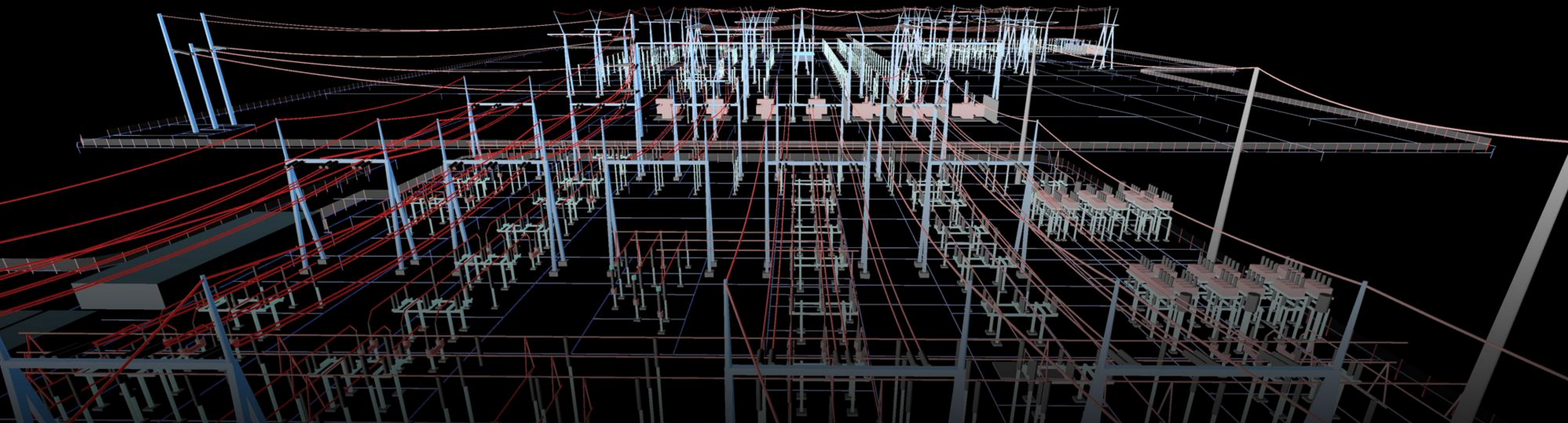

New Approaches to Protection and Control Enabled with GPS-Synchronized Merging Units

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Presentation Outline

- Objectives and Driving Forces
- Error Correction within Merging Units
- Substation Centralized Protection Scheme
- Detection of Hidden Failures
- Real Time Correction (self healing)
- Numerical Examples
- Conclusion

Introduction

Objectives:

Core issues in Centralized Substation Protection: (a) ensure accuracy of input data to protection functions and (b) Monitor P&C systems for detecting problems that affect zone protection such as hidden failures, incorrect data, etc.

Driving Forces:

Avoid Desensitization of Protective Functions

- Uncertainties in input data require safety margins in protection settings

Minimize Protection system Mis-Operations

- About 10% relay mis-operations (65% due to hidden failures)

Cope with new changes in power system

- Renewable resources, Micro grids
- Power electronics based interfaces

Technological Advancements

- Separation of data acquisition from logical functions
- Advances in software technology
- Communication infrastructure

Accuracy of Input Data

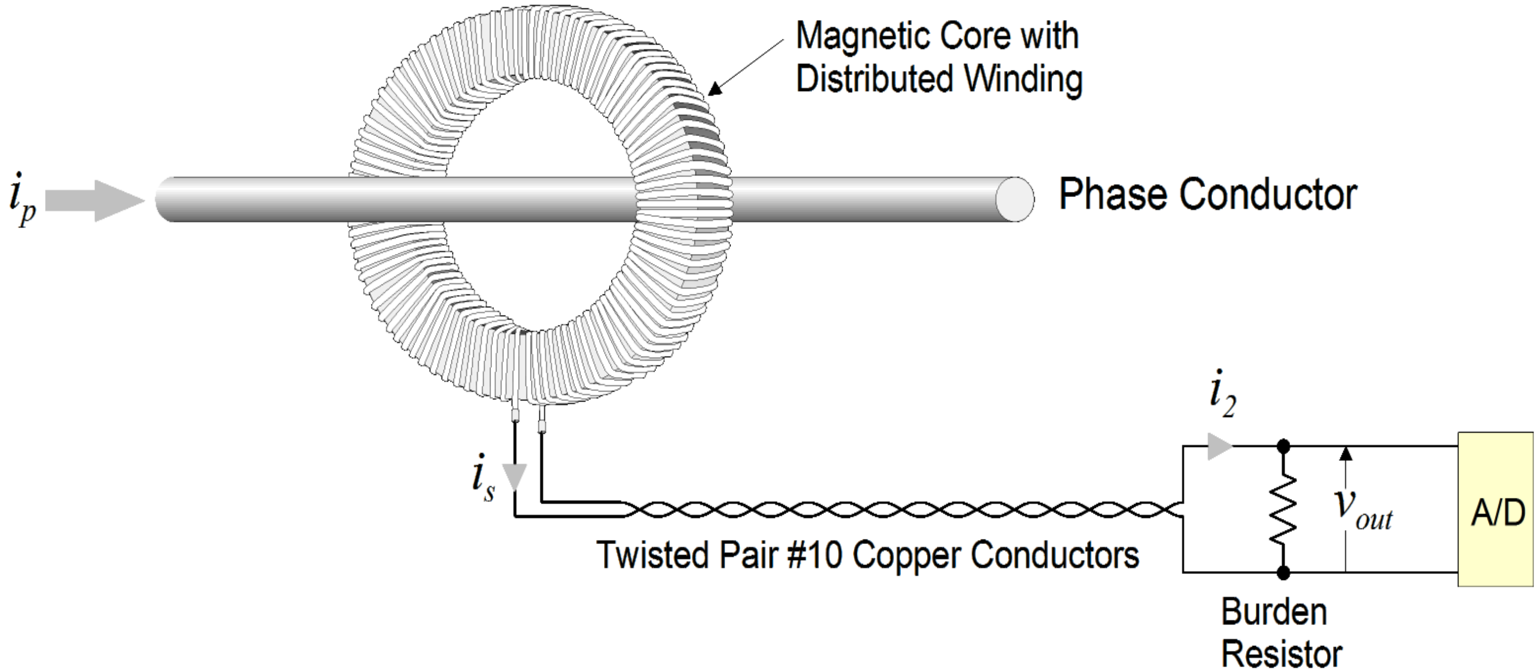
Relays and merging units are becoming more accurate by using higher resolution in data acquisition and higher sampling rates.

Errors from instrumentation channels are practically remain the same. Instrumentation channel errors have been much higher than the errors introduced by the data acquisition even in earlier generations of sensor less systems.

Efforts to account and correct for instrumentation channel errors date back several decades.

