Lecture on

Protection of Large Interconnected Power Systems

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Organization of the talk

- Introduction
- Recent Trends
- Special Protection Schemes
- Controlled System Separation and Load Shedding
- Simulation tools

Introduction

Reliability of a power system operation

Reliable:
Equipment used in the system are in operation and perform the function for which they are designed for

Reliability Index:
Performance index measured in terms of customer load affected in a year or particular duration

Introduction

Methods to enhance system reliability

Duplicate everything

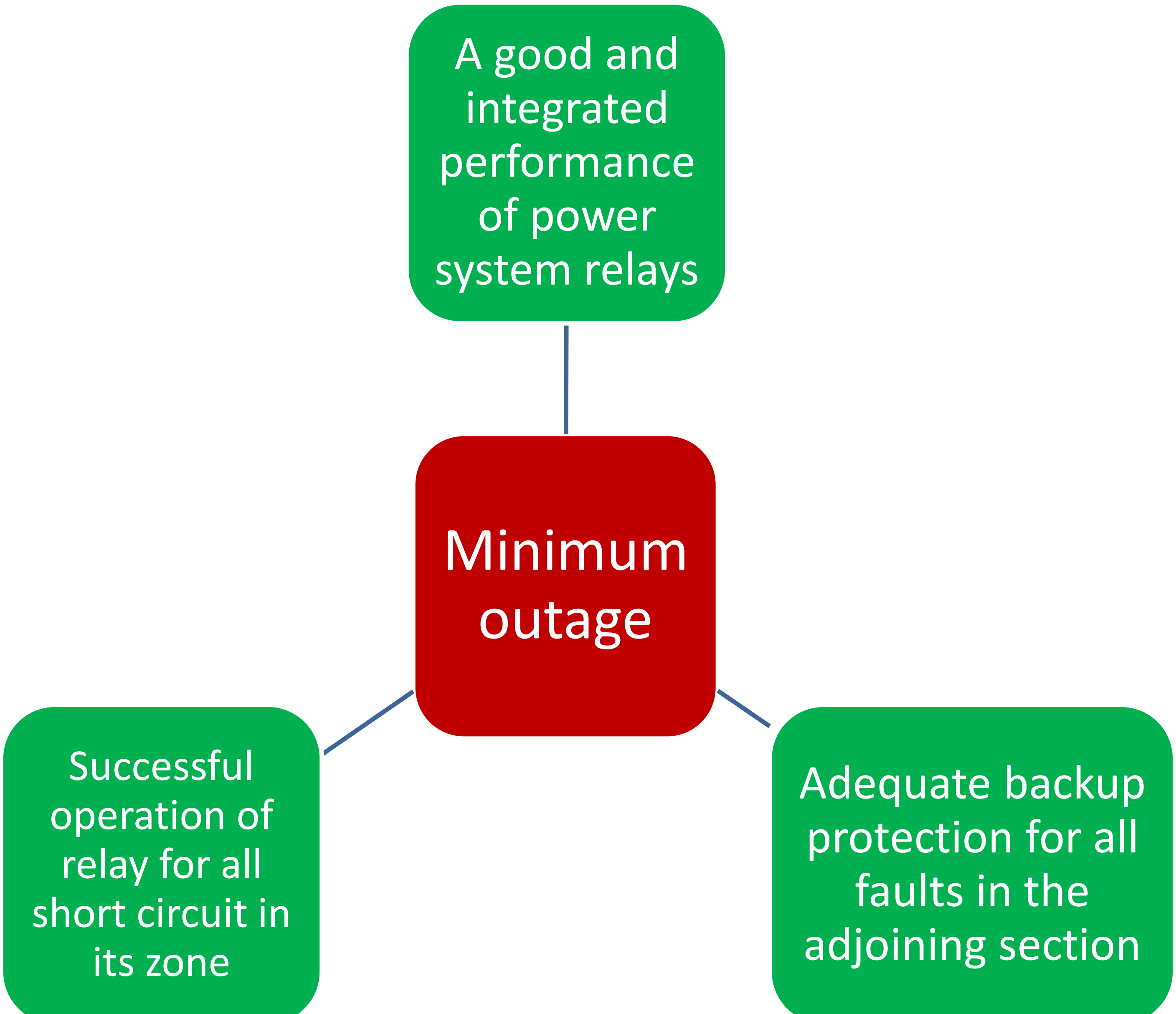
- n-1, n-2 in design
- Parallel feed
- Loading limit on transformers

Economics ?

