Insulation Co-ordination Studies and Selection of Surge Arrester in EHV/UHV Substations

D. Maheswaran, K. K. Jembu Kailas, W. Adithya Kumar, Vijaylakshmi Padshetty

W. Adithya Kumar

29. 04. 16

SURGEPROTECH

ieema

your link to electricity

INTRODUCTION

Growing at a rapid pace

Increased Voltage levels

Selection of insulation dictates the cost and safety

INSULATION COORDINATION

INEVITABLE

SURGEPROTECH

ieema
your link to electricity

INTRODUCTION

Why Insulation Co-ordination Study is required?

- To understand the behaviour of equipment during transient conditions.
- To verify whether the LA provided is sufficient enough to arrest the surges.

OVERVOLTAGES

Causes of Overvoltages

LIGHTNING OVER VOLTAGES

- Direct strokes
- Indirect strokes (travelling waves)
- Back flash-over

CAUSES OF OVERVOLTAGES

SWITCHING SURGES

- Energization of transmission lines & cables
- Line re-energization
- Fault initiation and clearing
- Auto re-closing
- Circuit breaker re-striking

-In view of above, a detailed system analysis for switching over voltages is very important especially at EHV & UHV. From such an analysis, the energy through the surge arresters also should be estimated. This will help select proper Long Duration class of the Surge Arresters.

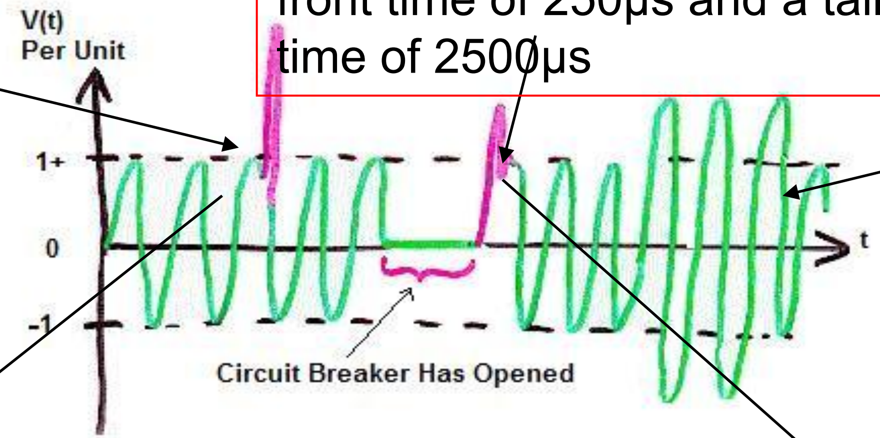
SYSTEM OVER VOLTAGES-WAVE SHAPE

Wave shape:

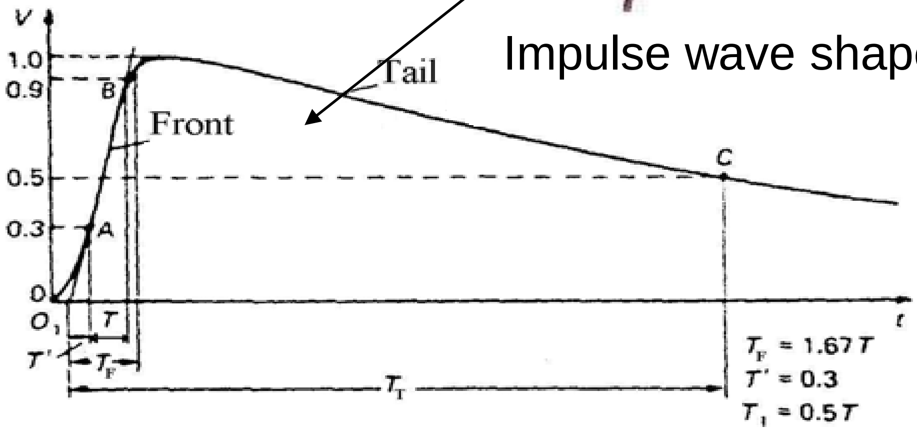
Impulse Over voltages 1.2/50µs impulse having a front time of 1.2 µs and a tail time of 50 µs

Switching Over voltages 250/2500µs impulse having a front time of 250µs and a tail time of 2500µs

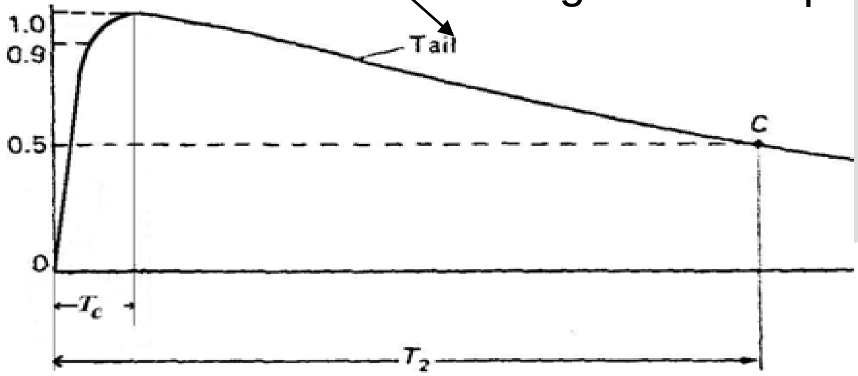
Frequency Overvoltages



Impulse wave shape



Switching wave shape



OVERVOLTAGES

Insulation Levels

Table 8 IEC 71.1: BILs are Tied to Max. System Voltages for Max. System Voltage from 1 to 245 kV

Max system voltage, kV	BILs, kV	Max system voltage, kV	BILs, kV
3.6	20 or 40	52	250
7.2	40 or 60	72.5	325
12	60, 75 or 95	123	450 or 550
17.7	75 or 95	145	450, 550, or 650
24	95, 125 or 145	170	550, 650, or 750
36	145 or 170	245	650, 750, 850, 950, or 1050

Source: Ref. 3.

