

Uses of Substation Data for Improved Operation and Maintenance

Mladen Kezunovic
Texas A&M University

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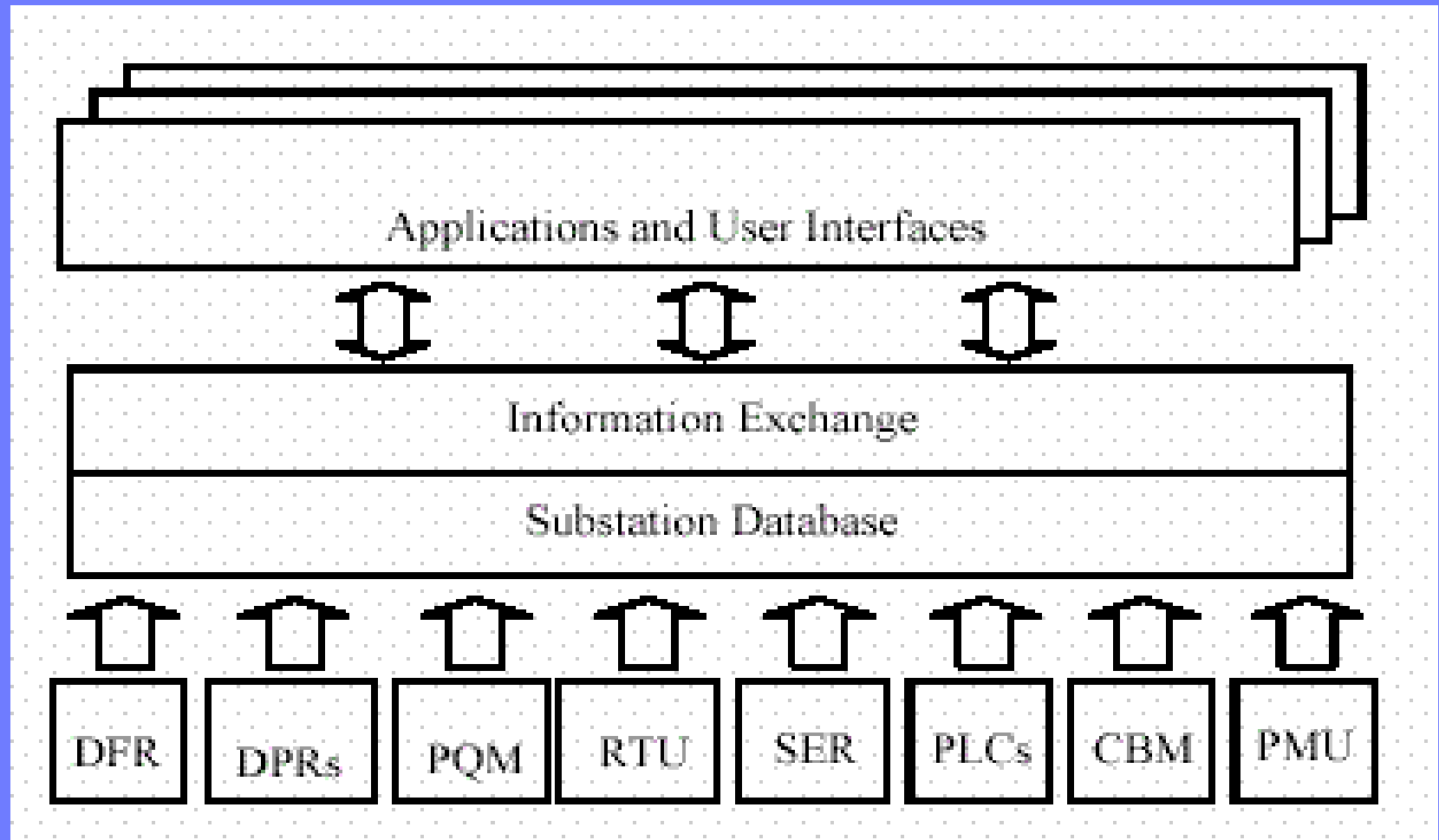
Outline

- Background
- The main idea:
 - Operational data
 - Non operational data
 - “Transparent” data
- Implementation examples
- Future steps
- Conclusions

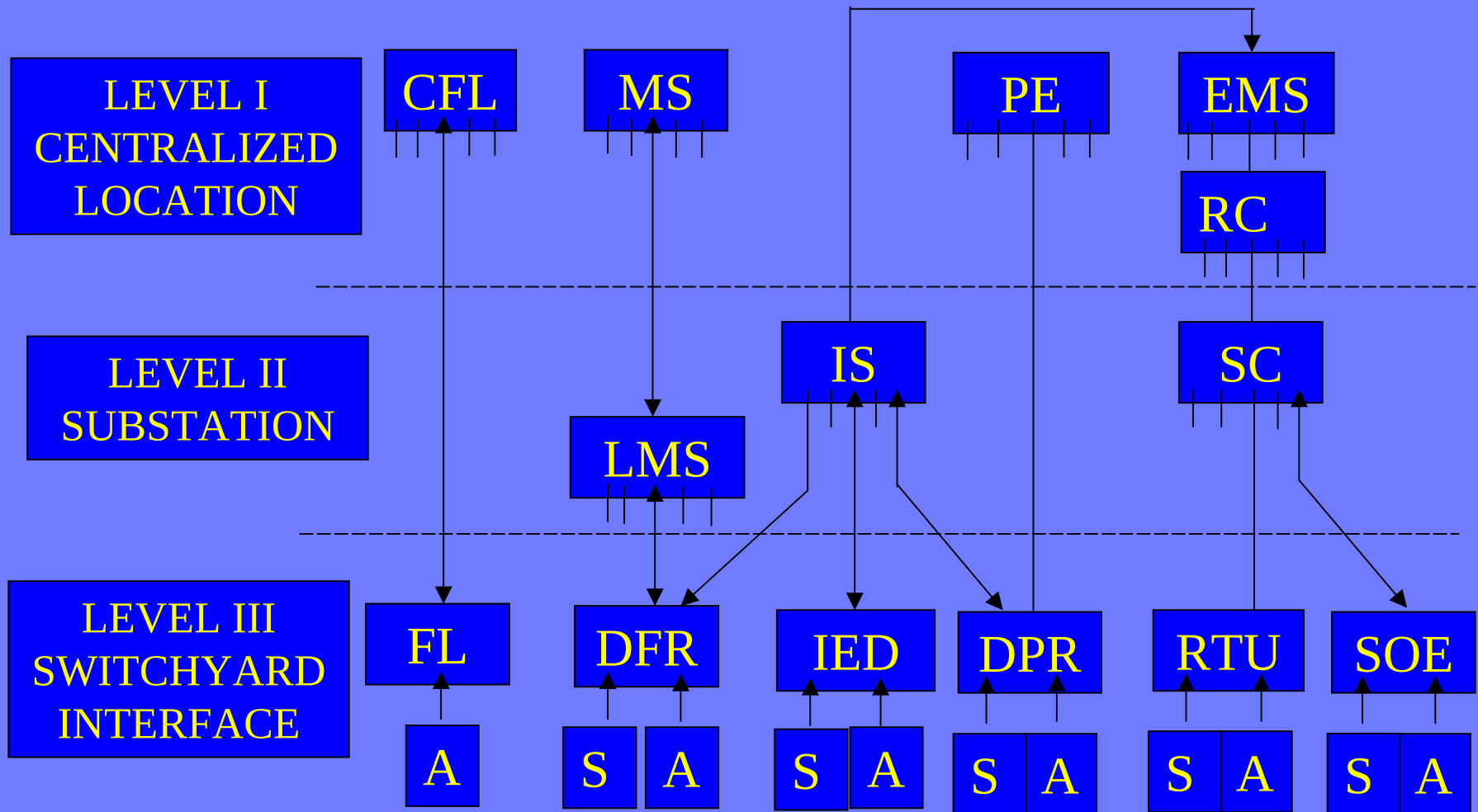
Background

- **Concept** of data integration and information exchange:
 - M. Kezunović, A. Abur, "Data Integration and Information Exchange: Impacts on Future Substation and EMS Applications," EPRI Final Report #1010898, May 2004.
 - M. Kezunović, A. Abur, A. Edris, D. Šobajić, "Data Integration/Exchange Part II: Future Technical and Business Opportunities," *IEEE Power & Energy Magazine*, pp 24-29, May/June 2004.
 - M. Kezunović, A. Abur, A. Edris, D. Šobajić, "Data Integration/Exchange Part I: Existing Technical and Business Opportunities," *IEEE Power & Energy Magazine*, pp 14-19, January/February 2004.
 - M. Kezunovic, A. Abur, "Merging of Temporal and Spatial Aspects of Data and information for Improved System Monitoring Applications," *IEEE Proceedings*, Vol. 93, No. 11, November 2005