Merging Units offer a unique opportunity to perform error correction within a merging unit → MU provides corrected data in primary quantities.

Basic Question

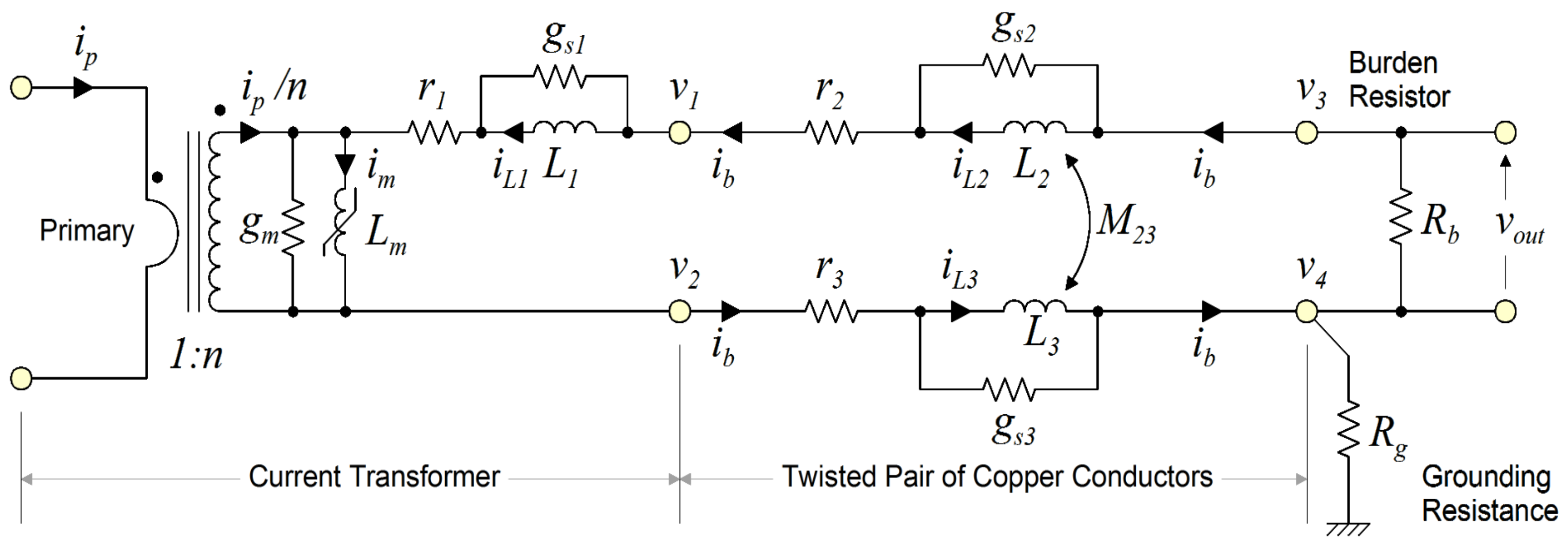


Given a measurement at the secondary of an instrumentation channel, can we extract the correct value of the primary quantity?

Can it be done on a sample by sample basis?

Basic Approach to Error Correction

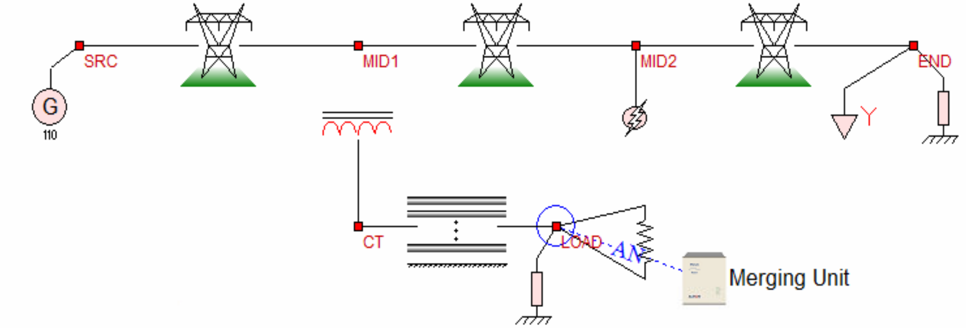
Construct the mathematical model of the instrumentation channel:
Example CT Channel



Use actual measurement. Augment with: (a) virtual measurements, (b) derived measurements and (c) pseudo measurements. → redundant measurements.

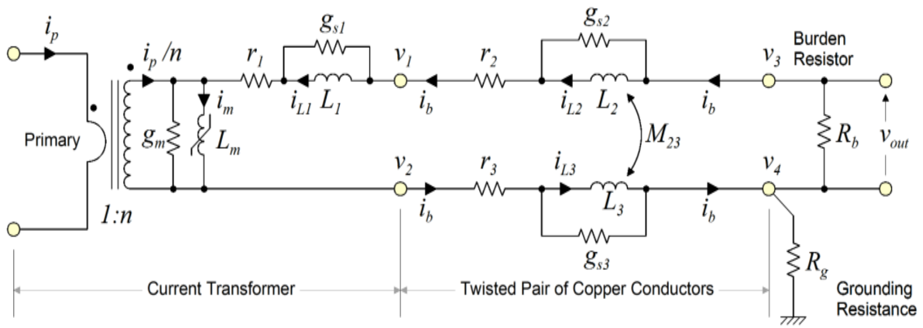
Perform dynamic state estimation → best estimate of primary

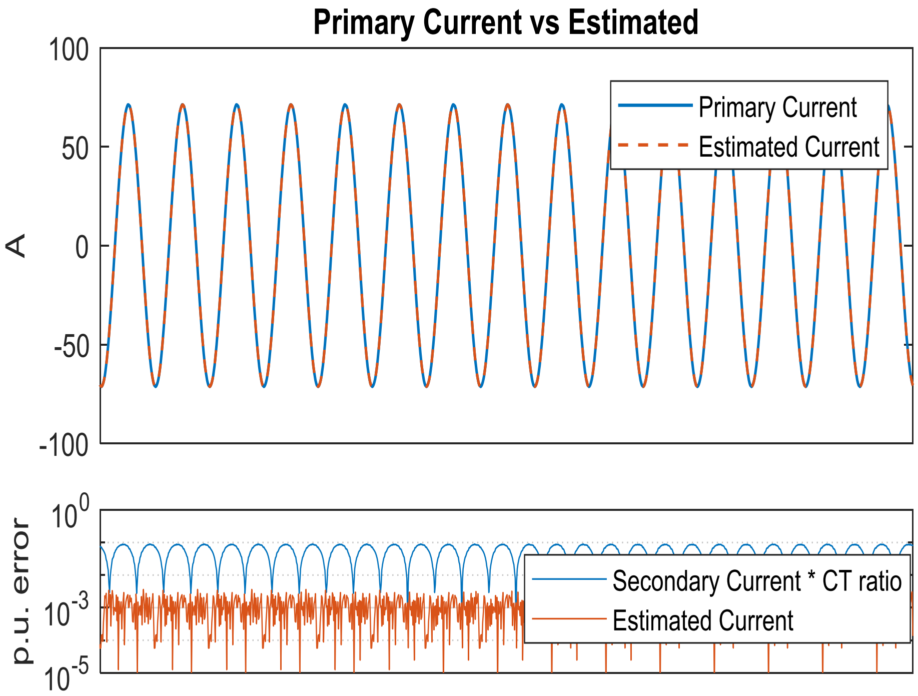
CT channel Error Correction



- Normal operation:
- CT measures the current through phase A at bus MID1.

