ENEL 601 Advance Power System Analysis

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Grad-Project

Department of Electrical & Computer Engineering

ENEL 601

Graduate Project

Please note that:

- You must submit the report by 11:59 PM of the specified date. Submissions up to 2 hours after the deadline has no penalty. Submissions between 2 and 12 hours after the deadline will automatically get a 15% penalty; submissions within 12 and 24 hours after the deadline will get a 25% penalty; and, submissions will be graded as zero after 24 hours passed the deadline.

There are two options for the graduate project.

A. Doing a literature review on a topic related to power systems (targeted mostly towards the thesis-based graduate students)
B. Switching Over-Voltages and Modeling of Surge Arresters using PSCAD/EMTDC (targeting mostly course-based students)

All students in the course are allowed to choose either A or B.

A. Literature Review
    a. Choose a topic from the following list and find at least 5 recent papers published in IEEE Transactions on smart grid, or IEEE Transactions on power systems, IEEE Transactions on sustainable energy.
    b. Study the papers and write a critical review of the papers within a maximum of five pages (double column, IEEE transactions paper format). It is up to you to organize your review into sections and subsection.
    c. Marking will be based on the content of the critical review of the reference papers (60%), flow and structure (20%), and formatting and editorial (20%)
    d. Topics:
        i. Stability of modern micro-grids
        ii. Load modeling (e.g., ZIP) for power systems studies
        iii. Forecasting the uncertainty of supply (e.g., wind, solar) or demand (e.g., system load, or node load)
        iv. Wide area monitoring and state-estimation of power systems
        v. Power system planning under extreme growth of variable renewables
        vi. High-Performance and Parallel computing applied to power systems studies
        vii. Integration of energy storage systems into power systems
        viii. Applications of data science and analytics, artificial intelligence, and machine to power systems
        ix. Active distribution systems operation and planning
        x. Utility of the future

B. **Switching Over-Voltages and Modeling of Surge Arresters using PSCAD/EMTDC (PSCAD)**

All voltages higher than nominal values are defined as Temporary over Voltage (TOV). TOV can be from a few cycles to several hours. From IEC standard number of 60099-1, a temporary overvoltage is: “An oscillatory phase-to-ground or phase-to-phase overvoltage at a given location of relatively long duration and which is undamped or only weakly damped. Temporary over voltages usually originate from switching operations or faults (e.g., load rejection, single phase faults) and/or from non-linearities (e.g., ferroresonance effects, harmonics). They may be characterized by their amplitude, their oscillation frequencies, their total duration or their decrement. Transient over voltages are of fundamental importance in selecting equipment insulation levels and surge-protection devices. We must, therefore, understand the nature of transmission-line transients[1].

During our study of the steady-state performance of transmission lines, the line constants R, L, G, and C were recognized as distributed rather than lumped constants. When a line with distributed constants is subjected to a disturbance such as a lightning strike or a switching operation, voltage and current waves arise and travel along the line at a velocity near the speed of light. When these waves arrive at the line terminals, reflected voltage and current waves arise and travel back down the line, superimposed on the initial waves.

Because of line losses, traveling waves are attenuated and essentially die out after a few reflections. Also, the series inductances of transformer windings effectively block the disturbances, thereby preventing them from entering generator windings. However, due to the reinforcing action of several reflected waves, it is possible for voltage to build up to a level that could cause transformer insulation or line insulation to arc over and suffer damage.

Circuit breakers, which can operate within 50 ms, are too slow to protect against lightning or switching surges. Lightning surges can rise to peak levels within a few microseconds and switching surges within a few hundred microseconds—fast enough to destroy insulation before a circuit breaker could open. However, protective devices are available, called surge arresters, which can be used to protect equipment insulation against transient over voltages. These devices limit voltage to a ceiling level and absorb the energy from lightning and switching surges[2].

The characteristic impedance or surge impedance (usually written Z0) of a uniform transmission line is determined by the geometry and materials of the transmission line and. The SI unit of characteristic impedance is the ohm. In practice, power lines are not terminated by their surge impedance. Instead, loadings can vary from a small fraction of SIL during light load conditions up to multiples of SIL, depending on line length and line compensation, during heavy load conditions. If a line is terminated by its surge impedance, then the voltage profile is flat. That is, the voltage magnitude at any point along a lossless line at SIL is constant.

In this project, the switching overvoltage is analyzed and simulated with the PSCAD software. At the first step, the impact of transmission line length and switching time on the magnitude of overvoltage is studied. Then, the application of surge arrester as a protective device is investigated to mitigate the overvoltage. Finally, the case that the transmission line is terminated

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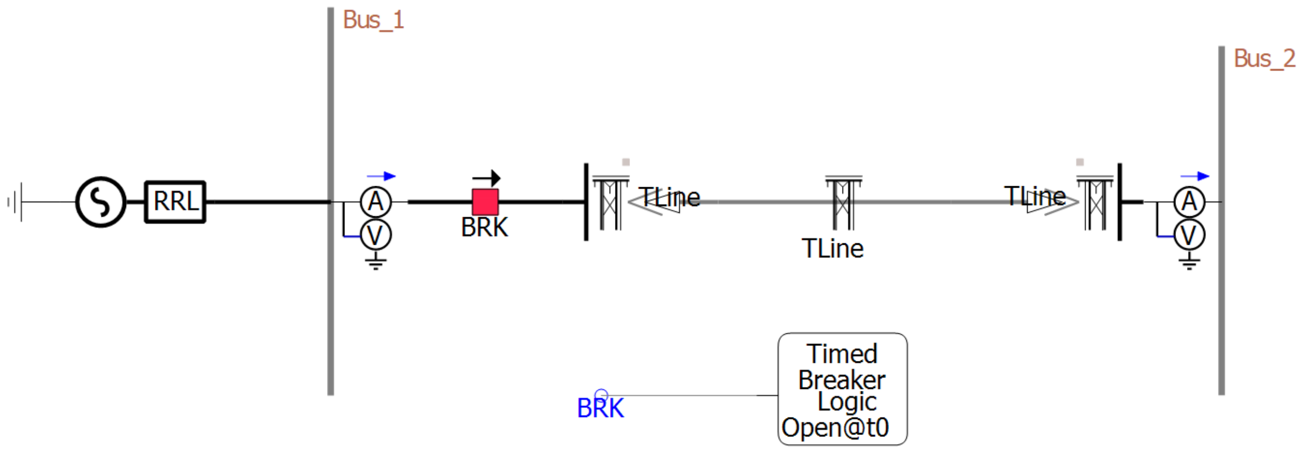
[1]Lou Van Der Sluis, *Transients in Power Systems*, Wiley, 2001, (available in the University of Calgary library)

2 Glover, J. Duncan. *Power systems analysis and design*. PWS Publishing Co., 1987, (available in the University of Calgary library)

by its surge impedance is studied and is investigated if the voltage profile remains flat in this conditions.

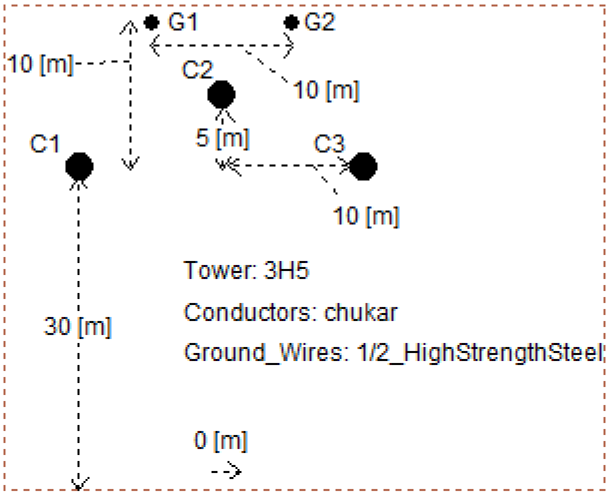
MODELING:

A simple power network is modelled in which a long transmission line connects the voltage source to the electrical load.



- The Source:
  $Magnitude(AC; L - L; RMS) = 500.00\ kV$
  $other\ values\ are\ default\ settings\ in\ the\ master\ library$

- The Transmission Line:
  $Number\ of\ Conductors = 3$
  $Transmission\ Style = remote\ end$
  $Bergeon\ Model$



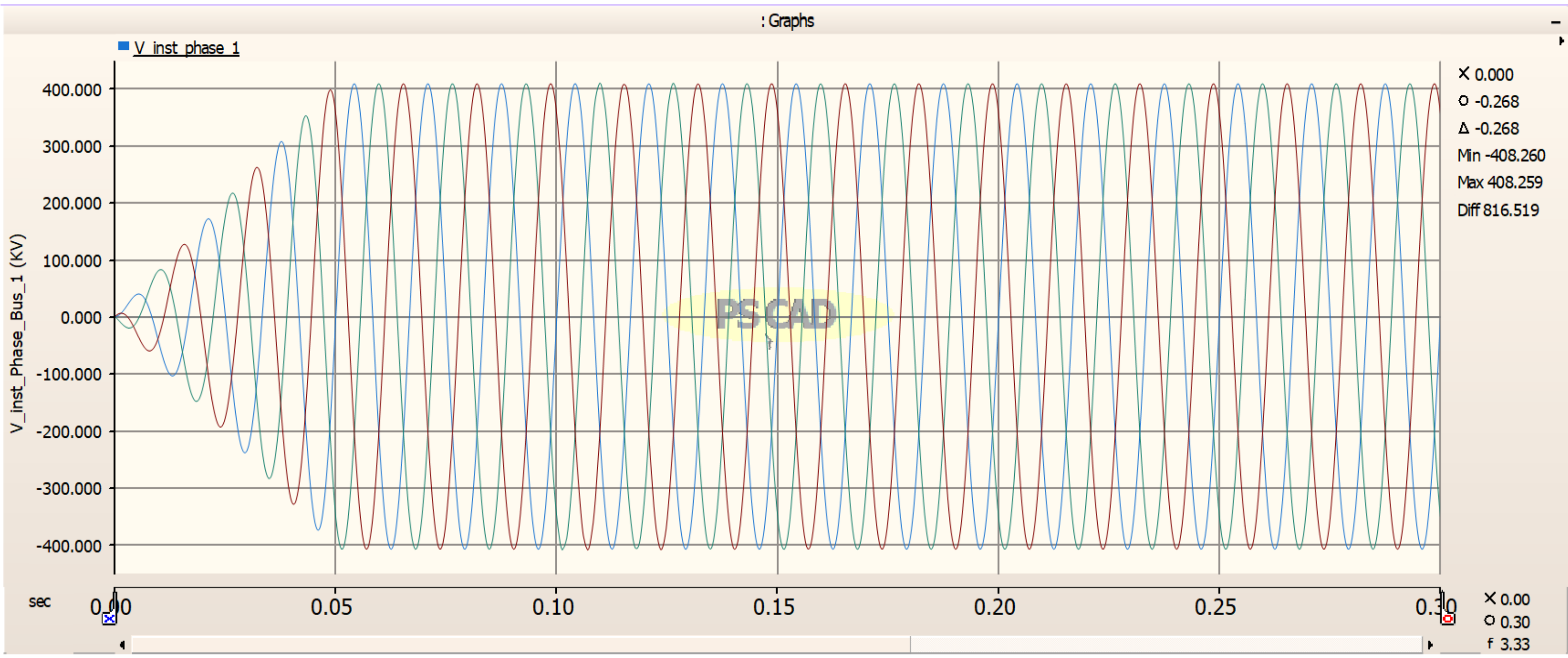
EXPERIMENTS:

1. As the first experiment, we consider an open circuit situation which means that there is no load connected at the end terminal of the transmission line. We study the effect of line length and switching time on the magnitude of overvoltage.

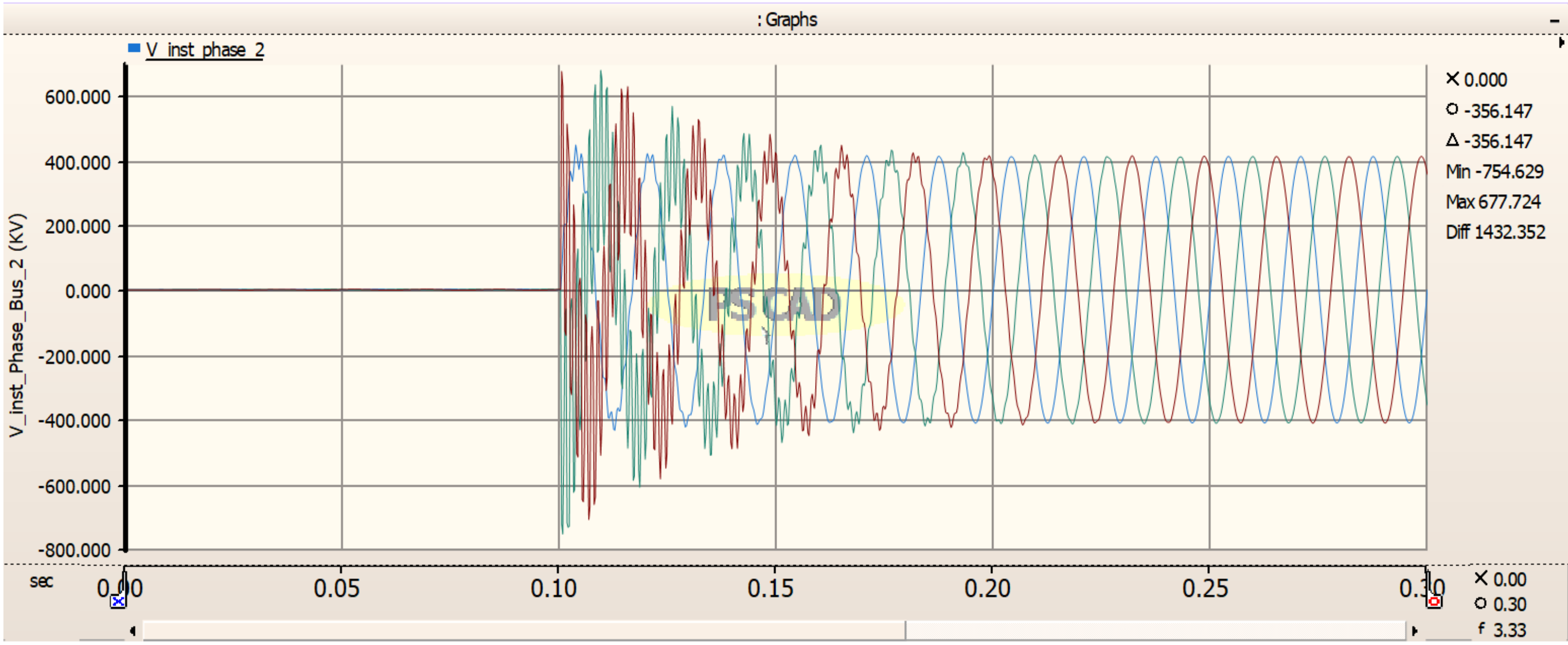
   1.1 Plot the following waveforms for $t = 0.3\ second$, when the breaker is closed at $t = 0.1\ second$ and $line\ length = 100\ km$

