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Open Fault Trace Tool – GTC Case Studies

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SUMMARY

Georgia Transmission Corporation (GTC) provides transmission services to 38-member cooperatives. In order to provide system reliability, they deployed a suite of open source, automated fault location tools. This paper describes the motivation, challenges, and selected solution for getting more accurate fault location information on the transmission system. In addition, the paper presents several case studies where the tools were able to improve the situational awareness to the field staff during remediation activities.

KEYWORDS

Fault Location, Fault Trace, Geographic Information System (GIS)

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Background

Georgia Transmission (GTC) is responsible for providing transmission services between 38-member electric cooperatives and the generation companies in the state of Georgia. GTC is a member of the Integrated Transmission System in Georgia, along with Georgia Power, Dalton Utilities, and MEAG Power. Figure 1, below, shows the service area for GTC.

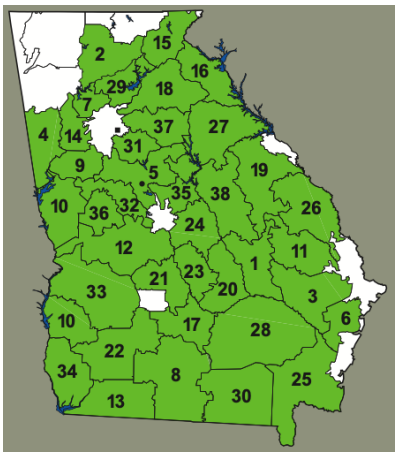

Figure 1 - GTC Service Area

Reliable and affordable energy, innovative technology, and Smart Grid are all key priorities for GTC. In keeping with these priorities, the protection department deployed digital fault recorders across the system. These devices record faults on the system and reports the events to a centralized collection system. The collection system, in turn, performs an automated analysis of the data and calculates a distance to faults on the lines. Investment in these tools have improved the speed with which maintenance crews can respond to faults on the lines. Figure 2, below, shows an overview of the automated fault location system.

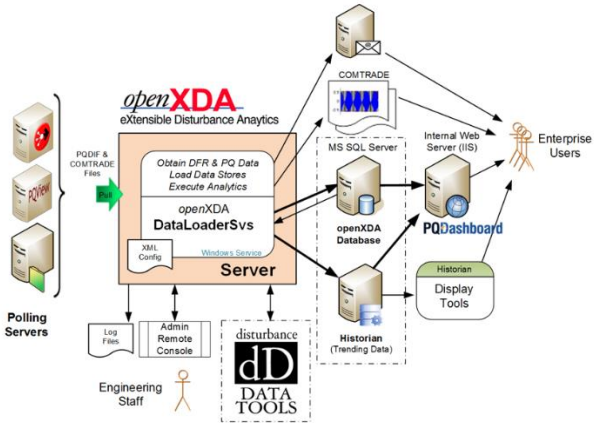

Figure 2 - Overview of GTC Fault Location System

In 2014 GTC began researching a Fault Trace Tool (FTT) and tried working with several different vendors in search of a solution to display an X on the transmission line at a measured fault distance. During this search, GTC discovered that the cost to create custom software with existing vendors was not only cost prohibitive, but left GTC footing the bill only to have a vendor own the final product. In 2020, GTC connected with the current vendor and found a solution for a Fault Trace Tool that had acceptable costs and allowed GTC to have the copyright of the product.

In the fall of 2020, the Fault Trace Tool was rolled out at GTC. The phase 1 rollout included using fault distance data from GTC Digital Fault Recorders (DFRs) to provide an automatic fault location map within the GTC fault email, a FTT webpage to display a map using manually input fault distances, a manual entry double ended analysis displaying fault distances from both ends of the transmission line, and the ability to click on a structure and measure back to a substation.

Spring 2021 included additions to the FTT, such as: an automatically generated lightning overlay on the fault map, the ability to run a lightning study from the FTT webpage, inclusion of Georgia Power DFRs in the automatic fault email maps, and display of fault indicator status at the time of a fault on the map.

Challenges

While the fault location system improved the response time of the maintenance crews, enhancements were developed to provide additional insights into fault locations. The existing tools informed crews about the distance to the fault along a transmission line. However, GTC has many lines which are tapped. Consequently, a single fault distance may result in multiple physical locations. Consider figure 3, below, which shows how a single fault distance could be at multiple locations on a transmission line.