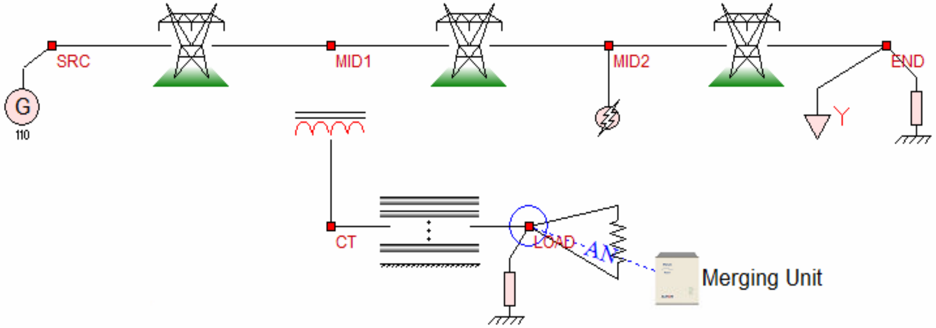
CT Channel math Model



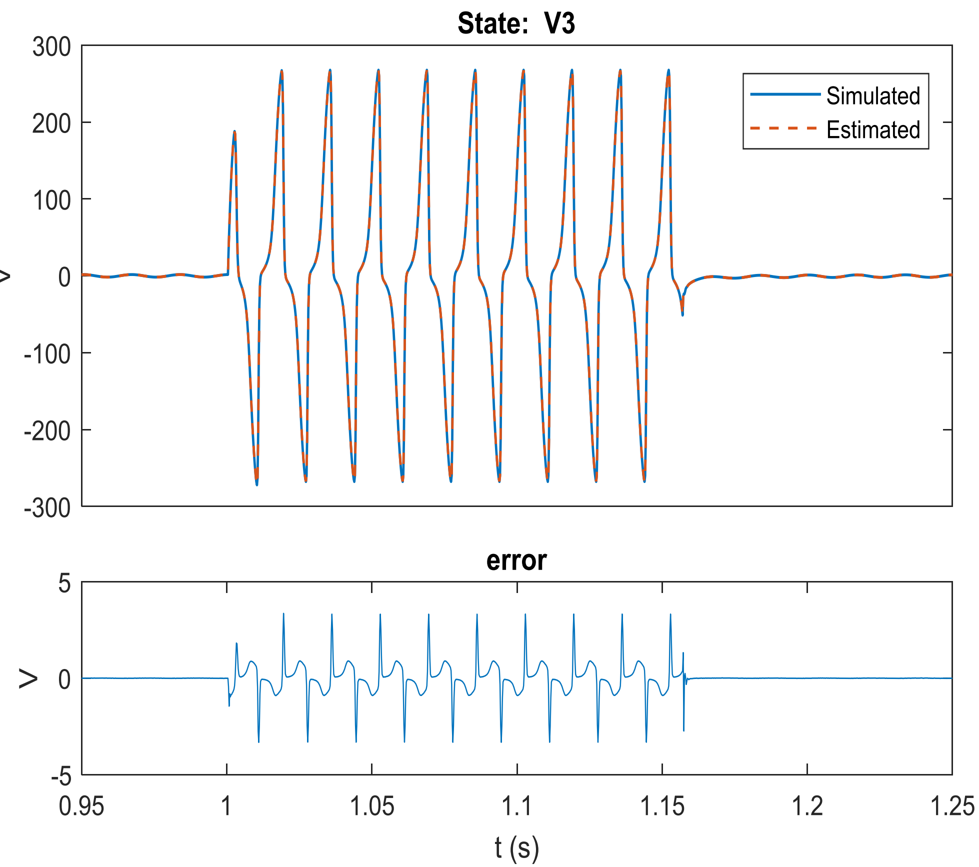


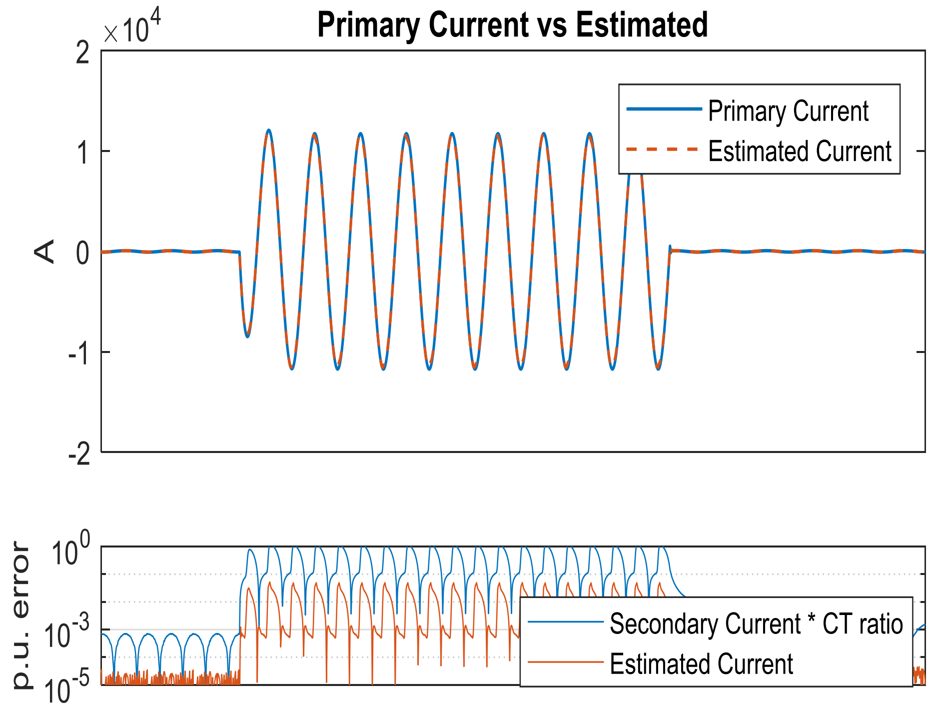
- States: 15
- Actual Measurements: 1
- Virtual Measurements: 14
- Derived Measurements: 4
- Pseudo measurements: 1

