# 1 Comparison of Approaches (SESTLC, ROW & HIFREQ) for AC Interference Study

Yexu Li and Simon Fortin

## 1.1 Introduction

Three independent tools are available in the SES software packages to carry out an AC interference study: SESTLC, ROW (TRALIN/SPLITS) and HIFREQ. To help select the best program for your study, it is important to be aware of the advantages and limitations of the different tools.

The objective of this article is to have an overall look at those three tools and illustrate their advantages, limitations, and applicability.

## 1.2 The Fundamentals behind the Three Tools

**SESTLC:** SESTLC is based on a circuit approach. Line parameters (line constants) are computed using the method originally developed in FCDIST. The bundle reduction, ground-wire elimination and sequence components algorithms are derived from the TRALIN module. It is a simplified analysis tool to quickly estimate the line parameters, magnetic and electric fields of arbitrary configurations of **parallel** transmission and distribution lines in **uniform soil**. It can also compute the inductive, conductive and total interference levels on a metallic utility path such as pipeline or railway that **runs parallel** to the electric lines in **uniform soil**. SESTLC provides a very fast and efficient tool for estimating the magnitude of the AC interference for simple right-of-way configurations.

**ROW (TRALIN/SPLITS):** ROW is also based on a circuit approach. From a specification of the location and characteristics of the physical elements of a system (phase and shield/neutral wires, pipelines, soil characteristics, etc…), the program derives an equivalent circuit model. The line parameters for the circuit are computed using line constant formulas originally developed in TRALIN. Lumped elements such as ground impedances of substation grids and transmission tower grounds can be added to the circuit. These are normally computed using appropriate grounding tools, such as MALT or MALZ.

This circuit model is then solved using SPLITS to yield the inductive interference component. Next, a MALZ model is built. This model provides an option to include an EMF term in the energization of the conductors (the EMF is used to account for the induced effects on a victim line). As a result, the MALZ model gives the total interference level.

ROW is flexible and fast for detailed designs involving complex right-of-way network configurations. The main approximations in the program are made in the computations of the line parameters, which assume that (1) conductors are parallel to each other; and (2) conductors are infinite in length.

ROW solves the first problem by representing non-parallel conductors using average separation distances for each section cut to compute the inductive coupling. This is a good approximation as long as the sections are sufficiently short.

The second approximation will cause noticeable inaccuracy at current discontinuity locations, such as a fault location and line ends etc.

**HIFREQ:** HIFREQ is based on a field-theoretical approach which solves Maxwell's equations directly. HIFREQ models the complete conductor network under consideration in three-dimensional space, and accommodates angled conductors without making any approximations. The inductive, capacitive and conductive interference effects between all the elements in the network are simultaneously taken into account. Therefore, HIFREQ calculates the total interference level accurately. However, computation times can be considerably higher compared to SESTLC and ROW, for complicated networks.

## 1.3 Comparison of the Three Tools

In this section, computation results obtained with the three tools described above are presented and compared. The study is based on a reference computer model from which several series of simulations are created by varying one or more parameters at a time. The reference computer model consists of a single phase conductor of a transmission line (T/L) and a pipeline (P/L). The height of the T/L is 10 m above the earth surface. The center of the P/L is 2 m below the earth surface. Its outer and inner radii are 0.2 m and 0.19 m, respectively. The relative resistivity of the P/L wall is 12 and its relative permeability is 250. The P/L is well coated, with a 0.005 m coating thickness and 3,048,781 $\Omega$-m coating resistivity. The soil resistivity is 100 ohm-m. A 1000 amp current is assumed to be flowing in the T/L phase conductor under steady state conditions. Under fault conditions, a current of 1000 amp is assumed to be flowing from both sides of the fault location. The base case section length is 100 m.

The following cases are examined under steady-state conditions:

- **Parallel**: The T/L and P/L are parallel.
- **Non-Parallel**: The T/L and P/L are at a constant angle to each other.
- **Crossing**: The P/L abruptly crosses over to the other side of the T/L.
- **Phase Transposition**: In this variation, a balanced three-phase T/L system with a transposition somewhere along the line.

For the **Non-Parallel** study, the P/L is placed at an angle of 15 degrees with respect to the T/L. The T/L (and associated pipeline sections) is subdivided into section lengths of 50 m and 100 m, respectively, in order to estimate the sensitivity of the results to the subdivision of the ROW into quasi parallel sections.

