TEXAS A&M ENGINEERING EXPERIMENT STATION

Voltage Sag Based Fault Location Algorithm

EPRI Workshop 04/21/2017

Mladen Kezunovic

Agenda

- **Motivation**
- Existing Approaches
- Our Proposed Approach
- Advantages
- Use Cases
- Practical Implementation
- Next Step

Motivation

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Fault location is the core of outage management and service restoration.
- Faster and accurate fault location → Improves reliability indices i.e. customer average interruption duration index (CAIDI) and system average interruption duration index (SAIDI) .
- The challenges include
  - large scale and complex power system models,
  - loading conditions changing over time,
  - the unbalanced nature of the system,
  - heterogeneous lines,
  - the presence of laterals,
  - load taps.

Agenda

- Motivation
- **Existing Approaches**
- Our Proposed Approach
- Advantages
- Use Cases
- Practical Implementation
- Next Step

Existing Approaches

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Based on the type of the data the fault location method uses:

Method	Drawback
Apparent impedance measurement	Multiple estimations of fault locations
Direct three-phase circuit analysis	Requires installation of fault indicators at the beginning of each tap increases the implementation cost
Superimposed components	Multiple estimations of fault locations
Traveling waves	Requires high-frequency sampling increases the cost; Presence of laterals and load taps maY reflect traveling waves
Artificial intelligence	Requires a large number of training data and a retraining subsequent to a change in power system structure (topology)

Agenda

- Motivation
- Existing Approaches
- **Our Proposed Approach**
- Advantages
- Use Cases
- Practical Implementation
- Next Step

Our Approach

TEES | TEXAS A&M ENGINEERING EXPERIMENT STATION

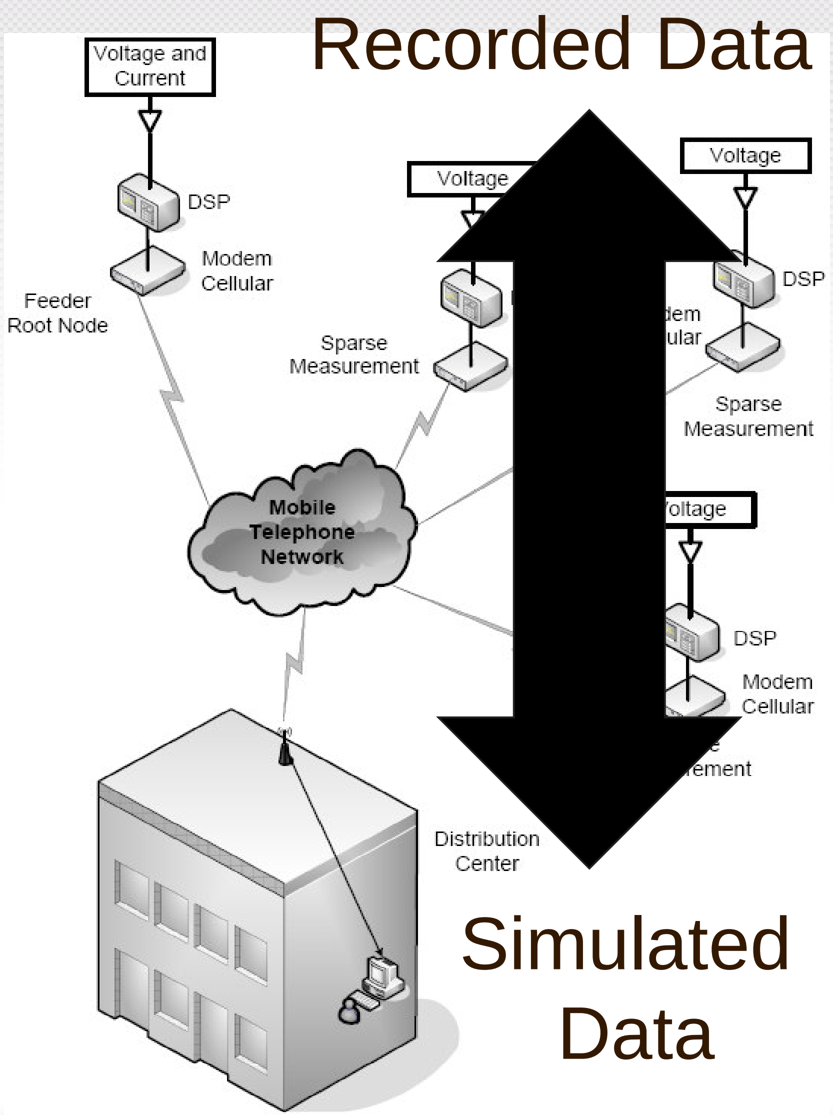
Voltage-Sag-Based Fault location method:

1. Voltage sag data ($V_{recorded}$) is recorded at the meter locations and sent to the local distribution energy management center.

2. Simulated voltage sag data ($V_{calculated}$) is computed, assuming in turn that the fault is located at each node and fault resistance is estimated based on the voltage match.