$$V_1, V_2, I_{line}, P_{line}, Q_{line}$$

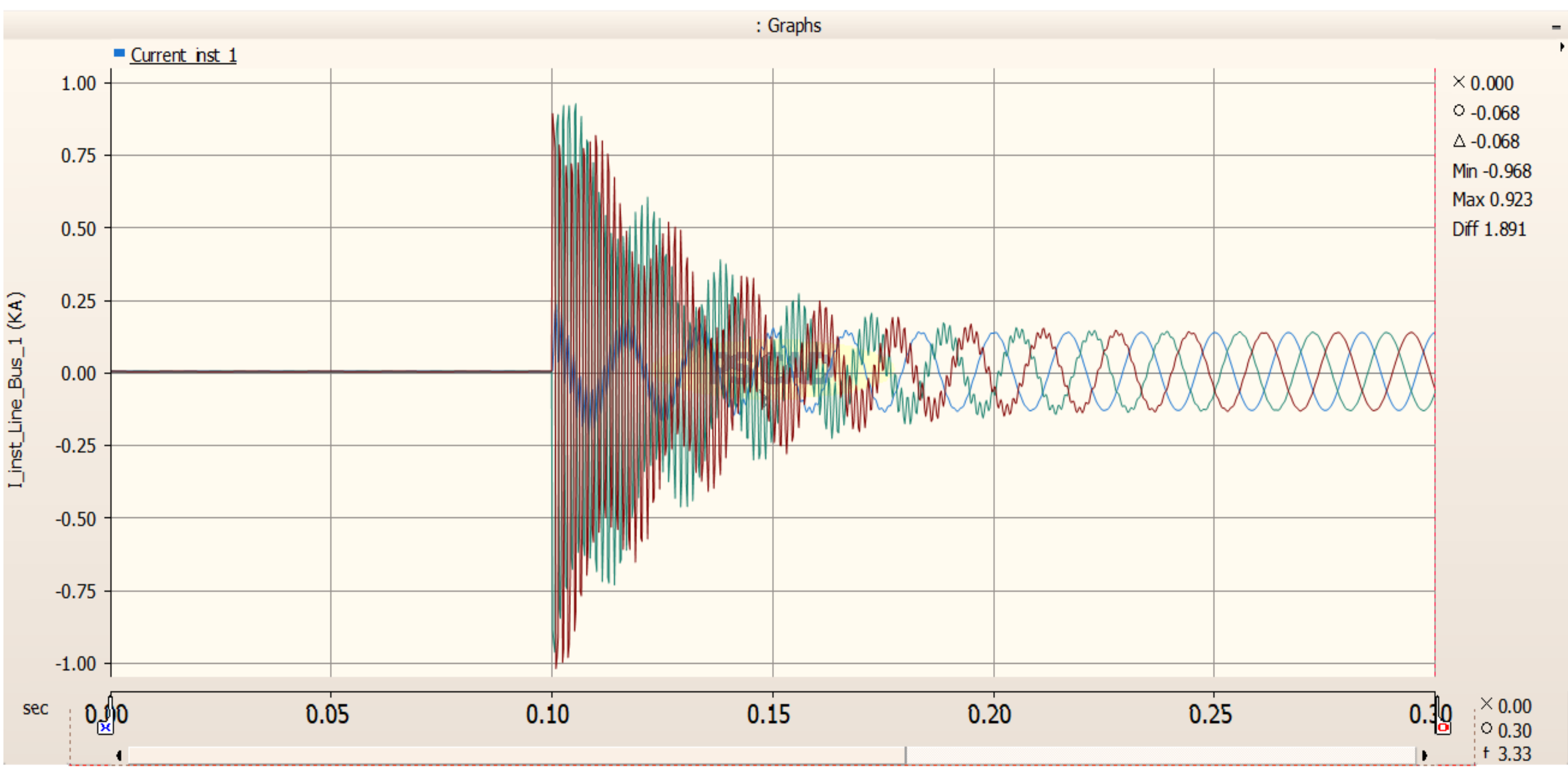
a) Voltage waveform at Bus-1 for 100 KM Transmission Line (breaker closing time = 0.1 second)



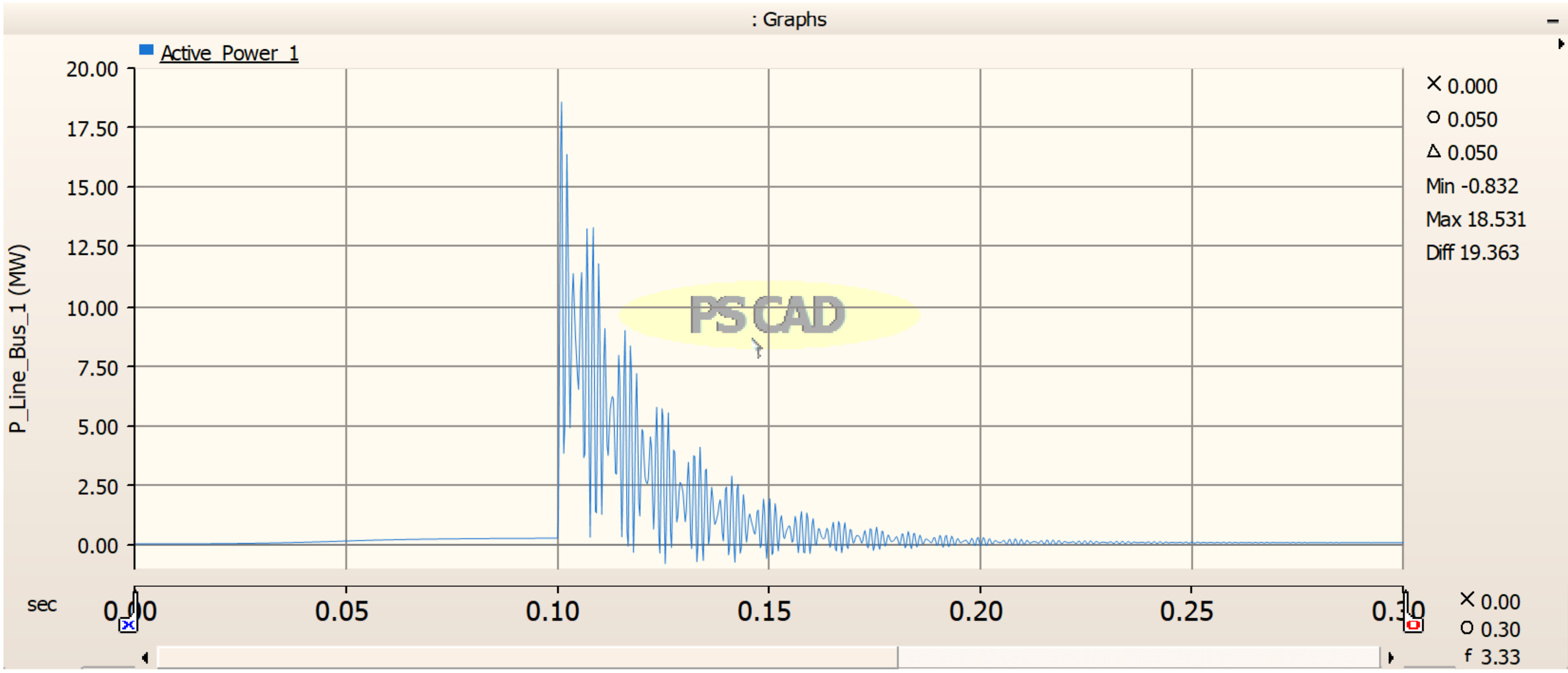
b) **Voltage waveform at Bus-2 for 100 KM Transmission line (breaker closing time = 0.1 second)**



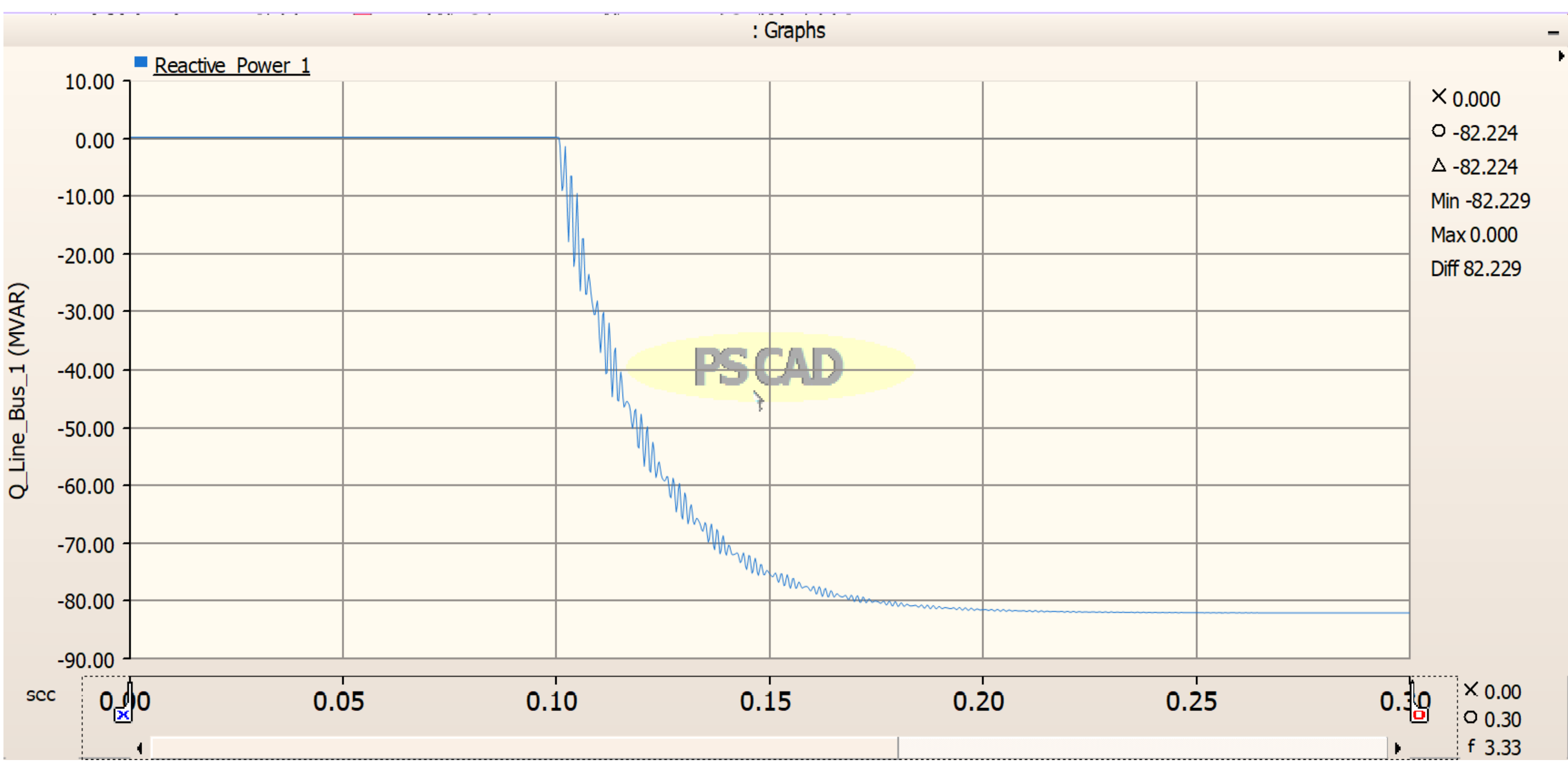
c) **Current *(I_{line})* waveform at Bus-1 for 100 KM Transmission Line (breaker closing time = 0.1 second)**



d) **Active Power *(P_{line})* waveform for 100 KM Transmission line (breaker closing time = 0.1 second)**