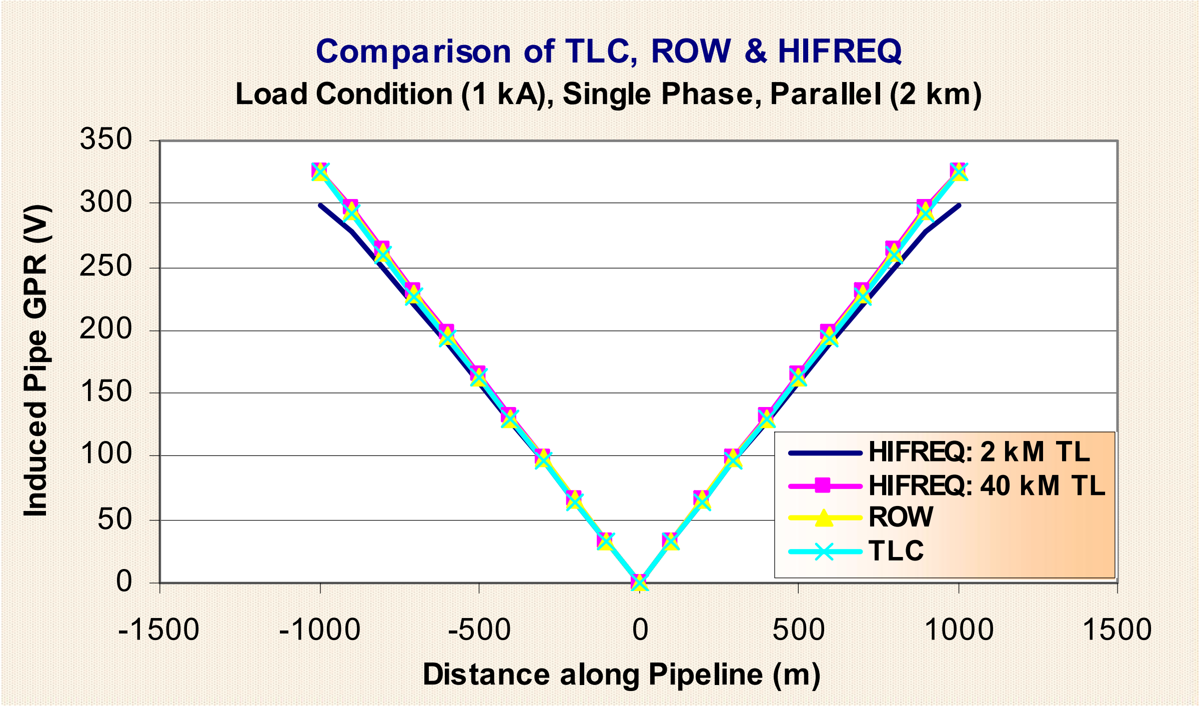
Under fault conditions, sensitivity tests have been made for the following parameters: fault locations, parallel lengths, and separation distances between the pipeline and the transmission line.

Note that for the conductive interference, SESTLC represents tower foundations and other sources of conduction current as point sources, which is a good approximation when the victim line (e.g. pipeline or railway) is relatively far from the energization source. ROW uses the MALZ approach, and can model tower or substation grounding systems as is, instead of as a point source. Both SESTLC and ROW take into account the voltage drop along the victim conductors. On the other hand, SESTLC and ROW do not account for the inductive and capacitive interactions between conductors of the grounding system, while HIFREQ does. The difference caused by this interaction is generally small for most right-of-way networks. However, significant differences can be obtained around a substation area, in which case use of HIFREQ could improve the computation accuracy [see Ref. 3].

The effect of the interaction between conductors is beyond the scope of this article. The comparisons made in this article apply only for the inductive interference.

The input files that are used in this article are available on your CD-ROM, in the folder "Users Group 2005\Input Files\Comparisons of TLC-ROW-HIFREQ\".

### 1.3.1 Steady State Conditions




<u>Objective:</u> Examine a simple **parallel network** case, and demonstrate the length effect.