3. The node with the best match between $V_{recorded}$ and $V_{calculated}$ is the declared the fault node.

4. Binary search (halving) is used on the lines connected to the detected fault node to pinpoint the fault on the lines.



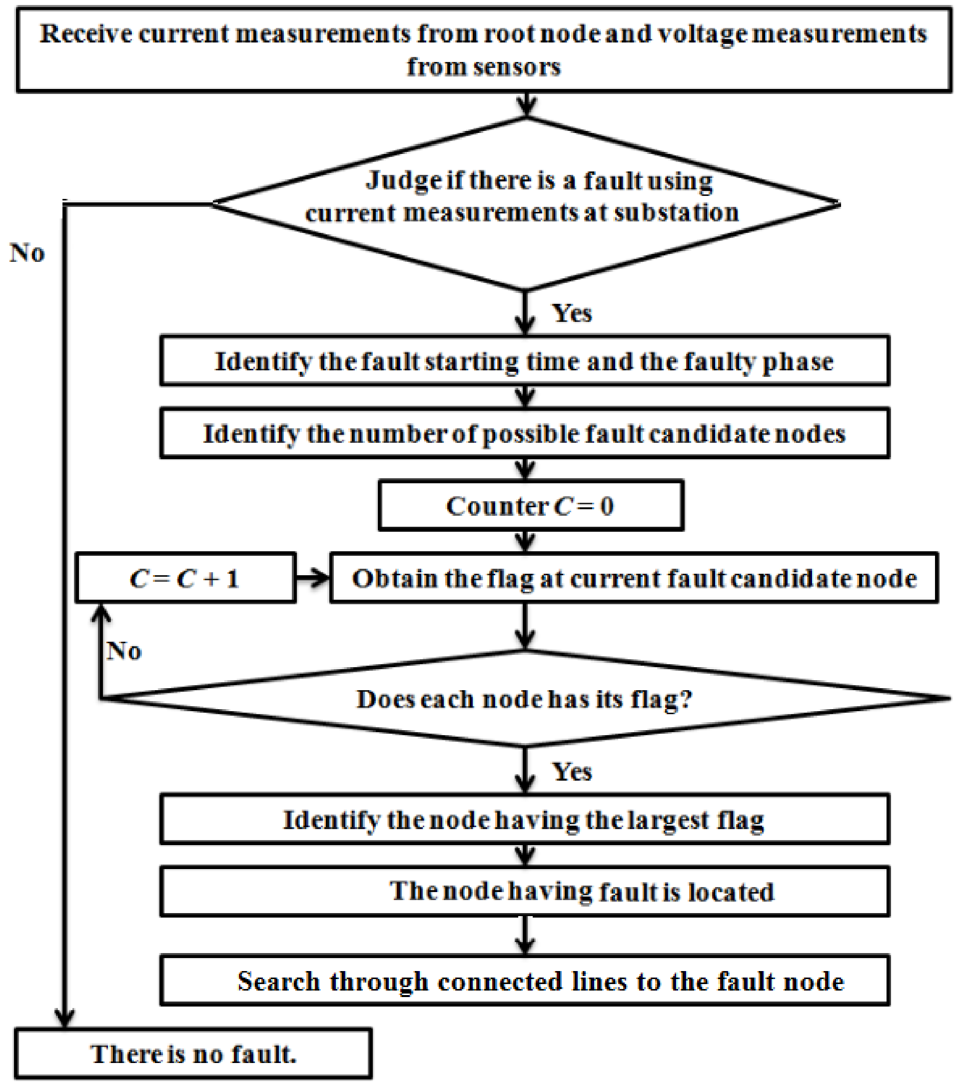
Model and Simulation

TEES | TEXAS A&M ENGINEERING EXPERIMENT STATION

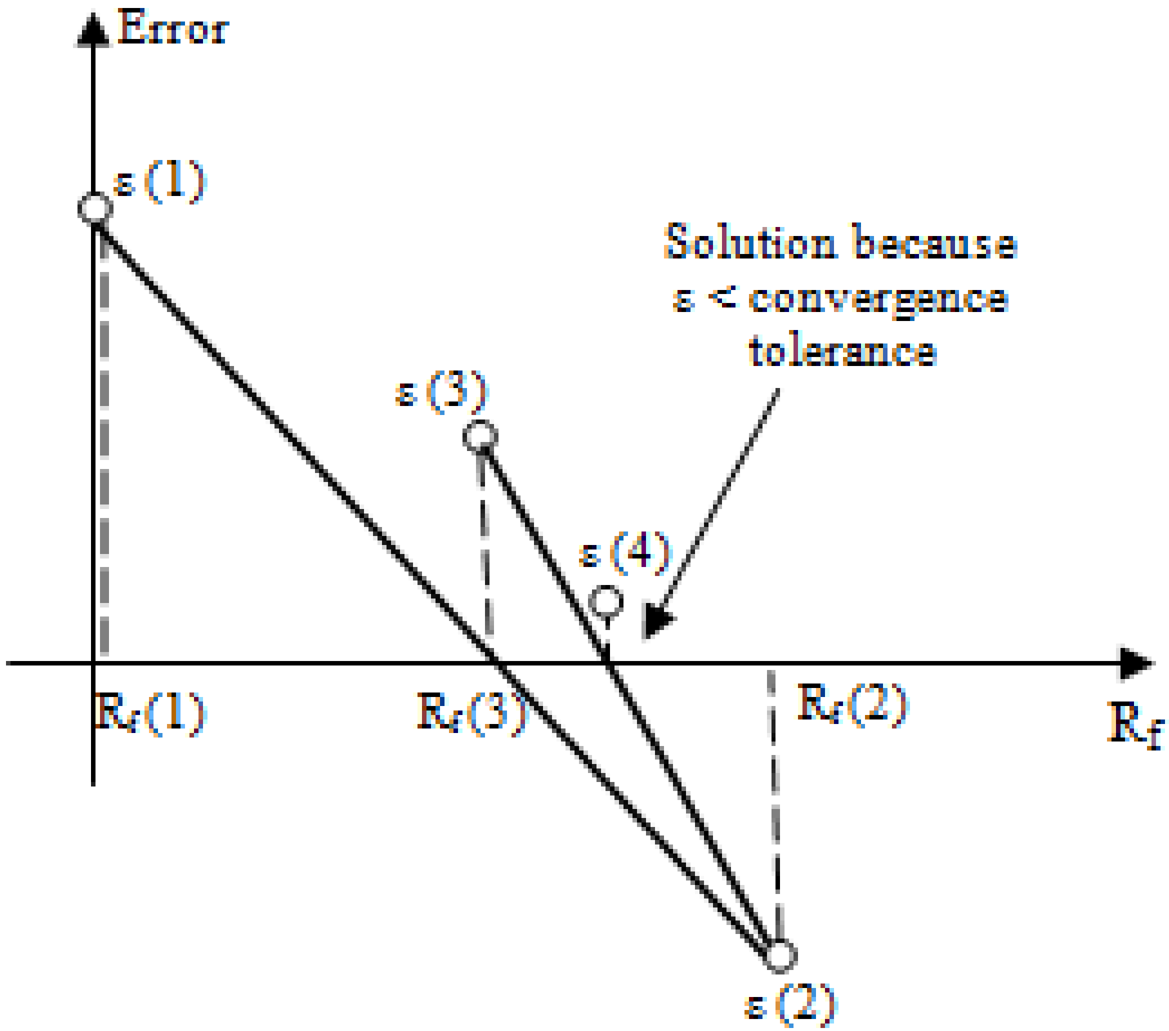
- Simulation model used: time-domain simulation model with detailed line impedance matrix and mutual coupling information.