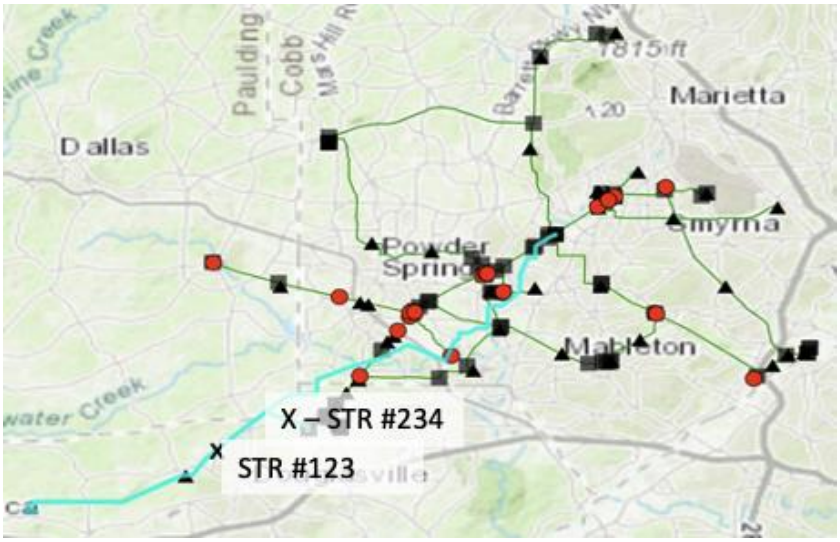

Figure 3 - System with multiple branches

In addition to users being able to manually interact with the tool, GTC wanted to be able to integrate the tool with the existing systems so that automatic fault location emails could be sent with maps included. This required there to be an application programming interface (API). Coordination meetings between multiple vendors were required to ensure that the systems could talk with each other.

Almost all the data about the transmission system was in the geographic information system (GIS) at GTC. However, GTC was in the middle of a significant effort to improve the data within the GIS. As a result, some of the data needed to be fixed during the project. In some cases, not all the data had the correct attributes. In addition, the GIS did not always contain a complete map of the connectivity between the substations and multiple line segments. Consequently, the tool would need to be able to be robust to ensure that changes to the GIS would not break the tool. In addition, the tool would need to be flexible to support the underlying changes in the data.

A high percentage of faults on the GTC system are caused by lightning. As a result, GTC also wanted the ability to show lightning in the line right of way that was time-correlated to the fault. GTC already had a different vendor in place to provide lightning data. Fortunately, the vendor provides their own API to access lightning information through the internet.

Finally, the data in the GIS represented the geographic representationn of the data. It did not also contain the network topology or connectivity between the lines, substations, and structures. In some cases, lines were comprised of multiple line segments. Necessarily, the tool needed to be able to develop the topology of the network on the fly keeping in mind that the GIS could change at any time as updates were made.

The Solution

Figure 4, below, shows the fault trace tool architecture. Each block is colored based on a vendor/stakeholder touchpoint. As is shown, a number of systems and support staff are needed to be engaged to have a successful project. In phase 1, the FTT was connected to the fault servers and GIS servers. In phase 2, the tool was connected to the lightning server. Finally, in phase 3, the tool was connected to fault indicator data in the SCADA system.

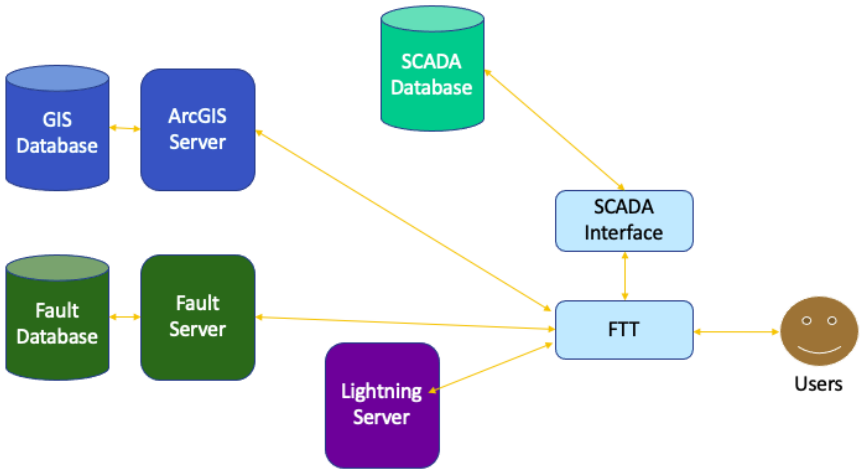

Figure 4 - Supporting Architecture for Fault Trace Tool

A user interface was developed to enable staff to manually locate faults on the power system. The map-centric user interface is shown in figure 5, below. The user interface has an input area where users can enter the fault time, select a line, select a substation, and enter a distance.