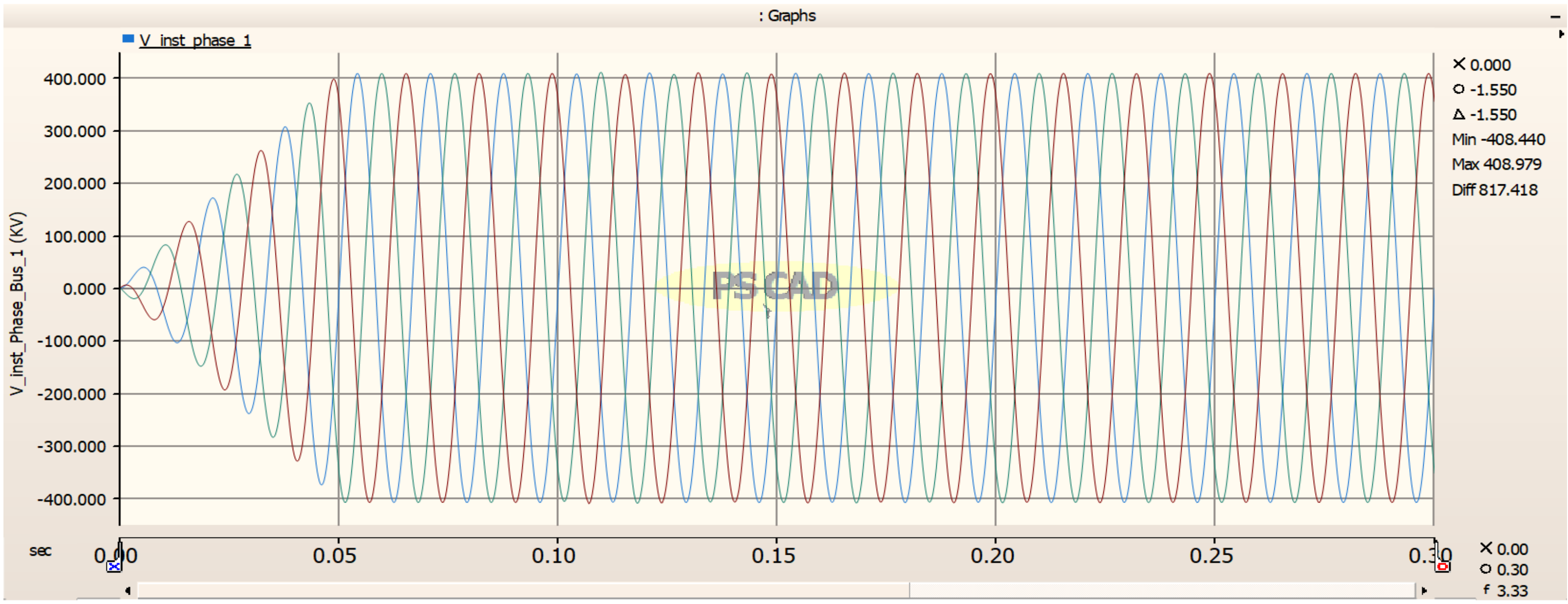
e) **Reactive Power *(Q_{line})* waveform for 100 KM Transmission line (breaker closing time = 0.1 second)**



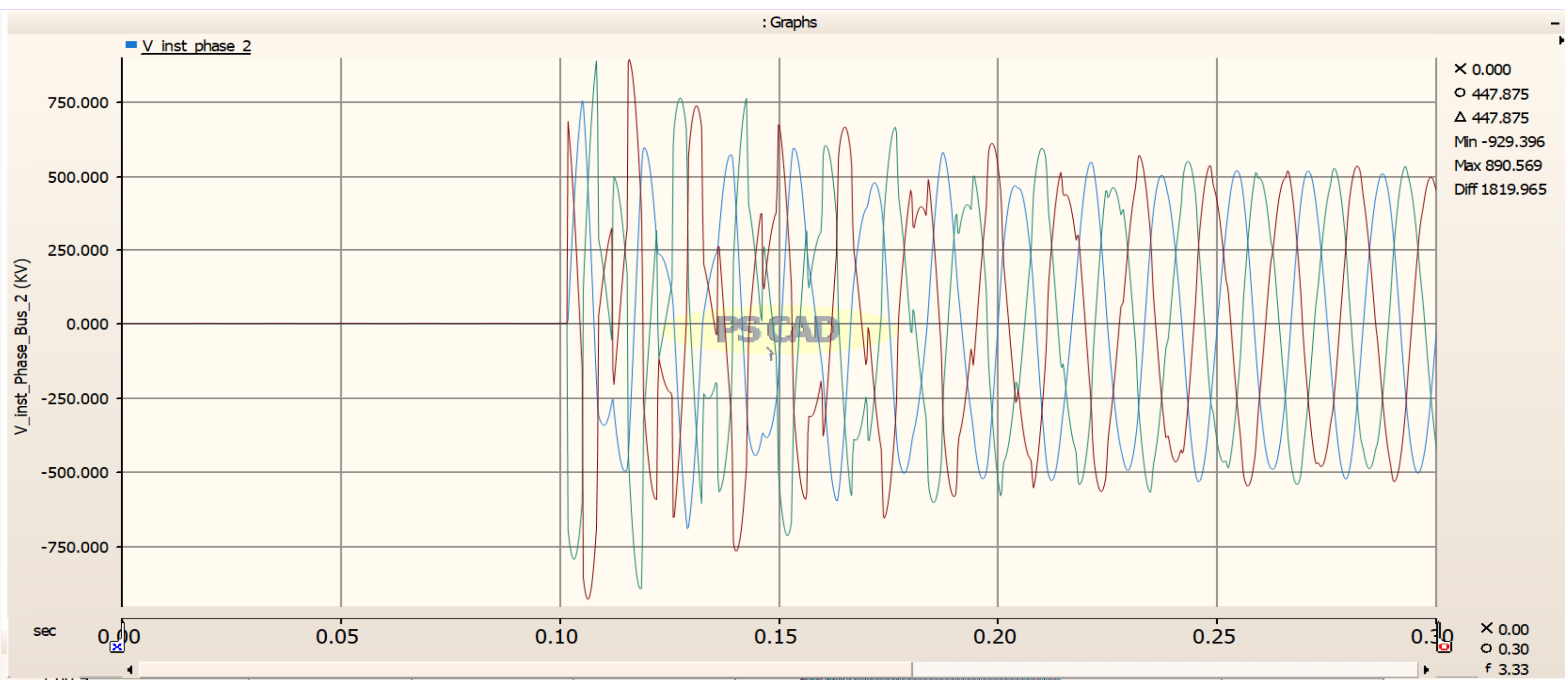
1.2 Plot the following waveforms for $t = 0.3\ second$, when the breaker is closed at $t = 0.1\ second$ and $line\ length = 500\ km$

$$V_1, V_2, I_{line}, P_{line}, Q_{line}$$

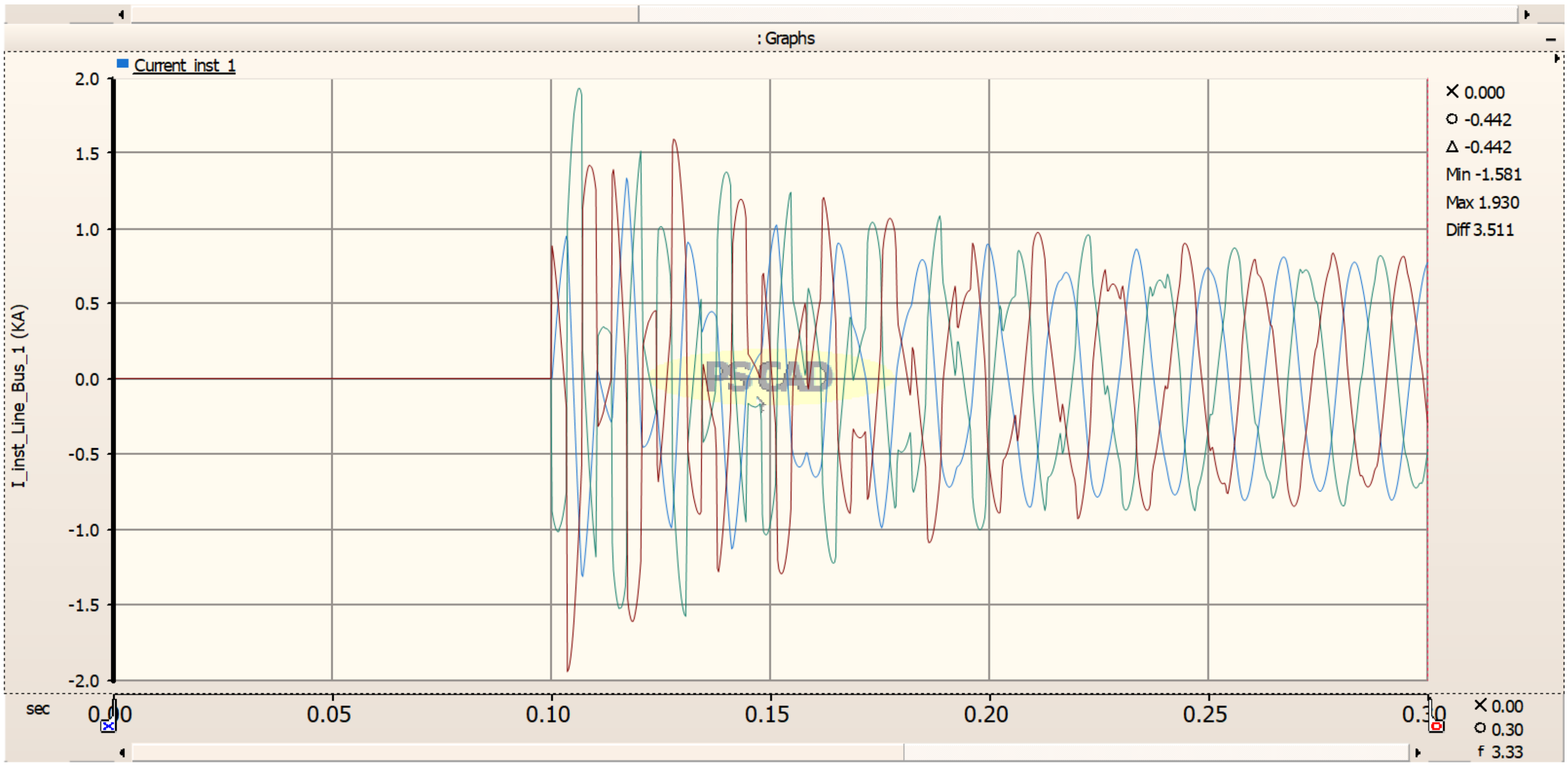
a) **Voltage waveform at Bus-1 for 500 KM Transmission line (breaker closing time = 0.1 second)**



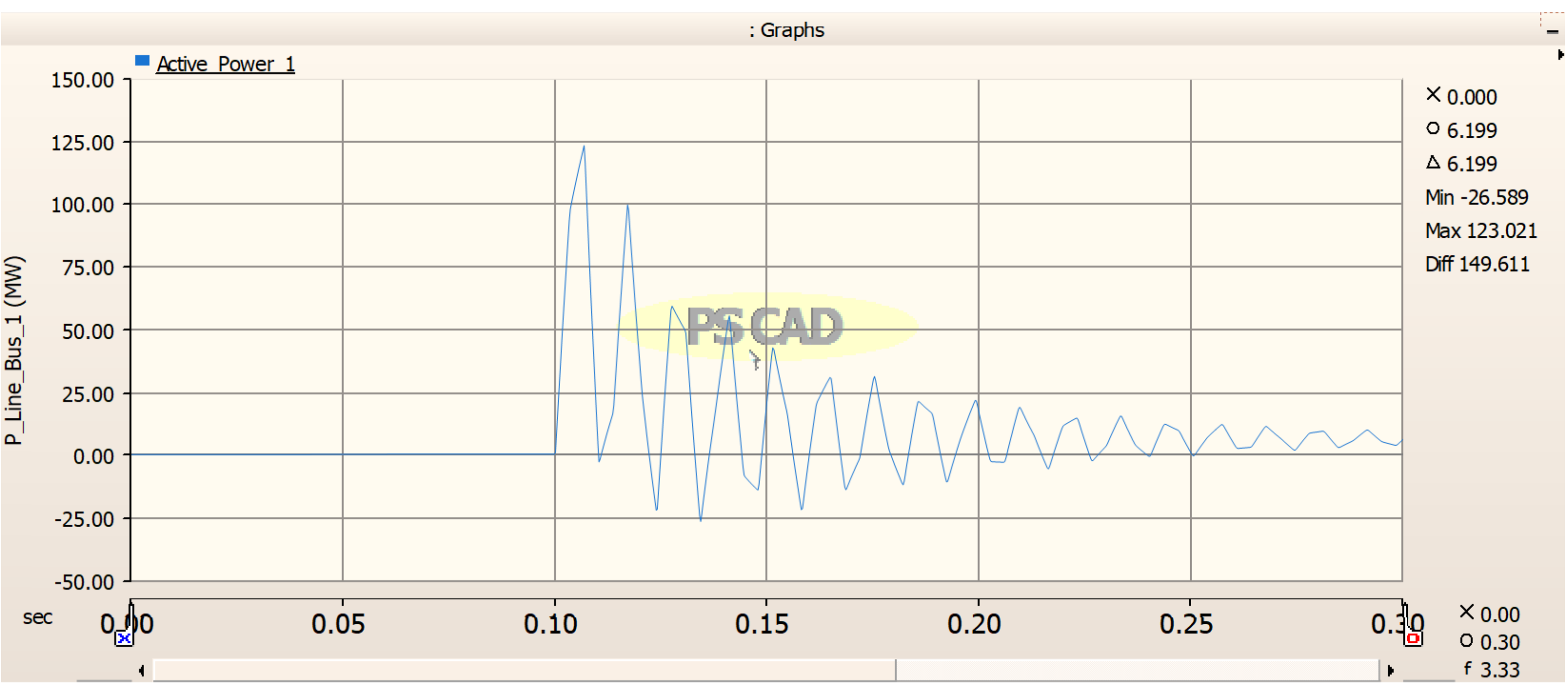
b) **Voltage waveform at Bus-2 for 500 KM Transmission line (breaker closing time = 0.1 second)**



