SmartAFL™

Centralized Fault Locating System

Applied Technical Systems Joint Stock Company

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A. Product Overview

SmartAFL™ is a Travelling Wave (TW)-based and Impedance-based distance-to-fault locating software package.

Vietnam is located in an area with dynamic weather of floods, thunderstorms and tropical typhoon. At the same time, Vietnam Power Grid consists of 7,183km of 500kV lines and 15,079km of 220kV lines (2015 data), passing through mountains and forests of rugged terrains. These conditions together result in high possibility for transmission line incidents while making operation management and line patrol to be highly complicated tasks.

HARDWARE

The hardware architecture design is critical for the stability and availability of the entire system; the choice ensures that any single-point failure shall not affect the whole system.

The hardware architecture of typycal system includes three substations and two transmission lines is displayed in figure 1.

SmartAFL™ utilizes SEL-411L with capability for TW and DFR data collection in order to calculate distance-to-fault using both TW and Impedance method.

SEL-3355 will be installed at the middle substation to collect, store and calculate fault location at the Centre. This industrial computer with no element rotation is designed specifically for use in environments that require high reliability.

ADVANTAGES

- System sizing capacity for over 500 substations, 2000 lines and 2 million stored records
- Hardware-vendor independent
- Analytic results include: Fault type, Inception time, Duration, Distance, Pre-fault current, Fault current
- Web-based visualized reports
- Automatic notifications to email and/or SMS

SOFTWARE

SmartAFL™ software is developed by ATS with standard-based features, making it a hardware-vendor independent software that can protect utility investment and lower total cost of project ownership throughout its lifecycle.

TW and Disturbance Impedance data is sent from Data Acquisition Units (DAU) to Data Acquisition Server via private WAN. Based on Travelling Wave and Impedance records of both ends and line parameters stored in system database appropriate distance-to-fault locating algorithms are executed with Automatic Fault Location calculation engine. Operators are able to set up fault locating calculation in automatic or manual mode.

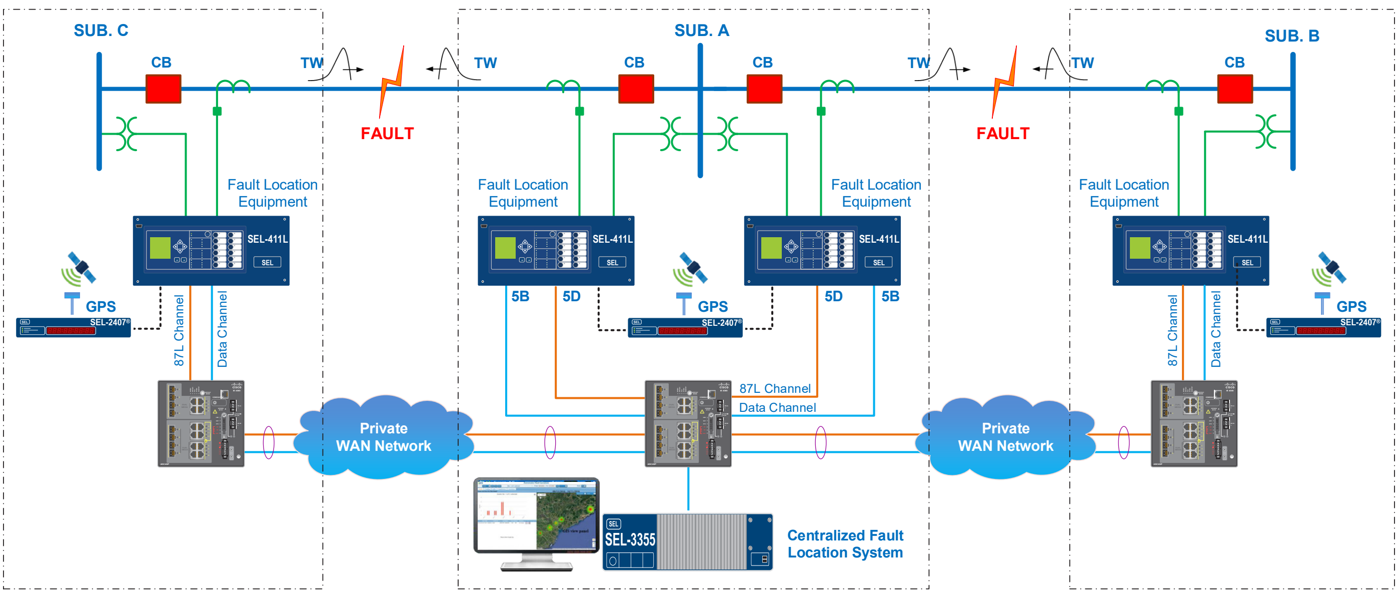


Figure 1. Hardware Architecture

1. DATA ACQUISITION

When a in-zone fault occurs in the protected OHL, Travelling Wave and Impedance Files will be recorded and automatically transfered to the Centralized Fault Location System for processing. SmartAFL™ software will detect and process COMTRADE (IEEE C37.111) format files at center. The *travelling wave COMTRADE* file will be processed with the travelling wave method, and the *impedance COMTRADE* file will be processed with the impedance method.