Table 9 IEC BIL/BSLs, from IEC Publication 71.1

Max. system voltage, kV	Phase–ground BSL, BSL_g, kV	Ratio BSL_p/BSL_g	BIL, kV
300	750	1.50	850 or 950
	850	1.50	950 or 1050
362	850	1.50	950 or 1050
	950	1.50	1050 or 1175
420	850	1.60	1050 or 1175
	950	1.50	1175 or 1300
	1050	1.50	1300 or 1425
550	950	1.70	1175 or 1300
	1050	1.60	1300 or 1425
	1175	1.50	1425 or 1550
800	1300	1.70	1675 or 1800
	1425	1.70	1800 or 1950
	1550	1.60	1950 or 2100

EFFECTS OF OVERVOLTAGES

EFFECTS OF OVERVOLTAGES

- Breakdown in the insulating dielectric of equipment
- Degradation of equipment through ageing
- Loss of power supply

SURGE ARRESTOR

SURGEPROTECH

ieema
your link to electricity

SURGE ARRESTOR

A device used in electrical power to protect the insulation & conductors of the system from the damaging effects

Used to clip or limit the peak values of the over voltages or their durations or both

Open switch for system voltages
Closed switch for Over voltages

SURGEPROTECH

ieema
your link to electricity

TYPES OF SURGE ARRESTORS

As per IEC 60099-4, 2014

Class	**Type**	**Nominal discharge current**
STATION CLASS	SH - Station High	20kA
	SM – Station Medium	10kA
	SL – Station Low	10kA
DISTRIBUTION CLASS	DH - Distribution High	10kA
	DM – Distribution Medium	5kA
	DL – Distribution Low	2.5kA

GROUND FAULT FACTOR

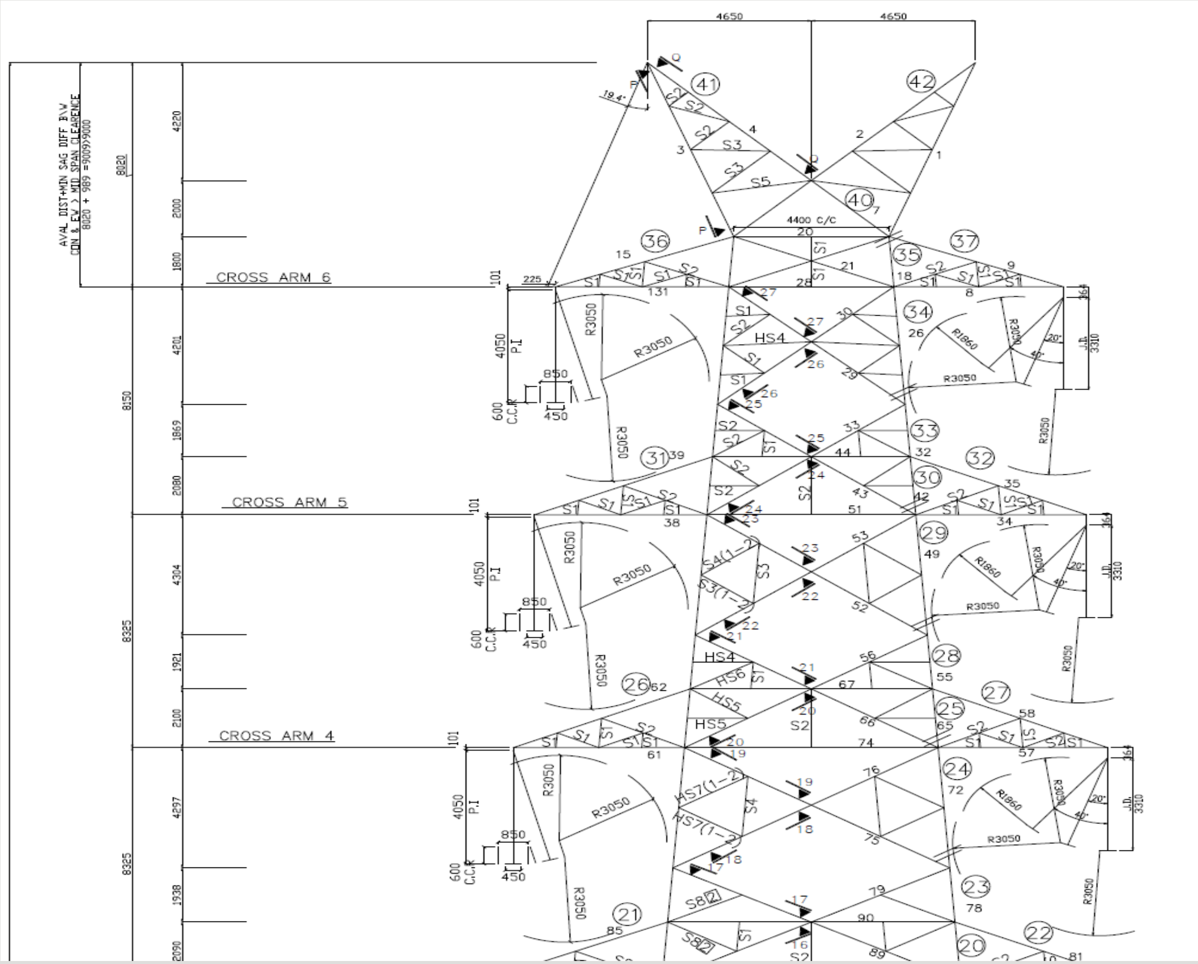
(As per IEC 60099-5 & IEEE C62.22)

Type of System	Ground Fault Factor
Solidly Grounded 4 wire systems	1.25
Uni-grounded 3 wire systems	1.4
Impedance grounded systems	1.732
Isolated Ground Systems and Delta Systems	1.732

SELECTION OF SURGE ARRESTOR

- Continuous operating voltage with respect to the highest system operating voltage
- Rated voltage of the arrester with respect to the temporary overvoltages
- BIL & BSL of the arrester during lightning, switching based on the V-I characteristics
- Location of Arrester
- Pressure relief class of the arrester with respect to the expected fault current
- Risk of lightning strikes in the region
- Type of electrical supply network feeding the site (overhead or underground)
- The network's earthing system
- Substation BIL, BSL

TYPICAL 400KV MULTI CIRCUIT TOWER STRIKE DISTANCES



Why These are required?

