Effects of Measurement Location and Fault Impedance on EMTR Fault Location Techniques

David Flynn, *Student Member, IEEE*, Reza Razzaghi, *Senior Member, IEEE*,
Lachlan L. H. Andrew, *Senior Member, IEEE*

***Abstract*—This paper discusses the effect of the location of measurement units on the electromagnetic time reversal (EMTR) based fault location method. It is shown that the location of the measurement point can greatly affect the accuracy of two EMTR-based techniques (L2 and Lmax). Furthermore, the impact of the fault impedance has been studied. The findings are presented by considering the distance from the guessed fault location to the true fault location for a number of fault cases.**

I. Introduction

Electromagnetic time reversal (EMTR) has recently gained a particular attention as an effective fault location method for power networks. A few variations of the EMTR-based fault location methods have been proposed that determined the fault location from measurements of the wave-transients that propagates upon the development of the fault. This technique was first presented in [1], where the energy of the time-reversed injected signal at a guessed fault location is used to determine the most likely of a set of guessed fault locations – which is known as the Fault current signal Energy (FCSE) method. We will refer to this technique as the L2 method. A variation is presented in [2] whereby the maximum amplitude of the back-injected signal is measured. It is shown that this technique can perform better given a significant amount of white Gaussian noise. This method is referred to as the Lmax method.

Although further variations of the EMTR method exist ([3], [4]), limited research has been conducted on the optimal placement of the measurement unit that records the fault-originated transient signals. This study investigate the impact of the location of the measurement point on the performance of the L2 and Lmax techniques. The simulation results show a complex, non-linear relation between the location accuracy and fault impedance, which require future studies to better understand them.

II. Simulation Studies

A branched radial power network with the total length of 60 km total (Fig. 2) is simulated in the EMTP simulation environment. Each line segment is split into increments of 200 m, giving 287 fault test points. Phase-to-ground faults are simulated at each location with fault impedances ranging from 0Ω to 100Ω. Voltages are measured at four points in the network, including one at the substation. The measured voltages are back-injected individually following the process of [1]. The simulation results are summarized in a 287x287 heat-map of fault/guessed fault locations (Fig.e 1).

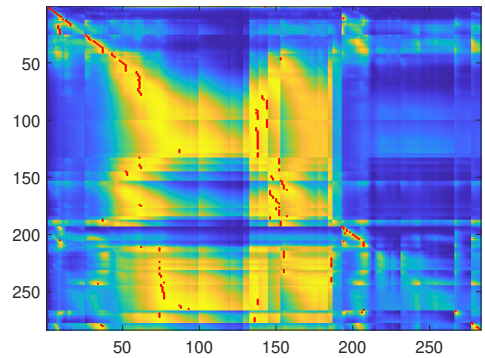

Fig. 1. Heat-map of the L2 fault location technique with a simulated 50Ω fault. Each row corresponds to a simulated fault location, and each column a possible guessed fault location. Ideal results would lay on the main diagonal. Red dots indicate highest peak per fault

An ideal algorithm would show strong main diagonal elements in the heat-map. Figure 1 shows the fault energy is not always maximized on the main diagonal, meaning that there are location errors for some fault tests.

We present the fault location accuracy in two ways. The first associates a colour with each location in the network (Figure 2). The network is then drawn again. To show that a fault at x was estimated to occur at y, the colour used to draw point x in the new plot is the colour associated with location y. Figures 3 and 4 show the results for a $50\,\Omega$ fault. For the L2 method, measurement locations (b) and (d) provide the best results, which are located at the farthest ends of the networks.

In the second visualization, the distances between all faults and their guessed locations are calculated. A contour plot is plotted. For example, a 70% contour line indicates the distance x for which 70% of all fault location/guessed fault location pairs are within x km of each other.

