Improved Protections
with
Wide Area Measurement Systems

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Lecture Outline

- Challenges and issues with modern protection
- PMUs and WAMs
- Scale of Grids and their protection systems
- Hidden Failures in Protection Systems
- Protection system improvements with WAMS
- Concluding remarks on protection system improvements

Challenges and issues with modern protection

1. Struggle between dependability and security

dependability  security

2. Protection for system under stress
3. Adaptive Relaying
4. Role of WAMS in protection

Overview of protection systems and practices

1. Equipment Protection (Primary)

Example: Lines, Transformers, Generators, Buses

Fairly straight forward: Protect against faults to avoid damage to the equipment, to get the fault off the system as quickly as possible to avoid cascading failures of the network.

Modern relays are autonomous, fast acting, and often duplicated or even triplicated to avoid failure to clear a fault.

Relay times may be as short as a cycle, and circuit breaker times may be 2-3 cycles.

These are primary protection systems.

Overview of protection systems and practices

1. Equipment Protection (Primary)

   Contest between security and dependability

   Biases

2. Equipment Protection (Back-up)

   Back-up operation is more damaging

   Of necessity it is slower

   It trips larger part of the system

   It is more difficult to set, depends too much on conditions of the network.

Overview of protection systems and practices

3. System Protection

The aim is to protect the power system from hurtful faults

Load shedding and restoration
Loss of field
Out-of-step
Islanding

It has the same performance characteristics as the Back-up systems:

Of necessity it is slower

It trips larger part of the system

It is more difficult to set, depends too much on conditions of the network.

4. Remedial Action Schemes

More complex, a start on wide area measurement based protections

Preliminary Remarks

- **Wide area measurements: PMU data**
- **High-speed protections not affected**
- **Slow speed protections – Back-up, Stability, Loss-of-field, RAS**
- **Adequate communication facilities implied: within substation, with neighboring substations, with remote substations, system-wide**

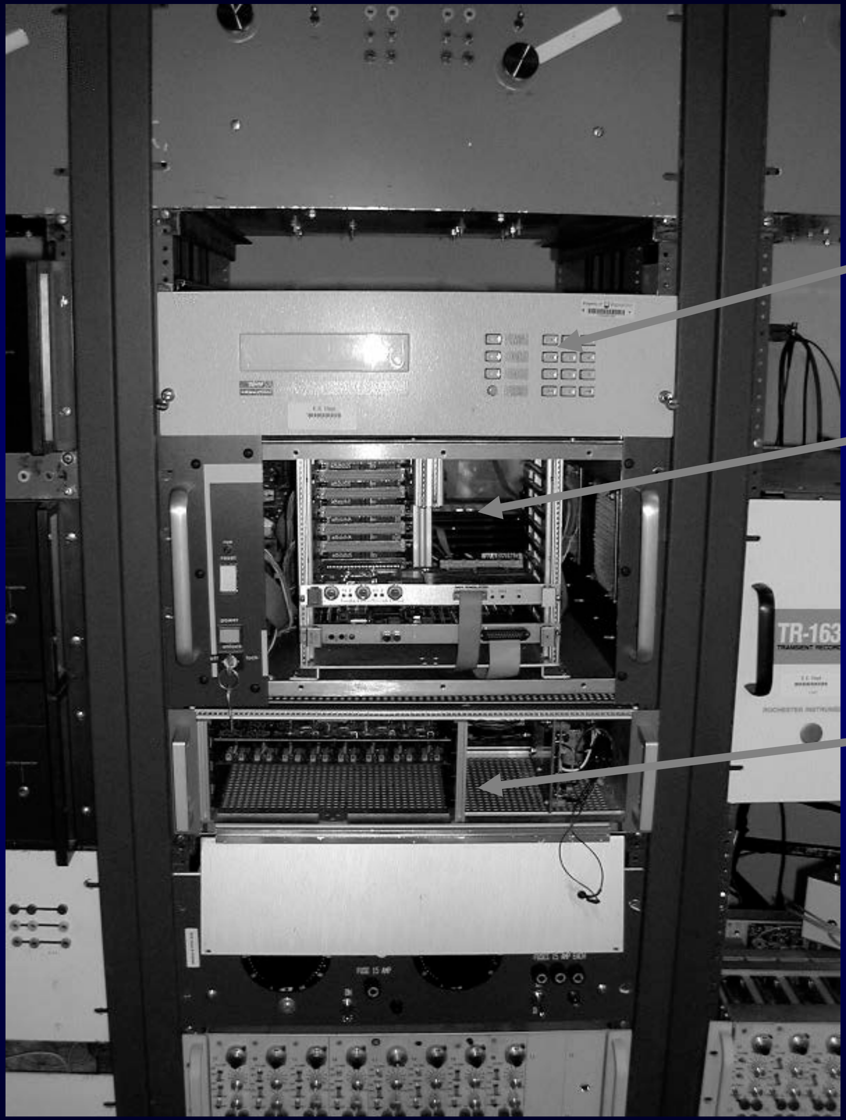
PMUs and WAMS

- **Synchronized Phasor Measurements with PMUs**
- **Elements of Wide Area Measurement Systems**
- **Communication systems**
- **Data volume and selection**

• The Birth of the PMUs

- Computer Relaying developments in 1960-70s.
- Symmetrical Component Distance Relay Development.
- Significance of positive sequence measurements.
- Importance of synchronized measurements.

- Development of first PMUs at Virginia Tech ~ 1982-1992
- Development funded by AEP, DOE, BPA, and later NYPA
- First prototype units assembled at Va Tech and installed on the BPA, AEP, NYPA systems.