CT channel error correction



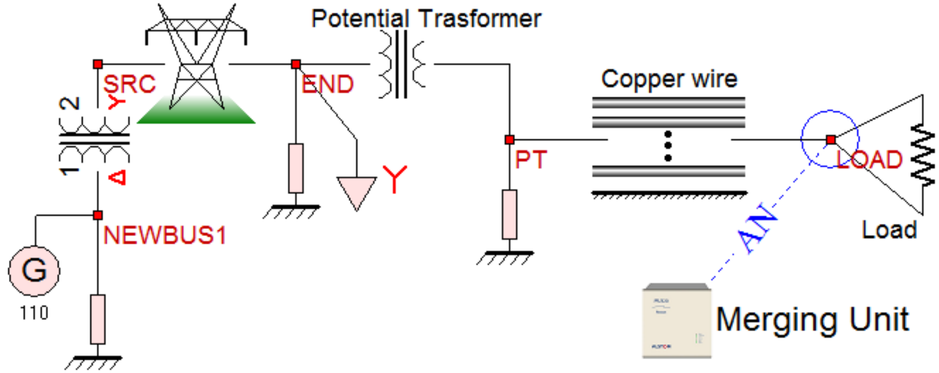
CT Drive to saturation due to a fault at 1 sec



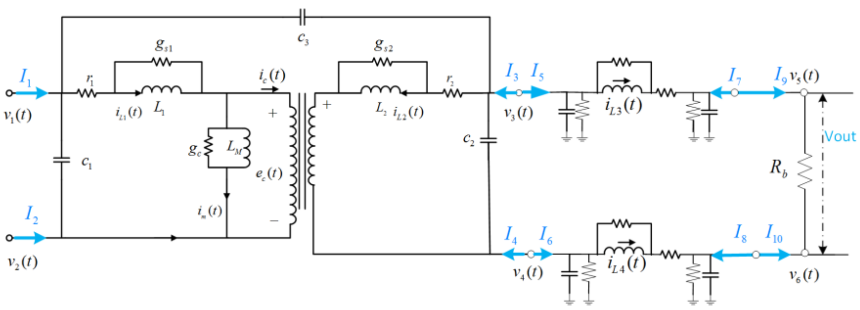


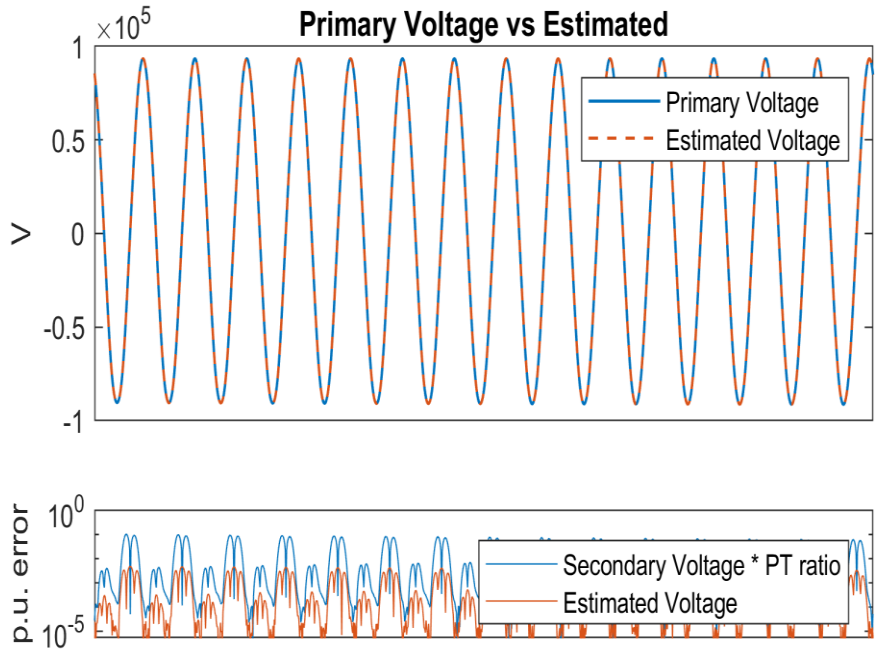
VT channel error correction

VT normal operation



VT Channel math Model





- States: 17
- Actual Measurements: 1
- Virtual Measurements: 15
- Derived Measurements: 6
- Pseudo measurements: 2

Limitation of Error Correction Methods

Error Correction methods work well when instrumentation is healthy.

In the presence of hidden failures in instrumentation channels, error correction methods do not have enough information to detect the condition. Data will be compromised.

Need redundant measurements to identify hidden failures and correct data.

Impact of Hidden Failures

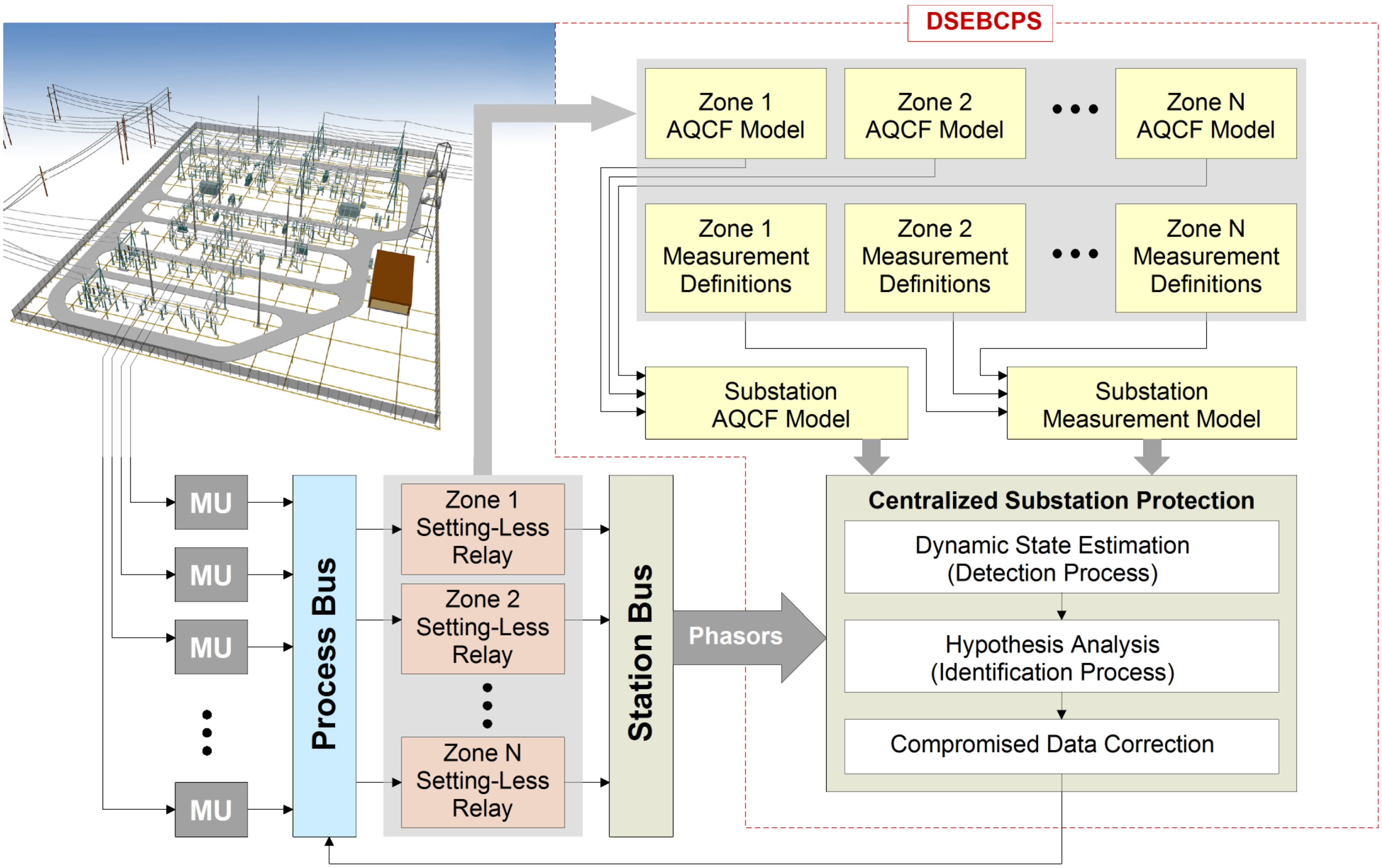
Hidden failures corrupt the data “seen” by a relay, legacy relay or setting-less protective relay.