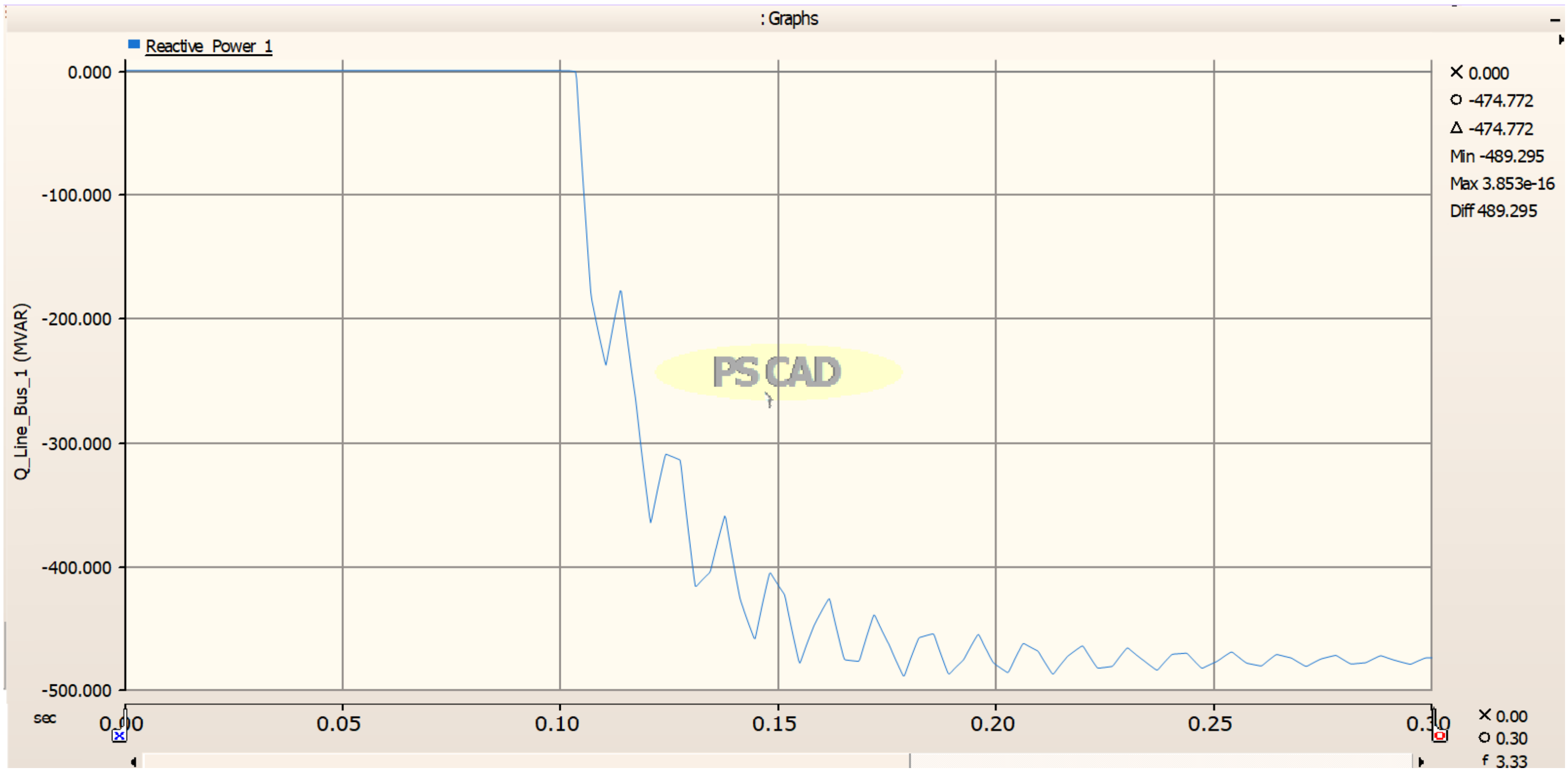
c) **Current *(I_{line})* waveform at Bus-1 for 500 KM Transmission Line (breaker closing time = 0.1 second)**



d) **Active Power *(P_{line})* waveform for 500 KM Transmission line (breaker closing time = 0.1 second)**

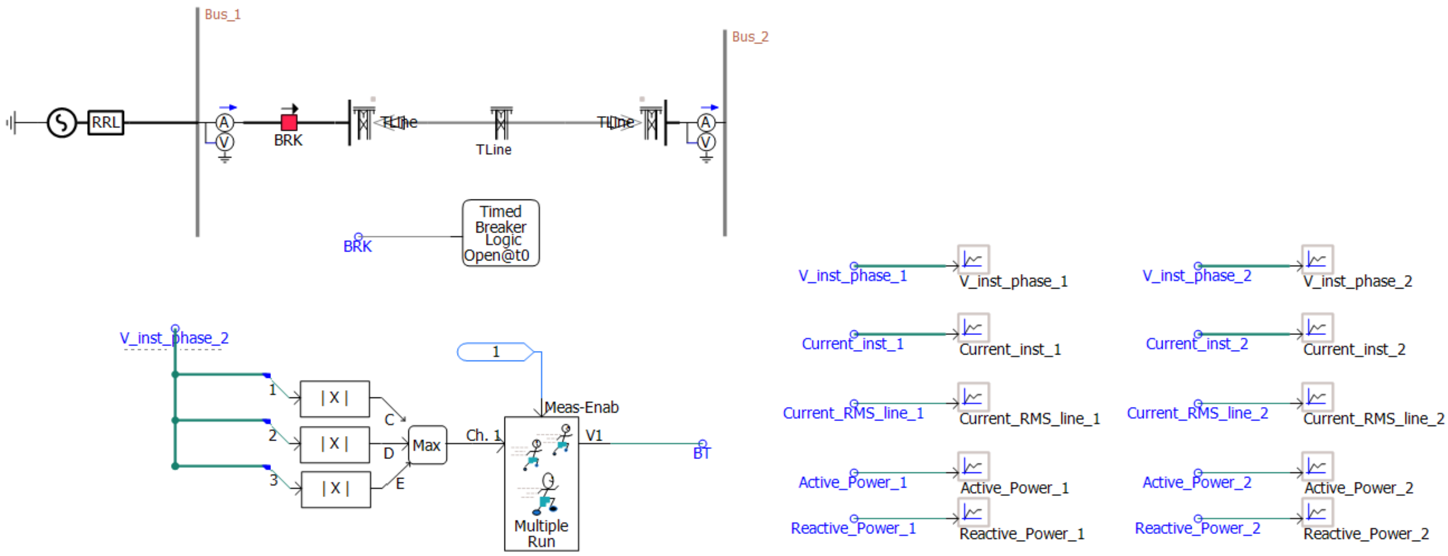


e) Reactive Power (Q_{line}) waveform for 500 KM Transmission line (breaker closing time = 0.1 second)



1.3 Find the worst case (i.e., the highest voltage) for TOV if the breaker could be closed at any time in the interval of $[0.1 - 0.5 \times cycle\,,\ 0.1 + 0.5 \times cycle]$ seconds for $line\ length = 500\ km$. Plot the waveforms of following signals during $t = 0.3\ second$ for the worst case of TOV

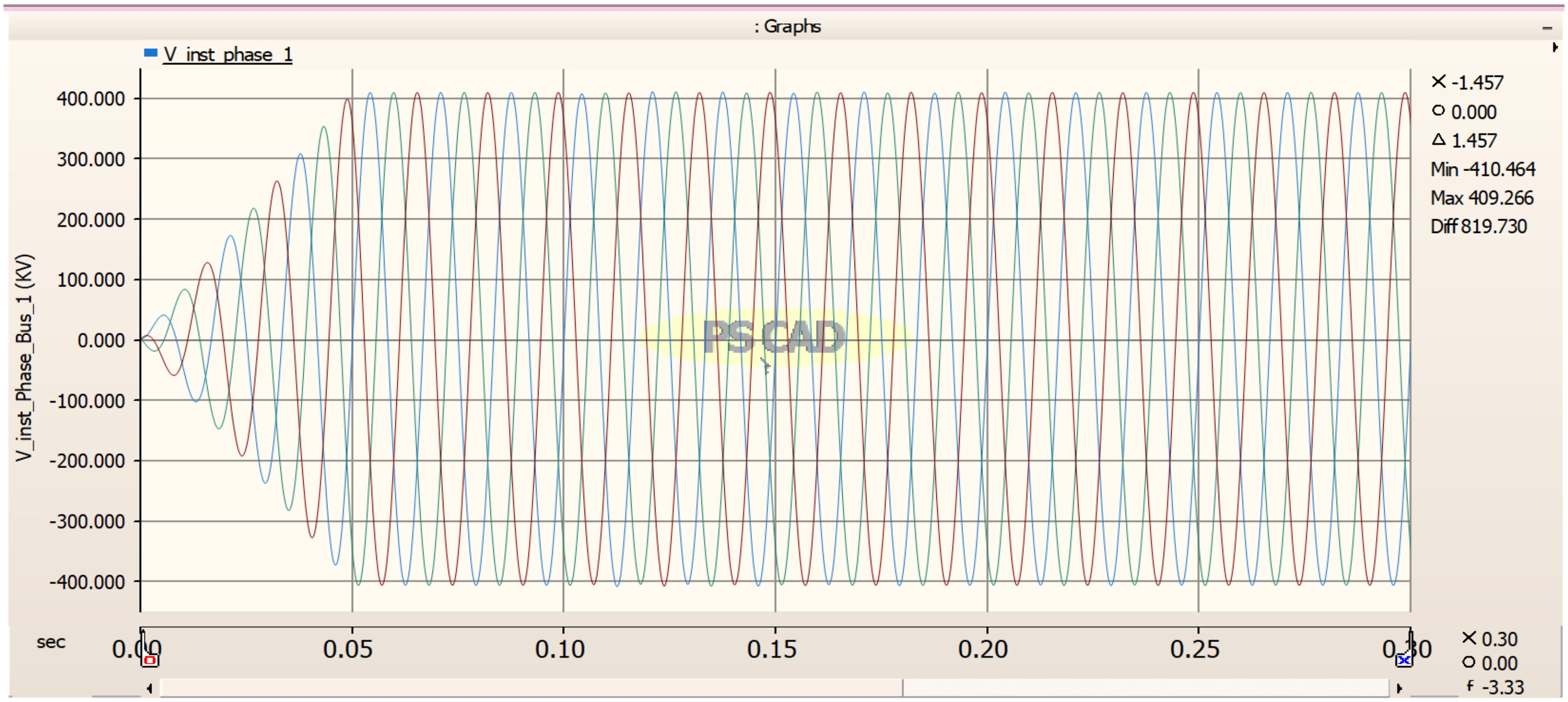
$$V_1, V_2, I_{line}, P_{line}, Q_{line}$$



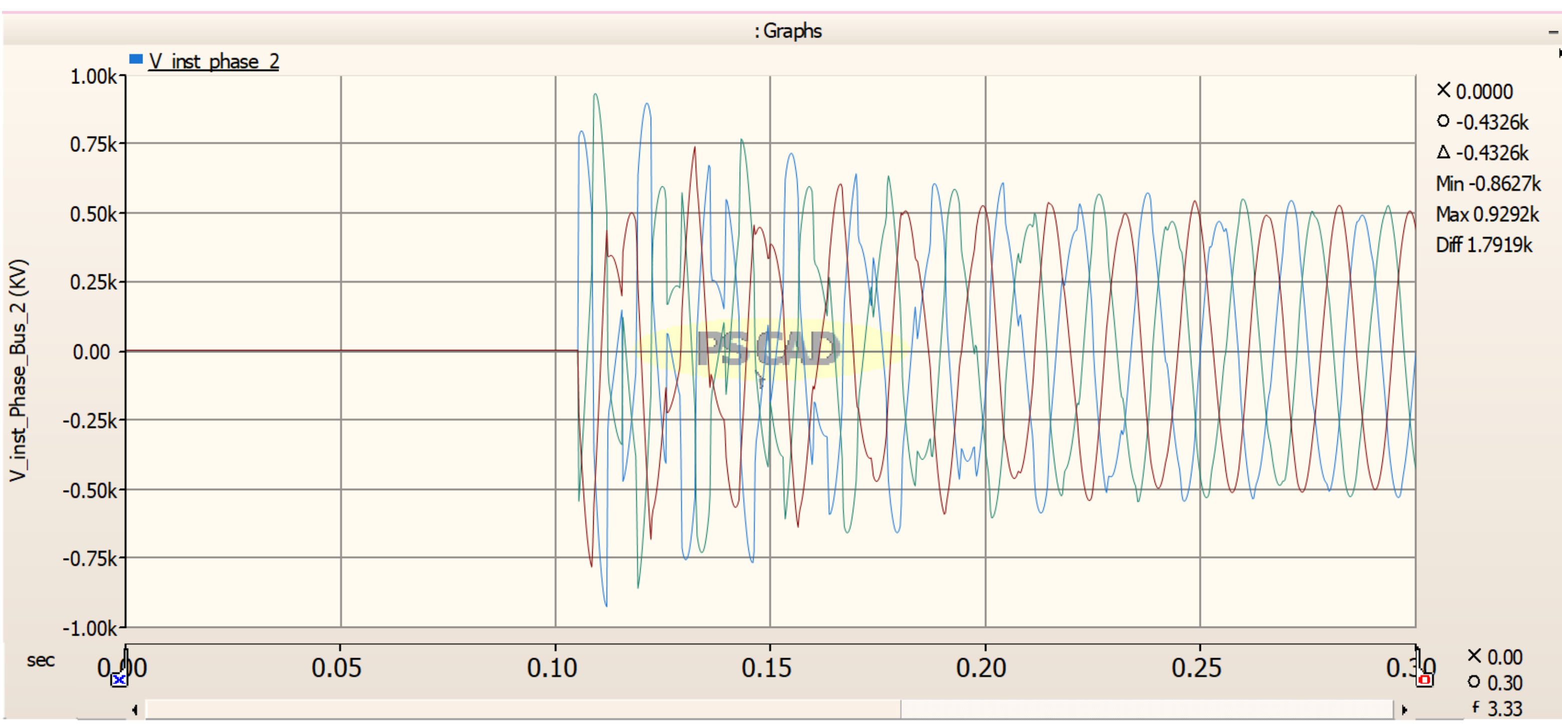
Here, in this section, I have considered step size as 0.0001 sec for the given time interval.

Conclusion: If we close the circuit breaker at time = 0.1050 sec in given time interval, we get the worst case of TOV at Bus – 2.