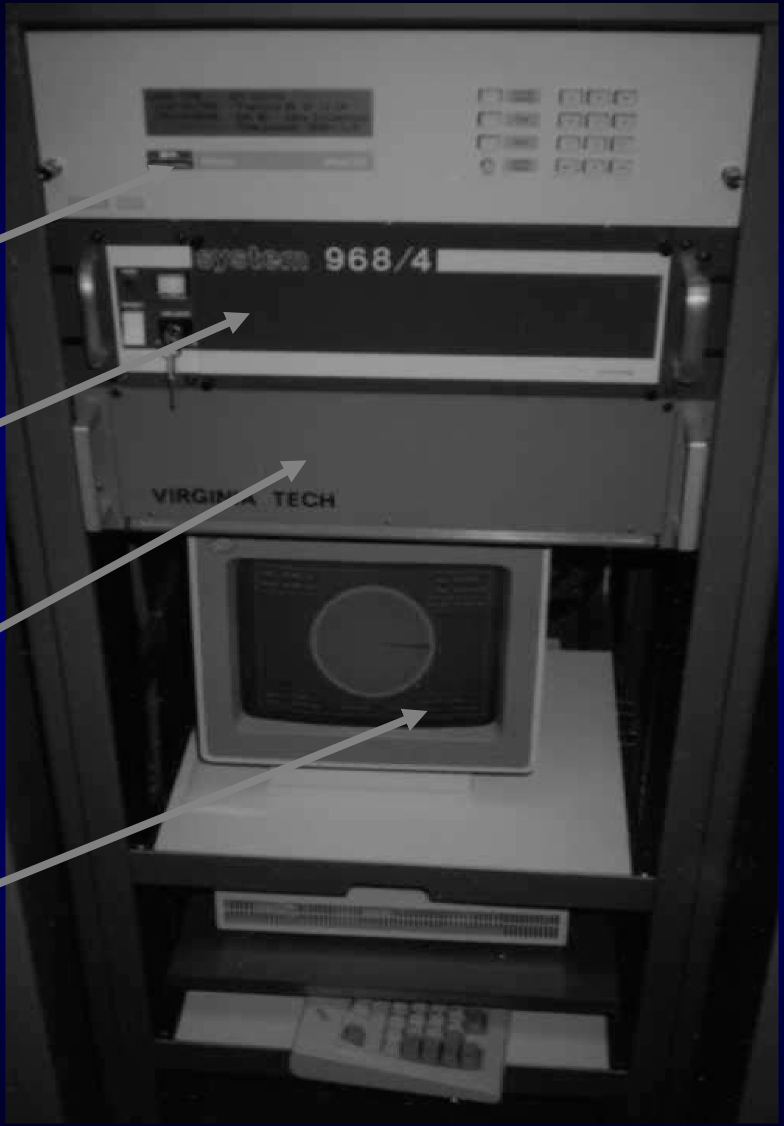


GPS receiver

PMU

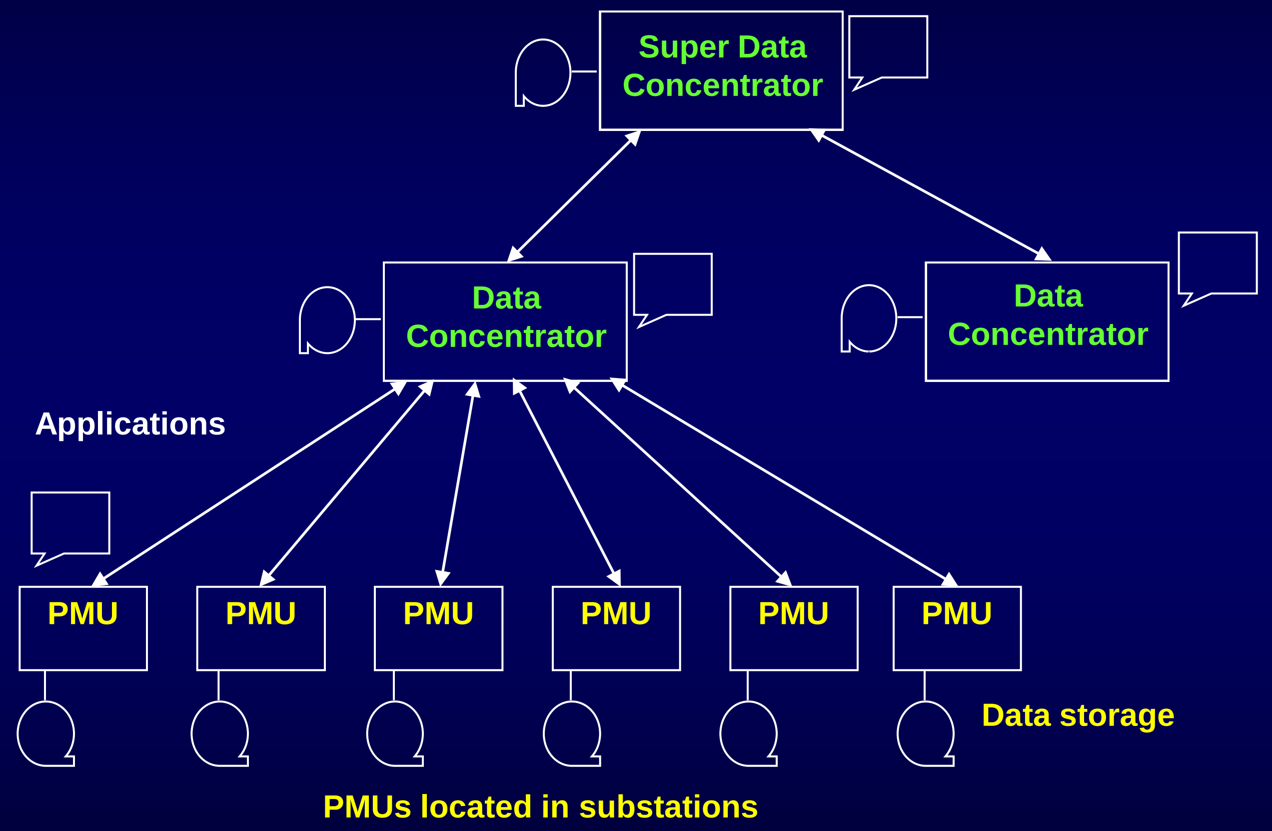
Signal conditioning unit

User Interface



PMU Test facility at Virginia Tech

WAMS



Super Data Concentrator
Data Concentrator
Data Concentrator
Applications
PMU
PMU
PMU
PMU
PMU
PMU
Data storage
PMUs located in substations

Scale of Grids and their protection systems

- **Very Large Power Grids in the world: VLPGO working group**
- **North American Power Grid**
- **Features of protection**
- **Evolution of protection systems and hardware**

NORTH AMERICAN SYSTEM AT A GLANCE:

870 GW capacity

Thermal: 71 %
Hydro: 14 %
Nuclear: 13 %

Transmission:
320,000 circuit-km

Transmission Voltages:
765, 500, 345, 138 kV

- Catastrophic failures of power systems

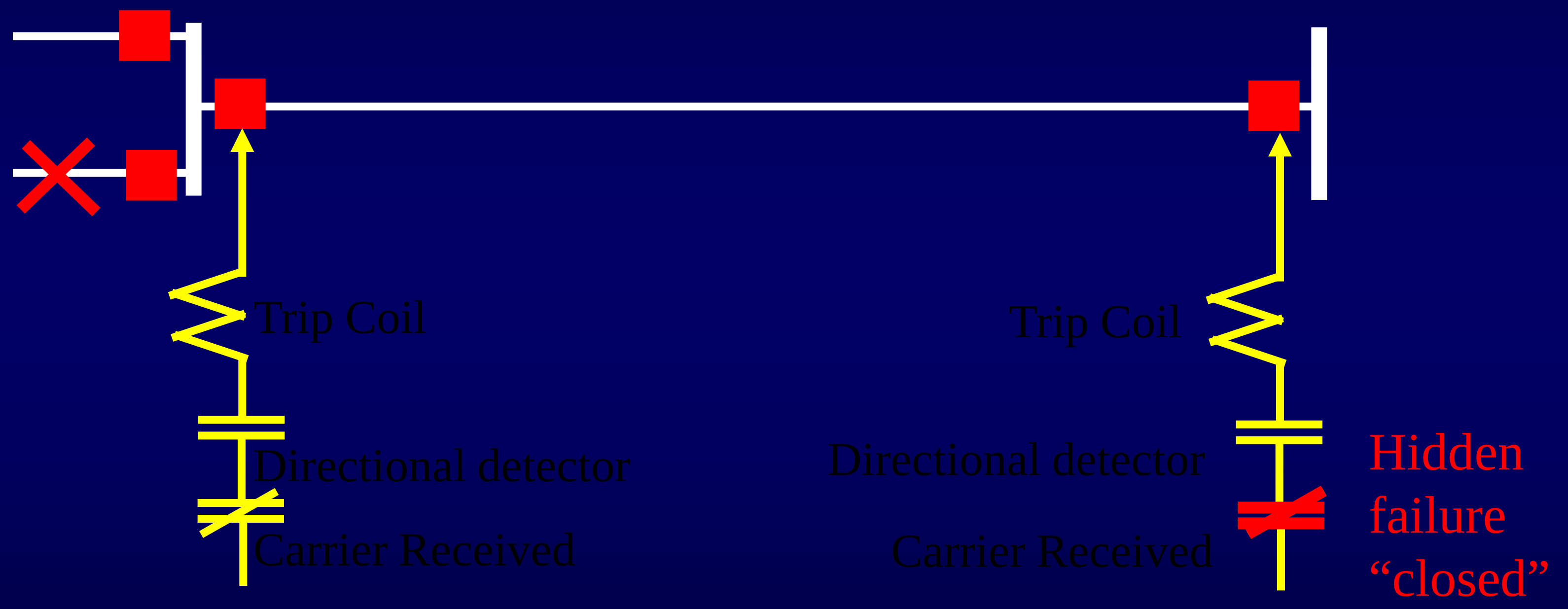
Some Statistics from NERC Reports

Report Year	Cases with Relay system Involvement
1984	71%
1985	92%
1986	83%
1987	60%
1988	64%