2. CENTRALIZED SYSTEM DATABASE

The Configuration Data is a CIM-based power system database, which includes:

- Fault location device information: Name of device, GPS location, Station where Device is located, and the monitored Line.
- Fault location channel definitions: Channel index number for each sample in the record.
- Line parameters: Name of the line, GPS location, Length of the line, Nominal impedance of the line (R1, R0, X1, X0, B1, B0).

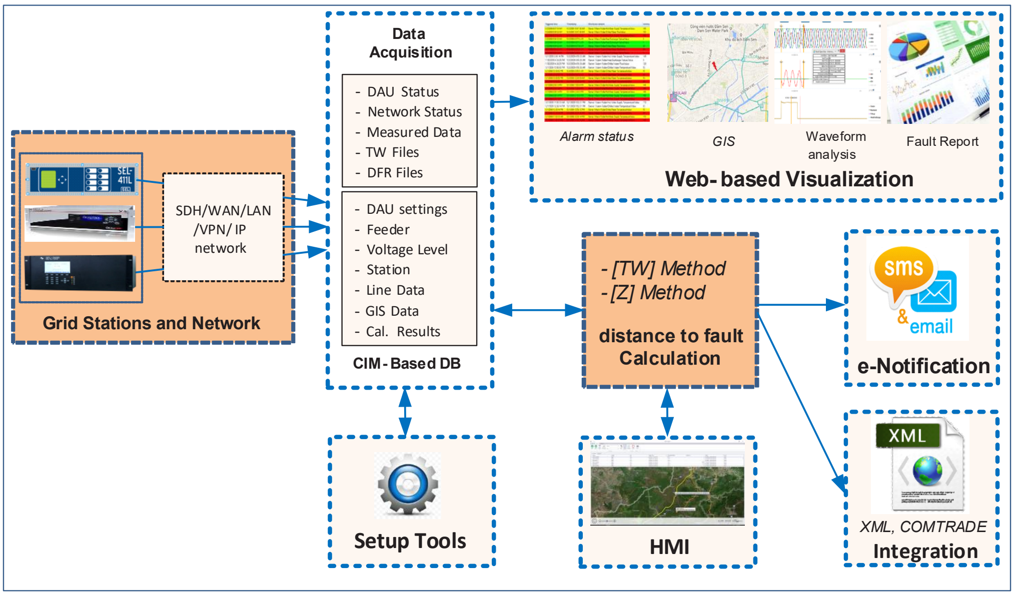


Figure 2. Main Functions of SmartAFL™

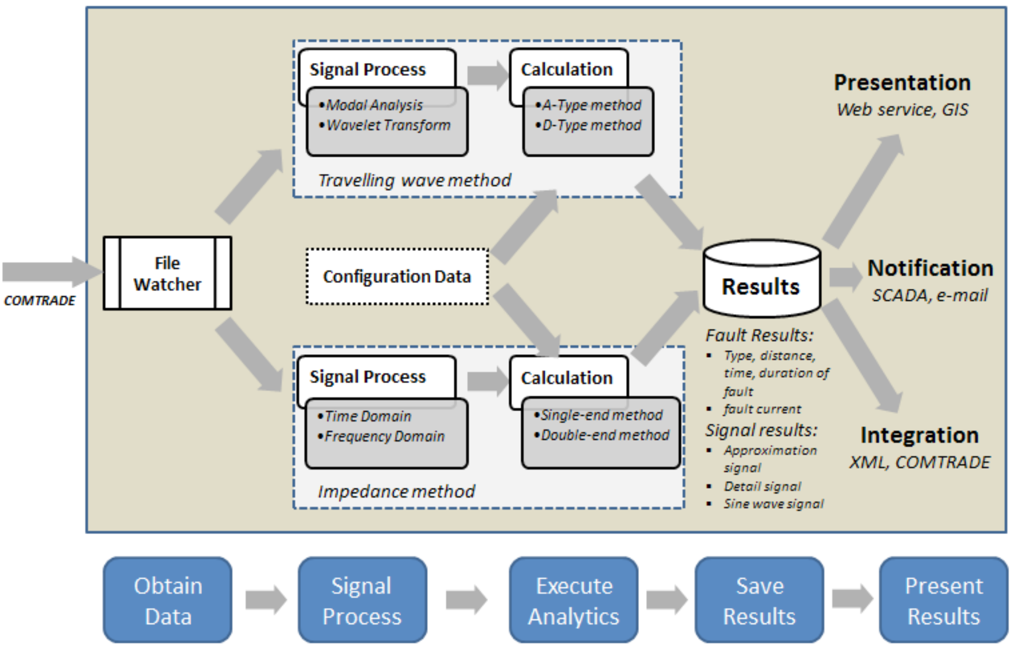


Figure 3. Data Flow and Process

B. Technical Highlights

3. HUMAN-MACHINE INTERFACE FOR MONITOR SYSTEM STATUS

HMI of Centralized System provides the ability to manage not only overall system status but also detail status of DAU devices at each bay feeder. It can also monitor communication status and record sequence of events occur on the system.

