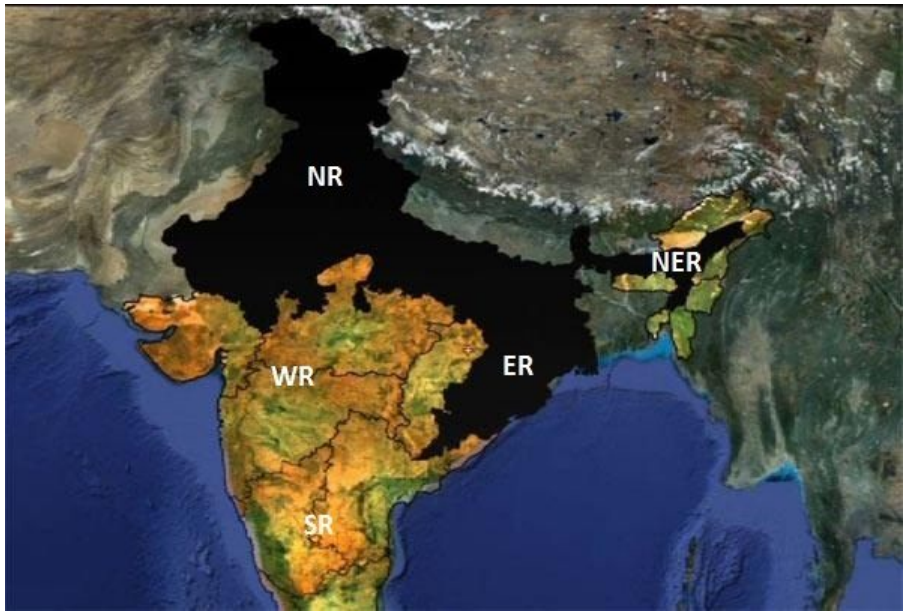

July 31, 2012 - Image curtsey: Power Grid Corporation Of India Ltd.

Vulnerability Analysis of Distance Relays using PMU Data

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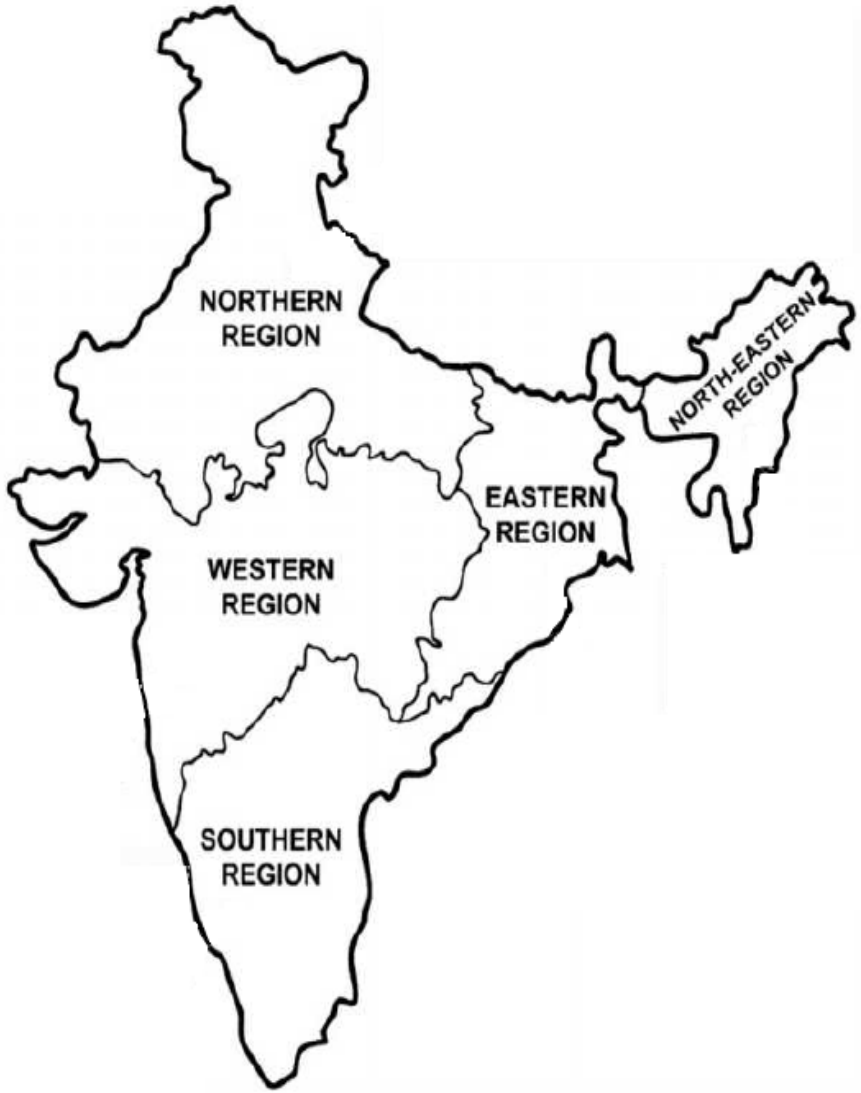
Outline

- Background
- WAMS Infrastructure in India
- Today’s Discussion

Unified Real Time Dynamic State Measu

- Power Grid of India – 50 HZ system
- PMU reporting rate is 25 Hz

  Phase-1 (Completed)
- PMUs (GE/Alstom) in Operation – ~ 1200 (1186)
  - Substations at 400kV level and above in the State & Central grids
  - All generating stations at 220kV level and above
  - HVDC terminals
  - Important inter-regional connection points
  - International connection points
- Number of PDCs - 59
- All State Load Dispatch Centers
- Regional Load Dispatch Centers, and
- National Load Dispatch Centre