Hidden failures will cause relay mis-operation whether it is a legacy protective relay or a setting-less relay.

Need to identify hidden failures and avert relay mis-operations.

Present State of Art: Some legacy relaying schemes can identify some hidden failures and inhibit relay operation. No capability to take corrective action.

Dynamic State Estimation Based Centralized Protection Scheme (DSEBCPS)



Dynamic State Estimation Based Centralized Protection Scheme (DSEBCPS)

Hypothesis Testing: Observations

At substation level redundancy is high (over 2000%)

System is continuously running.

Probability of simultaneous failure events is low

Hypothesis Testing: Mechanics

Identify suspect measurements from residuals

Group suspect data with certain criteria (see paper)

Determine “faulted devices” from setting-less relays output

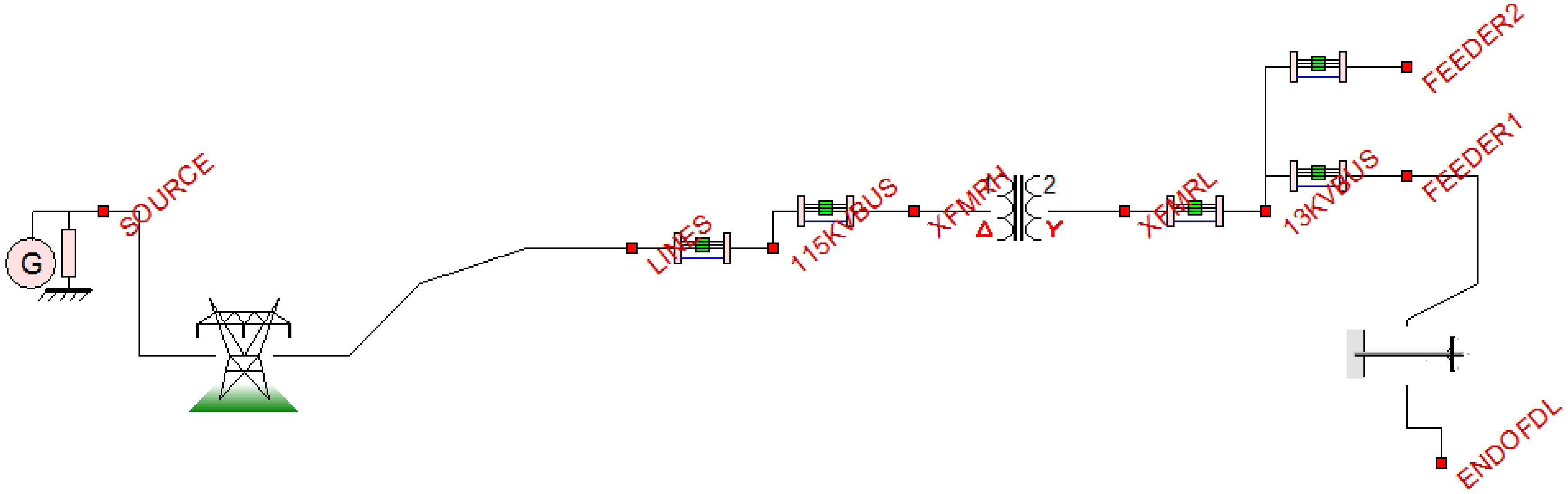
Dynamic State Estimation Based Centralized Protection Scheme (DSEBCPS)

Hypothesis Type 1 (H1): Remove suspect measurements and rerun DSE. If probability high → removed measurements are bad → identify root cause → issue diagnostics → replace bad data with estimated values. End hypothesis testing. Otherwise go to **H2**.

Hypothesis Type 2 (H2): (determine if a fault decision is correct). For the reported faulted device, remove all internal device measurements and remove the faulted device model from the substation model. Then rerun DSE. If probability high → the device is truly experiencing an internal fault. Allow zone relay to trip the faulted device. End hypothesis testing.

Hypothesis Type 3 (H3): This test combines type 1 and type 2 hypothesis testing to cover the case of a simultaneous fault and a hidden failure.