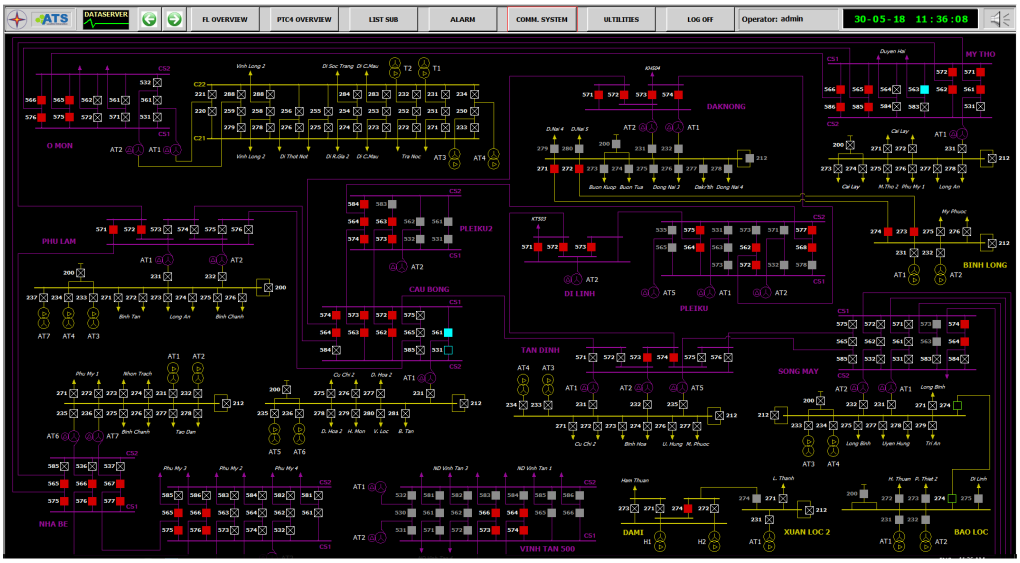


Figure 4. Overall Status of Relays on Centralize System

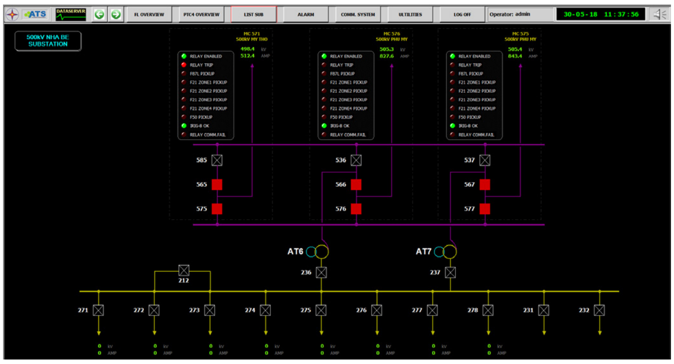


Figure 5. Bay Feeder Status of Substation

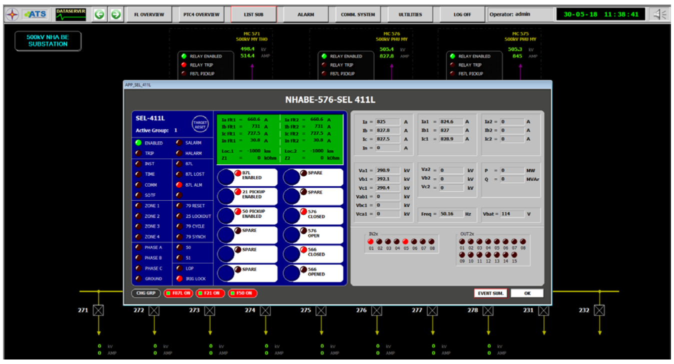


Figure 6. Relay Status

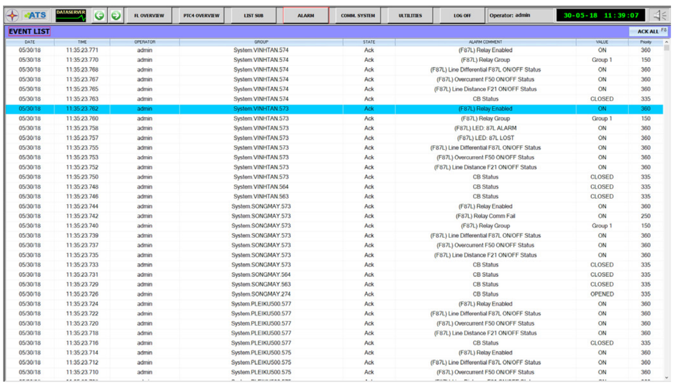


Figure 7. Sequence of Event Monitoring

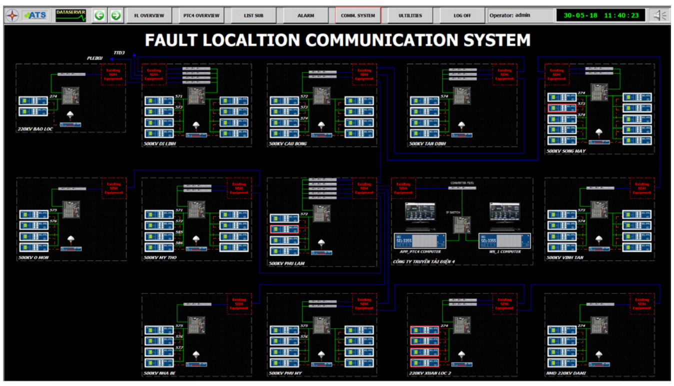


Figure 8. Communication System Monitoring

4. DISTANCE-TO-FAULT CALCULATION

4.1. Travelling Wave Method

» ***A-Type Method***

A-type locators perform measurements on one side of the line. The distance to the fault location is calculated by measuring the time between the moments when the first wave - generated at the fault location - reaches the locator, and the second moment when the wave reflected from the fault location reaches the locator. The electromagnetic wave is entirely reflected from the fault location if the occurring fault angle has a resistance less than the wave impedance of the line.