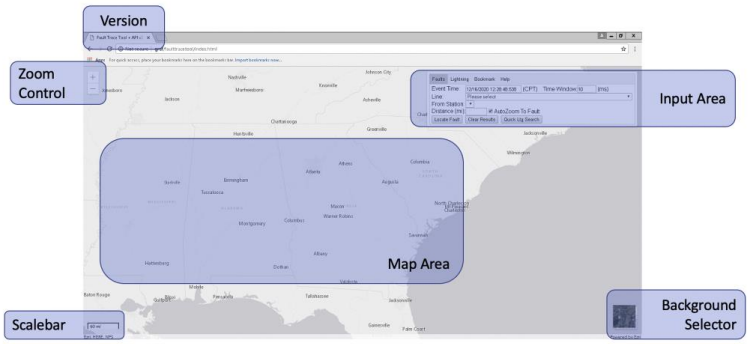

Figure 5 - Fault Trace Tool User Interface

After clicking the locate fault button, the results appear on the map as shown in figure 6, below. The user interface zooms to the selected line and the structure nearest to the fault. An X is used to denote the location of the fault on the map. In addition, a lightning query is run to see if there is lightning near the line. If lightning is found, then a lightning strike will appear on the map along with information like time stamp, signal strength, and location shown in a table.

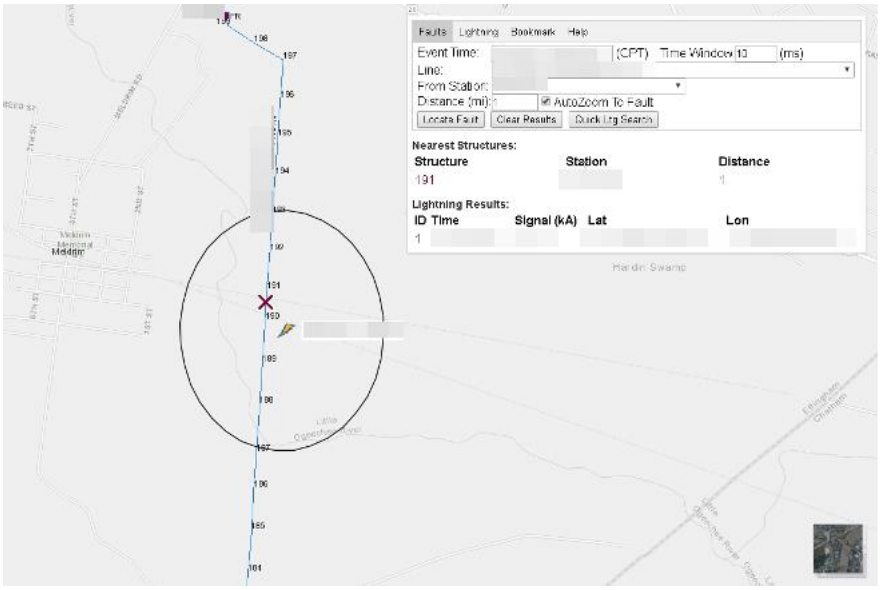

Figure 6 - Example output from fault trace tool (some areas redacted)

A web API was developed to enable 3rd party systems to generate output from the tool automatically. The API utilizes a standard web address with parameters that enable the systems to specify the station, the line, the distance, and time window to be used for analysis. An example of the API is shown below.

http://<<servername>>/faulttracetool/index.html?station=<stationid>&line=<lineid>&distance=<distance>&eventtime=<datetime>&timewindow=<timewindow>&outputType=jpg

- Station = Station Name
- Line = Line ID
- Distance = Distance in Miles from Station
- Eventtime = Timestamp for event
- TimeWindow = Number of seconds to search around event time.
- zoomToFault = {y = yes, n=no}
- OutputType = { jpg=jpeg, h=html, json=json }

Both the API and user interface are an HTML and JavaScript application built, in part, on ESRI's ArcGIS JavaScript API. This allows for a rich, map-based user experience. The line list is populated from the line features in the GIS. When a line is selected, the substation list is populated by automatically filtering substations physically close to the line. In addition, the structures associated with the line are displayed.

When the user clicks the Locate Fault button, the tool builds a topology from the map assets. Next, the topology is used to trace the line from the selected substation to the vertex on the line nearest to the fault distance. Finally, the structure nearest that vertex is selected.

After the fault is located, the tool produces a buffer around the selected line. The buffer geometry and the time window are sent to the lightning system. When the lightning data is returned, it is displayed on the map. Figure 7, below, shows the process diagram for the lightning module.