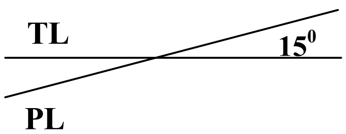
<u>Network:</u>

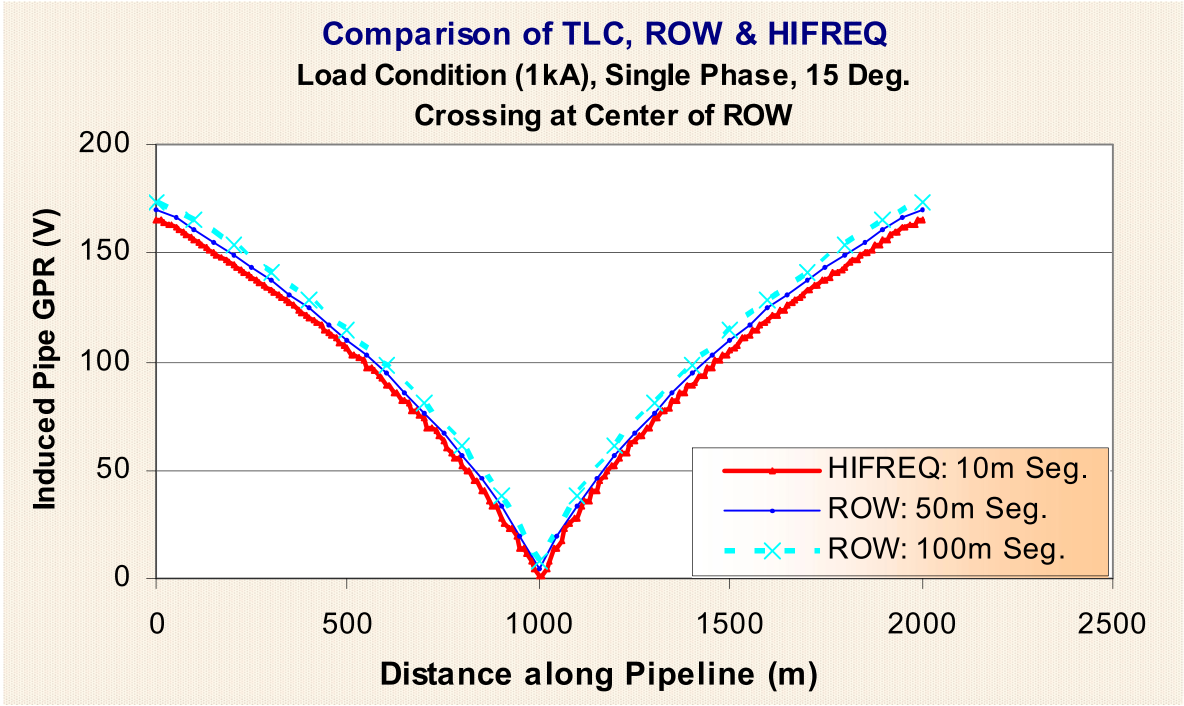
**Load Current:** 1 kA
**Phase Wires**: Single, 2 km (and 40 km for HIFREQ)
**Shield Wires**: No

**Pipeline**: 2 km
**Horizontal Separation Distance**: 0

<u>Comments</u>:

The figure shows that there are no visible differences between the results from SESTLC & ROW and HIFREQ approaches when the modeled transmission line is long enough (40 km) in HIFREQ compared to the pipeline length (2 km). In this case, the assumption that the transmission line is infinite is essentially correct [see Ref. 1].



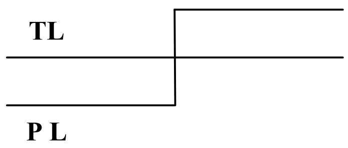

Objective: Examine a simple **non-parallel network** case, and demonstrate the sensitivity to the section length.

