

GOVERNMENT OF INDIA

Report on minimizing the effects of Electrical interference on Oil and Gas pipelines due to Electric Lines



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1. Introduction

In oil and gas industry, the seamless functioning of critical infrastructure is paramount. The growing integration of electric lines within these operations has unlocked groundbreaking advancements, yet it has also introduced challenges such as electromagnetic induction and interference, which must be carefully managed.

The AC interference on Oil and Gas steel pipelines can result into Pipeline failure either due to AC Corrosion during steady state conditions or Pipeline wall damage during transient conditions along with adverse effect on human safety. This may lead to failure of Oil & Gas pipelines, which may have following consequences:

- a) The release of Oil and Gas may lead to explosions and fire, putting nearby communities at risk. These incidents can result in injuries, fatalities and damage of public properties.
- b) Property damage of pipeline operator, resource wastage in terms of precious oil & gas.
- c) The environmental impact of a pipeline failure can extend to ecosystems. Spills can contaminate soil, water bodies, and wildlife habitats, having long-term ecological effects and emission of greenhouse gases.

Thus, the failure of a pipeline has far-reaching consequences and it is crucial to maintain pipeline integrity to prevent such failures and their associated impacts as it can have severe consequences for public, property & environment.

2. **Mitigation Practices adopted globally**

The electrical interference on a pipeline mainly depends on the proximity and parallel routing between a pipeline and Medium and high voltage power lines, traction etc. Mitigation can be primarily achieved by increasing the distances between the pipeline and powerline routes.

The mitigation measures includes ground electrodes consisting of either packaged sacrificial anodes, sacrificial anode ribbons packaged in special backfill materials, conventional grounding materials such as ground rods or cables or specially designed AC mitigators.

The brief overview of the above systems is as below:

- i. **Distributed Anodes:** Distributed anodes are strategically placed along the pipeline to bring down the electrical interference level on pipeline.
- ii. **Spiral Ground Mat** at Exposed Appurtenance: Appurtenances are components attached to the pipeline, like valves or meters. A spiral ground mat is a grounding system installed around these exposed components to prevent shock hazard to personnel in contact with the exposed appurtenance. Installation of Earthing Mats and spreading of gravels is carried out around the station piping and valves where

measuring and instrument piping are installed to maximize the tolerance level of touch & step potential above the Ground Potential Rise (GPR).

- iii. **Gradient Control Wire:** It is used to control the distribution of electrical current in the grounding system, ensuring uniform protection for the pipeline.
- iv. **Multiple-Connected Horizontal Ground Conductor:** This refers to the horizontal conductors laid in the ground to create a low-resistance path for the electrical current to flow away from the pipeline, minimizing corrosion.
- v. **Horizontal Ground Electrodes:** These are electrodes buried horizontally in the ground to provide additional grounding and help disperse electrical currents.
- vi. **Independent Ground Bed:** A separate grounding bed, usually made of conductive materials like graphite or coke breeze, used to improve the efficiency of the grounding system.
- vii. All of these grounding electrodes are connected to the pipeline through solid-state DC Decoupler.
- viii. **Solid-State DC Decoupler (SSD):** These decouplers provide a low-resistance path for the discharge of AC current, while simultaneously blocking DC to maintain the effectiveness of the cathodic protection system. This device is connected between pipeline and grounding system.
- ix. For protecting pipeline equipment AC surge protection devices such as spark gaps, arresters, zinc grounding cells, DC Decoupler and isolation surge protectors (ISP), have been recommended to be connected at required locations to provide an alternative fault current path.

3. Provisions existing in CEA Safety Regulations, 2023 regarding safeguarding of Oil/Gas Pipelines

To cater the problem of angle of crossing and proximity (horizontal and vertical clearances) of powerline with Oil and Gas pipelines following provisions are provided in Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations, 2023 also known as CEA, Safety Regulations, 2023 as mentioned below:

Regulation 60- Clearance in air of the lowest conductor of overhead lines.

60 (1): *“The minimum clearance above ground and across road surface of National Highway or Expressway or State Highway or other road or highest traction conductor of railway corridor or navigational or non-navigational river of the lowest conductor of an alternating current overhead line, including service lines, of nominal voltage shall have the values specified in Schedule VIII A of CEA, Safety Regulations, 2023”.*

60 (2): *“The minimum clearances regarding high voltage direct current line shall be as per Schedule VIII B of CEA, Safety Regulations, 2023”.*

60 (4): “No tower footing or structure of an overhead line of voltage 33 kV or above or high voltage direct current, shall be closer than twenty five metre from the edge of the right of way of a Petroleum or Natural Gas pipeline.”

60 (5): “Wherever overhead line of voltage 33 kV or above or high voltage direct current intending to cross the right of way of a Petroleum or Natural Gas pipeline, the angle of crossing of the overhead line with respect to the pipelines shall preferably be at right angles (90^0) and, in any case, the crossing angle shall not be less than seventy-five degrees (75^0).”

4. Constitution of Committee:

A committee under the Chairmanship of Chief Engineer, Chief Electrical Inspectorate, CEA was constituted to look into the issues faced by Oil and Gas pipelines due to electrical line crossing/running parallel with pipelines across RoU.

The committee was entrusted with the task to carry out the comprehensive study on the following ‘**Terms of Reference**’:

- a) Guidelines for minimizing the effects of electromagnetic induction/ interference on Oil and Gas due to Electric Lines.
- b) To ascertain the extent of the induction effect on the Oil / Gas pipelines due to crossing of Electric Lines.
- c) Mechanism for exchange of information during route selection and sharing of powerline configuration and loading pattern for AC interference Studies.

The committee would also give recommendations for pipeline operators for adopting best mitigating measures to minimize the effects of Electromagnetic Induction/ interference on Oil and Gas pipelines due to Electric Lines.

5. Meetings of the committee

- a) **First meeting was held under the Chairmanship of Chief Engineer, Chief Electrical Inspectorate, CEA on 18.10.2023. The meeting was attended by officials of CEA, MoPNG, Power line operators (PGCIL, Tata Power), Pipeline Operators (GAIL, IOCL, HPCL, BPCL) and others. Gist of the meeting is as below:**

- i. Various issues were discussed during the meeting such as effects of AC Interference on Carbon steel Pipelines due to parallelism of electric lines, earthing system of RE plants (Solar/wind) where pipelines also exist, effect of soil resistivity on Cathodic Protection (CP) of pipelines, earthing of pipelines, simulation studies to be conducted for better suggestion of mitigating measures, increasing of height of distribution lines, requirement of NOC from existing powerline/pipeline operator in case of upcoming line, mapping of powerline and pipeline network on PM Gati Shakti portal.

- ii. HPCL informed that the neutral earthing of transformer also affects the AC voltage on the pipeline. If the earthing part of single phase transformer is not effective / perfect and due to this improper earthing, the induction effect is observed in nearby pipelines. It was suggested that Distance of transformer feeding those lines and its earthing system may be more than 100 m from pipeline.
- iii. GAIL informed that in case of Solar Farms, earthing system should be at the farthest distance possible to avoid interference from DC current leakage and Transient conditions/ Faults.
- iv. Condition monitoring of Oil and Gas Pipelines shall be carried out by OMCs in accordance with prevailing standards.
- v. EIL informed that the cathodically protected pipeline may be grounded through DC Decoupling device and the pipeline grounding electrode may maintain maximum total earth resistance of one (1) Ohm for each location where pipeline crosses the power lines. Where the resistance is not within one ohm, mitigation measures should be taken.
- vi. EIL informed that the pipeline shall be grounded at regular intervals of maximum one (1) km where power lines run parallel beyond 25 m of the pipeline and wherever the interference is higher, distance of 1 km could be reduced accordingly. Interference study should be conducted and based on the outcome of the study, grounding at required locations to be carried out to avoid shifting of induced voltage peaks at other unknown locations.
- vii. EIL informed that the AC Interference Survey as well as AC interference study shall be carried out by a proven software modelling and simulation. Investigations shall be made for AC induction interference on pipeline due to various overhead pipe lines. For existing installations, frequency of such surveys/ monitoring to be increased from present practice of 5 years.
- viii. Member (PS) advised that Power Line and Pipeline operators shall map the entire network on PM Gati- Shakti Portal for easy access.

b) Second meeting was held under the Chairmanship of Chief Engineer, Chief Electrical Inspectorate, CEA on 09.02.2024. The meeting was attended by officials of CEA, MoPNG, Power line operators (PGCIL, Tata Power), Pipeline Operators (GAIL, IOCL, HPCL, BPCL) and others. Gist of the meeting is as below:

- i. DD (DP&T) informed that raising height of Electric Distribution lines or increasing the laying depth of Oil and Gas pipeline in case of colocation of Electric line and Oil and Gas Pipeline is not a solution as AC interference with 11 kV line is not a problem. However, improper earthing practice of 11 kV poles and location of Distribution Transformers in close vicinity of Oil and Gas pipelines is the major issue.
- ii. CE, CEI suggested that directions can be issued to DISCOMs (as a part of guidelines) for adhering to best practices while providing earthing for any electrical installation

as per relevant Indian Standard as mentioned in CEA Safety Regulations, 2023 where any Distribution Substation/line is in close proximity of Oil/Gas pipelines.

- iii. It was discussed to explore possible options ~~can~~ on issuing directions to State DISCOMs for minimum separation distance to be kept while installing Double Pole consisting of Distribution transformer of different ratings near to oil/gas pipelines. When it is not possible to achieve minimum separation distance, specific mitigation measures should be considered, these may be implemented on the pipeline system or on the AC Electric system or both along the RoU.
- iv. It was decided that a Coordination Committee consisting of concerned pipeline operators, Electric line operator and DISCOMs/TRANSCOs could be constituted at state level. Coordination committee may be entrusted with the work of identification of critical areas, joint inspection of critical areas, collection of data for simulations/software tools and the issues related to Hazard to Oil and Gas Pipelines by electric line crossing running parallel with pipelines across RoU. On the basis of findings of coordination committee the specific mitigating measures may be taken up by Electric line/Oil and Gas pipeline operators accordingly. The coordination committee may also exchange the information and look into the issues related to exiting/new Electric line or Oil and Gas pipe line existing/coming in that area.
- v. Standard Operating Procedures (SOP) may be formed for preventive maintenance and conditional monitoring.
- vi. Providing training to Power Line and Pipeline operators and maintenance personnel on the risks of AC induced corrosion and the proper procedures for mitigation.
 - Concerns were raised for lack of awareness among lineman/laborers of DISCOMs working near Oil and Gas pipelines.
 - Based on the above discussions and deliberations it was concluded that work of spreading awareness among the labors/electricians of DISCOMs working near pipelines may also be entrusted to the coordination committee members
 - It was suggested that the Electric line operators may be given training in the relevant area of hazard on pipelines due to Electric lines at OMC's Training Institutes.
- vii. While planning for upcoming Electric line/Oil and Gas Pipeline, angle of crossing, soil resistivity, co-location from existing electric line, horizontal/vertical distance from existing line etc. may be considered. It was also suggested that a study may be conducted to know the impacts of various electrical equipment/installation at different voltage levels on Oil and Gas pipelines. Simulation Software are available to analyze the problems and recommend mitigation measures based on surveys and study.

c) Third meeting was held under the Chairmanship of Chief Engineer, Chief Electrical Inspectorate, CEA on 13.05.2024. The meeting was attended by officials of CEA, TPDDL, Pipeline Operators (GAIL, IOCL, HPCL, BPCL) and others. Gist of the meeting is as below:

- i. Discussion was held on report of Rewa Ultra Mega Solar Limited (RUMSL) (presented to MNRE for NTPC Shajapur plant) in respect of mitigation measures to be taken to avoid interference due to direct current leakage/DC grounding from Underground cables in existing and upcoming RE Stations (Solar/wind).
- ii. Discussions were held in respect of proper earthing and keeping safe horizontal distance of Distribution transformers of different rating from center of Oil and Gas Pipeline.
- iii. Coordination group was finalized along with its Term of References (ToR).

A coordination committee has to be constituted in case where there exist hazard to Oil and Gas pipeline from overhead electric line with the following constitution:

- | | | |
|------|---|------------------|
| i. | Regional Inspectorate Organization (In-charge)- | in Chair |
| ii. | Concerned OMC- | Member Secretary |
| iii. | Concerned HoD of Discom/ Transco- | Member |

In the above mentioned case, Member Secretary shall request CEA in writing to nominate any officer to conduct meeting under his/her Chairmanship with the above said officers. The committee has to conduct meeting and prepare a report on the issue after detailed discussion/deliberation and recommend some specific mitigating measures, if any in addition to recommendations mentioned in these guidelines, to be adopted by OMCs for the safety of Oil and Gas pipelines. If needed, detailed AC Interference Study through Software Modelling could be done through any third party.

- iv. It was informed by all the OMCs that as of now, NOC is taken by electric line operator in case, any new electric line is coming in RoU of existing pipeline as per format of respective OMC.
- v. Status of mapping of Electric Line and Oil and Gas Pipeline network on PM Gati-Shakti Portal was discussed. Representatives from OMCs apprised that they are mapping the data of pipeline network in respect of their utility. Representatives from PGCIL also informed that electric line network of their utility is also mapped on PM Gati-Shakti portal and also getting mapped on regular basis. CEI suggested that mapping of all data in respect of pipeline of every OMC could be done on ministry level under this master plan for better coordination.
- vi. Chief Engineer, CEI also suggested to have field visit on some identified problematic site by few of the committee members to have the practical exposure of the problem persisting on Oil and Gas pipeline.

- vii. AD, RIO(N) apprised the committee members that CEA Safety Regulations, 2023 already consists of provisions in respect of following:
- a) Precautions to be taken against excess leakage current issues: (Reg. 37(6), 47(2), 48(5))
 - b) Precautions to be taken against excess leakage in case of metal sheathed electric supply lines. (Reg 49).
 - c) Earthing requirements for solar installations. (Reg. 121(2), 121(3))
 - d) To address ineffective soil resistivity issues. (Reg. 50(1), 50(8))
 - e) Depth requirement of cables: (Reg. 79)
- d) Fourth meeting was held under the Chairmanship of Member (Power Systems), CEA on 02.09.2024. The meeting was attended by officials of CEA, MoPNG, Power line operators (PGCIL, Tata Power), Pipeline Operators (GAIL, IOCL, HPCL, BPCL) and others. Gist of the meeting is as below**
- i. Representatives from Oil and Gas pipeline operators highlighted that provision for laying of Aerial Bunched Conductors (ABC) where LT powerlines are in close vicinity to pipelines, should be incorporated in recommendations of Guidelines/Report.
 - ii. Chief Engineer, CEI highlighted that loading of powerlines, which refers to the amount of electrical current flowing through the lines, can influence the magnitude of AC induced voltage on nearby underground pipelines. Higher loading on powerlines results in stronger electromagnetic fields.
 - iii. Representative from IOCL informed that modelling/profiling is being done by them for different loading patterns and at different voltage level of electric lines for steady state as well as transient state.
 - iv. Sh. K B Singh of K.B Singh and Associates, highlighted that most studies are conducted on induced voltage but not on fault currents. If fault current reaches upto 200 kA the Ground Potential Rise (GPR) could reach upto 200 kV which could damage the pipeline coating. So, detailed study is required on this subject.
 - v. Manav Energy suggested that a fault level study including lightning for next 25 yrs timelines shall be done for powerline and pipelines operator. Further Steady state study, max loading, environmental effects shall also be studied.
 - vi. It was informed that leakage current in soil from DC traction can cause hazardous effect on pipeline coating.
 - vii. Member (PS) suggested CPRI to develop/upgrade testing facility for lightning impulse current @ 8/20 μ s at min. 100 kA in India. This will help pipeline operators to select the DC-Decoupler of required rating to take care of the lightning protection.

- viii. Member (PS) suggested that training module for training of electric line operators (11 kV and above) in the relevant area of hazard on pipelines due to Electric lines at OMC's Training Institutes shall be prepared and updated time to time. Further, he suggested that effects of EV charging stations, Pantograph charging, Ground Level Induction etc. shall also be studied on Oil and Gas pipelines.
- ix. A sub-group was suggested to be formed that shall conduct software modelling consisting of case studies for different voltages of Electric lines at various current levels and their effect on pipelines having different collocation. The outcome of the case studies shall be included in the recommendations of the guidelines.

6. **Formation of sub-group to conduct Software modelling study:**

- a) Based on the discussions held in the 4th Committee meeting held on 02.09.2024 chaired by Member (Power Systems), CEA a sub-group was formed to study the effects on Oil and Gas pipelines in case of longer collocation with power lines. The sub-group consist of members from CEA, GAIL, IOCL, PGCIL, TPDDL and Manav Energy.
- b) AC interference study on pipelines from over-head HT power lines of voltage rating 66 kV, 132 kV and 220 kV as a hypothetical case considering collocation length of 1.5 km, 3 km & 10 km at varying separation distance from the power line. Right of Way (ROW) module of the SES CDEGS software package was used for creating AC interference model and simulating various interference scenarios.
- c) Data for 132 kV and 220 kV power lines was provided by PGCIL while that of 66 kV was provided by Tata Power. The power line data used in the study is tabulated as below:

	Power line	220 kV	132 kV	66 kV
1	Data source	PGCIL	PGCIL	Tata power
2	Rated load (in Amp): (Ambient: 45° C, Conductor temp: 85 ° C)	Zebra: 694 A	Panther: 465A	Goat: 634A
3	Fault level during single phase to ground fault (in Amp), Equipment rating	40kA/ 50kA for 1 sec	40kA/ 31.5kA for 1 sec	Last recorded max fault current 13kA
4	Protection response time during the fault (in msec)	160 ms	160 ms	100-150 ms
5	Type, Cross-sectional dimensions and electrical properties of conductor	As per conductor specification		
6	General conductor spacing and heights above ground (in meter)	Ph-Ph: 5.3 m, Ph-G: 17.39 m Tower height: 36.39 m	Ph-Ph: 4.6 m, Ph-G: 13.3 m Tower height: 30.15 m	Ph-Ph: 2.4 m, Ph-G: 11.5 m Tower height: 20.5 m Distance b/w circuits: 6.5 m

7	Maximum resistance at tower ground and Substation (in ohm)	10	10	10
8	Minimum ground clearance for power line (in meter)	7.01	6.33	6.1

d) The pipeline data used as input to the model is as mentioned below:

- (1) Diameter: 36 inch
- (2) Material of Construction: Carbon Steel, API 5L X70
- (3) Depth: 1.2 m
- (4) Coating Type: 3 Layer Polyethylene (3LPE)
- (5) Coating Resistivity: 50,000 ohm-m²
- (6) Coating thickness: 3 mm

e) The study has been carried out based on the following assumptions:

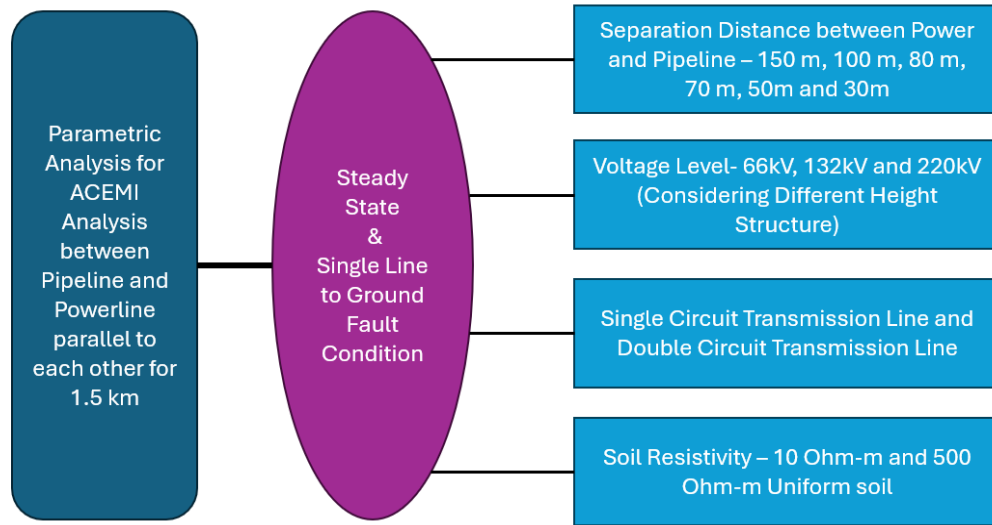
- i. **Ambient Conditions:** Modelling is based on standard ambient temperature and pressure. Humidity is not considered in the model. AC interference is expected to increase, if humidity is considered.
- ii. **Mitigation measures:** No previous mitigation measures have been considered in the model
- iii. **Ground Fault Current:** Ground fault current has been calculated using the software model, which is approximately 5% of the rated fault current, as tabulated at 2.1(h).
- iv. **Operating Load Current:** The operating load current for the 66 kV power line has been considered as 60% of the rated load current. The power line operators may run the power line at a higher load, potentially increasing interference on the pipeline.
- v. Other interference sources, such as electric traction lines, power-line substations, and transformer neutral earthing in the vicinity of the pipeline, have not been considered in the model.

This report is based on the assumptions as stated above to assess the possible interference effects of power lines on buried oil and gas pipelines located in vicinity. Further, detailed study covering but not limited to the following may be conducted on a case to case basis under actual conditions in lieu of above assumptions to study and design appropriate mitigation measures.

- **Variation of soil resistivity:**(25 ohmmeter for humid soil,100-ohm meter for dry and low humus soil,500-ohm meter for arid condition, 1500-ohm meter for stony condition)
- **Various Environmental effect** (Dry, Fog, Rainy)
- **Distance** (Width of share corridor, Distance of transmission line from pipeline)
- **Operational condition:** (Maximum demand of the line, Operation of the line during contingency condition)
- **Fault condition** (Designed earth fault value, Lightning condition)

- **Location of Other asset** (Electrical cables, Rail line in vicinity)

f) The followed interference scenarios have been modelled and simulated:



Note: Additional Scenarios are also considered, where the length of parallelism extends up to 10 km (with 150 m separation distance between Pipeline and Power line (66kV, 132kV, 220kV)

g) For steady state operation of the transmission line, the following pipeline results are obtained:

- (1) **PSP-Pipe to Soil Potential (AC) (in Volt):** As a first step, the AC voltage on the pipeline should be decreased to a target value, which should be 15 V rms or less. This value is measured as an average over a representative period of time (e.g. 24 h).
- (2) **Leakage Current Density** from 1 cm² Holiday* from the pipeline (in A/m²): In order to control AC corrosion with acceptable limit, the AC current density should not exceed a time- weighted average of:

- a) 30 A/m² if DC current density exceeds 1 A/m²
- b) 100 A/m² if DC current density is less than 1 A/m²

*(coating defect)

h) For single line to ground fault in the transmission line, the worst fault location is obtained from all the possible fault locations for each scenario and the following pipeline results are obtained:

- (3) **Coating Stress Voltage (in Volt):** Multiple references offer varying coating stress limits and are generally considered to be in the range of 1-1.2 kV for Bitumen, as low as 3 kV for coal tar, 3-5 kV for FBE and polyethylene, for a short duration fault.
- (4) **Touch Voltage (in Volt)**
- (5) **Step Voltage (in Volt)**

Detailed report based on the outcomes of the study, consisting of recommendation on separation distance between pipelines & powerlines is attached at **Annexure I**.

7. Right of User (RoU) of Oil and Gas Pipelines

- a) RoU is generally acquired as per “Acquisition of Right of User in land for laying pipeline for transport of Petroleum & Minerals Pipeline [P&MP (ARUL)] Act, 1962.
- b) RoU varies from entity to entity, pipeline size & future plans.
- c) It is declared by Competent Authority by MoP&NG as per recommendation of Chief Secretary of respective State Govt.
- d) It is publicized in Gazette by Govt. of India Press.
- e) Declaration of acquisition of right of user (RoU) as per Petroleum & Minerals Pipeline [P&MP (ARUL)] Act, 1962.