The distance to the fault location from station A results from the following dependence:

$$D = \frac{t_2 - t_1}{2} \times v$$

where:

D – distance to fault location [m]

t_1 – time at which the first wave generated at fault location reaches station A [s]

t_2 – time at which the wave reflected from fault location reaches station A [s]

v – wave propagation velocity [m/s].

» ***D-Type Method***

D-type locators perform measurements on both sides of the line. Waves generated at a fault location run towards stations A and B, and reach them within several microseconds. For a correct determination of the fault location, a D-type locator requires the use of two devices synchronized with each other in time (e.g. by means of precise GPS clock), installed at the two ends of the line. The locator determines the moment when the wave reaches stations A and station B, which is used to calculate the distance from fault location.

The distance to the fault location from station A results from the following dependence:

$$D = \frac{L + (t_A - t_B) \times v}{2}$$

where:

t_A – time at which the first wave generated at fault location reaches station A [s]

t_B – time at which the first wave generated at fault location reaches station B [s]

L – line length [m].

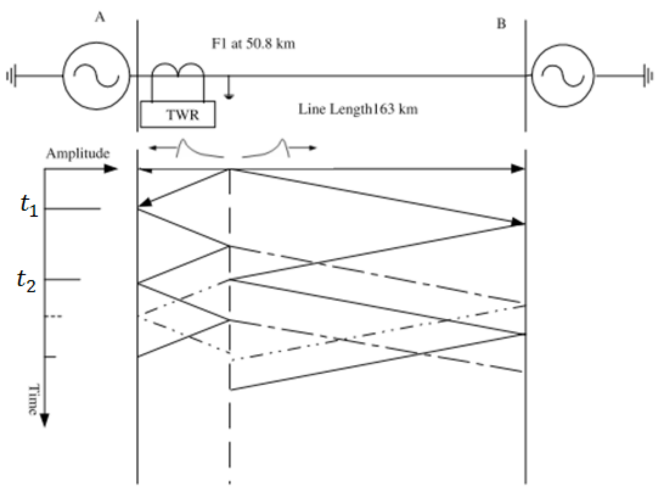


Figure 9. Lattice Diagram for A-Type Method

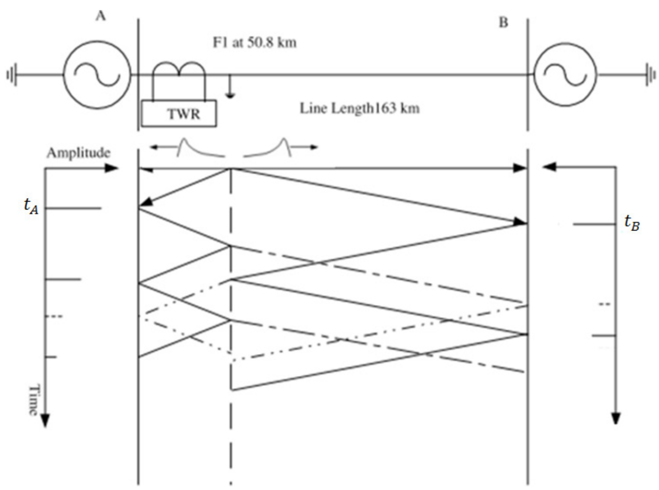


Figure 10. Lattice Diagram for D-Type Method

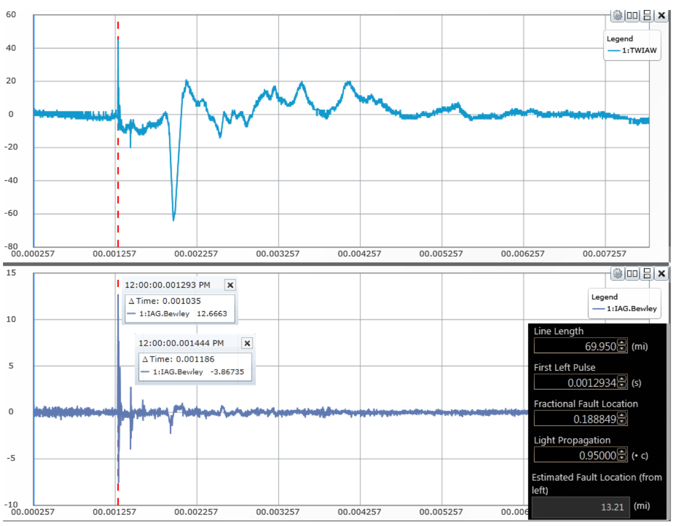


Figure 11. A-Type Method Result

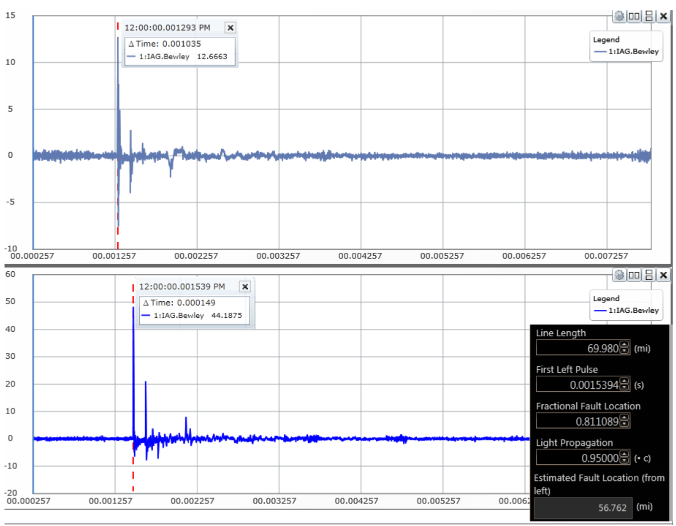


Figure 12. D-Type Method Result

B. Technical Highlights

4.2. Impedance Method

» ***Single-End Method***

Single-end fault location algorithms usually use variables from the sending end. Sending end voltage can be defined as:

$$V_S = I_S(mZ_L) + I_f R_f \qquad (1)$$

where:

m – distance to fault location
R_f – fault resistance
I_f – fault current
Z_L – line impedance
V_S and I_S – voltage and current at the sending end bus respectively

Simple Reactance Method

This method compares the measured line impedance (Z_L) and calculated impedance (V_S/I_S) to find the fault location. Accuracy of this method depends on the angle of I_S being equal to the angle of I_f.

If the fault resistance is ignored, the simple form of the distance to the fault can be obtained as given in equation:

$$m = Im(V_S/I_S) / Im(Z_L) \qquad (2)$$

Takagi Method

The Takagi method requires additionally pre-fault current values. This method improves simple reactance method by reducing the effect of load flow and minimizing the effect of fault resistance. Superposition current (Isup) can be described as follows:

$$I_{sup} = I - I_{pre} = I_f/d \qquad (3)$$

where:

I – fault current
I_{pre} – pre-fault current

If the source and line have the same impedance, d becomes a real number. Accuracy of this method depends on this assumption.
Through Eq. (3) and Eq. (1):

$$V_S = I_S(mZ_L) + I_{sup} dR_f \qquad (4)$$
$$V_{Sr} = mR_L I_{Sr} - mX_L I_{Si} + I_{supr} dR_f \qquad (5)$$
$$V_{Si} = mX_L I_{Sr} + mR_L I_{Si} + I_{supi} dR_f \qquad (6)$$

By multiplying Eq. (5) with I_{supi} and Eq. (6) with I_{supr} and subtract Eq. (6) from Eq. (5):

$$m = a/(b-c) \qquad (7)$$

Where:

$$a = V_{Sr} I_{supi} - V_{Si} I_{supr} \qquad (8)$$
$$b = R(I_{Sr} I_{supi} - I_{Si} I_{supr}) \qquad (9)$$
$$c = X(I_{Sr} I_{supr} + I_{Si} I_{supi}) \qquad (10)$$

Modified Takagi Method

Modified Takagi method replaces superposition current with zero sequence current of sending end.

This method is limited with ground faults since zero sequence current exists for ground faults. Then, the fault distance is calculated as follows:

$$m = Im(3_{VS} I_0 {}^* e^{-jT}) / Im(3Z_L I_S I_0 {}^* e^{-jT}) \qquad (11)$$

where:

I_0 – zero sequence current
T – angle between I_0 and I_f

» ***Double-End Method***

Double-end fault location algorithms calculate fault location from the impedance seen from both ends of the line. Because of their accuracy in detecting fault location, these algorithms are usually better than one-end fault location algorithms. Double-end fault location algorithms take V_f as a reference point.

V_f can be defines as:

$$V_f = V_S - I_S mZ_L \qquad (12)$$
$$V_f = V_R - I_R(1-m)Z_L \qquad (13)$$

Fault location can be calculated with Eq. (12) and Eq. (13):

$$m = (V_S - V_R + Z_L I_R) / (Z_L * (I_S + I_R)) \qquad (14)$$

4.3 Calculation Result Storage

The calculation results of Fault Location are stored in Centralized System Database for presentation and notification functions. The results includes:

- Fault parameters:
  - Type of fault,
  - Inception time,
  - Duration time,
  - Fault current,
  - Distance to fault location (in km or mile, in percentage of the total line length, or in the span between towers of the faulted line)
- Other processed signal results:
  - Travelling wave method: approximation signal, detail signal
  - Impedance method: sine wave signal

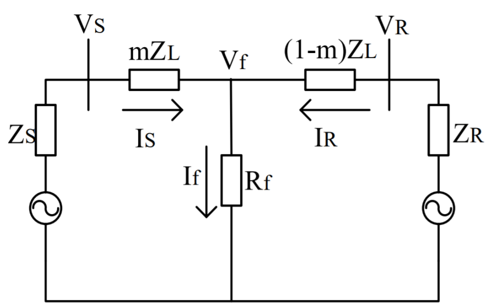


Figure 13. Circuit Representation of Line Fault

5. FAULT LOCATION PRESENTATION

SmartAFL™ software will provide a presentation function of the location on GIS. Having all the geographical coordinates of the line towers, a location can be generated, and the GOOGLE EARTH™ program can be used to see where the fault is located visually.

Figures 13 show dashboard display of SmartAFL™, which includes control bar, overview of faults and GIS view of faul Panels.

Users can view the fault record by clicking on a substation or line element in the GIS view, or select the fault in the list of records over the specified time range which display in the overview panel (Figure 14).