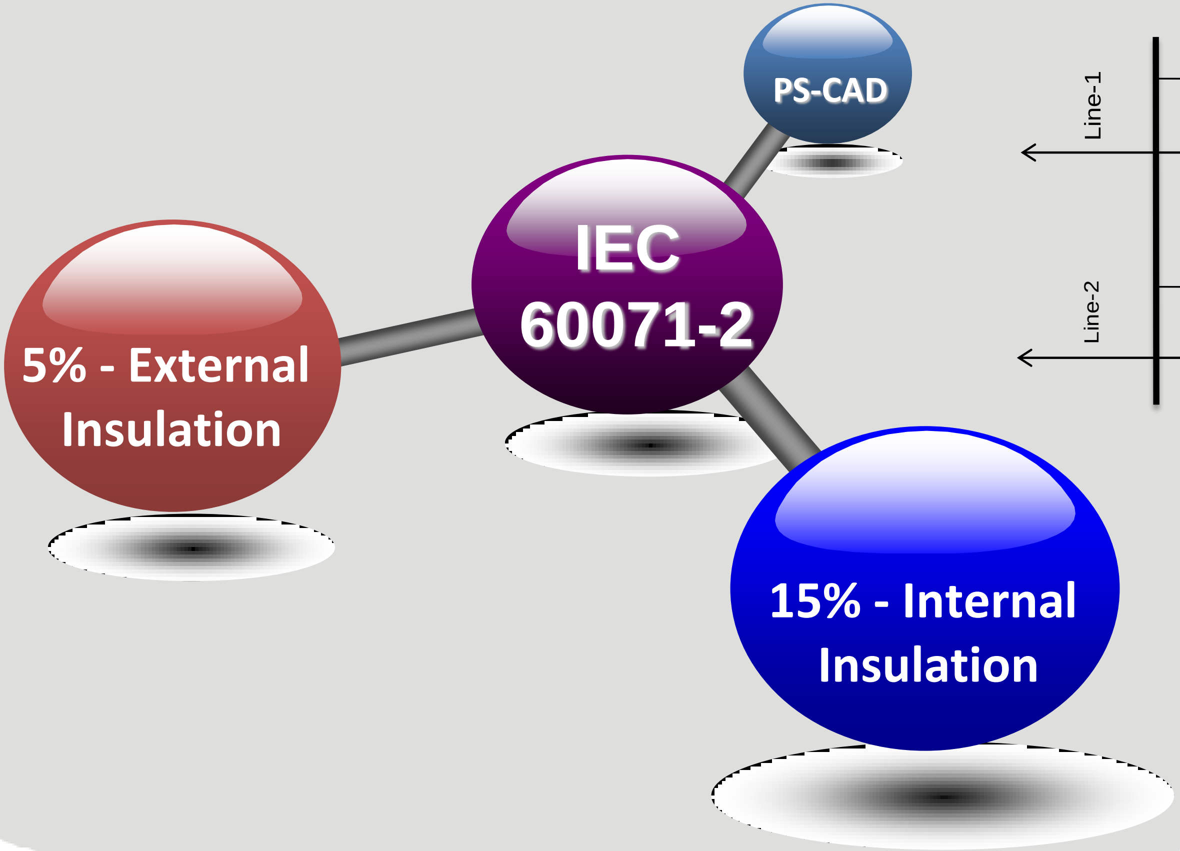
To calculate the Velocity of Travelling Wave

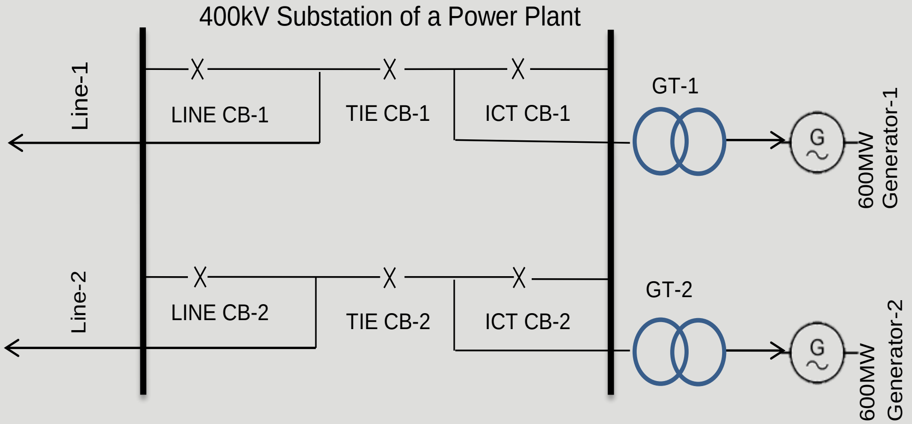
SURGEPROTECH

ieema
your link to electricity

CASE STUDY - DESCRIPTION OF THE SYSTEM

The system taken for case study is the 400kV Air Insulated Substation (AIS) of a 2x600MW Thermal Power Plant