- All Central Transmission Utility lines are monitored by PMUs from both ends
- Therefore, analytics includes monitoring, control and protection functions

Online Vulnerability Analysis of Distance Relays (VDAR)

- This is an online application
- Mimics distance relay operation from PMU streaming data at control center
  - Identifies relays that are vulnerable to tripping during power swings or load encroachment
  - Defines a vulnerability index and rank vulnerable relays
- Hidden failures (algorithmic defects/ incorrect settings) in distance relays are identified before they can cause any bigger damage to system
- Provides opportunity to protection engineers to investigate and improve protection system associated with vulnerable distance relays
  - Improve relay settings
  - Change to differential protection
  - Supervise and block Zone 3 selectively during stable power swings or load encroachment
  - Incorporate adaptive protection philosophy
- This analytic could have alerted system operator of impending false trip of Gwalior-Bina line which initiated the Indian grid blackout of 2012

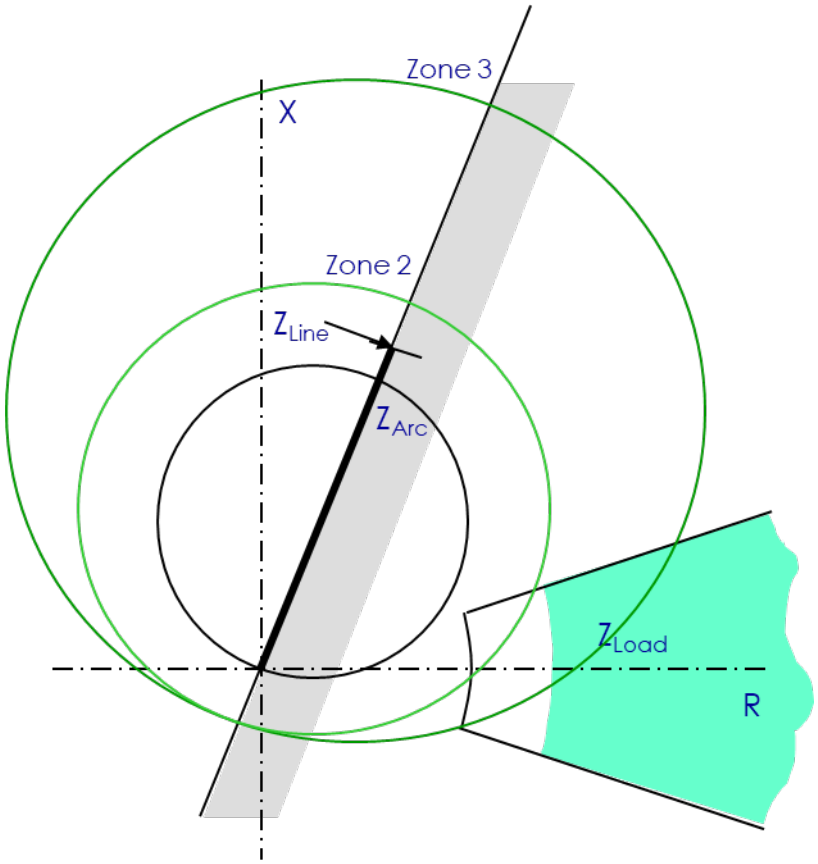
Distance Relay Security

- There is a vulnerability exposure with the impedance measurement principle that may lead to false tripping due to power swings and heavy load conditions
- Power swing is more pronounced on long lines with heavy power transfer or major tie-lines or corridors
  - Further exposure to possible hidden failure
  - Other reasons; possible incorrect set points
- Unexpected loss of such lines pose a risk to secure power system operation

It is not practical for large systems to immediately change protection solution when operating system conditions change; e.g. sudden demand on high transfer of power

Motivation

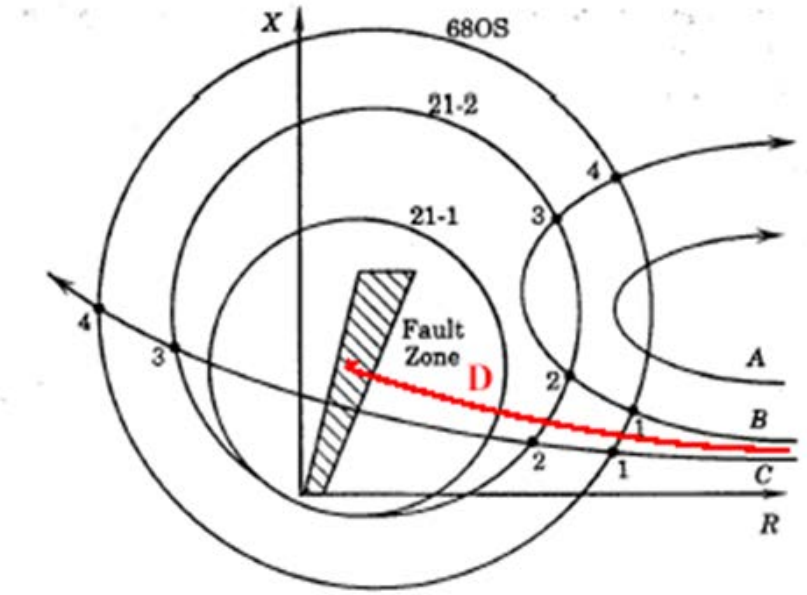
- A method to identify the vulnerable relays using PMU measurements
- Main objective: To identify relays that are exposed to false operation due to power swings or load encroachment
- Can be applied in online or offline studies