The system integrates with SEL Synchroware Event so that operators can analyze travelling wave time tags and waveforms, fault impedance, and determine the distance to fault (Figure 15).

Users can also view the real-time alarms (new and/or unconfirmed events) and history alarms (old and/or confirmed events) (Figure 16).

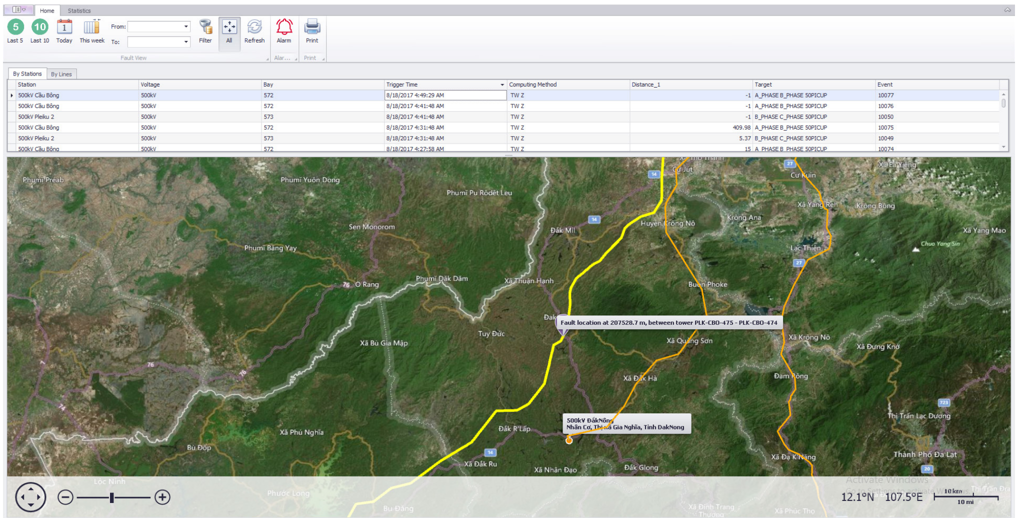


Figure 14. Operator's Fault Location

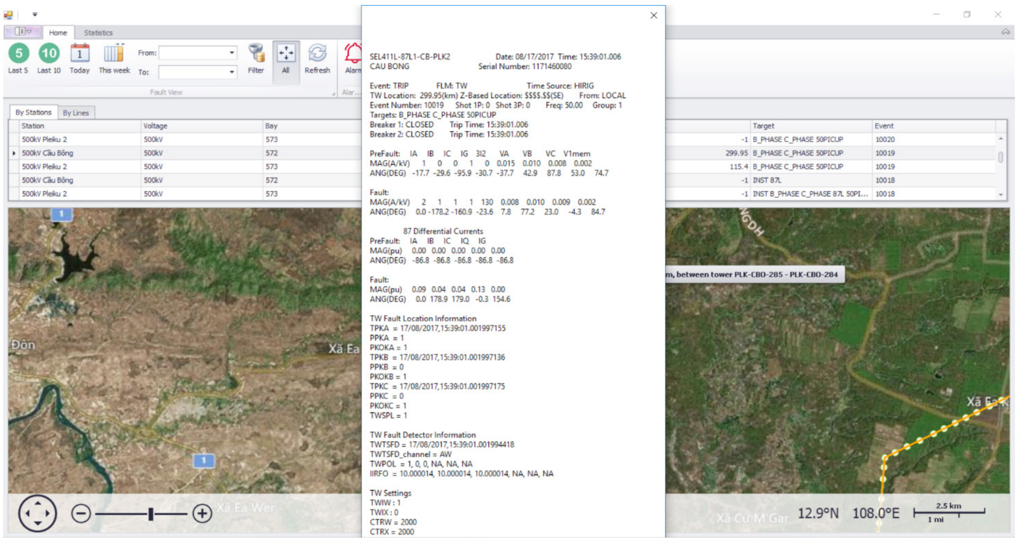


Figure 15. Detail view of specified event

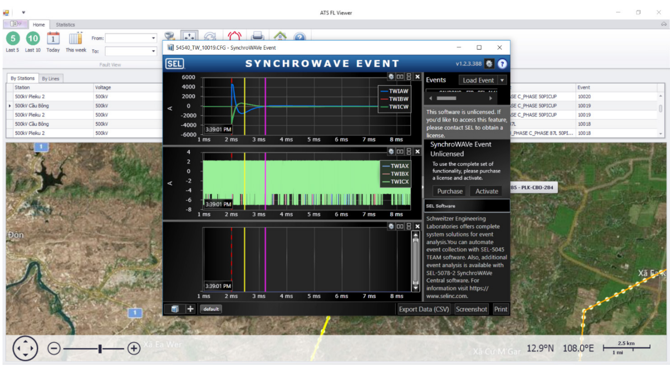


Figure 16. SEL synchroWAVe Event Software

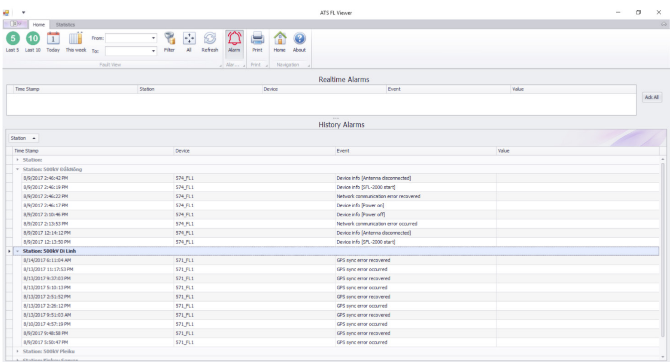


Figure 17. Real-time and Historical Alarms

B. Technical Highlights

6. WEB-BASED PRESENTATION AND E-NOTIFICATION

6.1. Web-based Presentation

SmartAFL™ will also provide web-based presentation function of faul location on map. It will allow user to view the geographical coordinates of fault location and other essentials information that are useful for line patrol team visually from web browser.