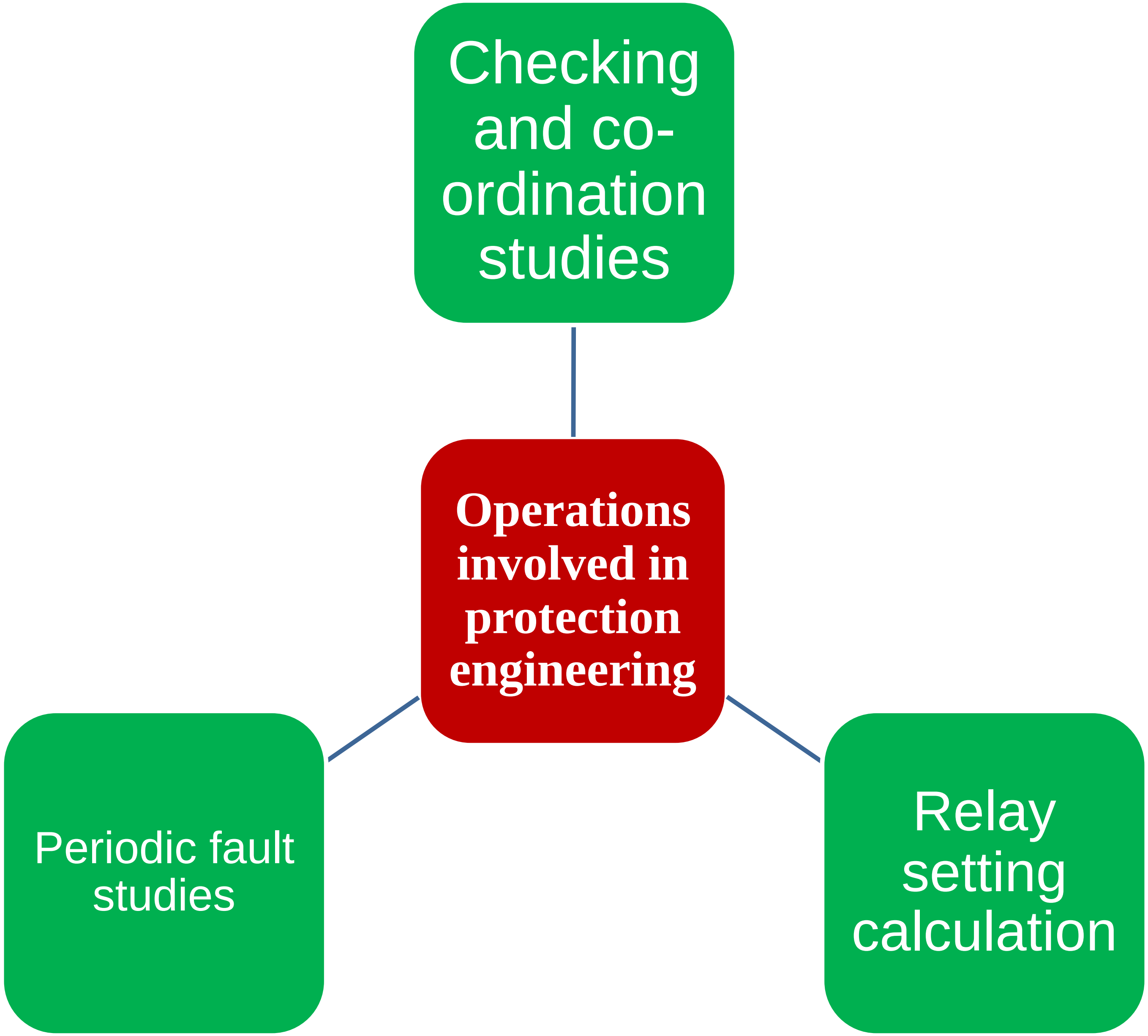
Minimize the outage during the fault

- Proper relay coordination
- Only primary relay operates
- Maintenance of all equipment protection chain

Introduction



Introduction



Introduction

Difficulties:

- Wide variety of relays in operation.
  - Functionality
  - Manufacturer
  - Technology
- System operational changes.
- System growth.

It is just impossible to overcome the above difficulties by a human (Operator).

Solution???

Apply judiciously the computer and simulation tools.

Damage minimization

To minimize damage to equipment and interruption to the services

To incorporate features of design aimed at preventing failures

To include provisions for mitigating the effects of failures when it occurs

Preventing electrical failure

Provision for adequate insulation, instantaneous setting, overload and unbalance factors

Co-ordination of insulation strength with capabilities of lightning arrestors

Use of overhead ground wires and low tower footing resistance

Design for mechanical strength to reduce exposure, and to minimize the likelihood of failure causable by animals, birds, dirt sleet etc.

Mitigating the effects of failure

Features that mitigate the immediate effects of failure	Features for promptly disconnecting the faulty elements
• Design to limit the magnitude of short circuit current • Design to withstand mechanical stresses and heating • Time delay under voltage relays on circuit breakers to prevent dropping loads during momentary voltage dips • Ground fault neutralizers (Petersen coils)	• Protective relaying • Circuit breakers with sufficient interrupting capacity • Fuses

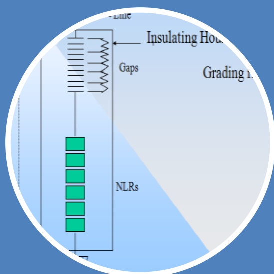
Mitigating the effects of failure

Features that mitigate the loss of faulty element	Features that operate throughout the period from the inception of the fault until after its removal, to maintain voltage and stability of protective relaying
• Alternate circuits • Reserve generator • Automatic re-closing	• Automatic voltage regulators • Stability characteristics of generator

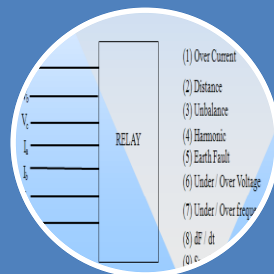
Mitigating the effects of failure

Means for observing the effectiveness of the foregoing features	Frequent surveys as system changes or additions are made, to be sure that the fore going features are still adequate
• Automatic oscillographs • Efficient human observations • Record keeping	• Simulation studies • Technology update

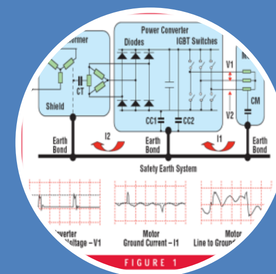
Types of protection



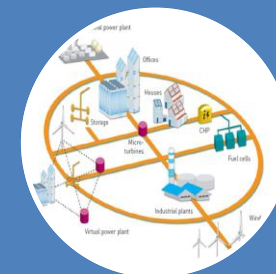
Over voltage protection – Lightning/Surge arrestors, insulation co-ordination



Fault protection - Application of relays

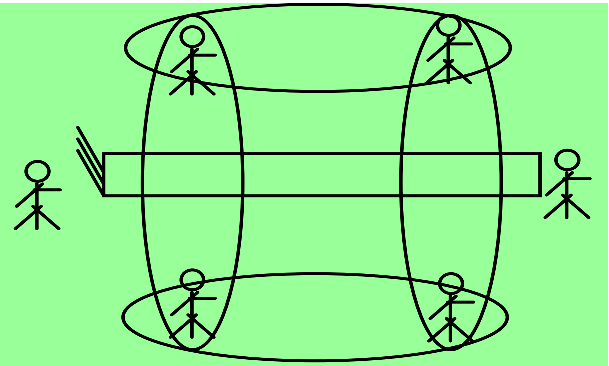


Protection for human (safety) – Earthing and Earth mat design, clearances, insulation



Environmental protection?? – Integration of more and more renewable energy to grid