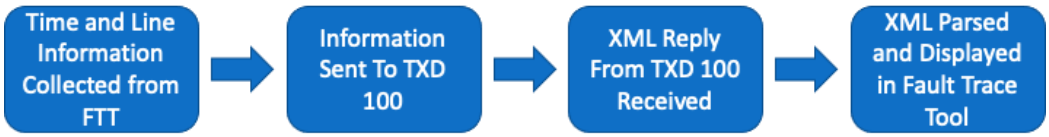

Figure 7 - Lightning Process Diagram

Results

GTC decided to incorporate a map from the Fault Trace Tool into our existing PQ Dashboard DFR fault emails and also have a new FTT website created. These two outlets enable the creation of an email with a map of DFR fault distance locations as well as the ability to manually plug in relay fault distance into a webpage to produce a map.

Figure 8, below, shows what the original PQ Dashboard fault email looked like.

Fault 1 - 2021-05-04 21:16:03.8862496
DFRs: R103 at triggered at 21:16:03.7335413 (click for waveform)

Files: 210504,211603833,-5t,

Line: 115kV LINE (19.57 miles)

	- R103
Fault Type:	AN
Inception Time:	21:16:03.8862496
Fault Duration:	133.750 msec (8.03 cycles)
Fault Current:	1331.6 Amps (RMS)
Prefault Current:	235.3 Amps (RMS)
Postfault Current:	18.8 Amps (RMS)
Distance Method:	ModifiedTakagi
Single-ended Distance:	8.243 miles
Is Breaker Restrike?:	N/A
Short file name:	R103F4640.dat
openXDA Event ID:	1534220

Figure 8 – Original Email from Automated Fault System

The FTT project added an additional map below the fault email information above, and now includes an X on the transmission line, as seen below.

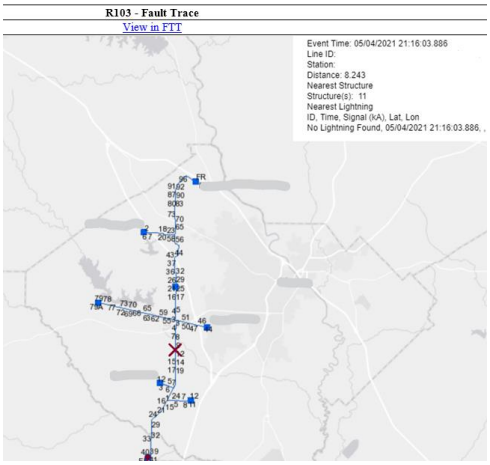

Figure 9 – Email with OpenFTT

One of the huge benefits of the Fault Trace Tool is the ability to show multiple faults on a transmission line and its taps, not only a fault on the main transmission line. Seeing all possible fault locations enables more factors to be considered and ruled out regarding where a fault may be.

In Figure 10, below, the DFR gave fault information from a substation in the middle of the transmission line. From this location, two possible fault locations are possible on either side of the substation, as seen by the maroon X's near structure 14 and 36-37. Meanwhile, the information box is quick to show the ownership of all three of these poles being GTC. This structure information is a key piece for GTC, as it quickly shows who owns the pole that may have a fault, and which crews should be recommended to troubleshoot the fault. In this example, the GTC patrol found a bird at structure 13, near one of the maroon X's on the map.