Source: V. Madani, D. Novosel, A. Apostolov, S. Corsi, Bulk Power System Dynamics Cortina d'Ampezzo, Italy 2004

Fault Conditions

- A fault is observed by several PMUs in the network
- Impedance moves in to either second or third zone for several lines
- When fault is cleared the impedance settles back outside the zones
- Fault clearance is identified by change of status of circuit breaker associated with faulted line



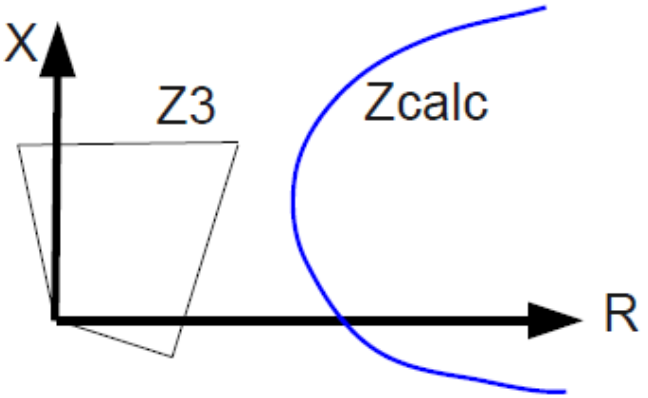
Less worrisome

Such situation is normal : Can happen few times a day in large systems due to line faults

Characteristic of Swing

- Power swing on a line is a consequence of post-fault electromechanical oscillations.
  - Stable swings - distance relays should not be allowed to trip.
  - Unstable swings - requires OST.

- Severe power swings may occur during heavy load con due to low damping.
- The apparent impedance seen by the distance relay on varies slowly and can be observed from PMU data.
- Even minimum PMU reporting rate of 10 Hz can easily power swings (as they are < 5 Hz).
- Only positive sequence voltage and current are observed during power swings.



Relay vulnerability detection logic

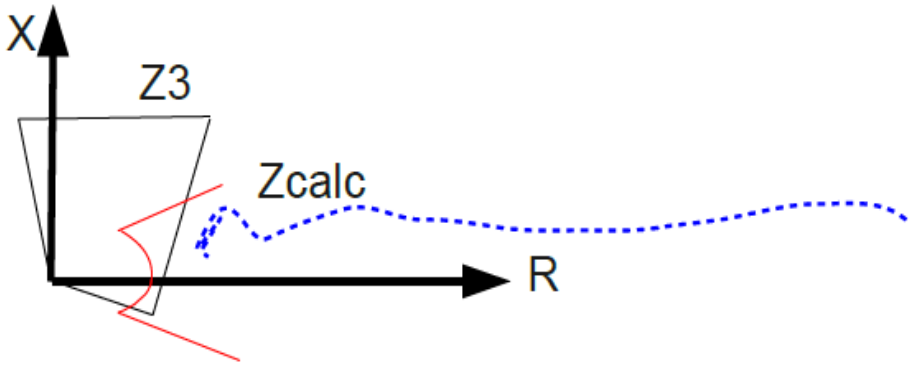
When calculated impedance comes close to the third zone or enters any zone it is flagged as a relay vulnerability event.

Characteristic of Load Encroachment

- Load encroachment occurs during heavy loading condition (including contingencies) with low voltage.
- The apparent impedance measured by PMU reduces and comes near to or enters the third zone.
  - Impedance remains at same ‘low’ value for long time i.e. in the order of a few minutes.

Detection of load encroachment event

A load encroachment event is flagged when calc



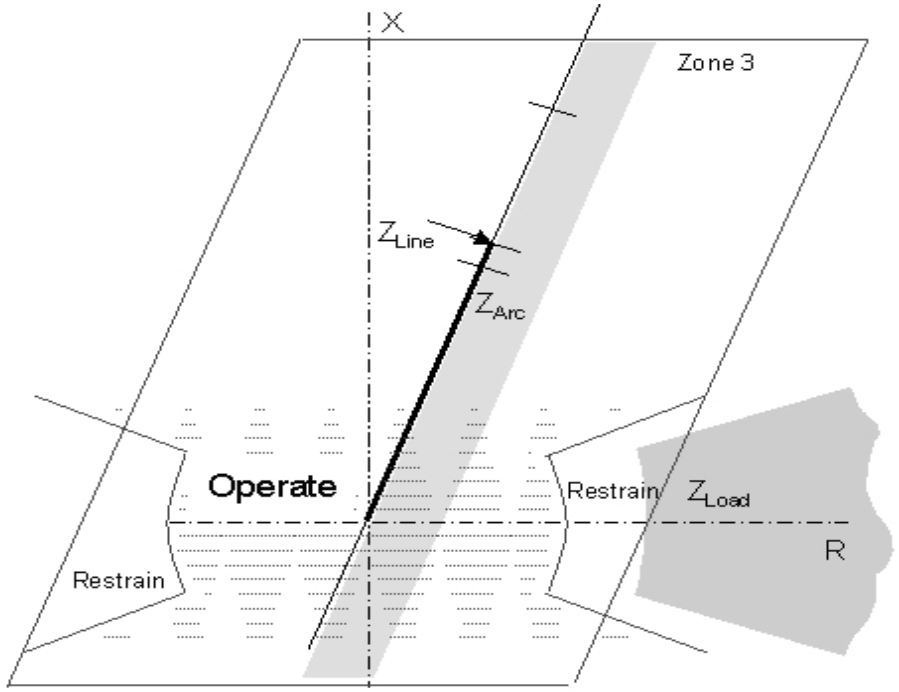
- Approached third zone or enters any zone
- Stays in zone 3 for a long time
- is predominantly resistive in nature

Impedance calculation

- The three phase voltage and current are obtained from PMUs.
- Positive sequence quantities are calculated from these three phase quantities.
- Phase impedance and positive sequence impedance are calculated.

$$Z_{ab} = \frac{(V_a - V_b)}{(I_a - I_b)}$$

$$Z_{pos} = \frac{V_{pos}}{I_{pos}}$$



Source: V. Madani, D. Novosel, A. Apostolov, S. Corsi,
Bulk Power System Dynamics Cortina d'Ampezzo, Italy 2004

- Ground fault loop is not considered separately, as our aim is different from protection relay.

