STUDY OF TRANSIENT OVER VOLTAGE FOR INSULATION COORDINATION IN 220kV GAS INSULATED SUBSTATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF ELECTRICAL ENGINEERING

By

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CONTENTS

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ABSTRACT

The Gas Insulated Switchgear (GIS) substation has a high level of dependability and is simple to maintain. However, the specific issue with the GIS substation is the creation and spread of very fast transient overvoltage (VFTO) caused by the activation of circuit breakers, disconnector switches, or earth faults can put the insulation of equipment linked to the GIS under stress. This study covers the history of VFTO, its spread, and its effects on GIS. Power Systems Computer Aided Design (PSCAD) software is used to simulate various switching conditions. The results demonstrate that VFTO magnitudes are greater along the GIS bus nodes when the circuit breaker is activated than when the disconnector switch is activated. Switching transients influence equipment selection, protection, and tower air clearances. The two most common sources of transient overvoltage in power systems are lightning and switching. This work compares the modelling and simulation of a switching transient overvoltage investigation using PSCAD/EMTDC, a commonly used simulation tool. The purpose of the thesis is to provide modelling principles for the digital simulation of very fast transients (VFT) in gas insulated substations (GIS). Two lighting situations that may result in Fast Transient Overvoltages are analyzed and discussed: Direct Strike and Back Flashover. Overvoltages are unpredictably damaging to the electrical power grid. Overvoltages can be caused by a variety of factors, with lightning being one of the most hazardous. As a result, high voltage substation overvoltage protection is critical. To safeguard the substation as much as possible from the consequences of overvoltages, incorporate features that can help decrease these effects, such as surge arresters. The consequences of using surge arresters in a high voltage, gas SF6 insulated substation, as modelled in the PSCAD (Power Systems Computer Aided Design) program, are shown in this study.

NOMENCLATURE

D	Electric flux density
E	Electric field
ε_0	Permittivity of vacuum
U_0	Step voltage source
σ_0	DC conductivity
C_0	Geometric capacitance
ω	Frequency of applied voltage
AC	Alternating Current
BIL	Basic Insulation Level
BSL	Basic Switching Level
CB	Circuit Breaker
ETAP	Electrical Transient Analysis Program
HV	High Voltage
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical & Electronic Engineers
kA	Kilo Ampere
kV	Kilo Volt
kVA	Kilo Volt Ampere
L-G	Line to Ground fault
MCOV	Maximum Continuous Operating Voltage
MVA	Mega Volt Amp
OHTL	Over Head Transmission Line
OV	Over Voltage
PSCAD	Power System Computer Aided Design Electromagnetic
EMTDC	Transients including DC
RMS	Root Mean Square
SA	Surge Arrestor
SOV	Switching Over Voltage
TOV	Temporary Over Voltage

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CHAPTER-1

INTRODUCTION

Due to its high level of dependability and ease of maintenance, Gas Insulated substation has seen extensive application in the power system sector over the past few decades. The generation and propagation of very fast transient overvoltage (VFTO), which is brought on by the activation of circuit breakers, disconnector switches, or earth faults, is a special problem with the GIS substation. The VFTO that is produced stresses the insulation of equipment connected to the GIS, including power transformers, bushings, and spacers. Here, the development of VFTO, its dissemination, and its impacts on GIS have all been discussed. In this study, the 220 kV GIS substation's components are simulated and taken into account during modelling. Different switching scenarios are simulated using PSCAD (Power Systems Computer Aided Design) software. For various trapped charge magnitudes, the variation in VFTO magnitude along the GIS bus nodes has been investigated. When the circuit breakers and disconnectors are operating, the VFTO peak along the GIS bus nodes are compared. The findings show that activating the disconnector switch resulted in smaller VFTO magnitudes along the GIS bus nodes than activating the circuit breaker. According to the results, the VFTO levels increase as the trapped charge on the conductor increases. Tower air clearances, protection, and equipment selection are all impacted by switching transients. Lightning and switching are the two most typical causes of transient overvoltage in electrical systems. In this study, a commonly used simulation tool called PSCAD/EMTDC is utilized to model and simulate a switching transient overvoltage examination. Both simulations offer thorough explanations of the statistical analysis and overvoltage modelling techniques. As a result, it is necessary to decide on the proper representation for a number of components, including transformers, loads, circuit breakers, and transmission lines and cables. In order to digitally simulate very fast transients (VFT) in gas insulated substations (GIS), this work aims to present modelling techniques. The causes of VFT overvoltages, their spread, and their effects on GIS hardware are briefly discussed. The study includes modelling guidelines for GIS elements that have been put forth in earlier works. Equivalent circuits and distributed parameter lines that take transients into consideration have been used to describe the internal components and equipment of a gas-insulated substation (GIS). Two lighting scenarios have been analysed that could lead to fast transient overvoltages: (Direct Strike); (Back Flashover). The electrical power grid suffers unpredictable damage from overvoltages. There are many potential causes of overvoltages, with lightning being one of the most dangerous. High voltage substation overvoltage prevention is therefore essential. Include components, such as surge arresters, that can aid in reducing the effects of overvoltages to protect the substation as much as feasible.

The consequences of using surge arresters in a high voltage, gas SF6 insulated substation, as modelled in the PSCAD (Power Systems Computer Aided Design) programme, are shown in this study.

The system comprises of 220 kV grid connected to 20 km over head transmission then 220 kV GIS and then to 150 MVA 220/132/11 kV transformer connected through 1C X 800 mm^2 1000 meter long cable.

1.1 SCOPE OF THE THESIS

In this work, the contribution of surge arresters in the lightning protection of an operational 220kV double circuit shielded overhead transmission line using the PSCAD program is studied. The primary objective is to study and evaluate the HV transmission line protection with metal oxide surge arresters when a lightning strike hits the conductor. A dynamic arrester model is utilized in this study to explore the feasibility of various solutions corresponding to various arrestor sites, and recommendations for improving the lightning performance of the transmission line are provided based on simulations. PSCAD EMTDC (Electromagnetic transient power system analysis software) has been used for the insulation coordination and transient overvoltage investigations. In this thesis, assessment of the overvoltage exposure have been prepared which likely to be encountered by the GIS network and components resulting from SOV (energisation/de-energisation/grounding [FAES]-slow front), due to LIOV (lighting stroke terminating at a phase/shield conductor-fast front) and also resulting from VFTO (operation of disconnector switches w/wo trapped charges at various GIS nodes).The insulation coordination and transient overvoltage studies have been carried out using PSCAD EMTDC electromagnetic transient power system analysis software.

1.2 CONTRIBUTION OF THE THESIS

The case studies covered in this report, using electro-magnetic transient software (PSCAD-EMTDC), are as summarized below. Case studies have been carried out with & without surge arrester at each voltage to determine their requirements & ratings.

1.2 THESIS OUTLINE

Chapter 2	In this chapter, overall information of the PSCAD modeling of the different study cases and the contribution of this thesis have been discussed.
Chapter 3	In chapter 2, the components used in these two 20KV GIS network including the indoor substation and outdoor transformers have been discussed.
Chapter 4	In this chapter, the types of transient over voltages found in GIS network including the lightning overvoltage (LIOV), switching over voltage (SOV) and disconnector over voltage (VFFT) have been discussed.
Chapter 5	In this chapter, the importance of lighting arrester or surge arrester in GIS network which basically improves the insulation coordination of overall system and protects the overall GIS network from any surge including internal or external have been discussed.
Chapter 6	In this chapter, the model preparation of 220 kV GIS network including the indoor substation and the outdoor power transformer standard component parameter used for the study cases have been elaborated.
Chapter 7	In this chapter all the simulations regarding the lighting over voltage, switching over voltage and VFFT cases have been discussed and have analysed the results showing the propagation of overvoltages by using appropriate surge arrester in proper location of this 220 kV network.
Chapter 8	In this chapter, the conclusion of this thesis paper and the future scope of this study for 220kV GIS network have been discussed.

CHAPTER-2

COMPONENTS OF 220kV GIS SUBSTATION

2.1 INTRODUCTION

The gas-insulated switchgear (GIS) used in high voltage applications is continuously being improved. Globally, GIS are accessible and span the whole 11 kV to 800 kV voltage range. All of the substation requirements are taken into account while designing the thermal current-carrying capacity and the fault-withstanding capabilities.

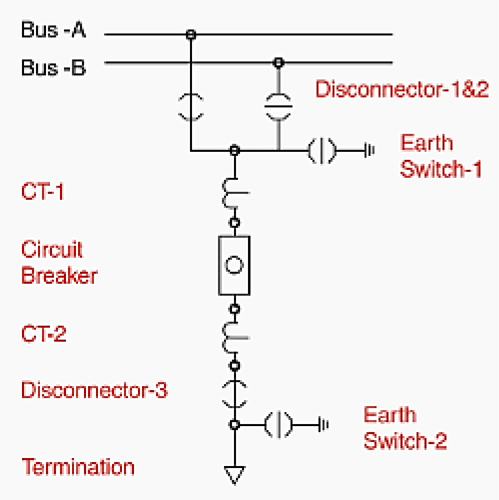


Fig. 2.1 Single line diagram for a Double bus section

Fig. 2.1 depicts a part of a substation with a single line diagram identifying several components. At substations, the single busbar, double busbar, and 3/2 circuit breaker layouts are common.

2.2. COMPONENTS OF GIS

The modular GIS components are put together to create the appropriate section or bay configuration. A cross-section of a double bus GIS section is shown in Fig. 2.2. The individual parts are put together side by side in this situation. In this new layout, all porcelains and connections (ACSR Conductors), which are necessary in a yard substation, are completely eliminated.

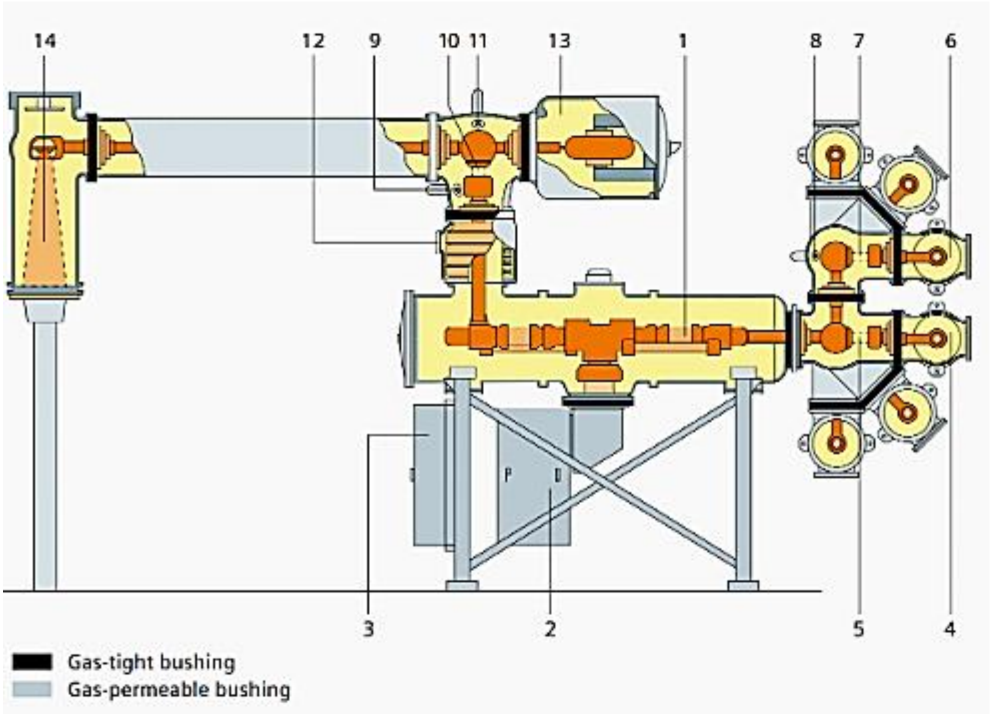


Fig. 2.2 Cross – section of a Double bus GIS section. 1)Circuit-breaker interrupter unit, 2) Stored energy spring mechanism, 3) Circuit breaker control unit, 3) Busbar – 1, 4) Busbar disconnector 1, 5) Busbar – 2, 6) Busbar disconnector 2, 7) Work in progress earthing switch, 8) Work in progress earthing switch, 9) Outgoing feeder disconnector, 10) Make proof earth switch (High Speed), 11) Current transformer, 12) Voltage transformer, 13) Cable sealing end.

2.2.1 BUSBAR

One of the most fundamental parts of the GIS system is the busbar. In isolated-phase GIS, co-axial busbars are typical because they produce the best stress distribution. In GIS, busbars of various lengths are utilized to accommodate the needs of circuit or bay information. The cross-section of a GIS bus-bar has been shown in Fig. 2.3.

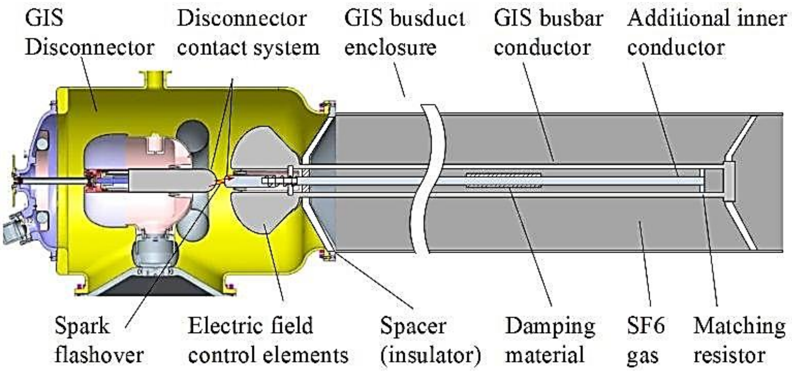


Fig. 2.3 Cross-section of a GIS Bus-bar

2.2.2 CONNECTORS

The spring-loaded plug-in contacts are used to make high voltage and high current electrical connections between modules in a gas insulated substation system. The greatest degree of flexibility is provided during installation and disassembly using plug-in contact systems. These connections are appropriate for tubular conductors and include plug-in functionality. The cross-section of a GIS connector has been shown in Fig. 2.4.

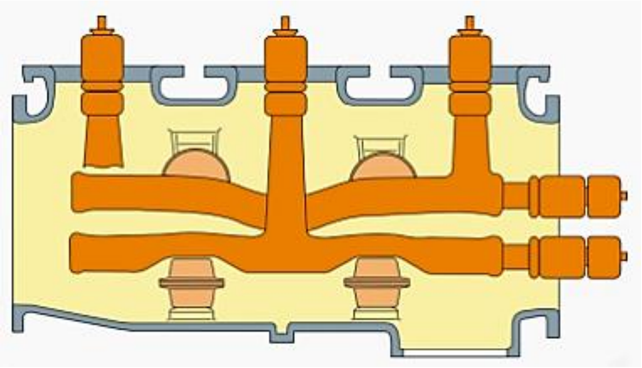


Fig. 2.4 Cross-section of a GIS Connector

2.2.3 DISCONNECTORS

To offer more safety and physical separation, disconnectors (or disconnect switches) are connected in series with the circuit breaker. Two disconnectors are often used in a circuit, one on the feeder side and the other on the line side. Disconnect switches are intended to stop induced or capacitively connected tiny currents. The moving contact fills this space during the closure process. An appropriate drive, to which the moving contact is connected, provides the necessary linear displacement to the moving contact at a predetermined design speed. Spring-loaded fingers or multi-lam contacts support to provide a solid connection between the two contacts. The voltage class of the isolator and the gas are taken into account while designing the isolation gap. The driving of the moving contact and isolation of the drive from the high voltage parts of the disconnector are accomplished via an insulator. The electrical and mechanical specifications of the isolator regulate the size and form of the insulator. Individual phase isolators are ganged together to work simultaneously in three-phase ac systems. Gas insulated isolators employ leak-tight rotating seals to transfer motion from an external motor to the gas. In high voltage GIS, disconnectors function at SF6 pressures of 0.38 MPa to 0.45 MPa. The disconnector moving contact's operating speed varies from 01 to 0.3 m/sec. A key component in guaranteeing the successful operation of a gas insulated disconnector is the design of the electrostatic shields on the earth side of the drive insulator and the two permanent contacts. The cross-section of a GIS disconnector has been shown in Fig. 2.5.

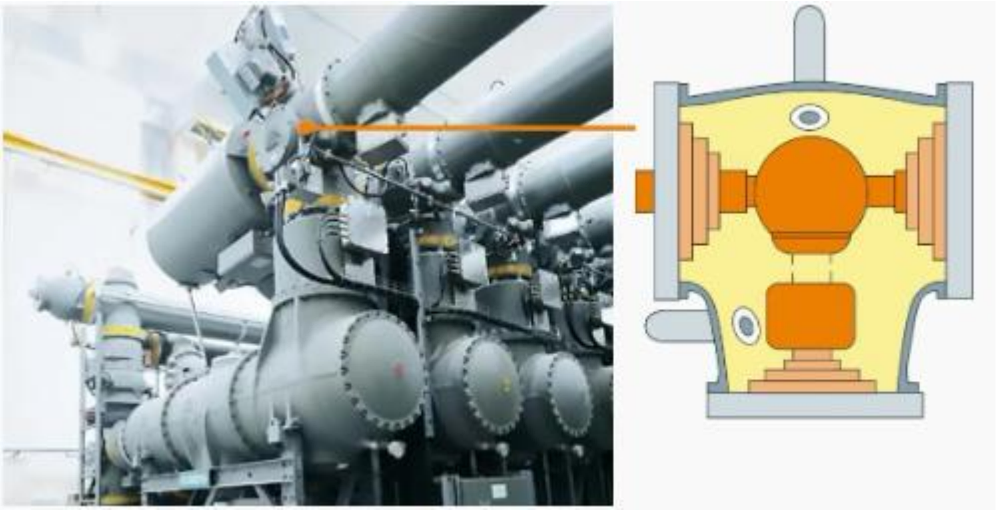
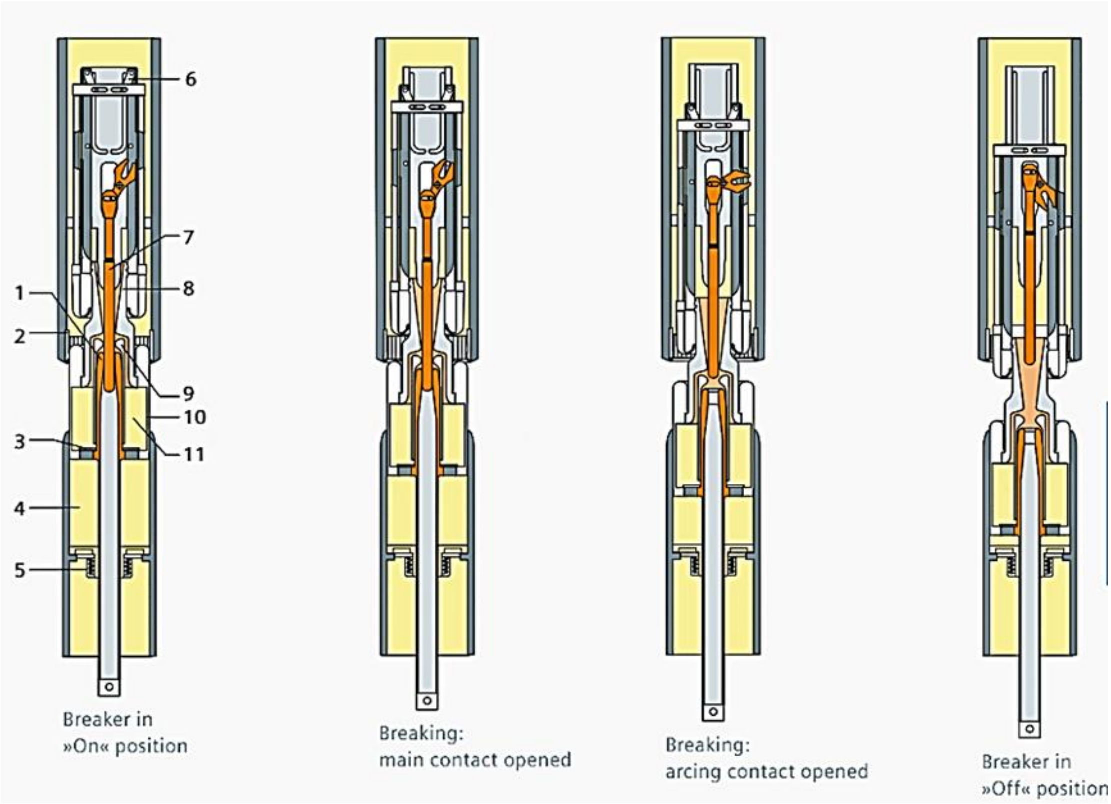


Fig. 2.5 Cross-section of a GIS Disconnector.