Protection – Cricket Field Analogy

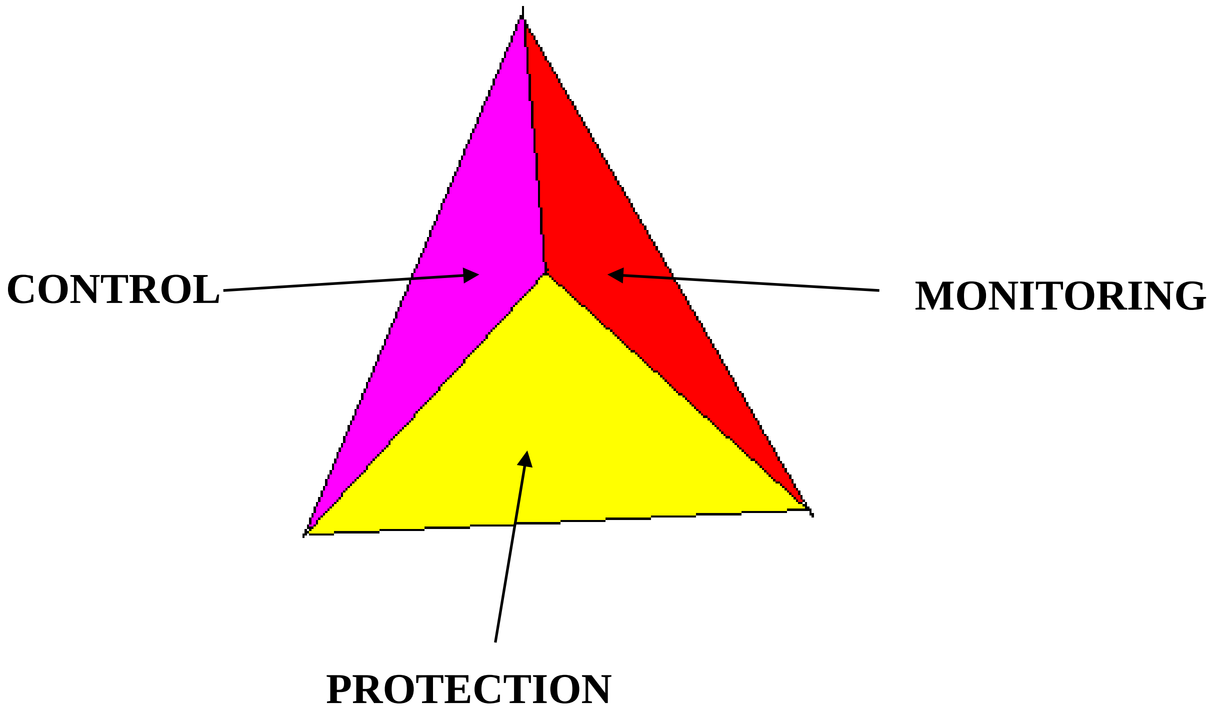


Sl. No.	Cricket Field (Fielding side Bowler)	Protection field (Protection Engineer)
1.	Positions the fielders	Designs the system and sets the relays
2.	Bowls the ball	Charges the system
3.	Batsman hits the ball	Fault occurs
4.	Mid-off stops/fails	Primary relay operates/ fails
5.	Long-off stops/ fails	Backup relay operates / fails
6.	If boundary, gets dropped	If fails, Has to face enquiry commission

Intelligent Electronic Device (IED)

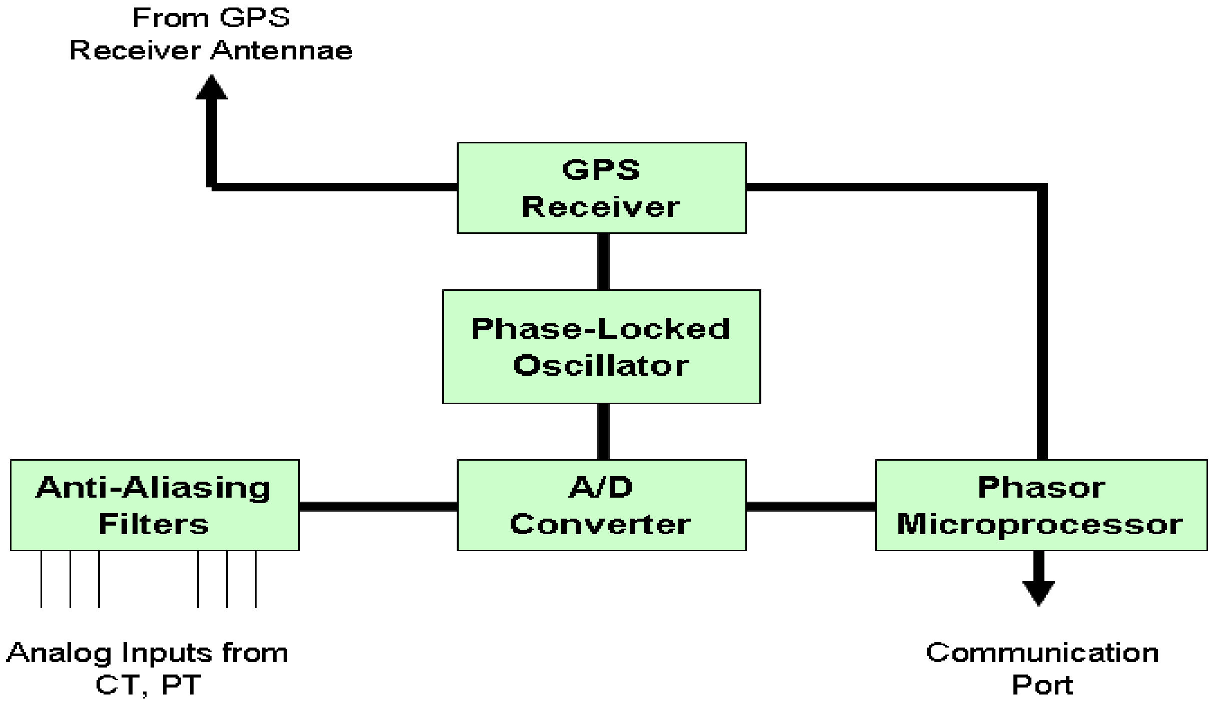
Relay has changed its functionality from protection to