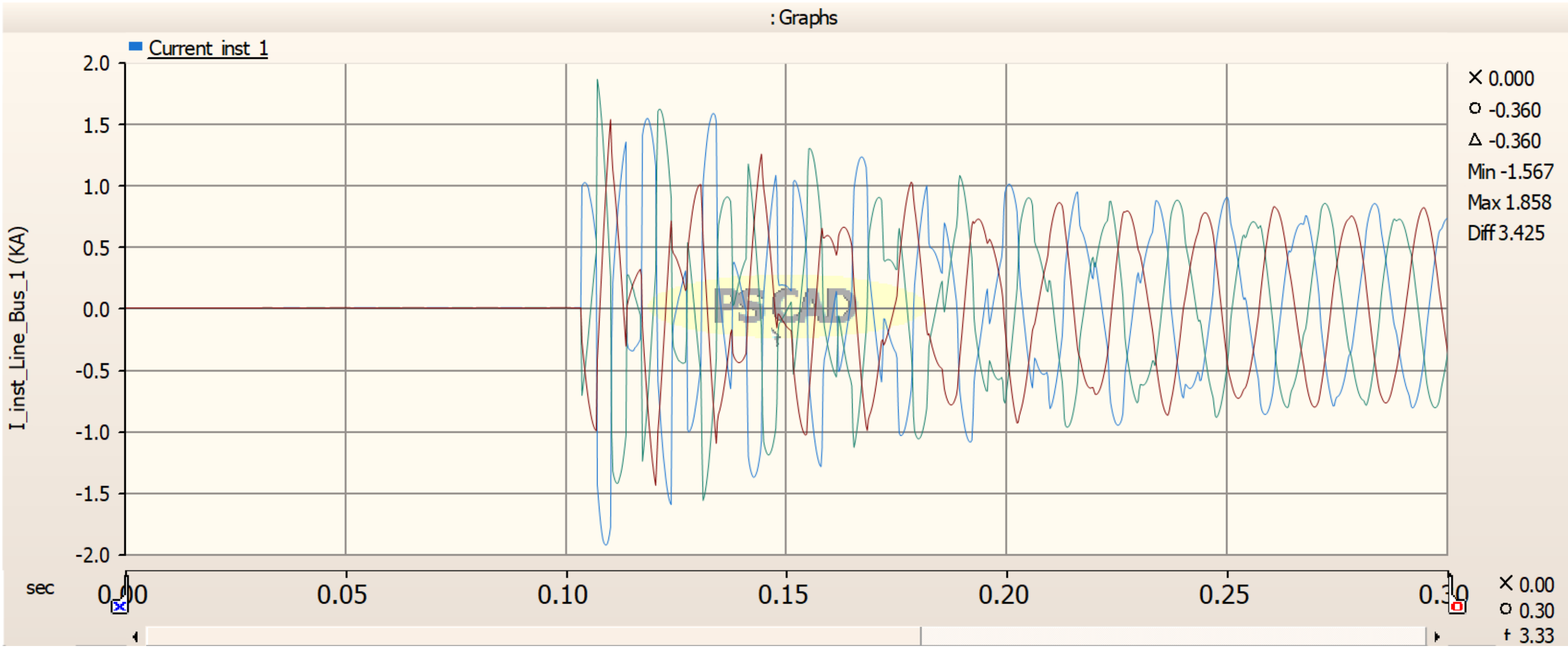
a) **Voltage waveform at Bus-1 for 500 KM Transmission line (breaker closing time = 0.1050 second)**



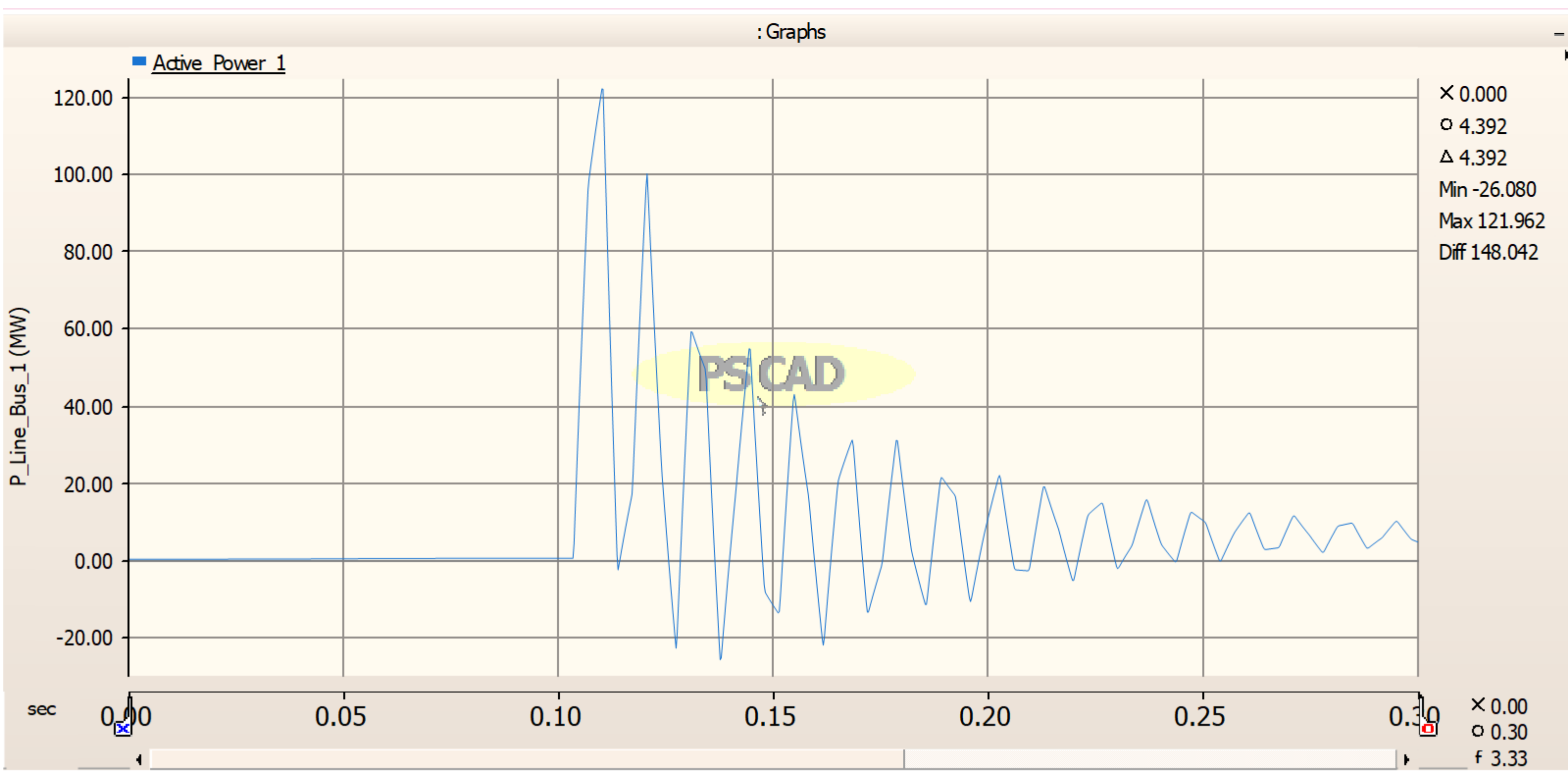
b) **Voltage waveform at Bus-2 for 500 KM Transmission line (breaker closing time = 0.1050 second)**



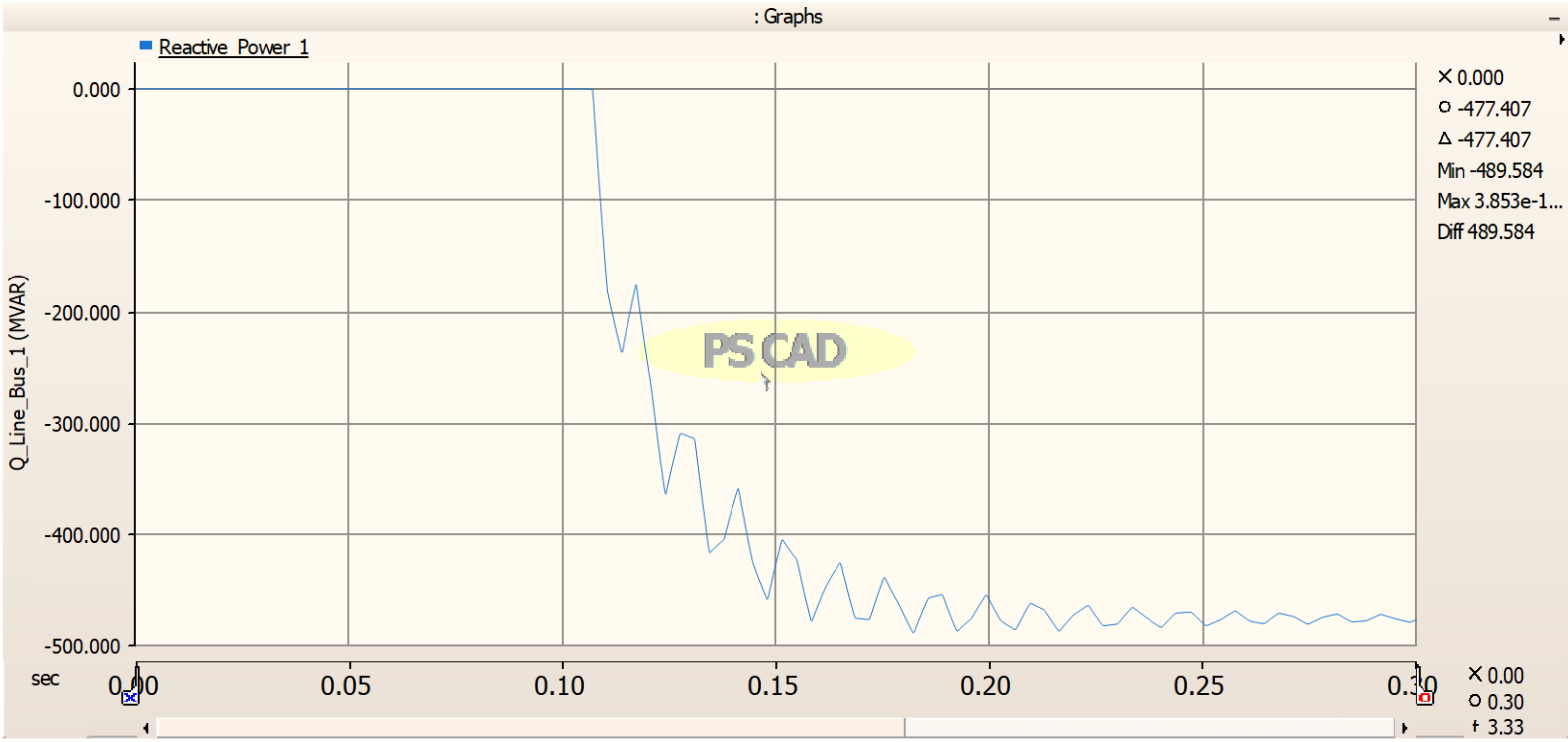
c) **Current *(I_{line})* waveform at Bus-1 for 500 KM Transmission Line (breaker closing time = 0.1050 second)**



d) **Active Power (P_{line}) waveform for 500 KM Transmission line (breaker closing time = 0.1050 second)**



e) **Reactive Power (Q_{line}) waveform for 500 KM Transmission line (breaker closing time = 0.1050 second)**



2. As it was simulated in the previous step, the magnitude of the steady state voltage at bus 2 is higher than bus 1 due to the impact of traveling waves. In this part, we analyze the application of surge arresters to protect equipment insulation against transient over-voltages.

    2.1 Place a surge arrester (Master Library/ PASSIVE ELEMENTS) at bus 2 to mitigate the observed overvoltage caused by transmission line switching. Implement your solution and verify by plotting the following waveforms for $t = 0.3\ second$, when the breaker is closed at $t = 0.1\ second$ and $line\ length = 500\ km$

$$V_1, V_2, I_{line}, P_{line}, Q_{line}$$

Note: Here, I have used 450KV Metal Oxide surge arrester to protect the equipment insulation against transient over-voltages.

Calculation for surge arrester rating:

Rated line voltage = 500 KV

Rated Phase voltage = 288.67 KV

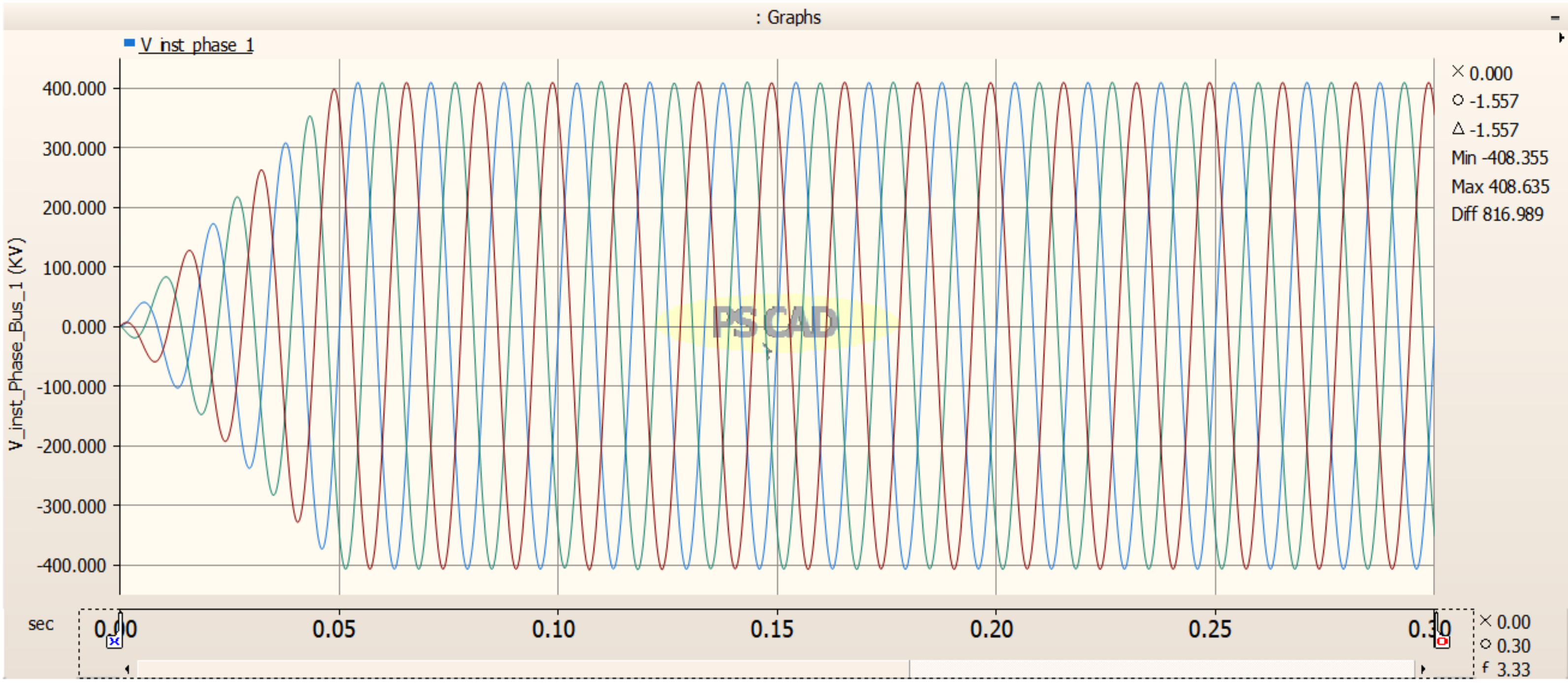
Peak value of phase voltage = $Phase\ voltage * \sqrt{2}$
= $288.67 * \sqrt{2}$
= 408.2484