Hidden Failures in Protection Systems

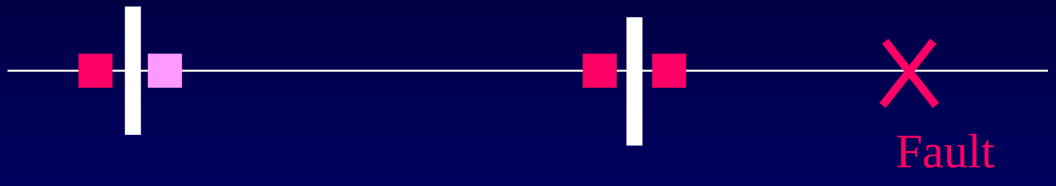
(1) Example of hidden failure

Directional Comparison Blocking Scheme

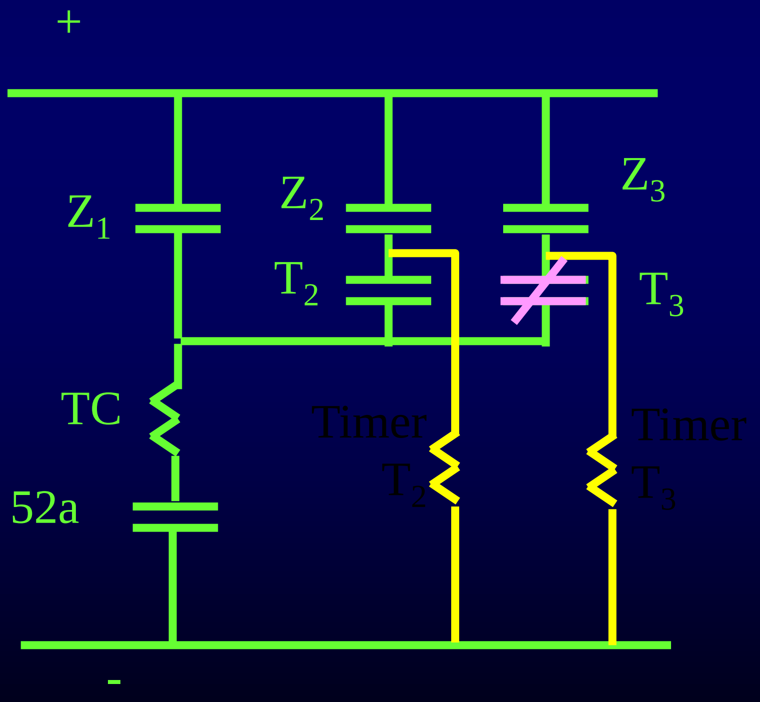


A hidden failure in the carrier circuit will trip the line whenever there is a fault in the forward direction.

(2) Back-up zone of distance relays:

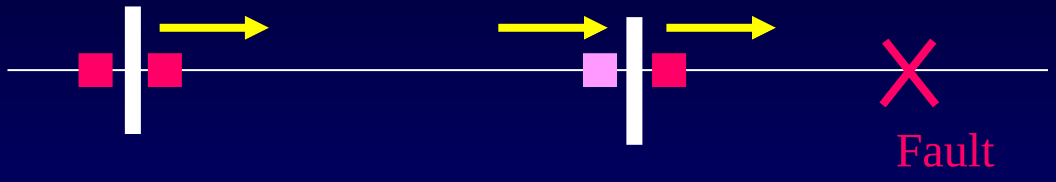


Transmission line with three zone step-distance relaying

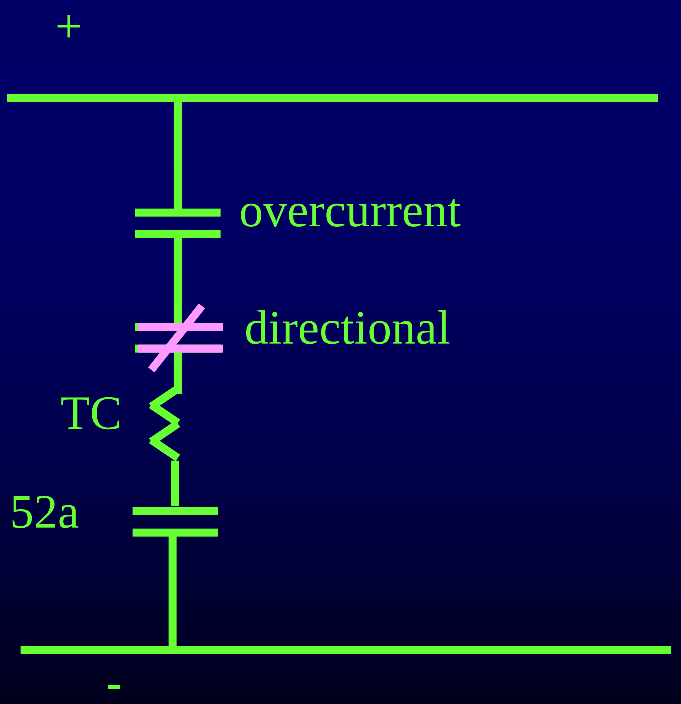


Control Circuit

(3) Directional overcurrent relay:



Transmission line with directional overcurrent relaying



Control Circuit

• Definition

Hidden failure of a protection system is a defect that will cause a relay or a relay system to incorrectly and inappropriately remove circuit elements as a consequence of another switching event such as a fault.

For example, a fault on the power system may lead to a fault detector to pick up in several relays, and thus armed, a relay could have a failed subsystem of a nature which would lead to a second undesirable operation, starting the system on the way to a cascading failure.

Note that a hidden failure in one of the subsystems does not immediately lead to an operation, but which gets ARMED when another fault occurs on the system.

A hidden failure does not imply a bad relay design, a misapplied relay, or an error in calibration. As explained earlier, these factors should be unlikely or should be discovered in normal engineering reviews. A hidden failure occurs as a random event, and by definition is undetected by normal alarms or monitoring.

- Protection system improvements with WAMS

- <u>**Moving towards fewer and less intense blackouts**</u>

Protection system performance issues

(1) Inappropriate settings for prevailing conditions

(2) Hidden failures in protection systems

(3) Security-Dependability balance

Topics for WAMS based protection

(1) Adjusting balance of security-dependability

Balance to be shifted when the power system is in emergency state as determined from wide area measurements.

(2) Alarming for relay characteristic penetration

Wide area measurements to determine trajectories and trends of relaying parameters.

(3) Adaptive out-of-step relaying

Wide area measurements to determine trajectories and predict outcome of stability swings in real-time.

Topics for WAMS based protection

Other possibilities:

(4) Supervision of back-up zones

(5) Intelligent load shedding using load-generation imbalance estimate in real time

(6) Adaptive loss-of-field relay

(7) System-wide integration of Remedial Action Schemes (RAS or SIPS)

(1) Adjusting balance of security-dependability

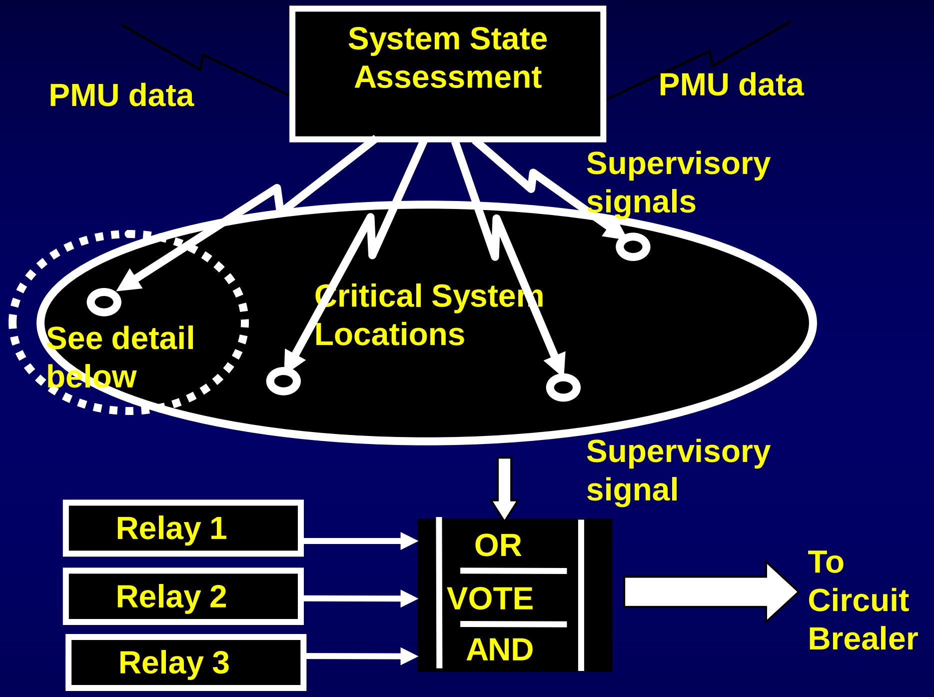
(Dealing with Hidden Failures)