8. Recommendations:

- a) Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations, 2023 (attached at **Annexure II**) shall be strictly adhered by powerline/pipeline operators as it already consists of provisions to minimize the Electrical Interference effect on Oil and Gas pipelines
- b) All power lines with Right of Way (RoW) and Oil and Gas pipeline with Right of User (RoU) shall be mapped on PM Gati Shakti National Master Plan (NMP) for better coordination.
- c) Awareness session/ training may be imparted to pipeline/ powerline operators in the relevant area of hazard on pipelines due to Electric lines.
- d) Tower footing structure of new overhead line/ transformer shall be installed at such a distance so that maintenance activities could be carried out by powerline & pipeline operator.
- e) While laying underground power cables joints shall be avoided as far as possible and they shall also be laid at such a distance (horizontal & vertical) so that maintenance activities, could be carried out by powerline operator and vice-versa. Wherever sufficient distance is not feasible while laying cable due to site constraints suitable measures to be adopted to minimize the risk of accidental damage to underground power cable during pipeline maintenance or any future work. Further, power cable is less likely to be impacted by any heat or potential leaks from the pipeline, improving the long-term integrity of the cable.
- f) Grounding/Earthing of tower footing or structure of 11 kV and above overhead lines should not be towards Pipeline.
- g) For existing Oil and Gas pipelines, frequency of surveys/monitoring to be increased from present practice where interference exists beyond acceptable limit. Where

collocation is more than 1.5 km, emphasis should be given on preventive maintenance and conditional monitoring.

- h) In case parallelism of powerline and pipeline exists, interference study should be conducted and based on the outcome of the study, grounding of oil and gas pipeline at required locations is to be carried out.
- i) Cathodically protected pipeline may be grounded through DC Decoupling device at required locations based on studies.
- j) Aerial Bunched Conductors (ABC) shall be preferred to lay overhead electric line of voltage below 33 kV where LT powerlines are in close vicinity to pipelines.
- k) Separation distance in case of collocation of pipeline and powerline:
 - i. **For 220 kV Transmission line and above:** whenever collocation length with pipeline is 1.5 km and above and separation distance is less than 70 meter, suitable mitigating measures may be adopted by pipeline/powerline operators.
 - ii. **For 132 kV and 66 kV Transmission line:** whenever collocation length with pipeline is 1.5 km and above and separation distance is less than 50 meter, suitable mitigating measures may be adopted by pipeline/powerline operators.
- l) In case where above requirements are not meeting due to site constraints, suitable mitigation measures should be implemented by pipeline/powerline operators.
- m) A coordination committee has to be constituted in case where there is hazard to Oil and Gas pipeline from electric line with the following constitution:
 - i. Regional Inspectorate Organization (In-charge)- in Chair
 - ii. Concerned pipeline operator Member Secretary
 - iii. Concerned HoD of Discom/ Transco- Member

In the above-mentioned case, Member Secretary shall request CEA in writing to nominate any officer to conduct meeting under his/her Chairmanship with the above said officers. The committee has to conduct meeting and prepare a report in time bound manner on the issue after detailed discussion/deliberation and recommend some specific mitigating measures, if any in addition to recommendations mentioned in this report for the safety of Oil and Gas pipelines.

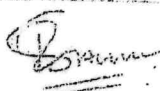
- n) This report is based on certain assumptions so as to assess the possible interference effects of power lines on buried oil and gas pipelines located in vicinity. Further, a detailed study may be conducted under actual conditions to study and design appropriate mitigation measures.

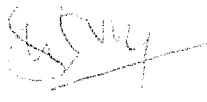
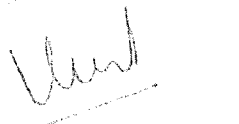
9. **References: -**

1. **NACE SP0177-2019:** *Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems.*
2. **NACE SP0169-2007:** *Control of External Corrosion on Underground or Submerged Metallic Piping Systems.*
3. **NACE SP21424-2018:** *Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring.*
4. **ISO 18086-2019:** *Corrosion of metals and alloys — Determination of AC corrosion — Protection criteria.*
5. **NACE Publication 35110-2010:** *AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements.*
6. **IEEE80-2013:** *Guide for Safety in AC Substation Grounding.*
7. **CEOCOR-2001:** *AC Corrosion on Cathodically Protected Pipelines: Guidelines for measurement techniques in cathodic protection.*
8. **OISD 188:** *Corrosion monitoring and control of offshore and onshore pipelines.*
9. **UKOPA/ GPG/ 027-2019:** *Good Practice Guide: AC Corrosion Guidelines.*
10. **CEPA-2014:** *AC Interference Guideline Final Report. Canadian Energy Pipeline Association.*
11. **CIGRE-1995:** *Guide on the Influence of High Voltage AC Power Systems on Metallic Pipelines.*
12. **DNV-GL. (2015). Final Report No. 2015-04:** *Criteria for Pipelines Co-existing with Electric Power Lines, INGAA Foundation.*
13. **EN 15280-2013:** *Evaluation of AC corrosion Likelihood of Buried Pipelines Applicable to*

10. Signature of Committee members

(Report on minimizing the effects of Electrical interference on Oil and Gas pipelines due to Electric Lines)

S. No.	Name and Designation	Designation w.r.t Committee	Name	Signature
1	Smt. Rishika Sharan, Chief Engineer, CEI, CEA	Chairman	Rishika Sharan	
2	Sh. Rahul Singh, Deputy Director, CEI, CEA	Convenor	RAHUL SINGH	
3	Representative from PGCIL	Member	AMIT KUMAR	
4	Representative from TPDDL	Member	Sarangapani Goswami	
5	Representative from MoP&NG	Member	SAILESH KUMAR	
6	Representative from EIL	Member	P. THIRUPATHI REDDY	
7	Representative from CPRI	Member	M.K. JAISWAL	
8	Representative from IOCL	Member	SUNIL S. KHODE	

9	Representative from GAIL	Member	Shiv Shanker Verma	
10.	Representative from BPCL	Member	Sunil Kamble Keshav Dewangan	
11.	Representative from HPCL	Member	T. J. RAMKISHORE GOPAL GARG	
12.	Representative from Manav Energy	Member	MUNISH MISHRA	

**Sub-group study report on
“Interference effect on Oil and
Gas carbon steel pipelines due to
collocation of different voltages
of overhead Electric Lines”**

1.0 Introduction

- (a) A Committee was formed constituting of representatives from CEA, MoPNG, Power line operators (PGCIL, Tata Power), Pipeline Operators (GAIL, IOCL, HPCL, BPCL) and EIL to study the *Hazards to Petroleum Pipelines by HT line crossing/ running parallel with pipelines across ROU* and formulate a Report on minimizing the effects of Electromagnetic Induction/Interference on Oil and Gas pipelines due to Electric lines.
- (b) In the 4th Committee meeting, held on 02.09.2024 it was advised by the chair to form a sub-group to further study the effects on pipeline in case of longer collocation with power lines. Accordingly, the sub-group committee of following members was formed:
- (6) Shri Rahul Singh, Dy. Director, CEA
 - (7) Shri Alok Kumar, Dy. Director, CEA
 - (8) Shri Shiv Shanker Verma, GM, GAIL
 - (9) Shri S. S. Khode, DGM, IOCL
 - (10) Shri Beni Madhav, DGM, PGCIL
 - (11) Shri Brajanath Dey/ Sarangapani Goswami, TPDDL
 - (12) Shri Munish Mishra, M/s Manav Energy
- (c) It was advised by CEI, CEA that the sub-group should conduct AC interference study on pipelines from over-head HT power lines of voltage rating 66 kV, 132 kV and 220 kV as a hypothetical case considering **collocation length of 1.5 km, 3 km & 10 km at varying separation distance** from the power line. Based on the outcomes of this study, the main Committee will take call for finalization of the guideline on separation distance between pipelines & powerlines.
- (d) In view of the above, the Right of Way (ROW) module of the SES CDEGS software package was used for creating AC interference model and simulating various interference scenarios.

2.0 Input data to software

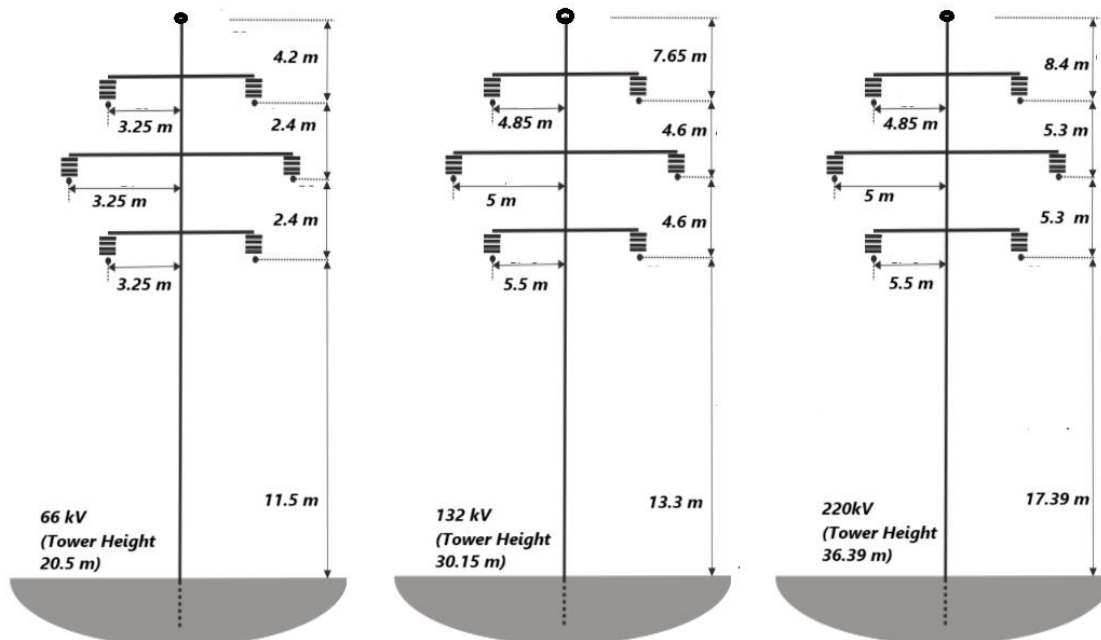
2.1 Power line data

- (a) The power line data for 132 kV and 220 kV power lines was provided by PGCIL while that of 66 kV was provided by Tata Power DDL. The power line data used in the study is tabulated as below:

	Power line	220 kV	132 kV	66 kV
1	Data source	PGCIL	PGCIL	Tata power
2	Rated load (in Amp): (Ambient: 45° C, Conductor temp: 85 ° C)	Zebra: 694 A	Panther: 465A	Goat: 634A
3	Fault level during single phase to ground fault (in Amp), Equipment rating	40kA/ 50kA for 1 sec	40kA/ 31.5kA for 1 sec	Last recorded max fault current 13kA
4	Protection response time during the fault (in msec)	160 ms	160 ms	100-150 ms
5	Type, Cross-sectional dimensions and electrical properties of conductor	As per conductor specification		
6	General conductor spacing and heights above ground (in meter)	Ph-Ph: 5.3 m, Ph-G: 17.39 m Tower height: 36.39 m	Ph-Ph: 4.6 m, Ph-G: 13.3 m Tower height: 30.15 m	Ph-Ph: 2.4 m, Ph-G: 11.5 m Tower height: 20.5 m Distance b/w circuits: 6.5 m

7	Maximum resistance at tower ground and Substation (in ohm)	10	10	10
8	Minimum ground clearance for power line (in meter)	7.01	6.33	6.1

- (b) Based on the above data, the following transmission line configuration (both in single circuit and double circuit configuration) is considered for the study:



- (c) Sag adjustment: The transmission lines are modelled in the software as straight lines between towers with an equivalent height that accounts for the maximum sag in the power line. The following sag is assumed for determination of equivalent height of conductor

SN	Voltage Level	Average Sag (m)
1	66kV	5.4 m
2	132 kV	7.2 m
3	220kV	10.38 m

Considering the sag from the table, the following average transmission line heights are chosen

Component Locations					
Location #	Name	Component Type	Y (m)	Z (m)	Associated Phase
1	Shield	OPT-GW_ALCOA 48/48/606	0	16.9	2 - Shield
2	R1	ACSR - British Standard Sizes_Goat	-3.25	12.7	3 - R1
3	Y1	ACSR - British Standard Sizes_Goat	-3.25	10.3	4 - Y1
4	B1	ACSR - British Standard Sizes_Goat	-3.25	7.9	5 - B1
5	R2	ACSR - British Standard Sizes_Goat	3.25	12.7	6 - R2
6	Y2	ACSR - British Standard Sizes_Goat	3.25	10.3	7 - Y2
7	B2	ACSR - British Standard Sizes_Goat	3.25	7.9	8 - B2
		Double-click to select			Select a Component T

66 kV powerline

Component Locations					
Location #	Name	Component Type	Y (m)	Z (m)	Associated Phase
1	Component #1	OPT-GW_ALCOA 48/48/606	0	25.35	2 - Shield
2	Component #2	ACSR - British Standard Sizes_	-4.85	17.7	3 - R1-132kV
3	Component #3	ACSR - British Standard Sizes_	-5	13.1	4 - Y1-132kV
4	Component #4	ACSR - British Standard Sizes_	-5.5	8.5	5 - B1-132kV
5	Component #5	ACSR - British Standard Sizes_	4.85	17.7	6 - R2-132kV
6	Component #6	ACSR - British Standard Sizes_	5	13.1	7 - Y2-132kV
7	Component #7	ACSR - British Standard Sizes_	5.5	8.5	8 - B2-132kV
		Double-click to select			Select a Compon

132 kV power line

Component Locations					
Location #	Name	Component Type	Y (m)	Z (m)	Associated Phase
1	Shield	OPT-GW_ALCOA 48/48/606	0	29.467	2 - Shield
2	R2	ACSR - British Standard Sizes_Zebra	-4.85	21.067	3 - R2
3	Y2	ACSR - British Standard Sizes_Zebra	-5	15.767	4 - Y2
4	B2	ACSR - British Standard Sizes_Zebra	-5.5	10.467	5 - B2
5	R1	ACSR - British Standard Sizes_Zebra	4.85	21.067	6 - R1
6	Y1	ACSR - British Standard Sizes_Zebra	5	15.767	7 - Y1
7	B1	ACSR - British Standard Sizes_Zebra	5.5	10.467	8 - B1
		Double-click to select			Select a Component Type

220 kV power line

- (d) The following average span lengths are assumed for the power lines

Sr. No	Voltage Level	Average Span Length (m)
1	66kV	200 m
2	132 kV	300 m
3	220kV	300 m

- (e) The tower footing details are provided as maximum value of 10 ohms for both 10 ohm-m and 500 ohm-m uniform soil. Therefore, to achieve the similar footing resistance, the following Tower grounding design are chosen. The designs yield 7.4 Ohm tower footing resistance for 10 ohm-m soil resistivity and 10.44 Ohm for 500 ohm-m soil resistivity.
- (f) For steady state analysis, rated current is considered for 132 kV and 220 kV Power lines and 60% of the rated current in case of 66 kV power line. The interference will be on higher side in case of rated steady state current is considered for 66 kV power line.

- (g) Coating stress, touch and step voltages are dependent on the magnitude of the fault current component discharged into the soil by the tower footings. It is therefore important to determine how much of the fault current returns to remote sources directly through the soil surrounding the grounding system. Part of the fault current which does not contribute to the conductive coupling, will return to the remote source terminals and to the transformer neutrals through overhead ground or shield wires, neutral wires and other metallic paths (such as counterpoises) connected to the tower footing grounding system. The ratio between the current flowing back to remote sources through the overhead wires and neutral wires of the transmission lines and the total fault current is described as the fault current split factor.

2.2 Pipeline data

The data of one of the pipelines is used as input to the model as mentioned below:

- (1) Diameter: 36 inch
- (2) Material of Construction: Carbon Steel, API 5L X70
- (3) Depth: 1.2 m
- (4) Coating Type: 3 Layer Polyethylene (3LPE)
- (5) Coating Resistivity: 50,000 ohm-m²
- (6) Coating thickness: 3 mm

2.3 Other Assumptions

The study has been carried out based on the following assumptions:

a. Ambient Conditions

Modelling is based on standard ambient temperature and pressure. Humidity is excluded but expected to further increase AC interference if considered.

b. Mitigation Measures

No earthing measures for the mitigation of expected AC interference have been considered in the modelling and simulations.

c. Ground Fault Current

The ground fault current has been calculated using the software model at approximately 5% of the rated fault current.

d. Operating Load Current

The operating load current for the 66 kV power line has been considered as 60% of the rated load current.

e. Other Interference Sources

Other interference sources, such as electric traction lines, power-line substations, and transformer neutral earthing in the vicinity of the pipeline, have not been considered.

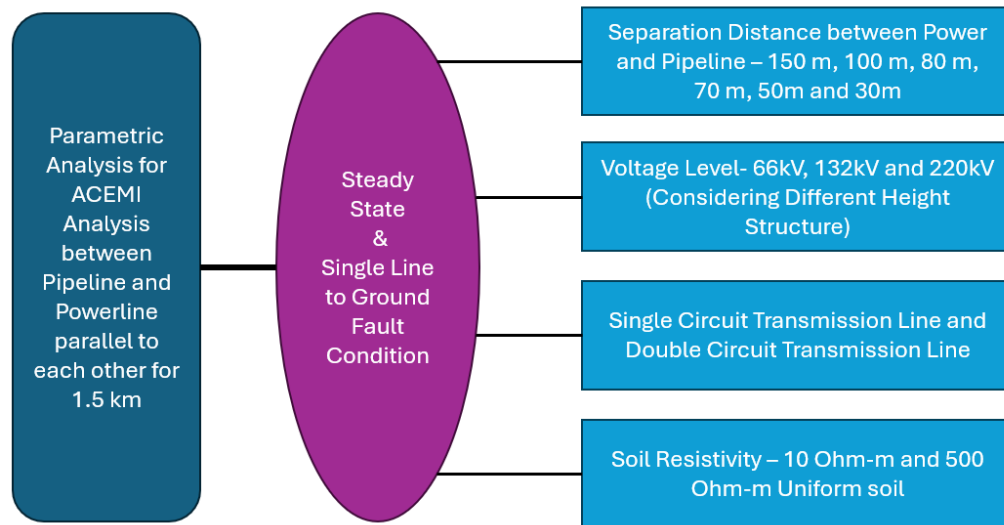
This report is based on the assumptions as stated above to assess the possible interference effects of power lines on buried carbon steel pipelines located in vicinity. Further, detailed study covering but not limited to the following may be conducted on a case to case basis under actual conditions in lieu of above assumptions to study and design appropriate mitigation measures.

- **Variation of soil resistivity:**(25 ohmmeter for humid soil,100-ohm meter for dry and low humus soil,500-ohm meter for arid condition, 1500-ohm meter for stony condition)
- **Various Environmental effect**(Dry, Fog, Rainy)
- **Distance** (Width of share corridor, Distance of transmission line from pipeline)
- **Operational condition:** (Maximum demand of the line, Operation of the line during contingency condition)
- **Fault condition** (Designed earth fault value, Lightning condition)

- **Location of Other asset** (Electrical cables, Rail line in vicinity)

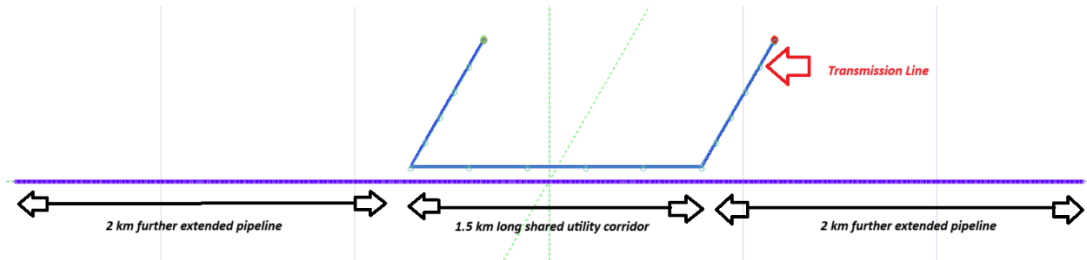
3.0 Modelled Scenarios

(a) The followed interference scenarios have been modelled and simulated

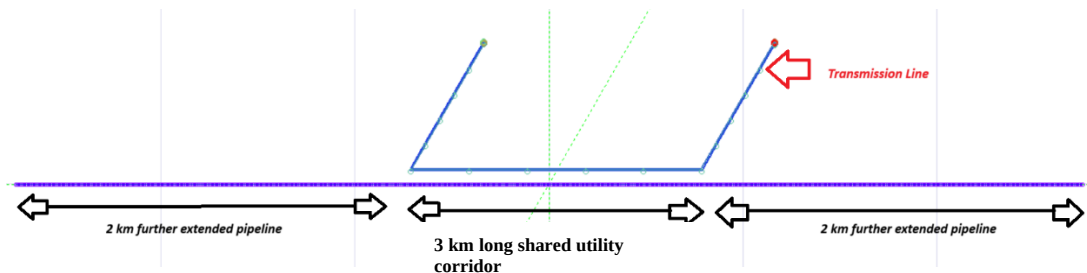


Note: Additional Scenarios are also considered, where the length of parallelism extends up to 10 km (with 150 m separation distance between Pipeline and Power line (66kV, 132kV, 220kV)

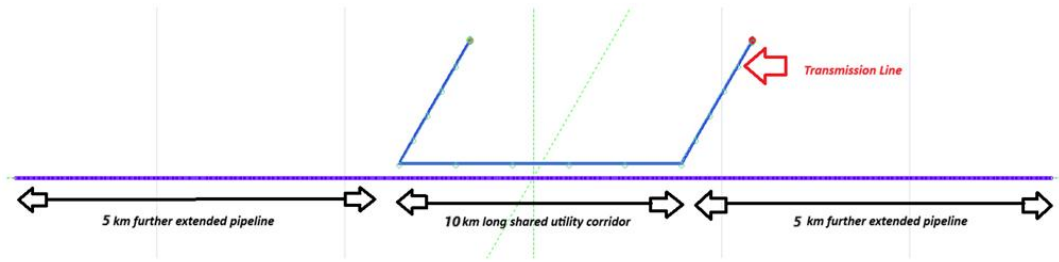
- (b) It is assumed that the power lines deviate perpendicularly to the pipeline, beyond the 1.5 km/ 3 km/ 10 km of shared utility corridor.
- (c) A plan view for the power line and pipeline is shown below:
- (7) Collocation length of 1 km



(13) Collocation length of 3 km



(14) Collocation length of 10 km



(d) For steady state operation of the transmission line, the following pipeline results are obtained:

(8) PSP-Pipe to Soil Potential (AC) (in Volt)

(15) Leakage Current Density from 1 cm² Holiday from the pipeline (in A/m²)

(e) For single line to ground fault in the transmission line, the worst fault location is obtained from all the possible fault locations for each scenario and the following pipeline results are obtained:

(9) Coating Stress Voltage (in Volt)

(16) Touch Voltage (in Volt)

(17) Step Voltage (in Volt)

(f) Interference scenarios considered in the study at collocation length of 1.5 km:

	Description of the parameters				Scenario Considered	
	Separation Distance b/w PL & TL	Voltage Level	Soil Resistivity (assumed)	Circuit Type	Steady State Operation of Pipeline	Single-Line-to-Ground Fault
Scenario 1	150 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 2	150 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 3	150 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 4	150 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 5	150 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 6	150 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 7	150 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 8	150 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 9	150 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 10	150 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 11	150 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 12	150 m	220kV	500 Ohm-m	D/C	Yes	Yes
Scenario 13	100 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 14	100 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 15	100 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 16	100 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 17	100 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 18	100 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 19	100 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 20	100 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 21	100 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 22	100 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 23	100 m	220kV	500 Ohm-m	S/C	Yes	Yes

Scenario 24	100 m	220kV	500 Ohm-m	D/C	Yes	Yes
Scenario 25	70 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 26	70 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 27	70 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 28	70 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 29	70 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 30	70 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 31	70 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 32	70 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 33	70 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 34	70 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 35	70 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 36	70 m	220kV	500 Ohm-m	D/C	Yes	Yes
Scenario 37	50 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 38	50 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 39	50 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 40	50 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 41	50 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 42	50 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 43	50 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 44	50 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 45	50 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 46	50 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 47	50 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 48	50 m	220kV	500 Ohm-m	D/C	Yes	Yes
Scenario 49	30 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 50	30 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 51	30 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 52	30 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 53	30 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 54	30 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 55	30 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 56	30 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 57	30 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 58	30 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 59	30 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 60	30 m	220kV	500 Ohm-m	D/C	Yes	Yes

(g) Interference scenarios considered in the study at collocation length of 3 km:

	Description of the parameters				Scenario Considered	
	Separation Distance b/w PL & TL	Voltage Level	Soil Resistivity (assumed)	Circuit Type	Steady State Operation of Pipeline	Single-Line-to-Ground Fault

Scenario 1	30 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 2	30 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 3	30 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 4	30 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 5	30 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 6	30 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 7	30 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 8	30 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 9	30 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 10	30 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 11	30 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 12	30 m	220kV	500 Ohm-m	D/C	Yes	Yes
Scenario 13	50 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 14	50 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 15	50 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 16	50 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 17	50 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 18	50 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 19	50 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 20	50 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 21	50 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 22	50 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 23	50 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 24	50 m	220kV	500 Ohm-m	D/C	Yes	Yes

(h) Interference scenarios considered in the study at collocation length of 10 km:

	Description of the parameters				Scenario Considered	
	Separation Distance b/w PL & TL	Voltage Level	Soil Resistivity (assumed)	Circuit Type	Steady State Operation of Pipeline	Single-Line-to-Ground Fault
Scenario 1	150 m	66kV	10 Ohm-m	S/C	Yes	Yes
Scenario 2	150 m	66kV	10 Ohm-m	D/C	Yes	Yes
Scenario 3	150 m	66kV	500 Ohm-m	S/C	Yes	Yes
Scenario 4	150 m	66kV	500 Ohm-m	D/C	Yes	Yes
Scenario 5	150 m	132kV	10 Ohm-m	S/C	Yes	Yes
Scenario 6	150 m	132kV	10 Ohm-m	D/C	Yes	Yes
Scenario 7	150 m	132kV	500 Ohm-m	S/C	Yes	Yes
Scenario 8	150 m	132kV	500 Ohm-m	D/C	Yes	Yes
Scenario 9	150 m	220kV	10 Ohm-m	S/C	Yes	Yes
Scenario 10	150 m	220kV	10 Ohm-m	D/C	Yes	Yes
Scenario 11	150 m	220kV	500 Ohm-m	S/C	Yes	Yes
Scenario 12	150 m	220kV	500 Ohm-m	D/C	Yes	Yes

4.0 Applicable standards

4.1 AMPP (NACE)

(a) **AMPP (NACE) SP0177 and its amendments: Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems**

- (1) A steady-state touch voltage of 15 V or more with respect to local earth or exposed sections is considered to constitute a shock hazard.
- (2) Stress voltage limits for coal tar, asphalt coating, fusion bonded epoxy (FBE) and 3LPE coating shall be as per mentioned in AMPP (NACE) SP0177 and its amendments.