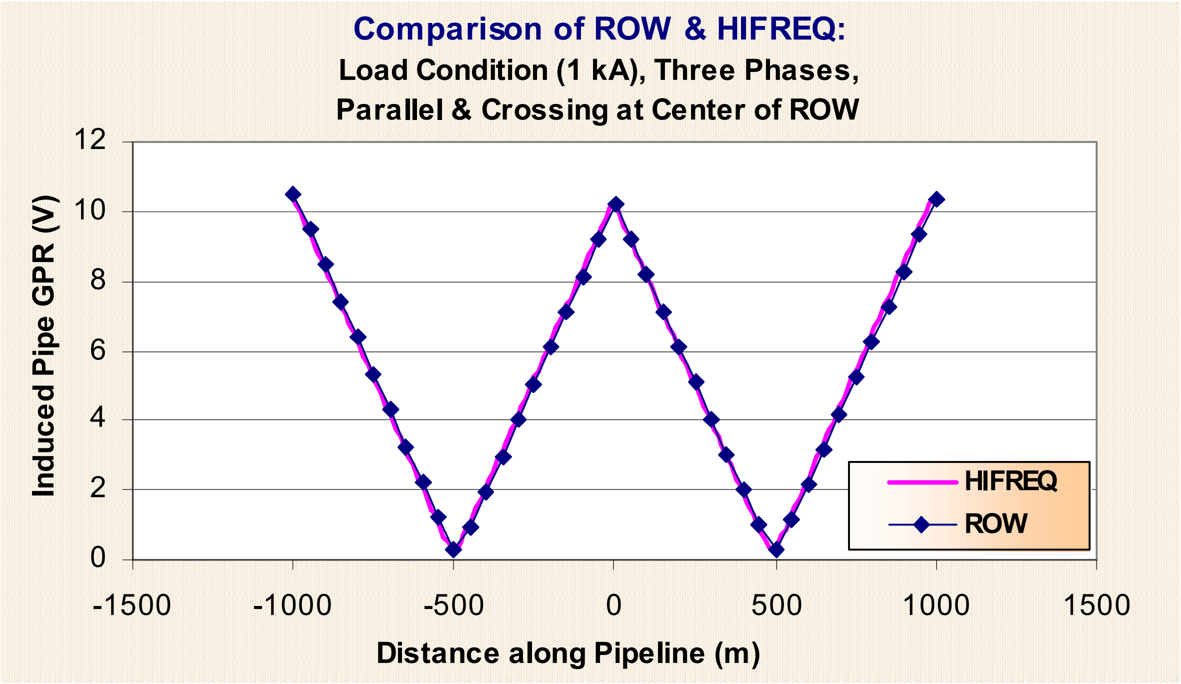
Network:

**Load Current:** 1 kA;
**Phase Wires**: Single, 2 km for ROW (and 40 km for HIFREQ);
**Shield Wires**: No;
**Pipeline**: 2 km, **15 degree to TL, cross at the center of ROW**

Comments:

For a non-parallel right-of-way network, decreasing the subdivision length (i.e., section cut length) in ROW can improve the accuracy of the results. This is because the average separation distances between conductors are better approximated with a shorter section length. However, an extremely small subdivision length can cause numerical errors in the circuit approach computations. A subdivision length of 50 m usually is quite adequate for a steady-state condition study. In this case, results are not presented for SESTLC, since it is difficult to represent this system as an equivalent parallel line network [see Ref. 2].




Objective: Examine a simple **3 phase system with a PL crossing**.

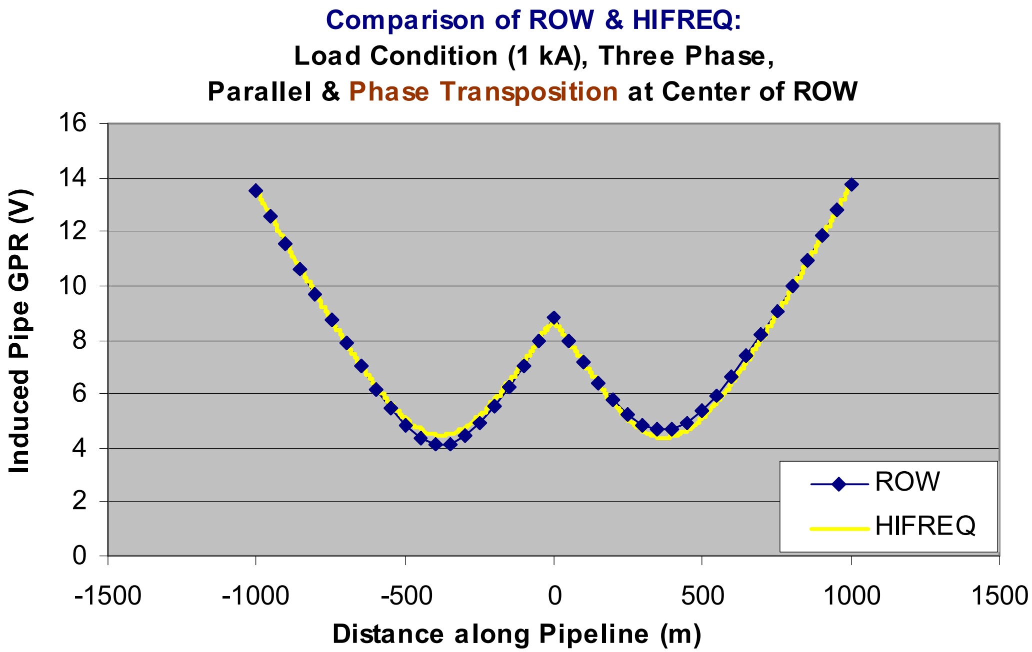
Network:

**Load Current:** 1 kA;
**Phase Wires**: Three phases, 40 km;
**Shield Wires**: No;
**Pipeline**: 2 km, Parallel to transmission line, **Cross at the center of ROW**

Comments:

For balanced three-phase currents (steady-state condition), with no shield wires, the discontinuity in pipeline GPR that is caused by a pipeline crossing a transmission line is nearly identical when computed with HIFREQ and ROW. This is because the source of EMF (the transmission line) is uninterrupted in this case. Hence, the transmission line effectively looks infinite in HIFREQ (as in ROW).

In this case, results are not presented for SESTLC, since it is difficult to represent this system as an equivalent parallel line network.




Objective: Examine a **phase transposition** case.

Network:

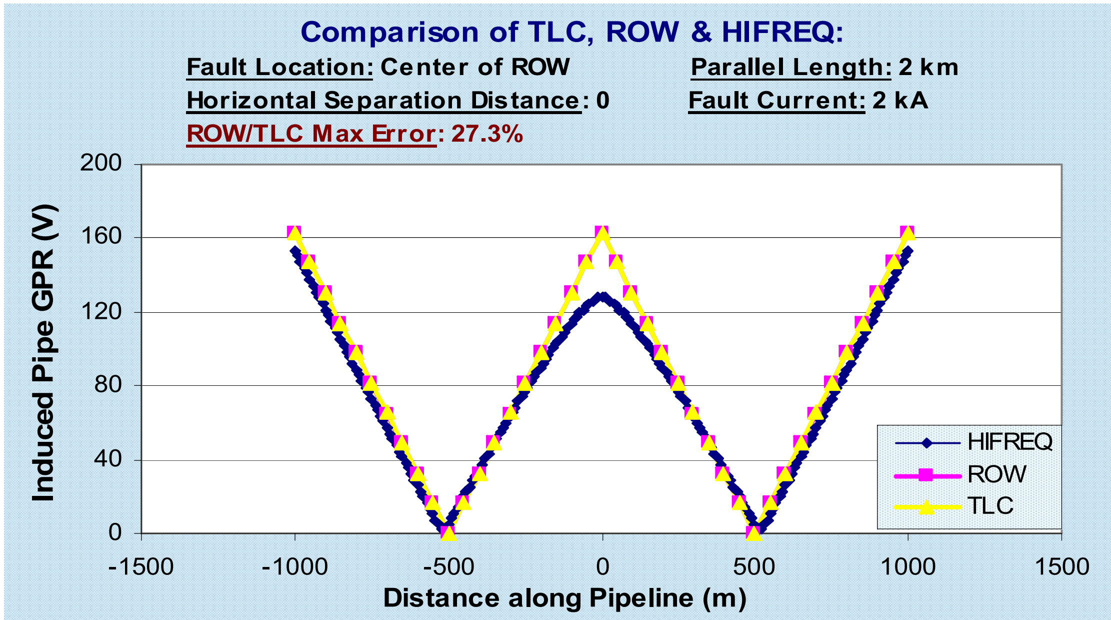
**Load Current:** 1 kA;
**Phase Wires**: Three phases, 40 km, **Phase transposition at the center of ROW**
**Shield Wires**: No;
**Pipeline**: 2 km, Parallel to transmission line

Comments:

For balanced three-phase currents (steady-state condition), no shield wires and with a transmission line discontinuity caused by a phase transposition, the results obtained using HIFREQ and ROW are very similar.

In this case, results are not presented for SESTLC, since it is difficult to represent this system as an equivalent parallel line network.

### 1.3.2 Under Fault Conditions




Objective: Examine a simple symmetric fault case.