The fault event can be viewed in the detail panel by selecting a corresponding record (Figure 17).

Users can view the waveform of the record by selecting the record in the detail panel. The waveform viewer provides tools allowing operators to analyze travelling wave time tags and waveforms, fault impedance, and determine the distance to fault (Figure 18).

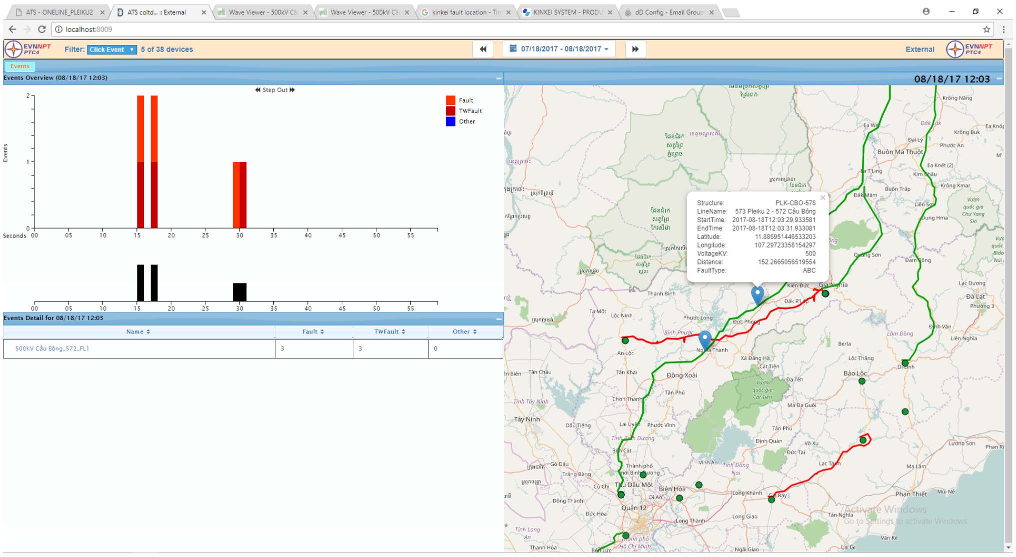
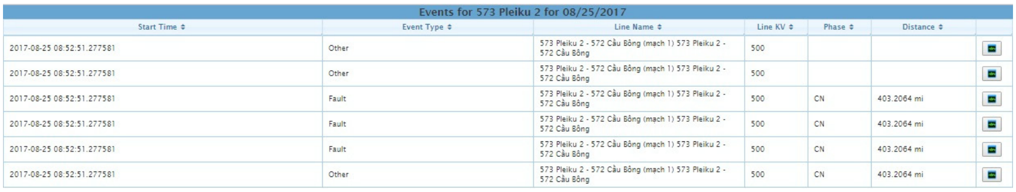


Figure 18. Visualization of Fault Location on Web



Events for 573 Pleiku 2 for 08/25/2017

Start Time	Event Type	Line Name	Line KV	Phase	Distance	
2017-08-25 08:52:51.277581	Other	573 Pleiku 2 - 572 Cầu Bông (mạch 1) 573 Pleiku 2 - 572 Cầu Bông	500			
2017-08-25 08:52:51.277581	Other	573 Pleiku 2 - 572 Cầu Bông (mạch 1) 573 Pleiku 2 - 572 Cầu Bông	500			
2017-08-25 08:52:51.277581	Fault	573 Pleiku 2 - 572 Cầu Bông (mạch 1) 573 Pleiku 2 - 572 Cầu Bông	500	CN	403.2064 mi	
2017-08-25 08:52:51.277581	Fault	573 Pleiku 2 - 572 Cầu Bông (mạch 1) 573 Pleiku 2 - 572 Cầu Bông	500	CN	403.2064 mi	
2017-08-25 08:52:51.277581	Fault	573 Pleiku 2 - 572 Cầu Bông (mạch 1) 573 Pleiku 2 - 572 Cầu Bông	500	CN	403.2064 mi	
2017-08-25 08:52:51.277581	Other	573 Pleiku 2 - 572 Cầu Bông (mạch 1) 573 Pleiku 2 - 572 Cầu Bông	500	CN	403.2064 mi	