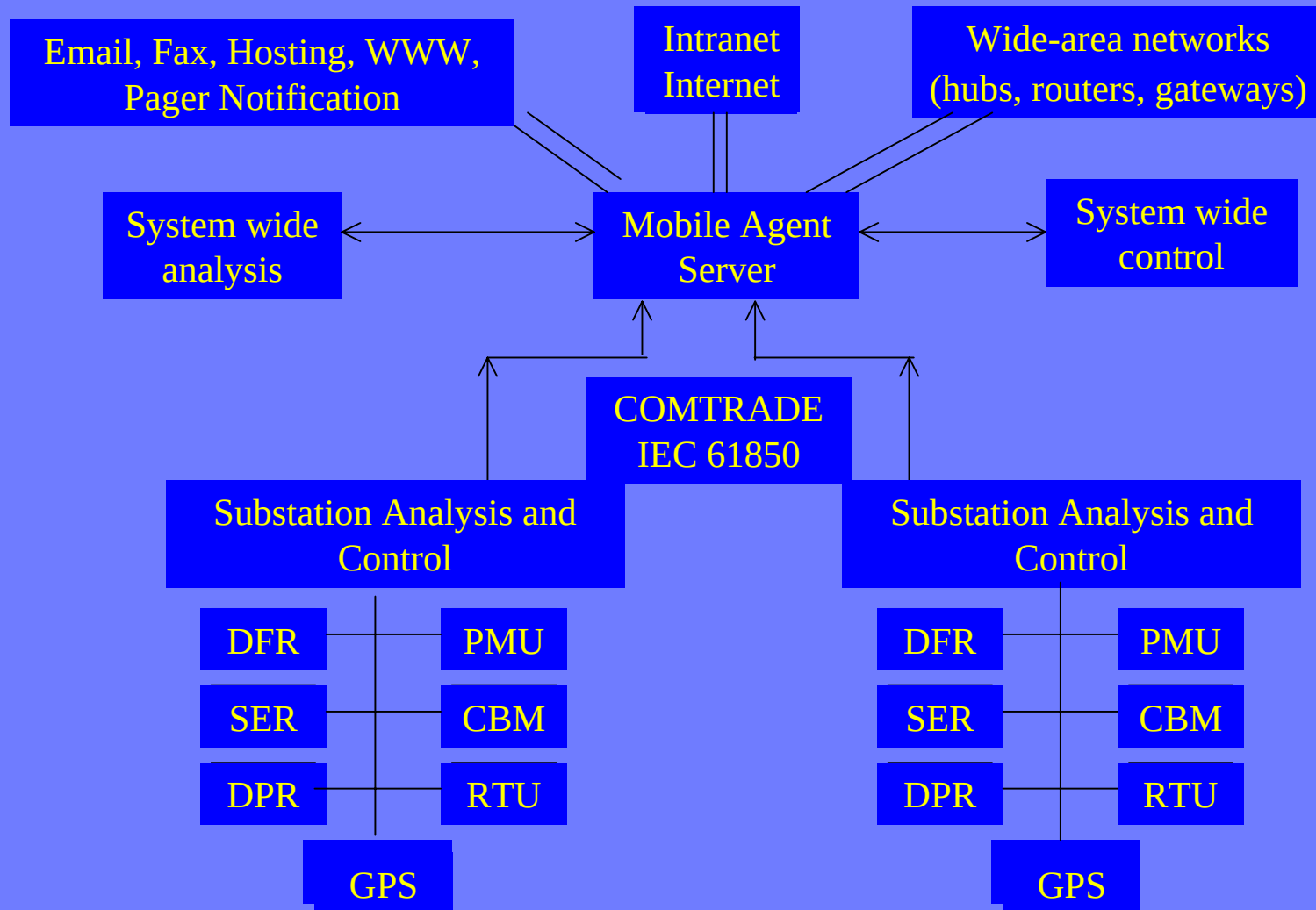
Concept



Concept



Concept

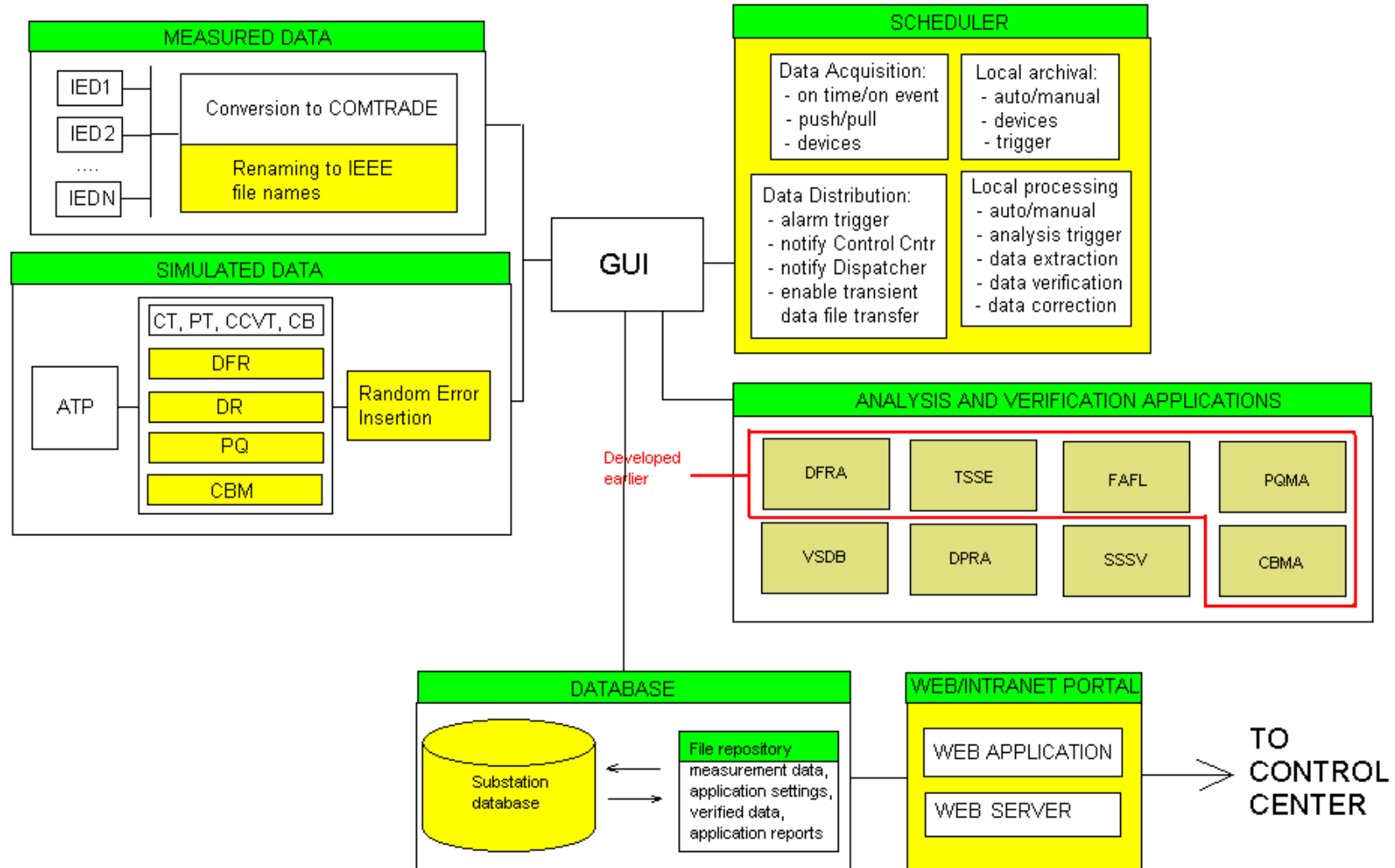


Background

- **Demonstration** of the concept using modeling and simulation of substation automation applications:
 - M. Kezunovic, A.Abur, “Enhanced Reliability of Power System Operation Using Advanced Algorithms and IEDs for On-Line Monitoring,” PSerc Project T-17 titled, Final report, September 2005.
 - X. Luo, M. Kezunović, “An Expert System for Diagnosis of Digital Relay Operation,” *13th Conference on Intelligent Systems Application to Power Systems*, Washington DC, USA, November 2005.
 - M. Kezunović, G. Latisko, “Requirements Specification for and Evaluation of an Automated Substation Monitoring System,” *CIGRE 2005*, Calgary, Canada, September 2005.
 - Y. Wu and M. Kezunović, “Automatic Simulation of IED Measurements for Substation Data Integration Studies,” *IEEE PES 2005 General Meeting*, San Francisco, California, June 2005.
 - M. Kezunović, G. Latisko, “Automated Monitoring Functions for Improved Power System Operation and Control,” *IEEE PES 2005 General Meeting*, San Francisco, California, June 2005.

Substation Developments

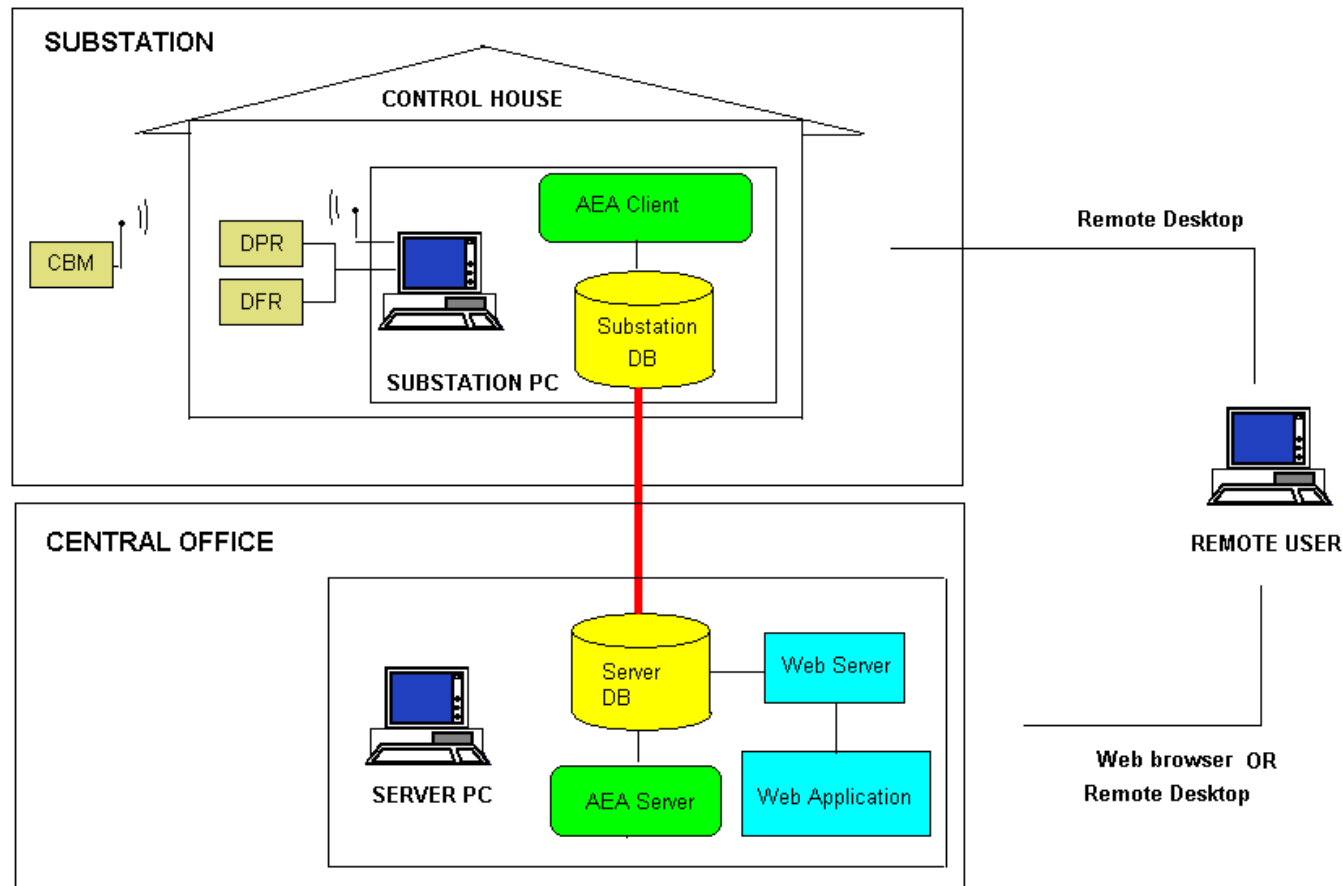
Software Architecture



Background

- **Implementation of the concept using field data/installations:**
 - M. Kezunovic, "Role of Substation Automation in Real Time Control," DOE CERTS, on-going.
 - M. Kezunovic "Multiple Uses of Substation Data," EPRI, on-going
 - J. Ciufu, K. Rolston, M. Kezunović, G. Latisko, A. Edris, "Requirements for Automated Analysis of Substation Data," *North American Transmission and Distribution Conference & Expo*, Toronto, Canada, May 2005.
 - M. Kezunović, G. Latisko, N. Ved, "Real-Time Monitoring and Assessment of Circuit Breaker Operations for Diagnostics and Control Applications," *EPRI Substation Equipment Diagnostics Conference XIII*, New Orleans, Louisiana, March, 2005.

