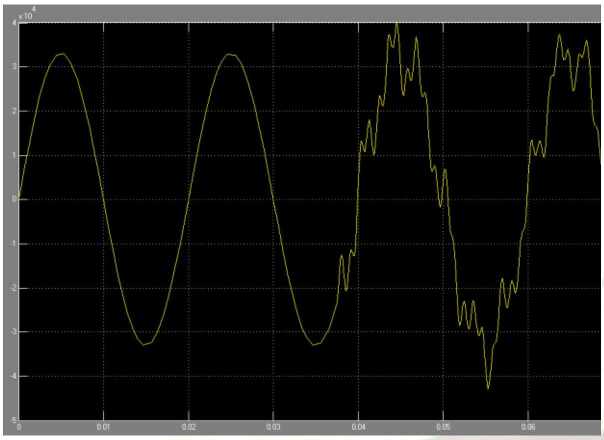


Fig.18.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.0375)

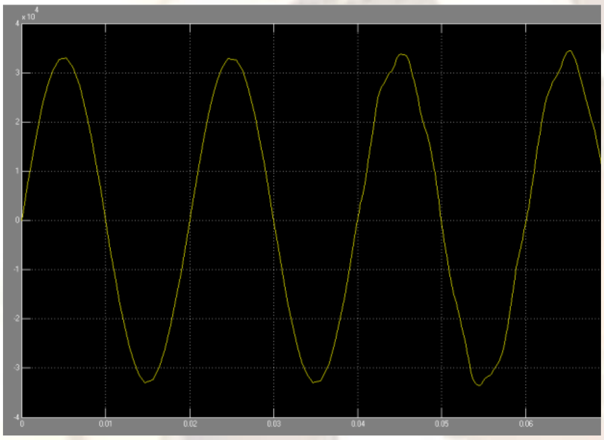


Fig.19.Oscillatory voltage appearing at MX1 transformer terminal. Switching time(0.04).

III. RESULT ANALYSIS

Terminal disturbance of 80 MVA 220/33kV distribution transformer MX1 have been investigated under the switching operation of capacitor connected to 33kV DSP MRS ASP O/D-LHS bus bar.

The developed transient voltages and current after switching of capacitor while compensating 35MVAR reactive power created high oscillatory transient overvoltage and current at the MX1 transformer terminal . The results shown indicates that arrestor protection will not affective for all types of system switching voltage and current wave-shapes. Damage of insulation from oscillatory overvoltages cannot be demonstrated by conventional dielectric tests on power transformers [12, 13]. However some action can be taken at the design level to improve winding’s response to oscillatory system, which will be communicated in the companion paper.

Table.1
Key Results:

Time of switching	**Peak Voltage due to closing of capacitor (kV)**	**Maximum Current due closing of capacitor (Amps)**
t=0 .02second*	33	0.021
t=0.0225 second	42	0.060
t=0.025 second	46	0.092
t=0.0275 second	42	0.075
t=0.03 second	33	0.018
t=0.0325 second	42	0.065
t=0.035 second	46	0.082
t=0.0375 second	41	0.068
t=0.04 second*	33	0.021
t=0.0425 second	42	0.060

VI. CONCLUSION

The findings of the present investigation reveals that the switching events quoted earlier can generate high frequency oscillatory transient in the system which could be of concern. As the terminal voltage of the transformer remains well below the basic insulation level (BIL) in capacitor switching cases, these low amplitude oscillatory transients may easily pass on to the transformer windings resulting in severe internal voltage stresses. The reported failure of several transformers in the DSP distribution system could be attributed to these transients actually caused resonance inside the transformer which is ascertained and demonstrated by the frequency response analysis (FRA) of this transformer.

VII. ACKNOWLEDGEMENT

This research work is a part of the consultancy work offered to the Development Consultants Private Limited, Kolkata by Poulomi Mitra for failure analysis of distribution transformers at Durgapur Steel Plant(DSP) of Steel Authority of India Limited(SAIL).