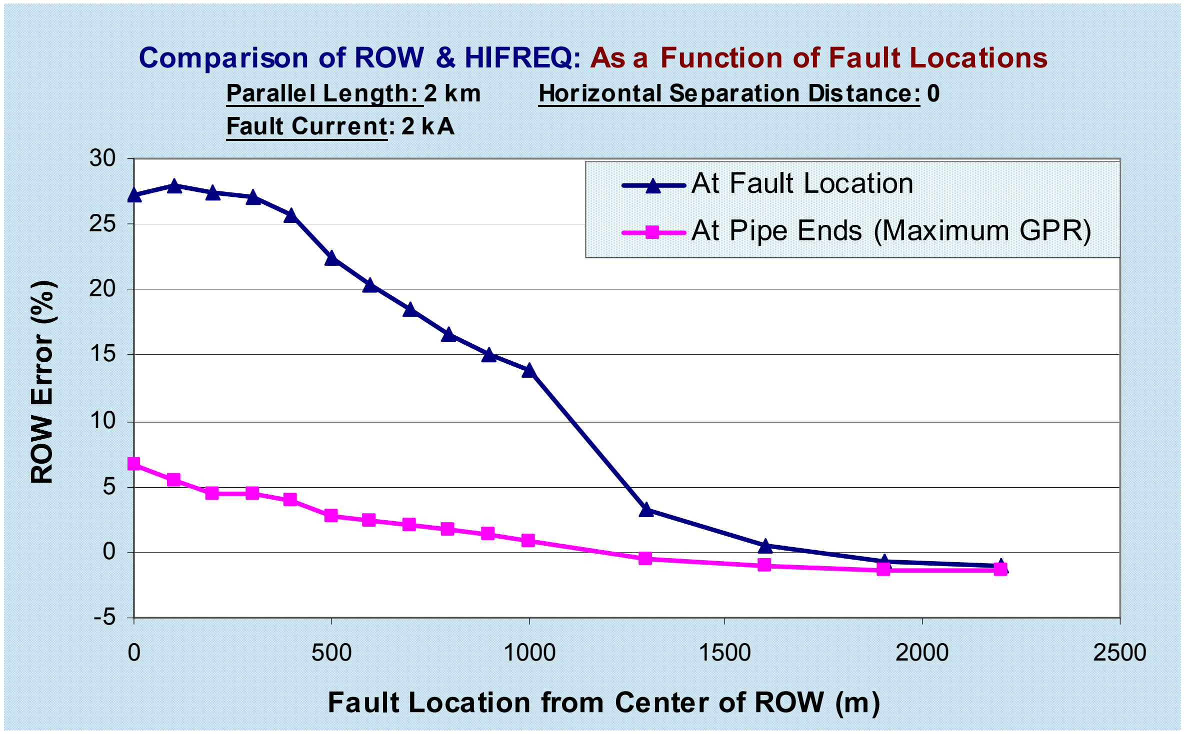
Network:

**Fault Current & Location:** 2 kA; at center of ROW;
**Phase Wires**: Single, 40 km;
**Shield Wires**: No;

**Pipeline**: 2 km, Parallel to transmission line;
**Separation Distance**: 0;
**Maximum ROW/SESTLC Error**: 27.3% for a 2 km exposure length.

Comments:

The maximum differences between the field approach (HIFREQ) and the circuit approach (SESTLC & ROW) results occur at the fault location, while these differences are less important at the pipeline ends. These differences are due to the magnetic field discontinuity at the fault location and at the pipeline ends. This discontinuity is larger at the fault the location than at the ends of the line, since the current jumps from 1 Amp to -1 Amp at the fault location, while it jumps from ±1 Amp to zero at the ends of the line. This magnetic field discontinuity is not taken into account in the circuit approach, which assumes an infinite line length when computing the line parameters.