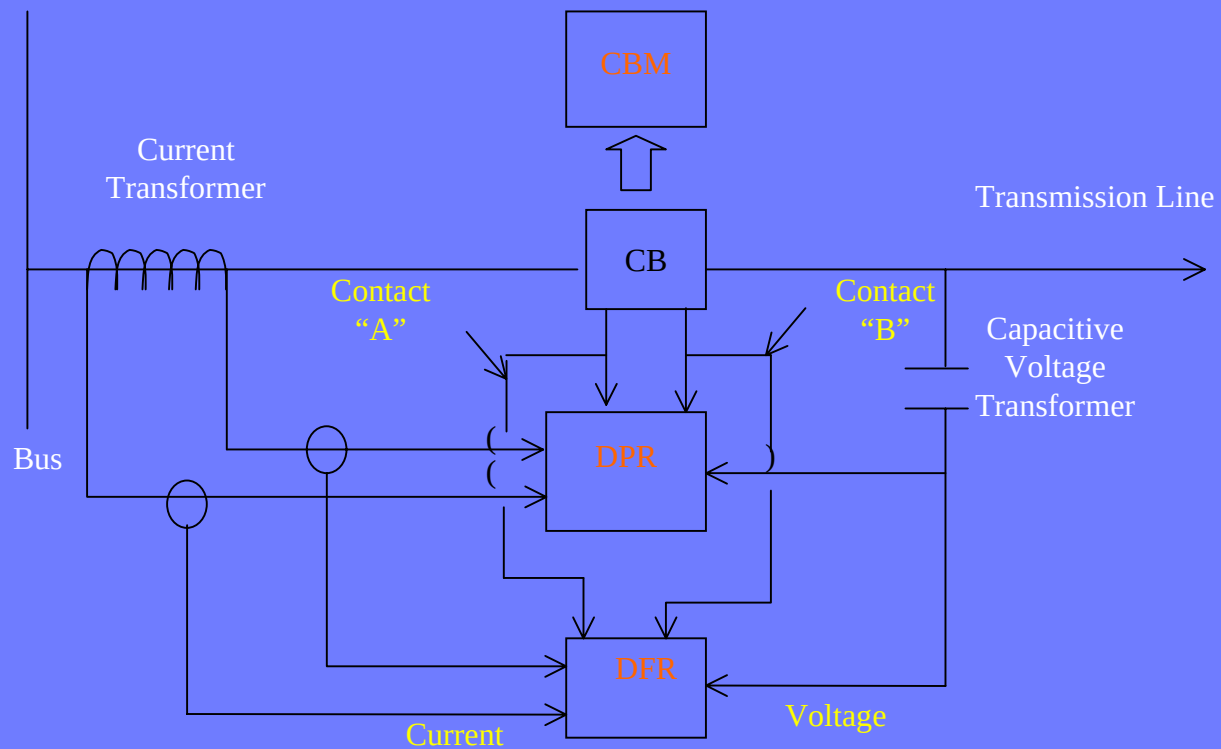
Implementation: Field installation



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The main idea



Data from DFRs, DPRs, and CBMs

Digital Fault Recorder

“A” and “B” contacts
Phase currents
Relay trip signal
Recloser timing signal
Breaker failure initiate
Comm. scheme signals

Digital Protective Relay

“A” and “B” contacts
Phase currents
Relay trip signal
Recloser timing signal
Breaker failure initiate
Comm. scheme signals

Circ. Breaker Monitor

“A” and “B” contacts
Phase currents
Trip and close initiate
Trip and close currents
“X” and “Y” coils
DC supply

Information Different Required by Utility Groups

Asset Managers	Maintenance	Dispatchers	Protection
Availability of CB	Repair scheduling	Real-time status	Operation timing
Cost of CB repair	Diagnostic tools	Breaker failure	Fault clearing
Risk of using CB	Failure rate	Switch. sequence	Switch. Sequence
Future purchases	Required parts	Autoreclosure	Autoreclosure
Impact on system reliability	Maint. strategy	Fault clearing	Restrikes

Better Data

Correlated Data

Interpreting CB cause effect sequences

Making relationship between status changes and changes in analogs

Redundant Data

Multiple IEDs measure CB status and analogs

Confirming CB status based on multiple indications of the status

Cumulative Data

Counting number of CB operations

Taking into account number of repairs and calculating failure rates

Better Information

Multiple Data Sources

CB monitors: control circuit signals, vibration, gas pressure

Digital fault recorders: “A” and “B” contacts, phase current changes

Protective relays: duty cycle currents, $I^2 \bullet t$

Temporal Analysis

Sequence of control signal initiations and changes in circuit breaker status

Sequence and correlation of changes of the status contacts and CB currents

Timing of CB operations and current interruptions

Historical Assessment

Number of operations and assessment of the opening/ closing times

Consistency of “A” and “B” contacts and their reliability

Assessment of the duty cycle over long time

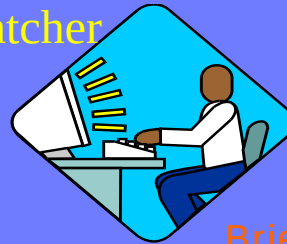
Information Users

Engineer



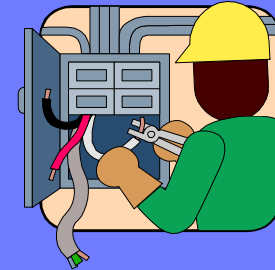
Comprehensive Report

Dispatcher

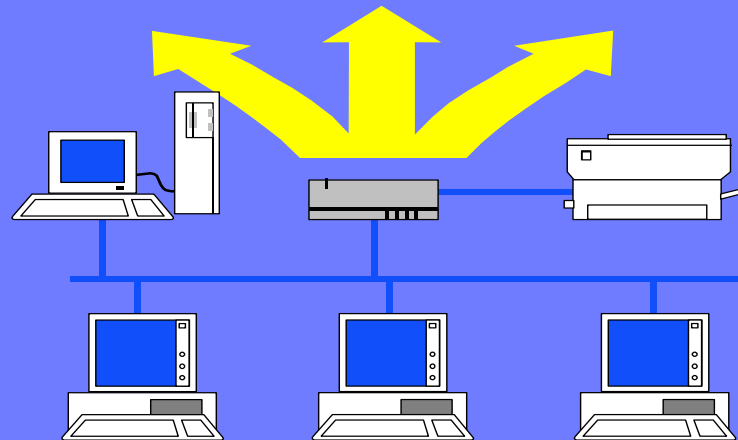


Brief Report

Technician



Summary Report

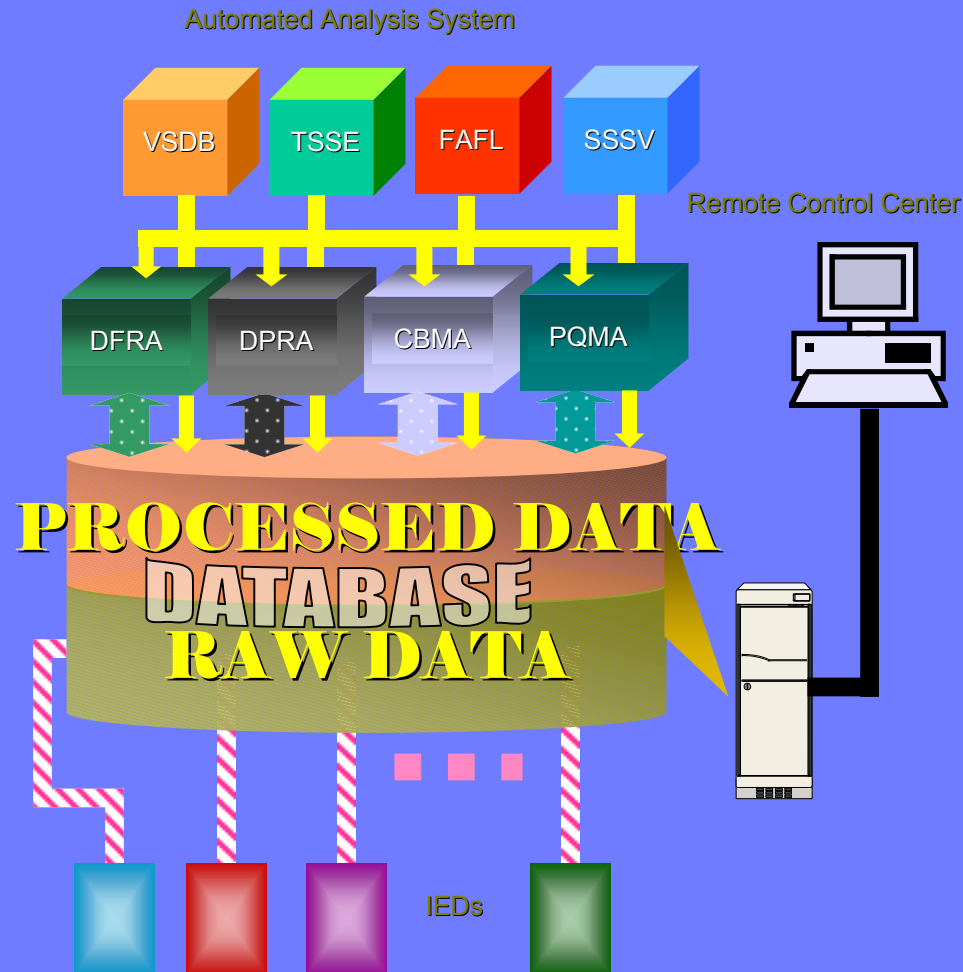


Electronic and paper reports can be **customized** according to the need of a particular category of users. Reports are disseminated via **fax, e-mail**, etc.

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Demonstration: Modeling and Simulation



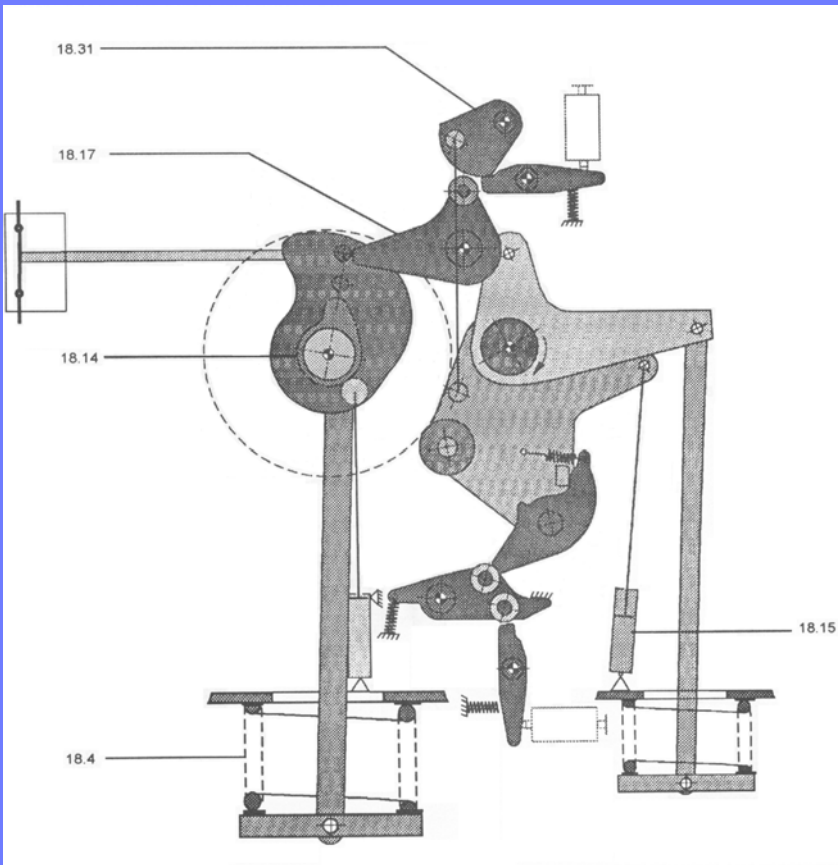
New Automated Analysis Functions

Function Name	Description
Circuit breaker monitor data analysis [CBMA]	Evaluates performance of the circuit breaker based on the analysis of data taken from the control circuitry
Digital Protective Relay Data Analysis [DPRA]	Checks consistency of data from various relay files. Verifies correctness of data from various relay files
DFR data analysis [DFRA]	Conducts automated analysis of fault records captured by Digital Fault Recorders (DFRs) and disseminates event reports