REFERENCES

[1] P. Mitra, A.de, A. chakarborty, Response of EHV grid transformers to system-originated oscillatory switching transients, *IEEE Transaction on Power delivery, 27(1), January 2012, 224-235.*

[2] Pawan Kumar Mehta, Tapash Debnath, Ranabir Mullick, Arijit Banerjee and Poulomi Mitra, Study and Analysis of switching Transient in the Power Distribution Network, *Int. J. on Recent Trends in Engineering and Technology, 6(1), Nov 2011, 247-251.*

[3] Bjorn, Gustavsen, Study of Transformer Resonant Overvoltages caused by cable-Transformer High frequency Interaction, *IEEE Transaction on Power Delivery,25(2),April 2010 .*

[4] Geardus chr. Paap, Abraham A.Alkema, Lou vander Sluis, Overvoltages in Power Transformers caused by No-load switching, *IEEE Transaction on Power Delivery, 10(1), January 1995.*

[5] R.J Musil, G. Preininger, E. Sehopper, S. Wenger, Voltage Stresses produced by aperiodic and oscillating system over-voltages in Transformer windings, *IEEE Transactions on PAS, PAS-100(1), January 1981.*

[6] Nilangawickrama, Yuriy V.serdyuk, Stanislaw M.Gubanski, High –frequency Modeling of Power Transformers for use in Frequency Response Analysis (FRA), *IEEE Transaction on Power Delivery, 23(4), October 2008.*

[7] A.De, D.Debnath and A. Chakrabarti, A Study on the Impact of Low-Amplitude Oscillatory Switching Transients on Grid Connected EHV Transformer Windings in a Longitudinal Power Supply System, *IEEE Transactions on Power Delivery(USA), 24(2), April2009, 679-686.*

[8] Shibuya,Y.Fujita,S.Shimomura,T, Effects of very fast transient Overvoltages on transformer, Generation, *Transmission and Distribution, IEE proceedings, 146(5) , sep1999, 459-464.*

[9] A. De, A. Chakrabarti and P. Hazra, Resonant Overvoltages Produced in EHV Transformer Windings due to Power system transients, *Proceedings of the IEEE INDICON 2004, 20-22 Dec, 2004, 74-77.*

[10] P. Mitra, A. De, A. Chakrabarti, Investigation on the Voltage Stresses developed on Transformer Insulation under Non-Standard Terminal Excitation, *Proceedings of IEEE TENCON 2009,* Singapore, *23-26 Nov, 2009.*

[11] A. De, and N. Chatterjee, Part winding resonance: Demerit of interleaved high-voltage transformer winding, *IEE Proceedings -Electric Power Applications, 147(3), May 2000, 167-174.*

[12] A. De, and N. Chatterjee, Recognition of Impulse Fault Patterns in Transformers using Kohonen's Self- Organizing Feature Map, *IEEE Transactions on Power Delivery, 17(2), 2002, 489 –494.*

[13] C. K. Roy, and J. R. Biswas, Studies on impulse behaviour of a transformer winding with simulated faults by analogue modelling, *IEE Proc. Gen. Trans. Distrib., 41(5), 1994, 401-412.*

[14] A. Greenwood, *Electrical Transients in Power Systems* (John Wiley and Sons, New York).

Appendix-I

To analyze the possible transient voltage stresses that could develop on the distribution transformers under different switching events in this distribution network, the relevant portion of the DSP's power distribution network has been modeled using Matlab. The developed model helps to prepare the transient overvoltage and current profiles [7] for the system, particularly at the transformer terminals [8].Analysis of these transient overvoltage and current profiles help toidentify potentially hazardous switching events [9] which may generate critical voltage stresses [10] inside the 220/33 kV transformers. All substation equipments were modeled by lumped parameter modeling approach.

Transformer Model

The transformers are capacitively modeled [11,12]. It should be noted that modeling of a transformer by capacitive model (which is justified for an interval of time of a few miliseconds)permits to determine the voltage at the transformer terminals.

Feeder Model

The Feeders are modeled using PI modeling technique of single section with suitable transpositions .

Circuit Breaker and Isolator Model

Circuit Breakers and Isolators are modeled in the form of voltage and/or time dependent switches along with lumped capacitances (primarily contributed by bushing capacitance) as PI sections. The effect of arc resistance is considered. Shunt capacitive effect is much pronounced in circuit breaker than isolator.

Bus-Bar Model

Bus Bars are modeled by ladder networks with series resistance and inductances and shunt capacitances. Each ofthe ladder section usually corresponds to a section of 5 or 10 meters of bus length. The inductance and the capacitance of the cells are selected on the basis of the surge impedance of bus-bars.

Static Capacitor Bank Model

It is modeled as set of parallel-grounded capacitors of suitable values connected at the bus bar. Switching of capacitor banks have been modeled by placement of time controlled switches.

Reactor model

Reactors are modeled by their equivalent inductances along with resistances.

Generator model
Model of the generators have been assumed to have the magnitude of constant voltage behind the d-axis transient reactance. Q-axis transient flux linkage has been assumed to be small and has been neglected.