2.2.4 CIRCUIT BREAKER

The most important component of a gas-insulated substation system is the circuit breaker. A metal-clad circuit breaker that uses SF6 gas for both insulation and fault interruption makes up a gas-insulated system. Approximately 0.65 MPa is the pressure of SF6 gas in a circuit breaker. Either current transformers or the gas isolators are directly linked to the circuit breaker. To maintain a pressure differential, a barrier is kept between the circuit breaker and the other connected equipment that uses lower gas pressure. In comparison to their spring-based rivals, hydraulic drives are dependable, strong, and compact. Without the need for any intermediary motion seals and linkAges, hydraulic drives may be interfaced directly to the circuit breaker. The spring drives are somewhat less expensive but can only be utilized with modern self-blast or hybrid circuit breakers. The GIS circuit breakers typically operate at opening speeds between 6.0 and 8.0 m/sec and operating energies between 4500 and 8500 Nm. Please take note that the values provided may vary depending on the manufacturer. The fundamental structural component for each GIS bay is the circuit breaker enclosure. Depending on the system needs and convenience of installation, the GIS circuit breakers are positioned both horizontally and vertically. The cross-section of a GIS circuit breaker has been shown in Fig. 2.6.



Breaker in »On« position

Breaking: main contact opened

Breaking: arcing contact opened

Breaker in »Off« position

Fig. 2.6 Cross-section of a GIS Circuit Breaker.

2.2.5 CURRENT TRANSFORMER

Current transformers of the live-tank or dead-tank types with oil/SF6 insulation are used in traditional substations. The low potential portion of the current transformer is separated from the high voltage zone by a porcelain insulator. For the magnetic circuit of the current transformer to achieve the necessary ratio and precision, ribbon or sliced silicon steel cores are utilized. The usual geometry for a dead-tank type current transformer is a primary conductor with a hairpin shape. In-line current transformers are essentially what current transformers are used for in gas insulated systems. The following components are found in gas-insulated current transformers with traditional coaxial geometry:

- Tubular primary conductor
- Electrostatic shield
- Ribbon-wound toroidal core and
- Gas-tight enclosure

A tubular metal conductor connecting two gas-insulated modules that are positioned on each side of the current transformer forms the primary of a current transformer. This high voltage cable is supported by disc insulators at either end of the current transformer container. The conductor has one end that is firmly fixed, while the other end has a sliding joint that makes it easier to assemble the current transformer module and accounts for the conductor's thermal expansion. The magnetic circuit of the current transformer is made up of a ribbon-wound silicon steel core that has been shaped into a toroid. To guarantee zero potential at the secondary side, a coaxial electrostatic shield is positioned between the current transformer's high voltage primary and toroidal magnetic core. This shield is at ground potential. The cross-section of a GIS current transformer has been shown in Fig. 2.7.

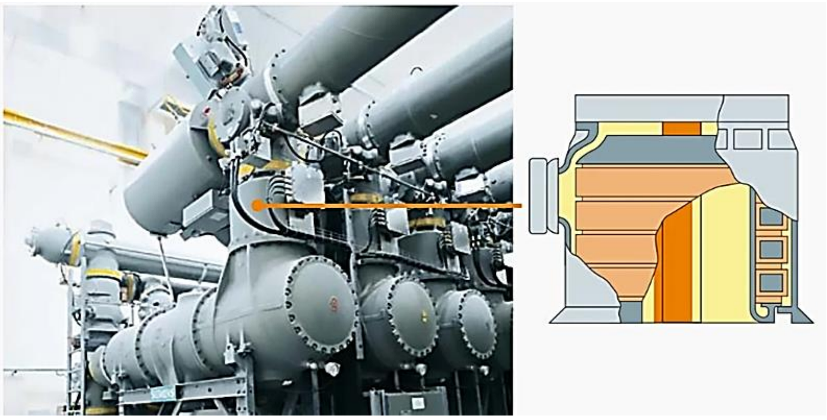


Fig. 2.7 Cross-section of a GIS Current Transformer

2.2.6 EARTH SWITCH

The two types of earth switches utilized for gas insulated substation systems are fast earth switches and maintenance earth switches. In order to protect the safety of the maintenance team, a slow mechanism called the maintenance earth switch is utilized to ground the high voltage cables during maintenance periods. While the quick earth switch is used to prevent residue charge (stored online during isolation/switching off of the line) from causing direct current to pass through the primary of the circuit-connected instrument voltage transformer and saturating its core, the former is used to safeguard circuit-connected instrument voltage transformers. In this circumstance, using a fast earth switch offers a parallel (low resistance) way to swiftly drain the leftover static charge, safeguarding the instrument voltage transformer from potential harm. These earth switches all have the same fundamental design. The smallest module in a gas-insulated substation system is the earth switch. The module consists of two sections:

- Fixed contact, which is a component of the main gas insulated system and is situated at the live bus conductor;
- Moving contact system, which is positioned on the main module's enclosure and is in line with the fixed contact.

The cross-section of a GIS earth switch has been shown in Fig. 2.8.

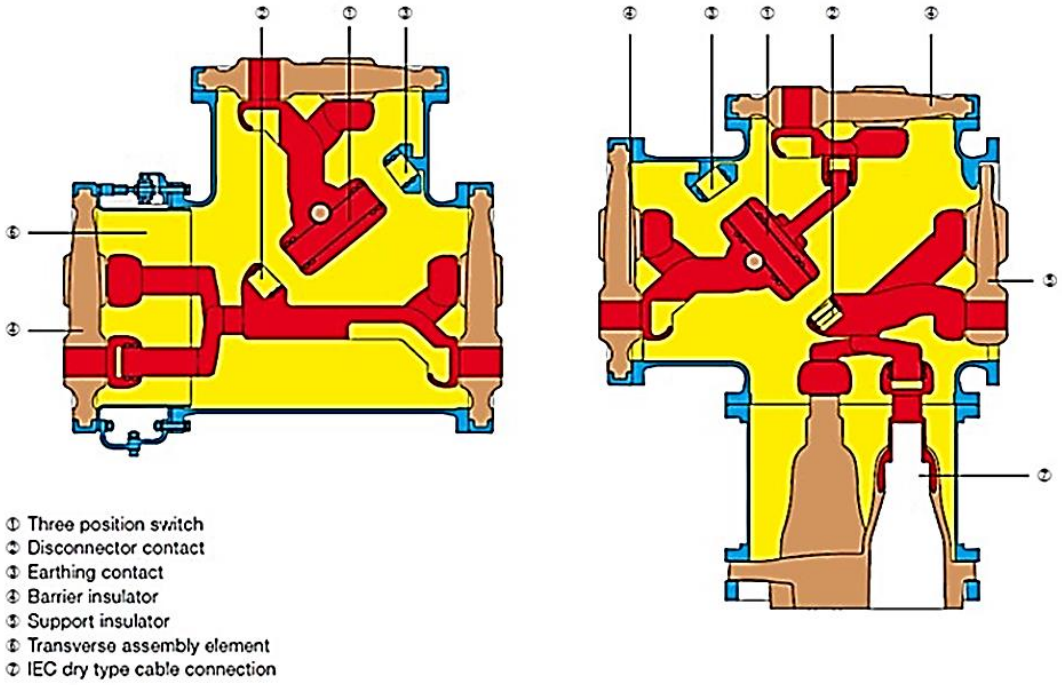


Fig. 2.8 Cross-section of a GIS Earth Switch

2.3 TRANSFORMER

In compared to a model used for insulation research, the transformer model used for switching surge transient studies is a lower order representation with fewer information. A lumped parameter coupled-winding model with enough R-L-C components often yields the proper impedance characteristics at the terminal within the targeted frequency range. Although the frequency characteristic of the core is frequently disregarded, it is generally recommended to include the non-linear feature. This may be oversimplified since the eddy current effect makes the transformer seem to be air-cored by preventing flux from entering the core steel at high frequencies. Even at frequencies in the range of 3 to 5 kHz, this impact starts to become noticeable. The model can be validated using the following strategies when it is practical to do so. If accessible, a frequency response derived through simulation can be contrasted with the real characteristic throughout the specified bandwidth. This should be carried out for any and all potential winding open and short circuit circumstances. A common check is to calculate the open and short circuit impedances to determine the fundamental frequency response. It is important to consider the turns ratio or the induced winding voltages at fundamental frequency. In contrast to factory tests Additionally verifies the model, if accessible. A comparison between observed and calculated responses is helpful if terminal capacitance measurements are available. The cross-section of a power transformer has been shown in Fig. 2.9.

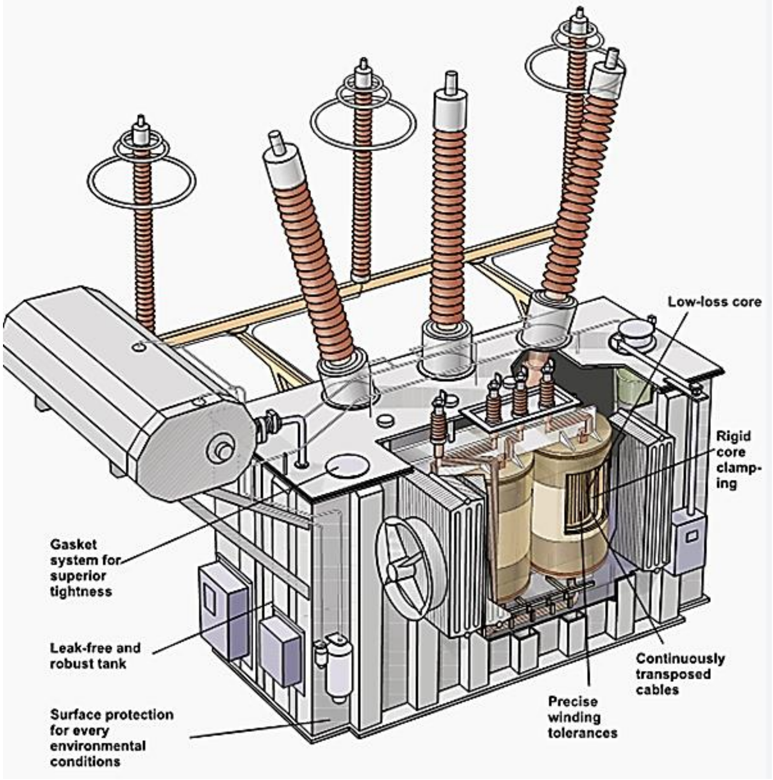


Fig. 2.9 Cross-section of a Power Transformer

2.4 TRANSMISSION LINES & CABLES

Due to the variety of frequencies involved, multi-phase models that take into account the scattered nature of the line parameters are used to describe the overhead cables. Only a small number of spans are typically taken into account, and phase conductors and shield cables are explicitly modeled between towers. Tower models take into account the impacts of tower geometry and grounding resistance, with a focus on the properties of the tower that are reliant on the lightning current magnitude owing to soil ionization.ts procedure using input from conductor data and the geometry of the tower construction. For lightning research, the parameters are often computed at 500 kHz while taking skin effect into account. Line mode surge impedances typically vary from 250 to 500 ohms, whereas ground mode surge impedances often hover around 700 ohms. When the line's trip time t is less than the simulation's integration step duration, the usage of nominal pi-circuits is often limited to the case of very short lines. For many investigations, such as line energization, cascaded pi-sections can be employed without suffering a great deal of accuracy loss. Choosing the right number of pi-circuits is crucial since it determines how accurate the system will be.The fundamental frequency impedance values used in load flow studies for positive and zero sequence overhead lines may easily be utilized to get the parameters for the pi-section. The schematic of transmission line and substation has been shown in Fig. 2.10.

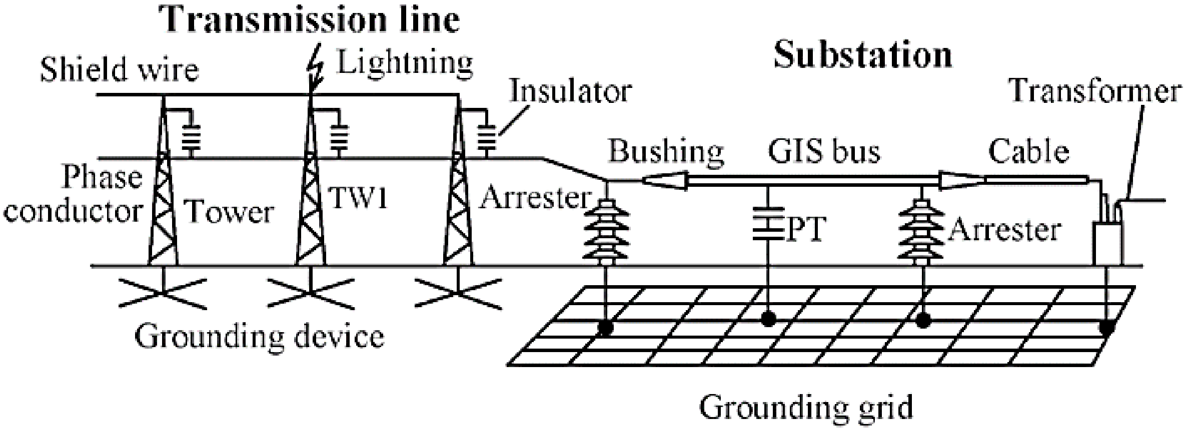


Fig. 2.10 Schematic of transmission line and substation.

CHAPTER-3

TYPES OF TRANSIENT OVERVOLTAGES IN A GIS SYSTEM

3.1 INTRODUCTION

Due to its high dependability, simplicity of maintenance, short ground space requirements, etc., Gas Insulated Switchgear (GIS) substations have a wide range of uses in power systems. Despite its advantages, GIS has certain specific issues, one of which is the insulation system's vulnerability to very rapid transients (VFTs) brought on by the operation of switching devices.

3.2 TYPES OF TRANSIENT OVERVOLTAGES

Three categories of transient overvoltage may be made:

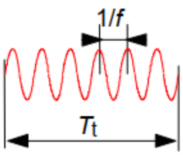
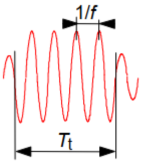
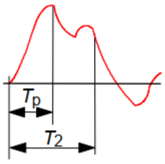
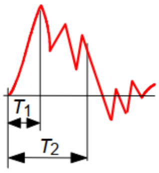
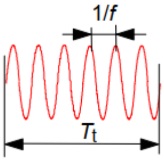
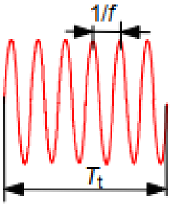
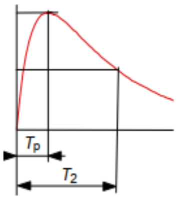
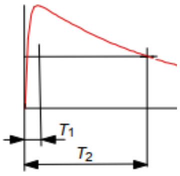
- External overvoltage, such as lightning. Natural occurrences are what led to this.
- Switching-related internal overvoltage.

Transient changes in the network's operational circumstances are triggered by transient switching overvoltages. Switching surges can be caused by a circuit being powered up or powered down, which are common occurrences.

- Short-term overvoltage

The details of classification of system over-voltages as per IEC 60071-1 are shown in Table 3.1.

Table. 3.1 – Classification of system over-voltages as per IEC 60071-1 [23]

Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	$f = 50$ Hz or 60 Hz $T_t \geq 3600$s	10 Hz $< f <$ 500 Hz 0,02 s $\leq T_t \leq$ 3600 s	20µs $< T_p \leq$ 5000 µs $T_2 \leq 20$ ms	0,1 µs $< T_1 \leq$ 20 µs $T_2 \leq$ 300 µs	$T_f \leq 100$ ns 0,3 MHz $< f_1 <$ 100 MHz 30 kHz $< f_2 <$ 300 kHz
Standard voltage shapes	 $f = 50$ Hz or 60 Hz T_t^a	 48 Hz $\leq f \leq$ 62 Hz Tt = 60 s	 Tp = 250 µs T2 =2500 µs	 T1 =1,2µs T2 = 50 µs	a

A GIS may experience very fast transient overvoltage’s (VFTO) at any time, which result in an immediate shift in voltage. The disconnector switch (DS) or isolator being opened or closed is the most common cause of this alteration. Other occurrences can also result in VFTO, including the tripping of a circuit breaker (CB), the occurrence of a line-to-ground fault, or the shutting of an earthing switch. However, because DS operates at a slower rate than a circuit breaker (opening time in seconds), there are a lot more re-strikes and pre-strikes during DS operations. As a result, the primary source of VFTO generation is DS switching.

Associated power frequency voltage fluctuations with a reasonably lengthy duration are known as temporary over voltages. The following categories can be used to group transitory overvoltage situations that are most important to insulation design: -

- Faults (unbalanced)
- Sudden changes in load (usually load rejection)
- Under-loaded long lines
- Ferro-resonance

Any electrical switching transient is the visible result of a quick change in circuit conditions, such as when a switch or circuit breaker opens and closes or when a system failure develops and disappears. When a system abruptly shifts from one steady-state condition to a new steady-state condition, a transient imbalance results. During this period, energy must be redistributed to match the new circumstances, which can happen when a switch is turned.

A transient often has a very short duration. The equipment insulations on circuit components are frequently subjected to the most severe strains during short time transients, despite the fact that these transients are normally designed to operate at rated values. For this reason, these short durations cannot be neglected.

The fundamental presumptions for comprehending the rapid switching effects are that :-

- An inductor's current cannot undergo a sudden change (it behaves as an open circuit at the time of switching)
- A capacitor's voltage cannot quickly change (when switching, it creates a short circuit).

- Energy conservation must be maintained, if current in an inductive (L) circuit with capacitance (C) is suddenly suppressed the electromagnetic energy stored in the inductance L i.e. ½LI^2 cannot be destroyed rather it is converted or transferred to the electrostatic energy stored in the capacitance (C) as ½CV^2 resulting in sudden transient voltage rise across the capacitance (C).

The basic phenomena in switching transients are thus related to interaction between electro-magnetic and electrostatic energy in circuit inductances and capacitances. This report's research cases were all completed using PSCAD-EMTDC software, version 4.5.

The following categories can be used to group the switching processes that are most important to insulation design:

- Line or cable or transformer energization and de-energization.
- Fault initiation & Fault clearing
- Transient overvoltage's in ungrounded generator transformer 3 phase systems

The magnitude of an overvoltage is typically specified in the unit P.U. (per unit). This unit is defined as

$$1p.u. = \sqrt{2} \times \left[\frac{U_m}{\sqrt{3}} \right] \tag{3.1}$$

(where, *Um* is the highest permissible voltage for the equipment, specified as the RMS line to line voltage in the normal system operation. The actual nominal value *Un* of the system voltage is usually less than *Um*.). The description of rated voltage and highest system voltage have been tabulated in Table 3.2.

Table. 3.2 Rated voltage & Highest system voltage

U_n=Nominal kV (LL) rms	U_n	220
U_m=Rated Or Highest System kV LL rms	U_m	242
1 P.U kV (U_n)	$P.U\ U_n$	144.9
1 P.U kV (U_m)	$P.U\ U_m$	159.4

- **Temporary power frequency over voltages: -**

Typically, these are long duration power frequency over voltages lasting 0.1 seconds to minutes arising from load throw or earth faults. Typically, their amplitude does not significantly exceed 1.732 x P.U i.e. (√3 x P.U., so that they do not as a rule pose a threat to the electrical equipment in the system. Nonetheless, they are a critical factor in the right choice of arrester.

- **Switching over voltages: -**

These switching over voltages typically exhibit a strongly damped, oscillating pattern. The frequency of the oscillation is often under a few kHz, and the crest value can go up to 3 P.U.

Transient over voltages that are created at the beginning of earth faults or short circuits in the electrical system are also considered switching over voltages in the most general way. In general, however, the amplitudes are rather small. On the other hand, if they occur in quick succession (intermittent earth faults), the frequent and repeated stress can lead to thermal overloading of gapless arresters.

- **Lightning over voltages: -**

Direct lightning strikes on overhead power lines produce sharp impulses with peak values of up to several thousand kilovolts, which cause line insulators to flashover and offer an indirect or more natural form of overvoltage protection. After such an insulator flashover, the surge amplitude can still be as high as 10 P.U.

A lightning strike in the vicinity of an overhead line also induces over voltages in the conductors. After a few microseconds, the crest value of these generated over voltages is reached before they swiftly fade once more. Crest values are typically about 10 P.U.

Lightning over voltages are the most extreme form of overvoltage stress in systems operating at voltages up to 220 kV.