- Protection
- Monitoring and
- Control



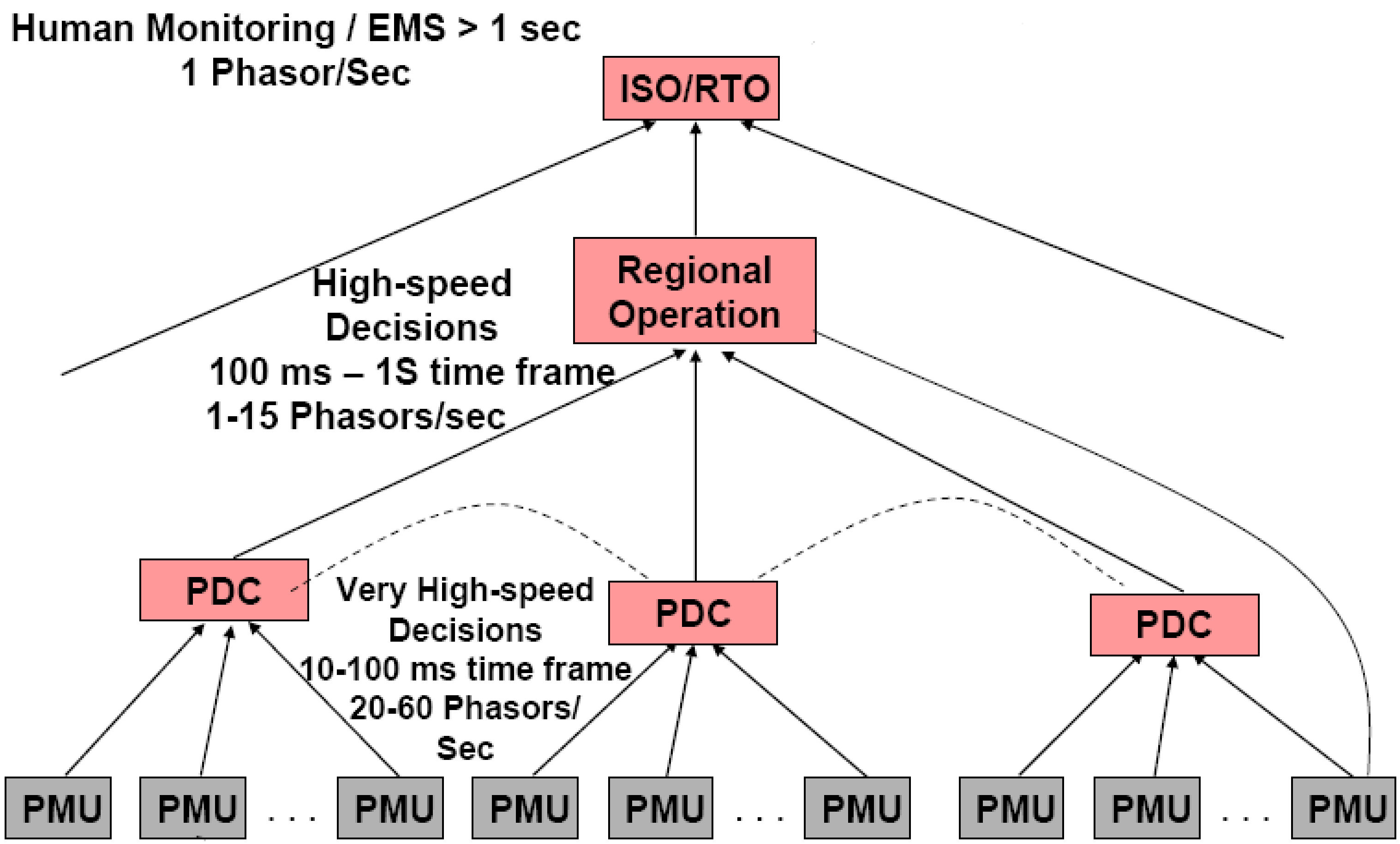
Recent Trends - Phasor Measurement Unit

A device that samples analog voltage and current data in synchronism with a GPS-clock.



Phasor Measurement Unit Block Diagram

PMU- Architecture Hierarchy



Applications of PMU

- Real time visualization of power system
- Design of advanced warning system
- Analysis for causes of total or partial blackouts
- Enhancement in state estimation
- Real time angular and voltage stability analysis
- Improved damping of inter area oscillations
- Design of adaptive protection scheme

Adaptive Relaying

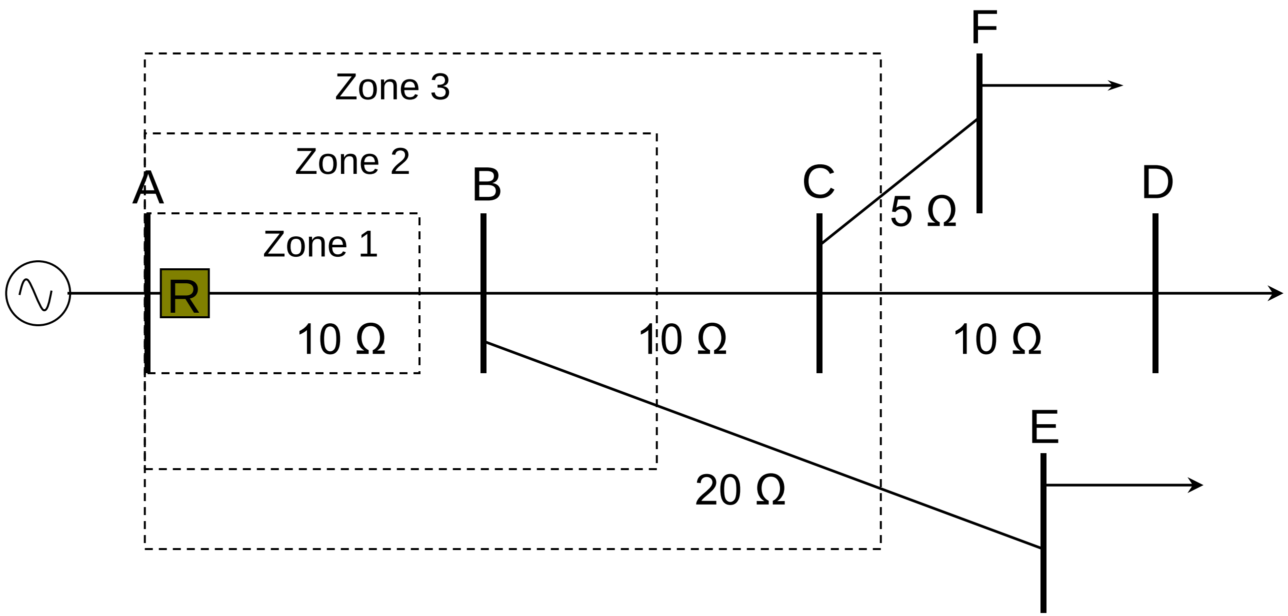
Online activity

Modifies preferred protective response to a change in system conditions or requirements.

Special application in case of -

- Multi terminal lines.
- Out of step protection.
- Back up protection of distance relays.