- Input Data:
  - Data needs to be synchronized
  - Minimum data requirement: voltage magnitude data from IED
  - Voltage angle data from IED and current angle data from the substation will improve the accuracy
  - Number of measurements will determine the precision of the result (optimal IED placement technique); we assume there are measurements available at the intersection and the end of lateral.
  - Load estimation

Flow Chart

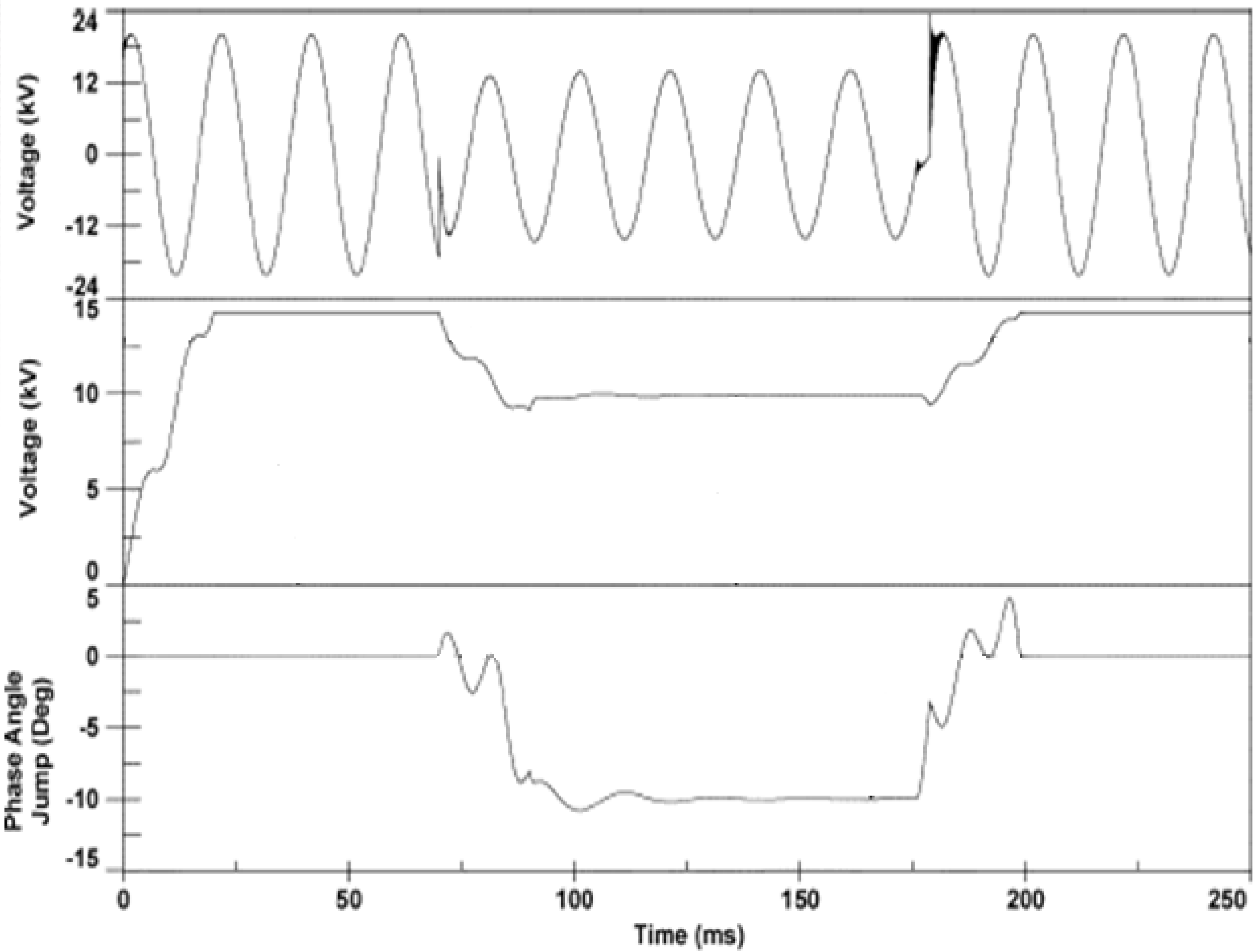
TEXAS A&M ENGINEERING EXPERIMENT STATION