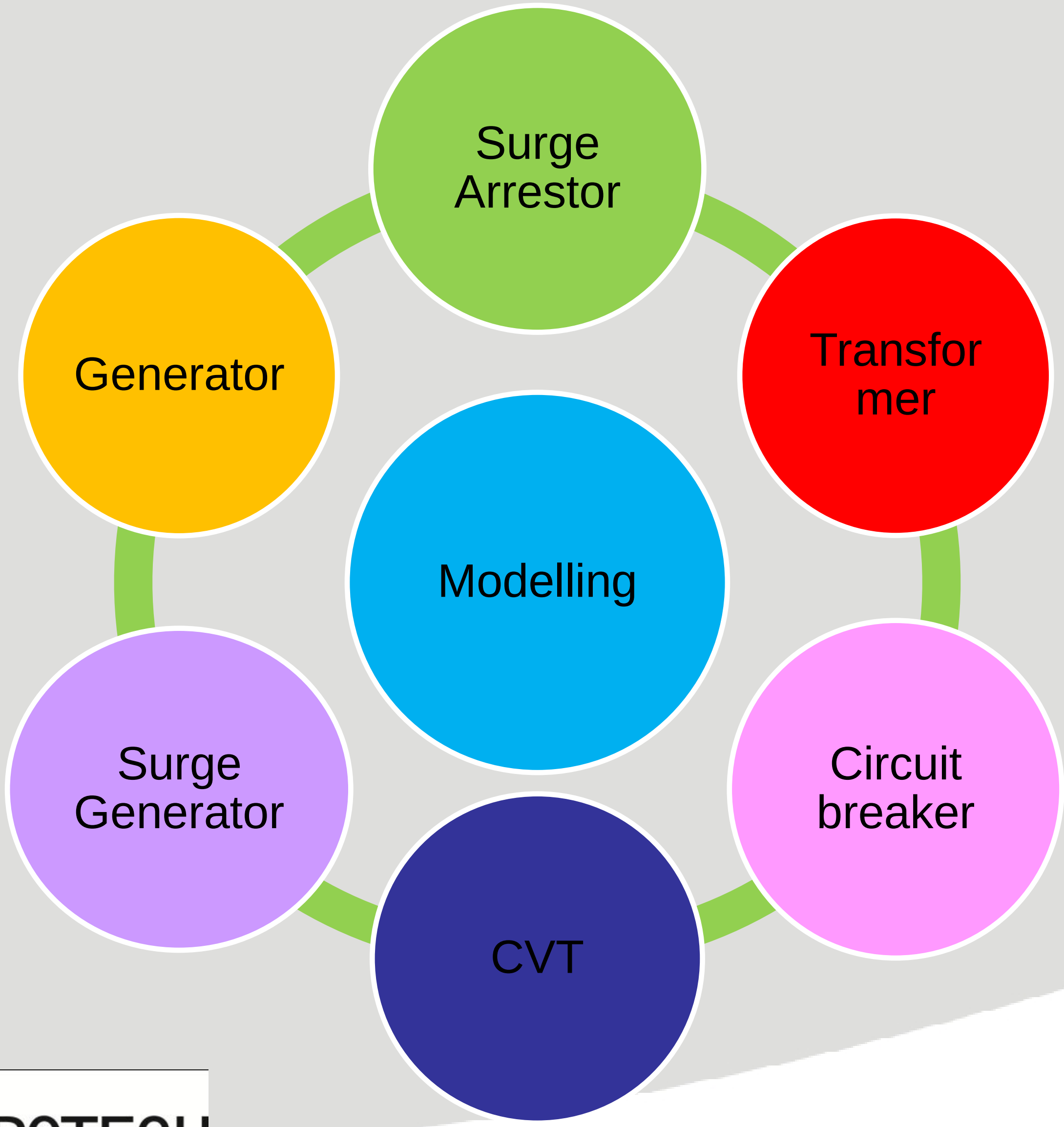




SURGEPROTECH

ieema
your link to electricity

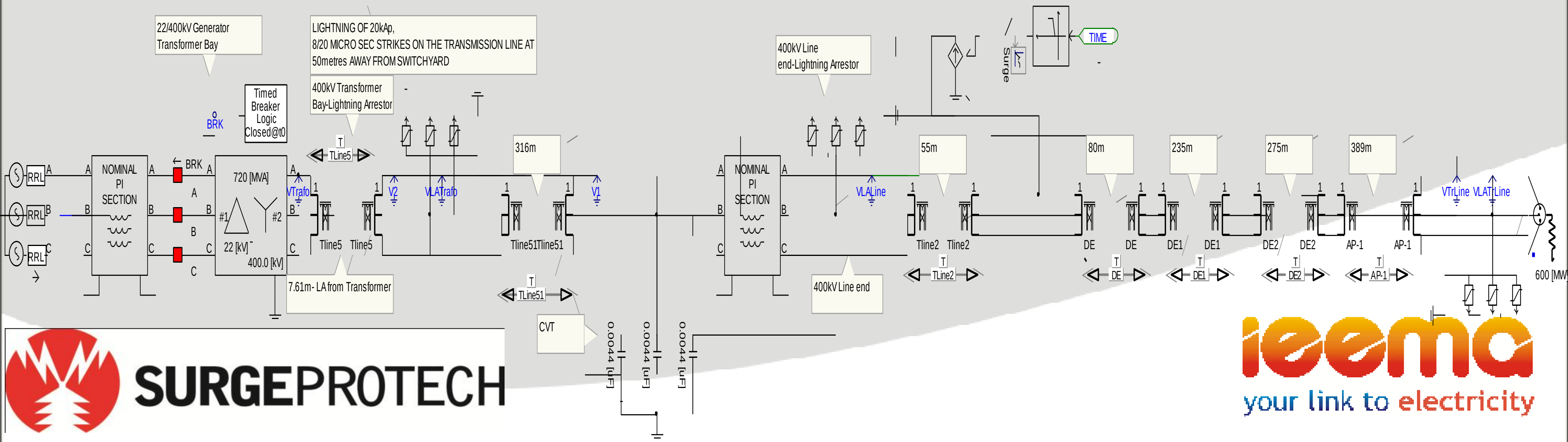
SYSTEM MODELLING



SYSTEM MODELLING

The system taken for case study is the 400kV Air Insulated Substation (AIS) of a 2x600MW Thermal Power Plant

System Voltage	Insulation Level (kVp)	Type of insulation	Margin	Maximum allowable voltage (kVp)
400kV	BIL= 1425	External	1.0815	1317.61
		Internal	1.15	1239.13
	BSL=1050	External	1.0694	981.85
		Internal	1.15	913.04