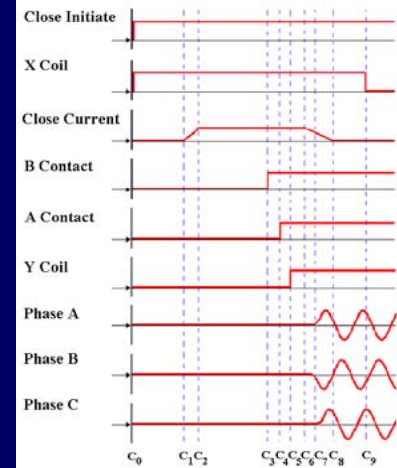
New Automated Analysis Functions

Function Name	Description
Verification of switching sequences [VSSS]	Determines optimal switching sequences for each type of fault condition or load transfer operation. Verifies the switching sequences
Fault analysis including fault location [FAFL]	Performs local as well as system wide analysis of the faults
Power quality meter data analysis [PQMA]	Performs power quality analysis and modeling
Two-Stage State Estimation [TSEE]	Detects and identifies the topology errors

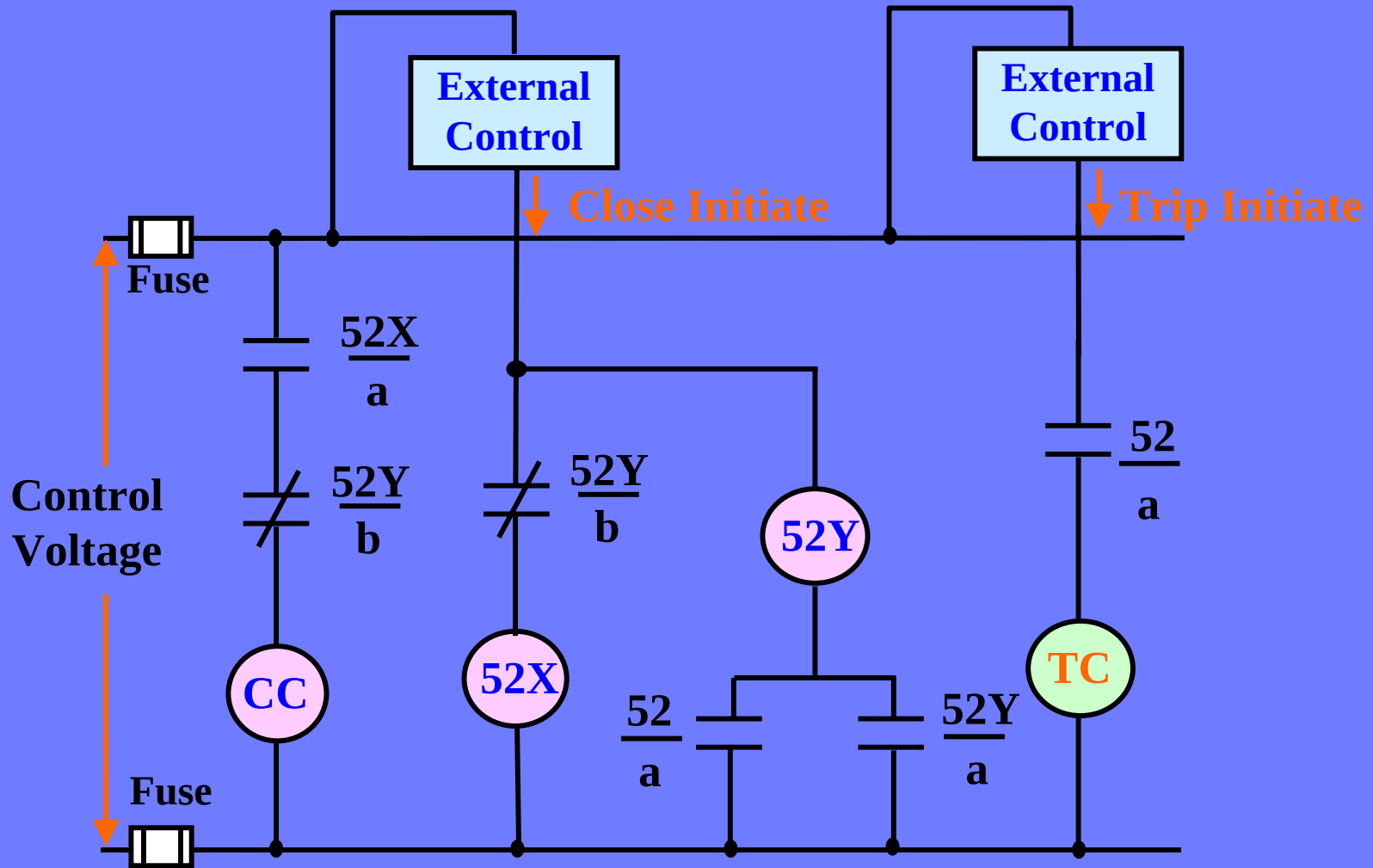
Background



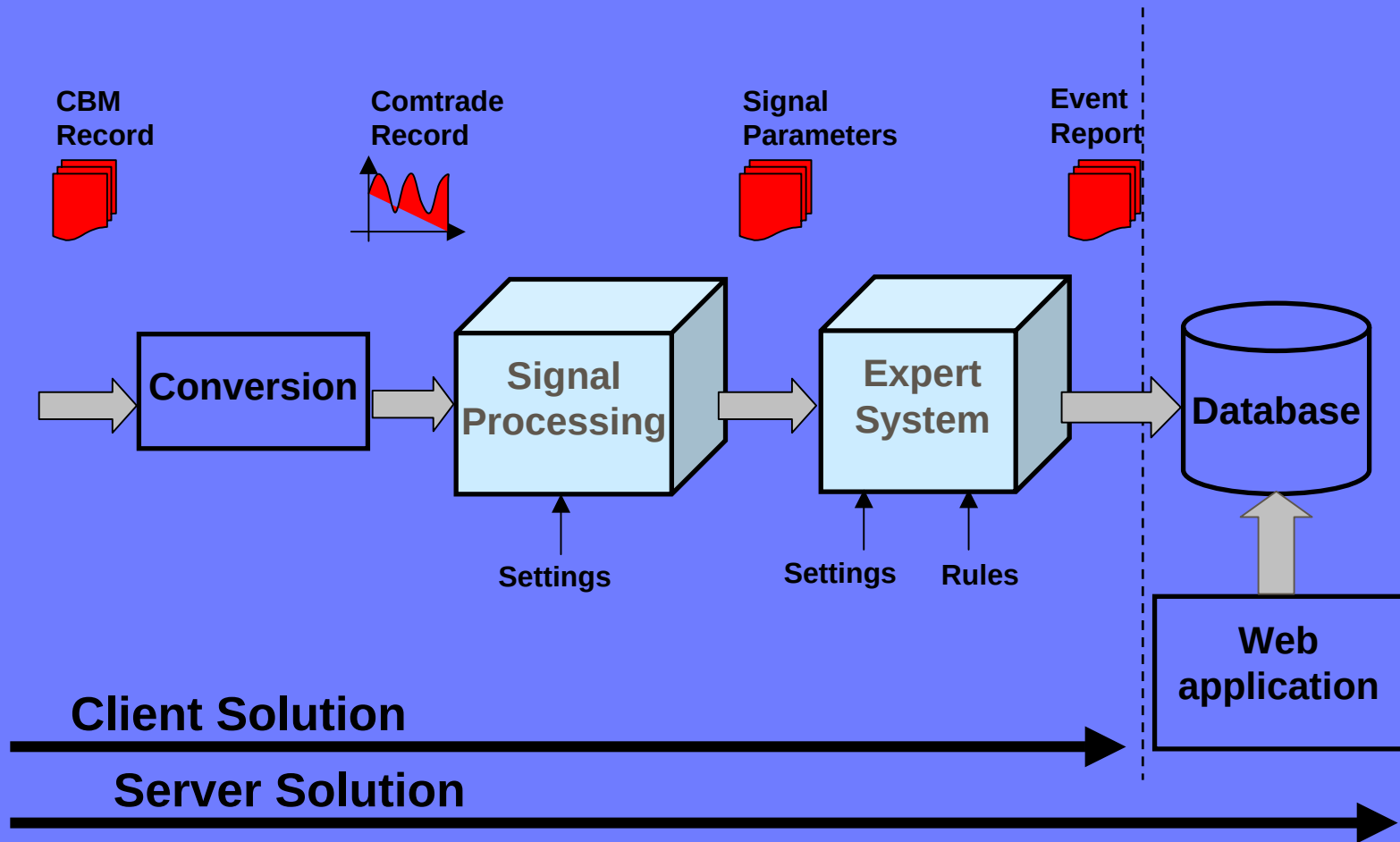