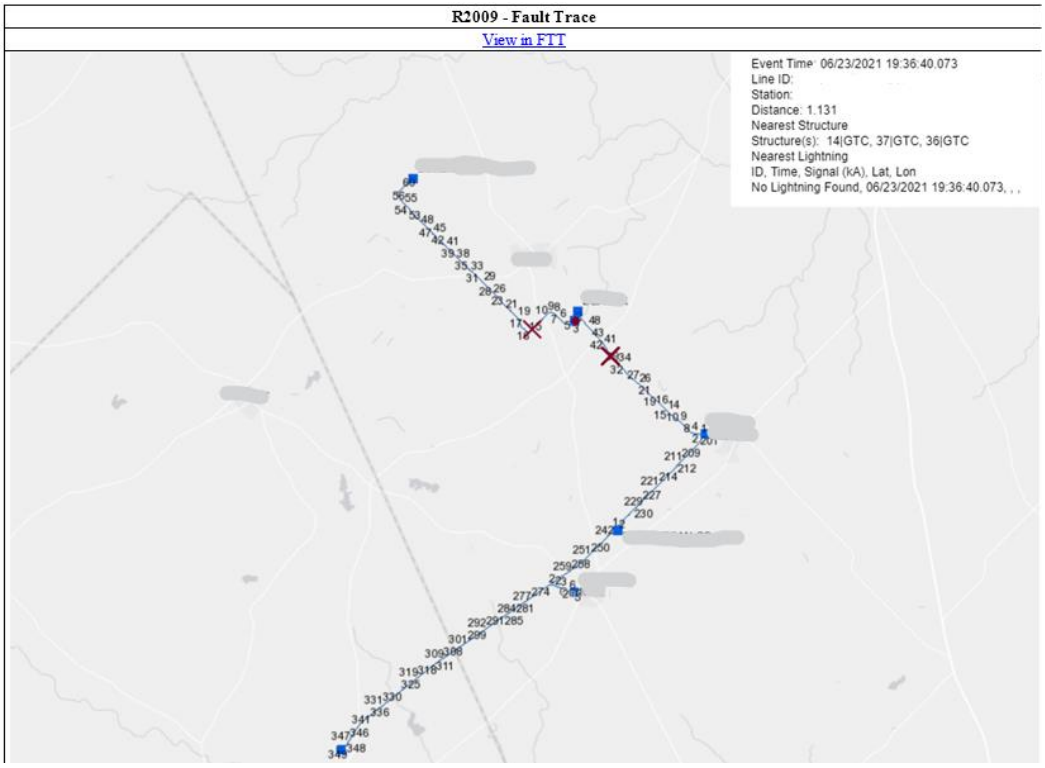

Figure 10 – Multi-Tap Case Study

In Figure 11, below, there were two locations for the fault from the DFR on the northern end of the transmission line. The first fault could have been at structure 58 on the tap, and the second fault could have been at structure 39 down the main line. The information box shows that both of these structures are owned by GTC, which again gives a quick indication of which crews need to find the outage location. In the end, a green tree fell from off the right of way into the line near structures 36-37, which was within a few spans of the lower X on the line.

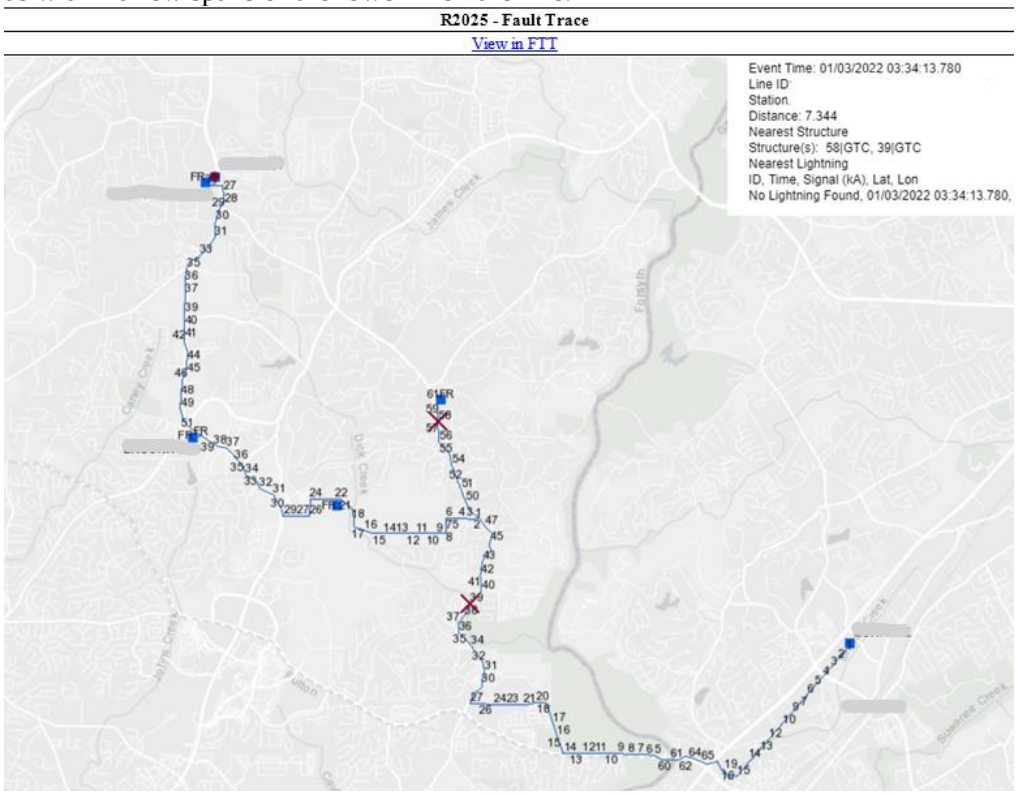

Figure 11 – Multiple Taps With A Tree In Line

Being able to automatically visualize one X on the line from DFR fault data has proven to be very beneficial to our field crews and control center operators. The additional capability of adding DFR or relay information from the other end of the transmission line at the time of the fault increases the understanding of what all available information is showing at the time of an event.
An email came from the "View in FTT" link in the PQ Dashboard email. It opened up the FTT webpage and the first substation is highlighted by a maroon dot, with a maroon X on the line. We manually entered the second DFR distance into the tool, and it is displayed by a red substation dot and red X on the line. The outage was due to a green tree between structures 106-107. Figure 12 shows the results of the analysis.