10% margin in peak value of phase voltage = $408.2484 * 110\%$
= 449.073 KV

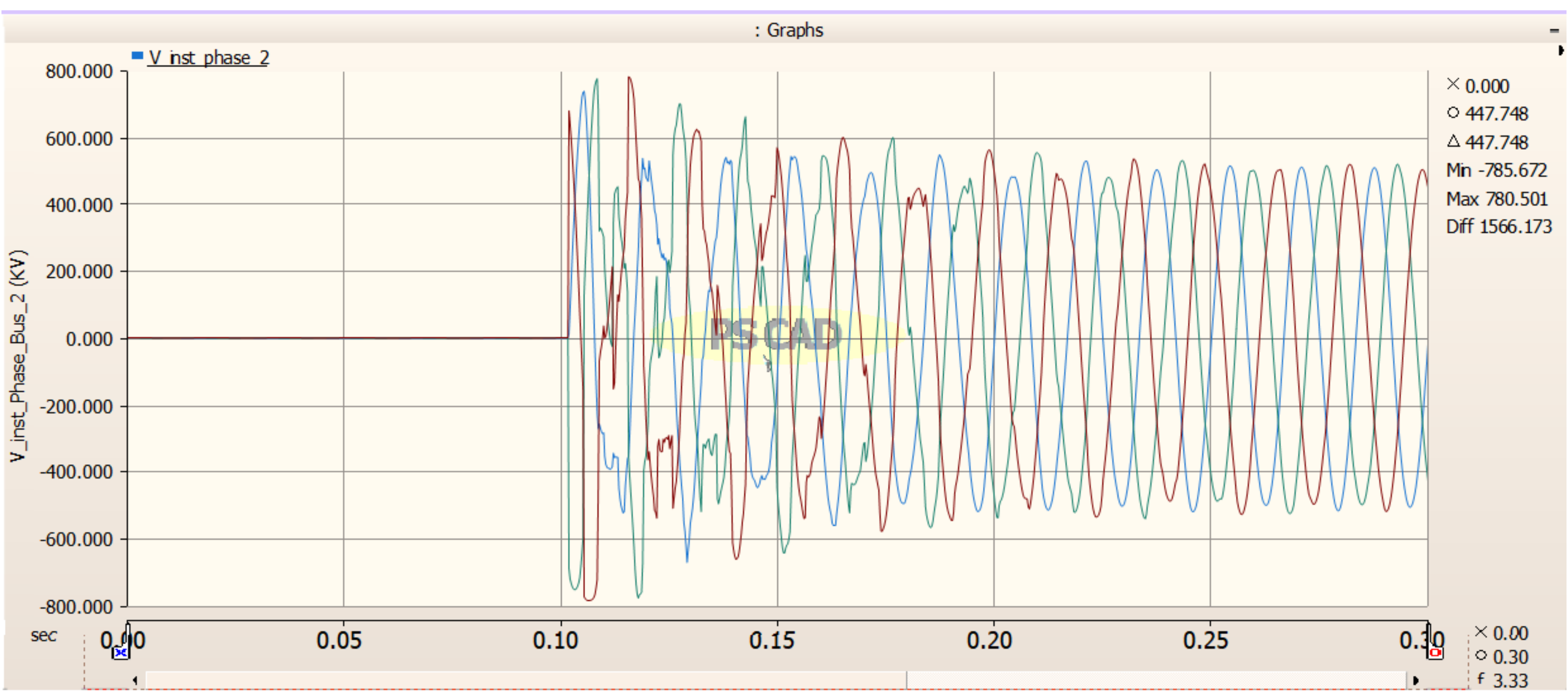
Thus, I have used 450KV Metal oxide surge arrester at receiving end to protect the equipment insulation against transient over-voltages.

Reference: - https://studyelectrical.com/2014/06/lightning-arrester-location-rating-and.html

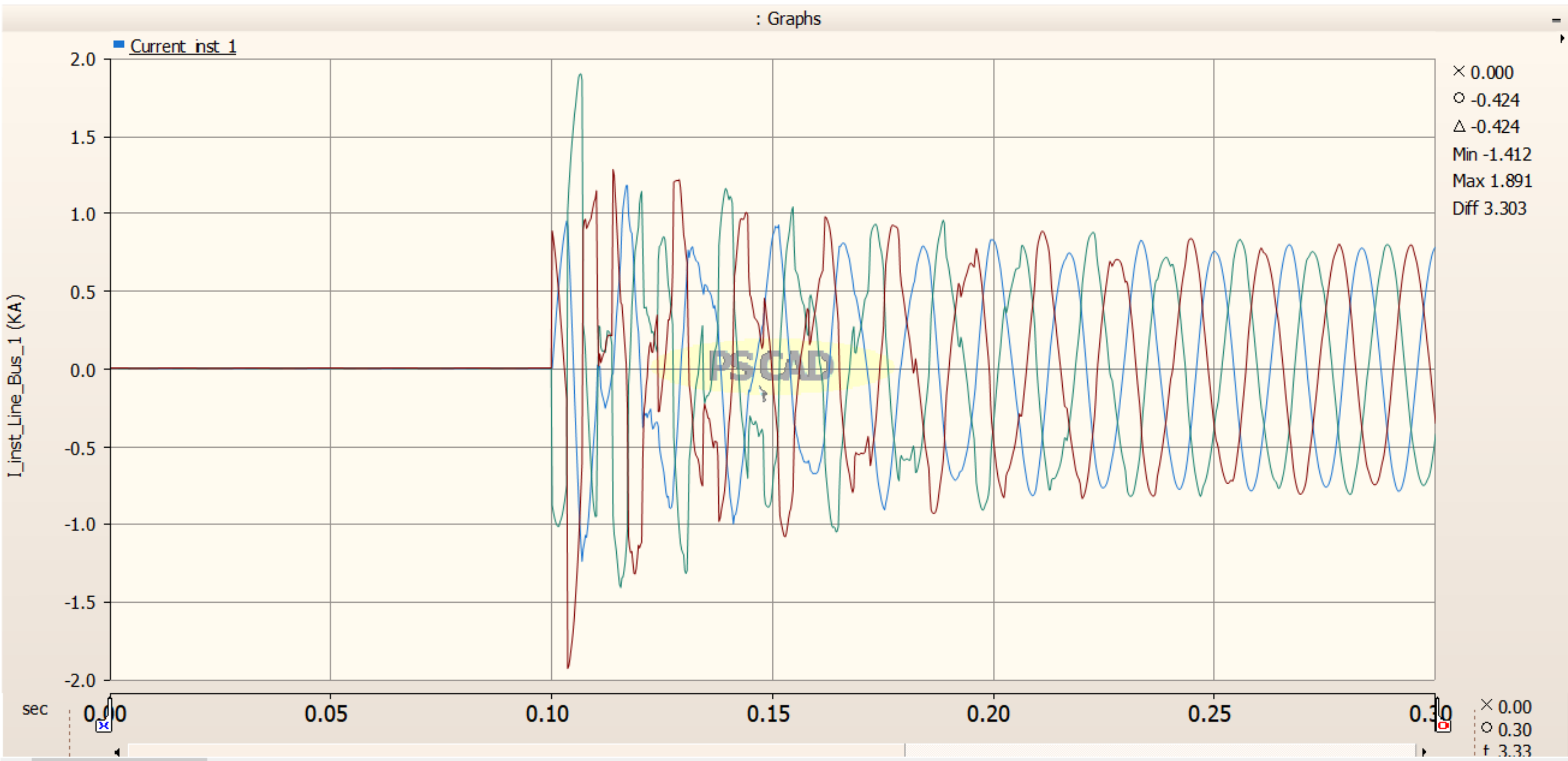
a) **Voltage waveform at Bus-1 for 500 KM Transmission line (breaker closing time = 0.1 second)**



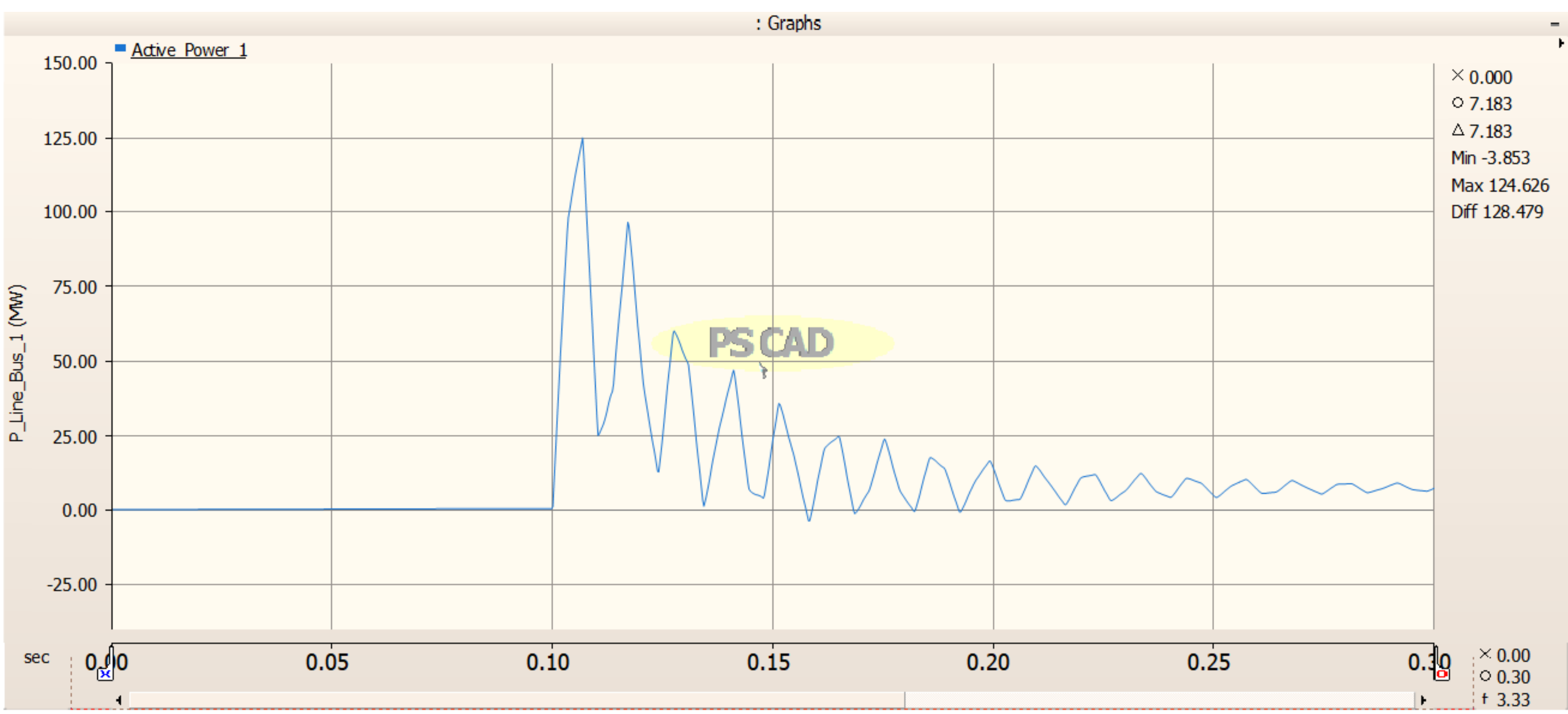
b) **Voltage waveform at Bus-2 for 500 KM Transmission line (breaker closing time = 0.1 second)**