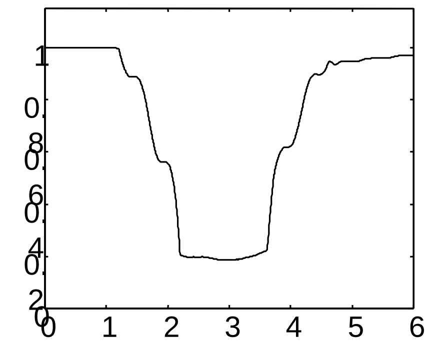


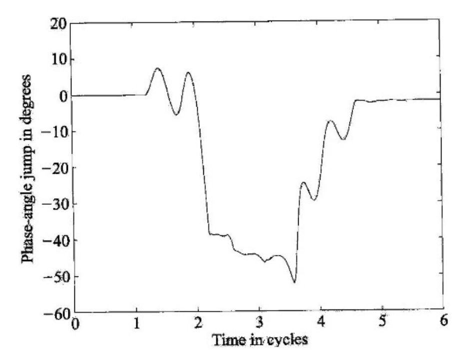
Fault Resistance Estimation



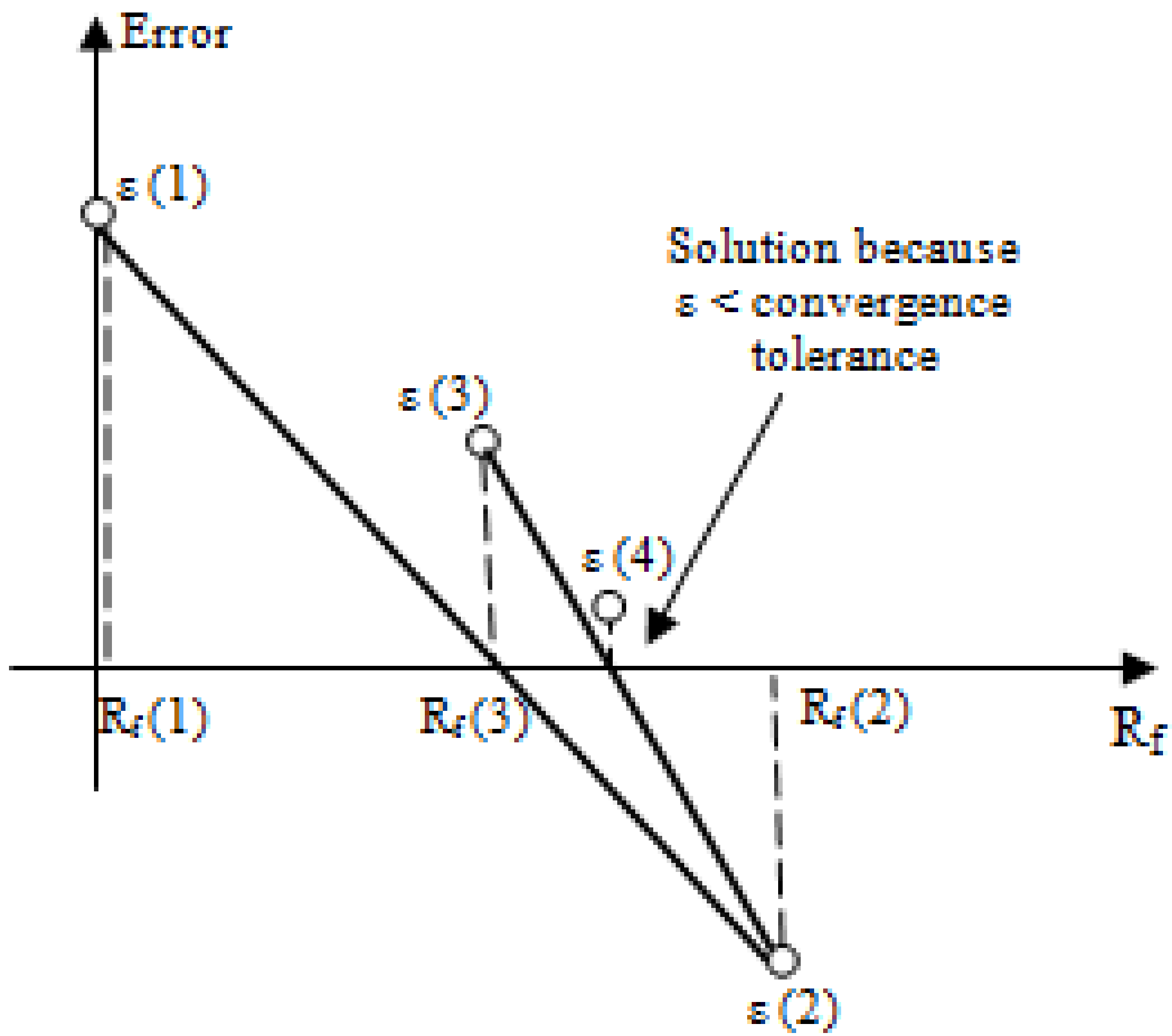
Voltage Sag Characterization







Fault Resistance Estimation



Agenda

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Motivation
- Existing Approaches
- Our Proposed Approach
- **Advantages**
- Use Cases
- Practical Implementation
- Next Step

Advantages