CHAPTER-4

IMPORTANCE OF LA / SA IN GIS NETWORK

4.1 INTRODUCTION

Electrical equipment is susceptible to transient over voltages brought on by faults, lightning strikes, and internally produced over voltages through proper, improper, or faulty switching.

Temporary over voltages, which are power frequency over voltages created by system disturbances owing to ground fault, ferro-resonance, etc., are another type of over voltage that electrical systems might encounter in addition to transient over voltages.

Surge arresters offer the best defines against these transient over voltages, and they ought to be located close to the equipment that needs protection. It serves as an impulsive overvoltage bypass.

4.2 IMPORTANCE OF SURGE ARRESTOR

The goal of a surge arrester is to protect the insulation of other equipment while lowering danger to the arrester itself. The arrester must flash over and carry the impulse current to ground at a certain level. The arrester can reseal once the applied voltage stabilizes. The arresters that are utilized the most are formed of metal oxide. The arrester must be placed as close to the protected device as is practical.

It is generally known that, unlike resistive components, experimentally observed arrester terminal voltage and current do not reach their maximum values simultaneously. The frequency dependent characteristics of arresters may be of crucial application when impacted by fast transient surges.

The IEEE Surge Arrester Committee's model, which is quite accurate for a wide variety of surge wavefronts is one of the few attempts to create frequency dependent surge arrester models.

A brand-new surge arrester model that could replicate the characteristics of metal oxide surge arresters across a broad frequency range, including lightning, switching, and transient overvoltage curves. Due to the model's single nonlinear component, computational efficiency is predicted. For this model, the complete circuit design and typical parameter values are provided. More arresters can be needed at the line entry and at middle locations inside the substation, depending on the BIL requirements. The ideal location for the arresters inside the substation is one of the findings of studies on substation design. In order to guarantee that the allowable maximum energy dissipation is not exceeded, the energy traveling through the arresters must constantly be monitored. Furthermore, because to the high rate of rise times associated with back flashovers, if the arrester current rises beyond 40 kA, it may result in hot spots in the blocks.

4.3 USE OF SURGE ARRESTOR IN THIS 220 kV MODEL

Various technical considerations should be applied for selection of ZnO surge arrester and the arrester should be selected with appropriate technical performance parameters in order to ensure the arrester withstands the following:-

- **Application of line to earth power frequency voltage under all system operating conditions: -** The surge arrester chosen should have a continuous operating voltage (UC in kV rms) that is greater than the typical system maximum line to earth voltage in order to ensure this. The excessive voltages experienced on phases without faults. Temporary power frequency overvoltages, also known as temporary power frequency overvoltages, occur at the site of the arrester during an earth fault on one phase. Providing they are for brief periods controlled by the maximum back up EF protection relay clearance time and after allowing for reduced voltage-time withstand of the arrester due to maximum pre-surge energy discharge already expended through arrester at maximum site ambient temperature conditions, this can exceed the maximum arrester voltage rating[24].
- **Switching energy discharge considerations: -**Only electromagnetic transient studies using PSCAD software can be used to determine the total discharge energy due to energy stored during over voltage. This information is then compared with the chosen discharge class and the kJ/kV (Ur) chosen for the arrester in accordance with IEC 60099-4.

In line with above discussions and as per IEC 60099, ZnO surge arrester voltage values are specified as

- Maximum Continuous Operating Voltage (MCOV) or UC as per IEC
- Rated Voltage.
- 1 and 10 second TOV Voltage withstand
- the 8/20 µs wave shape nominal discharge current (in kA peak), and
- the 4/10 µs maximum impulse discharge current (in kA peak)

- Residual voltage.

The rated voltage (Ur as per IEC) of the surge arrester characterizes the arrester's ability to deal with transient short-term over voltages in the system, and the MCOV (Uc as per IEC) is the power frequency voltage at which the arrester can be operated continuously without restriction or breakdown. If the temporary voltage (TOV) exceeds the rated voltage, it may cause a considerable rise in the arrester's temperature if the TOV lasts longer than the 10 seconds or authorized length specified in manufacturer's documentation. At rated voltage, there will be some leakAge current through the arrestor.

Typical discharge class and energy capability of arresters considered for various system voltage ranges are typically as given in Table 4.1.

Table. 4.1 Typical discharge class and energy capability of Surge arresters

Line discharge class	**Energy capability (2 impulses) kJ/kV (U_r)**	**Normal Rated System Voltage Application Range (U_m)**
2	5.0	≤ 170 kV
3	7.0	170 - 420 kV
4	10.0	362 - 550 kV
5	15.0	420 - 800 kV

The selection of nominal discharge current of a surge arrester serves to classify ZnO surge arrester with respect to its line discharge classification. The classification of nominal discharge current as per IEC 60099 is given in Table 4.2.

Table. 4.2 Classification of nominal discharge current as per IEC 60099

2.5 kA	**3.0 kA**	**10.0 kA**	**20.0 kA**
$U_r \leq 36$ kV	$U_r \leq 132$ kV	3 kV $\leq U_r \leq$ 132 kV	360 kV $\leq U_r \leq$ 756 kV
Note: The above kA is 8/20 µs wave shape nominal discharge current (in kA peak)			

Since a surge arrester with a nominal discharge current of 10 kA may easily survive lightning impulses of larger amplitudes without suffering any harm, the nominal discharge current of a surge arrester is not connected to it withstand feature.

Since the nominal discharge current rating value changes with the nominal discharge current rating value, the true purpose of the nominal discharge current rating selection is mostly connected to extra high current short duration and low current long duration impulse test requirements, as shown in Table 4.3.

Table. 4.3. Impulse Current Withstand capability of Surge Arresters

Arrester Nominal Discharge Current (kA peak)	**4/10 µs High or Maximum Impulse Current Withstand (kA peak)**	**Low Current Long Duration Impulse Withstand (kA peak)**
10	100	150 A for 2000 µs
5	65	75 A for 1000 µs
2.5	25	50 A for 500 µs

CHAPTER-5

MODEL PREPARATION OF 220kV GIS SUBSTATION

5.1 INTRODUCTION

The details of the Project considered for modelling in PSCAD-EMTDC software have been based on the data provided in the above project documents. The system is developed on PSCAD.

5.2 GRID MODEL

The system comprises of 220 kV grid connected to 20 km overhead transmission then 220 kV GIS and then to 150 MVA 220/132/11 kV transformer connected through 1C X 800 mm^2 1000 meter-long cable. The parameters of the 220 kV grid short circuit have been tabulated in Table 5.1.

Table. 5.1 220 kV Grid Short circuit parameter

Summary of 220 kV Grid Short circuit level	
Voltage	220 kV
Current	8 kA (assumed)
X/R	14 (assumed)
MVAsc	3048.40 MVA
Z	15.87 Ω
R	1.13 Ω
X	15.83 Ω
L	0.50 H

5.3 220 kV CIRCUIT MODEL

The power evacuation circuit from 220 kV GIS to grid has been modelled as double circuit OHTL line length 20 km to enable lightning application for the studies. While underground cable between 220 kV outgoing GIS to 150 MVA transformer is assumed to be 1 km to enable the switching studies.

5.4 220 kV CABLE MODEL

Underground cable 1C X 800 mm^2 between 220 kV outgoing GIS to 150 MVA transformer is assumed to be 1 km As to the various models for system cables available in

PSCAD, studies were carried out using all the available models in PSCAD such as Bergeron model (suitable only for single close to power frequency studies), multiple PI and frequency dependent model all of which resulted in similar conclusions for surge protection measures required in the plant although Bergeron model resulted in higher frequency of oscillation with lack of damping. However, to optimise the calculation time for required time step, a multiple series PI model was considered in the study. The PI model parameters of the 220 kV cable are tabulated in Table 5.2. The snapshot of the PI model of the cable in PSCAD has been shown in Fig. 5.1.

Table. 5.2 220 kV Cable PI model parameter

R	0.0322	Ω /km
C	0.174	µF/km
L	0.23	mH/km
X_L	0.203	Ω /km
X_C	18.29	M Ω *km

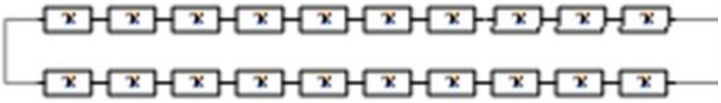


Fig. 5.1 Snapshot of Cable PI Model in PSCAD

5.5 EXTERNAL TYPICAL 220 kV OVERHEAD LINE MODEL

20 km overhead line (as an incoming feeder at 220 kV GIS) has been modelled using frequency dependent T-line component of PSCAD for transmission line model with towers for lightning studies. The T line model for transmission line has been modelled with conductors configured on the tower as per data in PSCAD model. The data for the overhead lines are assumed as per typical data. The external parameters of the 220 kV cable have been tabulated in Table 5.3. The snapshot of external cable model in PSCAD has been shown in Fig. 5.2.

Table. 5.3 220 kV External Cable parameter

Conductor details	ACSR, Jaguar conductor
Conductor size	210 sq.mm.
OHL configuration	Double circuit
Conductor spacing	6 m
Ground wire details	ACSR, 118.5 sq.mm.
Tower-to-tower spacing	300m
Tower height	15 m
Tower footing resistance	20 Ω

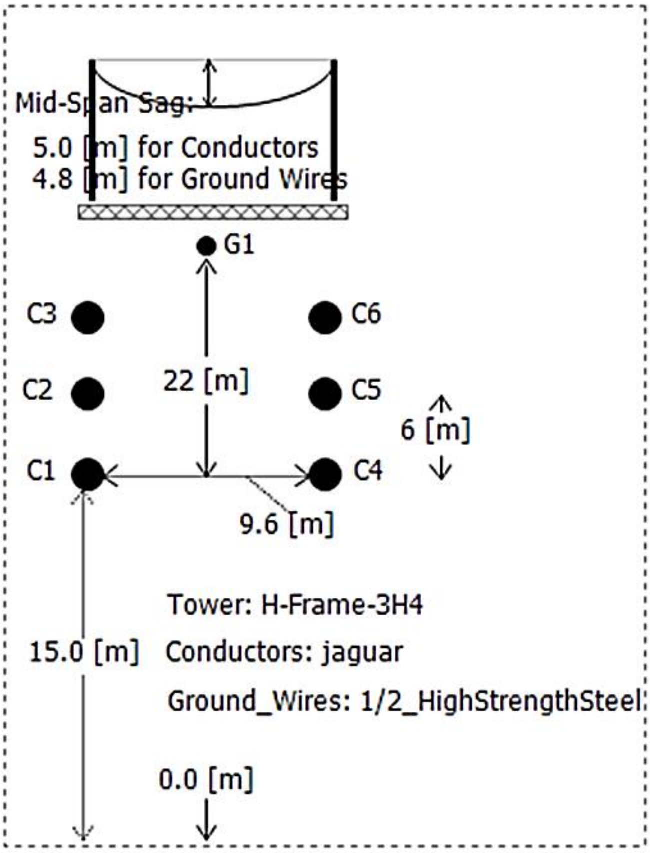


Fig. 5.2 Snapshot of External Cable Model in PSCAD

Fig. 5.2 shown the geometry of the tower 220 kV. A tower is represented as a radiating structure like a propagation line with damped inductance [23]. The surge impedance and the velocity propagation of the tower are enclosed in the model [27]. Parameters of the corresponding model are calculated according to [23,26,27].

5.6 SWITCHGEAR MODEL (220 kV)

The 220kV switchgear models on PSCAD have been developed considering the stray capacitances to ground of various switchgear components including CTs, VTs, earth switches, disconnector switches, bushing & circuit breakers. The capacitance values considered for each individual component are derived from relevant IEEE standards and are tabulated in Table 5.4 [25].

Table. 5.4 220 kV GIS component parameters

Equipment	**220kV**
	Capacitance (pF)
Bushing	5
Earth Switch	20
Voltage Transformer	150
Disconnector Switch	200
Current Transformer	420
Circuit breaker Capacitance to ground	20
Circuit Breaker interwinding	50

5.7 150 MVA 220/132/11 kV TRANSFORMER MODEL

The transformer technical data considered for the studies have been based on SLD, the transformers are modelled in PSCAD. The 220 kV OHTL PI model parameters have been tabulated in Table 5.5.

Table. 5.5 220 kV OHTL PI model parameter

INPUT DATA CONSIDERED FOR MODELING OF POWER TRANSFORMER IN PSCAD	
Parameters	**150 MVA transformer**
Primary Voltage(kV)	220
Secondary Voltage (kV)	132
Tertiary Voltage (kV)	11
Rated MVA	150
Z (%)	10%

CHAPTER-6

METHODOLOGY

6.1 INTRODUCTION

The coordination studies for lightning and switching overvoltage have been completed in accordance with IEC60071, and all of the associated processes have been handled in one way or another in the PSCAD studies completed for this report.

The PSCAD-EMTDC (Electromagnetic Transient Program) software has been used to analyse the various study cases with and without over voltage protection devices (surge arresters or RC surge suppressor, etc.) for the assessment of over voltage stresses within the system as required by the standard. With and without over voltage protection devices (surge arresters or RC surge suppressor etc.) and these have been compared with the standard insulation (Basic Insulation Level-BIL) withstand test voltage values as per voltage range I (<245 kV) of the standard after considering margins on the standard BIL and switching withstand voltage level stated in the standards.

Studies were used to check whether the insulation values 220 kV, 132 kV and 11 kV switchgear and equipment specified for the project were adequate for the implementation after considering safety/design margins.

6.2 STEPS FOR MODELLING

The studies as per the report have addressed all the steps of the standard and these are as described below with references to respective clauses of the report.

- **Step 1:** In the PSCAD study report, all studies have been carried out to determine the lightning, switching & temporary over voltages that are to be expected at various points on the system. These studies have been carried out with & without overvoltage protection devices. The results of the switching & other PSCAD studies include peak value of voltage stress in the documentation of each of the cases under the following categories: -

- Lightning Impulse Overvoltage
- Switching Impulse Over Voltage
- VFFT

The overvoltage stresses evaluated are referred to as Representative Over-voltage (U_{rp}) in Step 1 of Insulation coordination procedure in IEC standard 60071-1 [23].

- **Step 2:** The Overvoltage stresses calculated from PSCAD for each of the cases are compared with the selected standard equipment insulation (BIL used as reference) withstand voltage referred to in IEC as Coordination Withstand Voltage (U_{cw}) as per Step 2 of Insulation coordination procedure in IEC standard 60071-1 Fig.1. This has been based on the IEC for 220 kV, 132 kV and 11 kV

- **Step 3:** The limits of permissible/ required withstand voltage (U_{rw}) have been established in section 7 of report along with safety margins as per standard with respect to coordination withstand voltage

- **Step 4:** The table of standard power frequency and impulse test withstand voltage recommended for all HV equipment are given in PSCAD report

- **Step 5:** In line with the steps above the representative overvoltage (U_{rp})is calculated and it is ensured that it is within the permissible value U_{rw} which is based on a certain margin with respect to Coordination Withstand Voltage (U_{cw}) which is the BIL specified for all the 220 kV, 132 kV, 11 kV equipment as part of the project.

6.3 MODELLING PARAMETERS

For the high frequency transients occurring in sections of air insulated substation equipment, the following modelling approach will be considered (as tabulated in Table 6.1) [10].

Table. 6.1 – Model parameters of Overall Network

Equipment Modelling for Fast Transient Studies		
Switchgear Component		**Modelling Parameter**
Circuit breaker & Disconnector	Closed	Distributed transmission line or PI circuit as appropriate for short length with stray shunt capacitance
	Open	Distributed transmission line or PI circuit as appropriate for short length with stray shunt capacitance and contact open capacitances
Earth switch	Open	Lumped capacitor to earth
Cone insulator, Line bushing, Transformer with line bushing, Voltage and Current transformer		Lumped capacitor to earth
Bus bar		PI circuit representing distributed transmission line due to short lengths
Overhead line		Multiple series PI circuit representing distributed transmission line parameters

Equipment Modelling for Fast Transient Studies	
Switchgear Component	**Modelling Parameter**
	OR T line model for lightning studies with small simulation time steps and simulation runs`
Transformer	Transformer model

For switching transient studies simulation step plays a very important role along with equipment component modelling. Typically, the simulation (or calculation) time step should be smaller than the smallest time constant of any equipment or smaller than travelling time of electromagnetic wave propagation in different equipment. Typical values of solution time step applicable for various lightning, switching and ferro-resonance studies based on the actual system modelled are as tabulated in Table 6.2 [26].

Table. 6.2 – Time steps considered for case studies

Sl. No.	Switching Transient Case Study	Range of Time Step considered
1.	Cable Switching	0.09 µs
2.	Lightning Transients	0.09 µs
3.	VFFT/TEV	0.00001 µs
Note: Wherever time step was not found to be appropriate, it has been suitably varied to achieve the correct results.		

Modelling of the above lightning/ surge waveforms in PSCAD have been generated using standard equations, aspects of which are covered below:

- The standard waveshape for the surge100 kA 10/350 µs, 20 kA 8/20 µs, 100 kA 4/80 µs & 10kA 8/20 µs, can be written in terms of two exponentials,

$$I(t) = k(e^{-\alpha t} - e^{-\beta t}) \qquad (6.1)$$

Where k, α, β are constants and t is time in microseconds. The parameters are taken as shown in Table 6.3.

Table. 6.3 Reference Table for Wave-front and Wave-tail Basis

Waveform (µs)	**Reference**	**Wavefront and Wavetail Basis**	**Reference**		
			α	**β**	**k**
1.2/50	IEC 61000-4-5 IEC 60060-1	T1 = 1.67T T2 = 50	0.0145	2.8353	1.0328
8/20	IEC 61000-4-5 IEC 60060-1	T1 = 1.25T T2 = 50	0.1732	0.0866	4
1/50	IEC 69469-1	T1 = 1.25T T2 = 501	0.014576	2.5293	1.0363
250/2500		T1 = 1.25T T2 = 2500	0.00035239	0.0080519	1.2068
250/1500		T1 = 1.25T T2 = 1500	0.00072065	0.0065795	1.4741
10/700	IEC 60060-1	T1 = 1.67T T2 = 700	0.0010222	0.3063	1.0227
5/320	IEC 60060-1	T1 = 1.25T T2 = 320	0.0022548	0.51343	1.0288

6.4 SURGE ARRESTER SELECTED FOR THIS 220 kV SYSTEM

In line with the above considerations, the surge arresters considered for the project, as summarized below seems appropriate, but these will be confirmed by the various lightning, switching and temporary over voltage studies carried out as part of this report using PSCAD software [18]. The details of surge arrester selection has been shown in Table 6.4. The ratings of surge arrester has been tabulated in Table 6.5. The result of the VI characteristics of the surge arrester has been tabulated in Table 6.6.

Table. 6.4 Surge Arrester Selection Table

Selection of Surge Arrester		
Selection of Surge arrester	kV	220
Assessment		
Nominal System kV U_n	kV	220
Rated System kV U_m	kV	242
Three phase system type		3 ph 3 wire

K_d (EFF)		1.4
System Earth		Solidly Earthed
Surge arrester connection		Phase - Earth
Uc selection basis including factor for harmonics which is Maximum of ($U_n \times \frac{1.1}{\sqrt{3}} \times \text{Harmonic Factor}$)		$\left(Un \times \frac{1.1}{\sqrt{3}}\right) \times 1.05$
Surge Arrester U_c	kV	146.7
Surge Arrester U_r is Max of U_m*K_d/sqrt (3) or U_c/1.25	kV	195.6

Table. 6.5 Surge Arrester Rating

Surge Arrester Rating			
Surge Arrester	Rated U_r	kV	198
	Uc-MCOV	kV	146.7
	U_r/U_c		1.34
Surge Arrestor TOV Factor	For 1 sec	Typical Factor TOV/U_c	1.434
	For 10 sec	Typical Factor TOV/U_c	1.375
Surge Arrestor TOV in kV	For 1 sec	kV_p	227
	For 10 sec	kV_p	217
Nominal Discharge Current (8/20µs)		kA_p	20
Short Circuit Rating		kA_{rms}	40
BIL of all equipment		kV_p	1050
Permissible BIL Margin (20%)		kV_p	875
Permissible BSL of equipment (0.63 X BIL) (worst component 0.63 of BIL)		kV_p	551.2
Energy Absorption capability provided by vendor		(kJ/U_c (kV) arrester rating)	7
* Note: Kd or EFF is taken as 1.4 (for solidly earthed)			

Table. 6.6 Surge Arrester VI characteristics

VI characteristics (U_r =198 kV)	
I (kA)	V (P.U.)
0.0001	1.09
0.001	1.15
0.01	1.22
0.1	1.30
0.5	1.92
1	1.98
2	2.06
5	2.23
10	2.35
20	2.58
40	2.89

6.5 ACCEPTANCE CRITERIA

The details of the 220 kV plant equipment insulation withstand considered for the study are as given in Table 6.7.