Electrical Signals - Close-



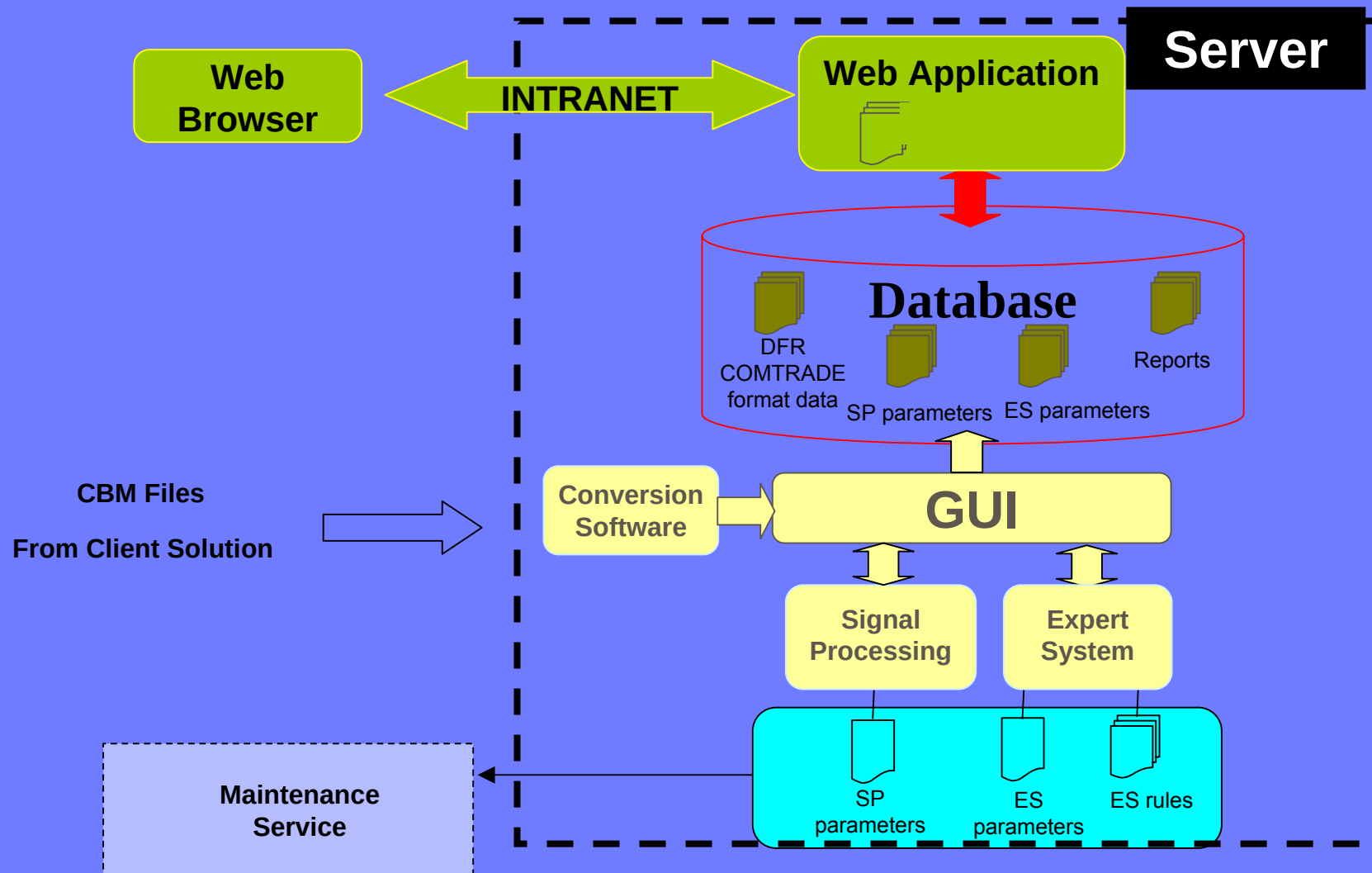
Automated Analysis of CBM Data



Automated Analysis of CBM Data

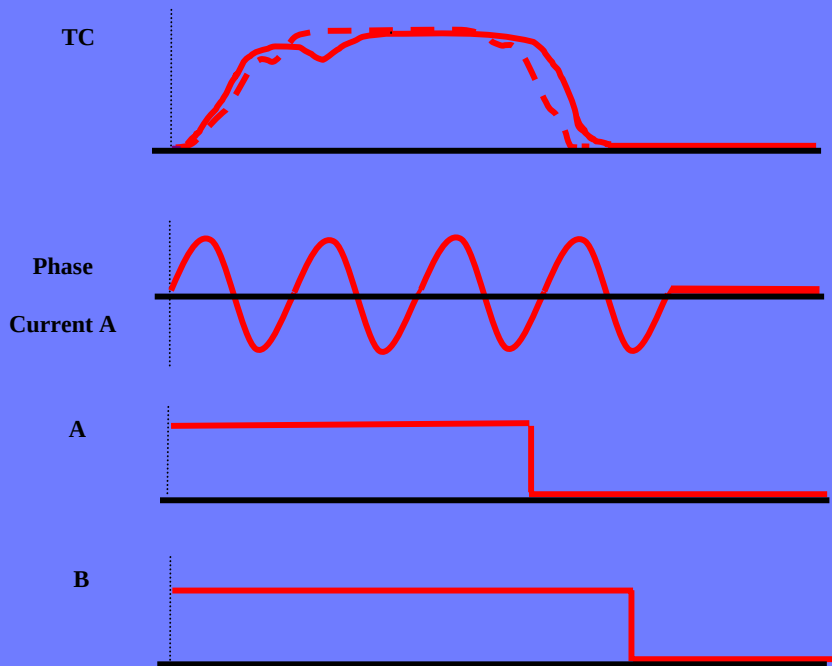


Automated analysis of CBM Data



Automated Analysis of CBM Data

Abnormal Input Signal



Output Event Report

-----Expert System Log-----

The record indicates an opening operation!

R1: Breaker opens!

R30: Trip coil current dip delayed!

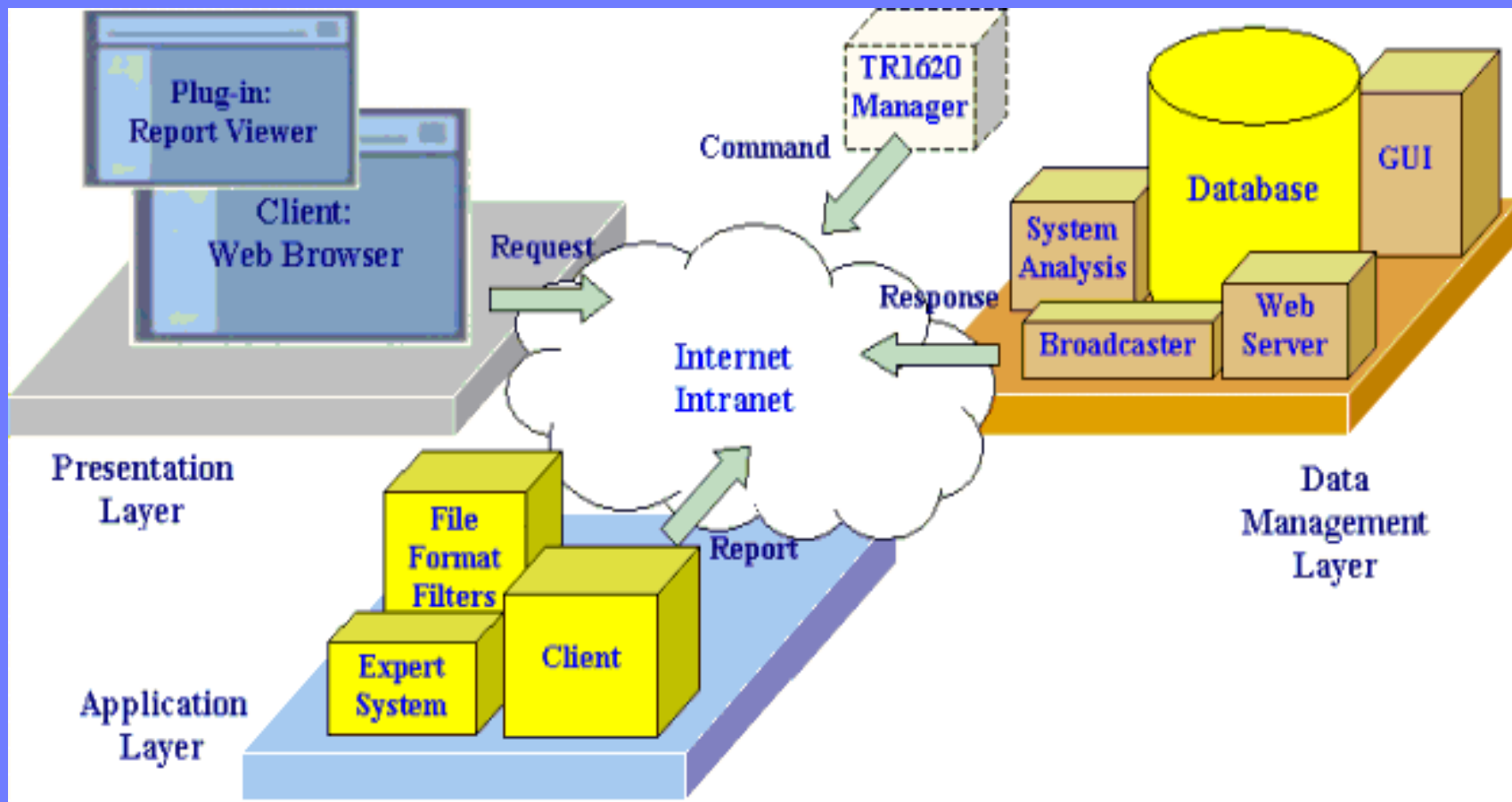
R75: Travel time reduced!

R77: Trip latch maladjustment!

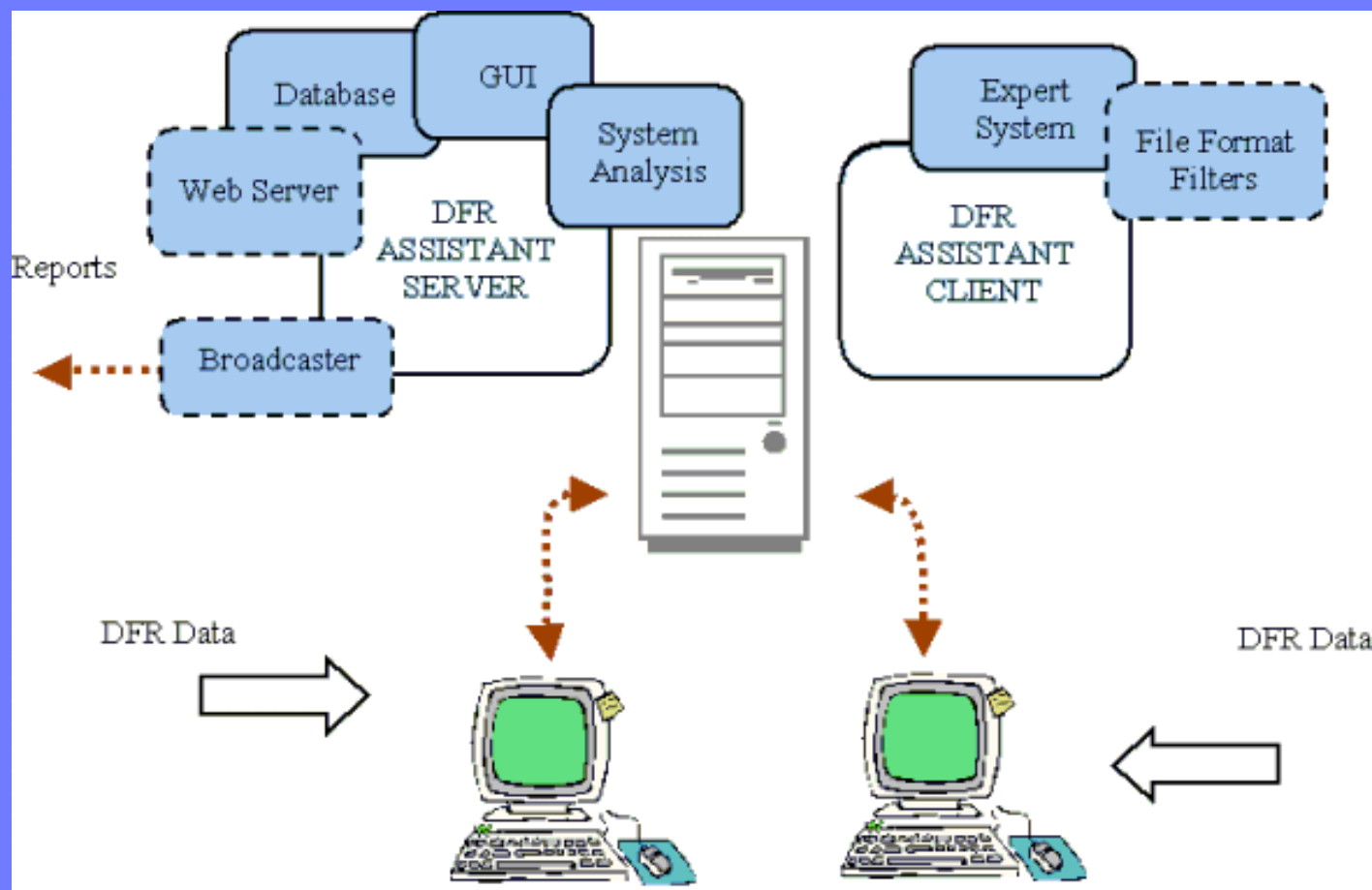
---Maintenance & Repair Information---

Check trip assembly for binding. It may require some adjustment.