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Using measurements (e.g. smart meter) from and substation; the input data quantity depends on the availability of measurement
- No ambiguity in feeder/lateral
- High accuracy performance
- Computationally efficient

Agenda

TEXAS A&M ENGINEERING EXPERIMENT STATION

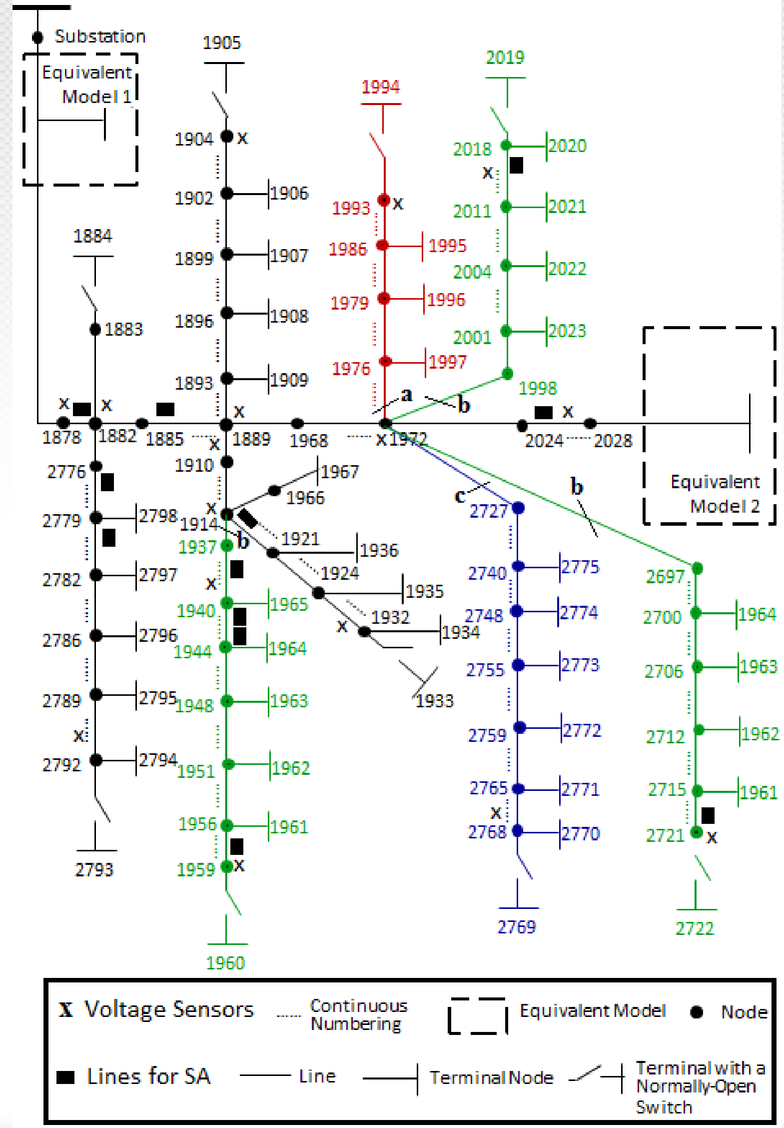
- Motivation
- Existing Approaches
- Our Proposed Approach
- Advantages
- **Use Cases**
- Practical Implementation
- Next Step