Implementation

- A MonitZone is defined which envelopes Zone 3
- VADR monitoring begins when Zcalc enters MonitZone

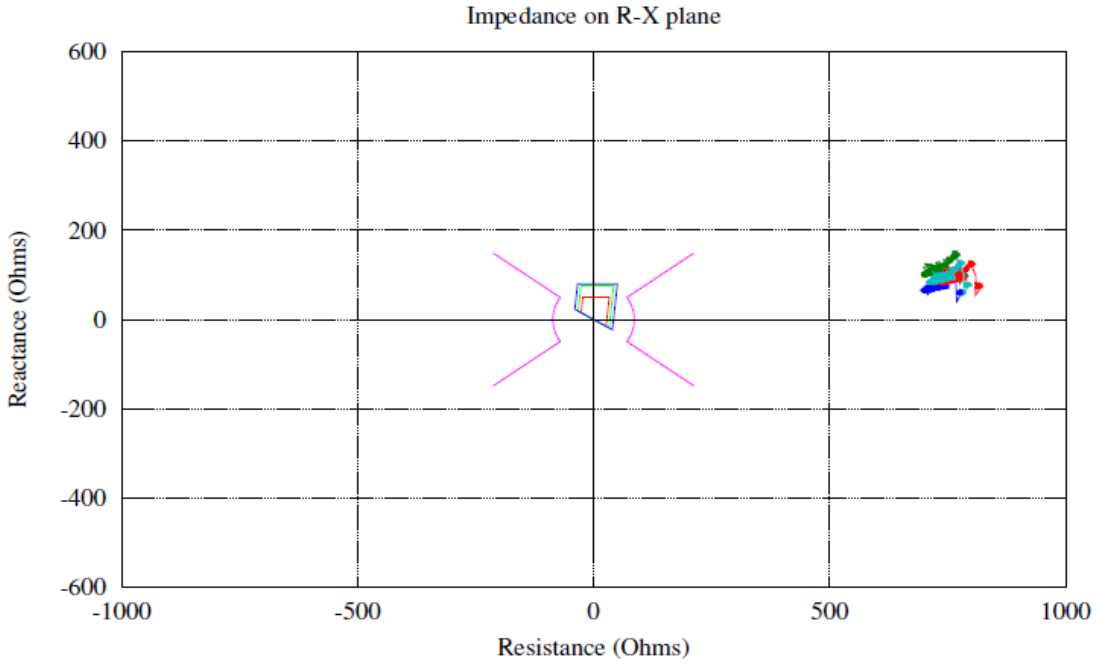
Features

- Alarm and create log when vulnerable distance relays are detected
- Ensures operator is not overburdened by frequent alarms
- Capability can be extended to detect fault conditions

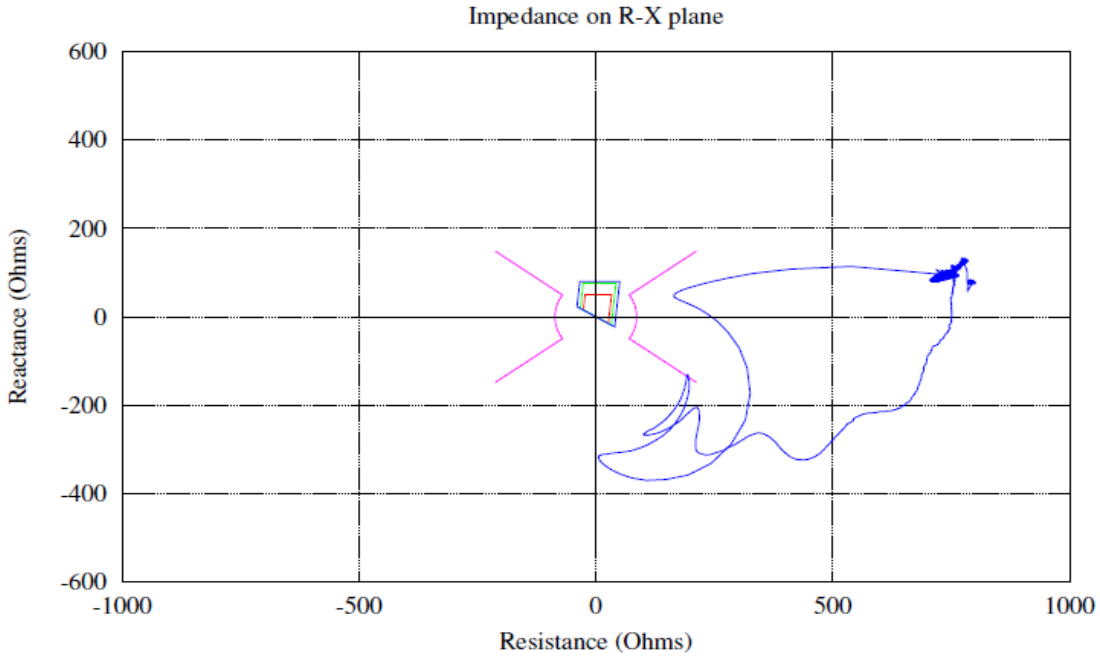
Application Notes

- Distance relays are to be emulated at control centers. Generic relay settings are adequate
- ‘Exact’ relay characteristics may not be essential
- The apparent impedance seen by a distance relay is the ratio of positive sequence line voltage to the positive sequence line current