Protection system bias:

High dependability

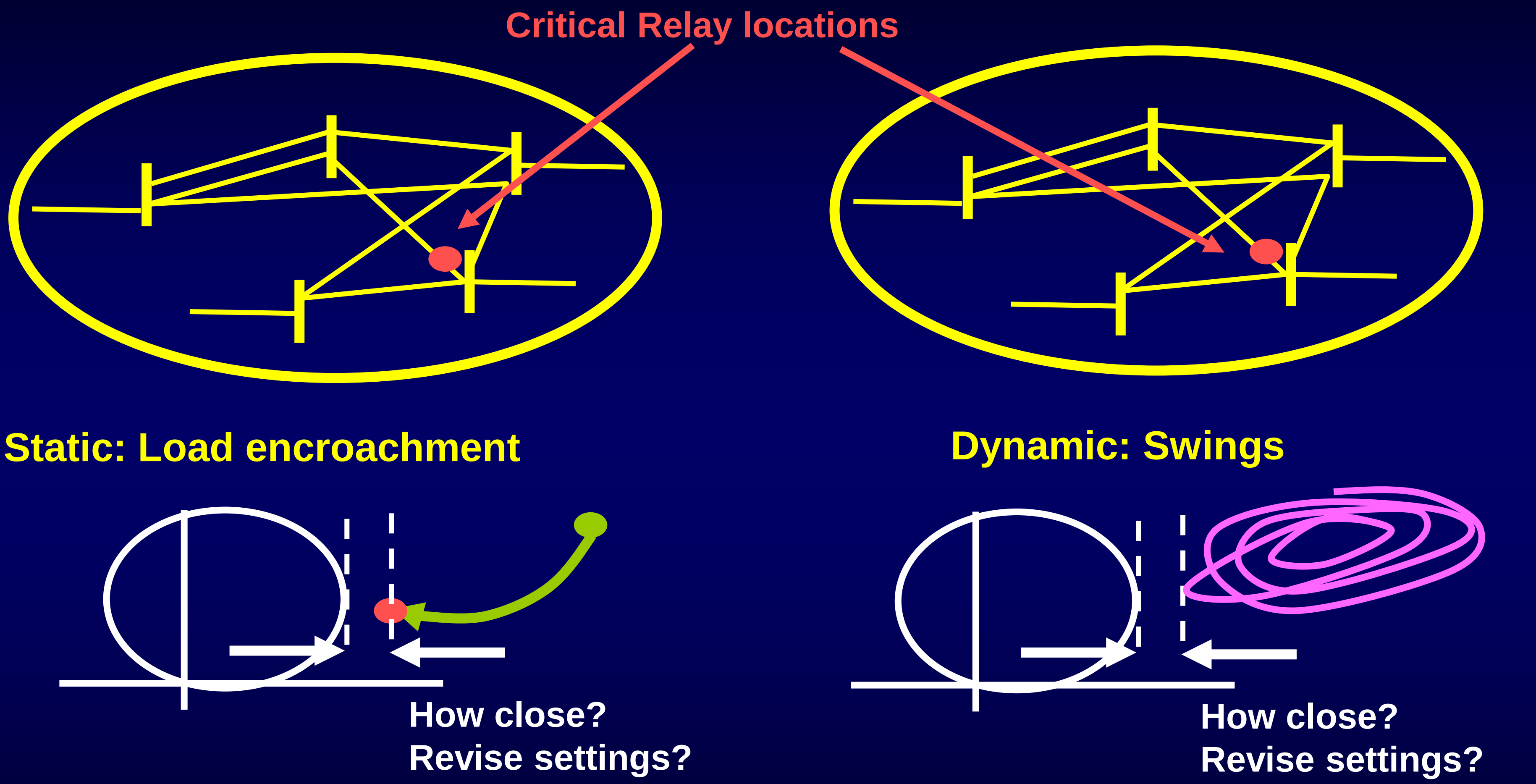
Corresponding

best possible security



Adjustment of Dependability-Security balance under stressed system conditions.

(2) Alarming for relay characteristic penetration

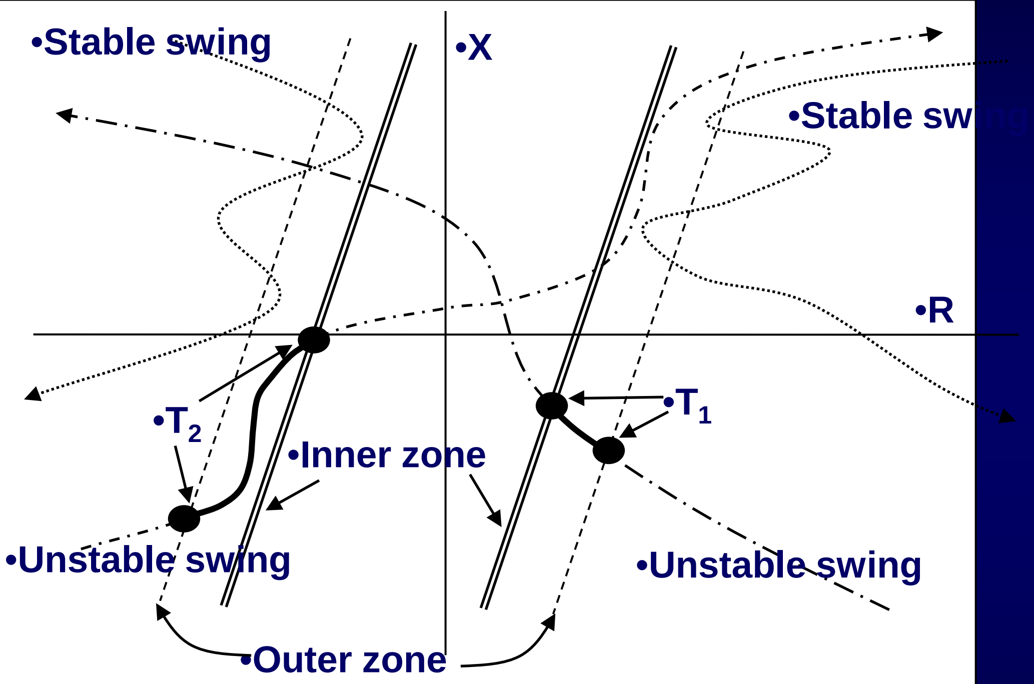


(3) Adaptive Out-of-Step Relays

Inadequacies in present systems

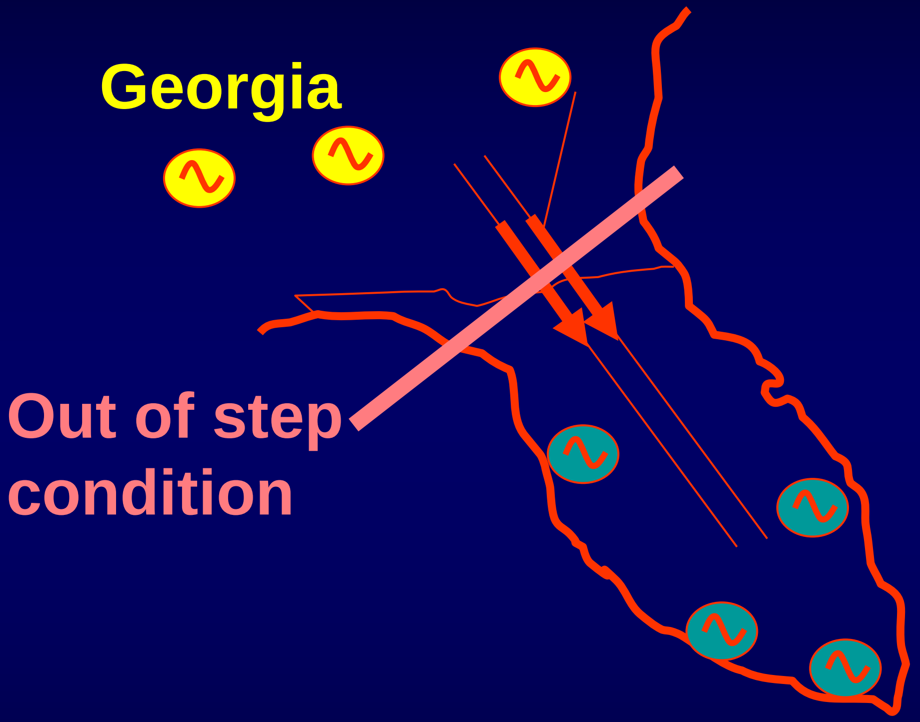
Impedance relays and timers are used to detect and protect against unstable oscillations