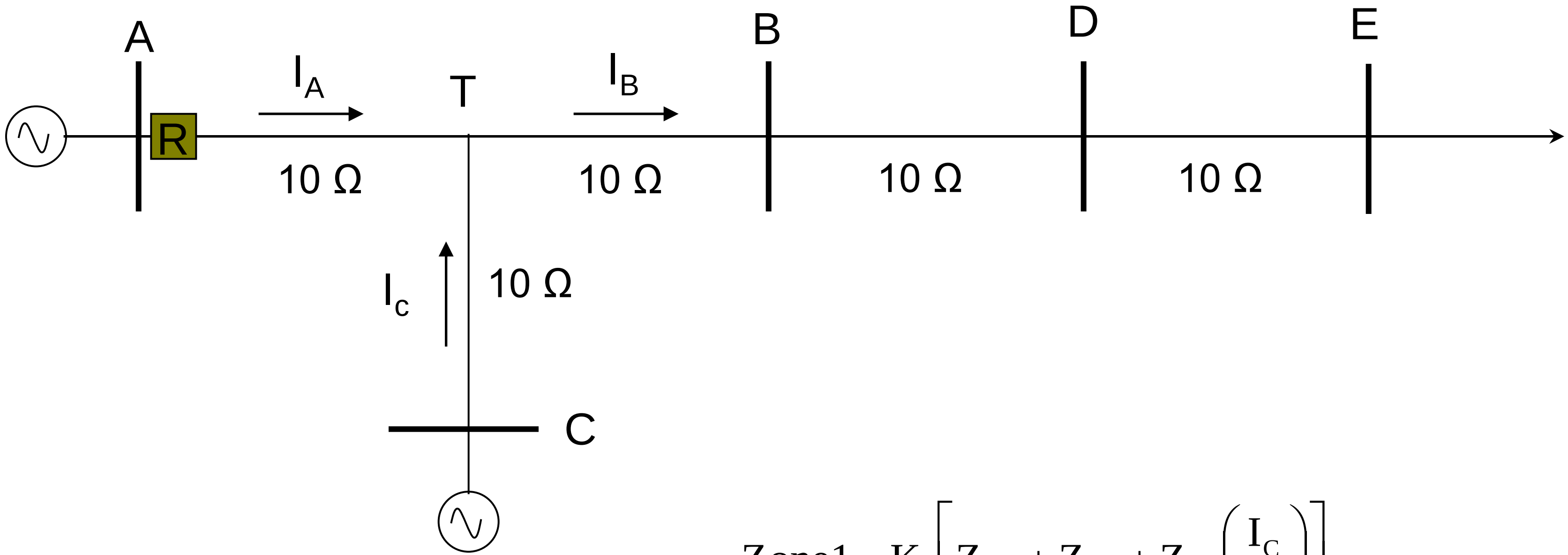
Distance Protection



Distance relay zone settings

- Zone 1 = 85% of AB = 0.85*10 = 8.5 ohm
- Zone 2 = AB+50% of BC (shortest line) =10+0.5*10 =15 ohm
- Zone 3 = AB+BC+20% of CD (longest line) = 10+10+0.2*10 =22 ohm

Multi-terminal lines



$$\frac{V_R}{I_R} = \frac{(I_A * Z_{AT}) + (I_B * Z_{TB})}{I_A}$$

$$\frac{V_R}{I_R} = \frac{(I_A * Z_{AT}) + (I_A + I_C) * Z_{TB}}{I_A}$$

$$\frac{V_R}{I_R} = Z_{AT} + Z_{TB} + Z_{TB}\left(\frac{I_C}{I_A}\right)$$

$$Zone1 = K_1\left[Z_{AT} + Z_{TB} + Z_{TB}\left(\frac{I_C}{I_A}\right)\right]$$

$$Zone2 = \left[Z_{AT} + Z_{TB} + Z_{TB}\left(\frac{I_C}{I_A}\right)\right] + K_2 * Z_{BD}$$

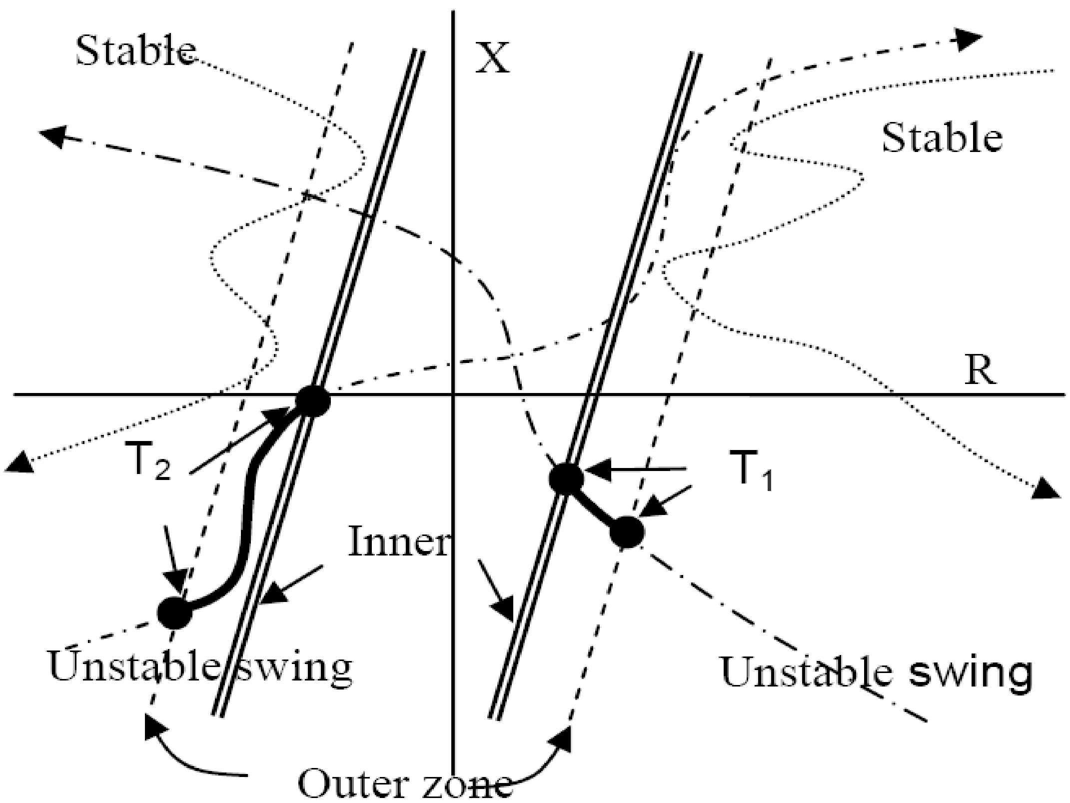
$$Zone3 = \left[Z_{AT} + Z_{TB} + Z_{TB}\left(\frac{I_C}{I_A}\right)\right] + Z_{BD} + K_3 * Z_{DE}$$