Table. 6.7 – Insulation Withstand Rating

Equipment Peak Insulation Withstand Rating			
System Nominal kV	kV_{rms}	220	132
Rated Equipment kV	kV_{rms}	245	145
BIL (1.2/50 µs Basic Lightning Impulse Insulation Withstand Voltage Level	kV_p	1050	650
Power frequency withstand voltage	kV_{rms}	460	275

The switching surge withstand for various equipment considered for the study are based on Table 5 of IEEE standard C62-22, which are as tabulated in Table 6.8.

Table. 6.8 Basic Switching Impulse Insulation Level (BSL)

Equipment	**Switching Impulse Duration**	**Basic Switching Withstand Voltage Limit (BSL)**
Transformer	250/2500 µs wave	0.83 x BIL
Bushings	250/2500 µs wave	0.63 to 0.69 x BIL
Note: - The Cable BSL will be lower than that of Transformer		

All switching transient over voltages at different voltage level will be compared with the lowest BSL of associated equipment connected after applying a margin of 20 % (as tabulated in Table 6.9).

Table. 6.9 Calculation method of Basic Insulation Level (BIL)

Equipment Nominal kV	**BIL (kV_p)**	**Permissible BIL Limit with 20 % Margin (kV_p)**	**BSL Value Considered With 20 % Margin (kV_p)**
		(BIL/1.2)	**(0.63*BIL/1.2)**
220 kV	1050	875	551.25
132 kV	650	541.6	341.25
Note: All lightning as well as normal and fault switching surge over voltages worked out in the study will be compared with permissible BIL (lightning overvoltage surges) & permissible BSL (switching overvoltage surges) Limit with 20 % margin calculated above. BSL/BIL ratio considered for all equipment voltages is 0.63.			

For VFFT (Very Fast Front Transient) over-voltage stress with fast front, the chopped wave withstand (CWW) values can be used as the withstand values for VFFT over-voltages. CWW for most equipment, except solid insulation, are higher than the respective equipment BIL.

The volt-time characteristic of air insulation turns up significantly for short duration voltage stress. The oil-filled insulation turns up less, and solid insulation, very little. For solid insulations like XLPE, the small turn up is why the CWW is the same as the BIL.

For transformers and other oil-filled equipment and insulators and other air mediums, CWW is typically = 1.10 to 1.15 x BIL. For cable insulation, CWW is considered to be equal to BIL.

The CWW withstand for various equipment considered for the study are based on Table 5 of IEEE standard C62-22, which are as tabulated in Table 6.10.

Table. 6.10 220kV CWW Rating

<table>
<tr><th colspan="4">Equipment CWW Ratings for Rated Voltages</th></tr>
<tr><th>Equipment Nominal Voltage (kV)</th><th>BIL</th><th>CWW / BIL Ratio Considered</th><th>CWW Value Considered for The Study With 15 % Margin</th></tr>
<tr><td>220</td><td>1050</td><td>1</td><td>$1.0 \times 1050/1.15 = 913\text{kV}$</td></tr>
<tr><td colspan="4">All VFFT surge over voltages worked out in the study will be compared with the CWW Limit with 15 % margin calculated above.</td></tr>
<tr><td colspan="4">**Note:** Equipment withstand limit with 15 % margin on BIL/CWW is as per IEC 60071-2 as well as per IEEE Standard C62.22-1997, Section 4.6</td></tr>
</table>

CHAPTER-7

RESULTS AND DISCUSSIONS

7.1 RESULT CASE STUDY

The transient over voltage case studies, using electro-magnetic transient software (PSCAD-EMTDC), have been carried out as part of this report covering the following cases. The resultant plots from each case are presented in the following figures and tables. Results and discussion of each study have been covered in the subsequent sub sections.

The different case studies have been simulated using PSCAD. List of different cases are summarized in Table 7.1.

Table. 7.1 List of Case Studies

Case	Case Description
Case 1.0	**220 kV OHL lightning impulse studies**
Case 1.A	Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation
Case 1.A.1	- Without Surge Arrester
Case 1.A.2	- With 1 Surge Arrester at OHTL end
Case 1.A.3	- With 2 Surge Arresters at both OHTL & GIS end
Case 1.B	Direct Lightning Over-Voltage Study For 220 kV OHL –20 kA, 1.2/50 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation
Case 1.B.1	- Without Surge Arrester
Case 1.B.2	- With 1 Surge Arrester at OHTL end
Case 1.B.3	- With 2 Surge Arresters at both OHTL & GIS end
Case 2.0	**Cable Switching Study for 220kV GIS Network**
Case 2.A	Cable Switching Study - Energization Of 220kV,1000m Cable Without Trapped Charge
Case 2.B	Cable Switching Study – De-Energization Of 220kV,1000m Cable Without Trapped Charge
Case 2.C	Cable Switching Study – Re Energization Of 220kV,1000m Cable With Trapped Charge
Case 3.0	**VFFT of 220kV GIS Disconnector**

7.2 220 kV OHL LIGHTNING IMPULSE STUDIES

Two types of lightning strike studies have been carried out on the 220kV OHL based on IEEE Guidelines for Modelling and Analysis of System Transients using Digital Programs.

- **Case 1A: Back flashover:** The lightning in this case is on 220kV OHL tower, which can cause tower top potential rise (based on tower footing resistance of 20ohm) resulting in insulator flashover causing lightning surge to divert to the live conductor (as per IEEE guideline the breakdown voltage flashover of the insulator is taken as 1457 kV).The strike impulse is modelled as a 4/80 μs impulse current with a peak of 100 kA as per IEEE guideline (as per details of limit distance Xp = 2 towers = 600min Annex F of IEC 60071-2).This case divided into 3 case studies. As follows :

  i)Without Surge Arrester,

  ii) With 1 Surge Arrester at OHTL end

  iii With 2 Surge Arresters at both OHTL & GIS end

- **Case 1B: Direct stroke/ Shielding failure:** The lightning in this case is struck on phase conductor of 220 kV OHL as per details of limit distance Xp = 1 span = 300 min Annex F of IEC 60071-2.The strike impulse is modelled as an1.2/50 μs impulse current with a peak of 20 kA as per IEEE guideline. This case divided into 3 case studies. As follows : i)Without Surge Arrester,

  ii) With 1 Surge Arrester at OHTL end

  iii) With 2 Surge Arresters at both OHTL & GIS end.

  All studies have been carried out with and without surge arresters to assess the need of surge arresters. Refer summary of result table herein this section. The PSCAD graphical plots are attached.

Result: Case 1.A.1

As mentioned above , after simulation of the Back flashover of LIOV study on this 220kV GIS network we obtained below results as mentioned in Table 7.2 and Table 7.3 for Case No. 1A.1 without Surge Arrester. Fig.7.1 and Fig.7.2 shows the maximum fast transient overvoltages due to indirect strike case without Surge arrester at OHTL end and GIS end respectively .

Table 7.2 - CASE 1.A.1 Results of Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (Without Surge Arrester) – measured at OHTL terminal end of the GIS

Case	**Case Details**	**Measured voltages at 220kV OHTL terminal (kVp)**	
		End 1	**End 2**
CASE 1.A.1	No Surge Arrestor	1451.9	1400.8

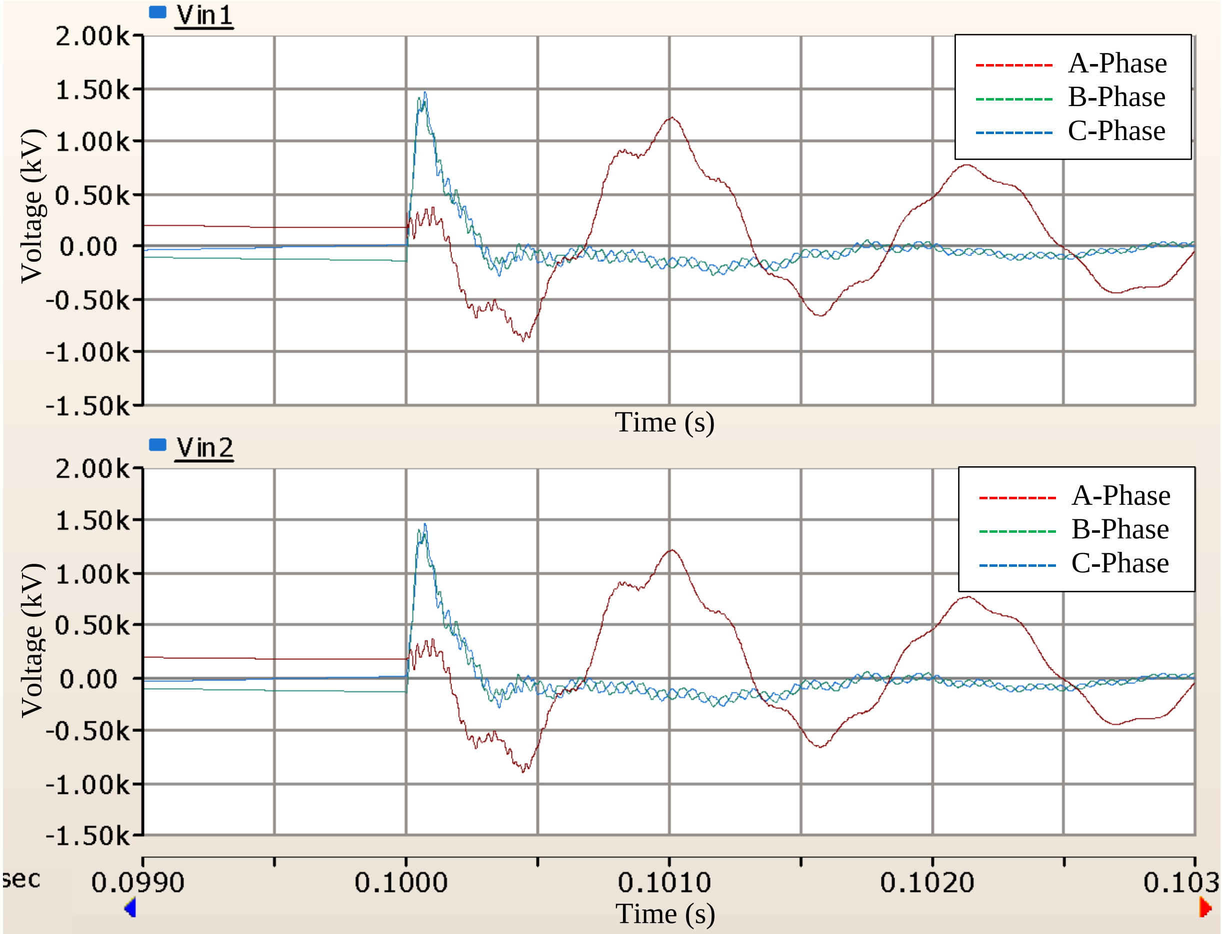


Fig. 7.1. Maximum Fast transient overvoltages at OHTL end due to indirect strike case without Surge arrester

Table 7.3 CASE 1.A.1 Results of Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (Without Surge Arrester) – measured at GIS terminal end of the GIS Network

Case	**Case Details**	**Measured Voltage at 220kV GIS end (kV_p)**			
		End 1	**End 2**	**End 3**	**End 4**
CASE 1.A.1	No Surge Arrestor	1403.10	1402.73	1401.16	1401.53

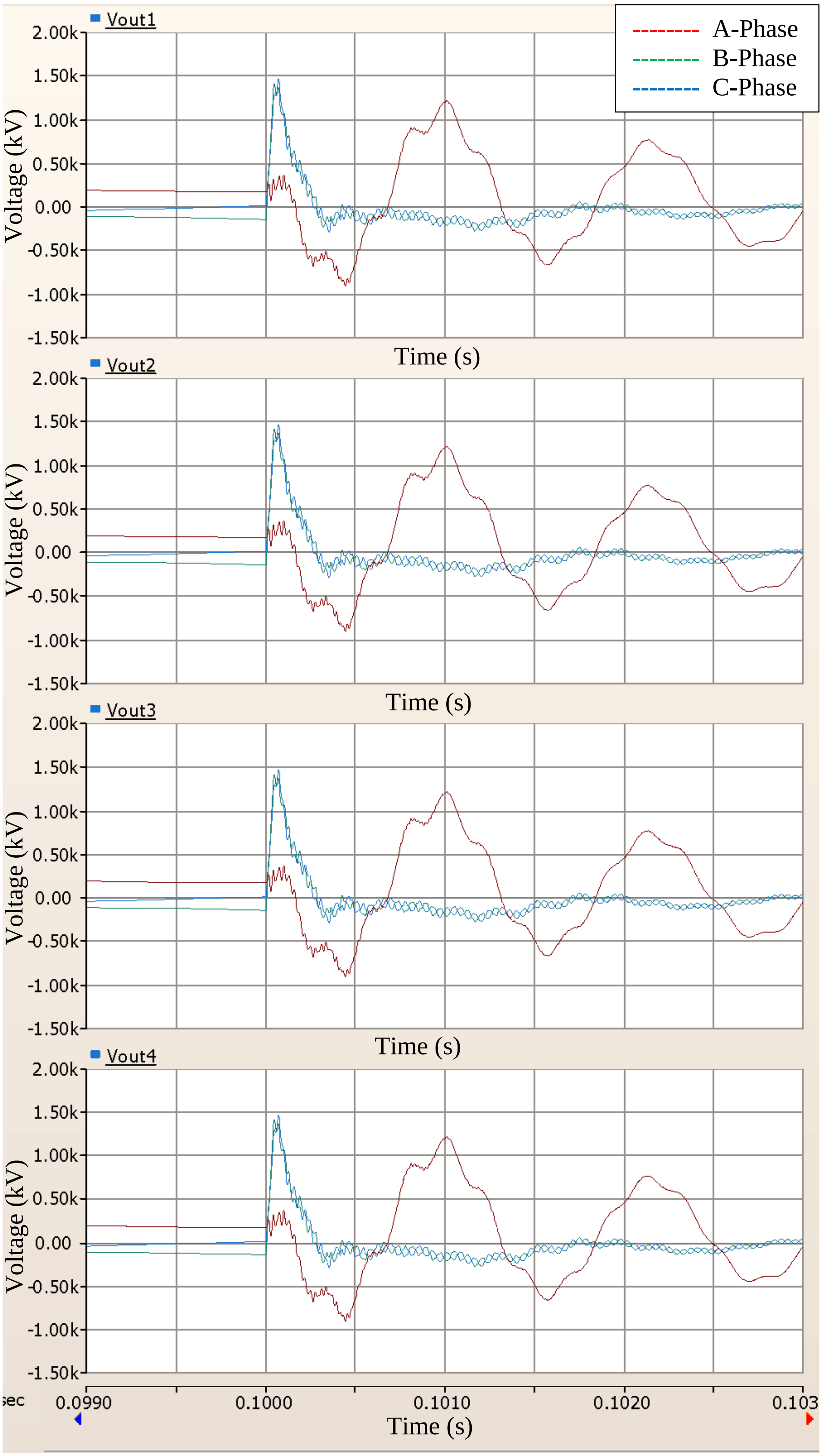


Fig. 7.2 Maximum Fast transient overvoltages at GIS end due to indirect strike case without Surge arresters

Result: Case 1.A.2

As mentioned above , after simulation of the Back flashover of LIOV study on this 220kV GIS network we obtained below results as mentioned in Table 7.4 and Table 7.5 for Case No. 1A.2 with 1 Surge Arrester at OHTL end. Which already showing that by installing only 1 surge arrester at OHTL end successfully limiting the LIOV effect on this GIS network. Fig.7.3 and Fig.7.4 shows the maximum fast transient overvoltages due to indirect strike case with 1 Surge arrester at OHTL end measuring the overvoltages in both OHTL end and GIS end respectively .

Table 7.4 - CASE 1.A.2 Results of Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (With 1 Surge Arrester at OHTL end) – measured at OHTL terminal end of the GIS Network

Case	**Case Details**	**Measured voltages at 220kV OHTL terminal (kVp)**	
		End 1	**End 2**
CASE 1.A.2	220kV Surge Arrestor only at 220 GIS Incoming	506.42	522.83

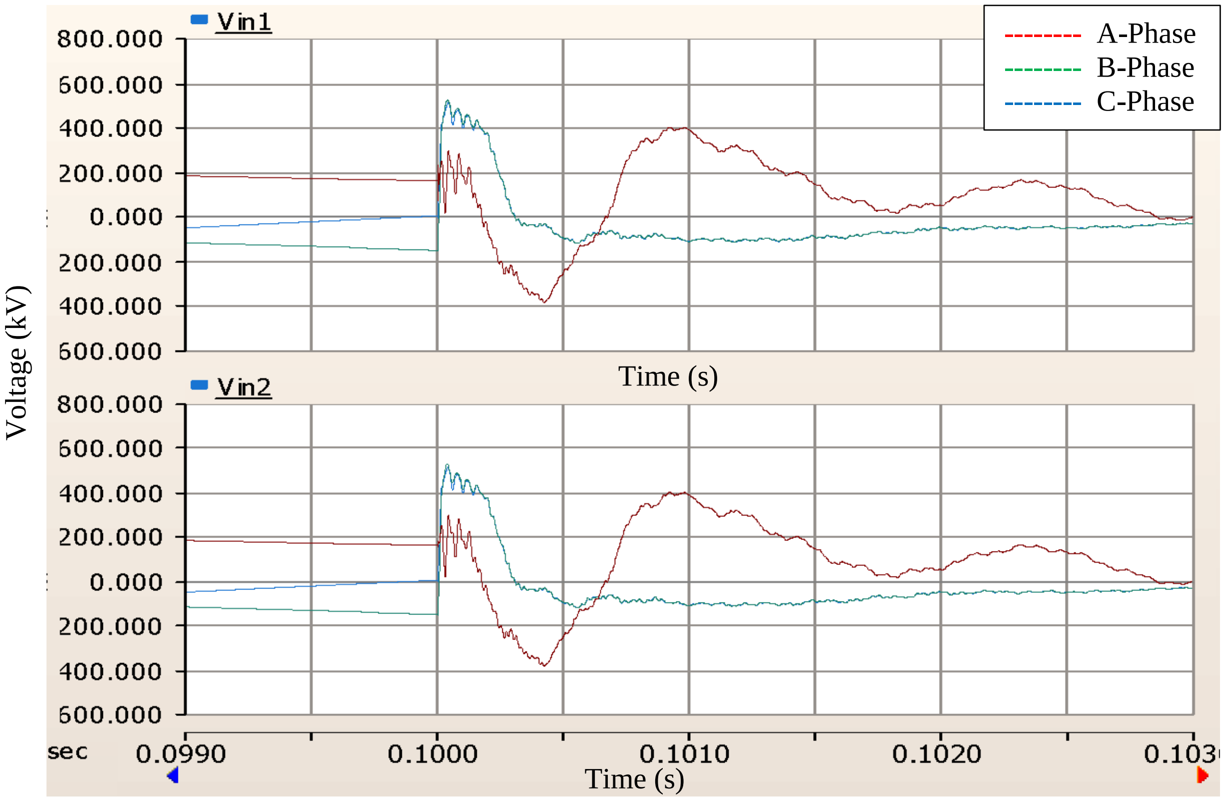


Fig. 7.3 Maximum Fast transient overvoltages at OHTL end due to indirect strike case with 1 Surge arresters at OHTL end

Table 7.5 - CASE 1.A.2 Results of Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (With 1 Surge Arrester at OHTL end) – measured at GIS terminal end of the GIS Network

Case	**Case Details**	**Measured Voltage at 220kV GIS end (kV$_p$)**			
		End 1	**End 2**	**End 3**	**End 4**
CASE 1.A.2	220 kV Surge Arrestor only At 220 kV GIS Incoming	524.11	523.96	523.06	523.28