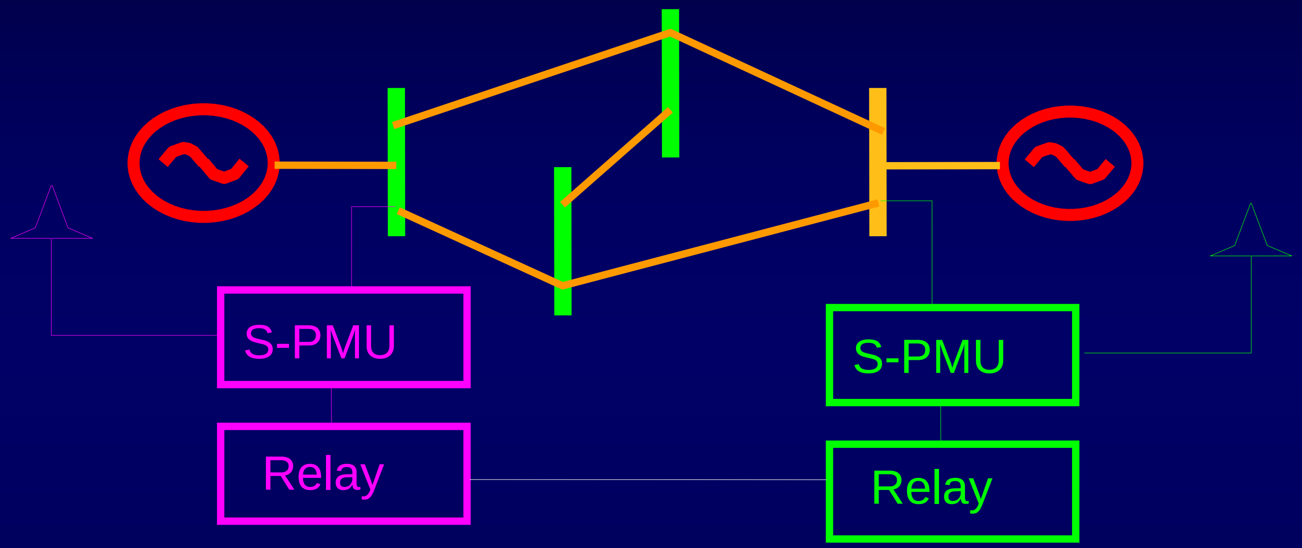
Setting are determined from results of a large number of simulations under different conditions



Traditional out-of-step relay parameters using reactance type relays and timers.