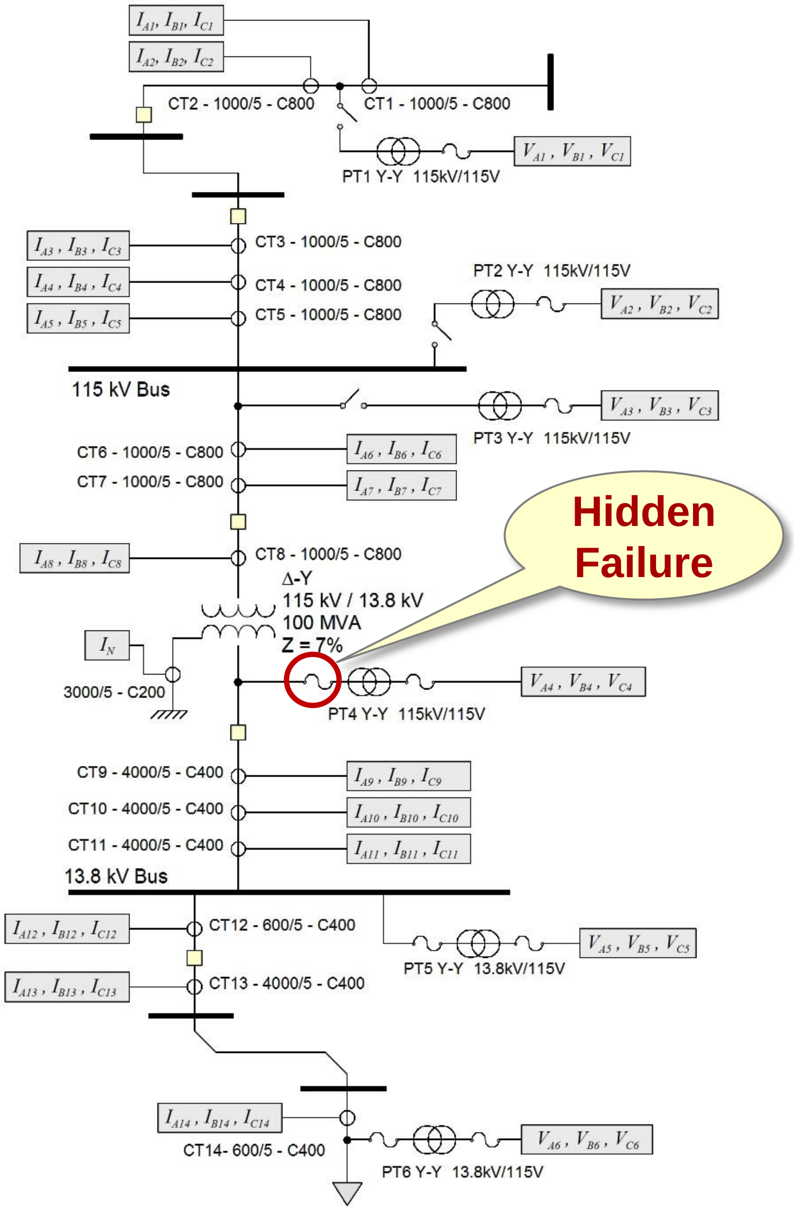
Numerical Example
Case Study:



5 Protection Zones:
- 115 kV Transmission Line
- 115 kV Bus
- 115/13.8 kV , 36 MVA Transformer
- 13.8 kV Bus
- 13.8 kV Distribution Line (one of the two)

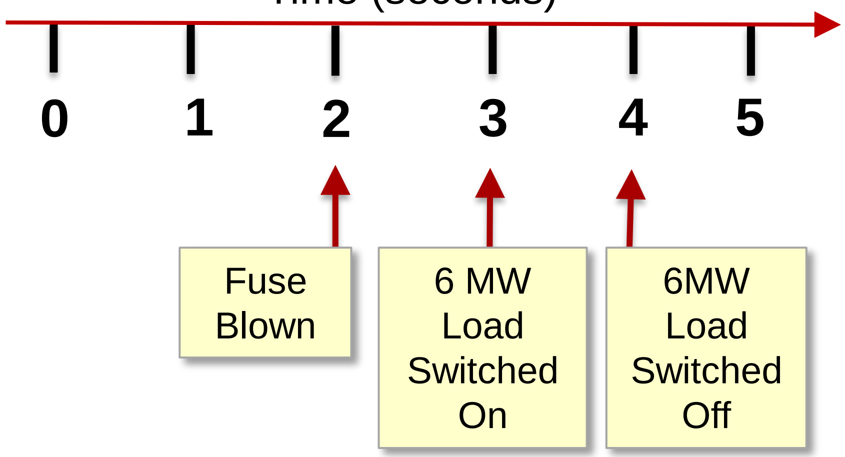
Numerical Example

Case1: Primary Fuse Blown Y-Y, PT-4A



Sequence of Events

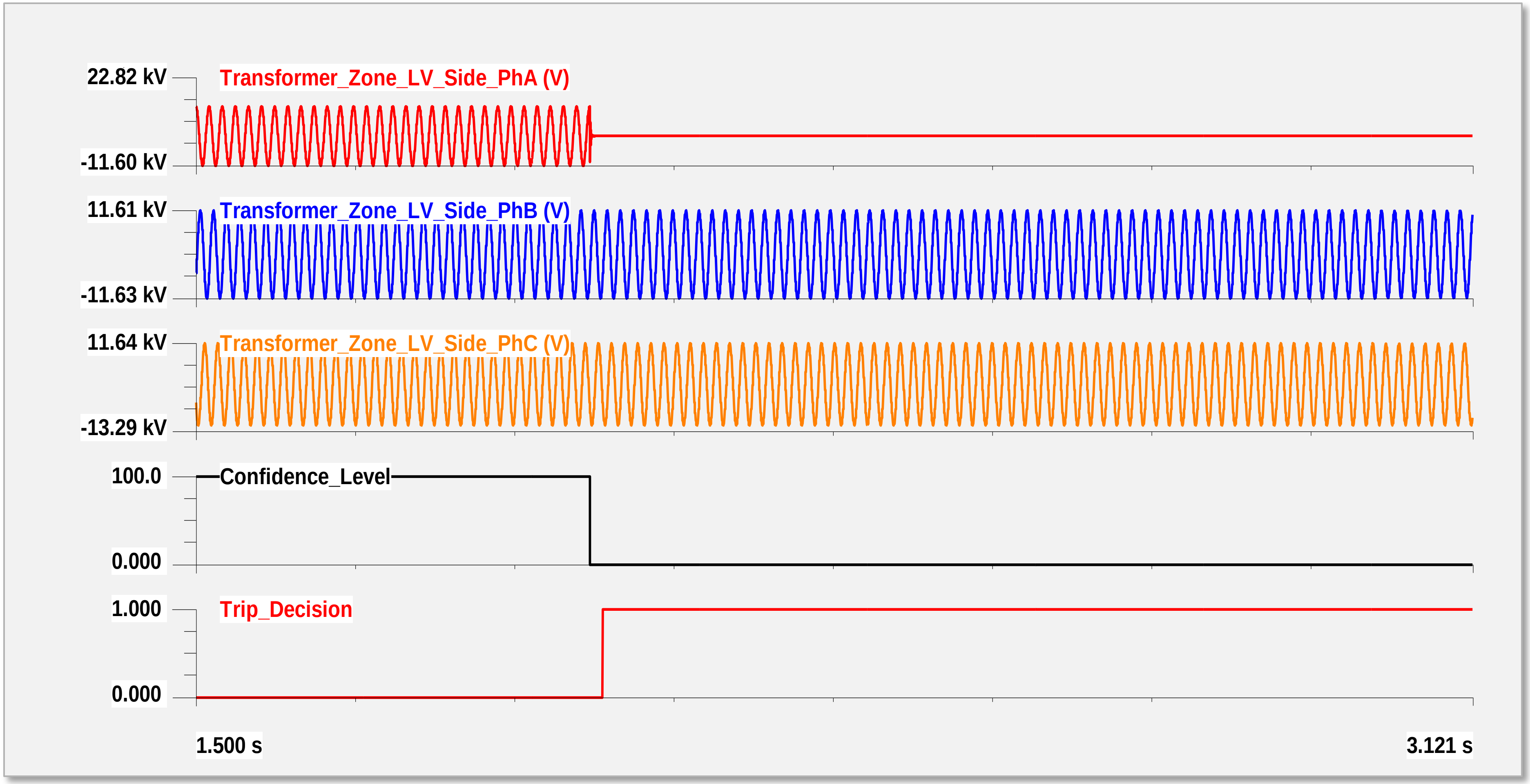
Time (seconds)