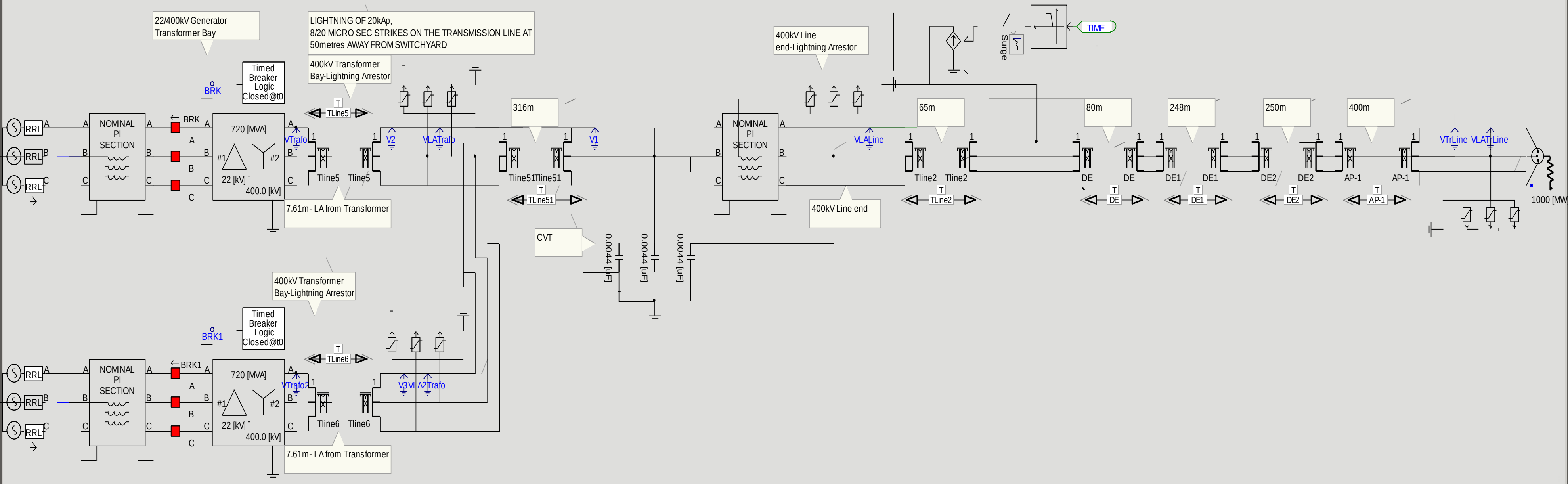


SURGEPROTECH

ieema
your link to electricity

SYSTEM MODELLING

Modelling with 2 Generators



SURGEPROTECH

ieema
your link to electricity

OVERVOLTAGE STUDY

Insulation Coordination study

System voltage = 400 kV

Surge Arresters are single phase devices, hence Phase to neutral voltage

$$= \frac{400}{\sqrt{3}} = 230kV$$

During single phase to earth fault, voltage on healthy phase will go up to 1.4 to 1.5 times.

$$= 230 \times 1.4 \; or \; 1.5 = 323 \; or \; 346kV$$

360kV LA Selected

Finalized by

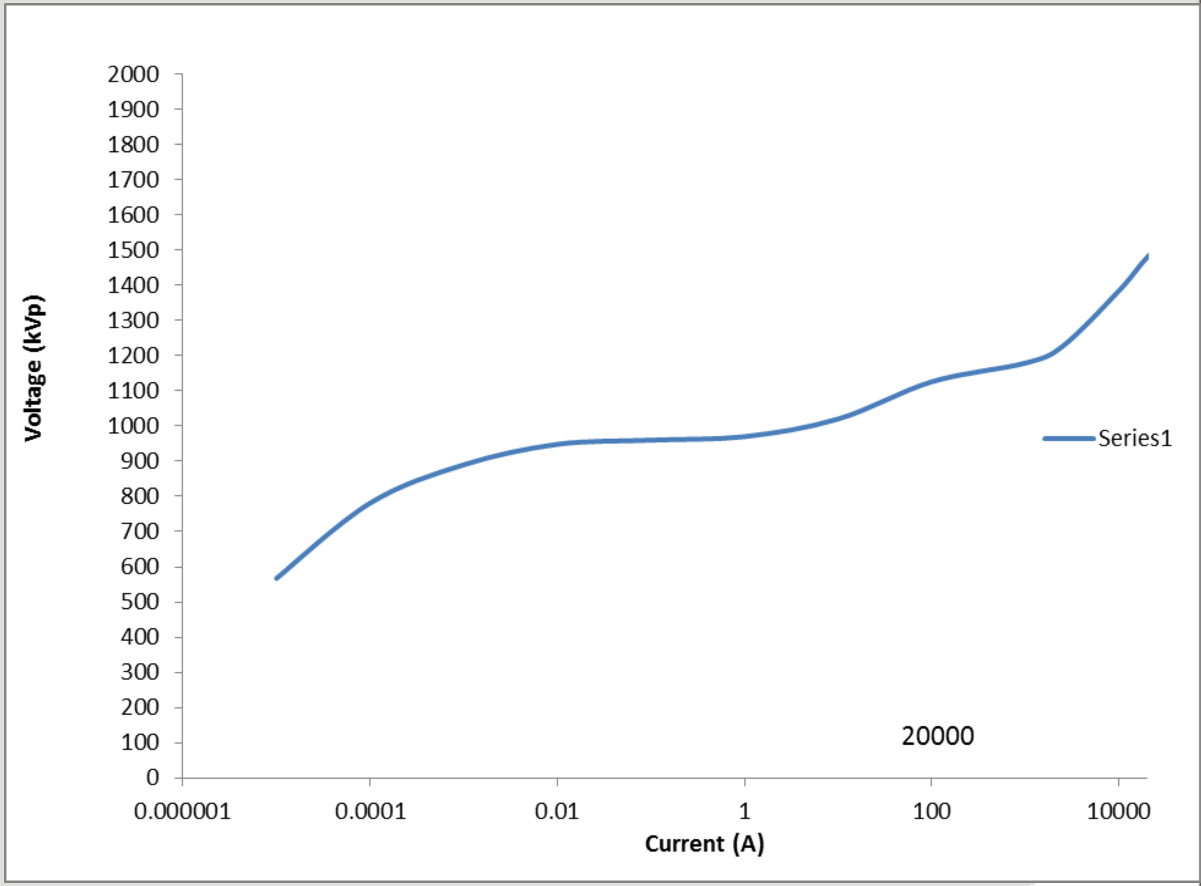
Energy dissipating capability of Surge Arrestor