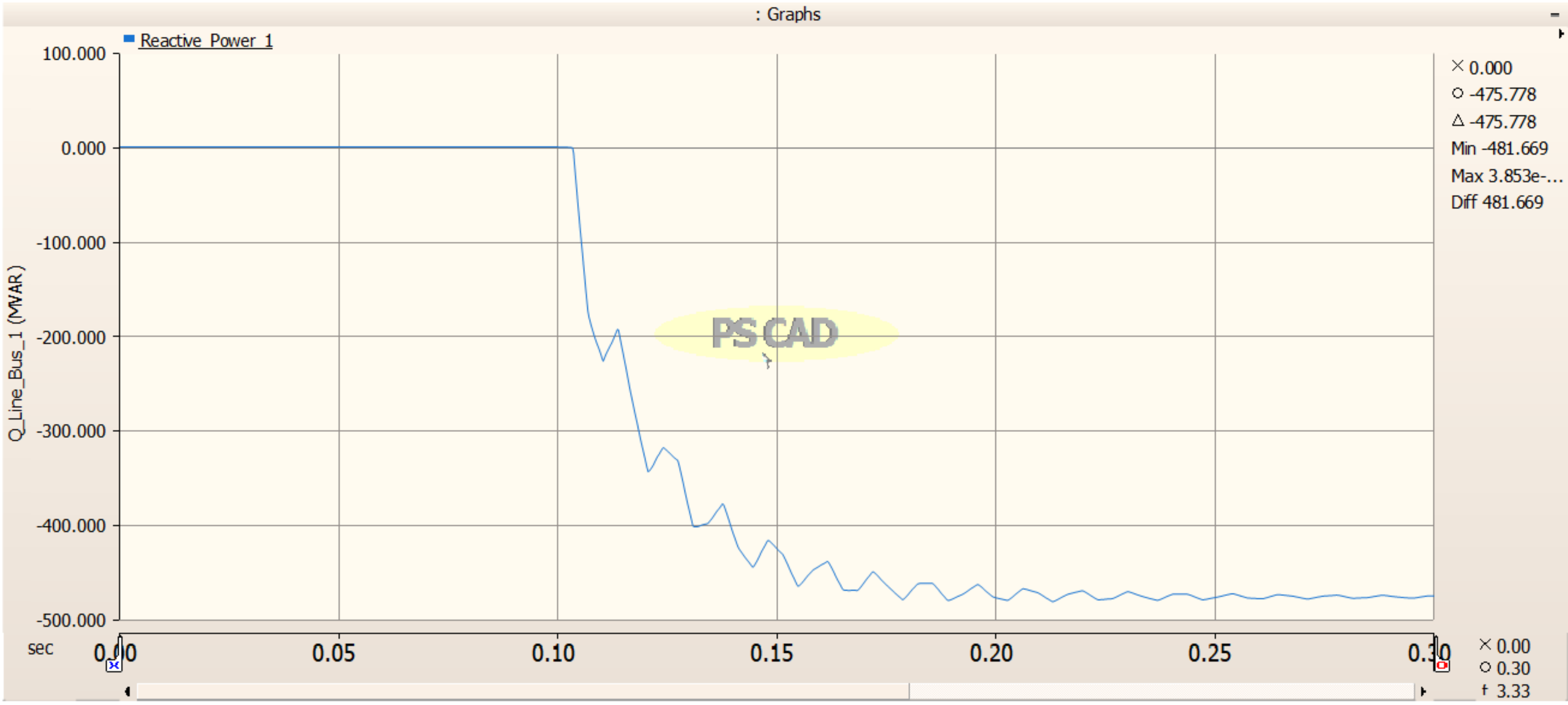
c) **Current *(I_{line})* waveform at Bus-1 for 500 KM Transmission Line (breaker closing time = 0.1 second)**



d) **Active Power *(P_{line})* waveform for 500 KM Transmission line (breaker closing time = 0.1 second)**



e) **Reactive Power *(Q_{line})* waveform for 500 KM Transmission line (breaker closing time = 0.1 second)**



2.2 Do some research and prepare a short report on surge arresters (1-2 pages). Discuss their characteristics, types, advantages, and how they help to limit voltage to a ceiling level and absorb the energy from lightning and switching surges.

Introduction: A surge arrester is a protective device for limiting voltage on equipment by discharging or bypassing surge current. In simple words, it is a protective equipment used to protect expensive devices such as transformer, generator, motors etc.… In other words, the purpose of a surge arrestor is to protect insulation /components from high DV/DT that peak at instantaneous values that are in excess of the breakdown of the insulation or component. Lightning is one common cause of voltage surges. Another common cause is switching in an inductive circuit.

Characteristics of Surge Arrester

- Maximum constant operating voltage.
- These are connected among the life conductors as well as the earth.
- While installing the arresters with above **52 kV**, surge arresters may be supplied by discharge operation counters.
- Resealing voltage (voltage across the arrester at which the follow current is still definitely interrupted after sparkover).
- Maximum continuous operating voltage (highest power-frequency – **50 Hz** or **60 Hz** – voltage that the arrester can withstand permanently).
- Rated short-circuit current
- Nominal discharge current, which common values are **5 kA, 10 kA and 20 kA**.

Types of Arresters

Surge arresters introduce shunting resistance to the ground when a surge appears, absorbing energy from the surge without the voltage becoming excessive. They then extinguish the power follow current after dissipating the surge. The most common arrester types in power systems are silicon carbide (Si-C) and zinc oxide (Zn-O).

1. Silicon carbide Arrester (Si-C)

The first surge arresters provided lightning protection utilizing an air gap connected between the line and the ground. Their main drawback was the requirement of a series linear resistance and a fuse to break the power follow current. Additionally, when the gap sparks over, it creates a fault in the circuit – and an unpleasant outage when cleared by a circuit breaker.

a. Silicon Carbide (Si-C) Valve-Type Surge Arresters

Si-C valve-type surge arresters employ a non-linear valve element (resistor) made of silicon carbide and inorganic binders. Silicon carbide is a compound of silicon and carbon.

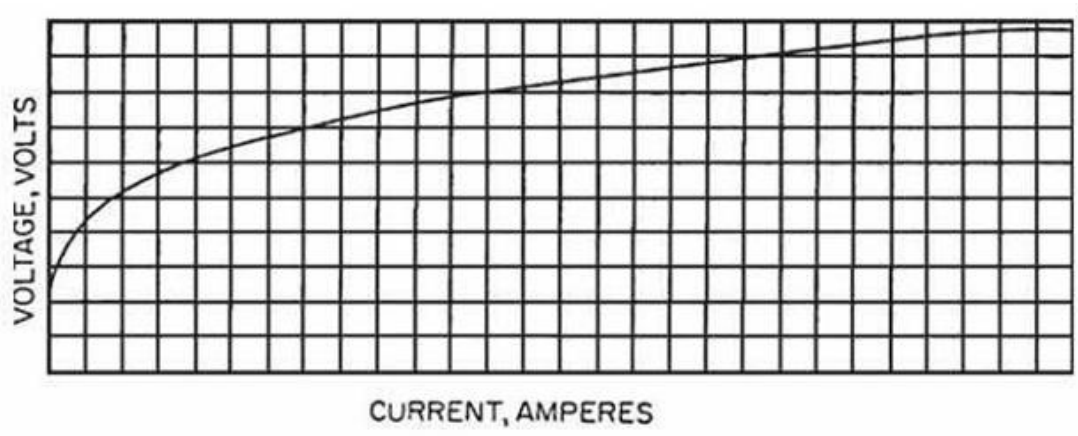


Figure 1. shows a volt-ampere characteristic for a gapped silicon-carbide arrester.

Some arrester applications require that the valve element have a low resistance value during steady-state conditions to deal with particular surge and power system characteristics, creating excessive power losses. Valve-type surge arresters have spark gaps in series with the valve elements to manage this difficulty.

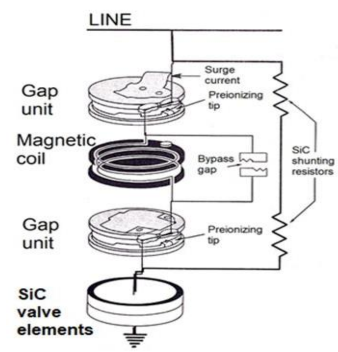


Figure 2 shows a diagram of a typical 6kV silicon-carbide surge arrester with its components: main gap units, magnetic coil, valve elements, bypass gap, and shunting resistors.

2. Zinc oxide (Zn-O)

A metal-oxide surge arrester contains non-linear metal–oxide resistive disc elements with excellent thermal energy withstand capabilities. Each disc includes powdered zinc oxide material mixed with other metal oxides. This type of surge arrester works like a high-speed electronic switch – opened at steady-state voltages and closed at over-voltages.

Zinc oxide surge arresters are highly non-linear – their non-linear characteristic is much more pronounced than that of silicon carbide – and have low losses under steady-state conditions.

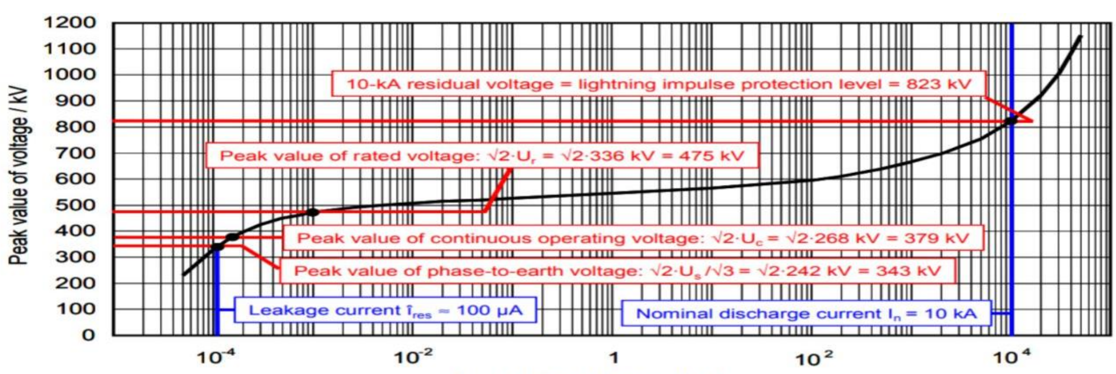


Figure 259: VI characteristics of a typical metal oxide arrester in a 420kV system

There are three types of metal-oxide arresters:

1. Gapless
2. Series-gapped
3. Shunt-gapped

Classes of Arrester: There are four main classes of surge arresters namely – station, intermediate, distribution and secondary. Out of all the four, station arresters are the ones which are most heavily constructed and are designed for the largest range of ratings along with the best protective characteristics. Intermediate arresters are designed for voltage level of 138kV and below; they are moderately built. Distribution 23 arresters serve the applications where economy is the prime concern. For system ratings lower than 1kV, secondary arresters come into play

A surge protection device (SPD) is configured for electrical installation protection system used in the power grid and communication systems.

It is one of the most powerful and commonly utilised forms of an overvoltage defence system. This can help to reduce the spontaneous voltage of transient energy spikes and electrical noise on the power supply line due to internal load, lighting and other transient disruption. It can also prevent or reduces all additional voltages above the secure level.

However, there are some crucial advantages and disadvantages of surge protector device which are in the following:

Advantages of SPD

- Protection of the circuit from transient voltage levels is an important and crucial element of this device.
- It can effectively manage the voltage ranges and ensure that electrical equipment is not damaged.
- The systems with the built-in surge protection circuit are secured from burst and surges.
- The installation and maintenance of these devices are very much easy.
- The maintenance, additional cost and restoration of these devices are very minimal.

Energy Consideration

When metal oxide surge arrester is energized, valve elements of the arrester will absorb energy resulting in an increase in the temperature of the elements. Under normal conditions, there is equilibrium between heat dissipated by valve elements and heat generated by the elements, so that the stable condition is maintained. But the occurrence of overvoltage disturbs this equilibrium causing the arrester to 24 increase their temperature (since the rate of energy dissipation is less than the rate of energy absorbed by the arrester subjected to overvoltage). This could to lead to uncontrolled behavior of the arrester i.e. increasing the element temperature until it self-destroys itself.

3. In this part of the project, we study the surge impedance loading situation of the transmission line to measure the magnitude of voltage value at the end terminal.

   3.1 Solve the transmission line constants in the PSCAD software to calculate the Surge Impedance (SI) value.

Transmission Line constants from PSCAD	
Resistance	0.00616928872
Reactance	0.0947043553
Susceptance	4.23649783
Surge Impedance	0.14951387

Surge Impedance Calculation from the above data

$$Surge\ Impedance\ (SI) = \sqrt{\frac{Z(Reactance)}{Y(Susceptance)}}$$

$$= \sqrt{\frac{0.0947043553}{4.23649783}}$$

$$= 0.14951387\ pu$$

Now,

$$Impedance_{actual} = Impedance_{pu} * \frac{Voltage_{base}^{2}}{Power_{base}}$$

$$Impedance_{actual} = 0.14951387\ pu * \frac{(500)^2\ KV}{100\ MVA}$$

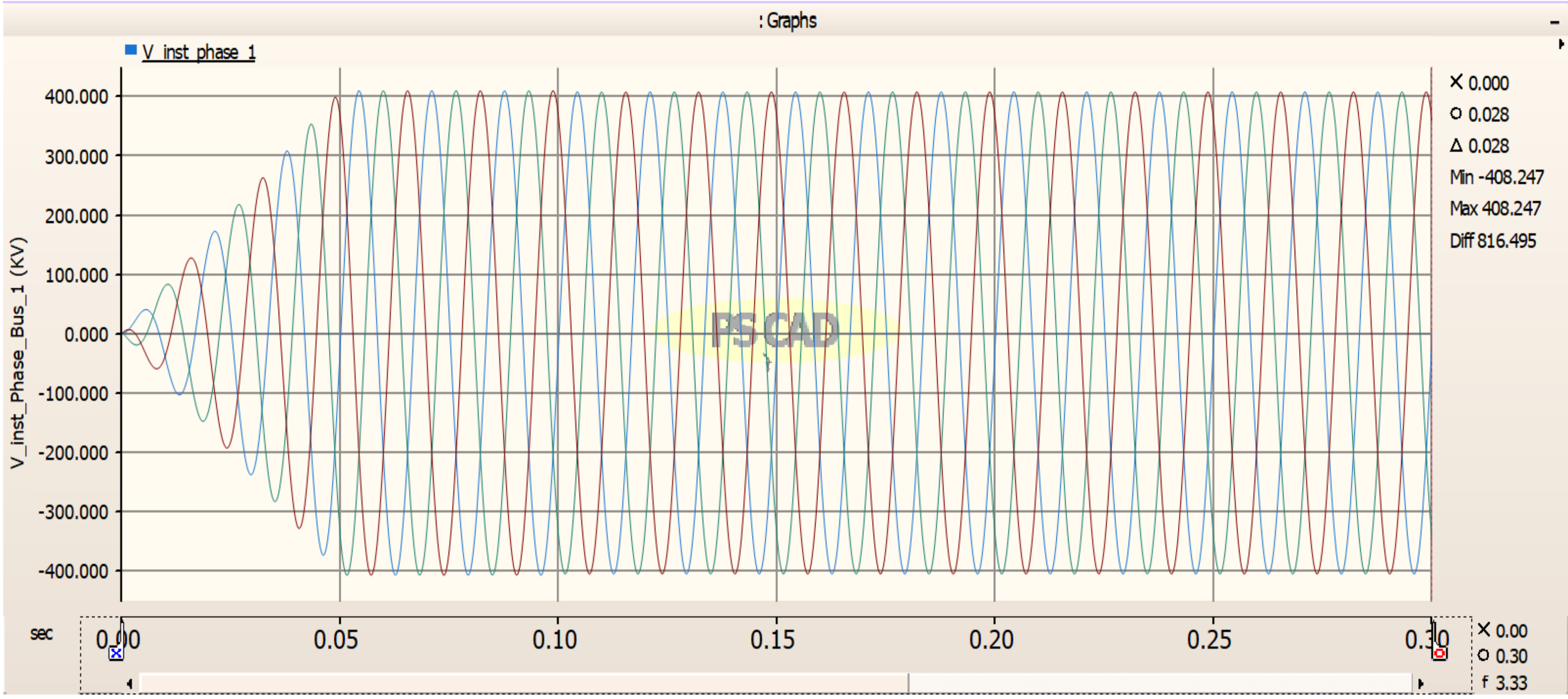
$$Impedance_{actual} = 373.784675\ \Omega$$