The results of the simulation studies can be seen in Figs. 5 and 6. While most studies based on the EMTR techniques have used a measurement device at the substation, these figures show that this may not be the most effective location to measure/inject fault transients. In particular, locations (b) and (d) show the best performance for the L2 method.

The L2 method has a peak in accuracy around $30\,\Omega$–$40\,\Omega$, however this is not reflected in the Lmax method.

III. Conclusion

Improved fault location can be obtained by using an optimal location for the measurement point. Interesting results were

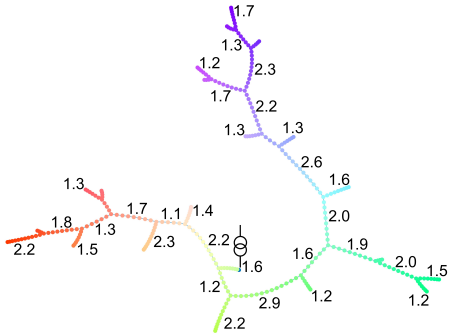

Fig. 2. Plot of the network with unique coloring throughout. Lines longer than 1 km are labeled with their lengths in km, and the substation is marked.

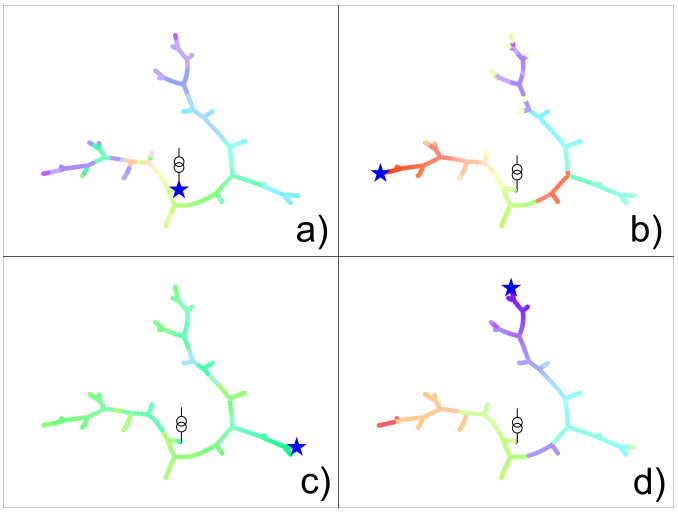

Fig. 3. Plot of the network using the L2 method. Colouring is based on the guessed fault location and the blue star shows the location of the measurement point. Each location in the network has a unique colour associated with it (use Fig. 2 as the reference). A location x in the figure, having been coloured by unique color c indicates that the algorithm guessed a fault at x was actually at the location in Fig. 2 that shares the same colour c.

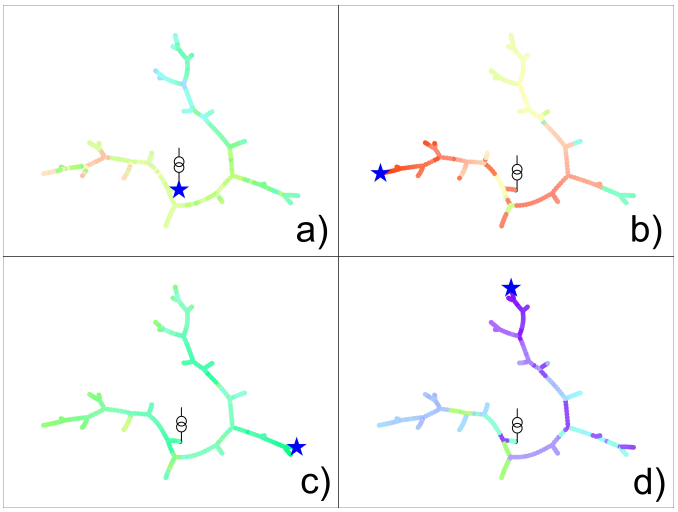

Fig. 4. Repeat of Fig. 3 for Lmax.