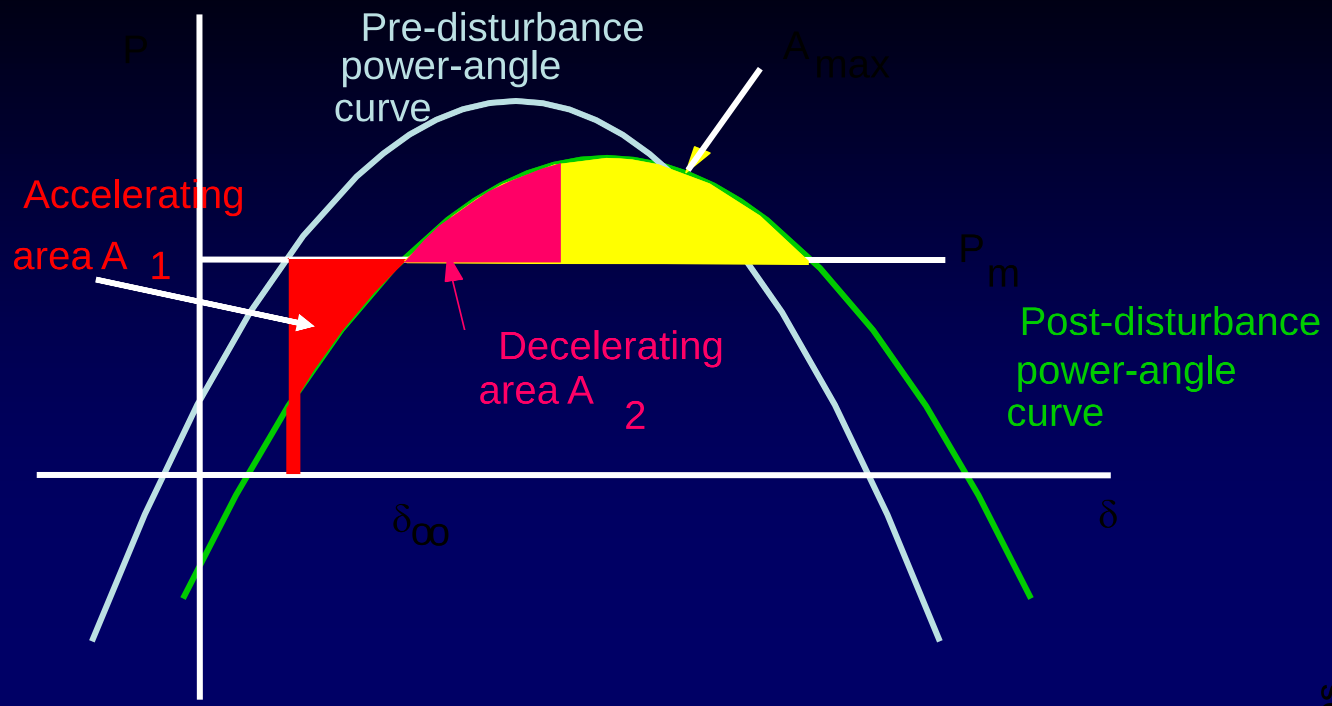
System behaving as a 2-machine system



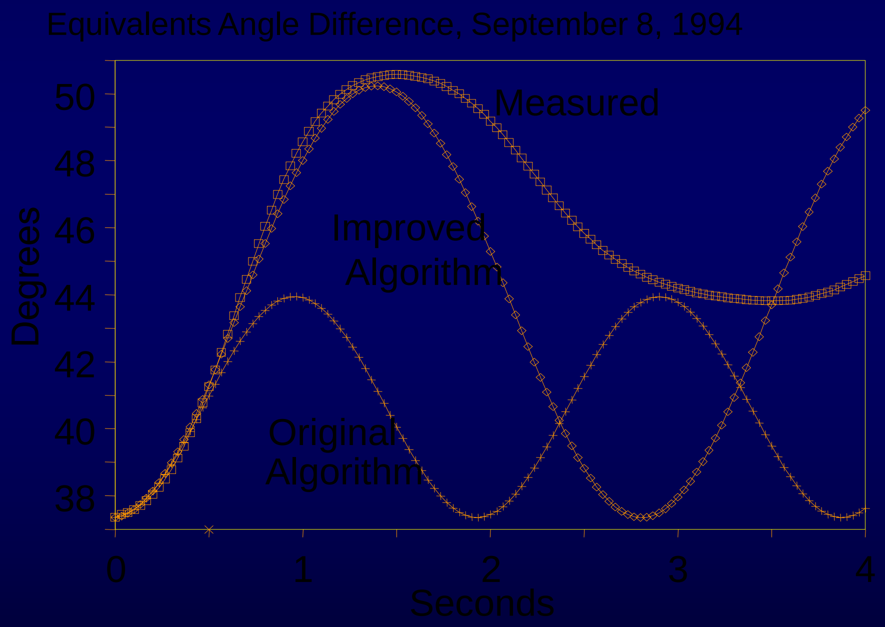


1993-1994

Equal Area Criterion



Swing Prediction for Florida-Georgia Interconnection



Out-of-step relaying for complex networks

(1) Identify critical PMU placement sites

(2) Real-time coherency determination

(3-a) Two machine equivalent

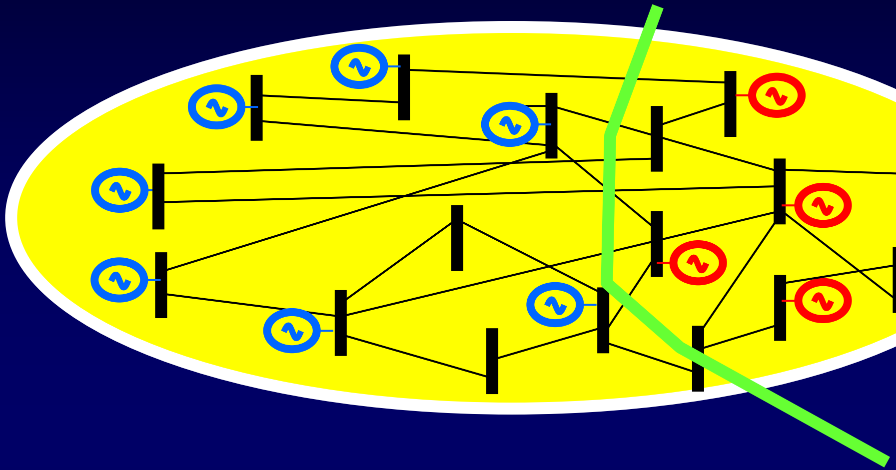
(4-a) Extended Equal Area Criterion application