SURGEPROTECH

ieema your link to electricity

LA V-I CHARACTERISTICS

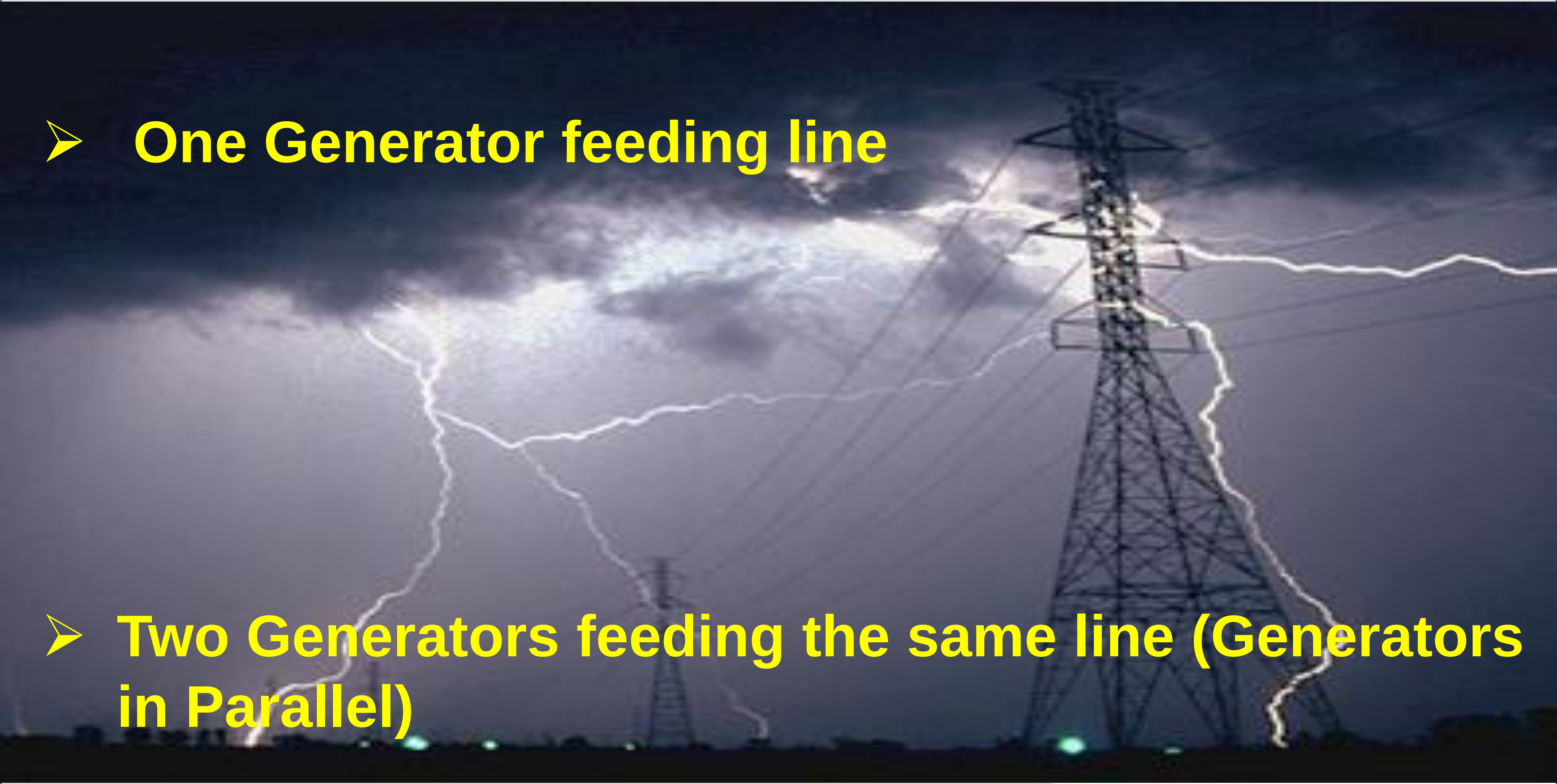
Sl.No	Discharge Current in (A)	Approximate Discharge voltage in (kVp)
1	0.00001	567
2	0.0001	781
3	0.001	890
4	0.01	948
5	0.1	960
6	1	970
7	10	1020
8	100	1126
9	1000	1179
10	2500	1227
11	10000	1385
12	20000	1480



SURGEPROTECH

ieema your link to electricity

LIGHTNING OVER VOLTAGE STUDY

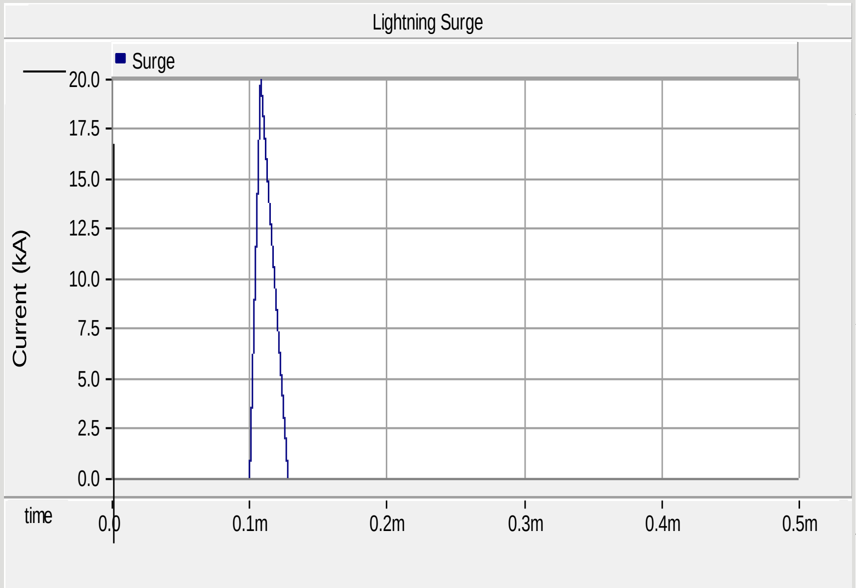


- One Generator feeding line

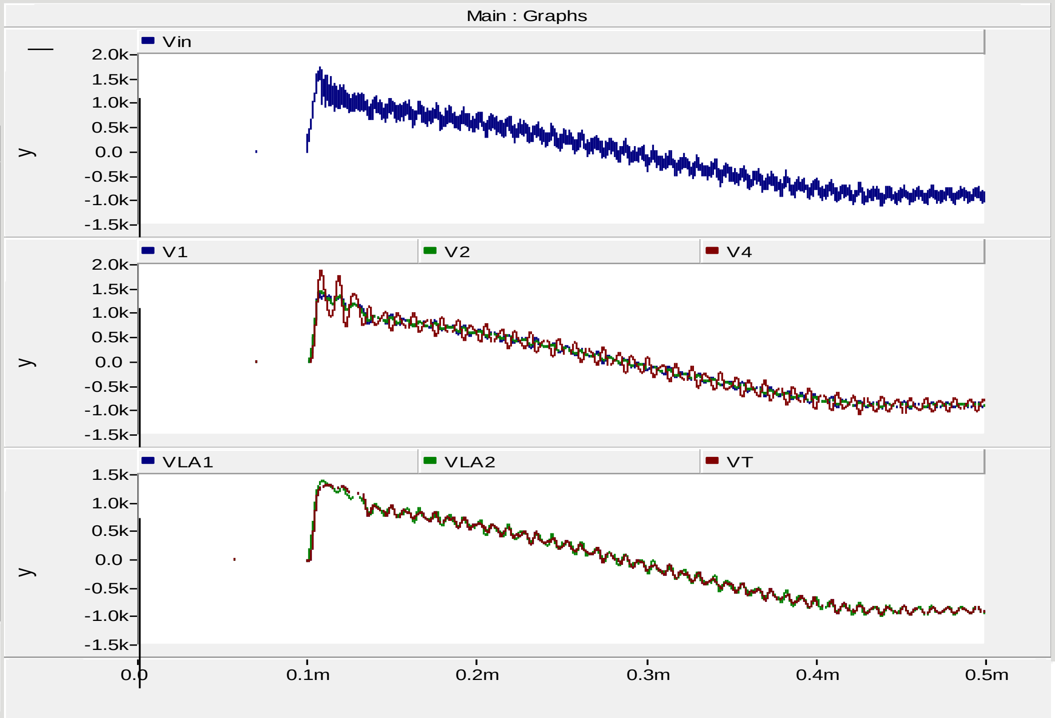
- Two Generators feeding the same line (Generators in Parallel)