Real Life Case Studies



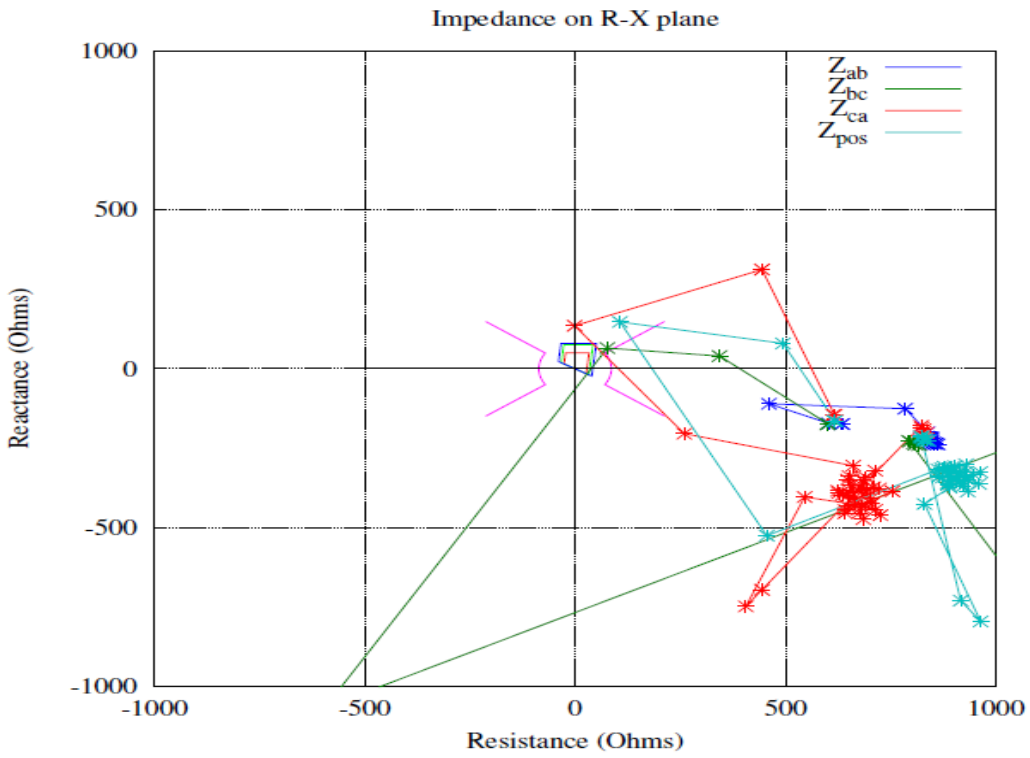
(a) Normal Load



(b) A Stable Swing - Relay Vulnerable

- Notice power swing can be clearly distinguished

Real Life Case Studies



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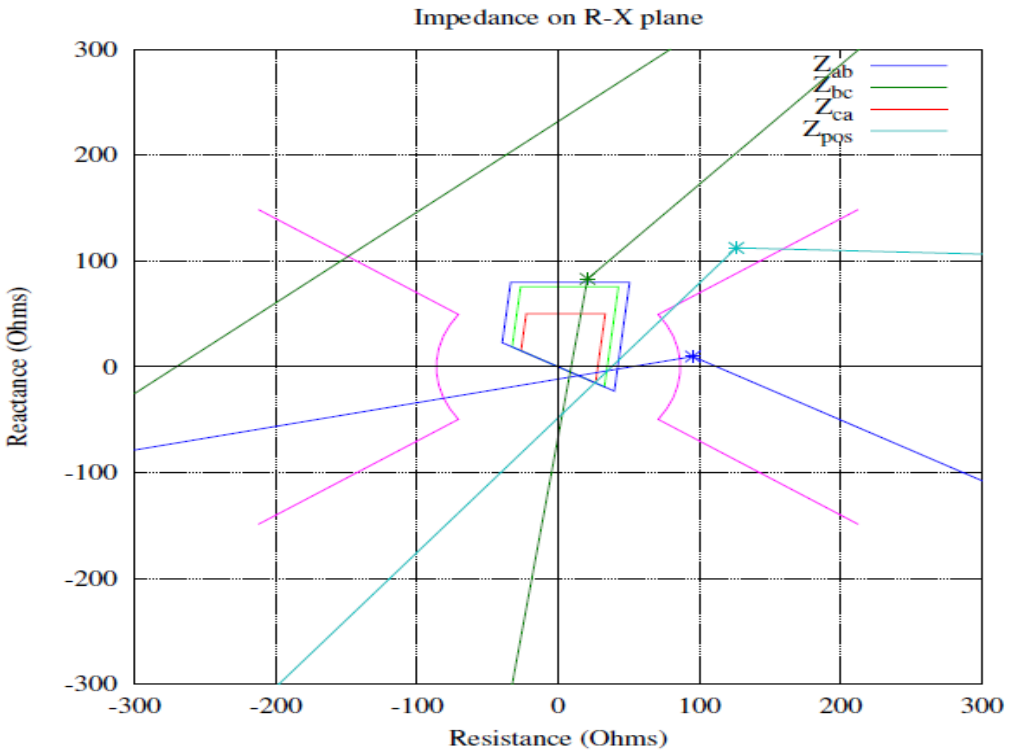