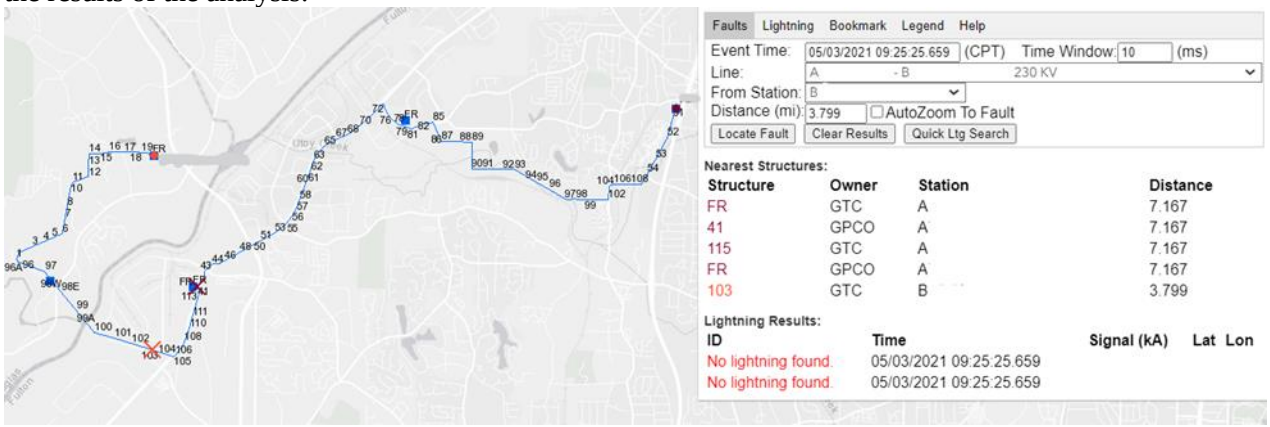

Figure 12 – Double Ended Fault Location

The combination of multi-tap fault location and double ended analysis enables a quick overview of all possible fault locations and a visual narrowing down of locations to one or two most likely spots. In Figure 13, below, the DFR email provided the two locations in maroon, and manually entering the DFR distance from the other end provided the red X, which narrowed down the fault location to a few spans on the main transmission line.

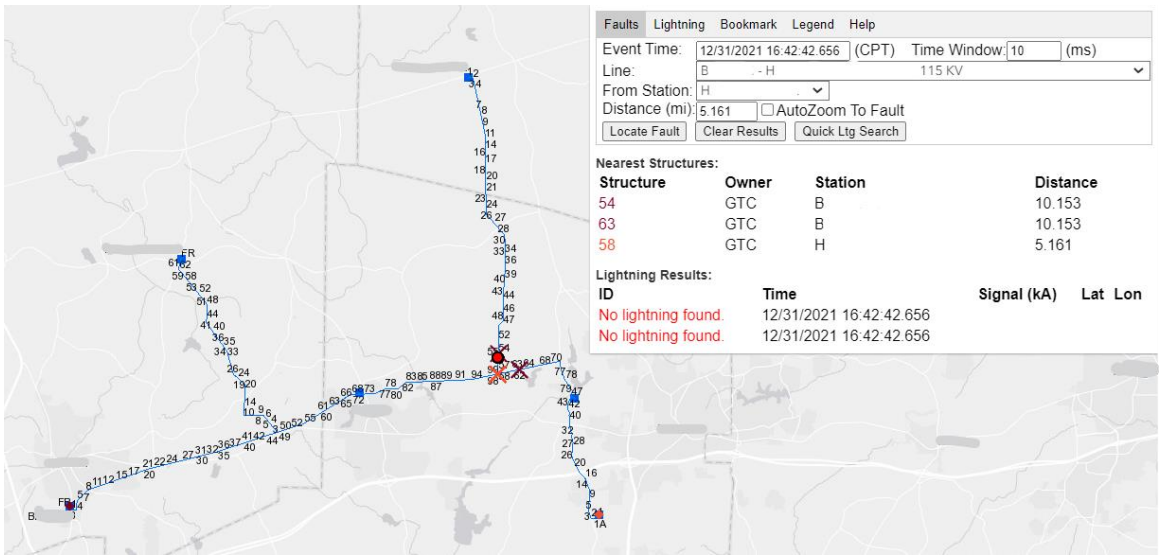

Figure 13 – Double Ended Analysis with a Tapped Line.