LIGHTNING OVER VOLTAGE STUDY

Lightning surge enter into the substation in the form of a travelling wave



Current Surge (20kAp, 8/20µs)



Voltage across Line end and Transformer bay

SURGEPROTECH

ieema
your link to electricity

SWITCHING OVER VOLTAGE STUDY

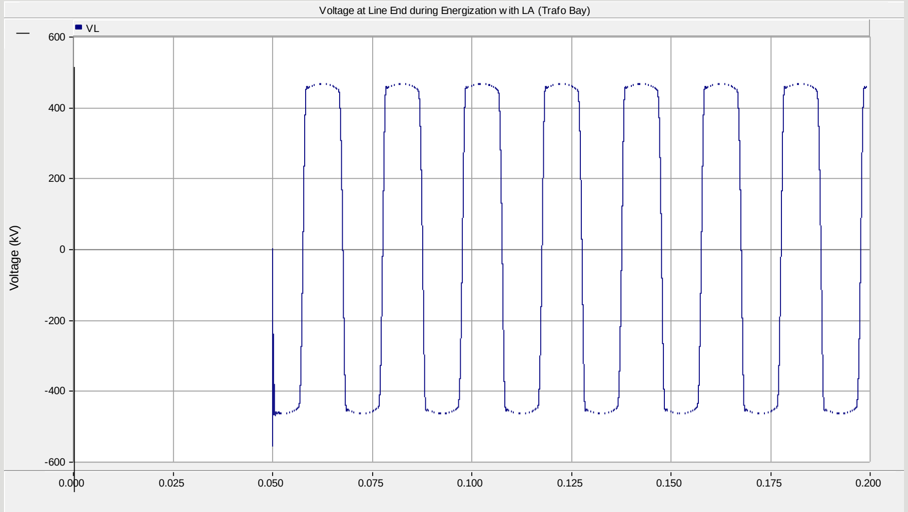
- Line energization
- Line re-energization
- Switching during Fault
- Switching during Fault clearing

SWITCHING OVER VOLTAGE STUDY

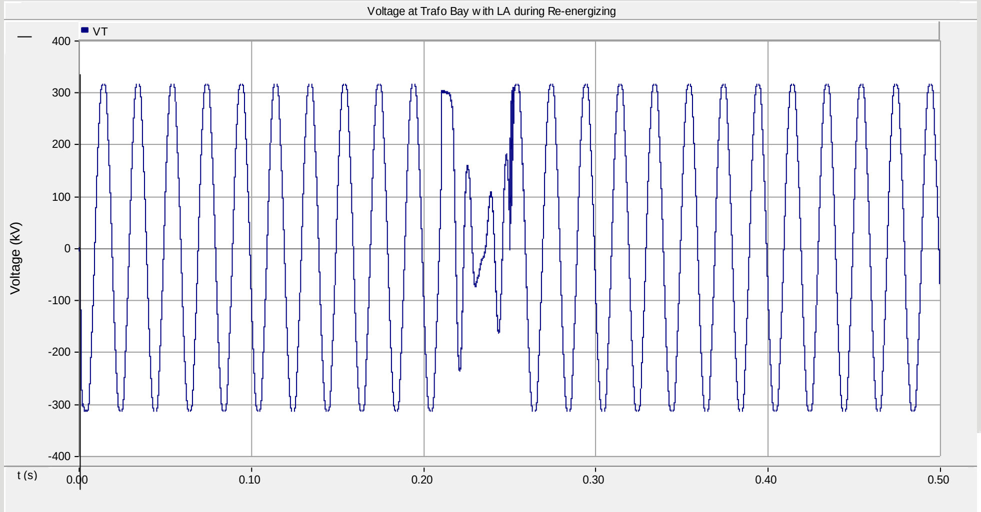
Line Energization & Re-Energization:

- A three-phase line energization or re-energization produces switching overvoltages on all three phases of the line.

- Closing time plays an important role on the value of overvoltage during energization.