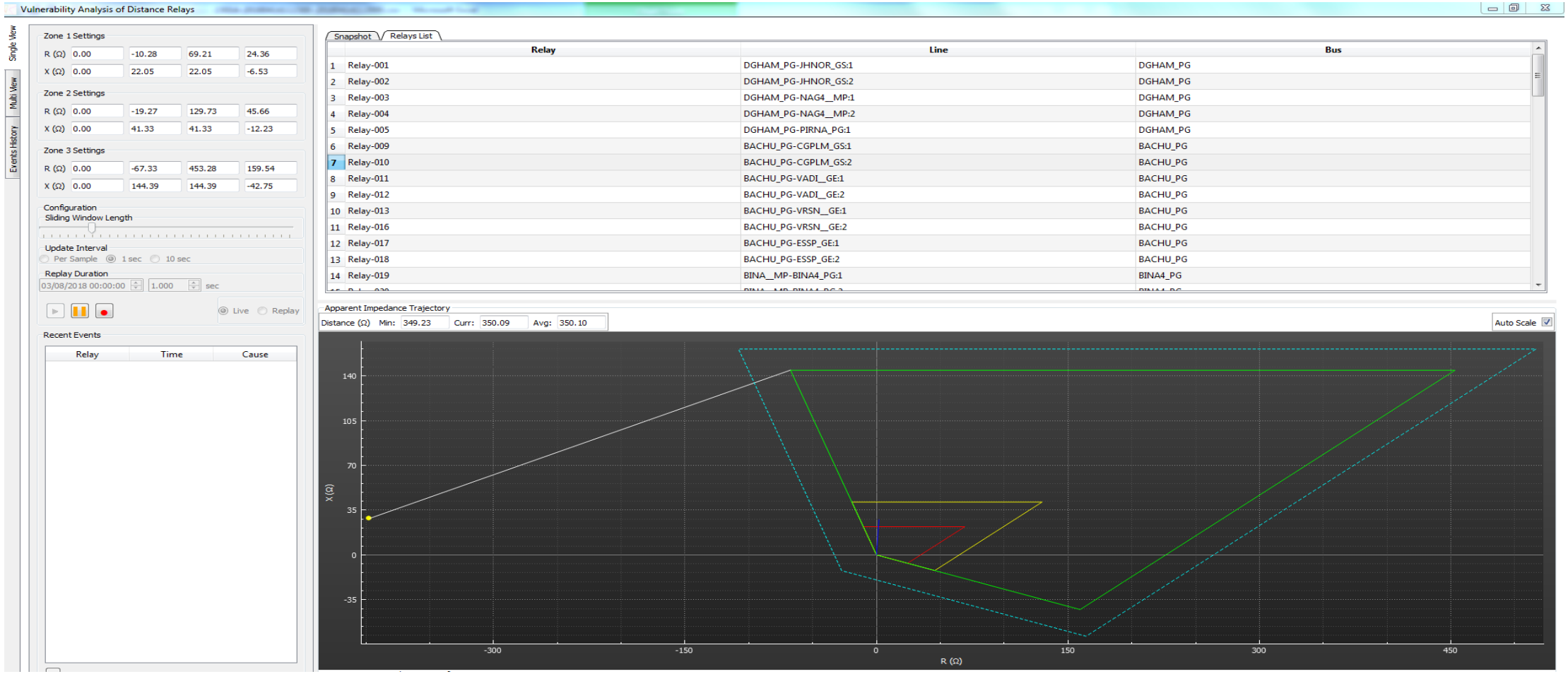


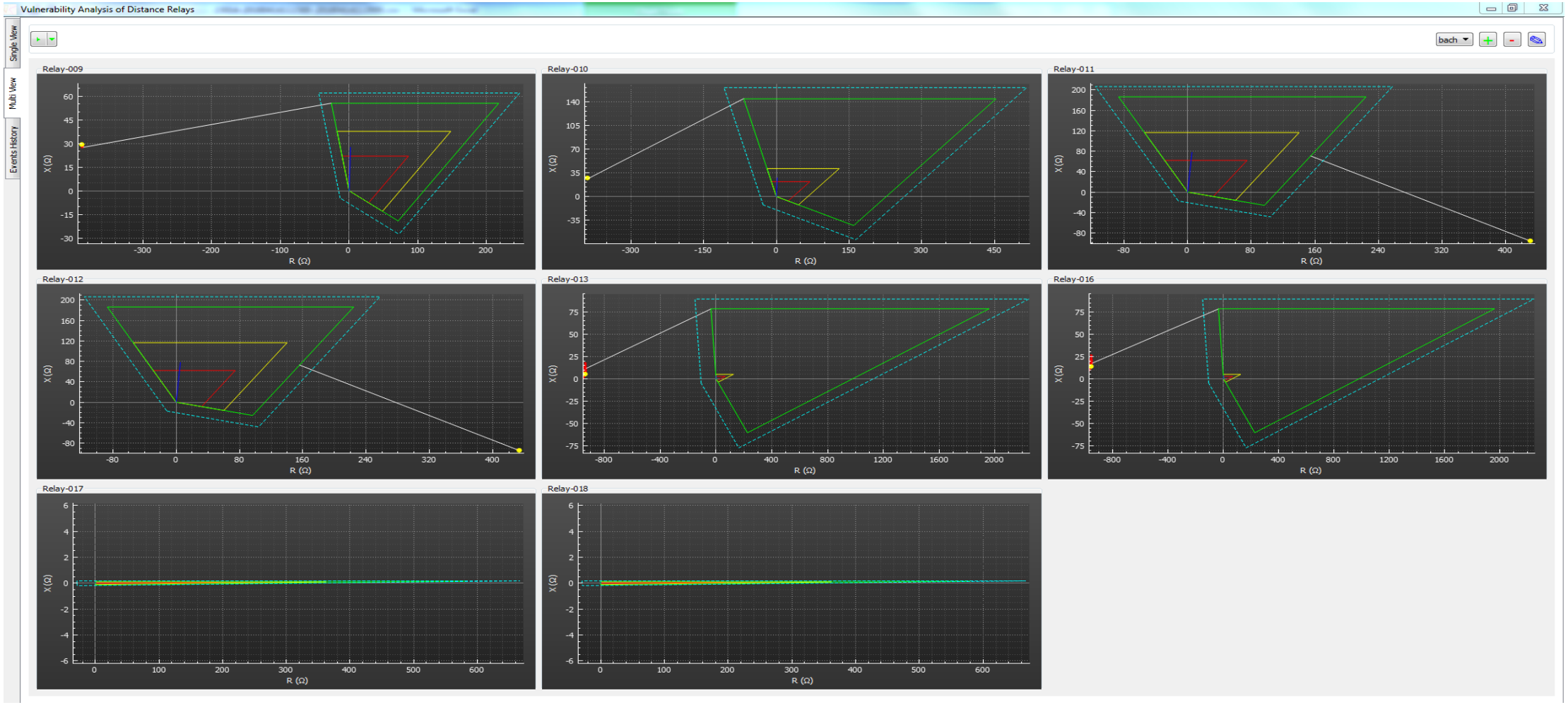
- PMUs are not intended to interfere with fast fault detection and clearing protection systems
- In this application, PMUs are not intended to monitor faults