(b) **AMPP (NACE) SP 21424: Alternating Current (AC) Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring**

In order to control AC corrosion with acceptable limit, the AC current density should not exceed a time- weighted average of:

- 30 A/m² if DC current density exceeds 1 A/m²
- 100 A/m² if DC current density is less than 1 A/m²

4.2 ISO Standard

(a) **ISO 18086: Corrosion of metals and alloys — Determination of AC corrosion — Protection criteria**

The design, installation, and maintenance of the Cathodic Protection system shall ensure that the levels of AC voltage do not cause AC corrosion. This is achieved by reducing the AC voltage on the pipeline and current densities as specified below:

- (1) As a first step, the AC voltage on the pipeline should be decreased to a target value, which should be 15 V rms or less. This value is measured as an average over a representative period of time (e.g. 24 h).
- (2) Effective AC corrosion mitigation can be achieved by maintaining the AC average current density (rms) over a representative period of time (e.g. 24 h) to be lower than 30 A/m².

5.0 Summary of Results (Simulation Plots attached)

5.1 220 kV Power line:

Scenarios	Steady State		Fault State	
	AC PSP (V)	AC Current Density (A/m ²)	Coating Stress Voltage (V)	Touch Potential (V)
Threshold as per Standards	15	30	3000	437
Collocation-1.5km, Separation- 30 m	18 (500 Ωm)	270 (10 Ωm)	8500 (500 Ωm)	8600 (500 Ωm)
Collocation-1.5km, Separation- 50 m	12 (500 Ωm)	150 (10 Ωm)	6000 (500 Ωm)	6000 (500 Ωm)
Collocation-1.5km, Separation- 70 m	9.5 (500 Ωm)	97 (10 Ωm)	5000 (500 Ωm)	5000 (500 Ωm)
Collocation-1.5km, Separation- 100 m	8 (500 Ωm)	64 (10 Ωm)	4200 (500 Ωm)	4200 (500 Ωm)
Collocation-1.5km, Separation- 150 m	6 (500 Ωm)	36 (10 Ωm)	3400 (500 Ωm)	3500 (500 Ωm)
Collocation-3km, Separation- 30 m	35 (500 Ωm)	560 (10 Ωm)	14000 (500 Ωm)	14000 (500 Ωm)
Collocation-3km, Separation- 50 m	24 (500 Ωm)	310 (10 Ωm)	11000 (500 Ωm)	11000 (500 Ωm)
Collocation-10km, Separation- 150 m	29 (500 Ωm)	240 (10 Ωm)	18000 (500 Ωm)	18000 (500 Ωm)

5.2 132 kV Power line:

Scenarios	Steady State		Fault State	
	AC PSP (V)	AC Current Density (A/m ²)	Coating Stress Voltage (V)	Touch Potential (V)
Threshold as per Standards	15	30	3000	437
Collocation-1.5km, Separation- 30 m	11 (500 Ωm)	150 (10 Ωm)	6500 (500 Ωm)	6500 (500 Ωm)
Collocation-1.5km, Separation- 50 m	6 (500 Ωm)	85 (10 Ωm)	4800 (500 Ωm)	4800 (500 Ωm)
Collocation-1.5km, Separation- 70 m	4.5 (500 Ωm)	55 (10 Ωm)	3800 (500 Ωm)	3800 (500 Ωm)
Collocation-1.5km, Separation- 100 m	4.5 (500 Ωm)	35 (10 Ωm)	3200 (500 Ωm)	3200 (500 Ωm)
Collocation-1.5km, Separation- 150 m	4 (500 Ωm)	22 (10 Ωm)	2800 (500 Ωm)	2800 (500 Ωm)
Collocation-3km, Separation- 30 m	19 (500 Ωm)	320 (10 Ωm)	9000 (500 Ωm)	9000 (500 Ωm)
Collocation-3km, Separation- 50 m	7 (500 Ωm)	180 (10 Ωm)	7500 (500 Ωm)	7500 (500 Ωm)
Collocation-10km, Separation- 150 m	17 (500 Ωm)	140 (10 Ωm)	14000 (500 Ωm)	14000 (500 Ωm)

5.3 66 kV Power line:

Scenarios	Steady State		Fault State	
	AC PSP (V)	AC Current Density (A/m ²)	Coating Stress Voltage (V)	Touch Potential (V)
Threshold as per Standards	15	30	3000	437
Collocation-1.5km, Separation- 30 m	5 (500 Ωm)	90 (10 Ωm)	4700 (500 Ωm)	4700 (500 Ωm)
Collocation-1.5km, Separation- 50 m	4.5 (500 Ωm)	55 (10 Ωm)	3500 (500 Ωm)	3500 (500 Ωm)
Collocation-1.5km, Separation- 70 m	3.7 (500 Ωm)	40 (10 Ωm)	3100 (500 Ωm)	3100 (500 Ωm)
Collocation-1.5km, Separation- 100 m	3.2 (500 Ωm)	30 (10 Ωm)	2600 (500 Ωm)	2600 (500 Ωm)
Collocation-1.5km, Separation- 150 m	2.5 (500 Ωm)	20 (10 Ωm)	2000 (500 Ωm)	2000 (500 Ωm)
Collocation-3km, Separation- 30 m	11 (500 Ωm)	180 (10 Ωm)	7000 (500 Ωm)	7000 (500 Ωm)
Collocation-3km, Separation- 50 m	9 (500 Ωm)	120 (10 Ωm)	6000 (500 Ωm)	6000 (500 Ωm)

Collocation-10km, Separation- 150 m	11 (500 Ω m)	90 (10 Ω m)	9500 (500 Ω m)	9500 (500 Ω m)
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6.0 Conclusion

6.1 Steady state condition

6.1.1 AC PSP:

- (a) It is observed that at collocation length of 1.5 km and separation distance of 30 m, the steady state AC PSP is exceeding the acceptable threshold of 15 V only for 220 kV power line constructed in 500 ohm-m soil. AC PSP is within limit for all the three power lines at separation distance greater than 70 m.
- (b) At collocation lengths of 3 km and 10 km, significant interference is expected.

6.1.2 AC Current Density

- (a) It is observed that at collocation length of 1.5 km and separation distance of 30 m, 50m & 70m, Interference is higher and AC Current density is exceeding the acceptable threshold of 30 A/m² for all the 3 power lines i.e. 66kV, 132kV, 220kV. At separation distance of 150 m, AC Current density is on higher side only for 220 kV power line. However, for 66kV powerlines too, if the load current is assumed for rated conditions, then it may result in higher AC current density.
- (b) At collocation length of 3 km and 10 km, interference is very high wherein AC Current density is reaching up to 560 A/m².

6.2 Fault state condition

6.2.1 Coating Stress Voltage

- (a) It is observed that at collocation length of 1.5 km and separation distance of 30 m, Coating Stress Voltage is exceeding the acceptable threshold of 3000 V for all the 3 power lines. At separation distance of 150 m, Coating Stress Voltage is on higher side only for 220 kV power line.
- (b) At collocation length of 3 km and 10 km, interference is very high wherein Coating Stress Voltage may reach up to 18000 V.

6.2.2 Touch Potential

- (a) It is observed that Touch Potential is on higher side in all cases but this would require mitigations at limited locations at stations where pipe surface is accessible.

6.2.3 Step Potential

- (a) It is observed that Step Potential is within acceptable limit in all cases and no mitigation is required

6.3 Recommended separation distance in collocation of new powerline & pipeline:

- (a) Considering the above simulation results with different scenarios for a collocation length of 1.5 km and above, collocation of new powerlines with pipelines should be avoided as far as possible.
- (b) However, where above is not feasible, the separation distance along with mitigation measures shall be as per given below

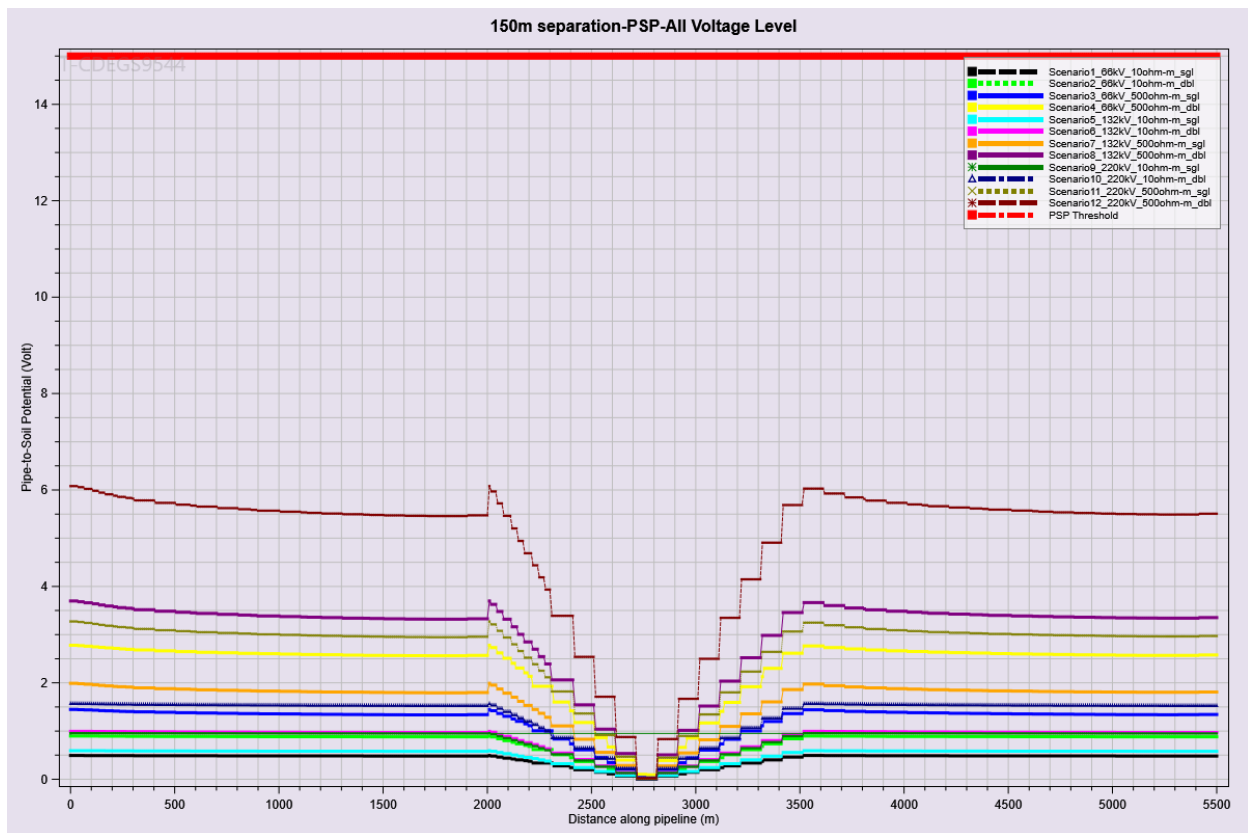
- iii. **For 220 kV Transmission line and above:** whenever collocation length with pipeline is 1.5 km and above and separation distance is less than 70 meter, mitigating measures as mentioned below may be adopted by pipeline/powerline operators.
- iv. **For 132 kV and 66 kV Transmission line:** whenever collocation length with pipeline is 1.5 km and above and separation distance is less than 50 meter, mitigating measures as mentioned below may be adopted by pipeline/powerline operators.
- v. **Mitigation measure**
 - **Earthing and grounding:** Reduce induced AC voltage through proper grounding.
 - **Shielding techniques:** Use gradient control mats and zinc ribbon grounding systems.
 - **Pipeline coating enhancement:** Increase coating resistivity and thickness.