Network under Study

TEXAS A&M ENGINEERING EXPERIMENT STATION

Table I: Network Component Details

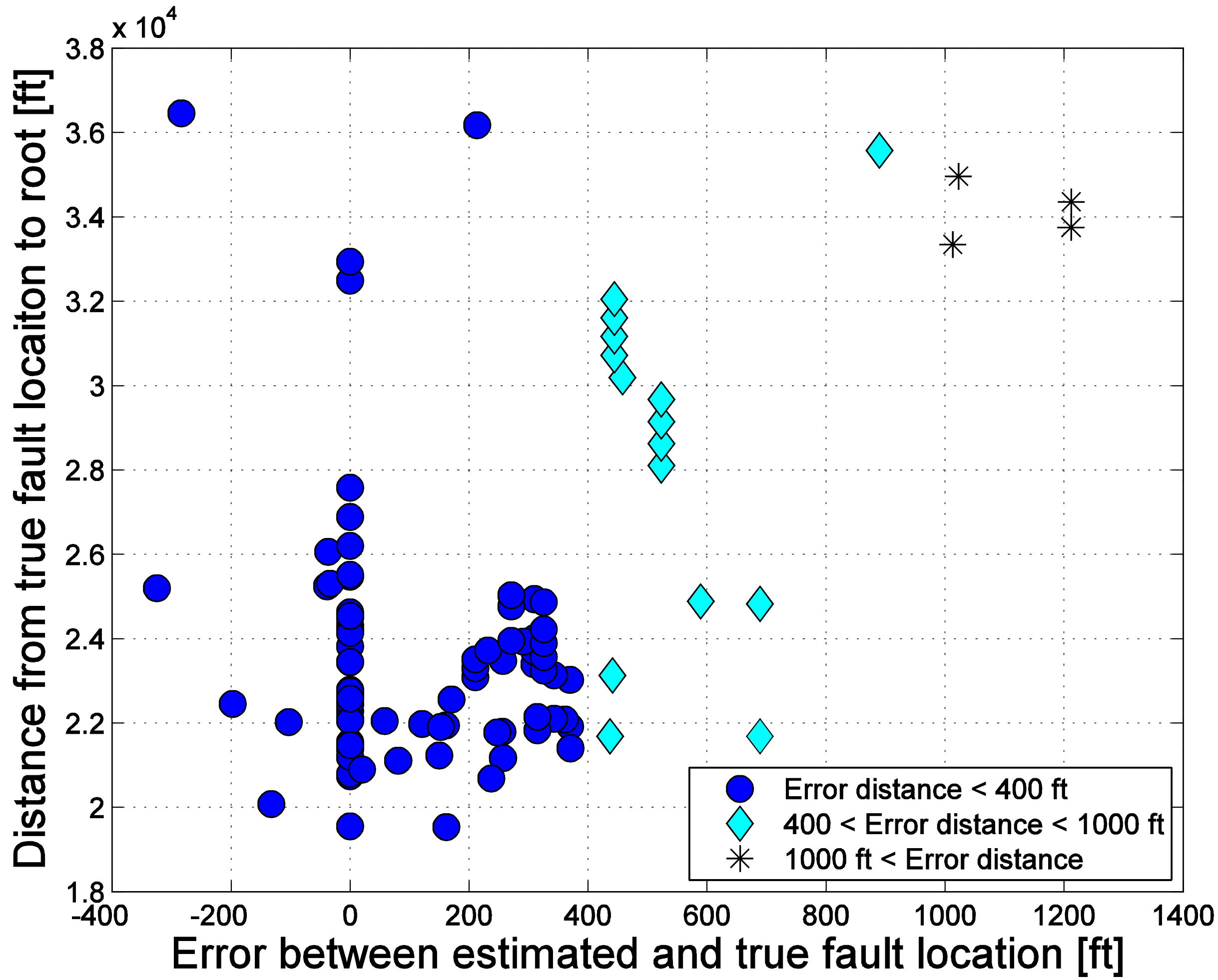
Total Number of Components	4352
Number of Line Components	1828
Total length of Line Components (Foot)	655617.6
Total Connected Load (kVA)	33606



Validations

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Always detects FL on the same lateral as the true FL.
- In most cases, the detected FL are downstream of the true FL.
- In 44% of cases, the error distance < 100 ft
- In 83% of cases, the error distance < 400 ft.