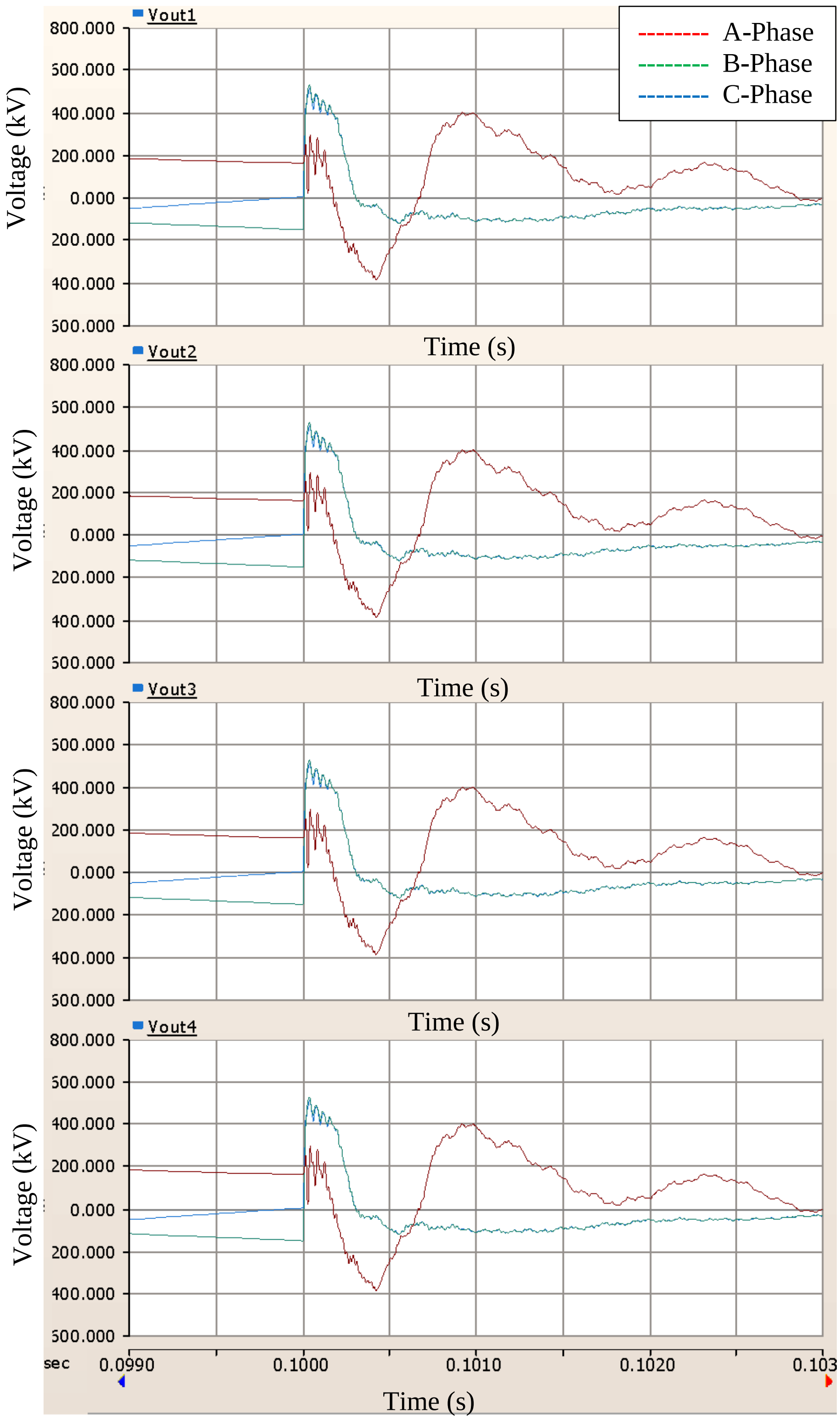


Fig. 7.4 Maximum Fast transient overvoltages at GIS end due to indirect strike case with 1 Surge arresters at OHTL end

Result: Case 1.A.3

As mentioned above , after simulation of the Back flashover of LIOV study on this 220kV GIS network we obtained below results as mentioned in Table 7.6 and Table 7.7 for Case No. 1A.3 with 2 Surge Arresters at both OHTL & GIS terminal end. Which already showing that by installing only 2 surge arresters at OHTL & GIS end successfully propagate the LIOV and optimum solution for this study. Fig.7.5 and Fig.7.6 shows the maximum fast transient overvoltages due to indirect strike case with 2 Surge arresters at OHTL end and GIS end then measuring the overvoltages in both OHTL end and GIS end respectively .

Table 7.6 - CASE 1.A.3 Results of Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (With 2 Surge Arresters at OHTL & GIS End)– measured at OHTL terminal end of the GIS Network

Case	**Case Details**	**Measured voltages at 220kV OHTL terminal (kVp)**	
		End 1	**End 2**
CASE 1.A.3	220 kV Surge Arrestor only at 220 GIS Incoming & Outgoing	448.36	455.98

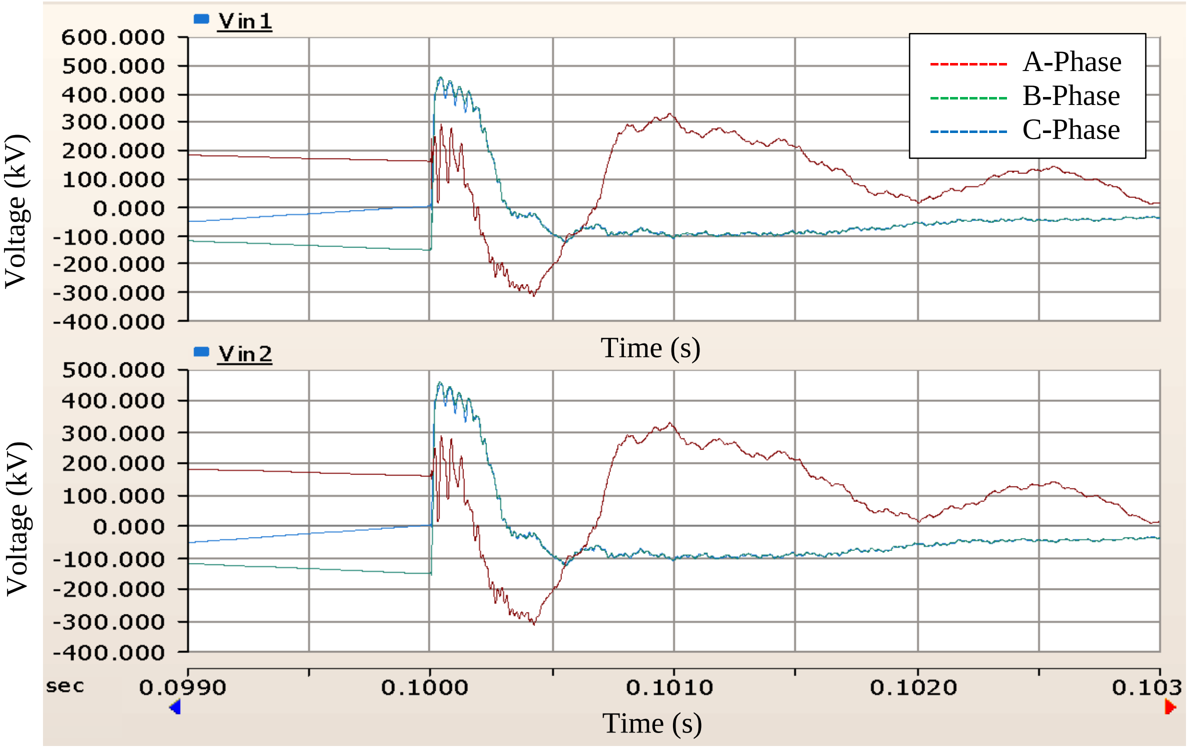


Fig. 7.5 Maximum Fast transient overvoltages at OHTL end due to indirect strike case with 2 Surge arresters at OHTL & GIS end

Table 7.7 - CASE 1.A.3 Results of Back Flashover Lightning Over-Voltage Study For 220 kV OHL –100 kA, 4/80 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (With 2 Surge Arresters at OHTL & GIS End)– measured at GIS terminal end of the GIS Network

Case	**Case Details**	**Measured Voltage at 220kV GIS end (kV$_p$)**			
		End 1	**End 2**	**End 3**	**End 4**
CASE 1.A.3	220 kV Surge Arrestor only at 220 GIS Incoming & Outgoing	456.37	455.93	455.96	456.02

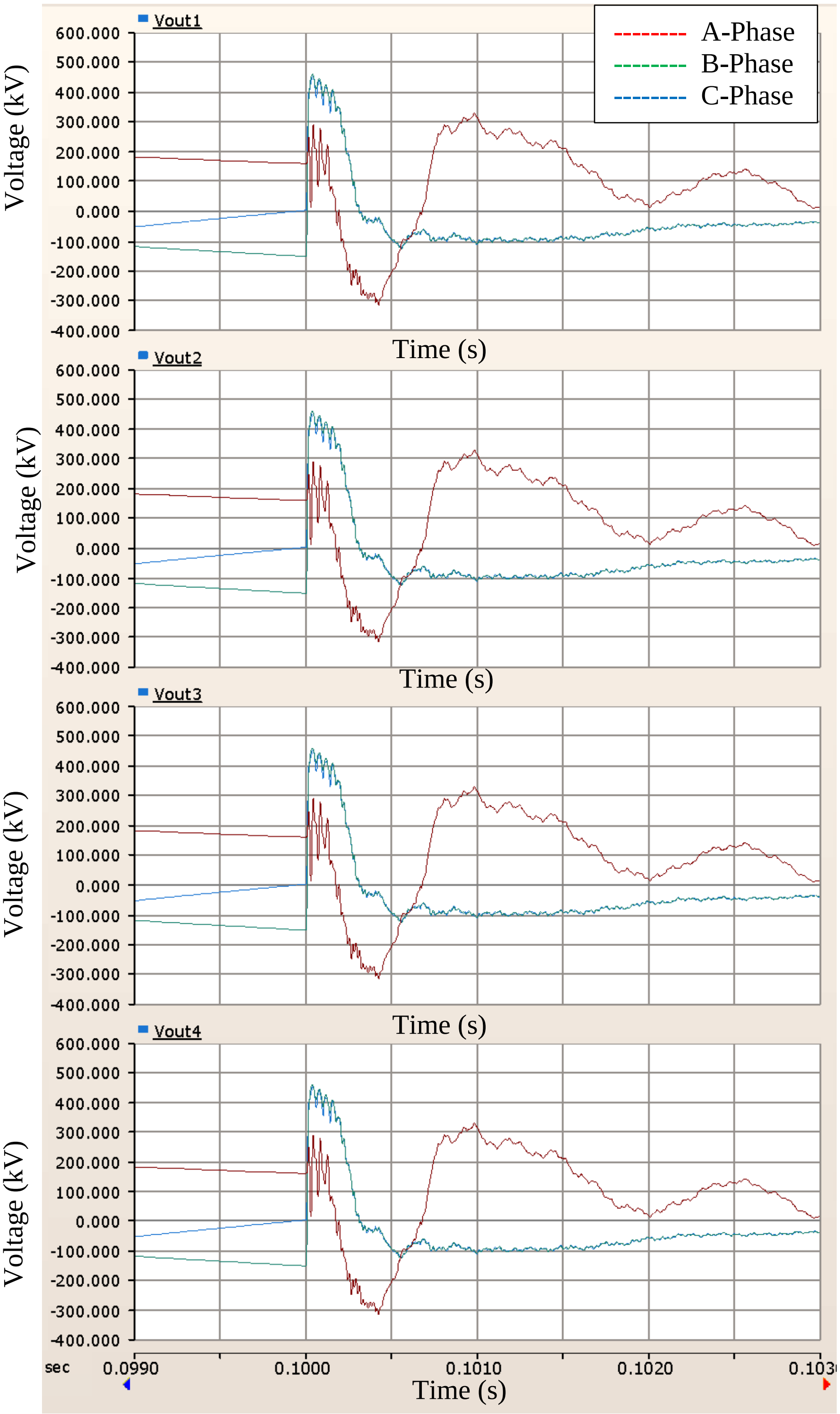


Fig. 7.6 Maximum Fast transient overvoltages at GIS end due to indirect strike case with 2 Surge arresters at OHTL & GIS end

Result: Case 1.B.1

As mentioned above , after simulation of the Back flashover of LIOV study on this 220kV GIS network we obtained below results as mentioned in Table 7.8 and Table 7.9 for Case No. 1A.1 without Surge Arrester. Fig.7.7 and Fig.7.8 shows the maximum fast transient overvoltages due to Direct strike case with No Surge arrester and measuring the overvoltages in both OHTL end and GIS end respectively .

Table 7.8 - CASE 1.B.1 Results Of Direct Lightning Strike Over-Voltage Study For 220kV OHL –20kA, 1.2/50µs Wave, Applied Directly On 220kV conductor at 300m away from 220 kV GIS Substation (Without Surge Arrester)– measured at OHTL terminal end of the GIS Network

Case	**Case Details**	**Measured voltages at 220kV OHTL terminal (kVp)**	
		End 1	**End 2**
CASE 1.B.1	No Surge Arrestor	1473.3	1473.4

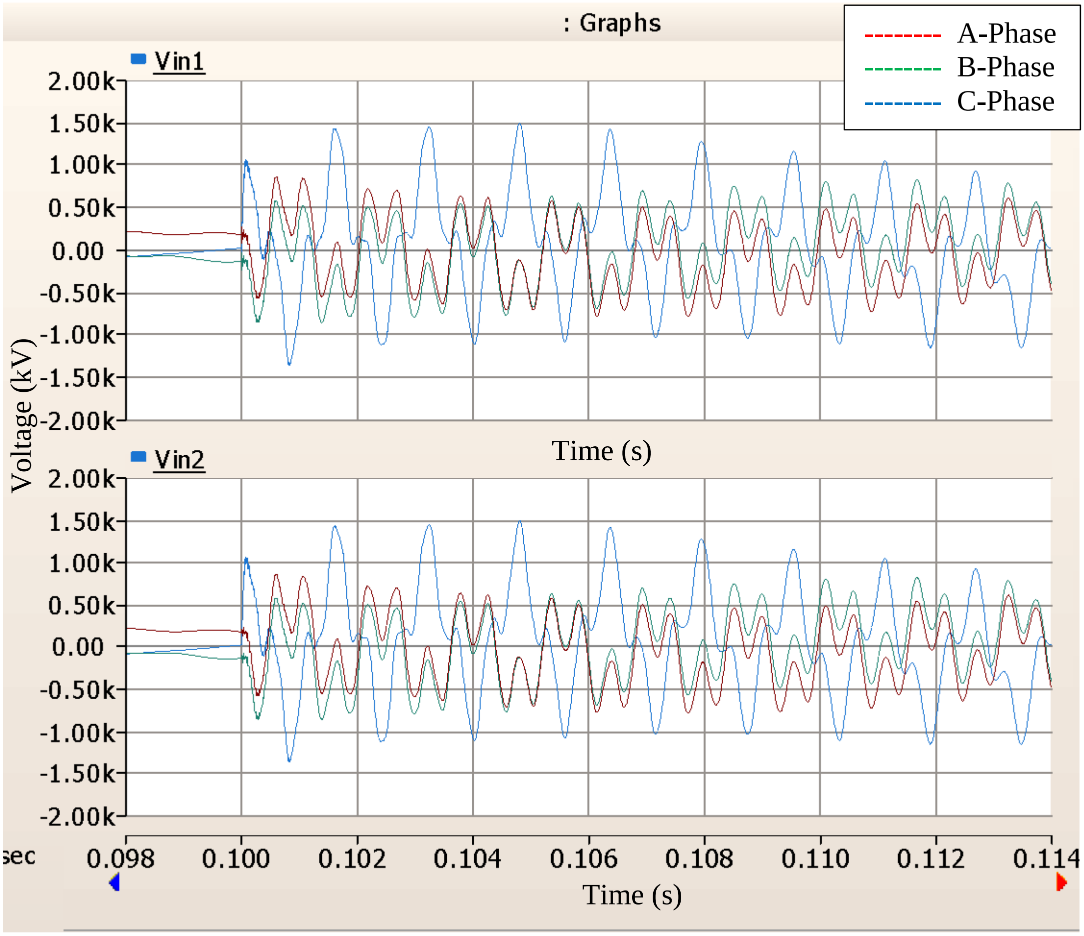


Fig. 7.7 Maximum Fast transient overvoltages at OHTL end due to Direct strike case without Surge arrester

Table 7.9 - CASE 1.B.1 Results Of Direct Lightning Strike Over-Voltage Study For 220kV OHL –20kA, 1.2/50µs Wave, Applied Directly On 220kV conductor at 300m away from 220 kV GIS Substation (Without Surge Arrester)– measured at GIS terminal end of the GIS Network

Case	**Case Details**	**Measured Voltage at 220kV GIS end (kV$_p$)**			
		End 1	**End 2**	**End 3**	**End 4**
CASE 1.B.1	No Surge Arrestor	1473.40	1473.44	1473.42	1473.45

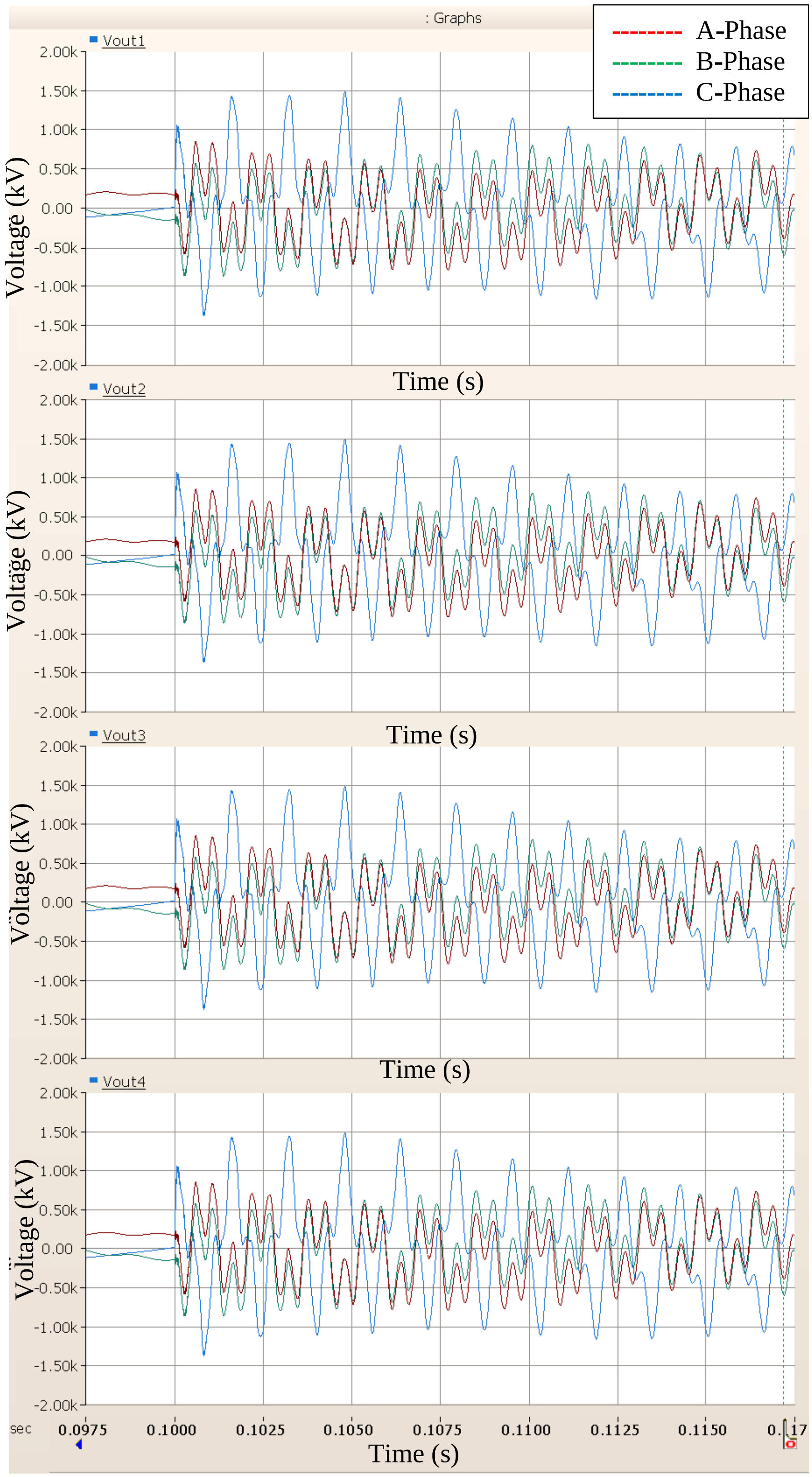


Fig. 7.8 Maximum Fast transient overvoltages at GIS end due to Direct strike case without Surge arrester

Result: Case 1.B.2

As mentioned above , after simulation of the Direct Lightning Overvoltage (LIOV) study on this 220kV GIS network we obtained below results as mentioned in Table 7.10 and Table 7.11 for Case No. 1A.2 with 1 Surge Arrester at OHTL end. Which already showing that by installing only 1 surge arrester at OHTL end successfully limiting the LIOV effect on this GIS network. Fig.7.9 and Fig.7.10 shows the maximum fast transient overvoltages due to Direct strike case with 1 Surge arrester at OHTL end and measuring the overvoltages in both OHTL end and GIS end respectively .