Figure 14, below, shows zooming into the fault locations from the example above, a red circle can be seen on the tap with one X heading north. This red circle gives a quick visual of the status of the Fault Indicator on the line. In this example with multiple maroon X locations it is extremely helpful to see the red Fault Indicators, which means that the Fault Indicators did not see a fault, to show that the tap line to the north did NOT see a fault. This would lead the user to search for a fault cause near the main transmission line maroon X. In this case, a tree was found on the line between structures 61-62 near the main line maroon X.

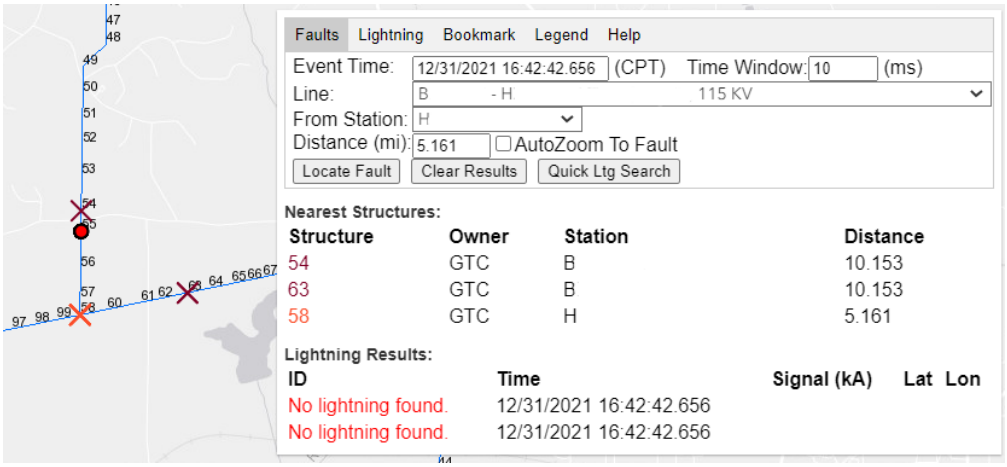

Figure 14 – Fault Indicator Status

Figure 15 shows the legend for what the colors of the Fault Indicators mean. When there is a fault, the indicator turns green. If there was no fault detected, the indicator turns red. There are some Fault Indicators on the system that are not operational due to connection issues, maintenance needs, or other reasons. We chose to still show them with an orange indicator, so that we know where planned maintenance may offer better data for future faults. If there is a fault indicator on the line, but no fault distance was requested, the indicator will stay clear. This is helpful so that a red indicator would not turn into a false negative in situations where no request was made for Fault Indicator status.

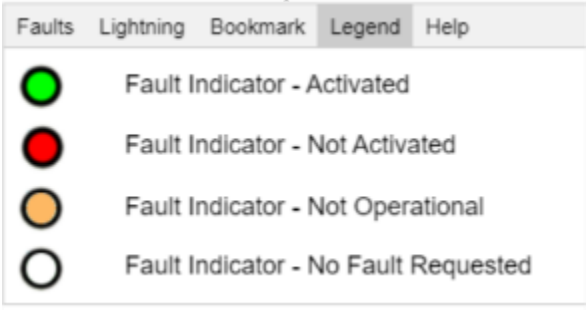

Figure 15 – Fault Indicator Legend

In fault maps with lightning strikes as shown in Figure 16, below, the smaller the "ellipse of confidence" around the lightning strike, the more confident the lightning software is in the location of the lightning strike, and vice versa. For the FTT example below, the lightning strike on the left has a tiny ellipse, so most likely the lightning strike was near the transmission line. Meanwhile the larger ellipse on the right, where the lightning could have been anywhere within the ellipse, indicates that the lightning strike could have impacted the transmission line, but the confidence of this being the exact location is lower. It would be suggested for crews to patrol the line between the red and maroon X's, especially the structures around the left lightning strike, to look for damage to the line.

It is also worth noting the details in the Information Box – the nearest structure, who owns the pole, the distance the FTT ran, and the lightning study results – were previously un-viewable before the Fault Trace Tool.