Numerical Example

Case1: Primary Fuse Blown Y-Y, PT-4A

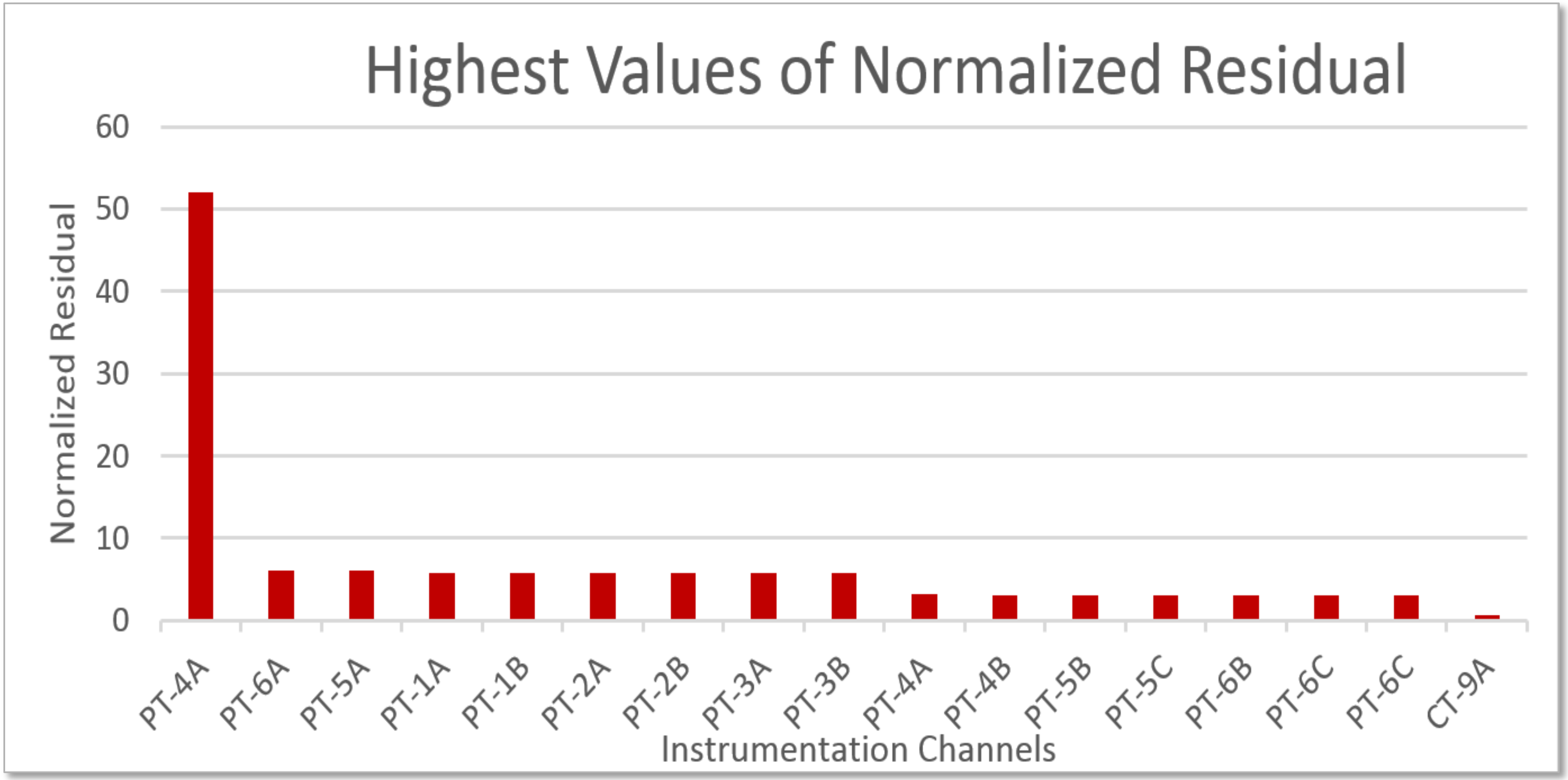
Setting-less Relay of Transformer Zone:



Numerical Example

Case1: Primary Fuse Blown Y-Y, PT-4A

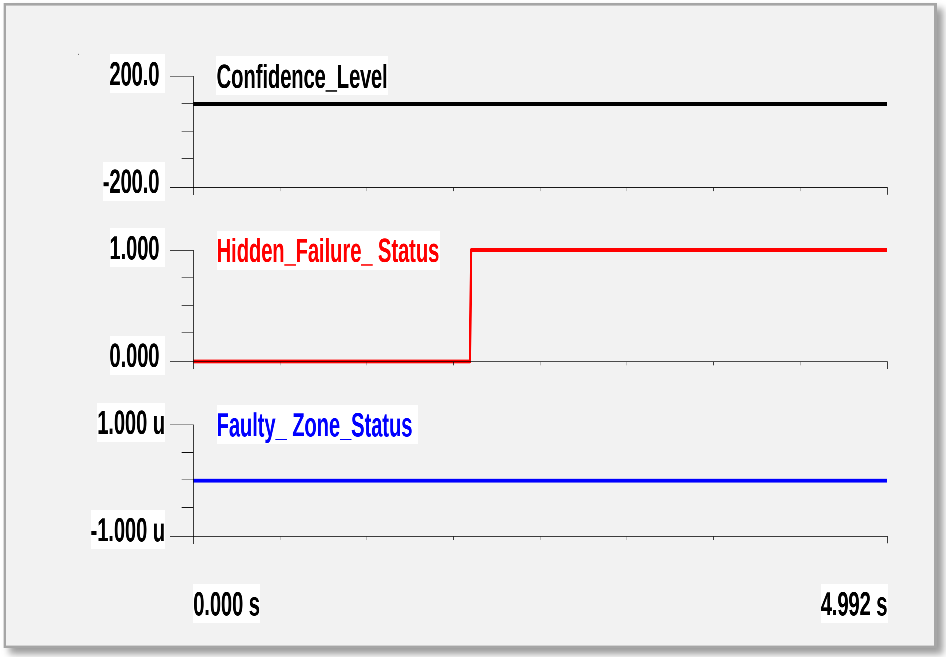
Centralized Protection Scheme :