Multi-terminal lines

	Without in-feed (I_c=0)	With in-feed (I_c=I_A)	Weak in-feed (I_c=0.5*I_A)	Strong in-feed (I_c=2*I_A)
Zone 1 (Ω)	17	25.5	21.25	34
Zone 2 (Ω)	25	35	30	45
Zone 3 (Ω)	32	42	37	52

Out of Step Relay

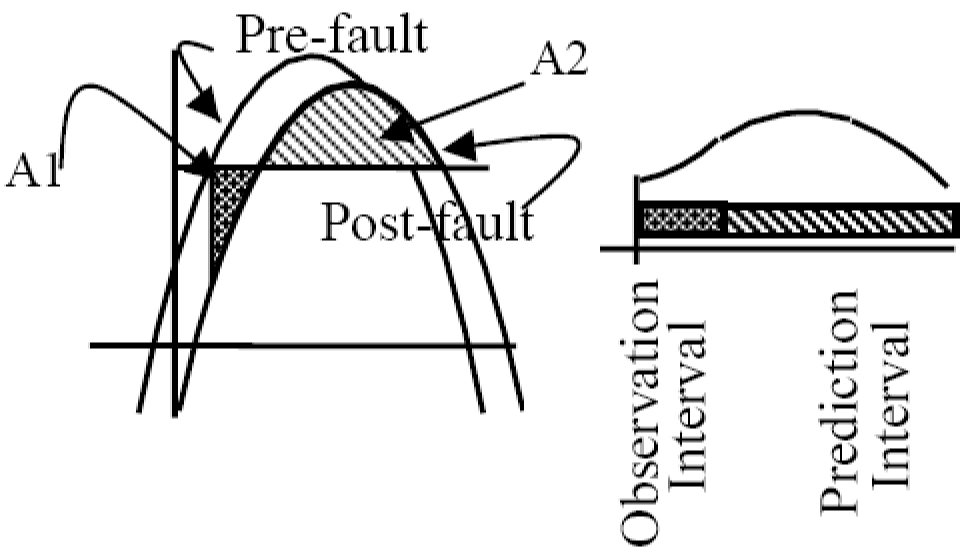
Traditional relays uses zones to determine whether electromechanical swing will lead to instability or not.



Out of Step Relay

- Large number of simulation need to be carried out to determine relay settings.
- Conventional settings are unsatisfactory and results in mis-operation because system changes quickly and tested swings are different from actual.
- Adaptive settings are required to cope up with such problem.
  - Adaptively changing the timer settings.
  - Adaptive Zone settings.
- New approach is suggested using equal area criteria.
- Implemented on Florida-Georgia interface project undertaken by Virginia Technology.

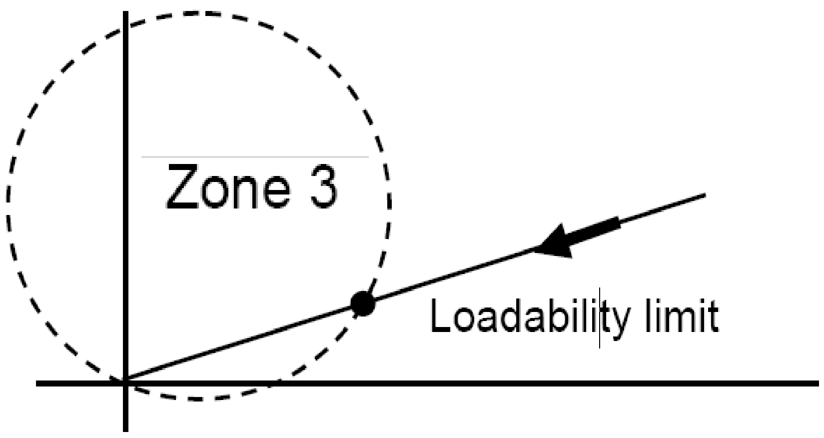
Out of Step Relay



Equal area criteria

Accelerating area must be smaller than decelerating area for system to be transient stable.

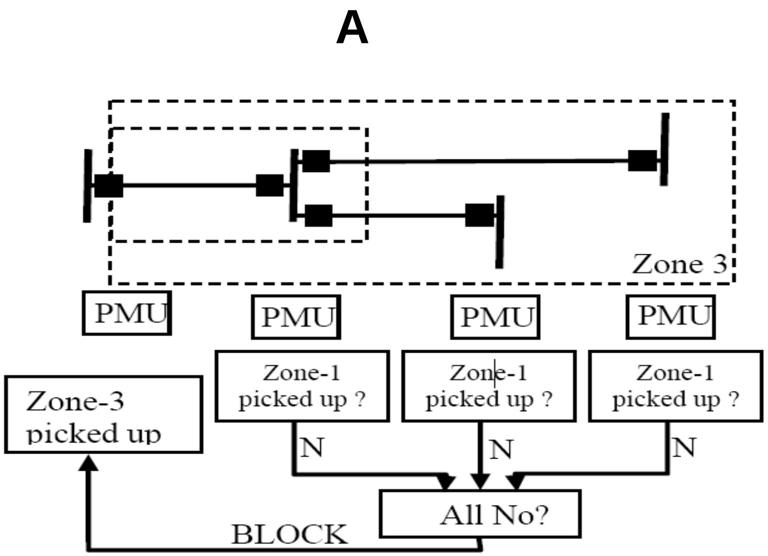
Back up Protection



Load encroachment

- *Back up zones of distance relay are prone to tripping due to load encroachment.*
- *Modification in relay characteristics is required.*
- *Same can be achieved by using phasor measurement unit.*