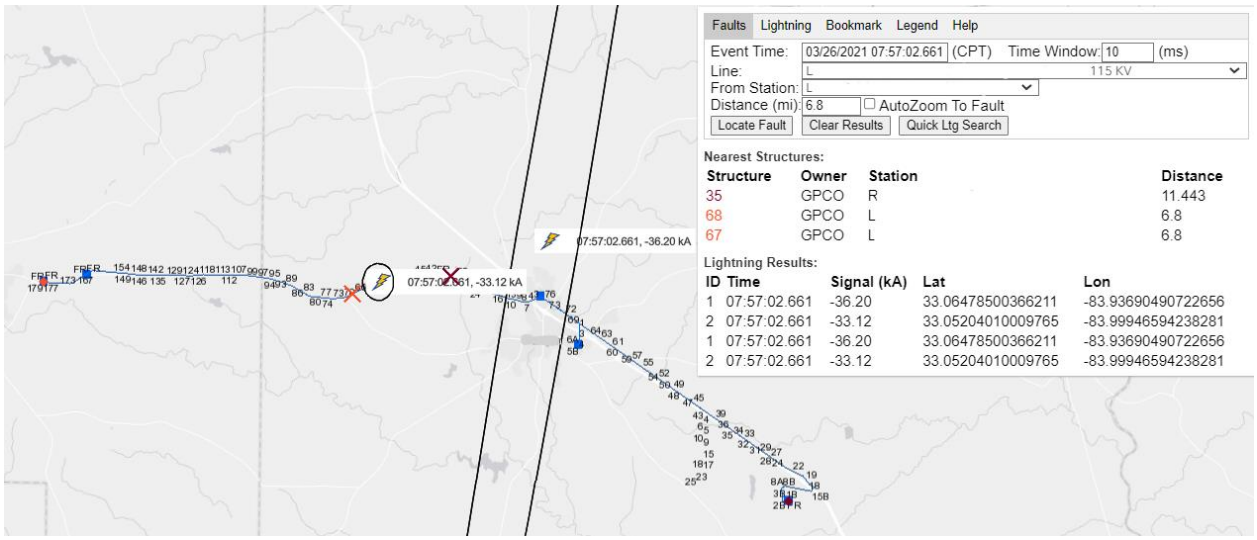

Figure 16 – Fault Analysis with Lightning

When the lightning strike information is overlaid with a fault map with multiple fault locations, it proves to be another beneficial piece of data to narrow down the probable location of the fault. In Figure 17, below, the addition of lightning on the map quickly narrowed down three possible fault locations to one.

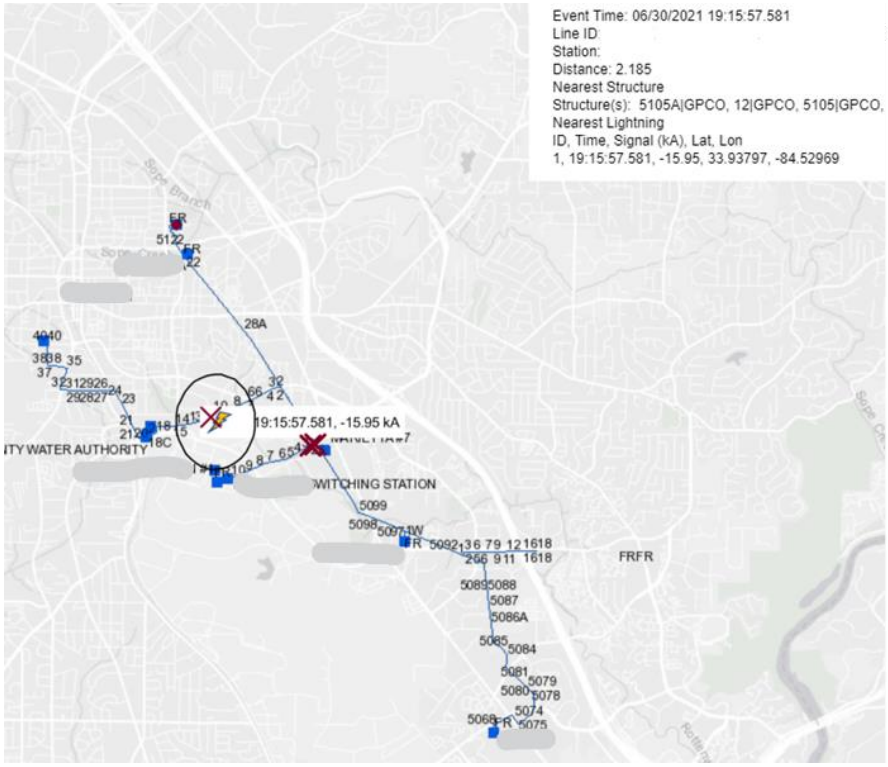

Figure 17 – Multiple Fault Locations with Lightning Analysis

Conclusion

The Fault Trace Tool was developed to help GTC respond to system events more quickly. The system has successfully helped GTC identify the fault location and the cause when the fault is lightning. The project was complex due to the number of different vendors that needed to be coordinated. GTC continues to improve the tool with user input and learning from other utilities. The tool is available as an open-source project on GitHub (https://github.com/Lifescale-Analytics/OpenFTT). There are no license fees to use the product.