Agenda

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Motivation
- Existing Approaches
- Our Proposed Approach
- Advantages
- Use Cases
- **Practical Implementation**
- Next Step

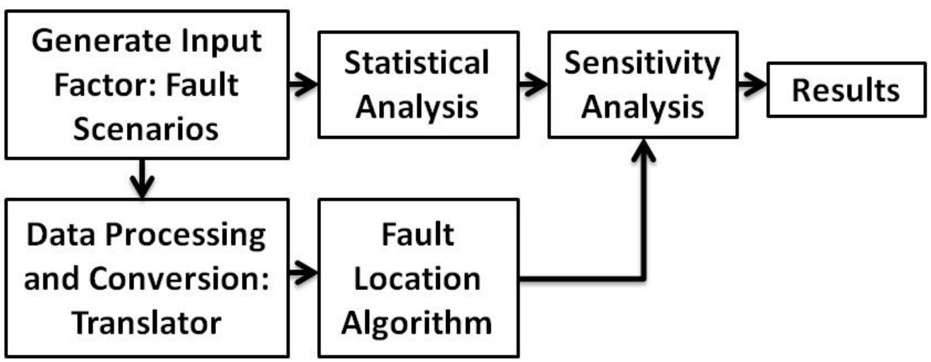
Algorithm Implementation

TEXAS A&M ENGINEERING EXPERIMENT STATION

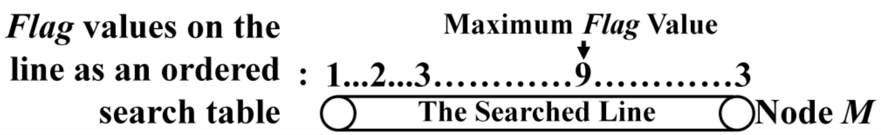
Software Utilization

Software	Fault Simulation	Fault Location	Sensitivity Analysis
ATP-EMTP	X	X	
C++		X	
SimLab			X
Matlab			X

Study Procedure



Search Precise FL on A Line



FL Algorithm Implementation: Coding

```
Output: Estimation of fault location and fault resistance
read ABB network file in .csv format
read input settings in .txt format
read input factor file in .csv
for each group of input factor of the sensitivity analysis do
    convert the ABB network .CSV file into an ATP netlist .NET and call it as "base case no fault"
    run base case no fault in ATP and obtain results
    store data into network data vector
    check input settings and obtain information of desired fault type and locations
    create an ATP netlist and call it as "fault base case", which represent the real case of fault
    run fault base case in ATP and obtain results, which is referred as "recorded data"
    {recorded data obtained}
    store data into network data vector
    add assumed random error from user-given error range into recorded data which represents
    the IED errors
    for each potential candidate fault node do {i.e. 3-phase fault cannot be at 1-phase node}
        run fault resistance estimation and determine if this potential candidate fault node is a
        candidate fault node
        if this is a candidate fault node then
            {Step 1}
            obtain fault resistance by fault resistance estimation procedure using substation
            current difference.
            {Step 2}
            obtain the "calculated data" {including voltage sag data at measurement nodes and
            substation   current phase difference} from the case running with fault resistance
            estimated from previous step.
            {Step 3}
            obtain the flag value by comparing the "calculated data" and "recorded data"
    if find the fault node A which has the largest flag value then
        if there are lines connecting to END A then
            pinpoint the fault location by performing sufficient enough number of binary search
            from Step 1 to 3 on the lines connecting to A {divide the lines}
            return the estimated fault location and fault resistance of the maximum flag value on
            the lines connected to END A
        else
            return the fault node A and the estimated fault resistance of A {cannot find any
            larger flag value}
    else
        return the guesses of fault location and fault resistance
```