Back up Protection

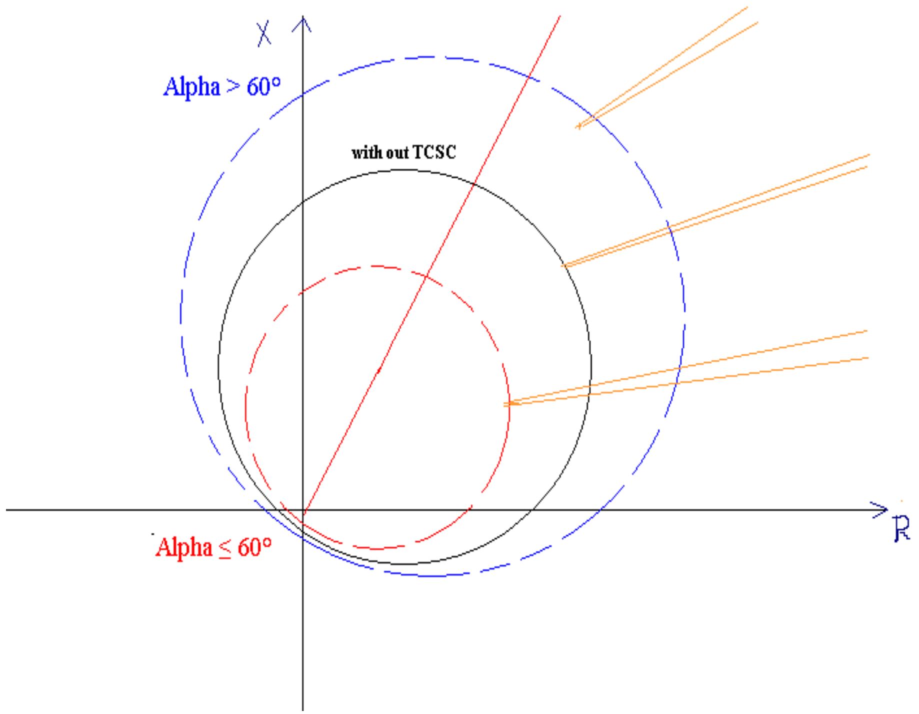


- Assume zone 3 of relay A has picked up.
- Determine for any zone 1 fault in other stations using PMU.
- If none of them exist restrain zone 3 of relay since it might have picked up due to load increase in the system.

Effect of TCSC on Distance Relay

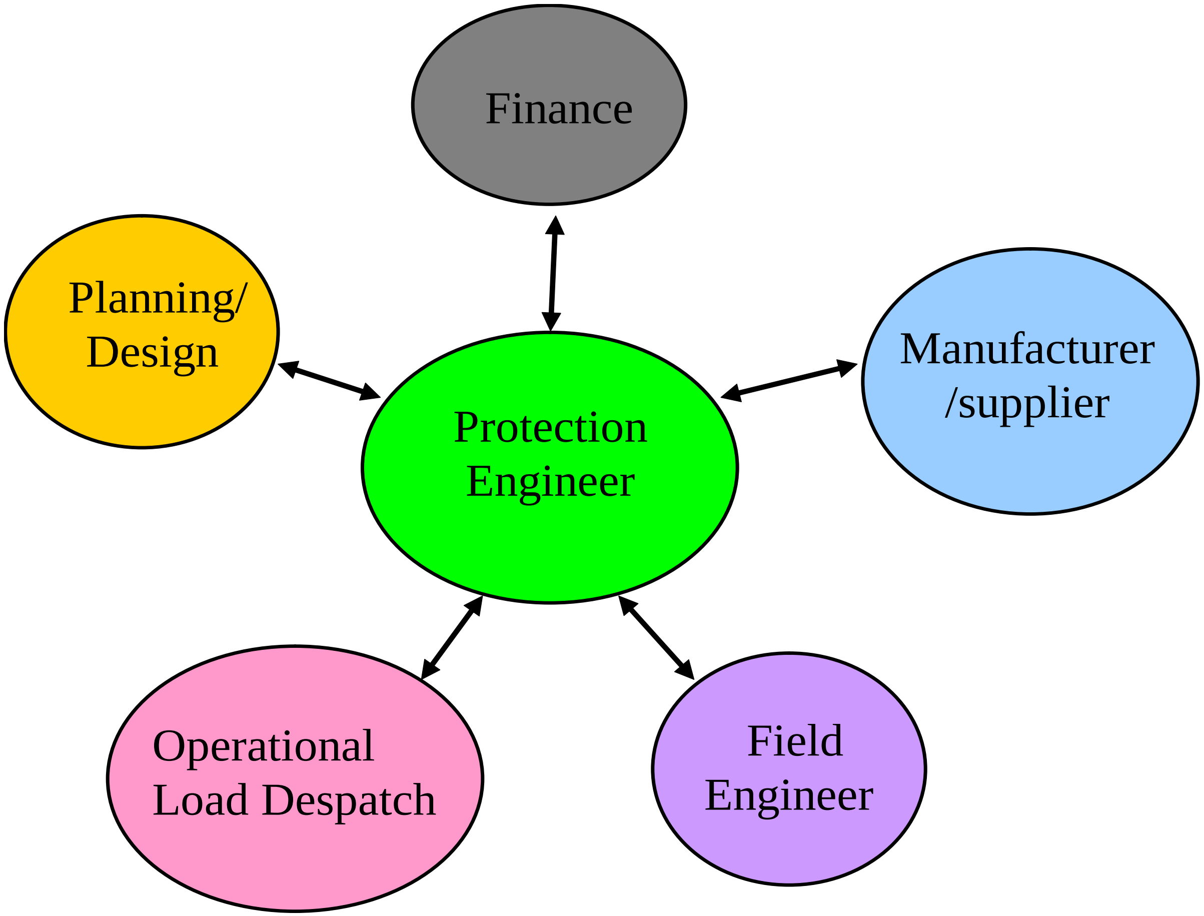
- When the delay angle by TCR is ≤ to 60° the value of X_{TCSC} will be low. In this case TCSC will be in capacitive mode and relay will over reach

- When the delay angle by TCR is > 60° the value of X_{TCSC} will be high. In this case TCSC will be in inductive mode and relay will under reach