1.0 Simulation Plots for collocation length of 1.5 km

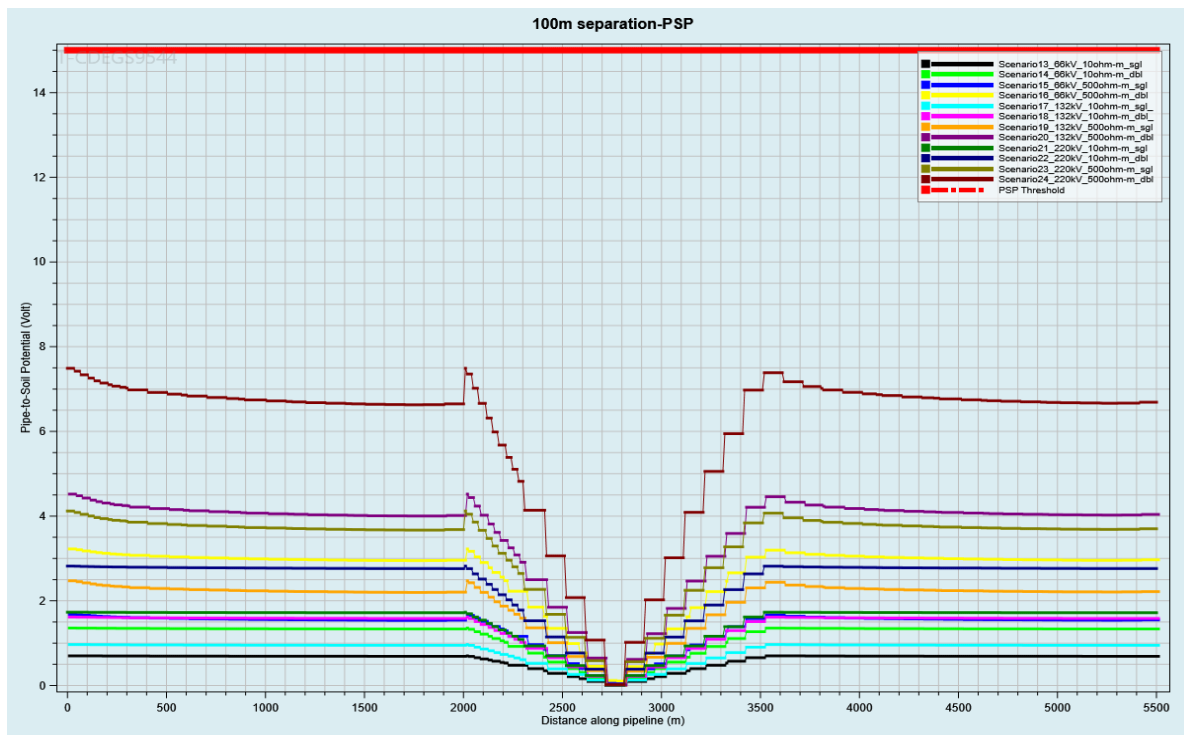
1.1 Steady-State Condition

(a) AC Pipe to Soil Potential

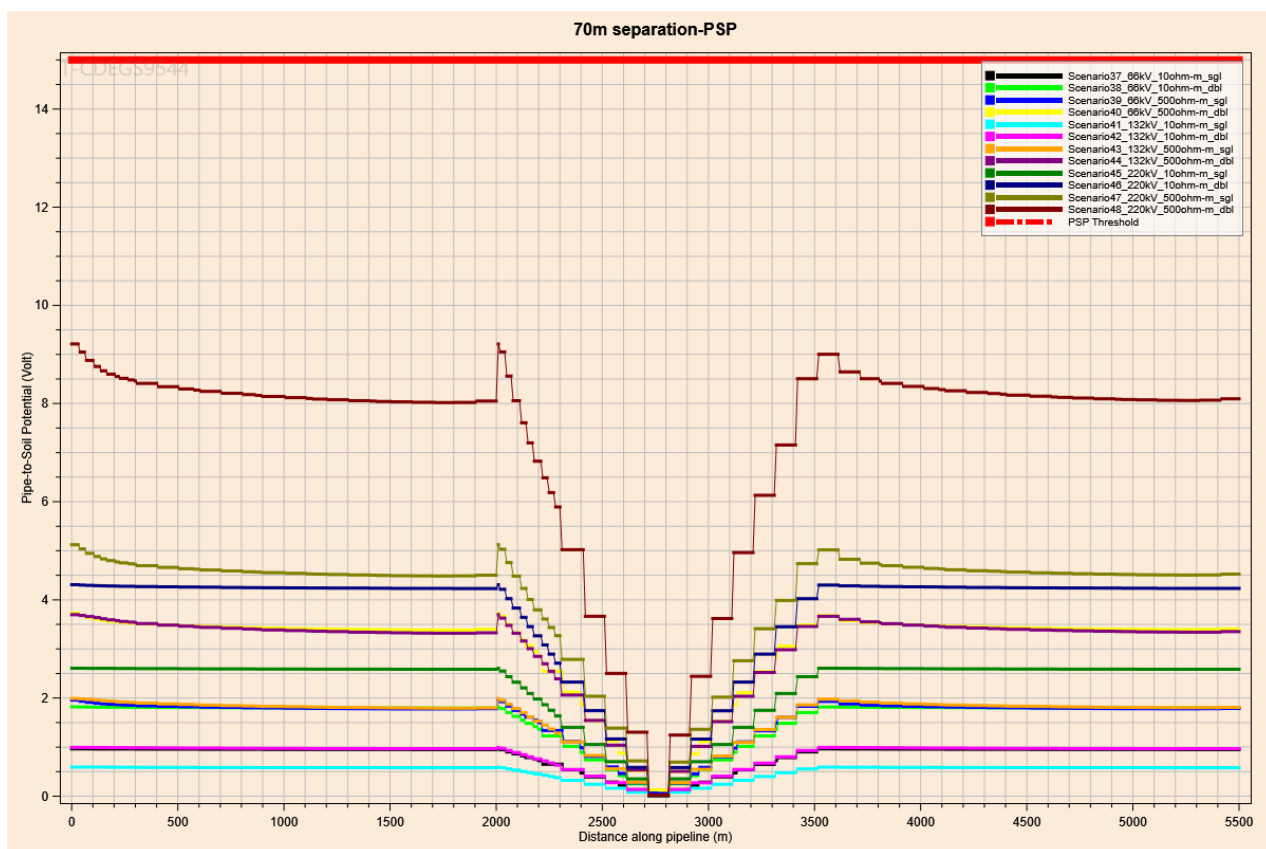
(3) 150 m Separation Distance



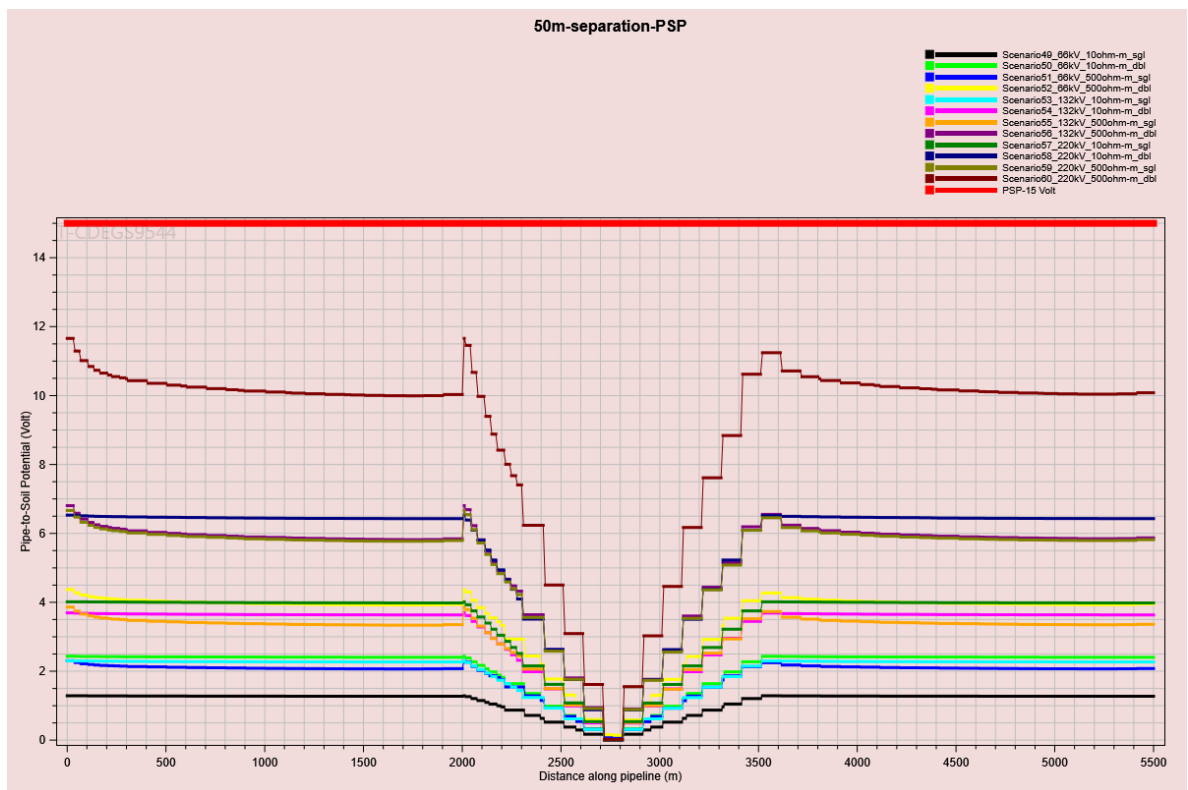
(18) 100 m Separation Distance



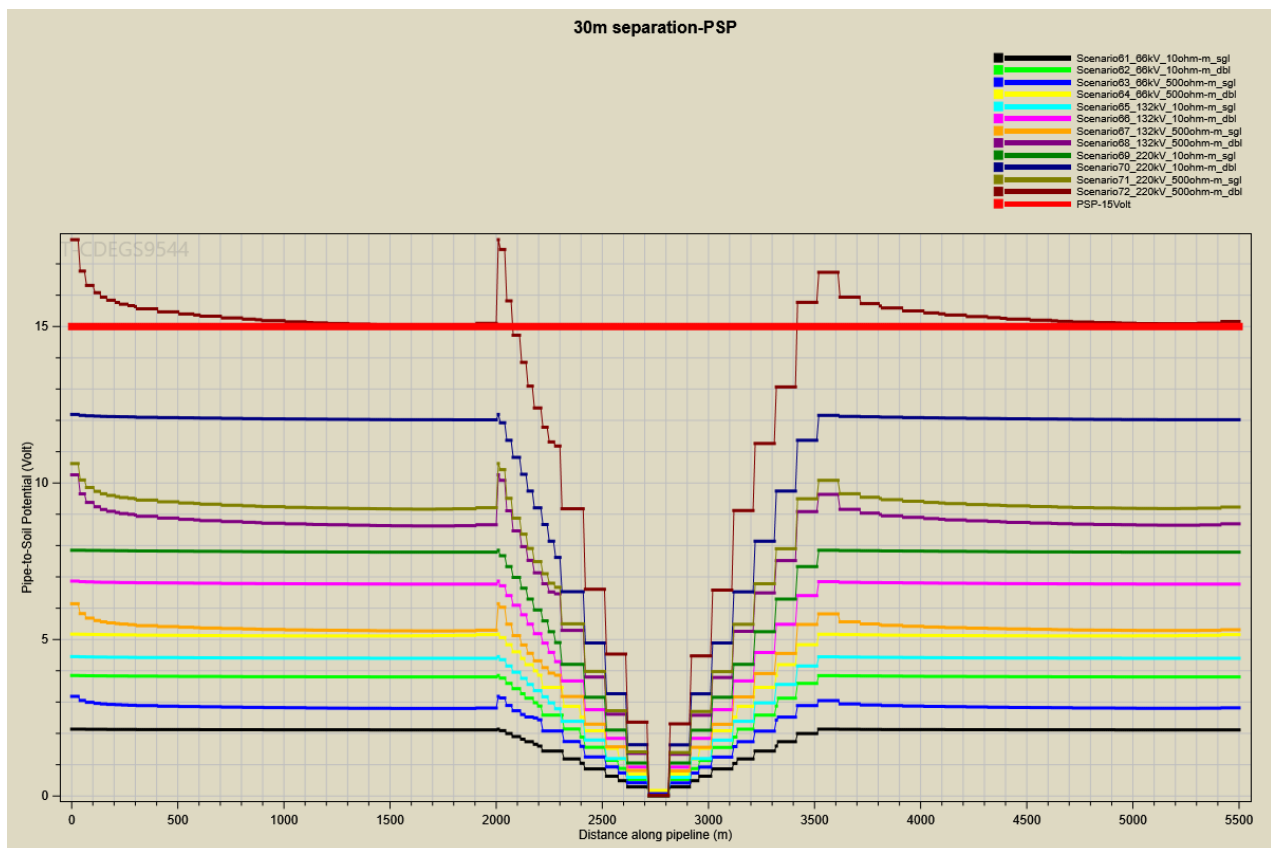
(19) 70 m Separation Distance



(20) 50 m Separation Distance

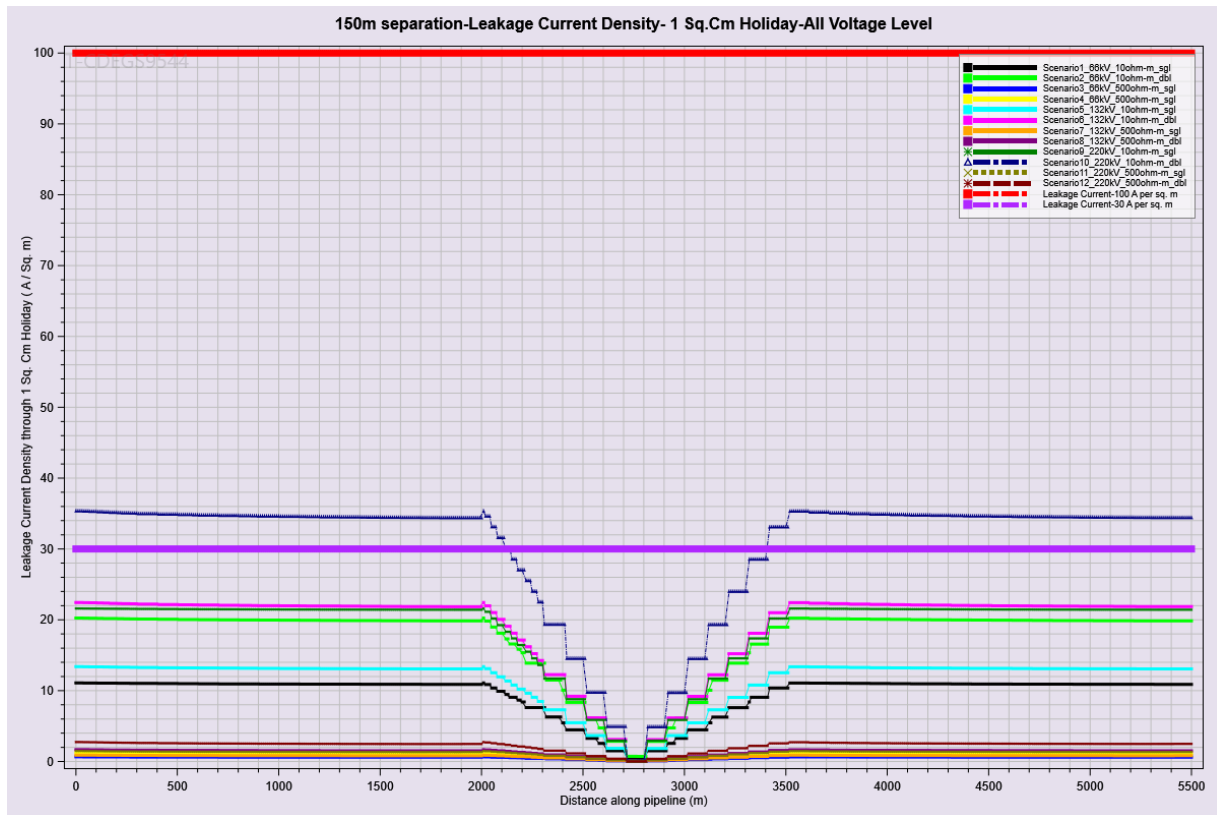


(21) 30 m Separation Distance

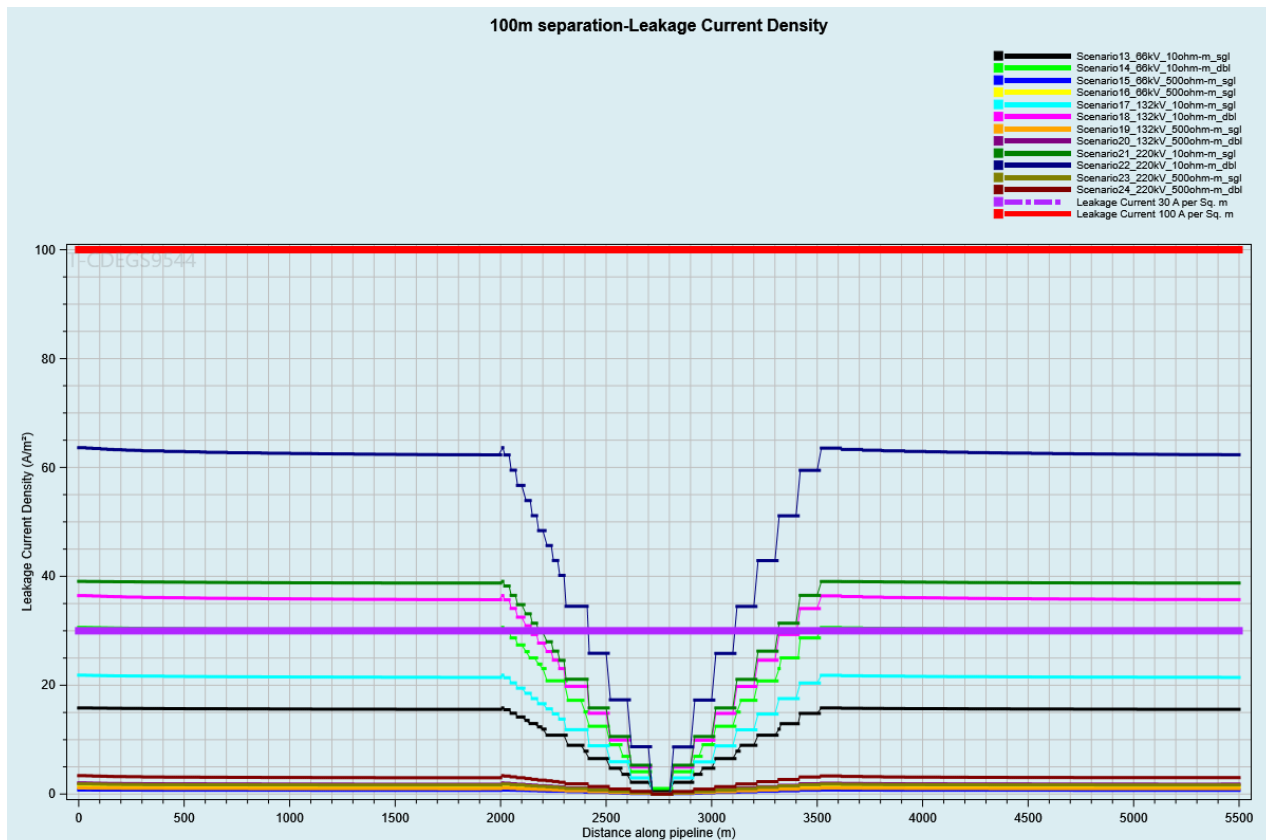


(b) AC Leakage Current Density from 1 cm² Holiday

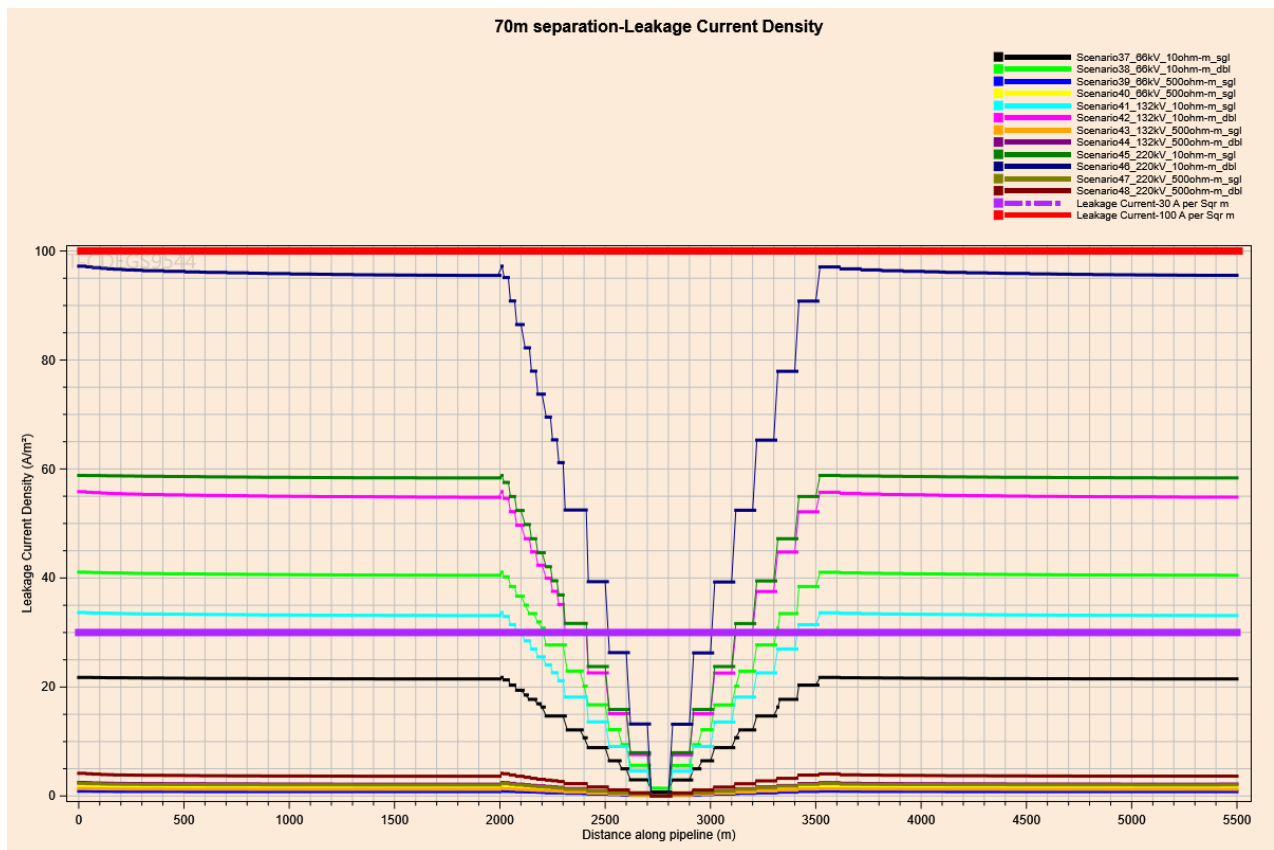
(4) 150 m Separation Distance



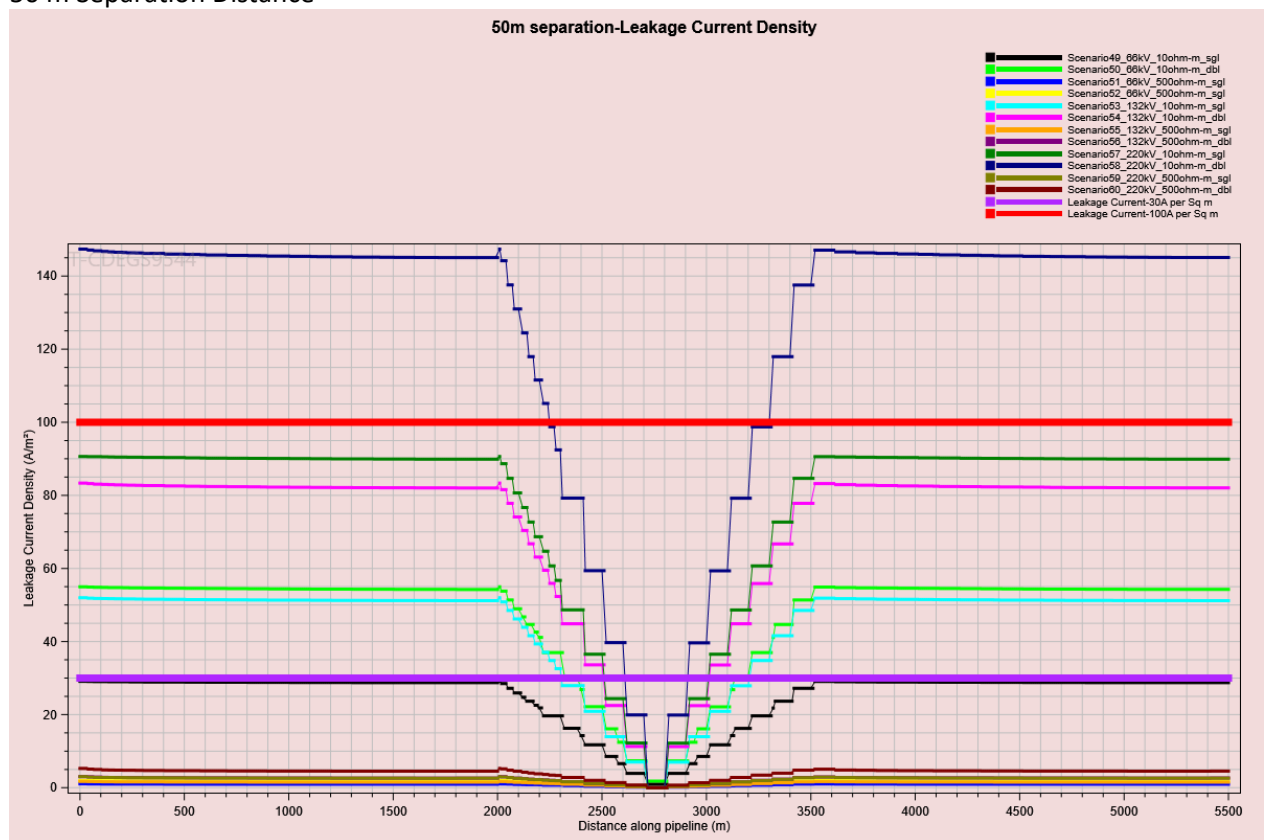
(22) 100 m Separation Distance



(23) 70 m Separation Distance

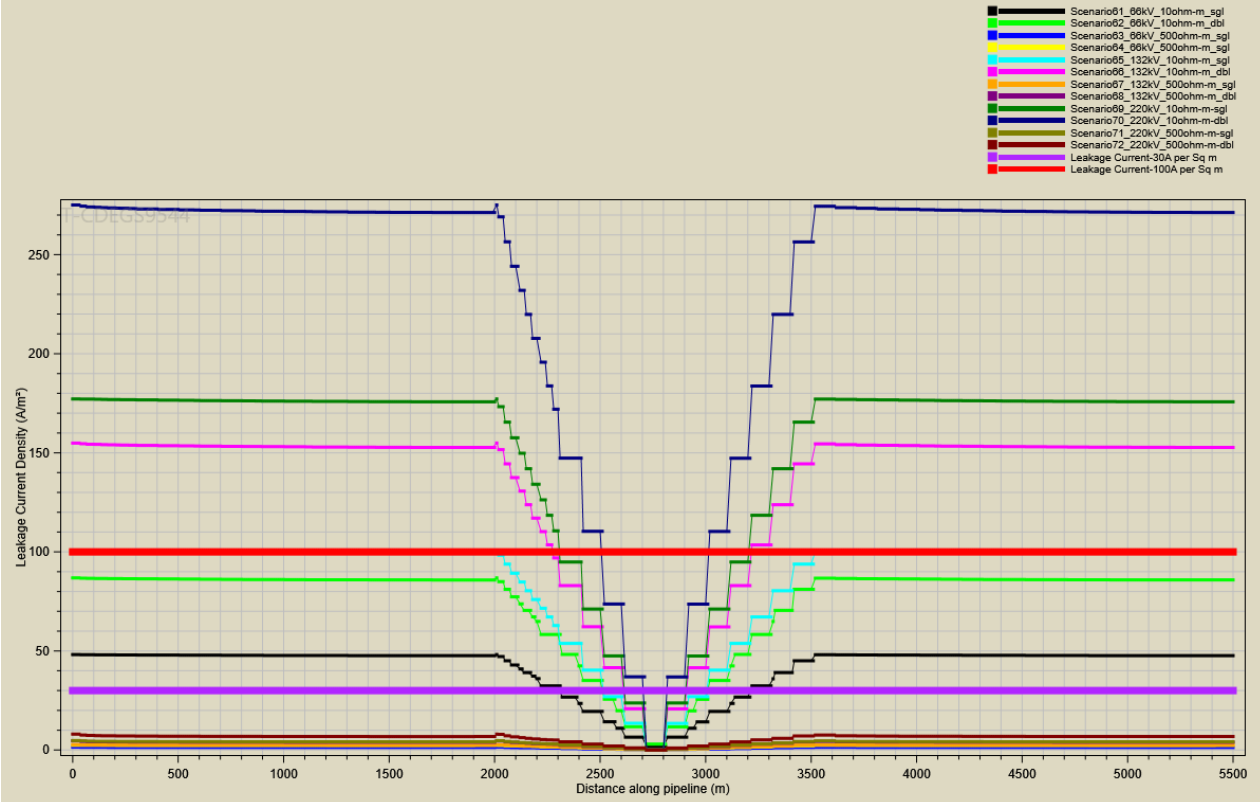


(24) 50 m Separation Distance



(25) 30 m Separation Distance

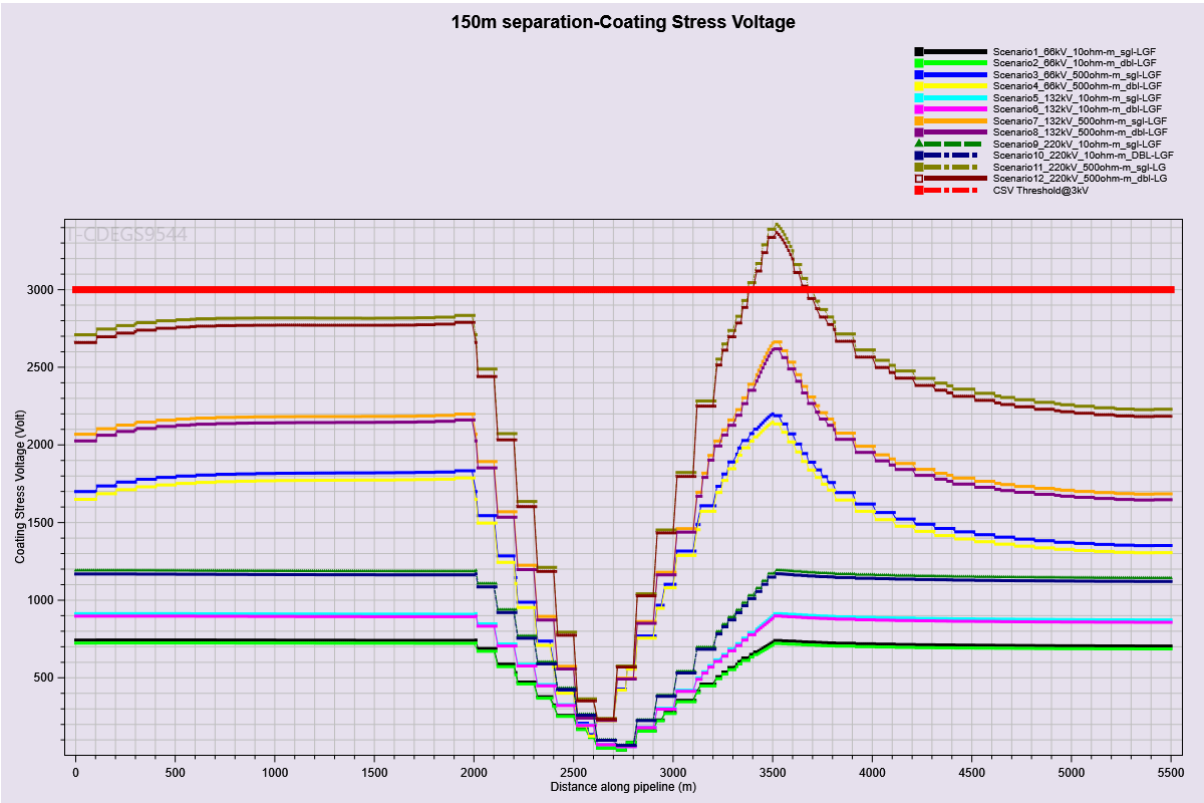
30m separation-Leakage Current Density



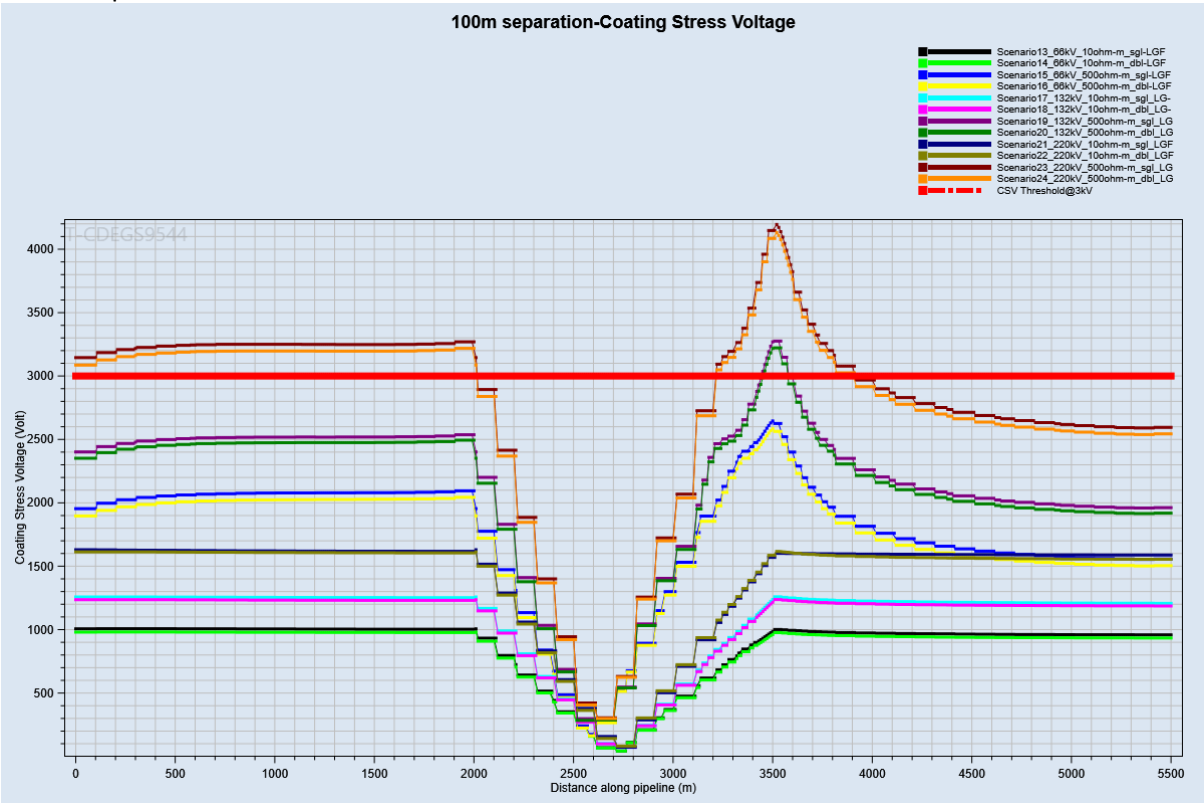
1.2 Single Line-to-Ground Fault Condition:

(a) Coating Stress Voltage:

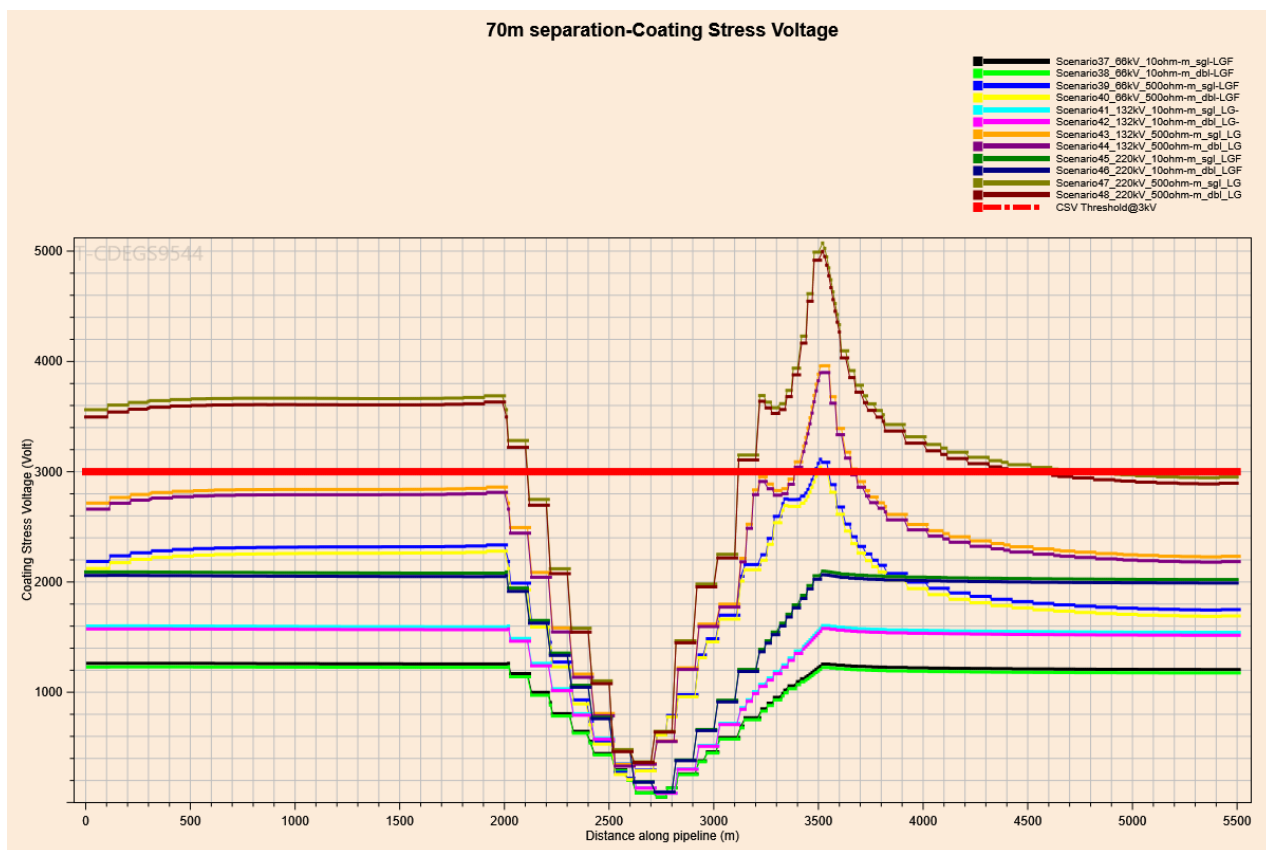
(5) 150 m Separation Distance



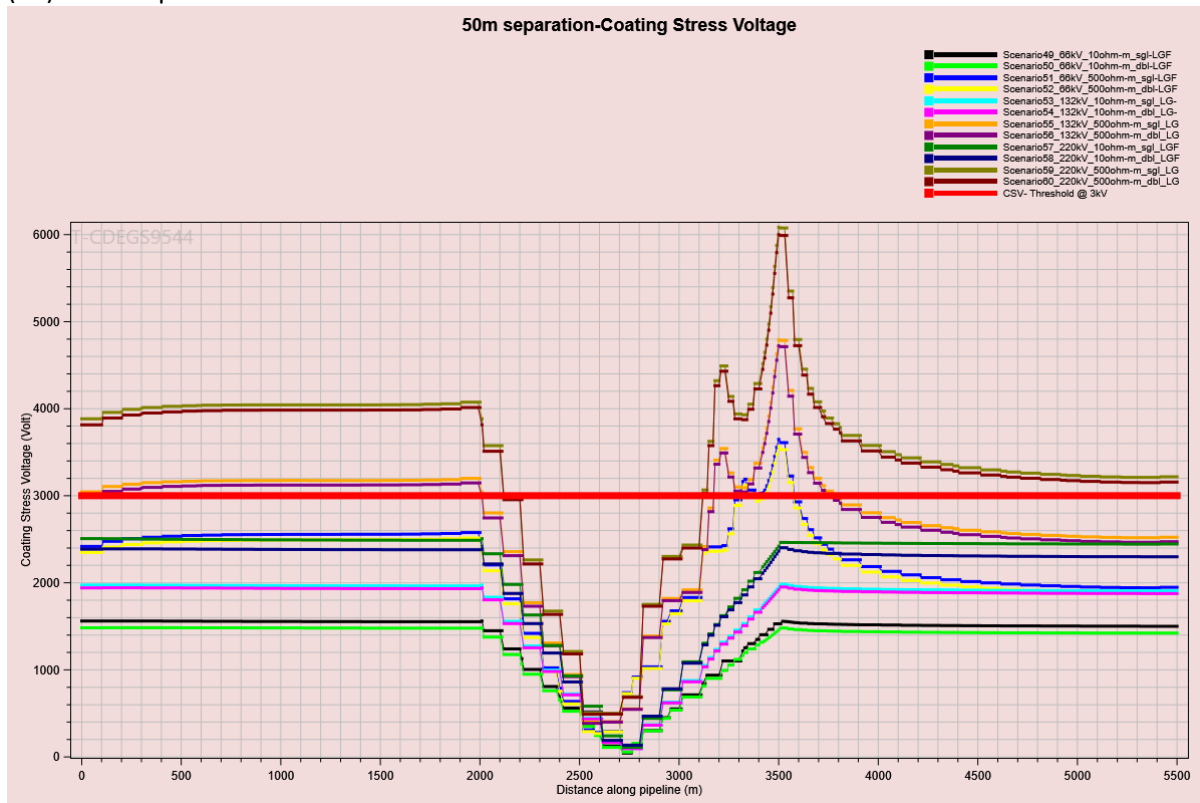
(26) 100 m Separation Distance



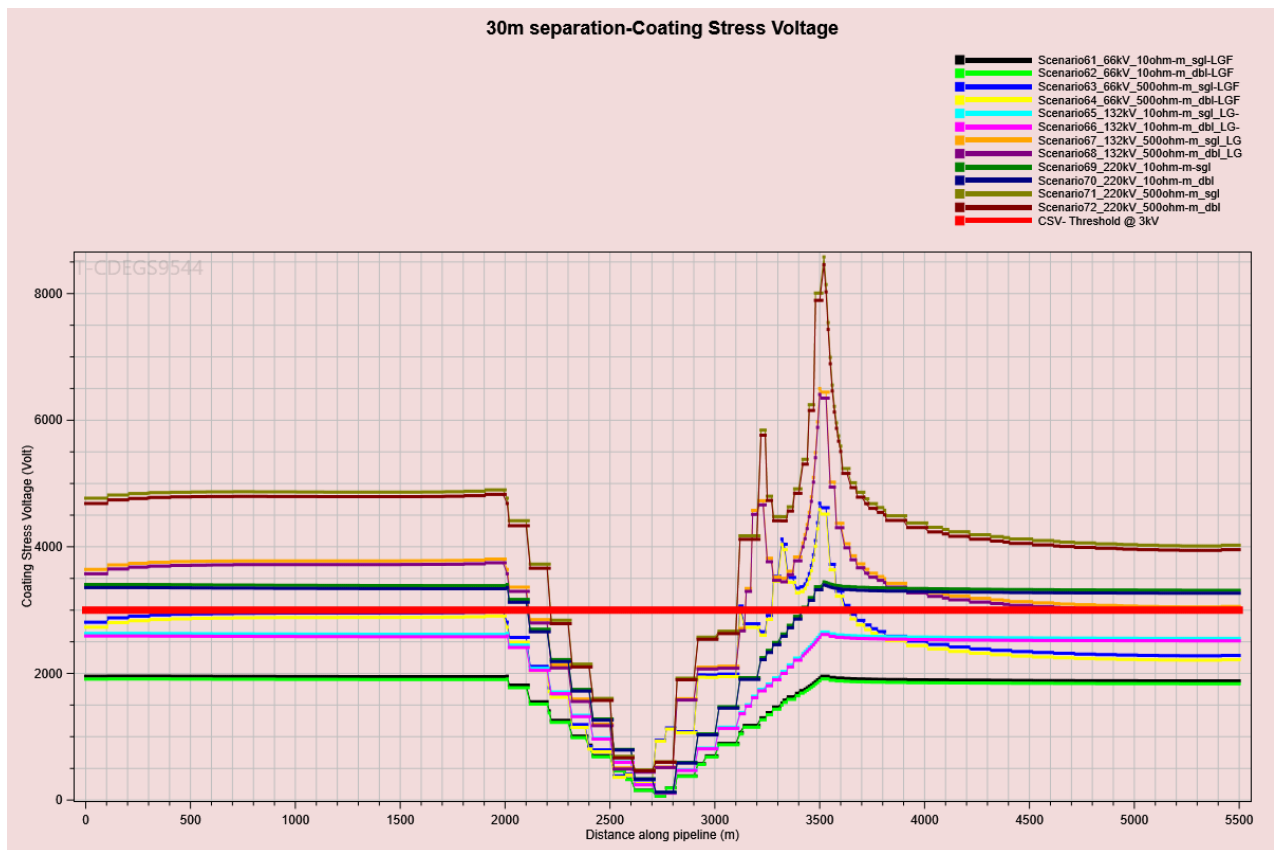
(27) 70 m Separation Distance



(28) 50 m Separation Distance

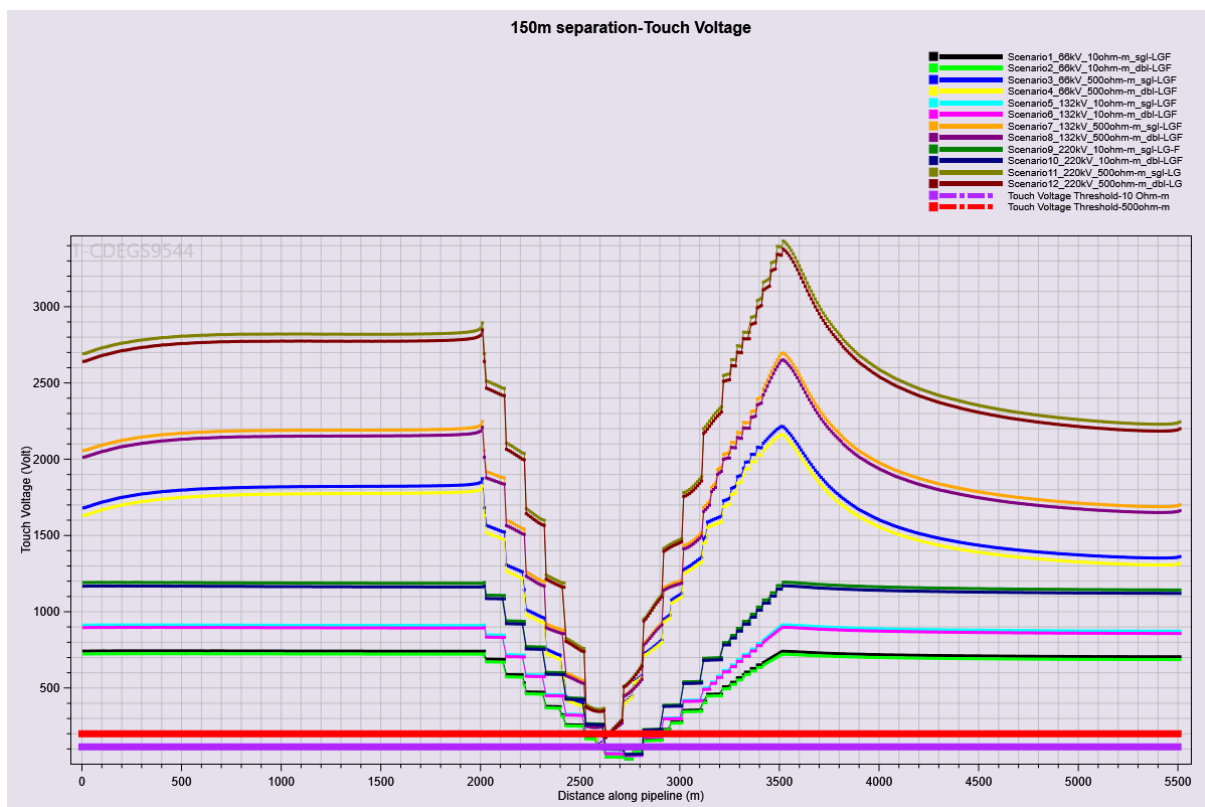


(29) 30 m Separation Distance

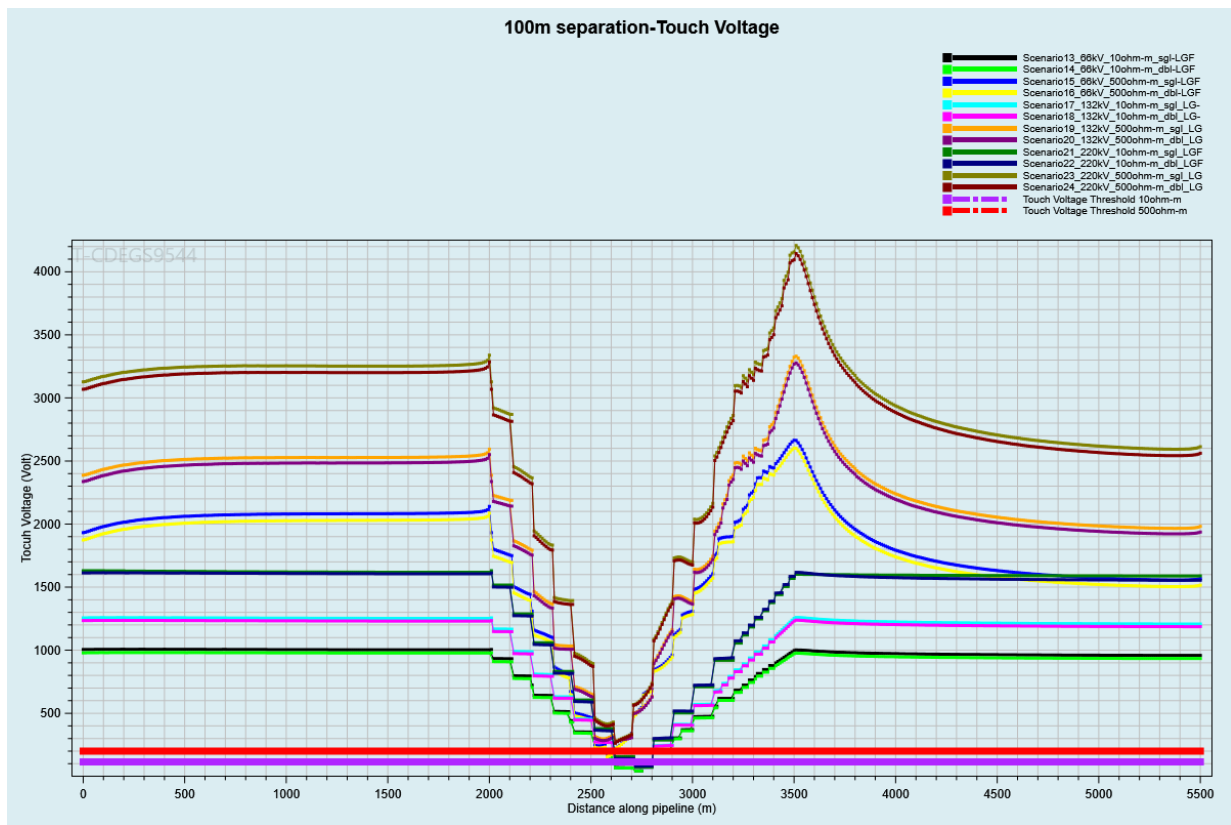


(b) Touch Voltage:

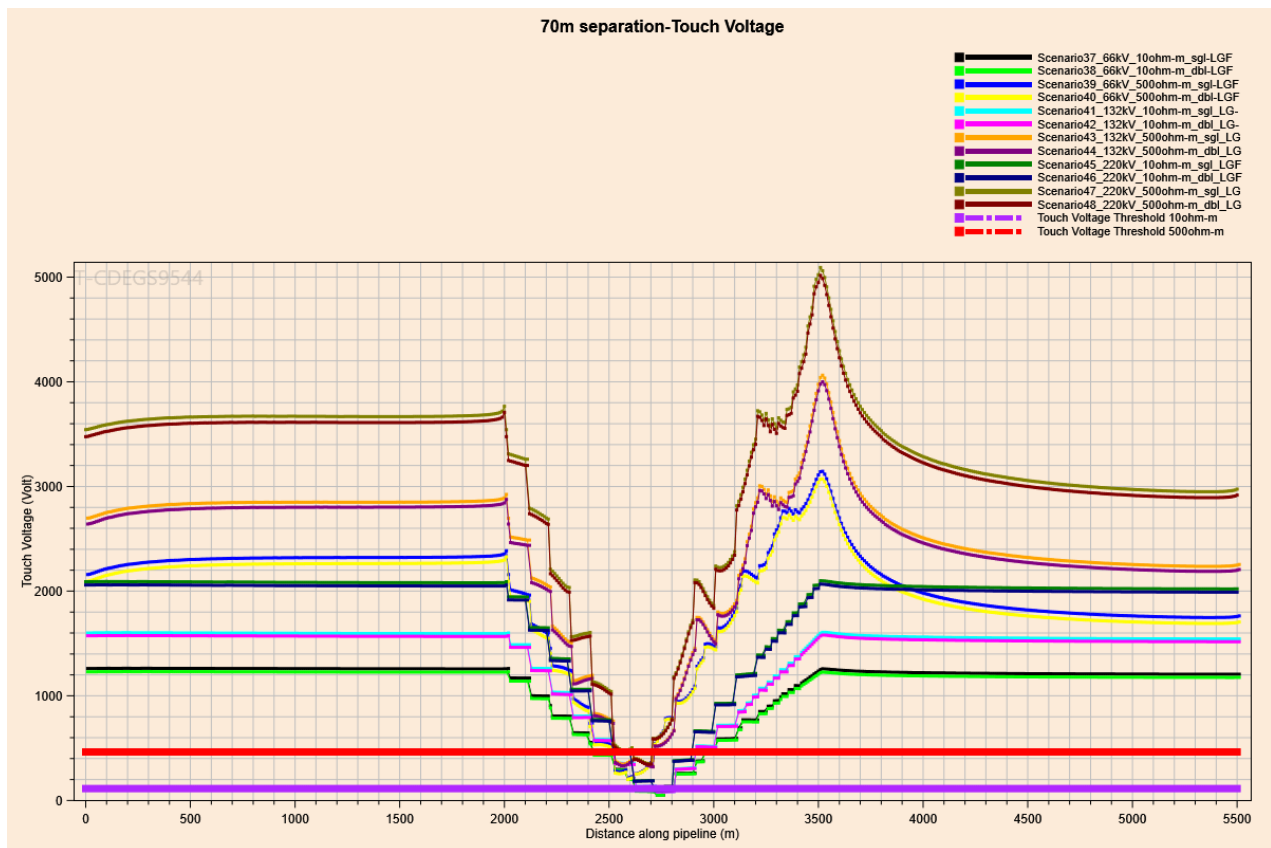
(6) 150 m Separation Distance



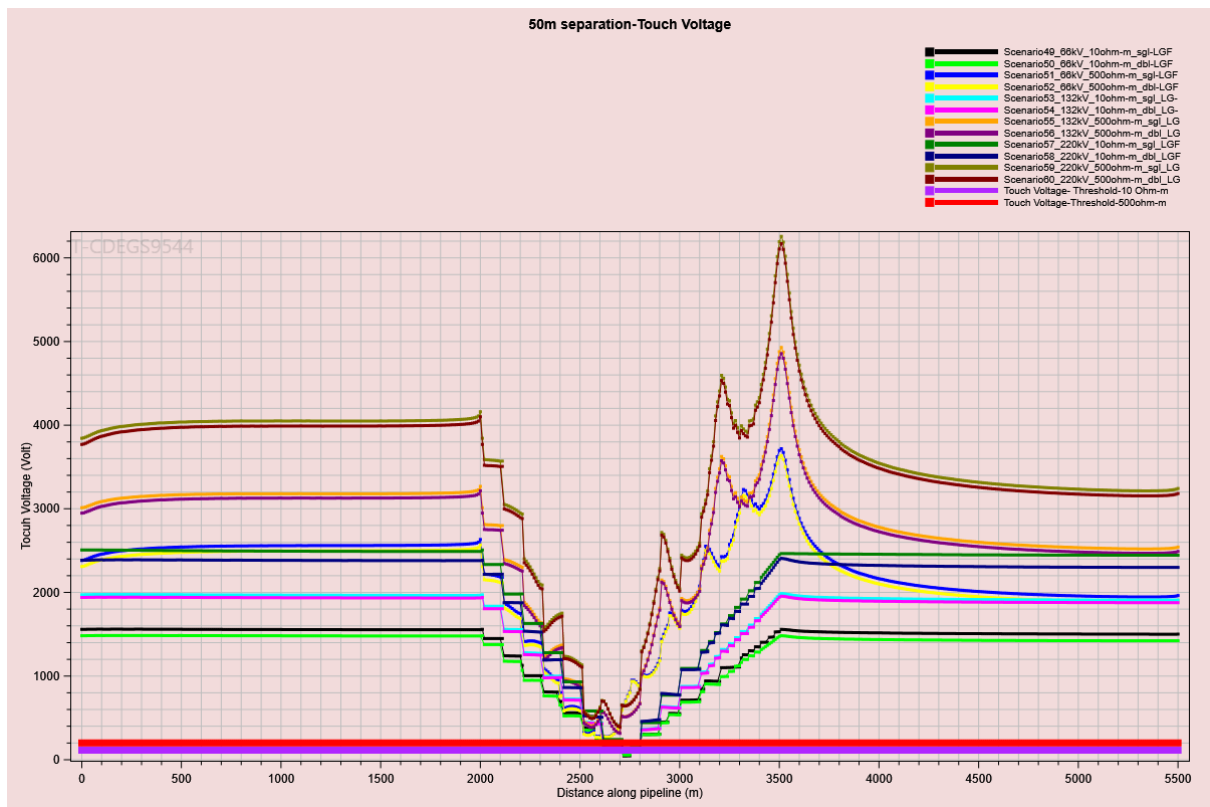
(30) 100 m Separation Distance



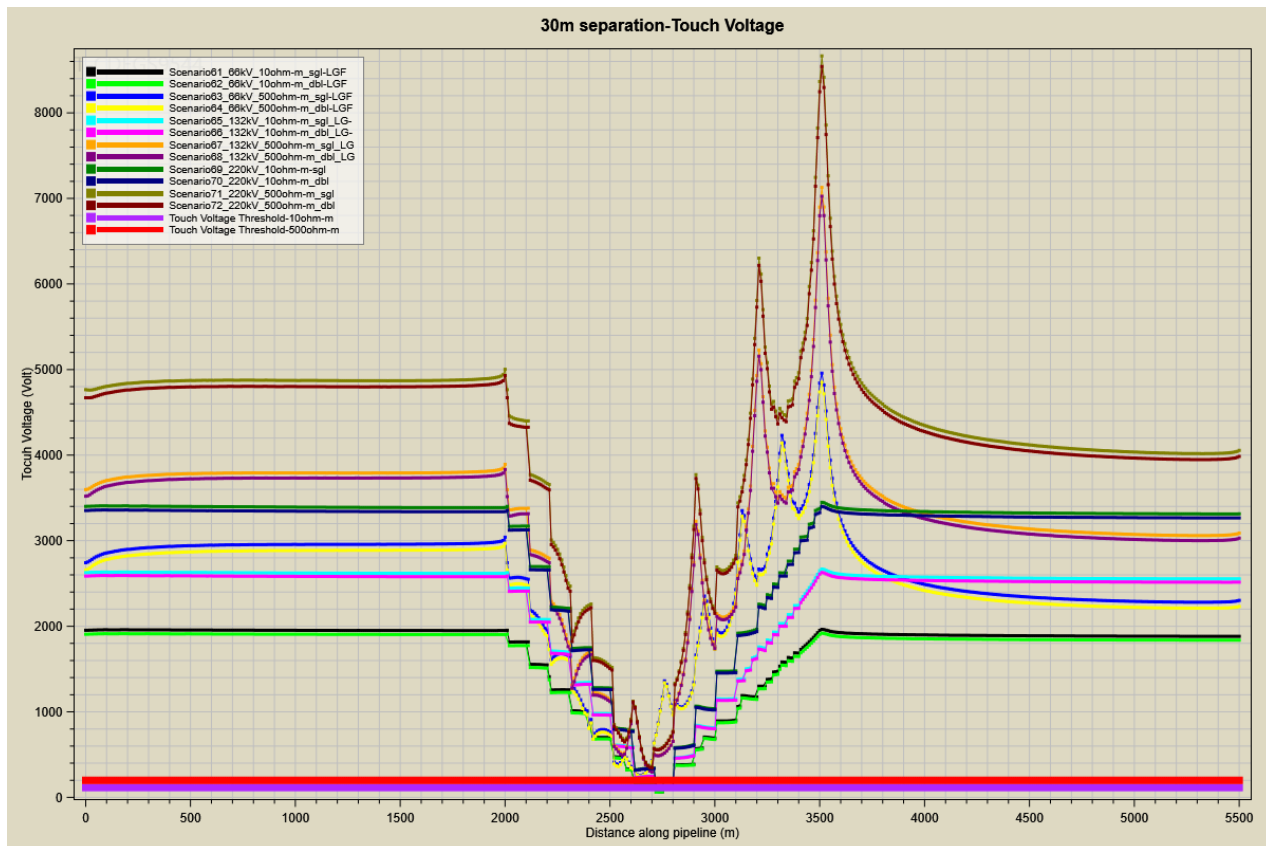
(31) 70 m Separation Distance



(32) 50 m Separation Distance

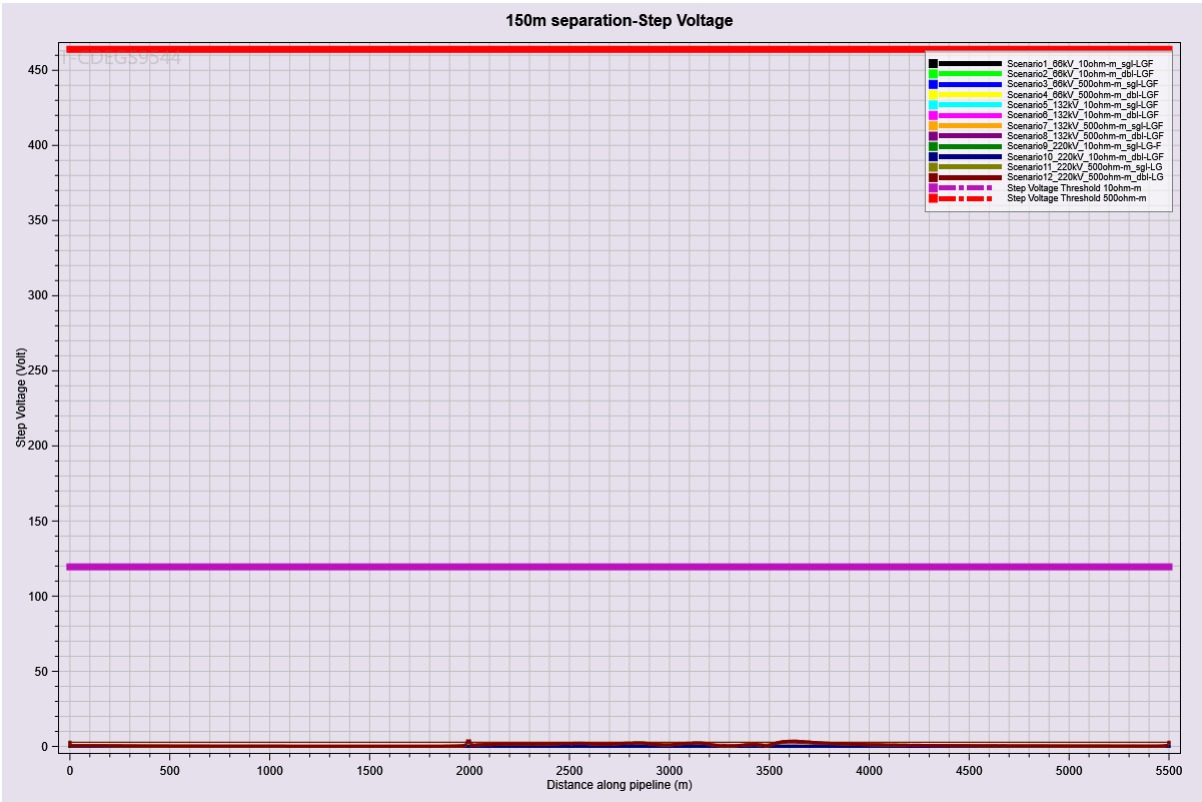


(33) 30 m Separation Distance

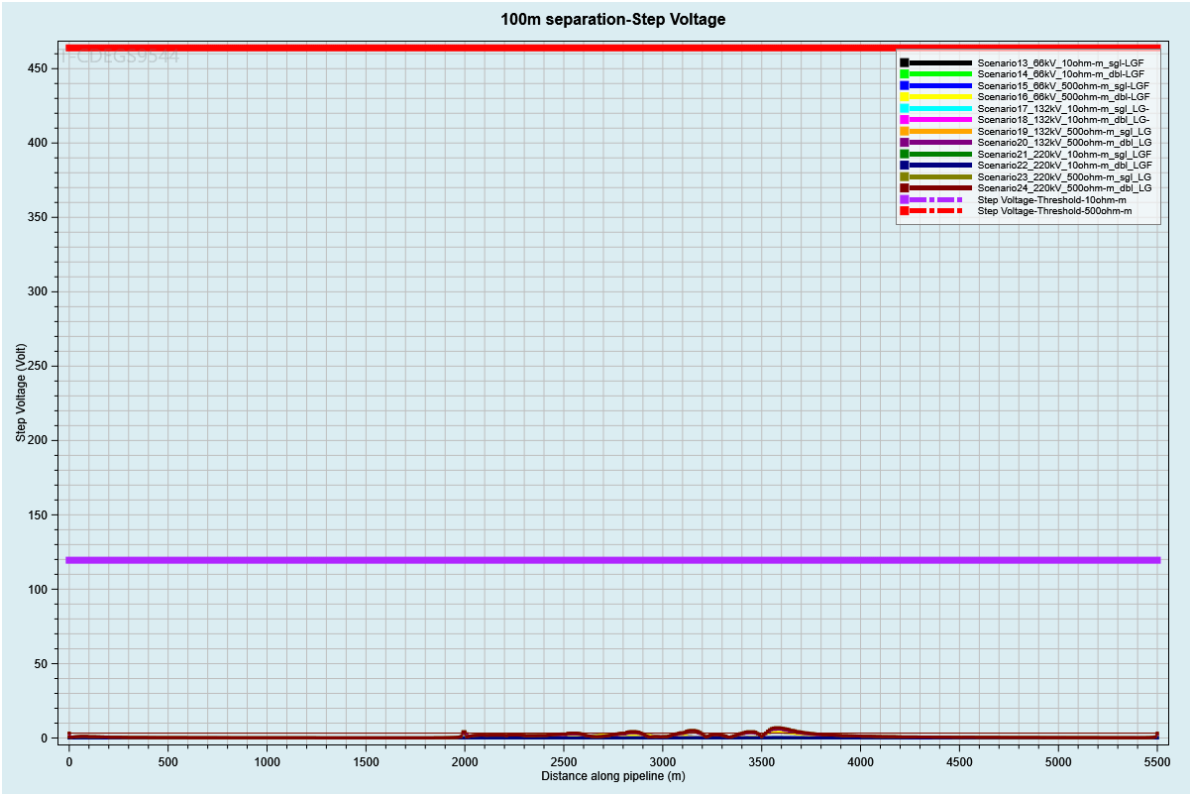


(c) Step Voltage:

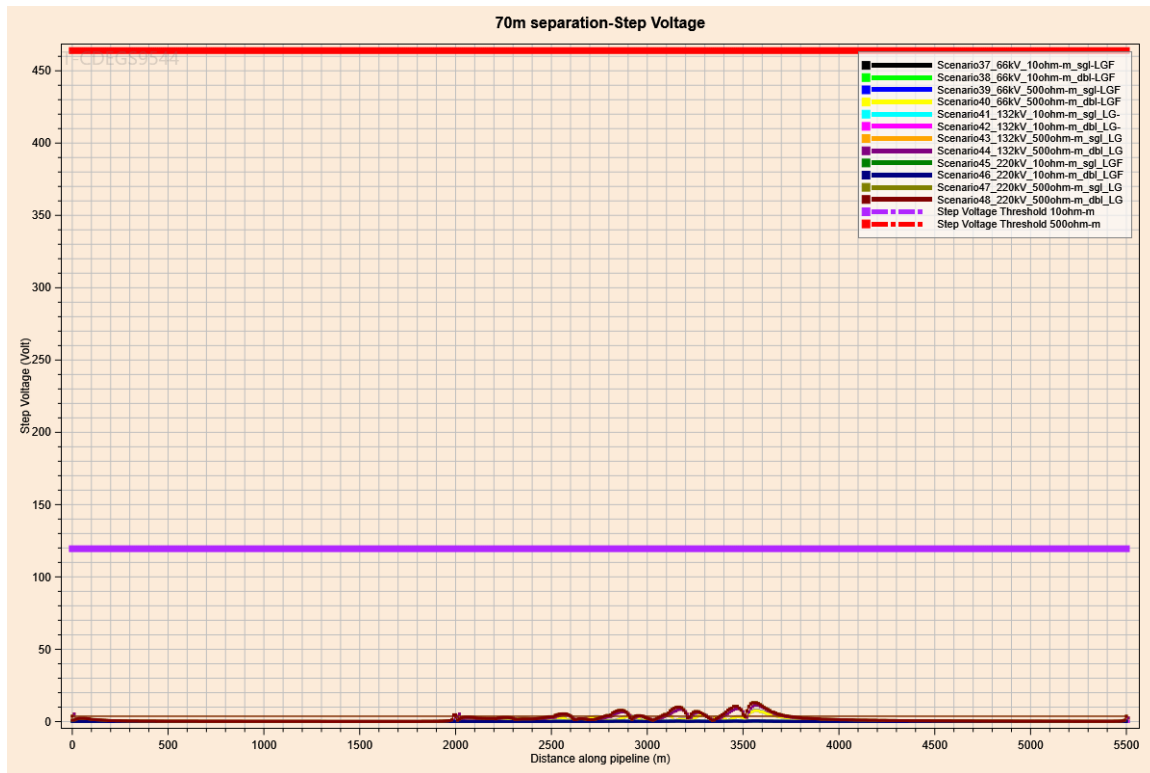
(7) 150 m Separation Distance



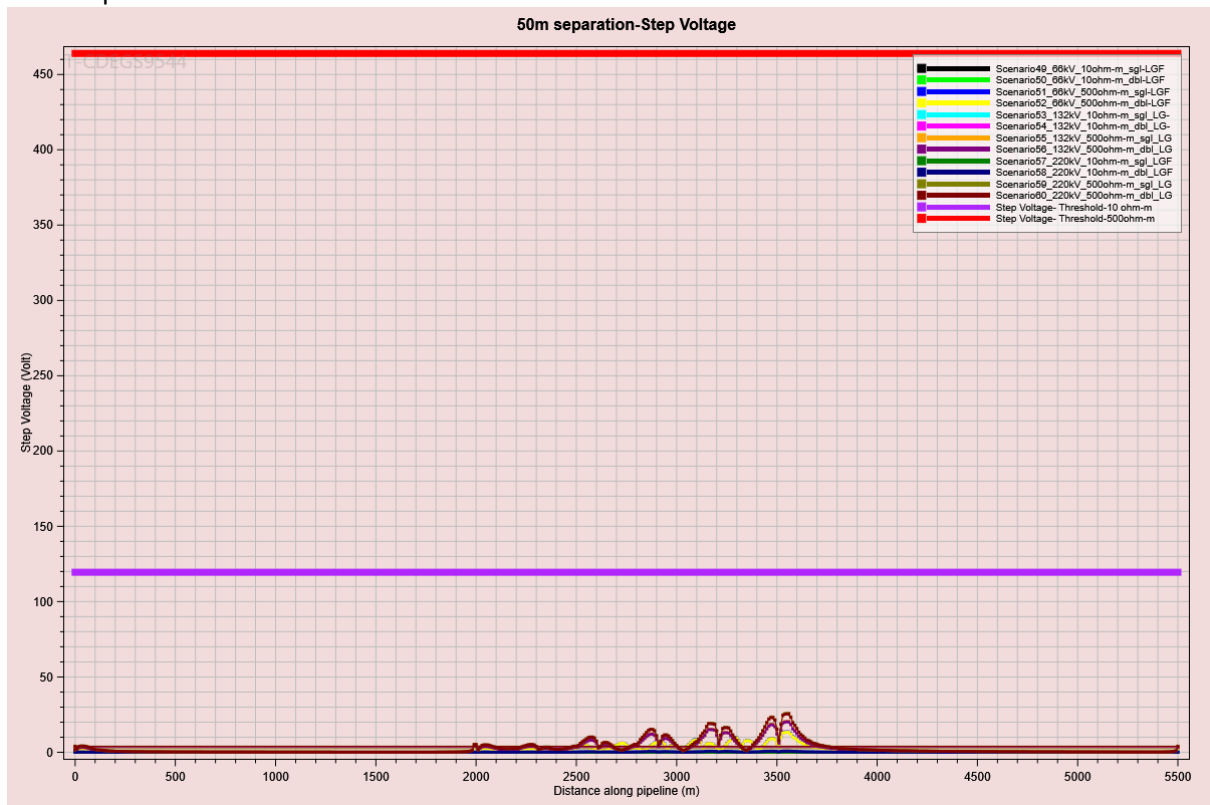
(34) 100 m Separation Distance



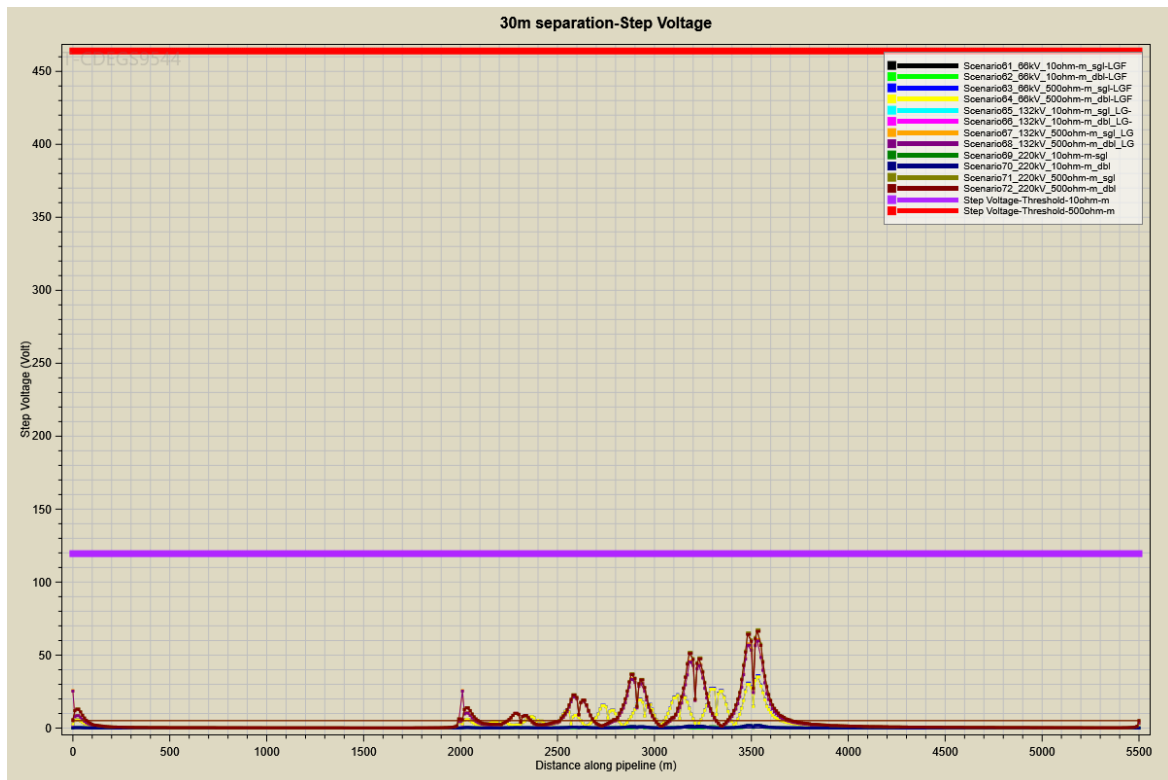
(35) 70 m Separation Distance



(36) 50 m Separation Distance



(37) 30 m Separation Distance

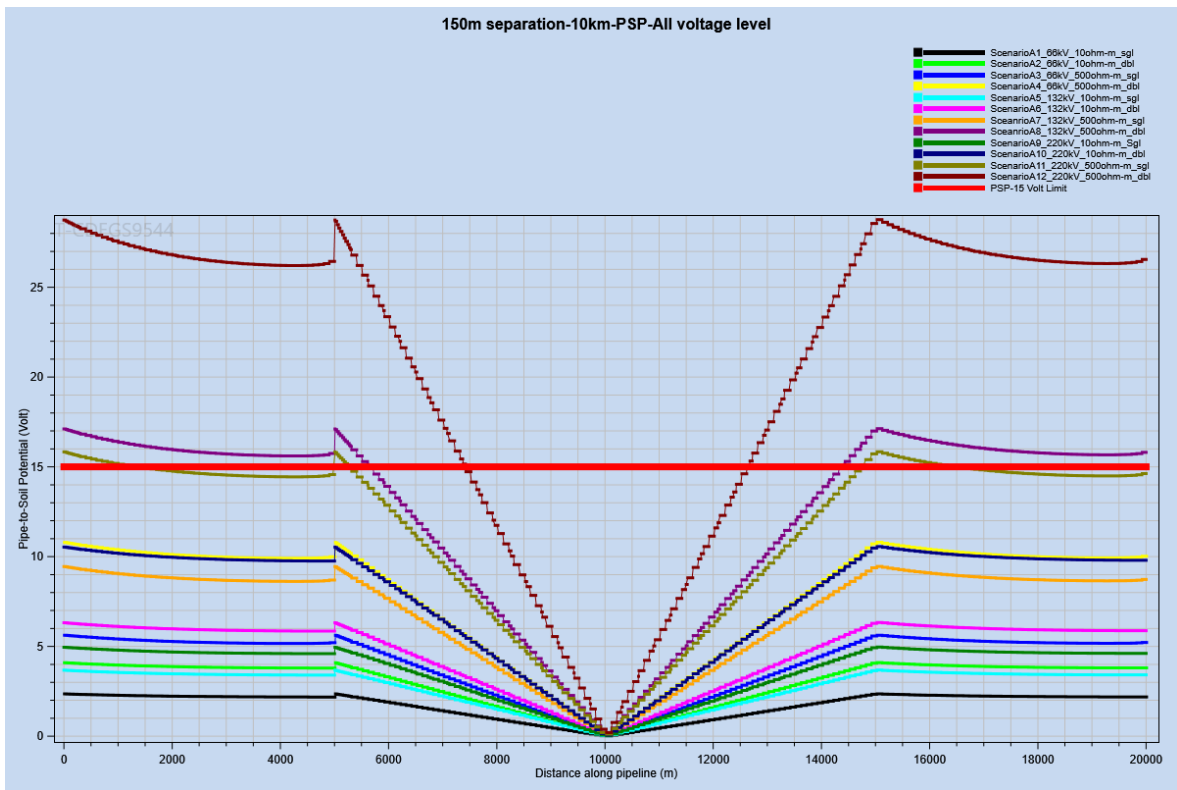


2.0 Simulation Plots for collocation length of 3 km and 10 km

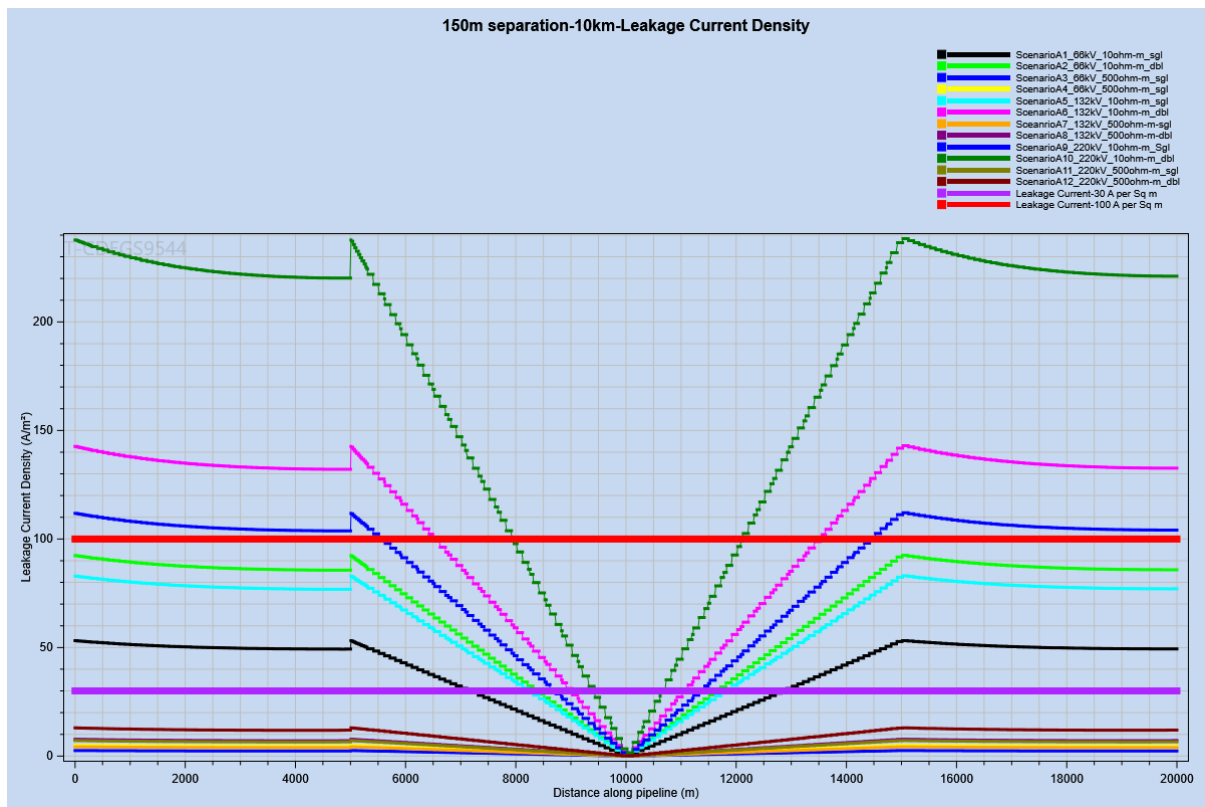
2.1 Steady-State Condition:

2.1.1 Collocation of 10 km and separation distance of 150 m

(a) AC Pipe to Soil Potential:

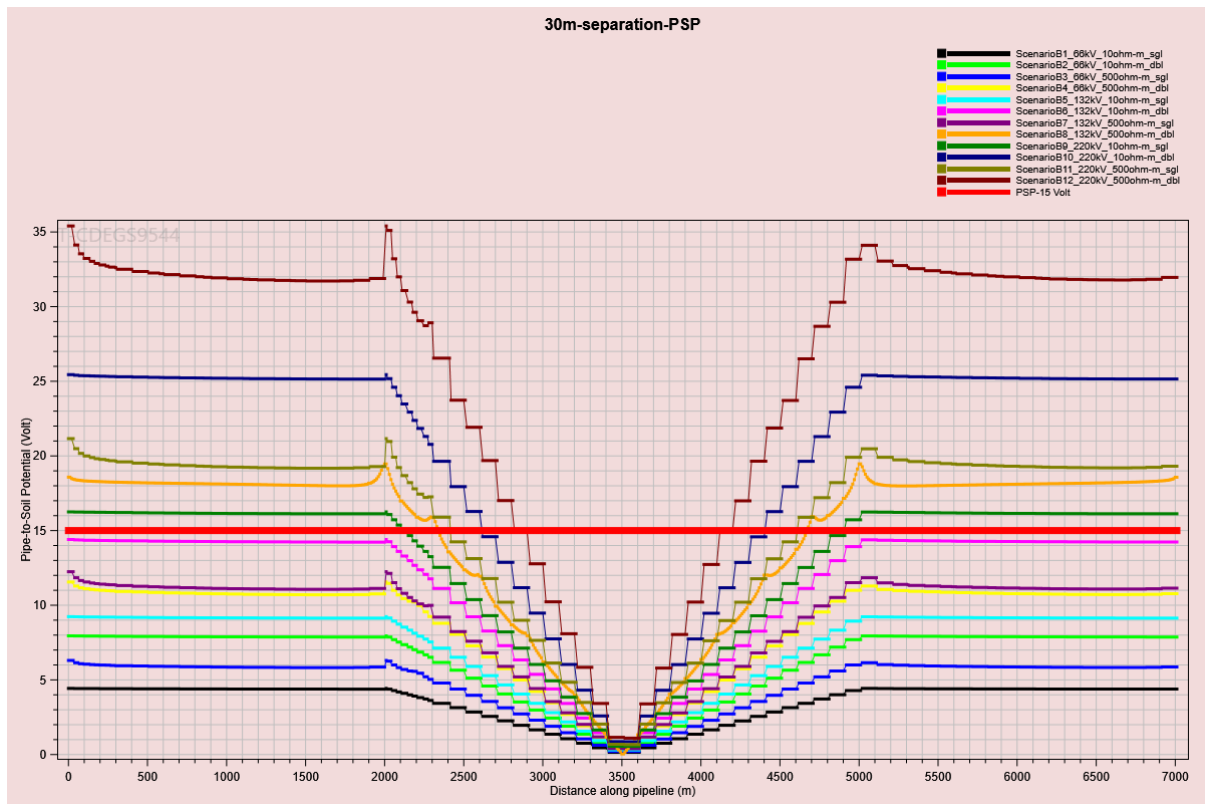


(b) AC Leakage Current Density:

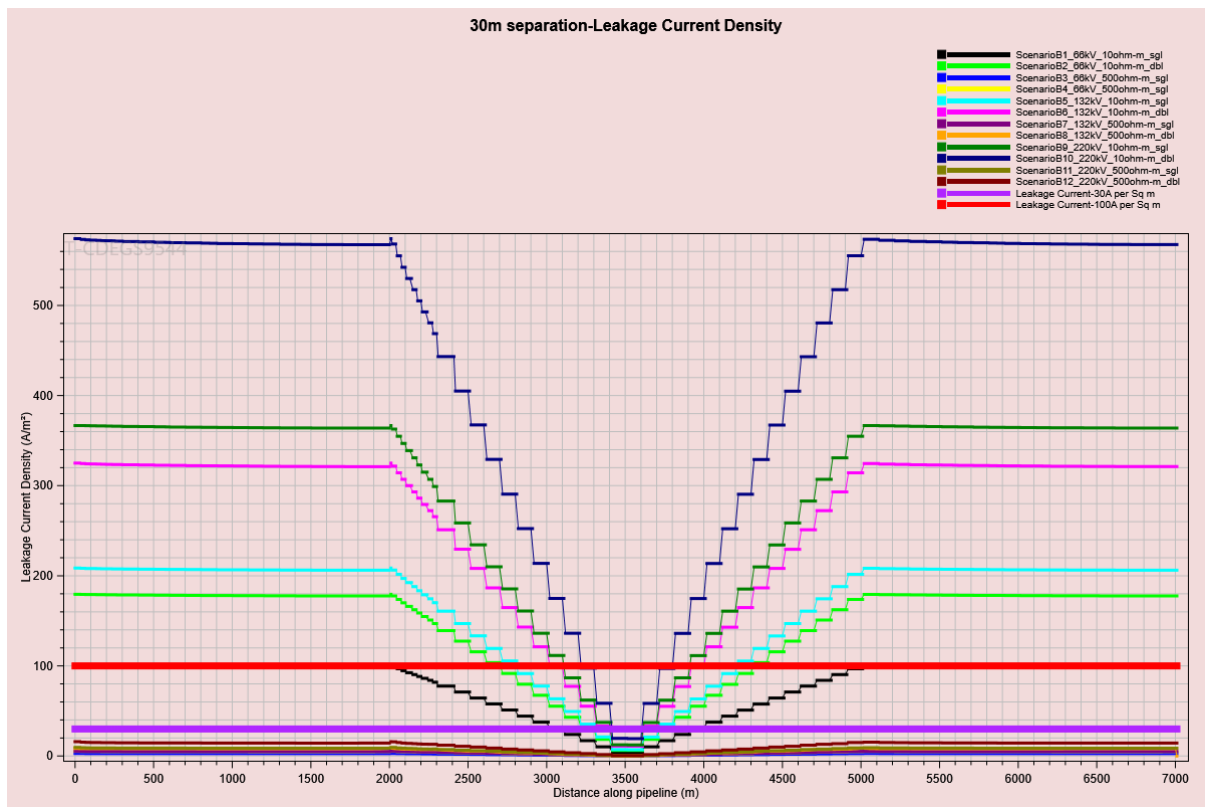


2.1.2 Collocation of 3 km and separation distance of 30 m

(a) AC Pipe to Soil Potential:

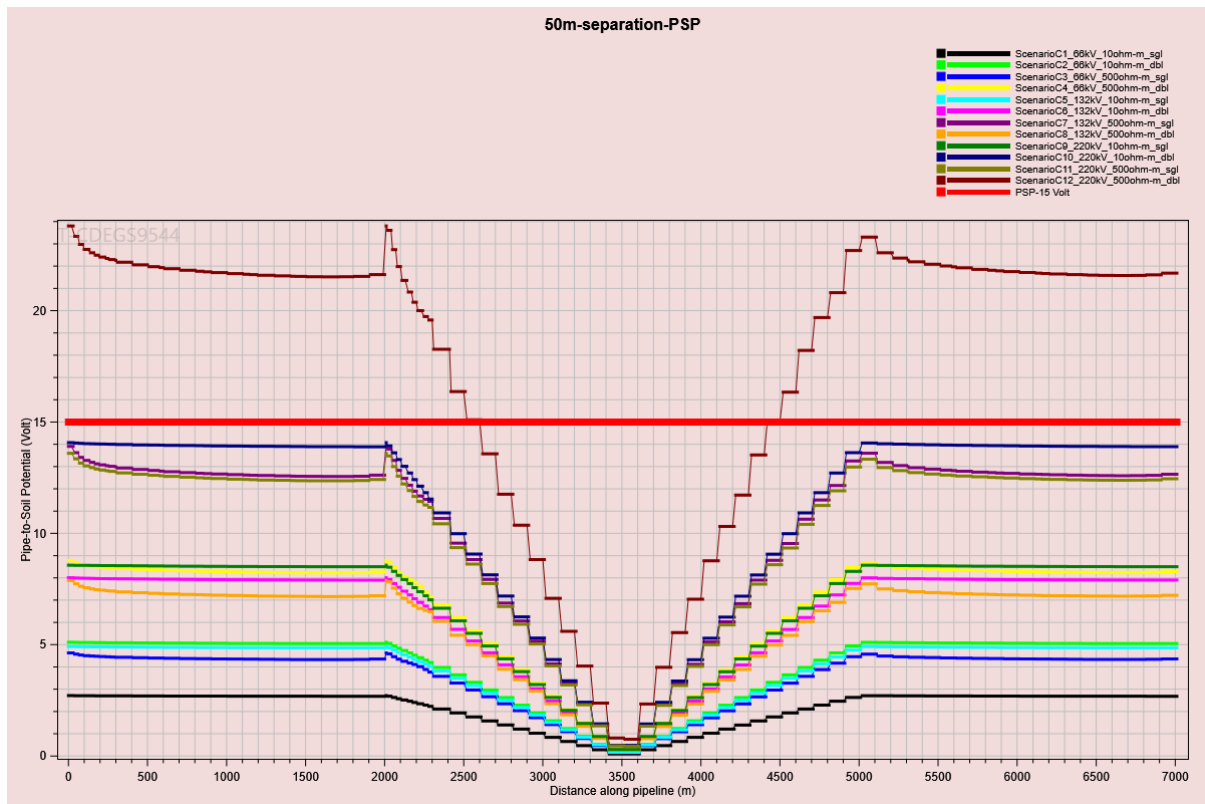


(b) AC Leakage Current Density:

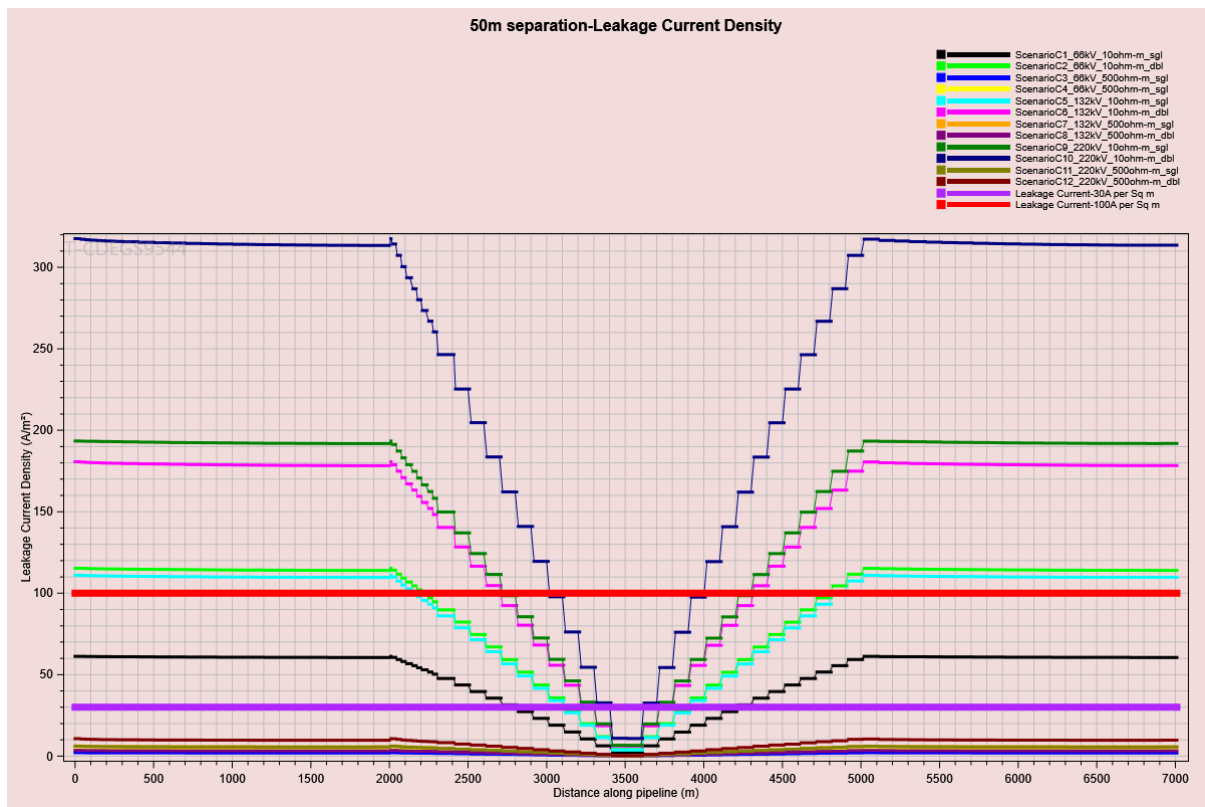


2.1.3 Collocation of 3 km and separation distance of 50 m

(a) AC Pipe to Soil Potential:



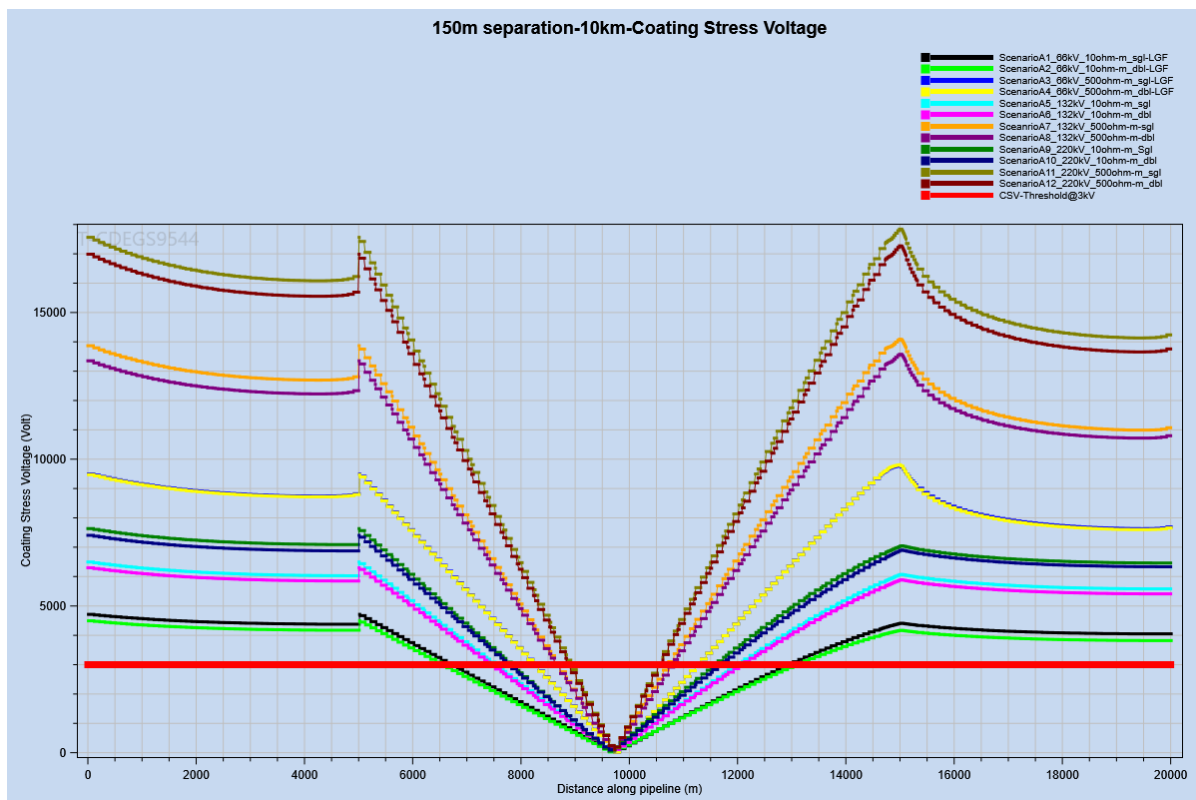
(b) AC Leakage Current Density:



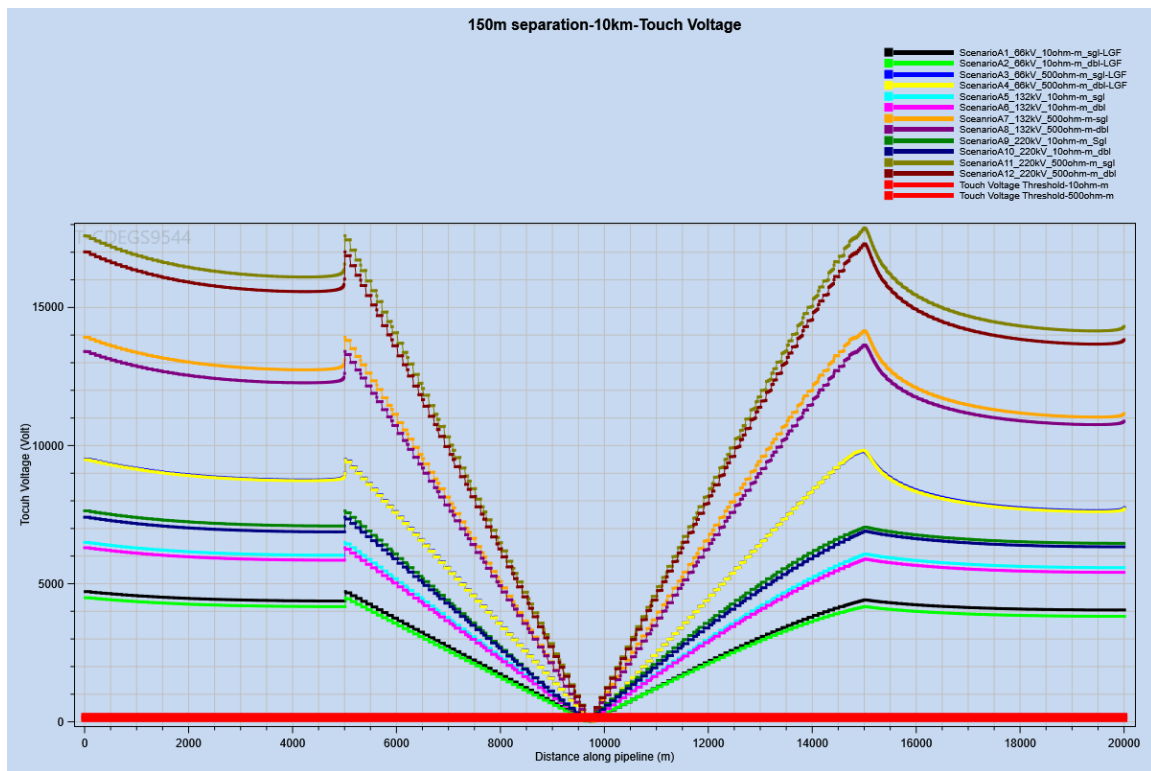
2.2 Single Line to Ground Fault Condition:

2.2.1 Collocation of 10 km and separation distance of 150 m

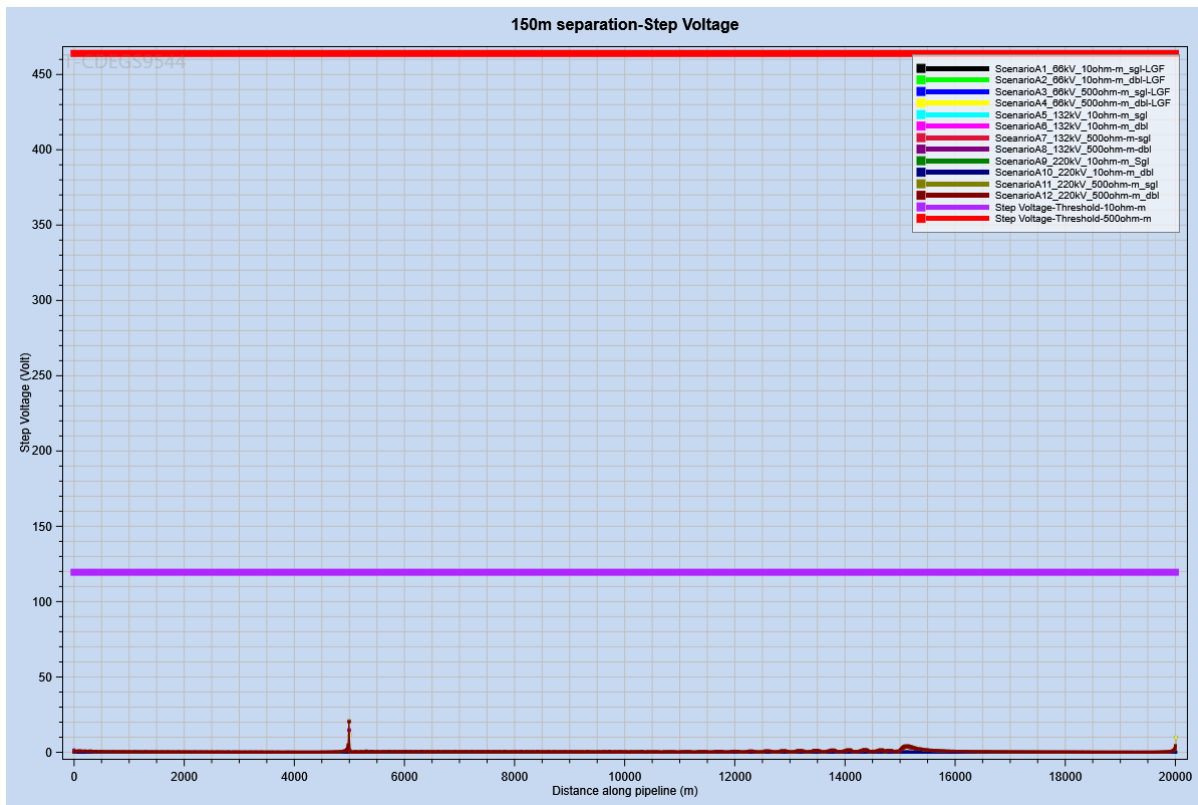
(a) Coating Stress Voltage:



(b) Touch Voltage:

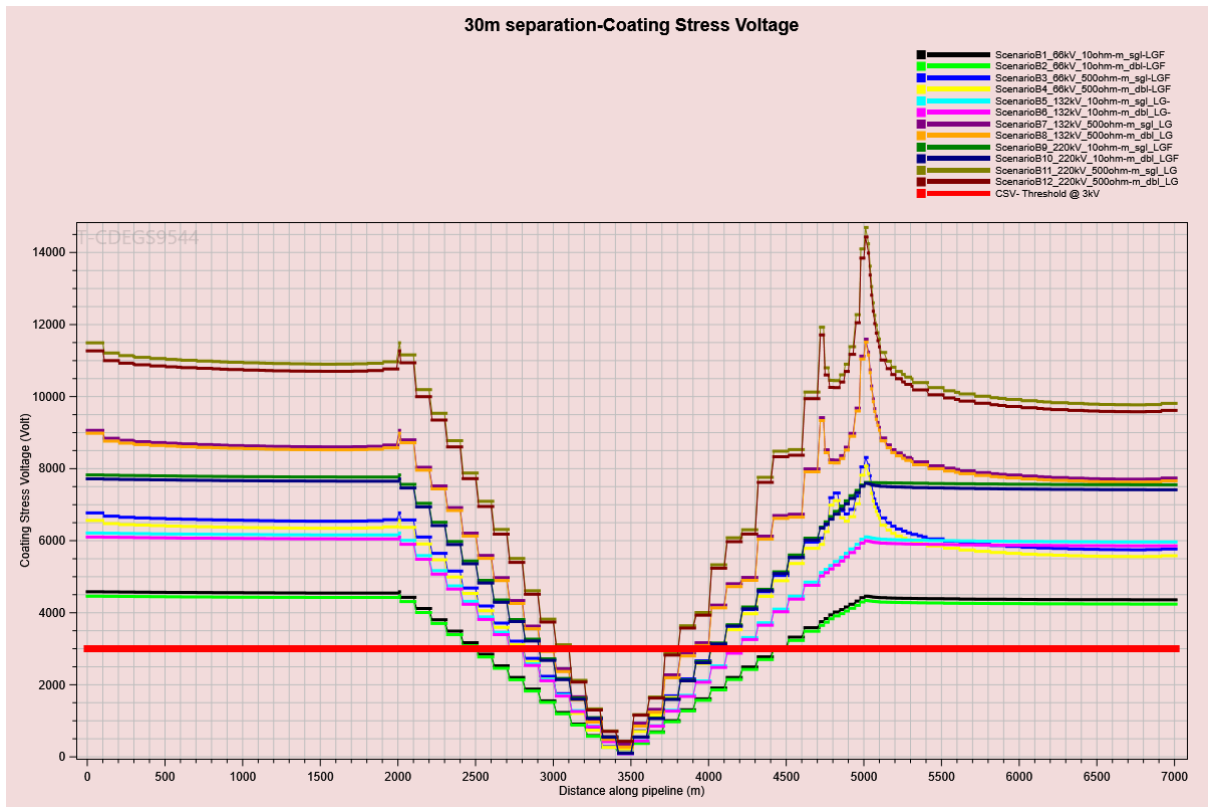


(c) Step Voltage:

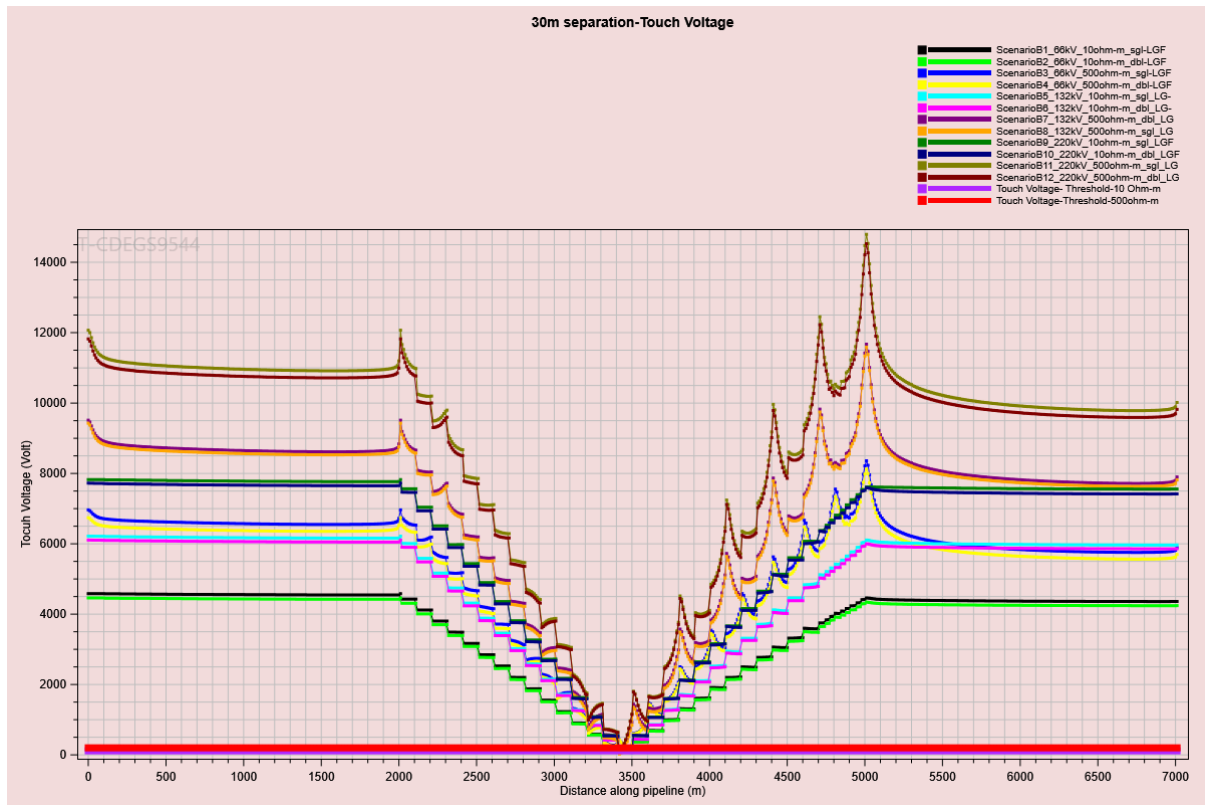


2.2.2 Collocation of 3 km and separation distance of 30 m

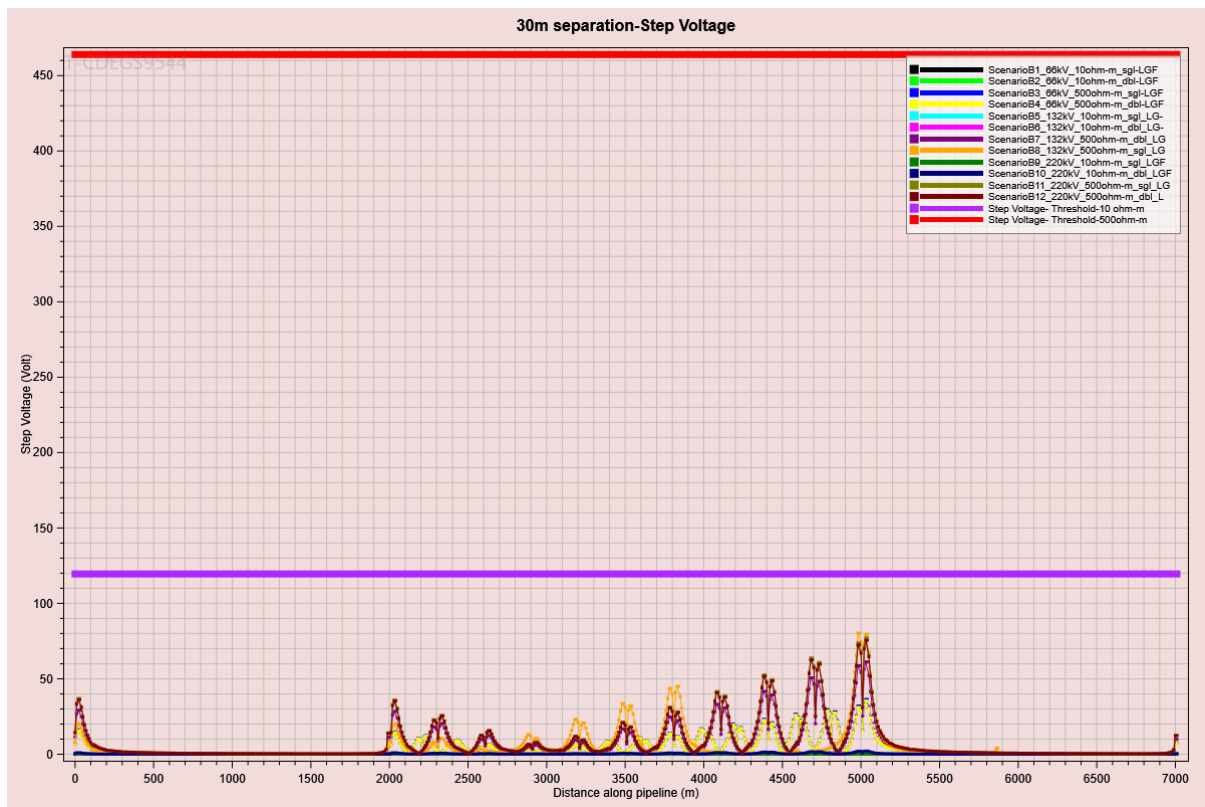
(a) Coating Stress Voltage:



(b) Touch Voltage:

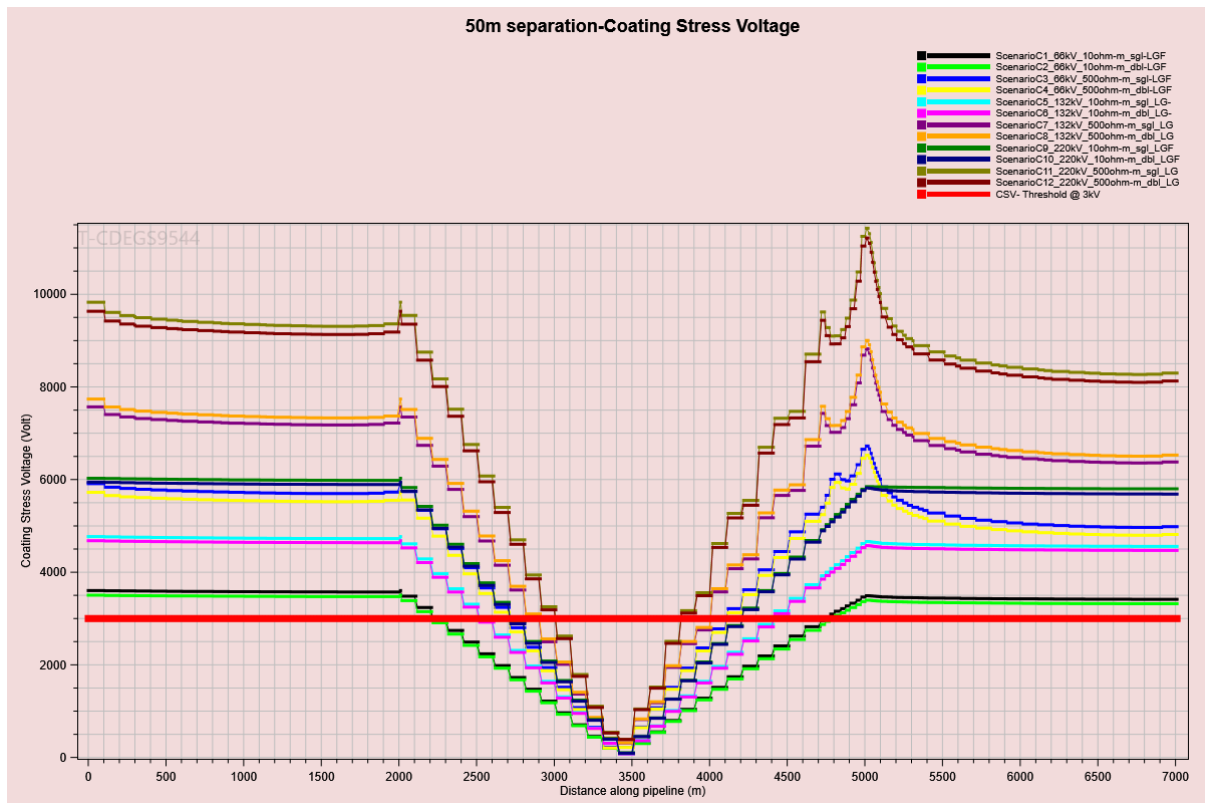


(c) Step Voltage:

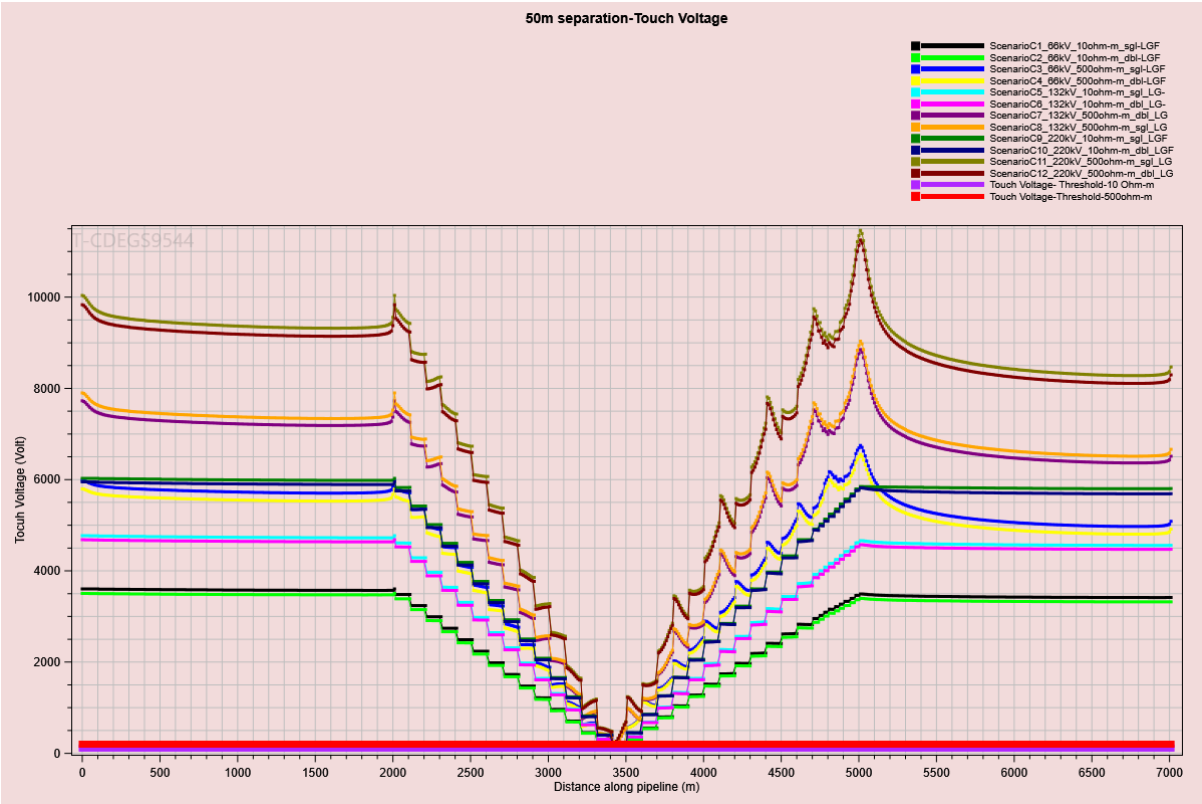


2.2.3 Collocation of 3 km and separation distance of 50 m

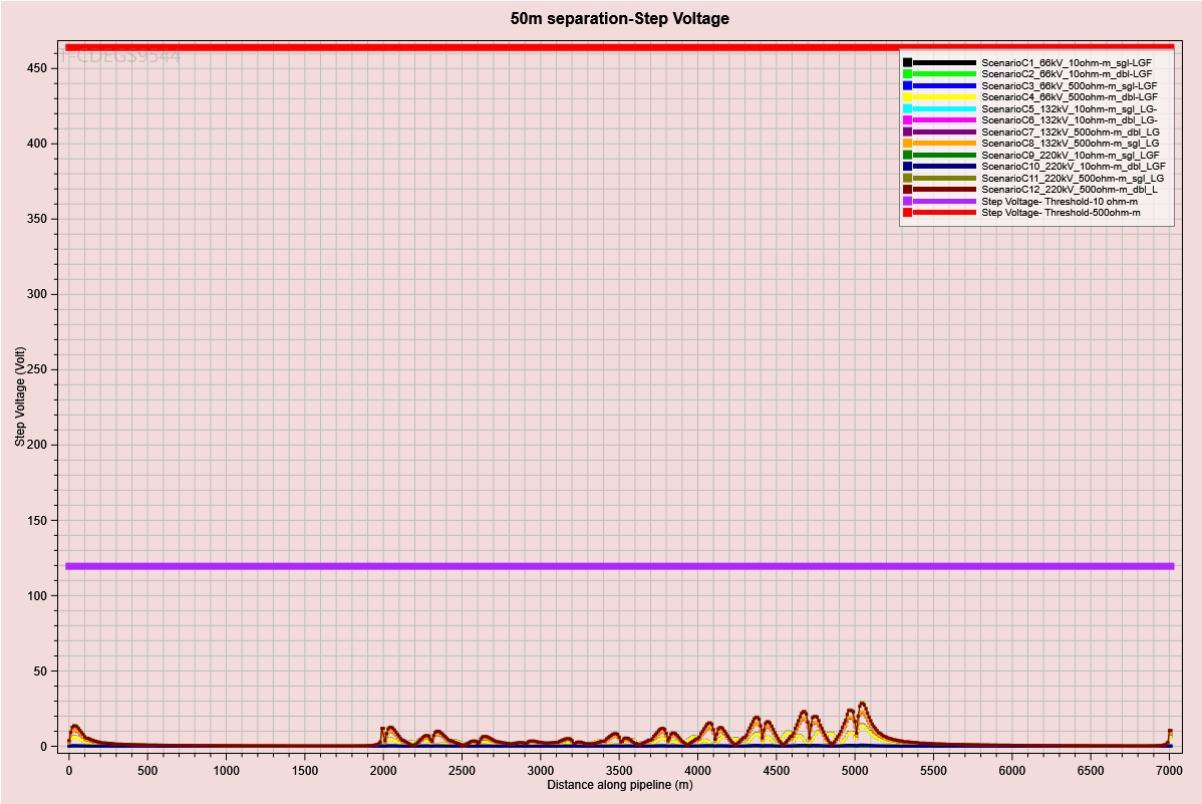
(a) Coating Stress Voltage



(b) Touch Voltage



(c) Step Potential



3.0 Touch & Step Threshold Calculation

(a) 500 Ohm-m Uniform Soil

```

Report #1:
>>  Safety Report

DATE OF RUN (Start)= DAY 19 / Month 12 / Year 2024
STARTING TIME= 11:55:30:58

===== Touch Voltage Threshold For Zone "Default" =====

Computed Touch Voltage.....( V ):  200.35
Main Computation Standard.....: IEEE Std.80

Network Specifications

System Frequency.....(Hertz):  50.000
Shock Duration.....(Seconds):  1.0000
X/R Ratio.....:  20.000
Computed Decrement Factor.....:  1.0313

Site Data

Surface Layer.....: NOT INSTALLED
Sub-Surface Layer Resistivity.....(Ohm-m):  500.00
Foot Resistance Calculation Method.....: IEEE Std.80-2013
Computed Foot Resistance.....( Ohm per foot ):  1562.5
User Defined Footwear Resistance.....( Ohm per foot ):  0.0000
User Defined Gloves Resistance.....( Ohm per hand ):  0.0000

Human Data

Fibrillation Current Calculation.....: IEEE Std.80-2013 (50kg)
Fibrillation Current Value.....( A ):  0.11600
Body Resistance Calculation Method.....: IEEE Std.80-2013
Body Resistance Value.....( Ohm ):  1000.0

===== Step Voltage Threshold For Zone "Default Step" =====

Computed Step Voltage.....( V ):  463.96
Main Computation Standard.....: IEEE Std.80

Network Specifications

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```

System Frequency.....(Hertz):  50.000
Shock Duration.....(Seconds):  1.0000
X/R Ratio.....:  20.000
Computed Decrement Factor.....:  1.0313

Site Data

Surface Layer.....: NOT INSTALLED
Sub-Surface Layer Resistivity.....(Ohm-m):  500.00
Foot Resistance Calculation Method.....: IEEE Std.80-2013
Computed Foot Resistance.....( Ohm per foot ):  1562.5
User Defined Footwear Resistance.....( Ohm per foot ):  0.0000
User Defined Gloves Resistance.....( Ohm per hand ):  0.0000

Human Data

Fibrillation Current Calculation.....: IEEE Std.80-2013 (50kg)
Fibrillation Current Value.....( A ):  0.11600
Body Resistance Calculation Method.....: IEEE Std.80-2013
Body Resistance Value.....( Ohm ):  1000.0

End of Report #1

```

(b) 10 Ohm-m Uniform Soil

```
Report #1:
>> Safety Report

DATE OF RUN (Start)= DAY 19 / Month 12 / Year 2024
STARTING TIME= 11:59:47:30

===== Touch Voltage Threshold For Zone "Default" =====

Computed Touch Voltage.....( V ): 114.23
Main Computation Standard.....: IEEE Std.80

Network Specifications

System Frequency.....(Hertz): 50.000
Shock Duration.....(Seconds): 1.0000
X/R Ratio.....: 20.000
Computed Decrement Factor.....: 1.0313

Site Data

Surface Layer.....: NOT INSTALLED
Sub-Surface Layer Resistivity.....(Ohm-m): 10.000
Foot Resistance Calculation Method.....: IEEE Std.80-2013
Computed Foot Resistance.....( Ohm per foot ): 31.250
User Defined Footwear Resistance.....( Ohm per foot ): 0.0000
User Defined Gloves Resistance.....( Ohm per hand ): 0.0000

Human Data

Fibrillation Current Calculation.....: IEEE Std.80-2013 (50kg)
Fibrillation Current Value.....( A ): 0.11600
Body Resistance Calculation Method.....: IEEE Std.80-2013
Body Resistance Value.....( Ohm ): 1000.0

===== Step Voltage Threshold For Zone "Default Step" =====

Computed Step Voltage.....( V ): 119.50
Main Computation Standard.....: IEEE Std.80

Network Specifications
```

```

System Frequency.....(Hertz): 50.000
Shock Duration.....(Seconds): 1.0000
X/R Ratio.....: 20.000
Computed Decrement Factor.....: 1.0313

Site Data

Surface Layer.....: NOT INSTALLED
Sub-Surface Layer Resistivity.....(Ohm-m): 10.000
Foot Resistance Calculation Method.....: IEEE Std.80-2013
Computed Foot Resistance.....( Ohm per foot ): 31.250
User Defined Footwear Resistance.....( Ohm per foot ): 0.0000
User Defined Gloves Resistance.....( Ohm per hand ): 0.0000

Human Data

Fibrillation Current Calculation.....: IEEE Std.80-2013 (50kg)
Fibrillation Current Value.....( A ): 0.11600
Body Resistance Calculation Method.....: IEEE Std.80-2013
Body Resistance Value.....( Ohm ): 1000.0

End of Report #1

```

4.0 Average Power Line Height Calculation

Average Height of Transmission Line Calculation-

A perfect catenary is the equation obeyed by the shape that an ideally flexible yet non-stretchable wire makes under its own weight in a constant homogeneous gravitational field. This equation is $y = \cosh(x)$. In practice, it can be well approximated by a parabola, a quadratic equation

One can compute the average height of the transmission line with equal level supports (towers) to be $Sag/3$ above its lowest point, which can be expressed as,

$$h_{average} = h_{tower} - \frac{2}{3} \times sag$$

Here are some brief derivation steps to get the above expression:

The height of a point along the catenary is

$$H(x) = H_{min} + A(x - x_{min})^2,$$

where "min" refers to the position of the minimum of the catenary, A is some coefficient, and x is the horizontal distance of this point from the minimum height position.

The height of the catenary (approximated by a parabola) at the tower is then

$$H_{tower} = H_{min} + A(x_{tower} - x_{min})^2.$$

The sag is given as

$$Sag = H_{tower} - H_{min} = A(x_{tower} - x_{min})^2.$$

The average height is obtained by integrating $H(x)$ from x_{min} to x_{tower} and dividing by $(x_{tower} - x_{min})$. The result is

$$H_{average} = H_{min} + \frac{1}{3}A(x_{tower} - x_{min})^2 = H_{min} + \frac{1}{3}Sag = H_{tower} - \frac{2}{3}Sag$$

Note: This is an approximate formula. The amount of sag varies with the properties of the line and increases with the age of the line due to cumulative conductor heating.

*****-End of Report-*****