Table 7.10 **-** CASE 1.B.2 Results Of Direct Lightning Strike Over-Voltage Study For 220kV OHL –20kA, 1.2/50µs Wave, Applied Directly On 220kV conductor at 300m away from 220 kV GIS Substation (With 1 Surge Arrester at OHTL end)– measured at OHTL terminal end of the GIS Network

Case	**Case Details**	**Measured voltages at 220kV OHTL terminal (kVp)**	
		End 1	**End 2**
CASE 1.B.2	220 kV Surge Arrestor only at 220 GIS Incoming	456.08	458.13

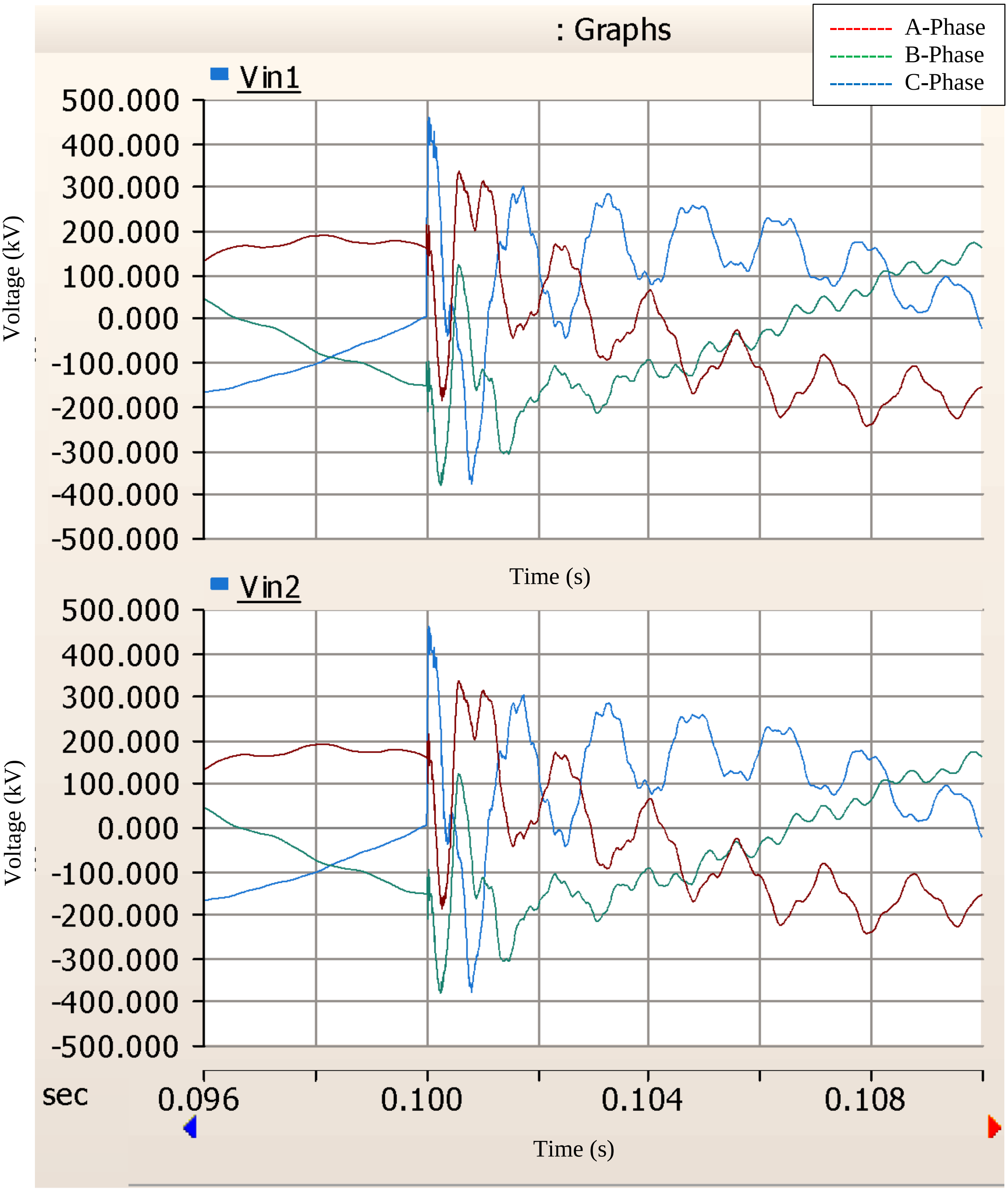


Fig. 7.9 Maximum Fast transient overvoltages at OHTL end due to Direct strike case with 1 Surge arrester at OHTL end

Table 7.11 - CASE 1.B.2 Results Of Direct Lightning Strike Over-Voltage Study For 220kV OHL –20kA, 1.2/50µs Wave, Applied Directly On 220kV conductor at 300m away from 220 kV GIS Substation (With 1 Surge Arrester at OHTL end)– measured at GIS terminal end of the GIS Network

Case	**Case Details**	**Measured Voltage at 220kV GIS end (kV_p)**			
		End 1	**End 2**	**End 3**	**End 4**
CASE 1.B.2	220kV Surge Arrestor only at 220 GIS Incoming	458.83	458.73	457.76	457.71

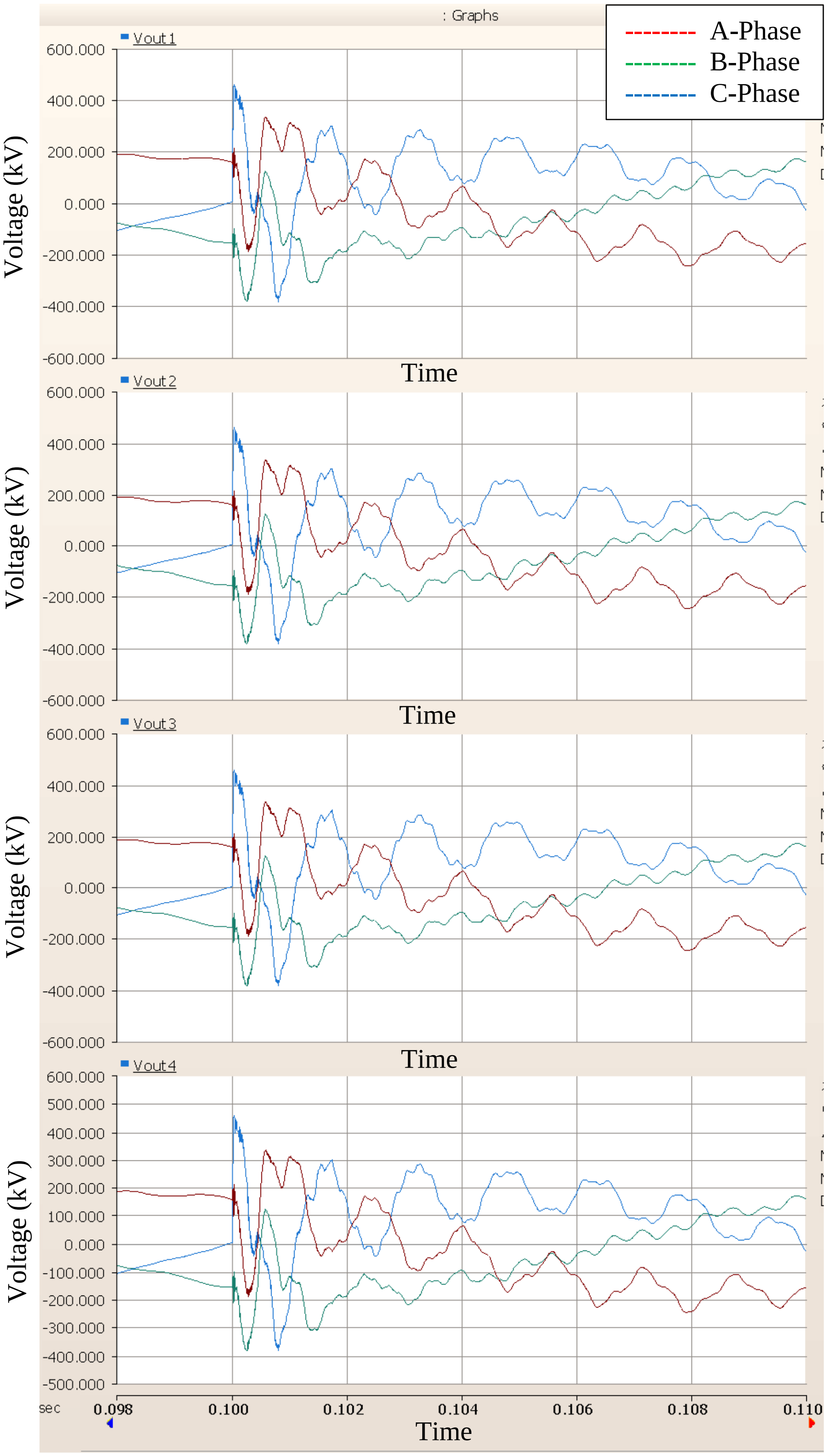


Fig. 7.10. Maximum Fast transient overvoltages at GIS end due to Direct strike case with 1 Surge arrester at OHTL end

Result: Case 1.B.3

As mentioned above , after simulation of the Back flashover of LIOV study on this 220kV GIS network we obtained below results as mentioned in Table 7.12 and Table 7.13 for Case No. 1B.3 with 2 Surge Arresters at both OHTL & GIS terminal end. Which already showing that by installing only 2 surge arresters at OHTL & GIS end successfully propagate the LIOV and optimum solution for this study. Fig.7.11 and Fig.7.12 shows the maximum fast transient overvoltages due to Direct strike case with 2 Surge arresters at OHTL end and GIS end then measuring the overvoltages in both OHTL end and GIS end respectively .

Table 7.12 CASE 1.B.3 Results of Direct Lightning Over-Voltage Study For 220 kV OHL –20 kA, 1.2/50 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (With 2 Surge Arresters at OHTL & GIS End)– measured at OHTL terminal end of the GIS Network

Case	**Case Details**	**Measured voltages at 220kV OHTL terminal (kVp)**	
		End 1	**End 2**
CASE 1.B.3	220 kV Surge Arrestor only at 220 GIS Incoming & Outgoing	414.65	416.08

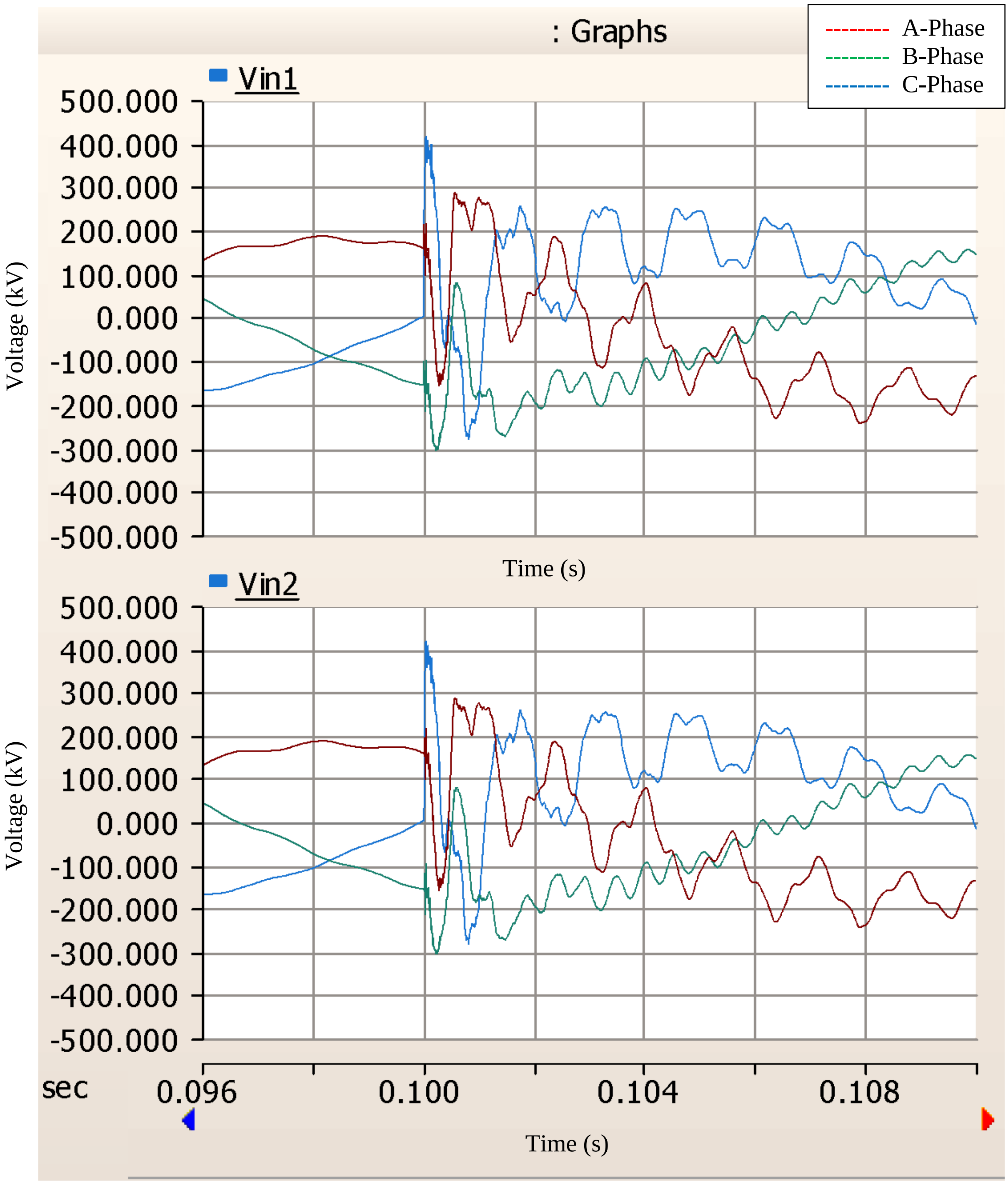


Fig. 7.11 Maximum Fast transient overvoltages at OHTL end due to Direct strike case with 2 Surge arresters at OHTL & GIS end

Table 7.13 CASE 1.B.3 Results of Direct Lightning Over-Voltage Study For 220 kV OHL –20 kA, 1.2/50 µs Wave, Applied on 220 kV tower at 300m away from 220 kV GIS Substation (With 2 Surge Arresters at OHTL & GIS End)– measured at GIS terminal end of the GIS Network

Case	**Case Details**	**Measured Voltage at 220kV GIS end (kV_P)**			
		End 1	**End 2**	**End 3**	**End 4**
CASE 1.B.3	220kV Surge Arrestor only at 220 GIS Incoming & Outgoing	416.28	416.23	415.96	415.98

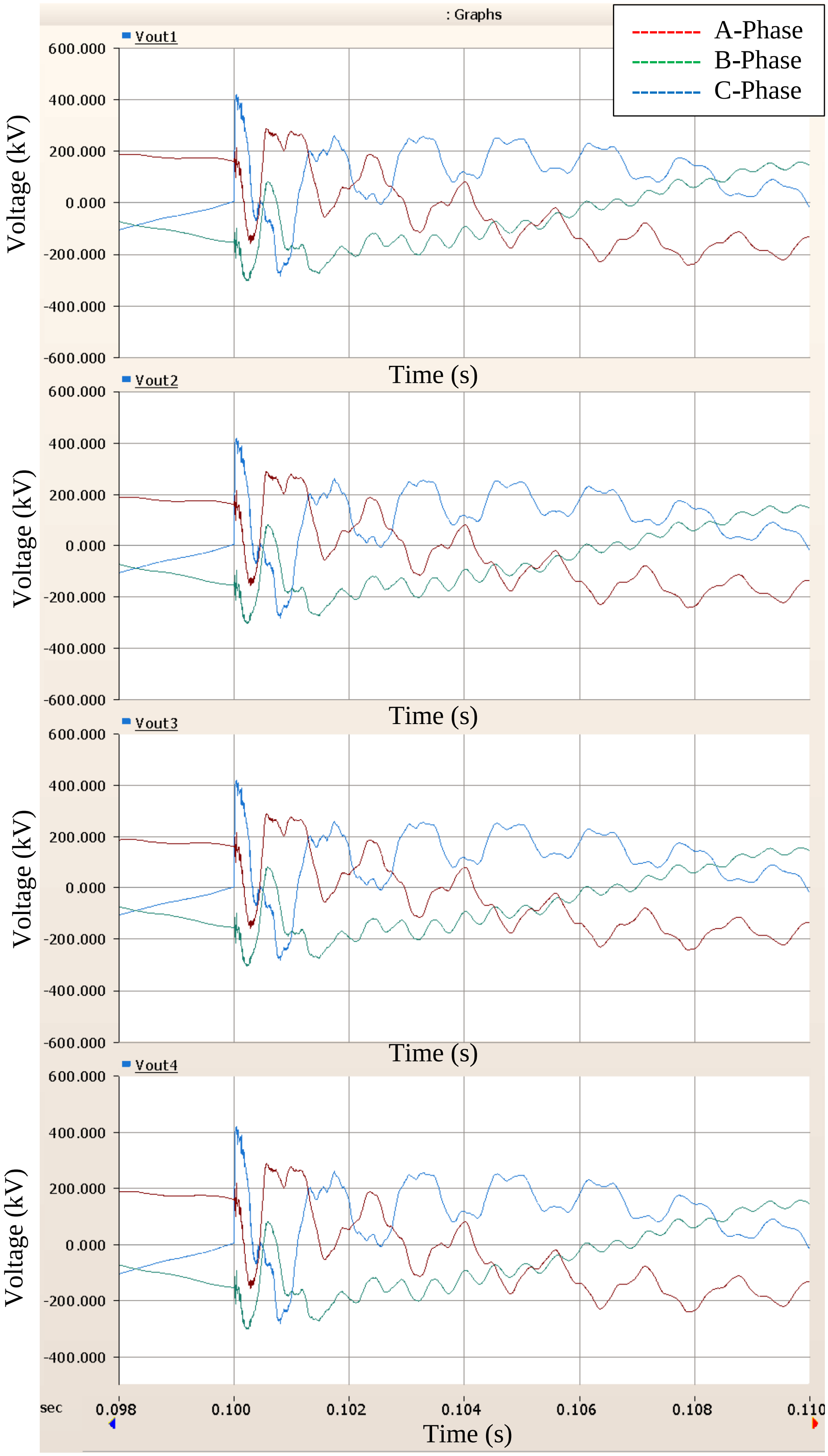


Fig. 7.12 Maximum Fast transient overvoltages at GIS end due to Direct strike case with 2 Surge arresters at OHTL & GIS end

Table 7.14 Lighting Surge transferred to system due to Lightning strike without Surge arrester

Measured Overvoltage (location)	Reference Voltage (kV)	Overvoltage due to Direct Strike	Overvoltage due to BackFlash	Withstand BIL
On gantry	220	1473.4	1451.9	1050
Entry of Substation	220	1473.7	1451.2	1050
Bus Section of GIS	220	1473.9	1450.3	1050
At the end of GIS	220	1472.6	1449.6	1050
220 kV HV side of TR	220	1472.9	1451.3	1050
132 kV LV side of TR	132	1011.6	1000.3	650
11 kV TV side of TR	11	988.3	967.8	95

Table 7.15 Lighting Surge transferred to system due to Lightning strike with Surge Arrester

Measured Overvoltage (location)	Reference Voltage (kV)	Overvoltage due to Direct Strike	Overvoltage due to BackFlash	Withstand BIL
On gantry	220	456.3	416.9	1050
Entry of Substation	220	458.7	415.3	1050
Bus Section of GIS	220	457.3	415.1	1050
At the end of GIS	220	456.8	415.7	1050
220 kV HV side of TR	220	456.2	414.3	1050
132 kV LV side of TR	132	170.3	165.3	650
11 kV TV side of TR	11	33.6	32.5	95

The 220 kV Grid side lightning application cases 1A to 1B studied in the report demonstrate that –

- Without surge arresters at 220kV, the GIS system magnitude of lightning over-voltages in the BLPC system are found to exceed the allowable 220kV BIL limits as stated in results of this report.
- With surge arresters provided on the 220kV OHL End (nearest to the GIS) which is optimum place for this study case. the magnitude of lightning impulse over-

voltages seen on the GIS 220 kV voltages are safely within the corresponding 220kV equipment BIL limits.