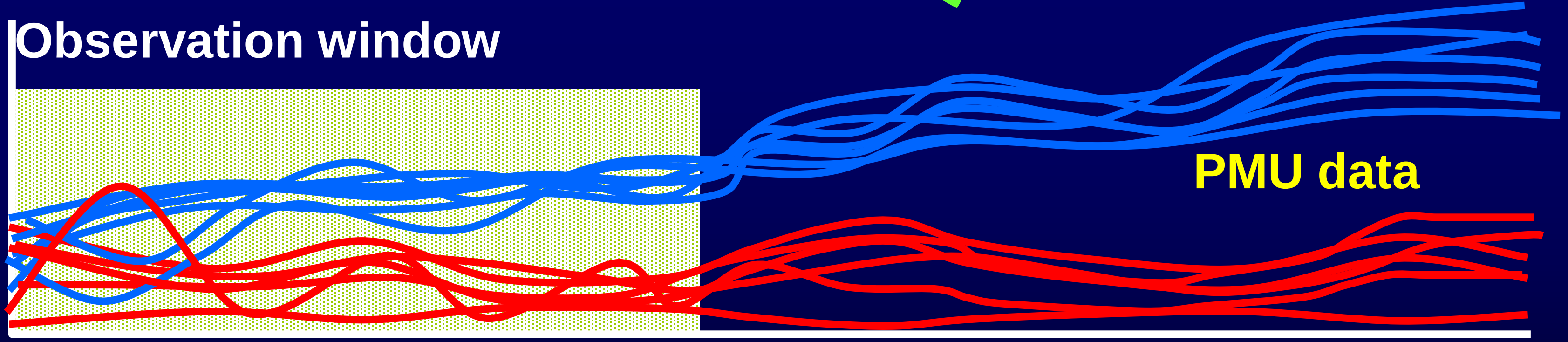
(3-b) Two machine equivalent

(4-b) Time-series of swing curves and prediction

Out-of-step relaying for complex networks

(2) Real-time coherency determination

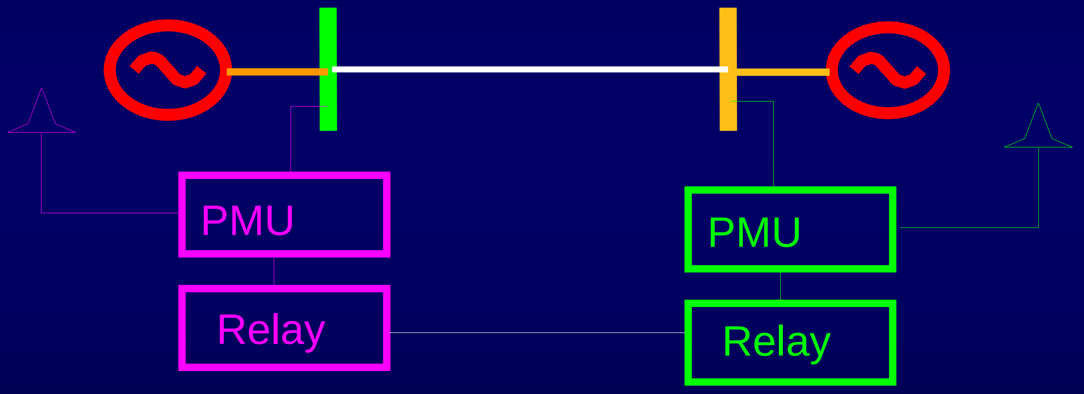


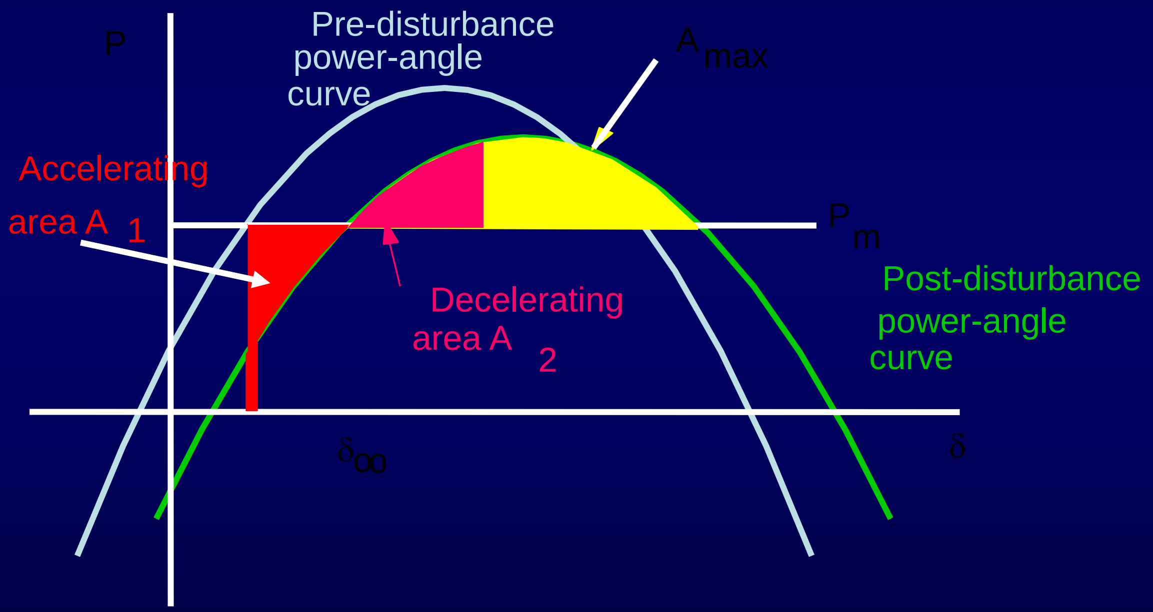


Out-of-step relaying for complex networks

(3-a) Two machine equivalent

(4-a) Extended Equal Area Criterion application

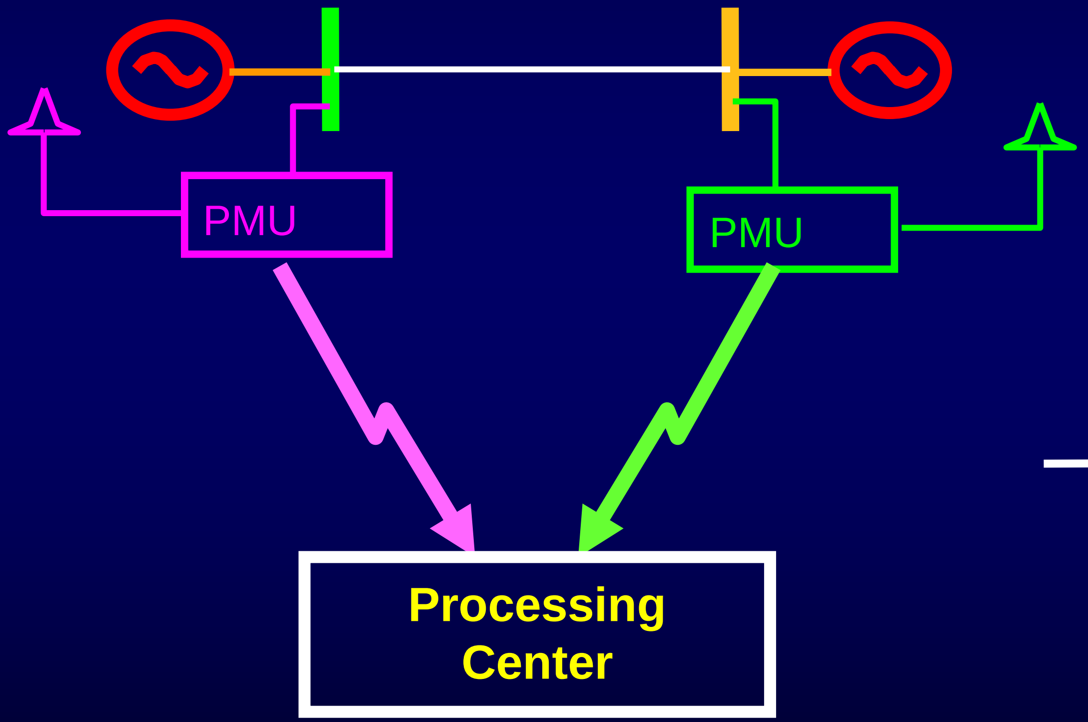


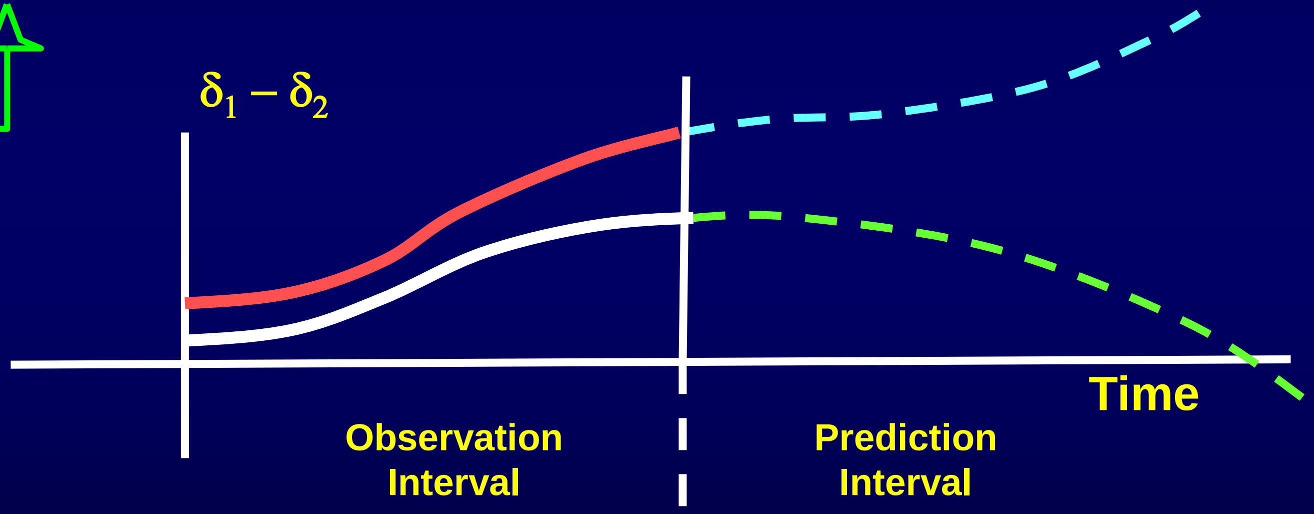


Out-of-step relaying for complex networks

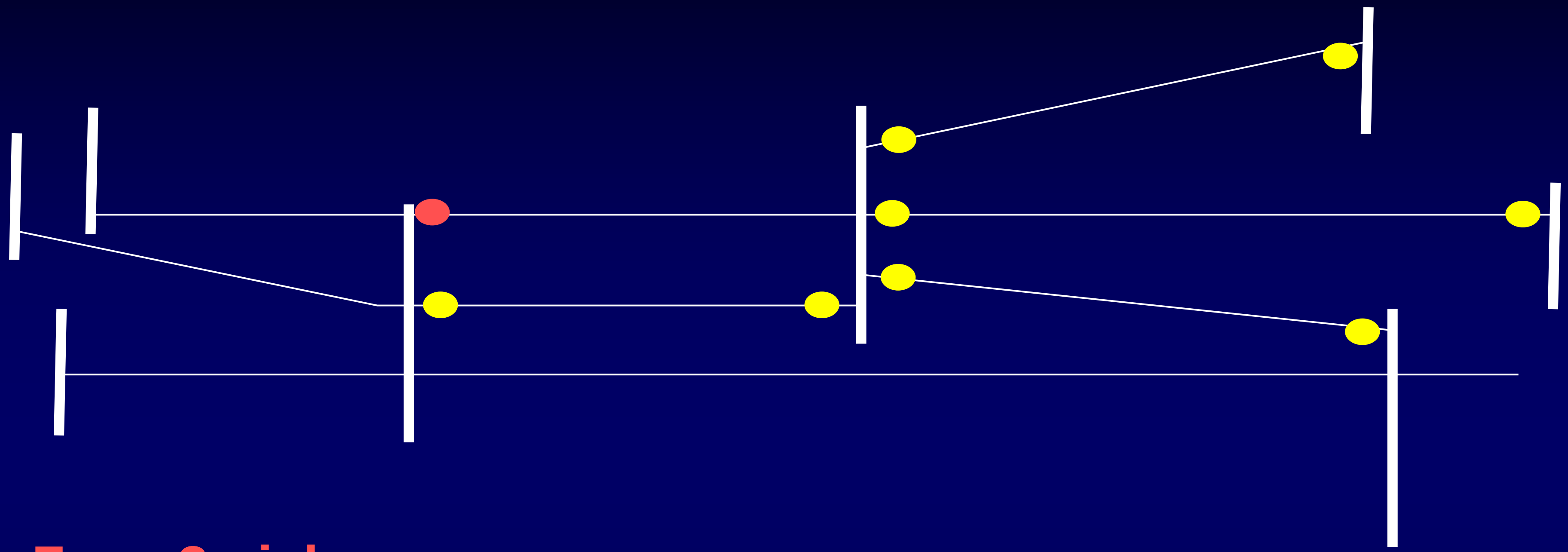
(3-b) Two machine equivalent

(4-b) Time-series of swing curves
and prediction





(4) Supervision of back-up zones

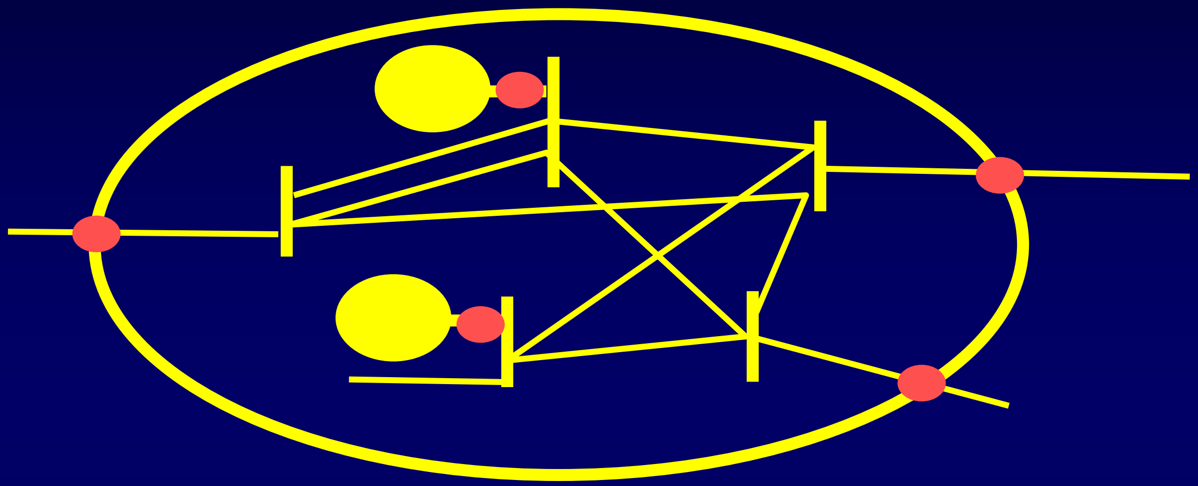


Zone 3 picks-up

Balanced Conditions?
Any Zone-1 picked up?