Figure 19. Detailed of Specified Event

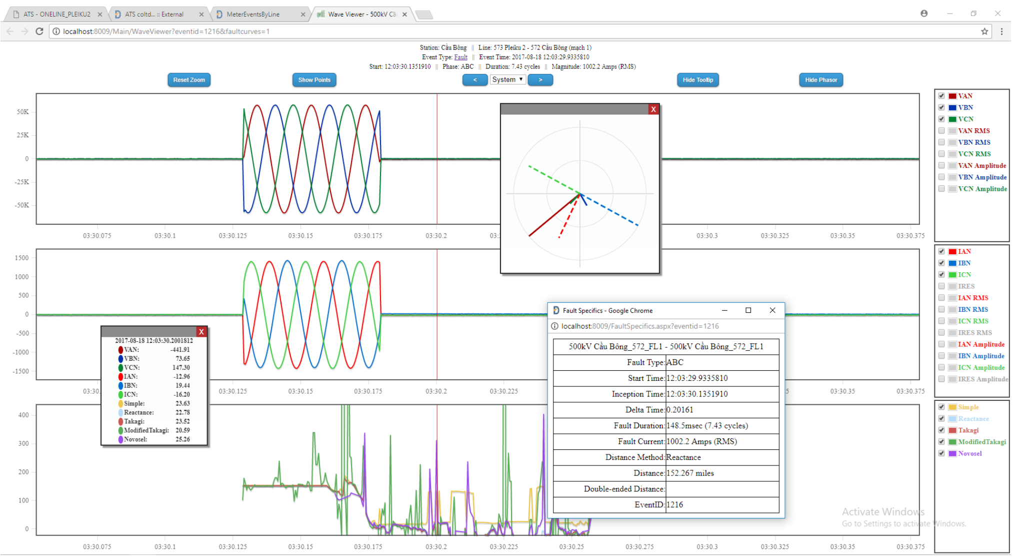


Figure 20. Display of Waveform Viewer

6.2. e-Notifications

SmartAFL™ automatically generates fault reports and sends them to registered emails for notification.

From: <prpfaultlocation@gmail.com>
Date: 2017-08-18 10:07 GMT+07:00
Subject: Fault detected on 573 Pleiku 2 - 572 Cầu Bông (mạch 1) (573 Pleiku 2 - 572 Cầu Bông)
To: anhthehtd@gmail.com

Fault 1 - 2017-08-18 03:06:37.8512250
DFRs: 500kV Pleiku 2_573_FL1 at Pleiku 2 triggered at 03:06:37.8501916 (click for waveform)
500kV Cầu Bông_572_FL1 at Cầu Bông triggered at 03:06:37.8509506 (click for waveform)

Files: TW_10041.DAT
TW_10067.DAT

Line: 573 Pleiku 2 - 572 Cầu Bông (mạch 1) (415.35 miles)

	Pleiku 2 - 500kV Pleiku 2_573_FL1	Cầu Bông - 500kV Cầu Bông_572_FL1
Fault Type:	INST 87L 50PICUP	INST 87L 50PICUP
Inception Time:	03:06:37.8512250	03:06:37.8519840
Distance Method:	TW	TW
Distance:	95.360 km	319.990 km
Event ID:	1133	1131
Structure ID:	PLK-CBO-241(click for location)	PLK-CBO-241(click for location)

Figure 21. Email Notification

7. INTEGRATION INTERFACES

SmartAFL™ can publish recorded and calculated data to other systems using COMTRADE format files which provides all fault-related information including name of the faulty line, time stamp, distance to fault location, TW and DFR files. Thus data can be shared to subscribed personnel or departments throughout client's organization for their usage.

SmartAFL™ also supports other *de-facto* interfaces to exchange archived data with other systems using XML table files of database and WEB Services. It can receive settings and configuration parameters from other systems as well as publish fault location results, travelling wave and impedance records and configuration files.

Figure 21 illustrates the exportation of record to COMTRADE Format.

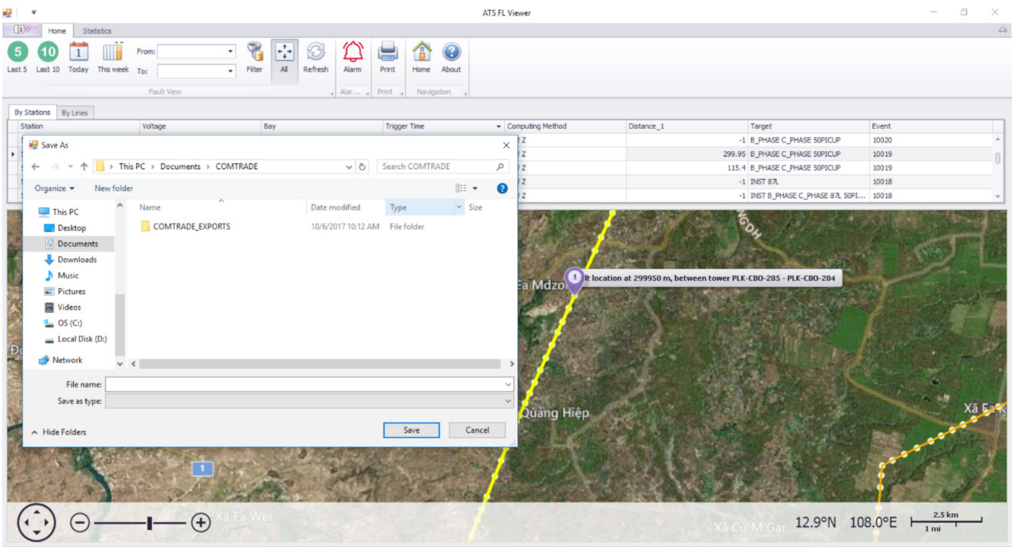


Figure 22. Export to COMTRADE Format File

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