Appendix-II

A number of 33 kV sub-stations: MRS DSP Indoor (I/D) -I, II and III, MRS DSP Outdoor (O/D) - I, II and III, MRS ASP O/D – I, II, Punabad – LHS & RHS, Sajaria – LHS & RHS, New Sajaria – I, II, III & IV and ASP handle a total load of 243.14 MW including export to DVC. Out of this total load, DSP load alone is 143.14 MW, ASP load is 72MW and export to DVC is 28 MW. The power distribution is through 33kV outgoing feeders from these substations. Major equipments installed in the network are as below:

a) 5 Nos. 80 MVA, 220/33KV, YNyn0 transformer with solidly grounded neutral and provided with ±10% OLTC. The transformer MX1 is connected to DSP MRS DSP I/D-3 33kV bus, MX2 is operated on DSP MRS DSP I/D-1 33kVbus,MX3 and MX4 are connected to DSP MRS ASP O/D-LHS 33kV Bus, MX5 is connected to DSP MRS ASP O/D-RHS 33kV bus and MX6 is operated on DSP MRS DSP-O/D-1 33 kV bus.

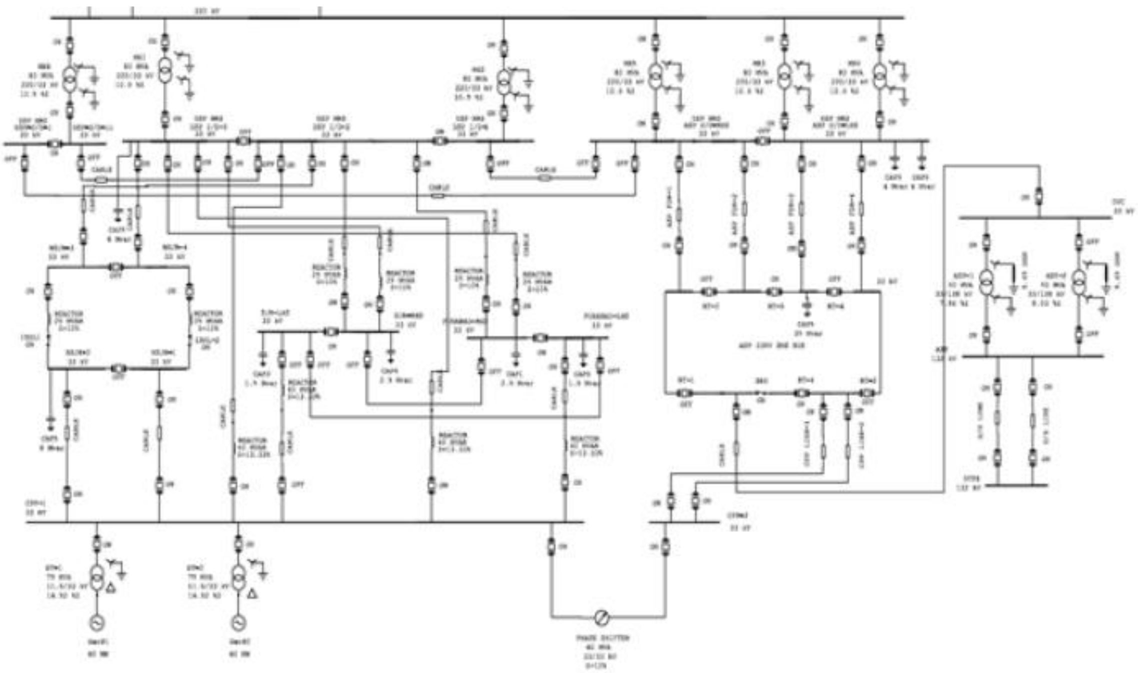
b) 7 nos. 1.5 ~ 2.5 MVAR VAR compensating Static Capacitor Banks at various buses. c) 10 nos. 25/40 MVAR Series Reactors.

d) 2 Nos. 11.5 KV, 68 MW, 0.8 p.f. (lag) Synchronous Generators.

e) 28 nos feeders of rated voltages 220/33/132 kV, where four feeders ASP FDR-1, ASP FDR-2, ASP FDR-3 &ASP FDR-4 are connected to 33 kV DSP MRS ASP O/D –RHS & LHS Bus Bars and

f) A number of circuit breakers of rated voltages 220/245/460/1050kV,33/36/75/170kV of corresponding continuous current and rupturing current ratings.

APPENDIX-III



Single line diagram of Power Distribution Network(DURGAPUR STEEL PLANT).