Practical Installation - VADR operation



- Relay list is available in the panel. Facility to replay of event from historian
- Chosen relay's settings (Z1, Z2, Z3) can be seen on the screen
- Zcalc and its distance from relay boundary is also shown

Practical Installation - Multipleview



- Multiple relays visualization feature is also available
- Same event observed by different relays may be viewed simultaneously in multiple relay visualization

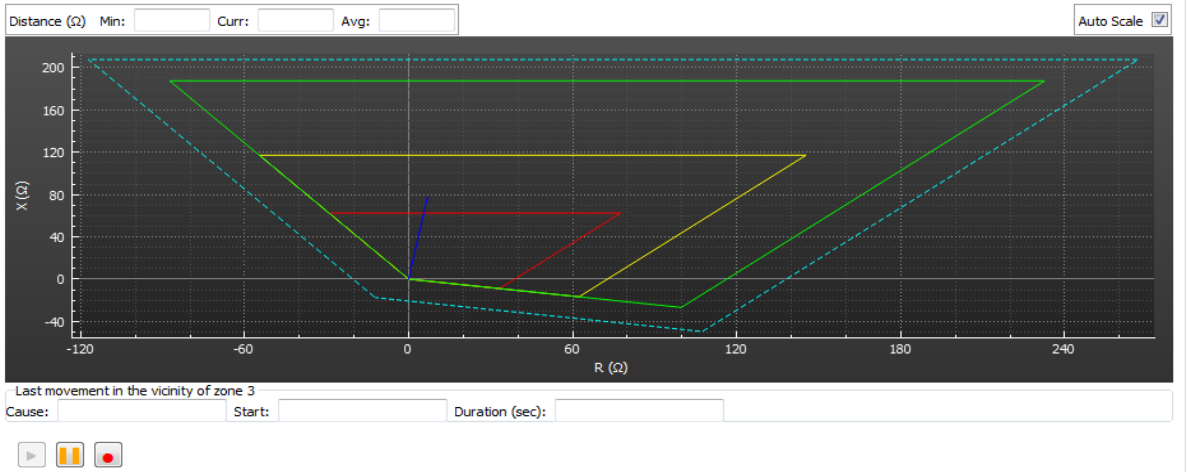
Practical Installation - VADR Log from Jan to July 2018 (Monitoring stage, corrective actions of VDAR software system installation)