Automated Analysis of DFR Data



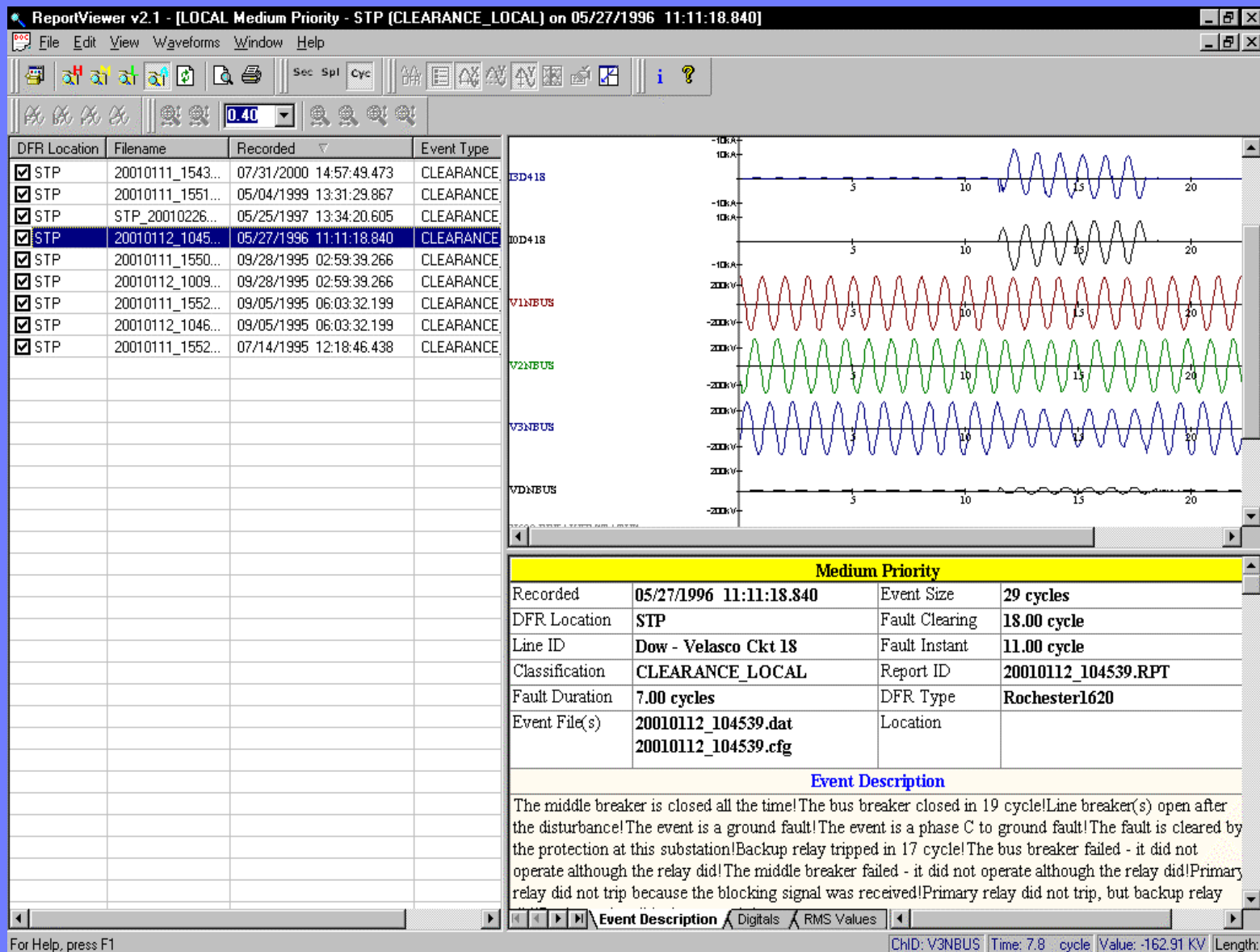
Automated Analysis of DFR Data



Automated Analysis of DFR Data

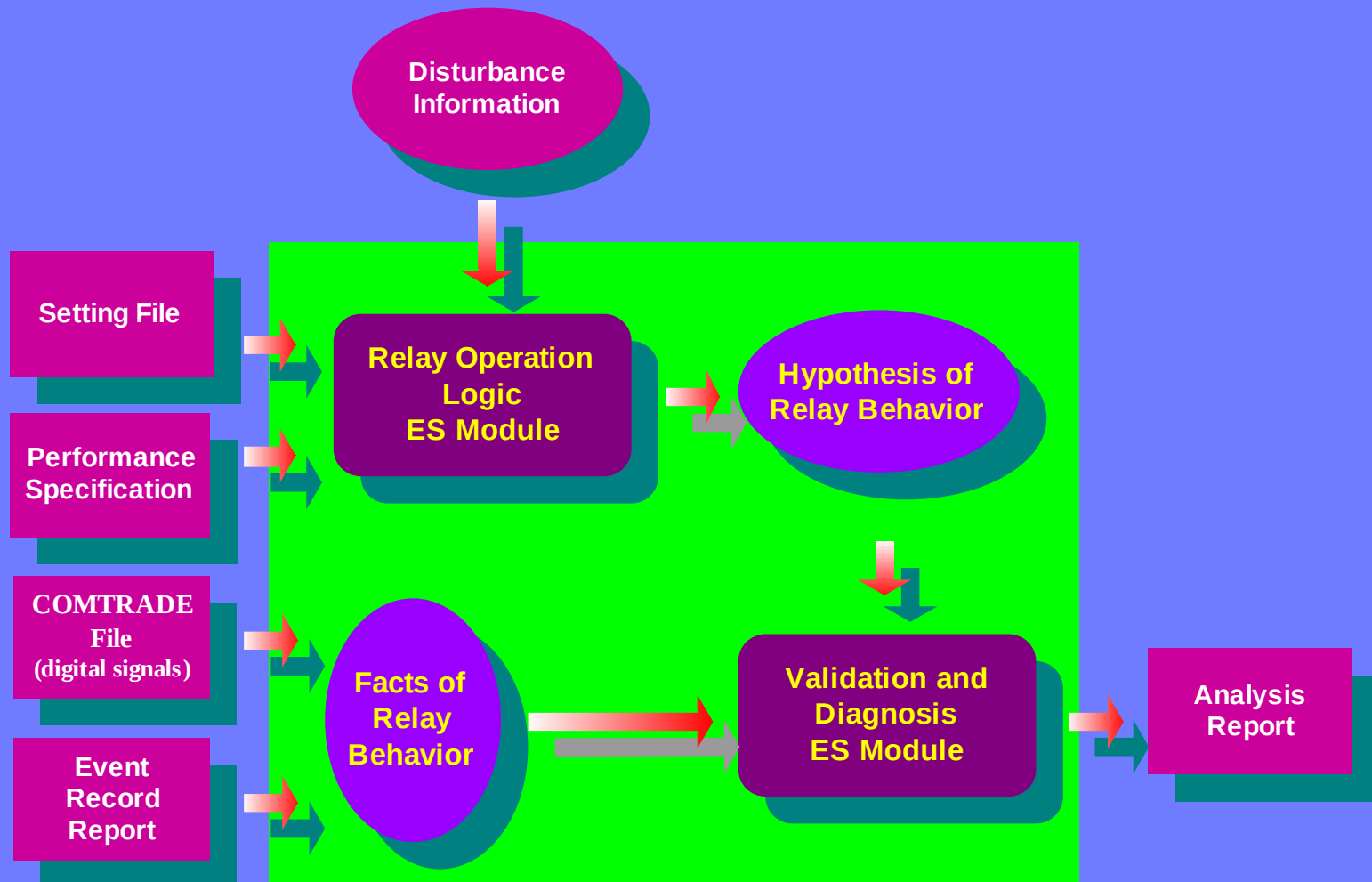
Digital	Primary and backup relay trip Breaker open position Breaker close position Breaker failure (BF) contact Carrier Start and Carrier Received contacts
Analog	At least two phase currents (I_a, I_b, I_c) Residual current (I_r) All three phase (bus side) voltages (V_a, V_b, V_c) Residual (neutral) voltage (V_r)

Automated Analysis of DFR Data

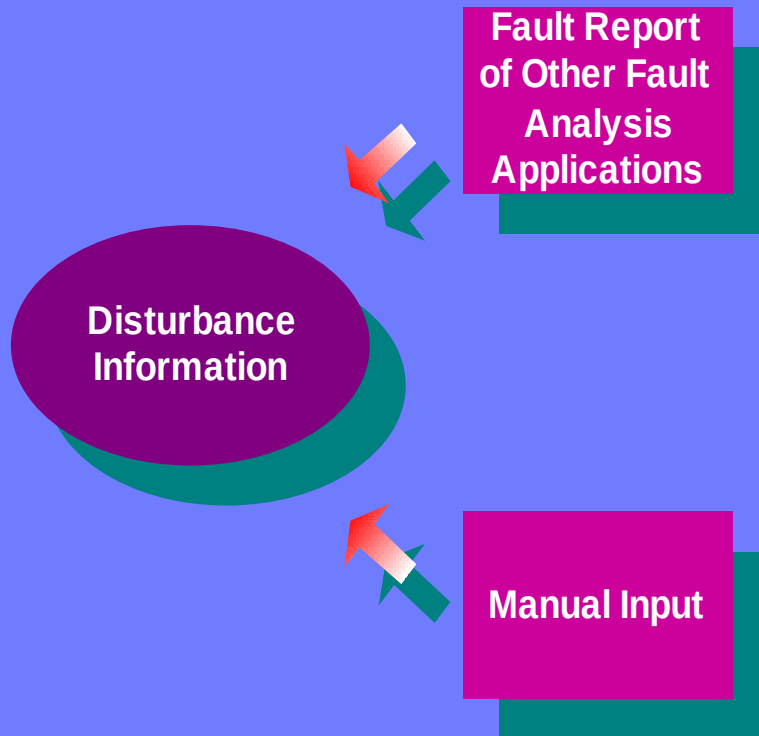


Automated Analysis of DPR Data

- Analysis is based on comparison of expected protection behavior and actual protection behavior