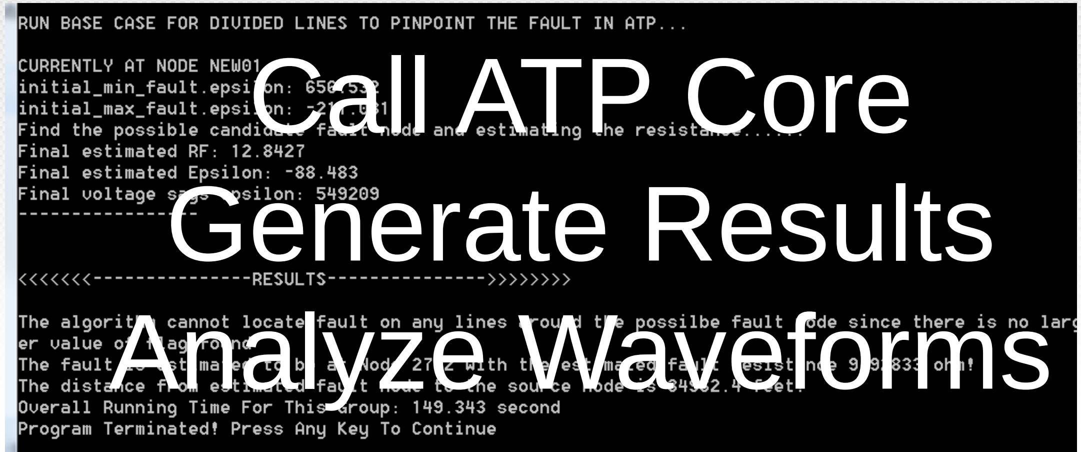
Generalization & Automation

TEXAS A&M ENGINEERING EXPERIMENT STATION

Electrical Component Database

Type	Asset ID	Sending N	Receiving	Phase	Status	Length(ft)	Rs(ohm)	Xs(ohm)	Rm(ol
line	111	1	1878	ABC	NaN	19226.7	0.8272	0.5023	0.4
Switch	127_6647	1878	1879	n/a	closed	0	NaN	NaN	NaN
xfmr	222	1878	GRD1	ABC	NaN	0	NaN	NaN	NaN
line	426_18286	1879	1880	ABC	NaN	160.3343	0.010014	0.006315	0.006
Switch	127_42201	1880	1881	n/a	closed	0	NaN	NaN	NaN
busbar	443_61203	1881	1882	ABC	NaN	10	NaN	NaN	NaN
busbar	443_61200	1882	1883	ABC	NaN	10	NaN	NaN	NaN
busbar	443_61202	1882	1885	ABC	NaN	10	NaN	NaN	NaN
busbar	443_61201	1882	2776	ABC	NaN	10	NaN	NaN	NaN
fuse	149_42601	1883	1884	ABC	open	0	NaN	NaN	NaN
Switch	127_42200	1885	1886	n/a	closed	0	NaN	NaN	NaN
line	426_13080	1886	1887	ABC	NaN	1126.089	0.070331	0.044354	0.043
Switch	127_42219	1887	1888	n/a	closed	0	NaN	NaN	NaN

Automation: One-click Simulation Features



Data

Translator

ATP Netlist: Descriptive Language as Inputs to ATP

```
BEGIN NEW DATA CASE
C -----------------------------------------------------------
C Fault Location Algorithm
C Author: Po-Chen Chen
C Email: pchen01@neo.tamu.edu
C Advisor: Dr. Mladen Kezunovic
C -----------------------------------------------------------
EXACT PHASOR EQUIVALENT
POWER FREQUENCY                              60.
C  dT  >< Tmax >< Xopt >< Copt >
   8.E-5      .4       60.      60.
C    IOUT    IPLOT   IDOUBL   KSSOUT   MAXOUT    IPUN    MEMSAV     ICAT   NENERG  IPRSUP
C ------><-------><-------><-------><-------><-------><-------><-------><-------><------->
     5000        1        1        1        1        0        0        1        0
C         1         2         3         4         5         6         7         8
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
/BRANCH
C < n 1>< n 2><ref1><ref2>< R  >< L  >< C  >
C < n 1>< n 2><ref1><ref2>< R  >< A  >< B  ><Leng><><>0
C line  LINEA
1     5A     6A           2.6e-15.6e-2
```

Agenda

TEXAS A&M ENGINEERING EXPERIMENT STATION

- Motivation
- Existing Approaches
- Our Proposed Approach
- Advantages
- Use Cases
- Practical Implementation
- **Next Step**

Next Step

TEXAS A&M ENGINEERING EXPERIMENT STATION

- How the algorithm uses the accessible data may be different from the raw data seen by the IEDs depend upon functionality of that IED.
- How to reduce the error comes from the difference between the simulated model and the real system.
- How to more effectively estimate the fault resistance.

Related Publications

- R. A. F. Pereira, et al., "Improved Fault Location on Distribution Feeders Based on Matching During-Fault Voltage Sags,“ IEEE Trans. Power Del., Vol . 24., No. 2, pp852-862, Apr. 2009
- S. Lotfifard, M. Kezunovic, M. J. Mousavi, "Distribution Fault Location Using Voltage Sag Data" IEEE Trans. Power Del., Vol. 26, No. 2, pp 1239-1246, Apr. 2011.
- M. Kezunovic, "Smart Fault Location for Smart Grids," IEEE Trans. Smart Grid, vol. 2, no. 1, pp 61-69, Mar. 2011.
- S. Lotfifard, M. Kezunovic and M. J. Mousavi,"A Systematic Approach for Ranking Distribution Systems Fault Location Algorithms and Eliminating False Estimates," IEEE Trans. Power Del., vol. 28, no. 1, pp. 285-293, Jan. 2013.
- Y. Dong, C. Zheng, M. Kezunovic, "Enhancing Accuracy While Reducing Computation for Voltage-Sag Based Distribution Fault Location," IEEE Trans. Power Delivery, vol. 28, no. 2, pp.1202-1212, Apr. 2013.
- P.-C. Chen, V. Malbasa, and M. Kezunovic, “Locating Sub-Cycle Faults in Distribution Network Applying Half-Cycle DFT Method,” IEEE/PES Transmission and Distribution Conference and Exposition (T&D), Apr. 2014.
- P.-C. Chen, Y. Dong, V. Malbasa, and M. Kezunovic, “Uncertainty of Measurement Error in Intelligent Electronic Devices”, IEEE/PES General Meeting, Jul. 2014.
- P.-C. Chen, V. Malbasa, and M. Kezunovic, “Sensitivity Analysis of Voltage Sag Based Fault Location Algorithm,” in Proceeding 18th Power Systems Computation Conference (PSCC), Aug. 2014.
- P.-C. Chen, et al., “Sensitivity of Voltage Sag Based Fault Location in Distribution Network to Sub-Cycle Faults”, in Proceeding 46th North American Power Symposium (NAPS), Sep. 2014.
- P.-C. Chen, V. Malbasa, Y. Dong, and M. Kezunovic, “Sensitivity Analysis of Voltage Sag Based Fault Location with Distributed Generation,” IEEE Trans. Smart Grid, Jan. 2015.

Thank you for listening!

Questions and Comments?