7.3 220 kV GIS CABLE SWITCHING STUDIES

Cable switching transient studies refer to transients caused by switching of circuit breakers under normal circuit energizing or reclosing.

The current drawn by a cable (capacitance) will directly rely on the instantaneous voltage at which it was closed when it is connected to a source voltage with inductive internal reactance. Inrush current will grow gradually from zero if CB/ switch is closed at voltage zero crossing.

High capacitive current flowing via the source's internal inductive reactance when CB is closed at the voltage peak might cause high transient switching over voltages. Voltage increase across capacitance is caused by a high capacitive leading current across the source inductance.

Transient over voltages and over currents are mostly produced at the point of switching on the voltage wave. In this regard, the following features for energizing capacitive circuits may be noted:

- The biggest capacitive inrush current and thus the highest over voltages result from turning on the cable at the peak of the voltage wave.

- The lowest inrush current and lowest over voltages—both of which appear to be under control—are produced when the cable is turned on at the zero point of the voltage wave.

However, complicated networks with greater source impedance and numerous system inductances and capacitances may differ from this. It's possible that the worst wave point won't always be at the voltage wave's peak.

The effect of cable energizing can be further exacerbated by the presence of trapped charges in the cable, which can result in higher over-voltages if switched ON at unfavourable point on the voltage wave[25].

Table 7.14 shows the results of the Cable switching Study for Energization condition of 220kV, 1000m cable without any trapped charge of previous switching. And Table 7.15 shows the results of the cable switching Study for De-Energization condition and after Switching on the breaker we get the result Table 7.16 which shows Cable switching Study for Re-

Energization condition with trapped charge, but as we have placed 2 surge arresters at the optimum place of this GIS network, all these switching values are in acceptable BSL limit. Fig. 7.13 and Fig.7.14 shows maximum switching overvoltages at GIS Sending end and receiving end due to Energization without Trapped charge and inrush current in Fig.7.15.

Table 7.16 CASE 2.A Results of Cable Switching Study - Energization Of 220kV,1000m Cable Without Trapped Charge

Case	Details	Parameters measured during switching transient analysis				Remarks
		Maximum Cable Sending End Voltage	Maximum Cable Receiving End Voltage	Inrush Current	BSL Limit for 220kV System	
		(kV$_p$)	(kV$_p$)	(kA$_p$)	(kA$_p$)	
CASE 2A1.1	Energization of 220kV,1000 meter cable without trapped charge	230.4	370.8	5.49	551.25	Within BSL Limits.

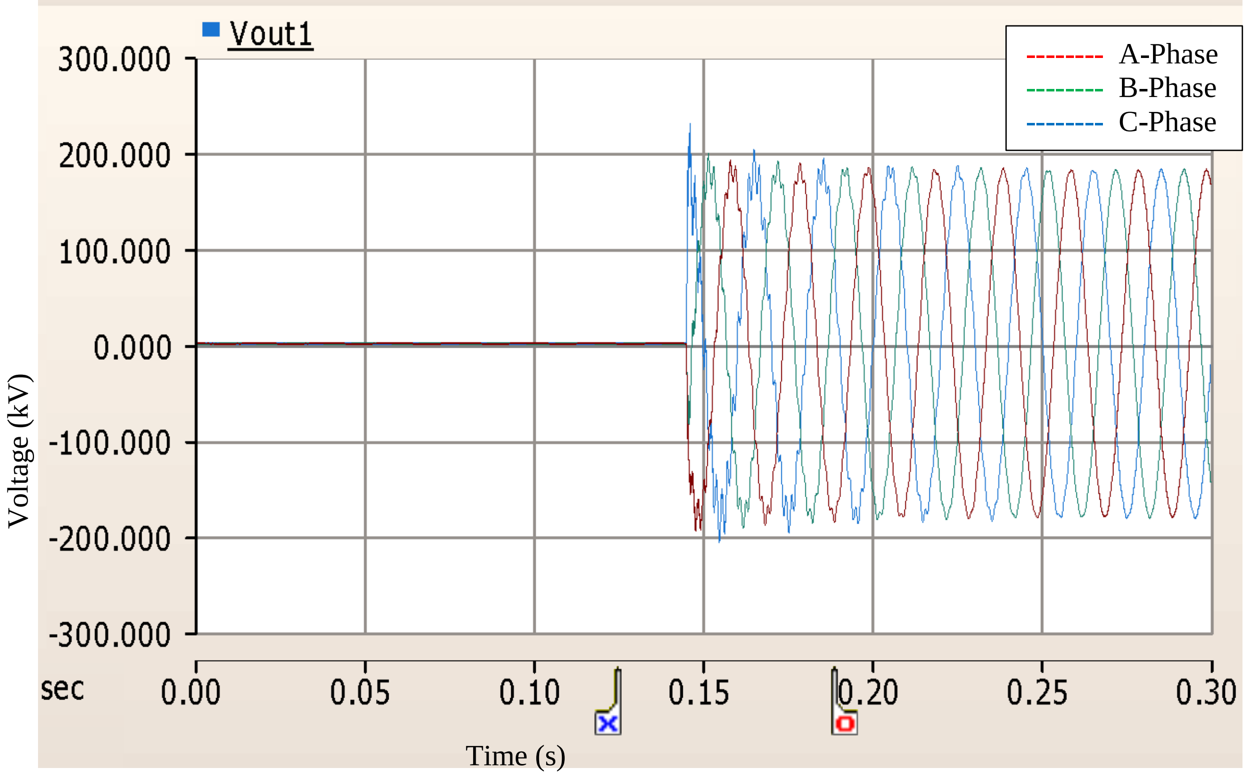


Fig. 7.13 Maximum Switching overvoltages at GIS Sending end due to Energization without Trapped charge

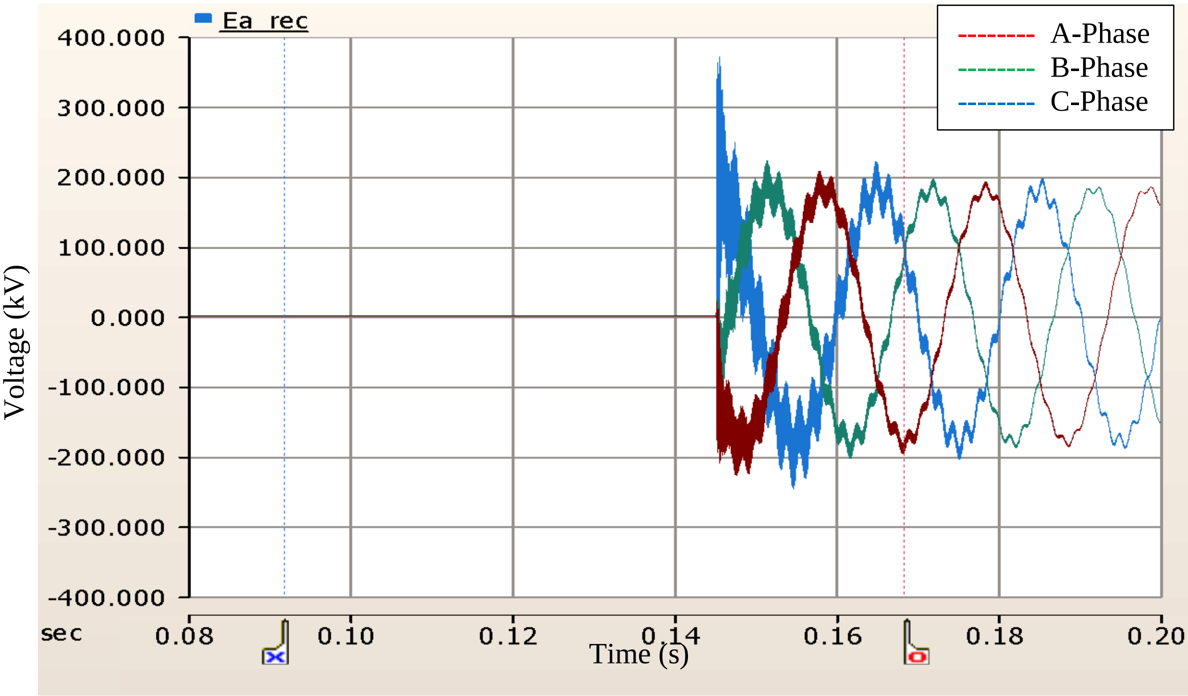


Fig. 7.14 Maximum Switching overvoltages at GIS Receiving end due to Energization without Trapped charge

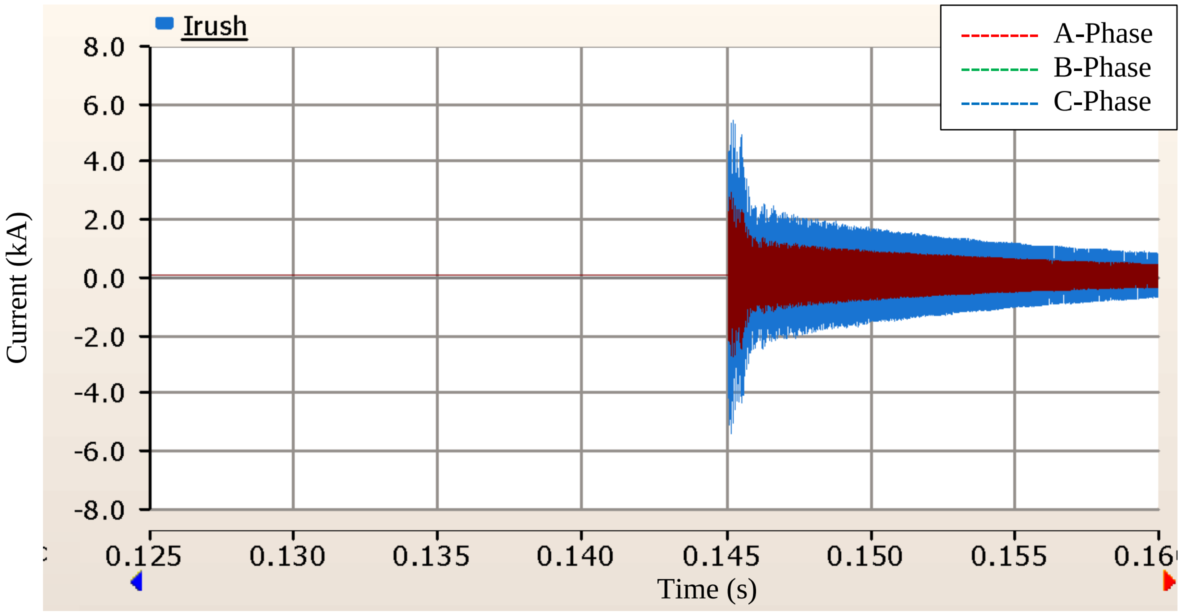


Fig. 7.15 Maximum Inrush Current at GIS due to Energization without Trapped charge

Fig. 7.16 and Fig.7.17 shows maximum switching overvoltages at GIS Sending end and receiving end due to De-energization without Trapped charge and inrush current in Fig.7.18.

Table 7.17 CASE 2.B Results of Cable Switching Study – De Energization Of 220kV,1000m Cable Without Trapped Charge

Case	Details	Parameters measured during switching transient analysis				Remarks
		Maximum Cable Sending End Voltage	Maximum Cable Receiving End Voltage	Inrush Current	BSL Limit for 220kV System	
		(kV_p)	(kV_p)	(kA_p)	(kA_p)	
CASE 2A1.2	De-energization of 220kV,1000 meter cable	181.9	184.6	0.011	551.25	Within BSL Limits.

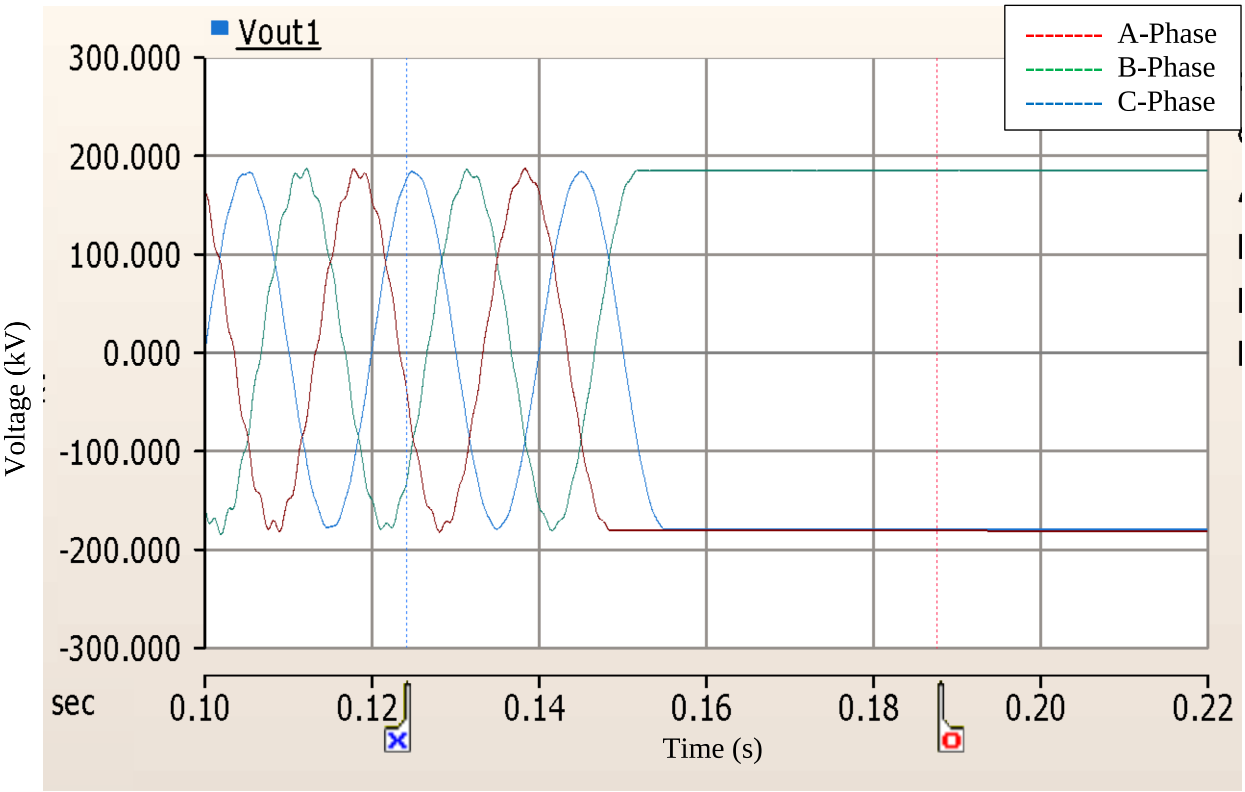


Fig. 7.16 Maximum Switching overvoltages at GIS Sending end due to De Energization without Trapped charge

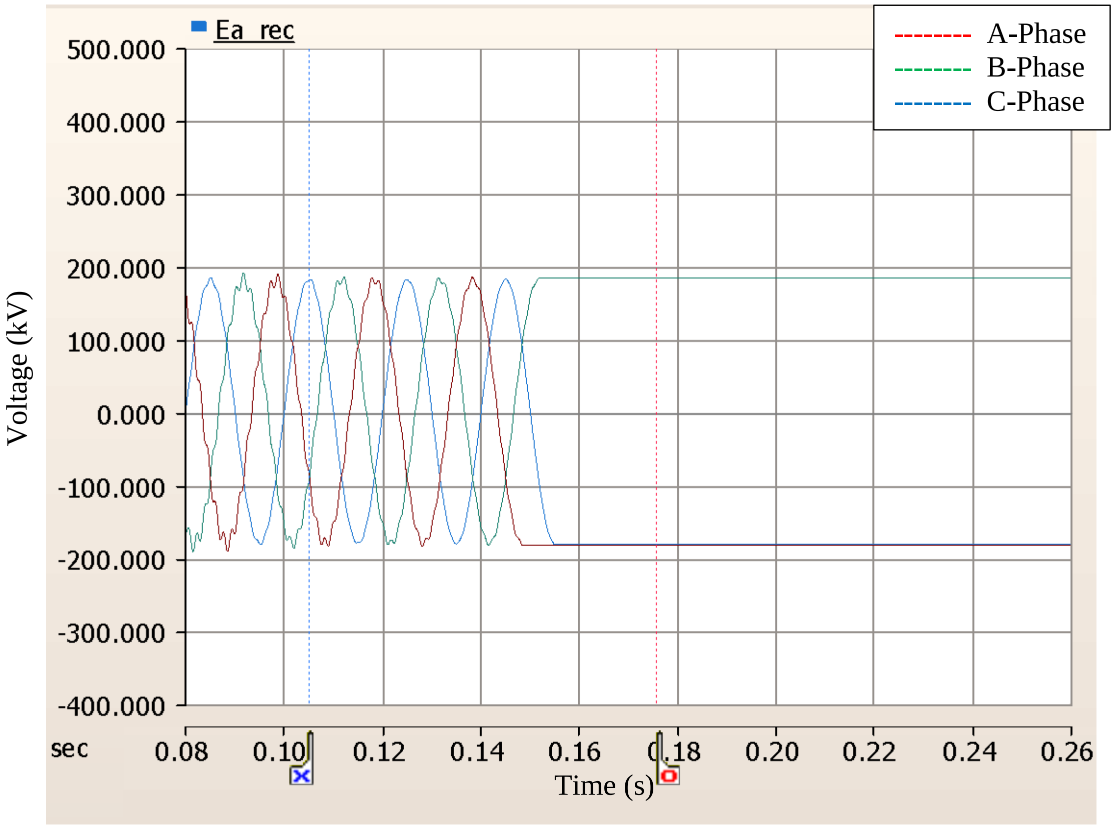


Fig. 7.17 Maximum Switching overvoltages at GIS Receiving end due to De-Energization without Trapped charge

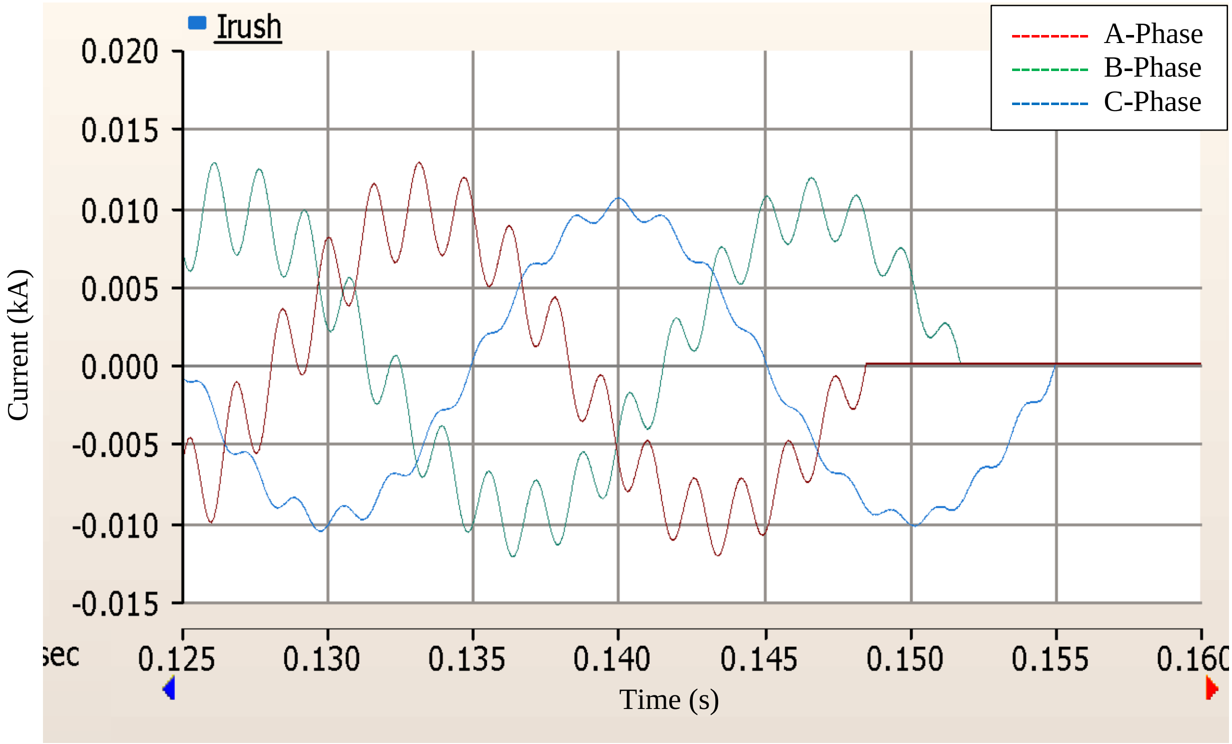


Fig. 7.18 – Maximum Inrush Current at GIS due to Energization without Trapped charge

Fig. 7.19 and Fig.7.20 shows maximum switching overvoltages at GIS Sending end and receiving end due to Re-energization with Trapped charge.