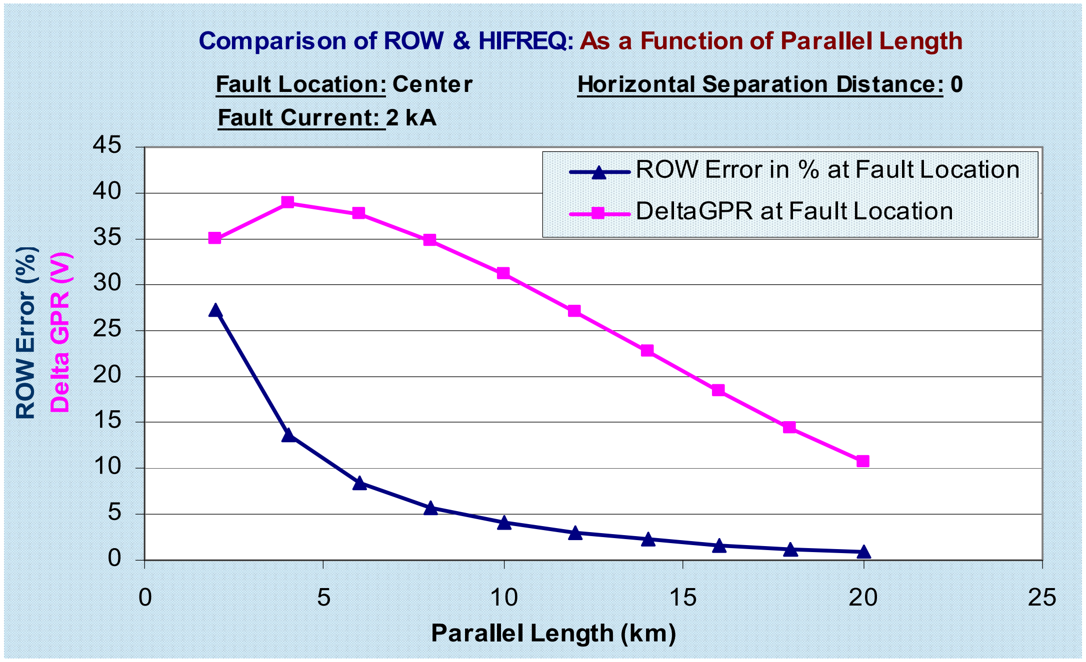

Objective: Examine the effects of **the fault location** on the computation accuracy.

Network:

**Fault Current & Location:** 2 kA; **the location varies between the center of the ROW and 2.2 km away from it**;
**Phase Wires**: Single, 40 km;
**Shield Wires**: No;
**Pipeline**: 2 km, Parallel to transmission line;
**Separation Distance**: 0;
**Maximum ROW/SESTLC Error**: 27.3%.

Comments:

The largest difference between the field approach (HIFREQ) and circuit approach (ROW, SESTLC) is observed for a fault located midway along the ROW.



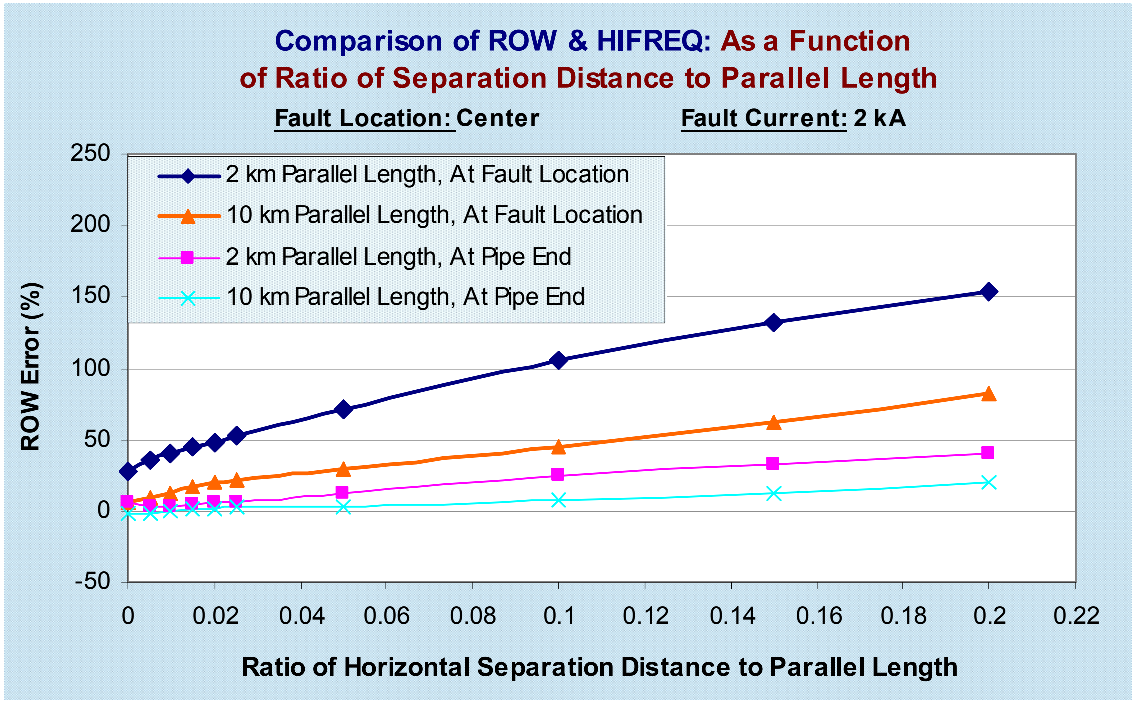

Objective: Examine the effects of the **length of parallelism** on the computation accuracy.