Voltage across Line-1 Bay with Surge Arrester during Line-Energization



Voltage across Transformer Bay with Surge Arrester during Line-Re-Energization

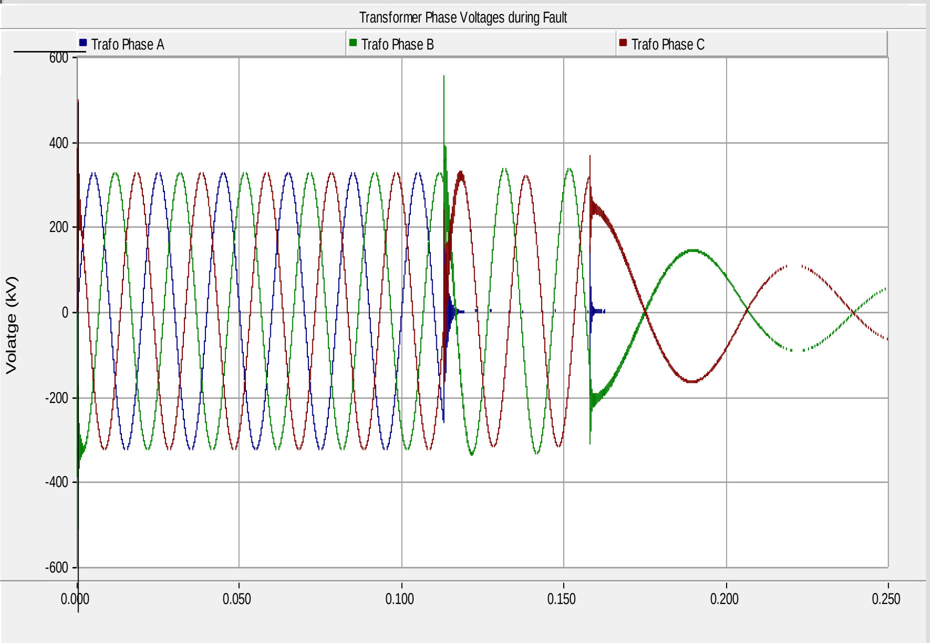
SURGEPROTECH

ieema your link to electricity

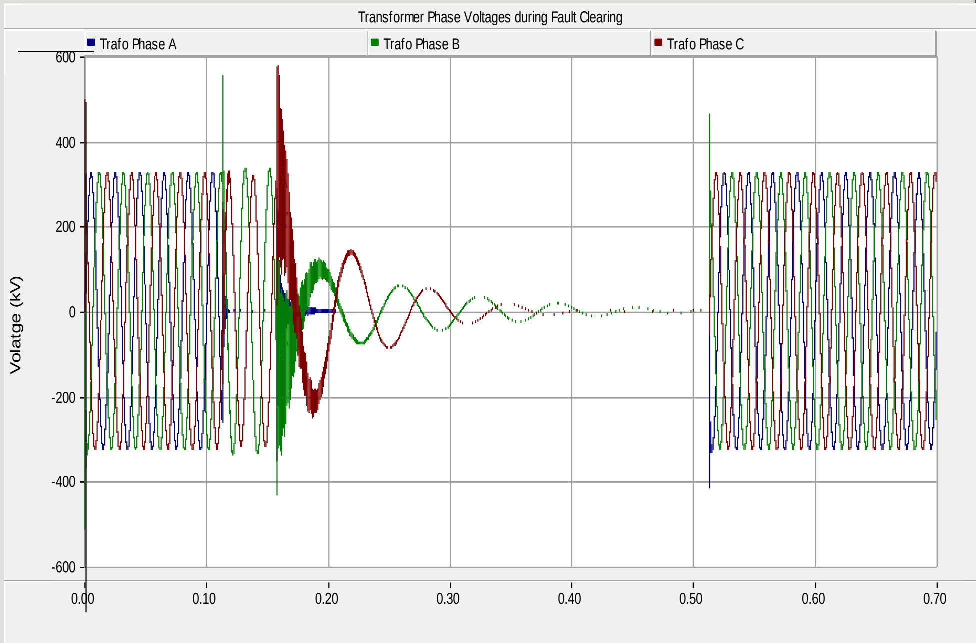
SWITCHING OVER VOLTAGE STUDY

Switching overvoltages due to faults and fault clearing

- Switching overvoltages can arise at the initiation of a fault and also during fault clearing



Voltage across Transformer Bay with Surge Arrester – Switching during Fault



Voltage across Transformer Bay with Surge Arrester – Switching during Fault clearing

SURGEPROTECH

ieema
your link to electricity

RESULTS - LIGHTNING

Voltage at	Maximum Allowable Voltage	With Surge Arrestors		W/O Surge Arrestor in Transformer Bay		W/O Surge Arrestor in Line End		W/O Surge Arrestors	
		1 Gen	2 Generators	1 Gen	2 Generators	1 Gen	2 Generators	1 Gen	2 Generators
Line End	1239.1 kVp (3.09 p.u)	2.52	2.45	2.9	2.9	5.5	5.63	5.5	5.7
Transformer Bay		1.9	1.67	2.1	1.89	2.58	2.37	5.4	5.6
Load End		1.56	1.47	1.6	1.47	2.09	2.01	5.6	5.8
Breaker Terminals		-	-	-	-	-	-	-	-

SURGEPROTECH

ieema your link to electricity

RESULTS - SWITCHING

Voltage at	Maximum Allowable Voltage	Switching Study Case	W/O Surge Arrestor in Transformer Bay		W/O Surge Arrestor in Line End	
			1 Gen	2 Generators	1 Gen	2 Generators
Line End	913.04 kVp (2.28 p.u)	Line Energization	2.05	2.4	1.17	1.39
		Line Re-Energization	2.03	3.2	1.92	2.3
Transformer Bay		Line Energization	12.26	13.1	1.97	1.65
		Line Re-Energization	12.33	13.4	1.92	2.3
		Switching during Fault	14.88	-	2.02	-
		Switching During Fault Clearing	18.47	-	2.02	-
Breaker Terminals		Line Energization	12.14	12.96	1.97	1.65
		Line Re-Energization	12.08	12.42	1.88	2.6
		Switching during Fault	14.88	-	2.19	-
		Switching During Fault Clearing	18.27	-	2.07	-

RESULTS

Maximum overvoltage due to lightning is 1068 kVp, which is well within the limits of the protective level of the offered Surge Arrestor (1425kVp).

Maximum overvoltages due to switching of Breaker is 848 kVp, which is well within the limits of the protective level of the offered Surge Arrestor (1050 kVp).

Voltage is within the limits in both Lightning and Switching studies, but the important parameter that needs to be evaluated is energy capability of Surge Arrestor

RESULTS

The minimum energy rating of 360kV LA :

1286.3/360 =
3.6 kJ/kV

This is sufficient for one generator feeding one line.

390 KV LA SELECTED

The minimum energy rating of 390kV LA :

2271/390 =
5.8 kJ/kV

This Arrester has passed all worst conditions

CONCLUSIONS

360kV and 390kV Surge Arrestors were analyzed based on the manufacturing data sheets available at that point. The voltage rating and energy handling capability of Surge arresters provide sufficient protection for the switchyard equipment.

The selection of Surge Arrestor can be done considering minimum rating of Surge Arrestors with high energy discharge capability available in the present manufacturing industry, but a detailed Insulation Co-ordination study is necessary to check the voltage profile of the EHV Substation.

Thank You !

SURGEPROTECH

ieema
your link to electricity