Table 7.18 CASE 2.C Results of Cable Switching Study – Re Energization Of 220kV,1000m Cable With Trapped Charge

Case	Details	Parameters measured during switching transient analysis				Remarks
		Maximum Cable Sending End Voltage	Maximum Cable Receiving End Voltage	Inrush Current	BSL Limit for 220kV System	
		(kV_p)	(kV_p)	(kA_p)	(kA_p)	
CASE 2A1.3	Re-energization of 220kV,1000 meter cable with trapped charge	183.5	417.5	7.5	551.25	Within BSL Limits.

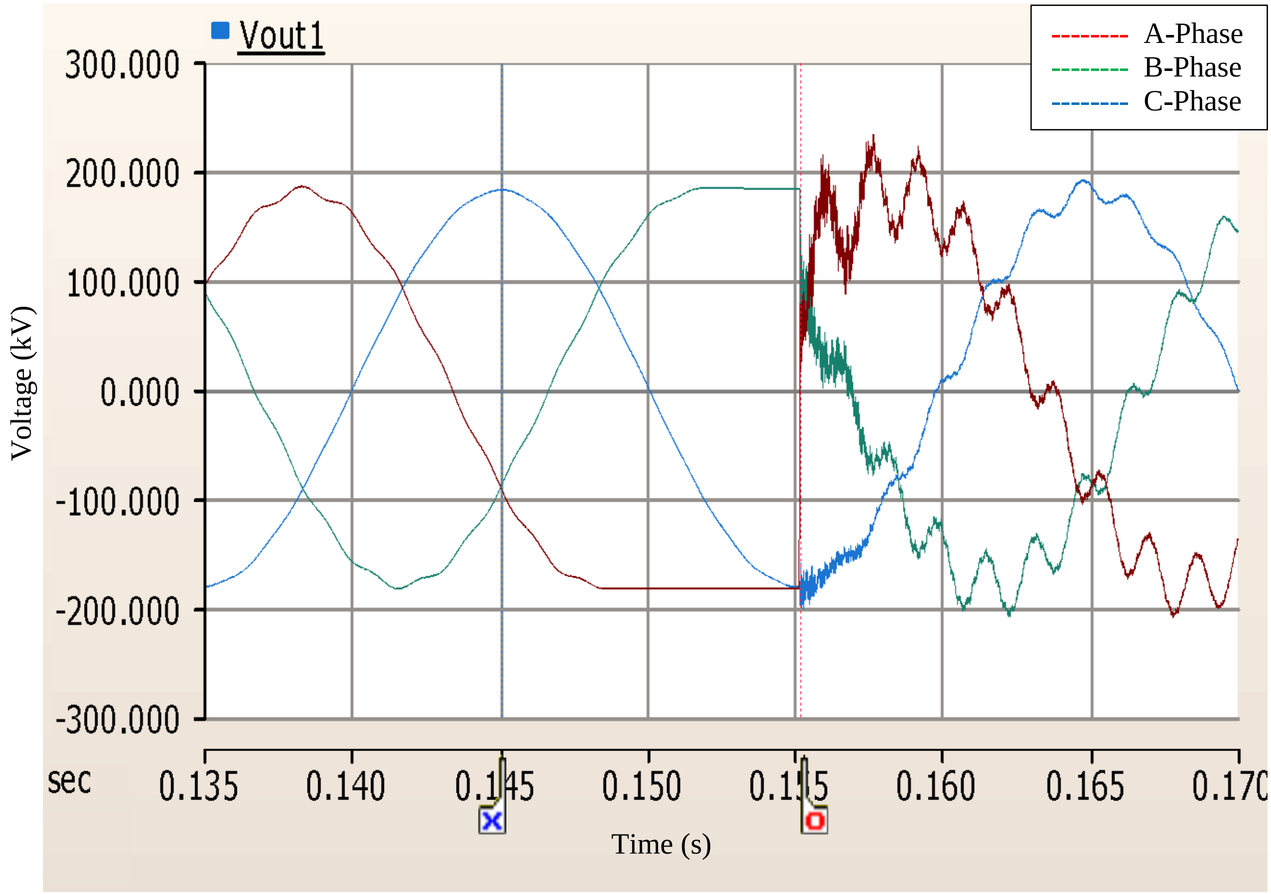


Fig. 7.19 Maximum Switching overvoltages at GIS Sending end due to Re-Energization with Trapped charge

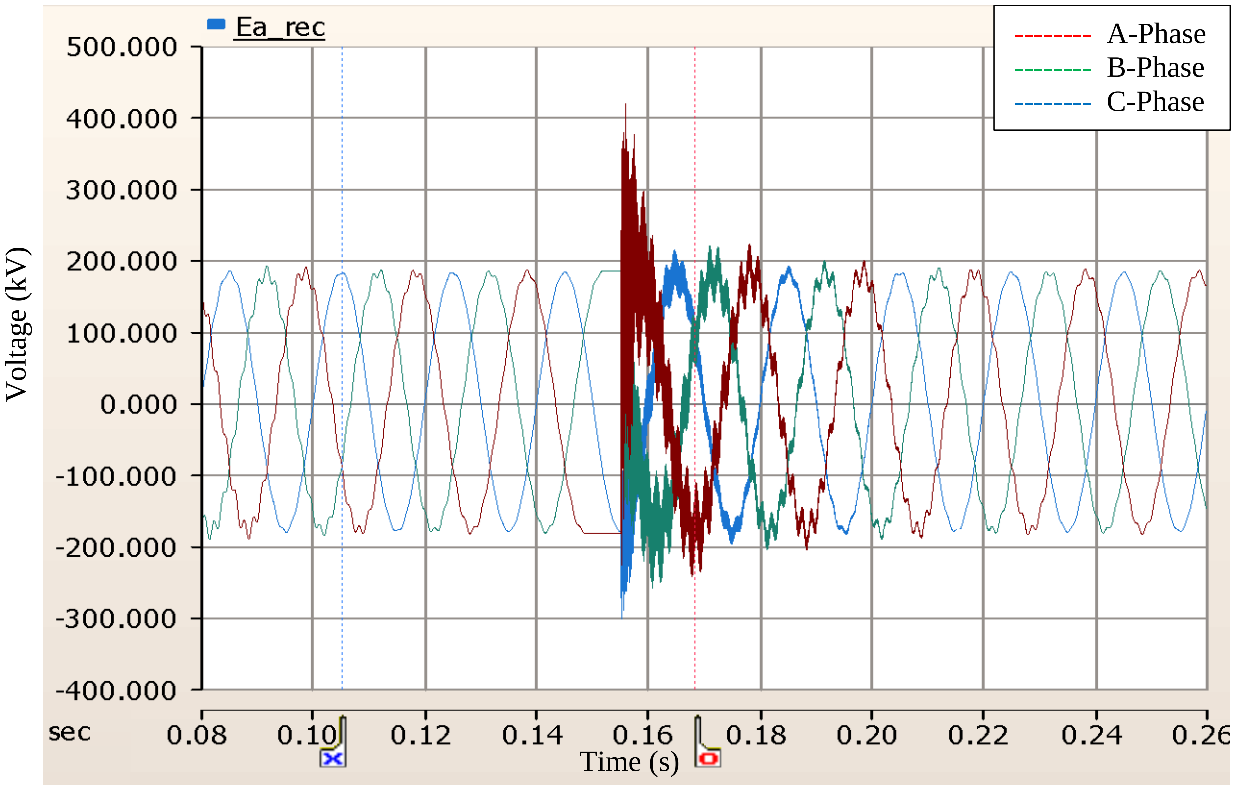


Fig. 7.20 Maximum Switching overvoltages at GIS Receiving end due to Re-Energization with Trapped charge

7.4 VFFT Due to Disconnector Switching in 220kV GIS STATION

Power system switching procedures related to GIS (Gas Insulated Switchgear) disconnector opening and shutting brought on by dielectric failures result in Very Fast Front Transient (VFFT) over voltages [1]. Due to the moving contact's relatively moderate speed during disconnector operation, several pre- or restrikes happen.

The electric field between the contacts will increase during closure as they get closer until sparking happens. Due to the sluggish working speed, the initial strike will almost always happen at the peak of the power frequency voltage. The capacitive load will then be charged to the source voltage by current passing via the spark. The spark will finally go out when the potential difference between the contacts decreases as it accomplishes this.. The behavior on opening is very nearly a complete reversal of the above description.

The behaviour of the spark in the GIS disconnecting switch during its operation has been modelled as per IEEE modelling guidelines by a fixed resistance of 0.5 ohms in series with an exponentially decreasing resistance, Rarc =R0 x e (-t/τ), with R0 = 1012 ohms and T = 1 ns, resulting in a time duration of voltage breakdown of about 10 nano-second. (As per IEEE modelling guidelines for Very Fast Transients in GIS).

These VFFT transients are distinguished by their extremely rapid rising periods, which are often measured in the nanosecond range. They are typically followed by oscillations with frequency spectra that are far above several MHz. The insulation of high-voltage equipment, such as transformer windings or bushings, can experience extreme voltage stress as a result of the VFFT overvoltages.

VFFT spread both inside and outside the GIS as traveling waves. The GIS elements should be modelled as electrical equivalent circuits made up of lumped elements as well as distributed parametric cables/lines (specified by surge impedance and travelling durations) due to the VFFT's travelling wave nature. The GIS must be separated into multiple smaller areas in order to get credible simulation results.

In its simplest form and for the purpose of Electromagnetic transient study modelling, the GIS installation can be regarded as series of distributed transmission lines and lumped capacitor elements. The values of each GIS section are taken from IEEE references.

The following case studies have been carried out to study the effects of 220 kV GIS disconnector switching. The effect of GIS disconnector switching is modelled as a variable resistor with an arcing equation (representing sparking) which is dependent on time instant of switching. Criteria for VFFT over voltage is considered as per CWW withstand criteria specified.

Fig. 7.21 and Fig.7.22 shows maximum switching overvoltages at GIS Sending end due to VFFT of Disconnectors and maximum switching overvoltages at GIS enclosure in Fig.7.23.

Table 7.19 CASE 3.A Results of Disconnector Switching Study Of 220kV Switchgear

CASE	Switchgear	Disconnector switch voltage		GIS Voltage
		Sending end	Receiving end	
3.A	220 kV GIS	312.5 kV	313.1 kV	380.5 kV

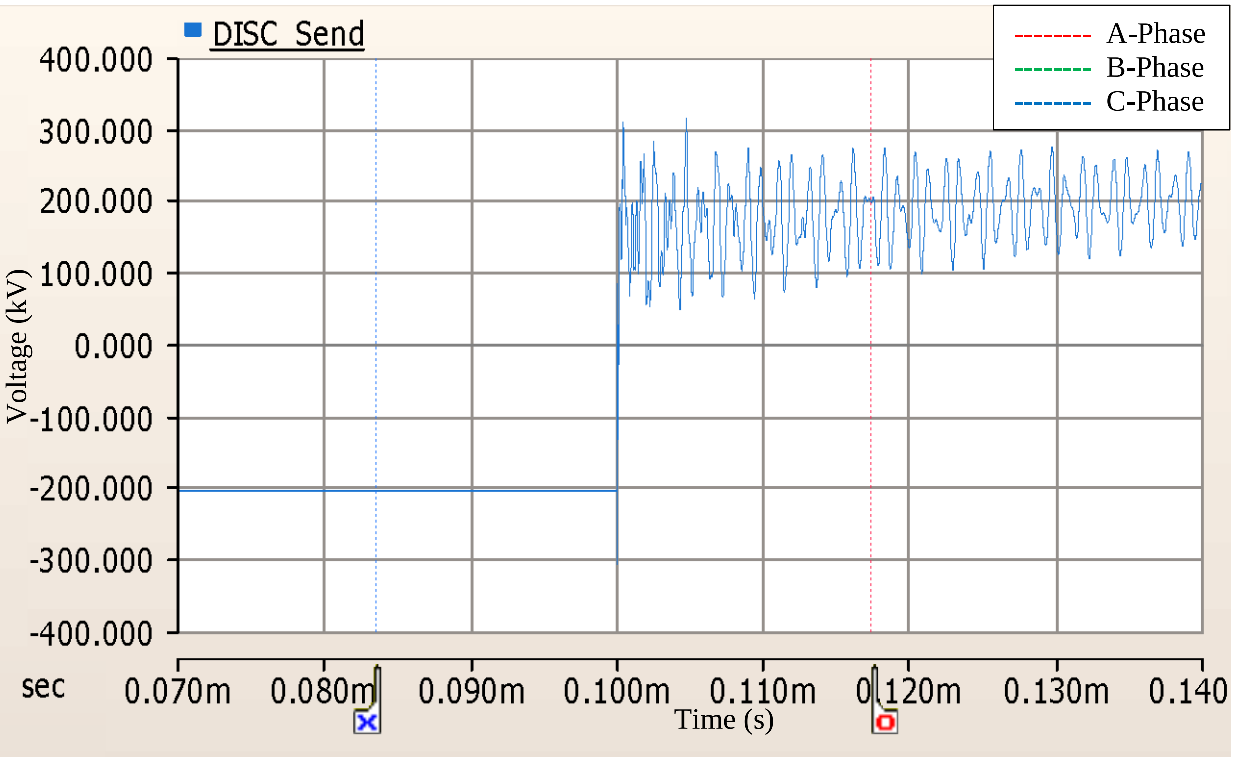


Fig. 7.21 – Maximum Switching overvoltages at GIS Sending end due to VFFT of Disconnectors

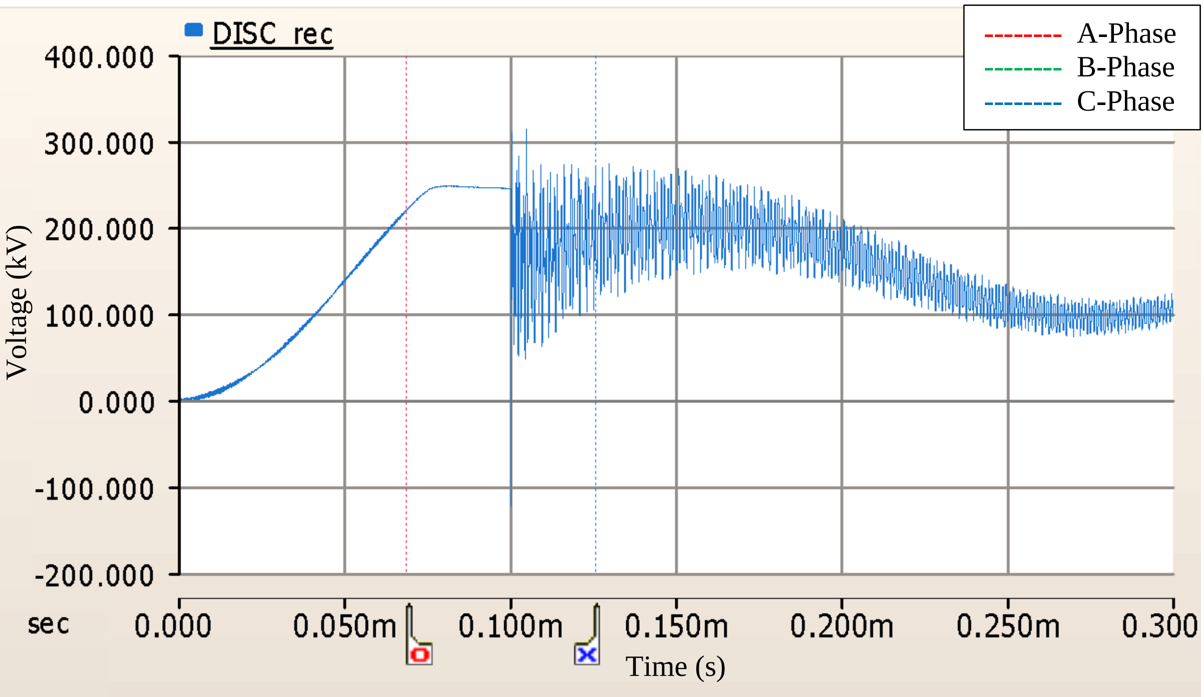


Fig. 7.22 Maximum Switching overvoltages at GIS Receiving end due to VFFT of Disconnectors

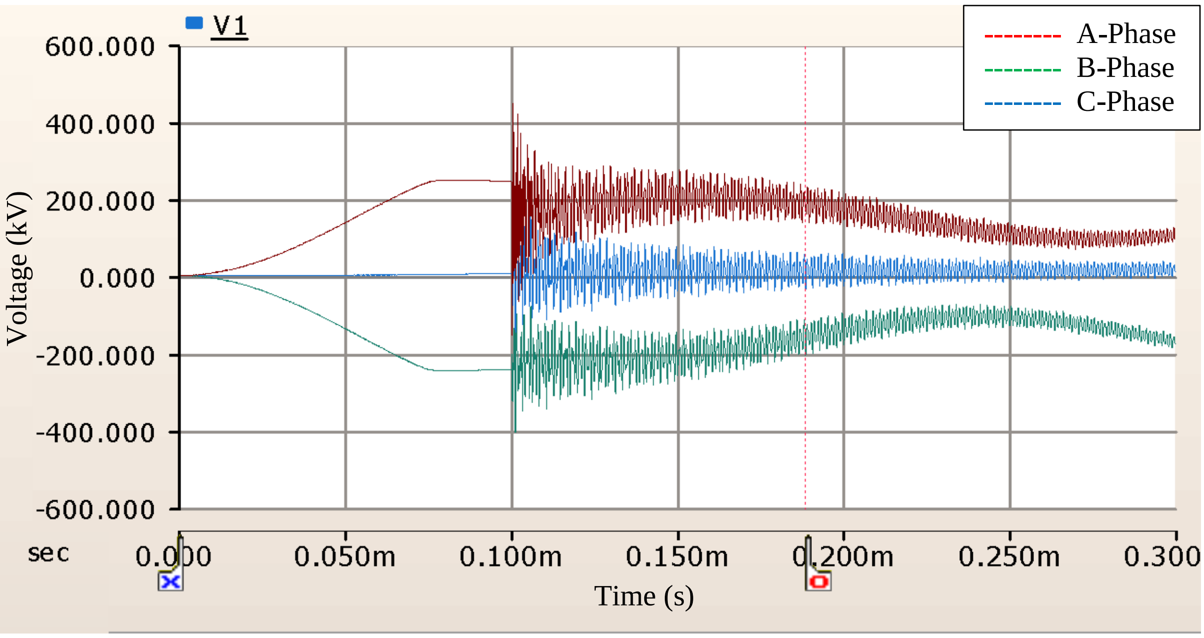


Fig. 7.23 Maximum Switching overvoltages at GIS Enclosure due to VFFT of Disconnectors

CHAPTER-8

CONCLUSIONS AND FUTURE SCOPES

8.1 CONCLUSIONS

The experimental investigations provide a concise summary of the history, key traits, and impacts of VFT on nearby equipment and substations in GIS. It has been addressed how to model GIS networks for digital simulation in VFT investigations. Three case studies served as examples of how they applied their theory. Validation studies have demonstrated that it is possible to get an excellent correlation between simulation results and field measurements, even though the recommendations suggested in this thesis omit propagation losses for many GIS components and extremely basic models are proposed for the majority of components. In some scenarios, it may be necessary to use more precise models and take into account propagation losses at extremely high frequencies.

According to lightning stroke studies, which involved injecting current of 20 kA on a phase conductor in the first tower close to the gantry of the MHR line and 100 kA on a shielding cable, it was found that voltages at various substation locations were exceeding the BIL levels at each location without using SA. In order to protect the GIS substation against direct strokes, the suggested surge arresters—one at the transmission line's gantry and one next to each HV, LV, and TV terminal of the transformer—are necessary. Studies have been done at three different locations: one close to the HV side of the transformer, one close to the Tertiary winding side, and one with a surge arrester in operation at the Gantry side (entrance of substation). Since there is adequate safety margin and the substations over voltages during direct stroke and reverse flashover are much below the BIL value, no extra surge arresters are needed at the 220 kV level. In order to shorten the route from the surge arresters to the protected units, it has been found that the protective device should be located closer to the protected equipment.

8.2 FUTURE SCOPES

In this experiment, the present work has been modelled for 220 kV Gas Insulated substations by using PSCAD software. The present work can also be extended for 1200 kV GIS by using EMTP / PSCAD software.

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