Network:

**Fault Current & Location:** 2 kA; Center of ROW; **Shield Wires**: No;
**Phase Wires**: Single, 40 km; **Separation Distance**: 0;
**Pipeline**: Parallel to transmission line, **Parallel Length varying between 2 and 20 km**;

Comments:

The difference between the induced pipeline potential calculated using the circuit approach (ROW) and the results using the field approach (HIFREQ) decreases with increasing exposure length. The difference is negligible when the exposure length is considerable (less than 5% when the exposure length is about 10 km). When the parallelism is significant, even though the end effect at the fault location still exists, the circuit approach gives accurate results because the total induced potential is predominantly due to the inductive coupling along the whole length, thus the presence of an abrupt electromagnetic field discontinuity at the fault location does not affect the results significantly.




<u>Objective:</u> Examine the effects of the **separation distance** on the computation accuracy.

<u>Network:</u>

**Fault Current & Location:** 2 kA; Center of ROW;
**Shield Wires**: No;
**Phase Wires**: Single, 40 km;
**Pipeline**: Parallel to transmission line, 2 km;
**Separation Distance: As a Function of the Ratio of Separation Distance to Parallel Length;**

<u>Comments:</u>

The difference between the induced pipeline potential calculated using the circuit approach (SESTLC, ROW) and the results using the field approach (HIFREQ) increases with increasing ratio between the horizontal separation distance and pipeline parallel length. This is due to the fact that as the distance between the pipeline and the transmission line increases, the magnetic discontinuities at the fault location and at the ends of the line affects a larger and larger portion of the pipeline

## 1.4 Conclusion

This article compared the performance of three tools (SESTLC, ROW, and HIFREQ) when computing AC interference effects caused by transmission lines. The main advantages and limitations of the three tools are listed below.

**SESTLC** provides a quick estimate of ac interference level for simple right-of-way configurations under steady-state and fault conditions. However, for more detailed studies or for a final design involving complex configurations, the ROW or HIFREQ modules should always be used.

**ROW** is fast and flexible. It can provide accurate results under steady-state conditions for most right-of-way network configurations: parallel, non-parallel, crossing, phase transpositions, etc. The difference between ROW and HIFREQ under steady-state conditions is usually small, especially when the transmission line is sufficiently long. Decreasing the section cut length can improve the computation accuracy for non-parallel cases.

Under fault conditions, the error, which is most noticeable at the fault location, can be important for some network configurations. The predictions from ROW, however, are usually conservative.

Furthermore, ROW can model different soil models along the right-of-way. It also allows the user to automatically create faults along any transmission line, at any given intervals (with the Monitor Fault module). Finally, it generates summary files containing certain information about the 'victim' phase conductor (i.e., pipeline/railway maximum GPR, maxim rail-to-rail voltages, GPR at fault locations etc.), a reference phase conductor (i.e.: tower injected currents) and phase conductors (i.e., fault currents for any fault location).

**HIFREQ** offers the most accurate model, and accounts correctly for the finite length of the transmission line conductors. It is also considerably simpler to specify the input data for HIFREQ. However, the program can be time consuming, especially for complicated right-of-way configurations. In addition, HIFREQ can only model one soil model along the entire right-of-way under study.

## 1.5 References

[1] Y. Li, F. P. Dawalibi, and J. Ma, "Effects of Conductor Length and Angle on the Accuracy of Inductive Interference Computations," Transmission and Distribution Conference and Exposition, IEEE/PES 2001, Atlanta, UAS, October 28-November 2, 2001.

[2] Y. Li, F. P. Dawalibi, and J. Ma, "Effects of Conductor Angle between Transmission Lines and Neighboring Utilities on the Accuracy of Inductive Interference Computations," PowerCon2002, Kunming, China, November 2002.

[3] R. Southey, F. P. Dawalibi, Y. Li and W. Yuan, "Increasing the Cost-Effectiveness of AC Interference Mitigation Designs with Integrated Electromagnetic Field Modeling," Corrosion/2005 NACE International Conference, Huston, USA, March 2005.