Automated Analysis of DPR Data



DISTURBANCE INFORMATION

☐ AUTOMATIC INPUT
☒ MANUAL INPUT

TYPE

AG

FAULT LOCATION

☒ ZONE 1
☐ ZONE 2
☐ ZONE 3
☐ ZONE 4

DURATION INTERVAL

INCEPTION 0
DISAPPEARANCE 100

CIRCUIT BREAKER 1 CURRENTS

INTERUPTION TIME

☒ NOT INTERRUPTED
☐ INTERRUPTED 0

RESUME TIME

☒ NOT RESUMED
☐ RESUMED 0

CIRCUIT BREAKER 2 CURRENTS

INTERUPTION TIME

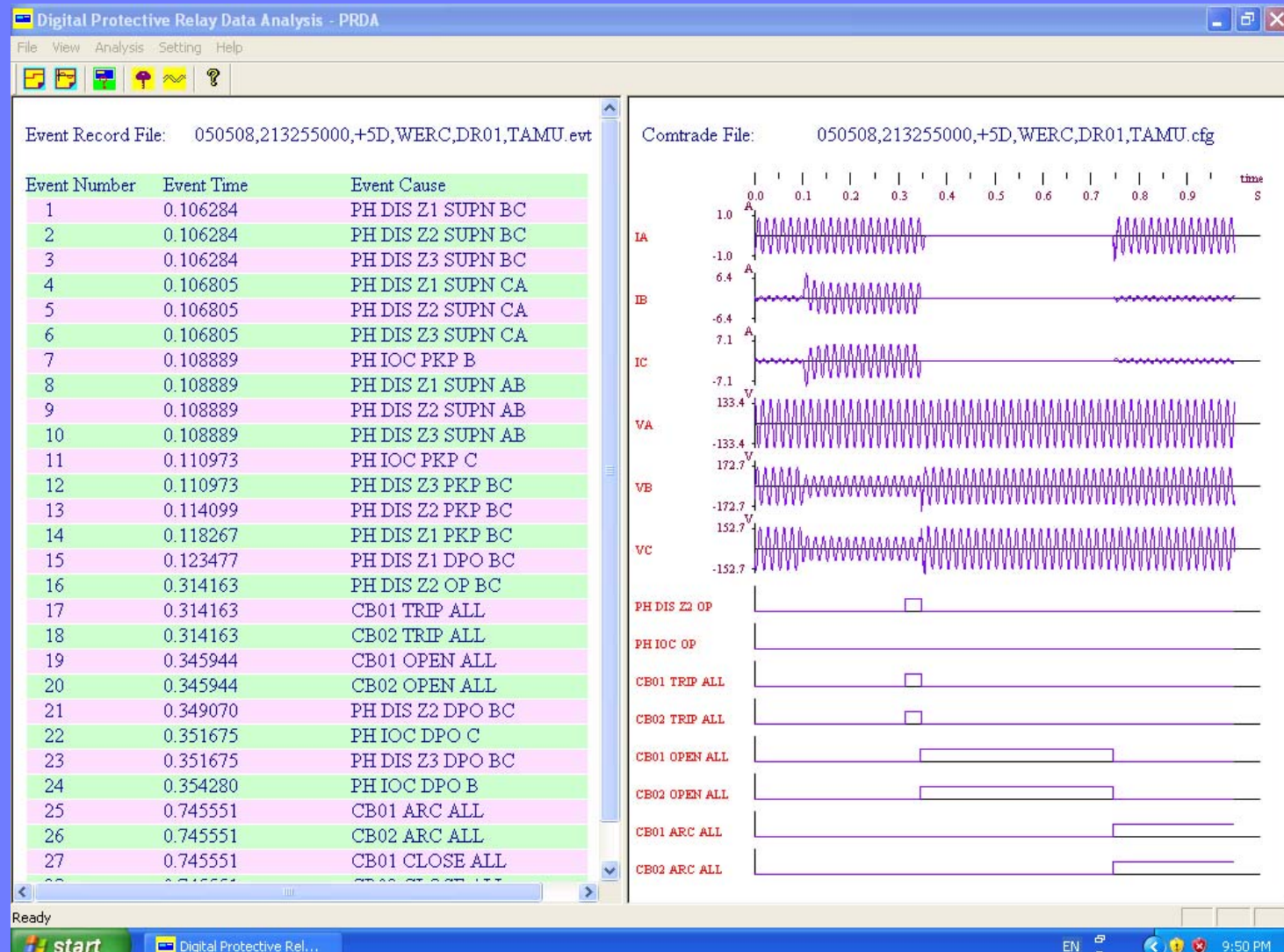
☒ NOT INTERRUPTED
☐ INTERRUPTED 0

RESUME TIME

☒ NOT RESUMED
☐ RESUMED 0

OK
Cancel

Automated Analysis of DPR Data



Automated Analysis of DPR Data



- Summary of protection operation
- Diagnosis information

ANALYSIS REPORT

SUMMARY OF PROTECTION OPERATION:

Expected Operation

PH DIS Z2 should operate at 0.1140 sec
Relay should trip at 0.1140 sec
CB02 should open at 0.1300 sec
CB01 should open at 0.1300 sec
CB01 should interrupt currents at 0.1340 sec
CB02 should interrupt currents at 0.1340 sec
CB01 should reclose at 0.2300 sec
CB02 should reclose at 0.2300 sec
CB01 should resume currents at 0.2320 sec
CB02 should resume currents at 0.2320 sec

Actual Operation

PH IOC operated at 0.1589 sec
Relay tripped at 0.1589 sec
CB01 opened at 0.1943 sec
CB02 opened at 0.1745 sec
CB02 interrupted currents at 0.1812 sec
CB01 interrupted currents at 0.1979 sec
CB01 reclosed at 0.2944 sec
CB02 reclosed at 0.2746 sec
CB02 resumed currents at 0.2755 sec
CB01 resumed currents at 0.2953 sec

Close

ANALYSIS REPORT

PH IOC operated at 0.1589 sec
Relay tripped at 0.1589 sec
CB01 opened at 0.1943 sec
CB02 opened at 0.1745 sec
CB02 interrupted currents at 0.1812 sec
CB01 interrupted currents at 0.1979 sec
CB01 reclosed at 0.2944 sec
CB02 reclosed at 0.2746 sec
CB02 resumed currents at 0.2755 sec
CB01 resumed currents at 0.2953 sec

DIAGNOSIS INFORMATION:

Relay was tripped by incorrect element
<- Relay should be tripped by PH DIS Z2 but it was tripped by PH IOC ***
** <- PH DIS Z2 failed to operate
<- All the phases of PH DIS Z2 expected to operate failed to operate *****
***** <- PH DIS Z2 BC failed to operate
<- PH DIS Z2 BC failed to pick up
<- PH DIS Z2 pickup characteristic setting was not correct

CB01 opened slower than expected by 0.0194 sec and out of tolerance
<-CB01 had mechanical problem

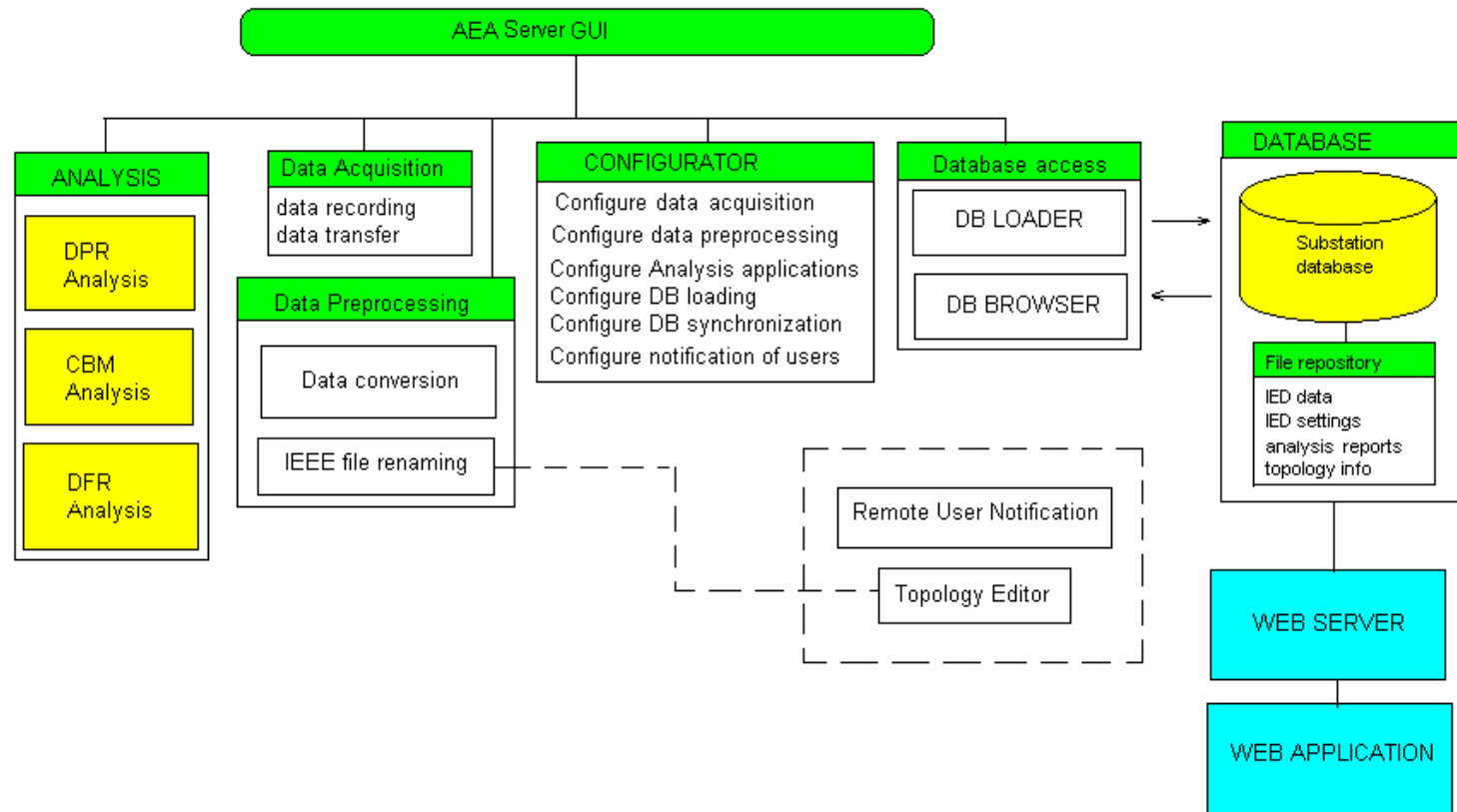
CB01 interrupted currents slower than expected by 0.0190 sec and out of tolerance
<-CB01 had mechanical problem