} Yes.
If not Block Zone-3

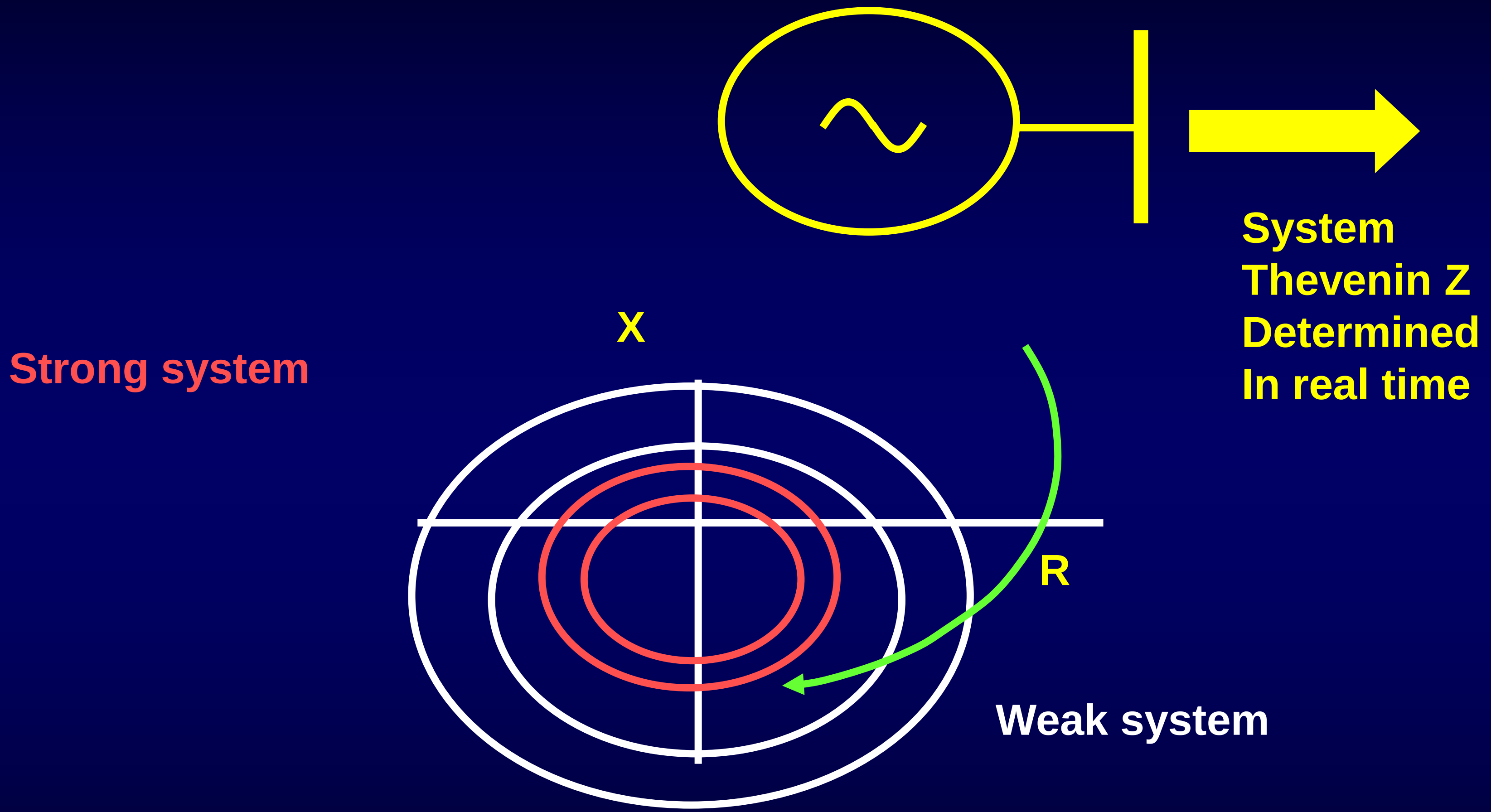
(5) Intelligent load shedding using load-generation imbalance estimate in real time



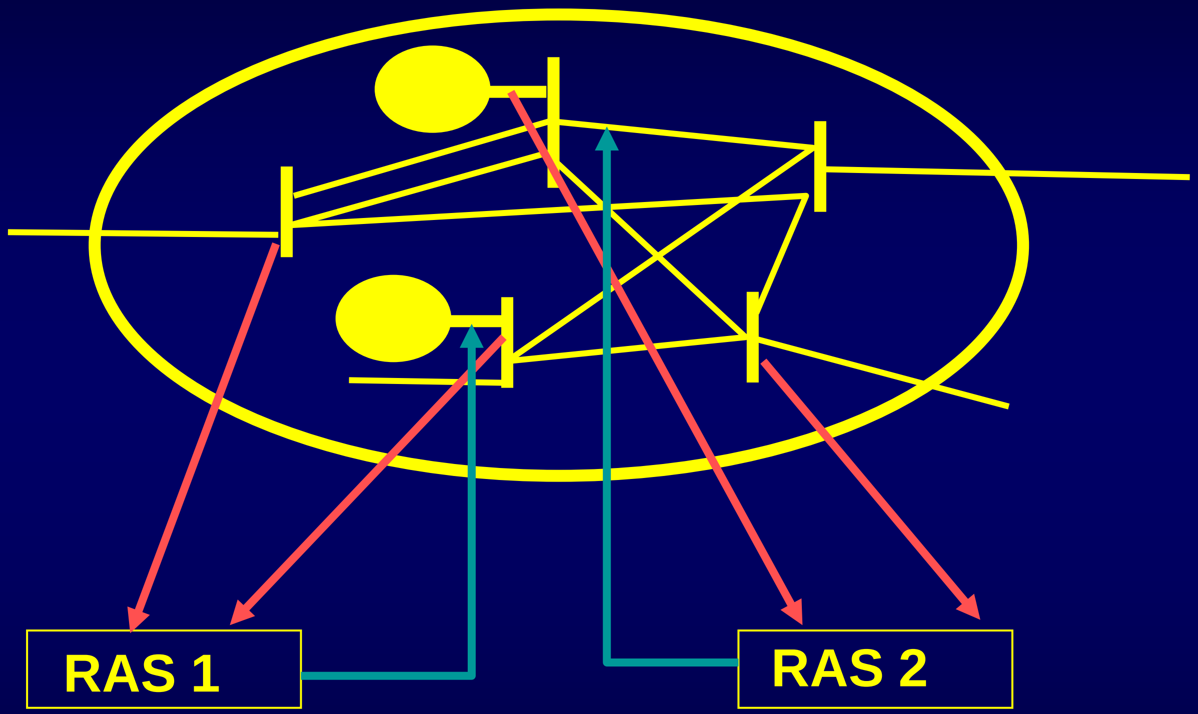
$$ACE = \Delta T - B\Delta F$$

Dynamic ACE measures
Load needed to be shed
To return to pre-disturbance state

(6) Adaptive loss-of-field relay



(7) System-wide integration of Remedial Action Schemes (RAS or SIPS)



Are RAS 1 and RAS 2
In conflict with each
other?

Make one RAS which
Will combine the
Objectives of the two
RAS schemes and
Create a unified
response.

Concluding remarks on protection system improvements

- Protection systems can be improved with the help of wide-area measurements
- Only slow-responding protections are appropriate candidates for such improvements
- Many improvements occur as steps to improve response to next contingencies, and are not intended to operate when a fault has occurred.

With careful implementation, frequency and intensity of blackouts can be reduced, and service restoration can be more rapid.