Vulnerability Analysis of Distance Relays

From 01/25/2018 To 07/31/2018

Events Record

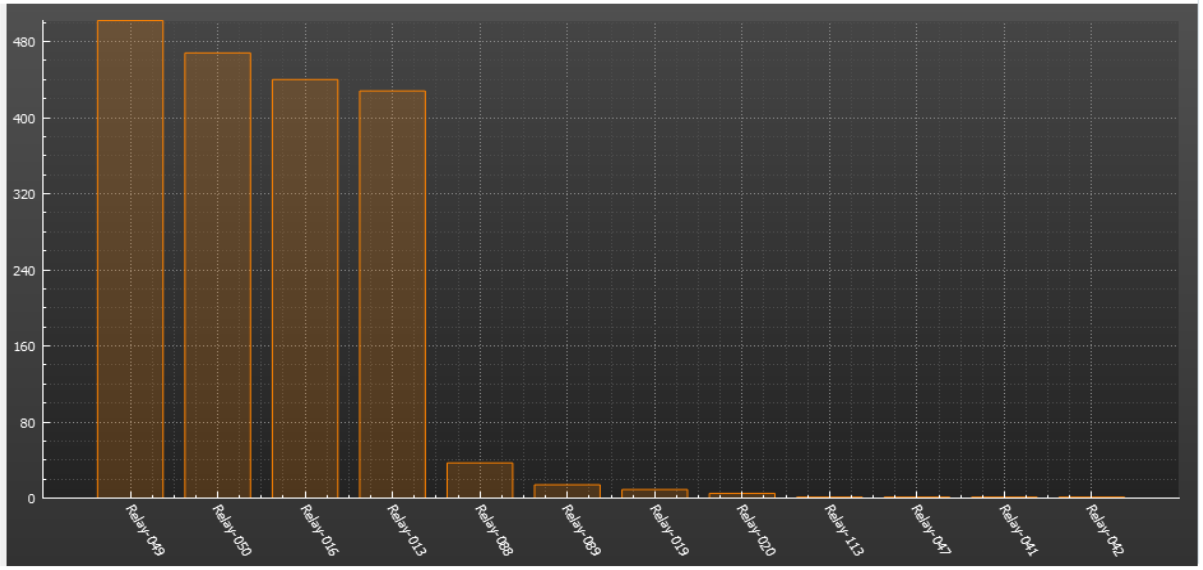
	Name	Cause	Date	Entry	Duration (sec)	Zone3
677	Relay-016	Load Encroachment	04/17/2018	08:42:07.880	162.36	Did Not Entered
678	Relay-016	Load Encroachment	04/17/2018	08:41:28.640	14	Did Not Entered
679	Relay-016	Load Encroachment	04/17/2018	08:39:51.120	0.12	Did Not Entered
680	Relay-016	Load Encroachment	04/17/2018	07:56:05.560	0.04	Did Not Entered
681	Relay-016	Load Encroachment	04/17/2018	07:54:36.040	0.4	Did Not Entered
682	Relay-016	Load Encroachment	04/17/2018	06:39:42.200	0.16	Did Not Entered
683	Relay-016	Load Encroachment	04/17/2018	06:16:54.600	10.72	Did Not Entered
684	Relay-016	Load Encroachment	04/17/2018	06:16:24.320	17.44	Did Not Entered
685	Relay-016	Load Encroachment	04/17/2018	06:16:00.960	15.92	Did Not Entered
686	Relay-016	Load Encroachment	04/17/2018	06:15:49.720	2.84	Did Not Entered
687	Relay-016	Load Encroachment	04/17/2018	05:44:42.720	1860.32	Did Not Entered
688	Relay-016	Load Encroachment	04/17/2018	05:43:59.600	36.44	Did Not Entered
689	Relay-016	Load Encroachment	04/17/2018	05:43:28.120	0.24	Did Not Entered



Events Summary

Day Wise Events | Most Vulnerable Relays

	Relay	Count
1	Relay-049	502
2	Relay-050	468
3	Relay-016	440
4	Relay-013	428
5	Relay-088	37
6	Relay-089	14
7	Relay-019	9
8	Relay-020	5
9	Relay-113	1
10	Relay-047	1
11	Relay-041	1
12	Relay-042	1

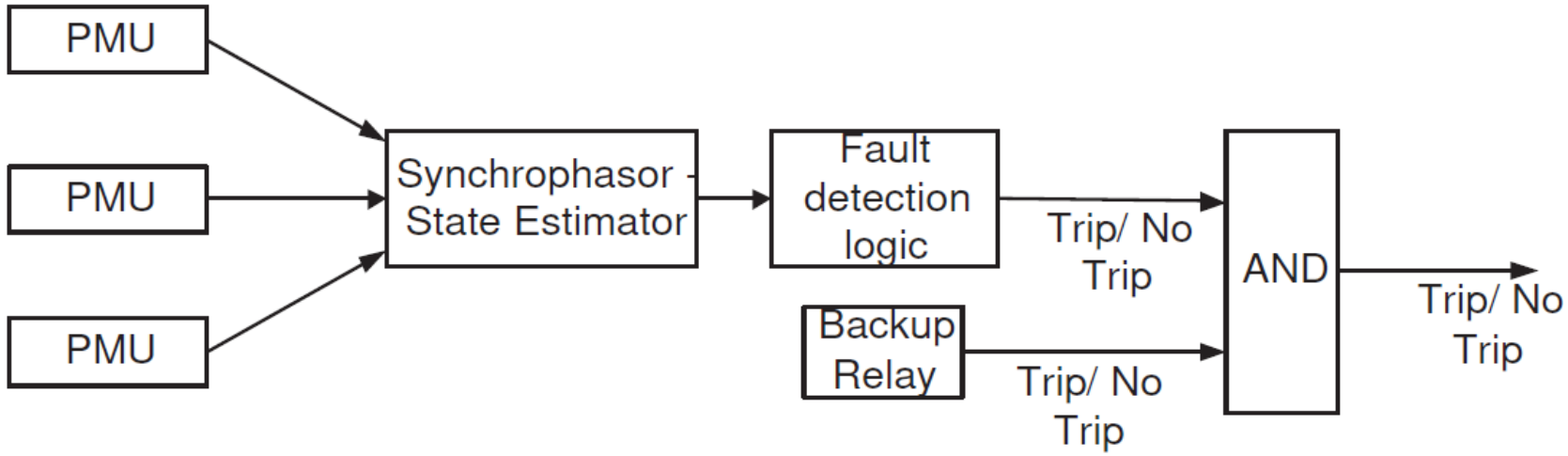


Histogram helps protection engineer decide which relays require further investigation

Supervised Zone-3 Protection

- Further actions can be planned, once some vulnerable relays are detected
- One method of supervised remote backup protection using PMU data was presented, by us, at NASPI working group meeting in June 2010
- With PMUs placed at both ends of the transmission lines, differential currents can be computed
- Once differential currents for all backed up lines are available, decision to block or not block Zone-3 of the back up relay can be taken
- The whole procedure
  - Obtaining synchrophasors from PMUs
  - Differential currents computation
  - Communicating appropriate decision to relay

  should happen well within one second.
- Prototype testing on a 400 kV line with false data injection was successfully completed. The round trip latency was observed to be around 200 ms



Thank You