Thus, the Surge Impedance = 373.784675 Ω

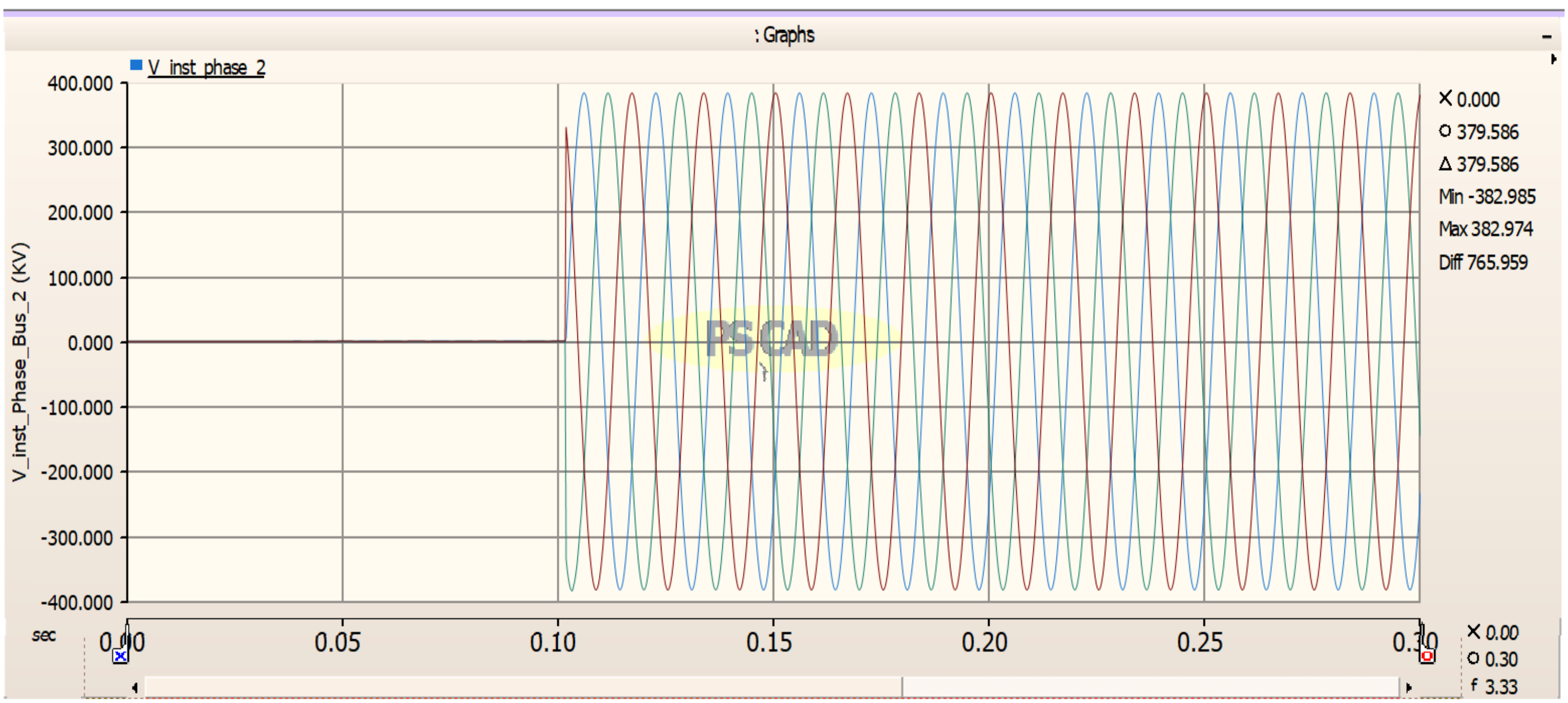
   3.2 Place a resistor at the end of transmission line with the value set to be equal to the SI. Plot the following waveforms for $t = 0.3\ second$, when the breaker is closed at $t = 0.1\ second$ and $line\ length = 500\ km$

$$V_1, V_2, I_{line}, P_{line}, Q_{line}$$

a) **Voltage waveform at Bus-1 for 500 KM Transmission line (breaker closing time = 0.1 second)**

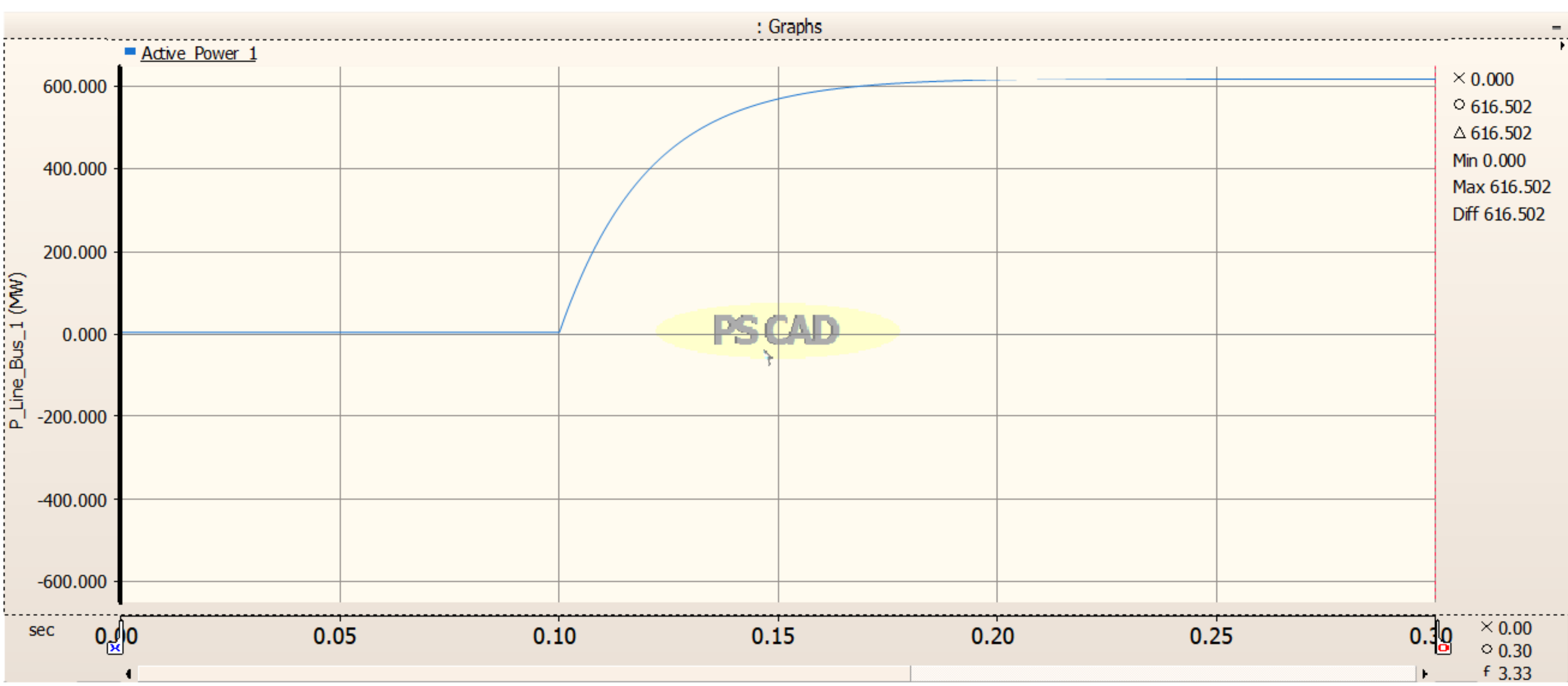


b) **Voltage waveform at Bus-2 for 500 KM Transmission line (breaker closing time = 0.1 second)**

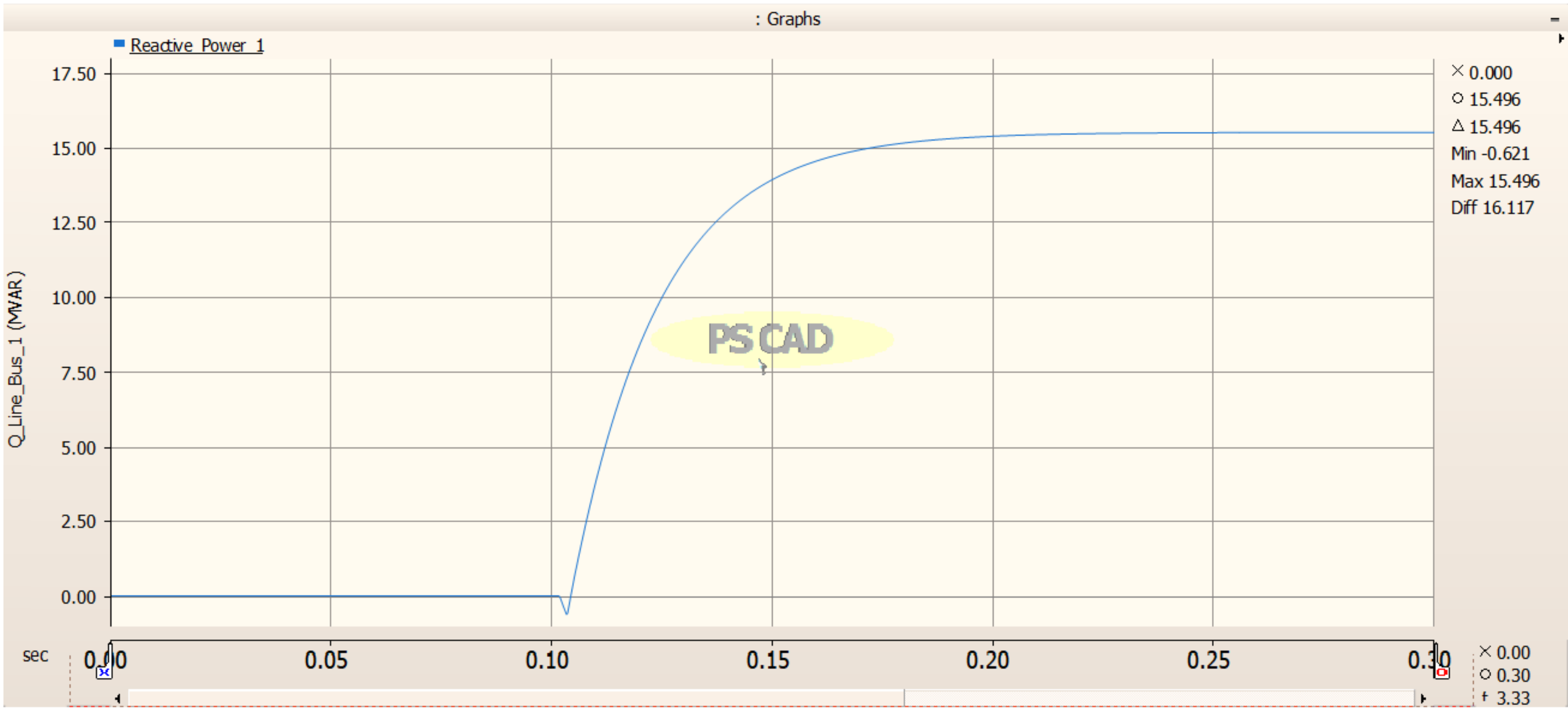


c) **Current *(I_{line})* waveform at Bus-1 for 500 KM Transmission Line (breaker closing time = 0.1 second)**

d) **Active Power *(P_{line})* waveform for 500 KM Transmission line (breaker closing time = 0.1 second)**



e) **Reactive Power *(Q_{line})* waveform for 500 KM Transmission line (breaker closing time = 0.1 second)**



PSCAD Project Report Guidelines:

- Please respond to the questions and plot the related figures in your report. Use this word file as your template.
- Please make sure you copy-paste the questions from these instructions into your answer sheet, so we know what question you are trying to answer!
- Every figure should include a caption.
- You must attempt all the parts that are required in the project reports.
- Prepare your report in a PDF, name it firstname-lastname-graduateproject.pdf, upload it through D2L.
- **Mark breakdown for the PSCAD project report:**

Section	Percent (%)
1.1	15 (3% each graph)
1.2	15 (3% each graph)
1.3	15 (3% each graph)
2.1	15 (3% each graph)
2.2	15
3.1	10
3.2	15 (3% each graph)

References:

https://www.eaton.com/us/en-us/products/medium-voltage-power-distribution-control-systems/lightning-arresters/surge-arresters--fundamentals-of-surge-arresters.html
https://www.berkeys.com/2016/11/18/surge-arrester-works/

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