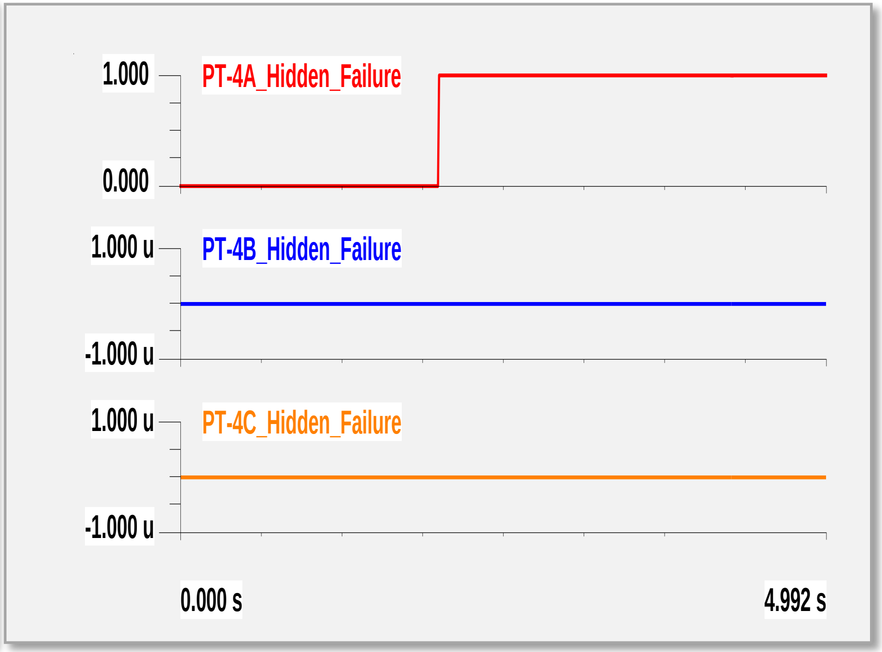


Numerical Example

Case1: Primary Fuse Blown Y-Y, PT-4A

Centralized Protection Scheme :

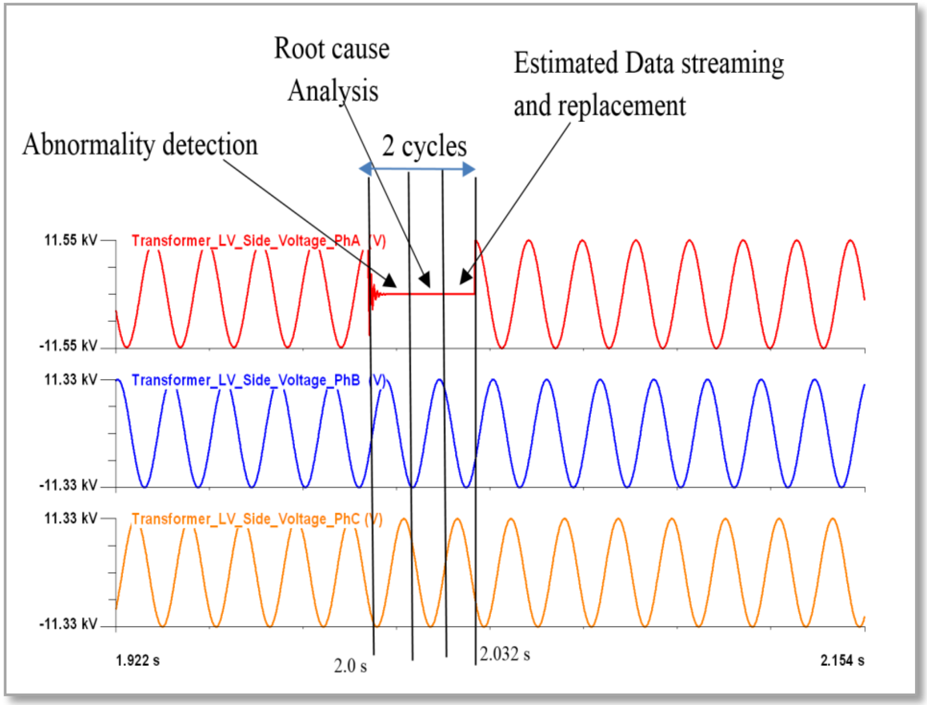


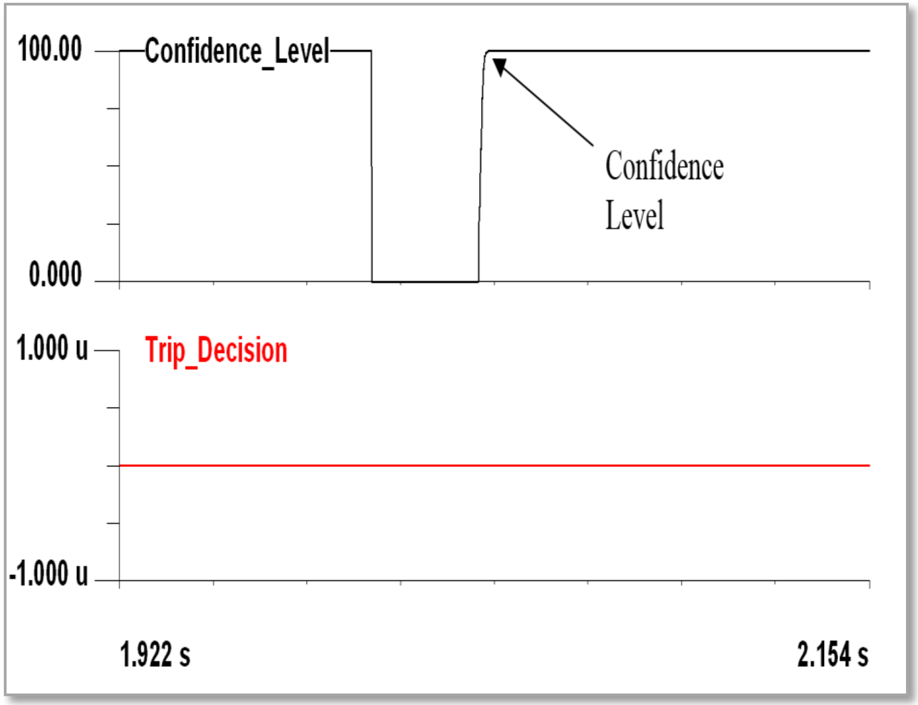


Numerical Example

Case1: Primary Fuse Blown Y-Y, PT-4A

Compromised Data Correction :





Conclusions / Recommendations

Two basic innovations for Centralized Substation Protection have been presented:

Innovation 1: Instrumentation error correction is embedded into intelligent Merging Units → provide corrected sampled values in real time – primary quantities

Innovation 2a: Supervision of protection functions (logical nodes) to determine that hidden failures do not exist.

Innovation 2b: Supervision of protection functions (logical nodes) to determine if hidden failures exist. In this case, use existing redundancy to replace compromised data with estimated data and enable continuous reliable operation of logical nodes (protection functions)


Τέλος