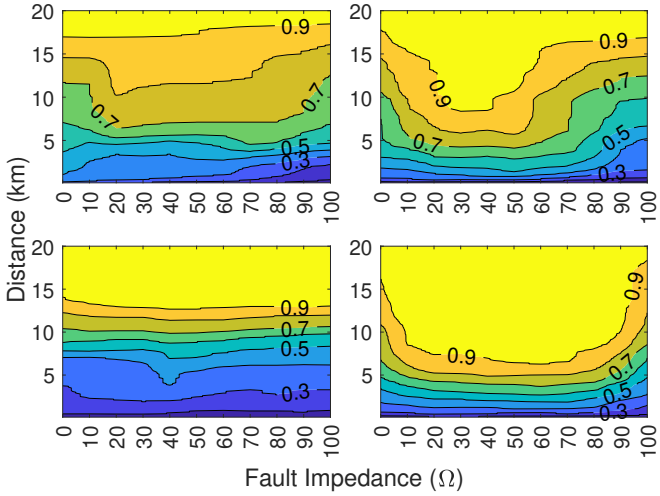

Fig. 5. Contour plot of distance to true fault for different impedance levels, with no noise using L2 method. The Y axis indicates distance from the guessed fault location to the true fault location (km). The X axis indicates the fault impedance in Ohms. Level lines indicate the contours of the plot in 10% increments. For example, the 0.7 line indicates that 70% of faults are guessed to within Y distance.

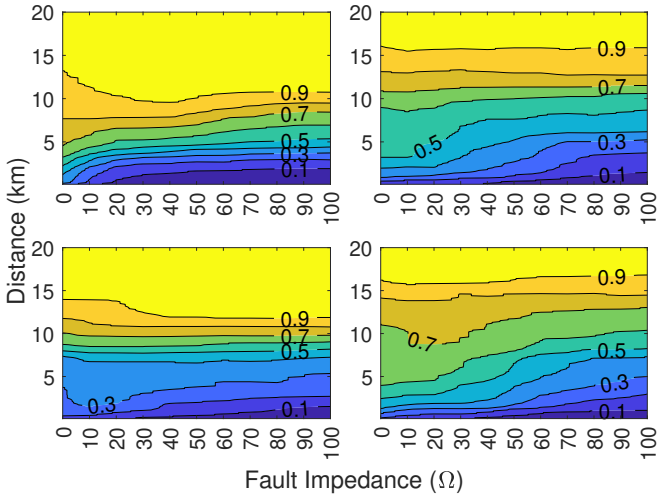

Fig. 6. Repeat of Fig. 5 for the Lmax method.

observed for different fault impedance values, which require further studies.

References

[1] R. Razzaghi, G. Lugrin, H. Manesh, C. Romero, M. Paolone, and F. Rachidi, "An efficient method based on the electromagnetic time reversal to locate faults in power networks," *IEEE Transactions on Power Delivery*, vol. 28, no. 3, pp. 1663–1673, 2013.

[2] S.-Y. He, Y.-Z. Xie, Z.-Y. Wang, F. Rachidi, B.-Y. Liu, Q. Li, and X. Kong, "Norm criteria in the electromagnetic time reversal technique for fault location in transmission lines," *IEEE Transactions on Electromagnetic Compatibility*, vol. 60, no. 5, pp. 1240–1248, 2018.

[3] S. He, A. Cozza, and Y.-z. Xie, "Electromagnetic time reversal as a correlation estimator: Improved metrics and design criteria for fault location in power grids," *IEEE Transactions on Electromagnetic Compatibility*, vol. 62, no. 2, pp. 598–611, 2020.

[4] A. Codino, Z. Wang, R. Razzaghi, M. Paolone, and F. Rachidi, "An alternative method for locating faults in transmission line networks based on time reversal," *IEEE Transactions on Electromagnetic Compatibility*, vol. 59, no. 5, pp. 1601–1612, 2017.