Close

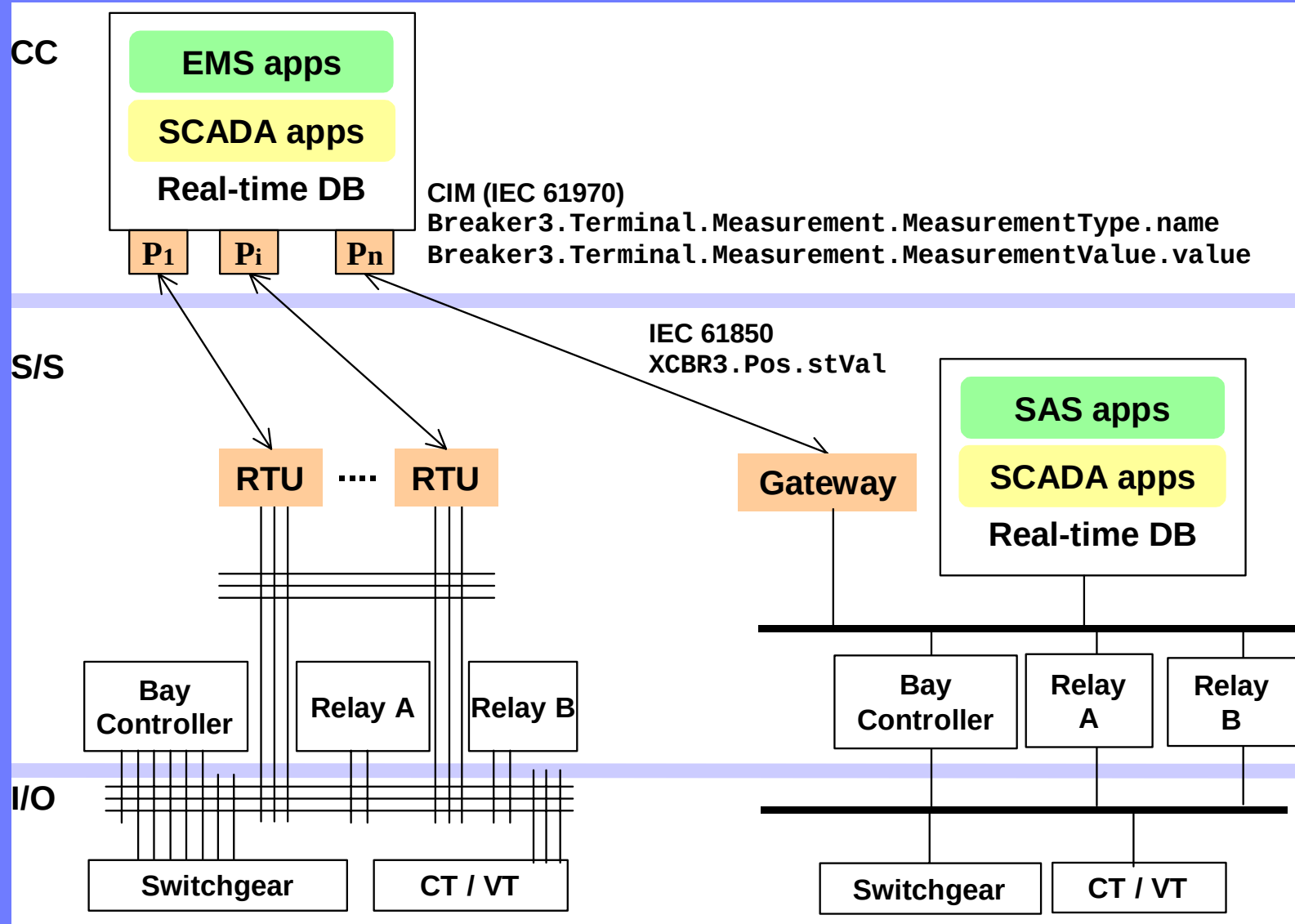
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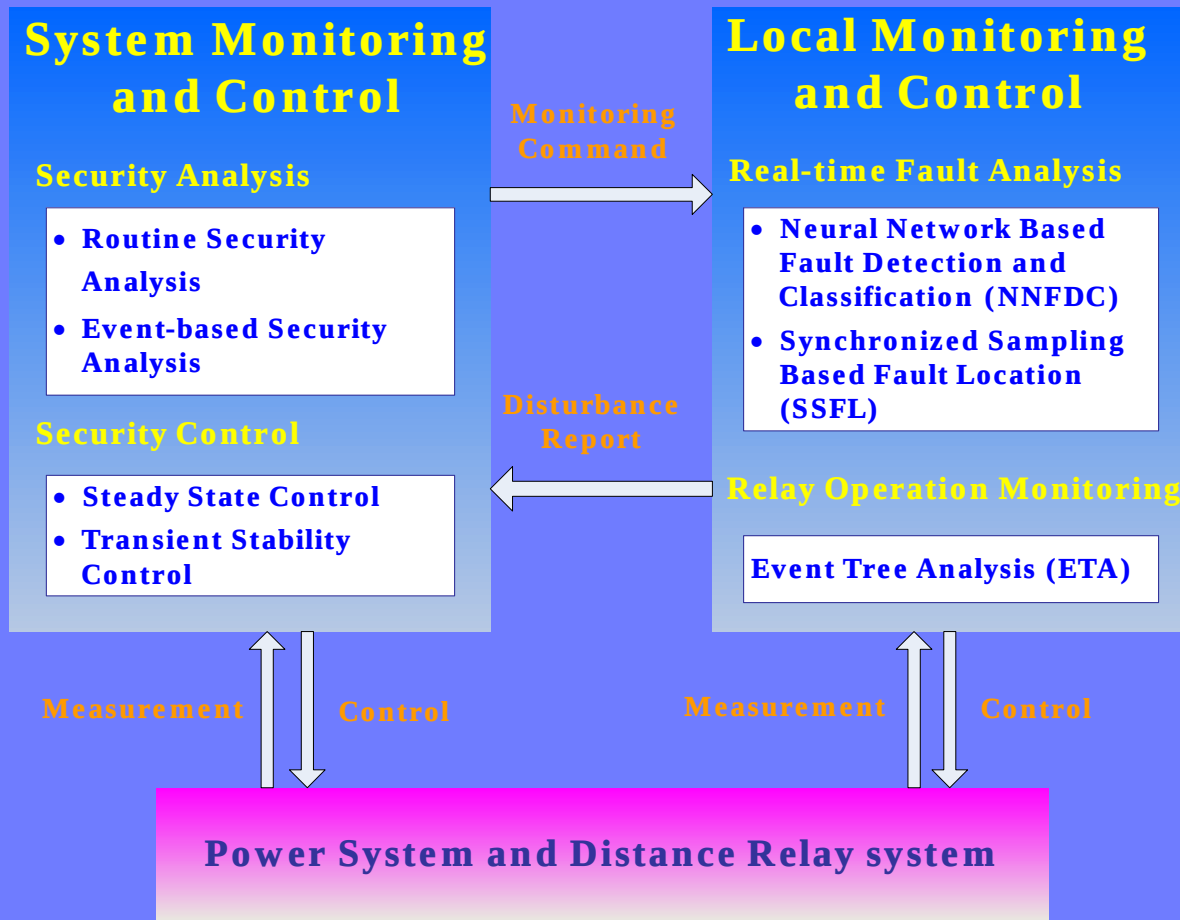
Substation Application



Interfacing Substation and SCADA Topology Data Models



Function Blocks

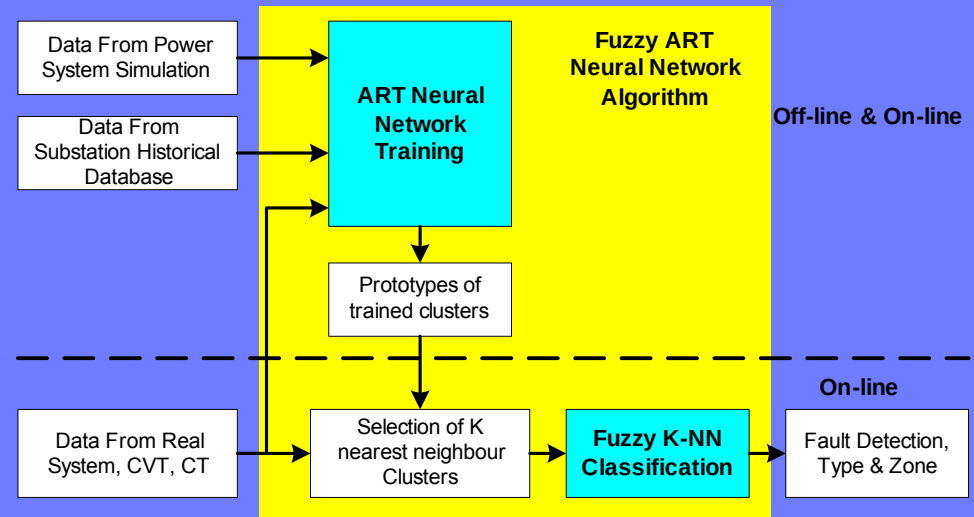


Local Monitoring and Control Techniques



- **Neural Network based Fault Detection & Classification (NNFDC)**

1. By using the ART neural network based on unsupervised & supervised learning, a set of clusters that represent the desired outputs are obtained.

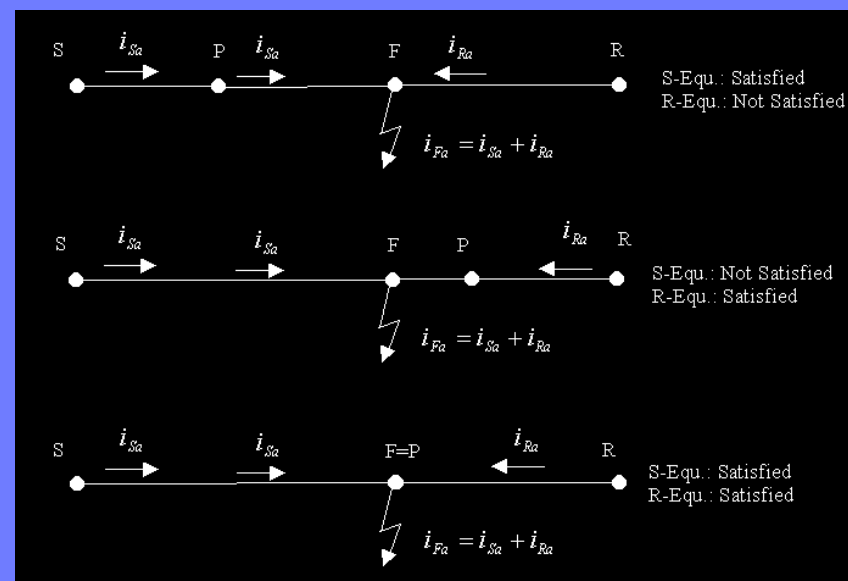
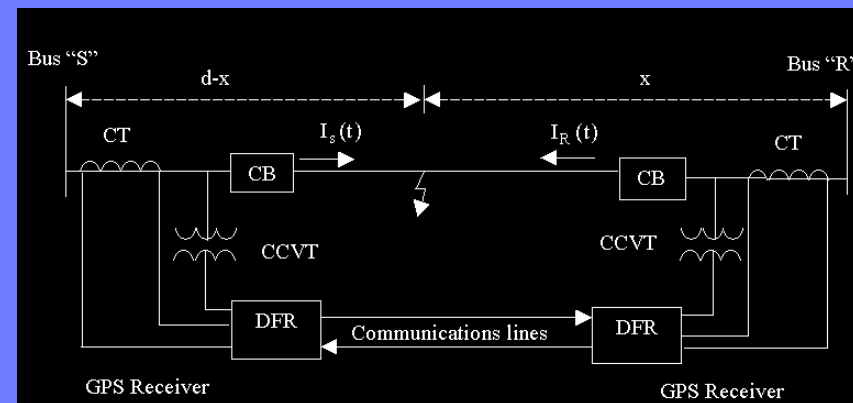


2. Using the prototypes of trained clusters, Fuzzy K-nearest neighborhood classifier can realize online analysis of unknown patterns for fault detection and classification

Local Monitoring and Control Techniques

Synchronized Sampling based Fault Location (SSFL)

- Raw samples of voltage and current data synchronously taken from the ends of the transmission line.
- Two time-domain algorithms to handle short and long transmission line.
- Any assumptions about system operating conditions, fault resistance, fault waveforms, etc.



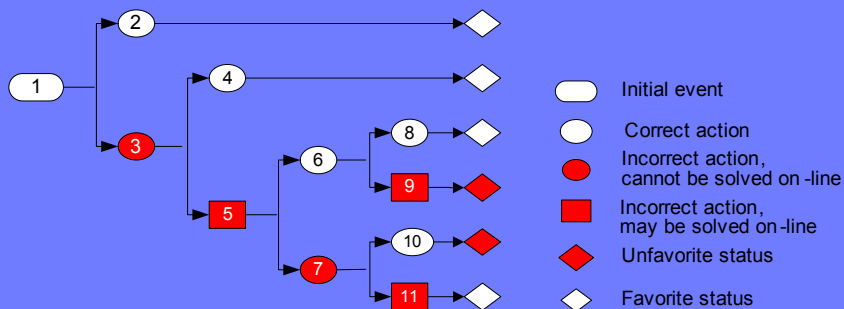
Local Monitoring and Control Techniques

Event Tree Analysis (ETA)

Design a set of event trees for each of distance relay systems to monitoring relay operations

Example

Non-Fault Conditions



Event explanation

Node	Scenarios	Reference Action
1	No fault in preset zones	Keep monitoring
2	Relay does not detect a fault	Stand by
3	Relay detects a fault and initiates a trip signal	Check the defects in relay algorithm and settings
4	Trip signal blocked by the other device in the system	
5	Trip signal failed to be blocked	Check communication channel Send blocking Signal if necessary
6	Circuit breaker opened by a trip signal	
7	Circuit breaker fails to open	Check the breaker circuit.
8	Autoreclosing succeeds to restore the line	
9	Autoreclosing fails to restore the line	Send reclosing signal to the breaker
10	Breaker failure protection trips all the breakers at the substation	
11	No Breaker failure protection or it doesn't work	Check the circuit of the breaker failure protection.

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