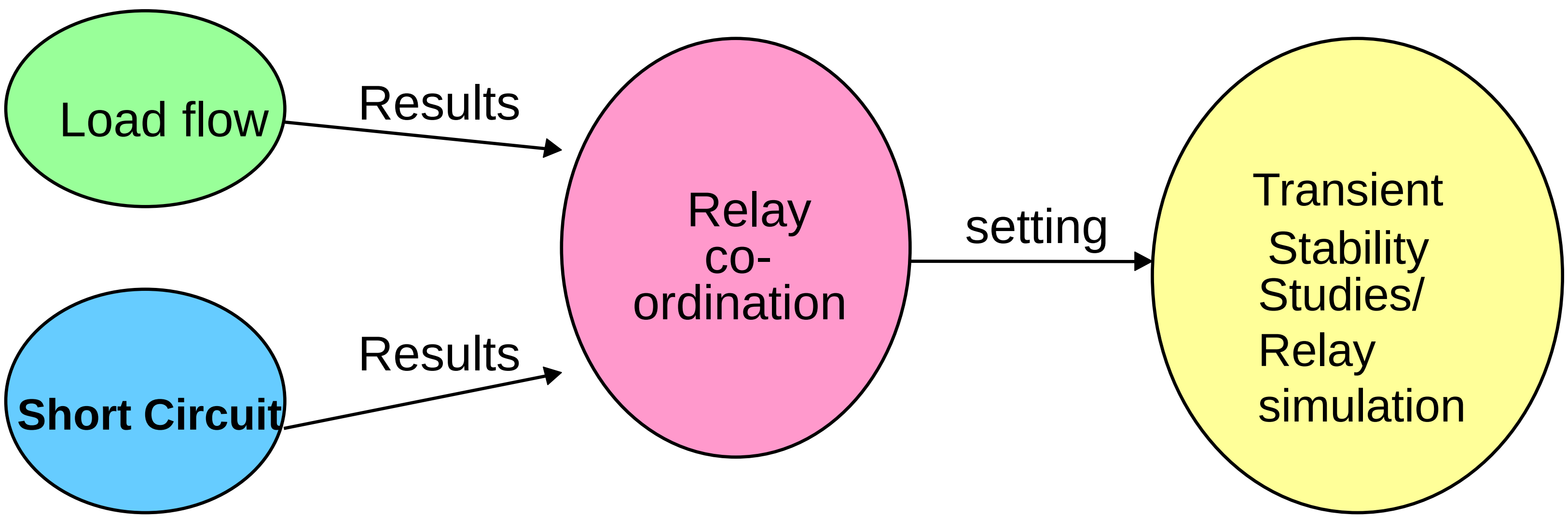


Thus information about the amount of compensation can help in modifying relay settings

Coordination with Different Departments



Data Flow in Simulation



Special Protection Schemes

- Specific Action following an outage/disturbance
- Fast acting and generally without any time delay
- Applicable for tie lines tripping, HVDC link tripping, major generation tripping
- Saves the system from complete collapse

Special Protection Schemes - Types

Hard wired scheme

- On tripping of a specific element/breaker other elements are tripped to get load/generation relief
- Generally ends up in more load shedding or generation curtailment
- Optimal action is not ensured
- At times may not get any relief

Intelligent System

- Ensures optimal load/generation tripping
- Needs system digital and analog information
- Network topology processing program
- Dynamically computes the load or generation to be tripped for any breaker tripping

Controlled System Separation and Load Shedding

- System separation based on over load, voltage collapse, angular increase, vector shift, out of step etc.
- In each island, generator tripping if surplus power and load shedding if surplus load
- To be coordinated with Generator over frequency and under frequency tripping

Automated Fault Analysis System - Need

Faults are unavoidable and analyzing their cause is must to protect equipment in future and reduce system stress and blackout.

Power companies are spending precious time and resources, dealing with system recovery.

Data available is very large and complex to understand.

Tools are required to handle such large data to arrive at proper conclusion.

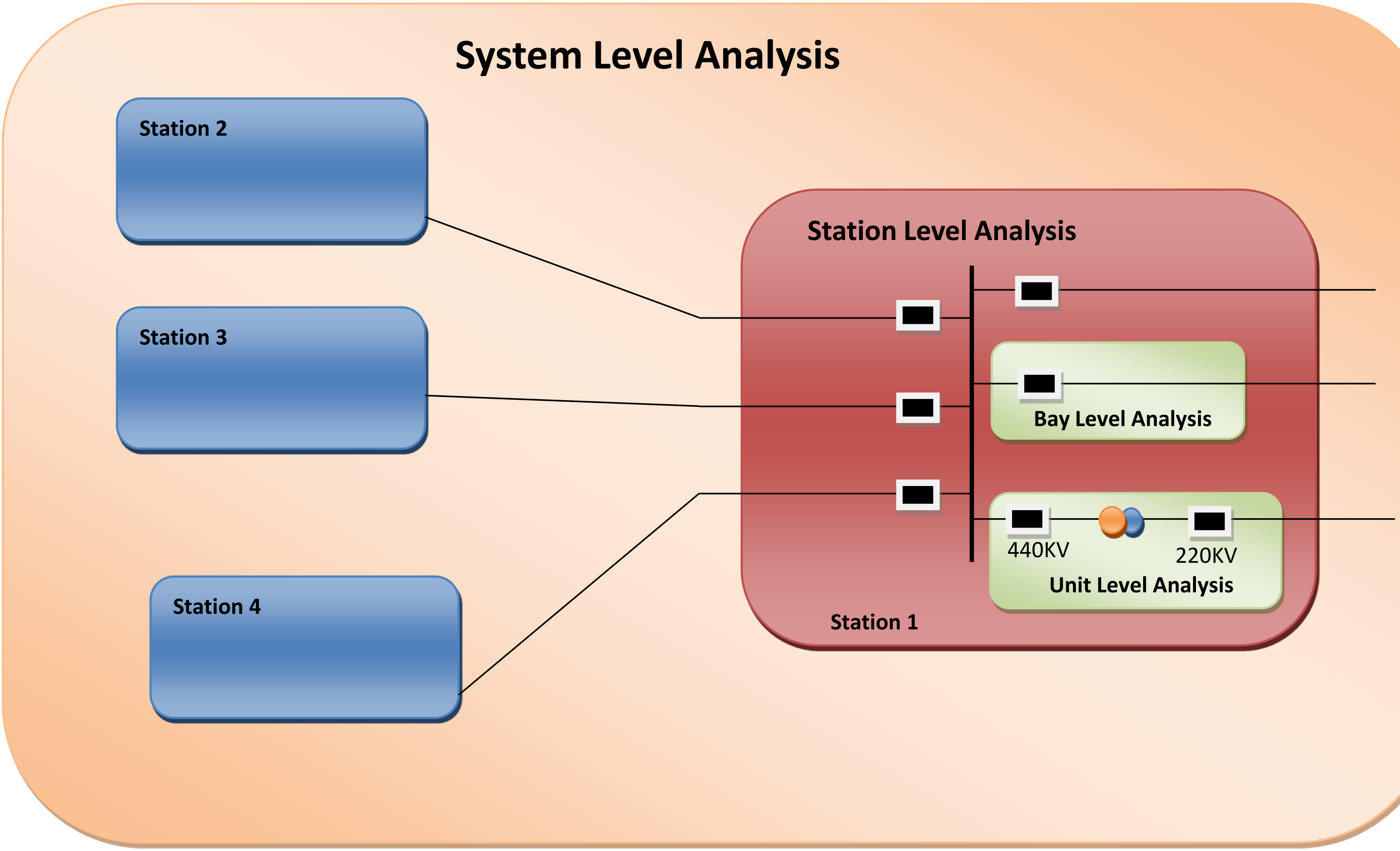
Basic Requirement of AFAS

- Remote downloading of disturbance data
- Remote access of relays status
- Fault analysis program
- Remote configuration of relay
- Generation of reports and intimation of occurrence

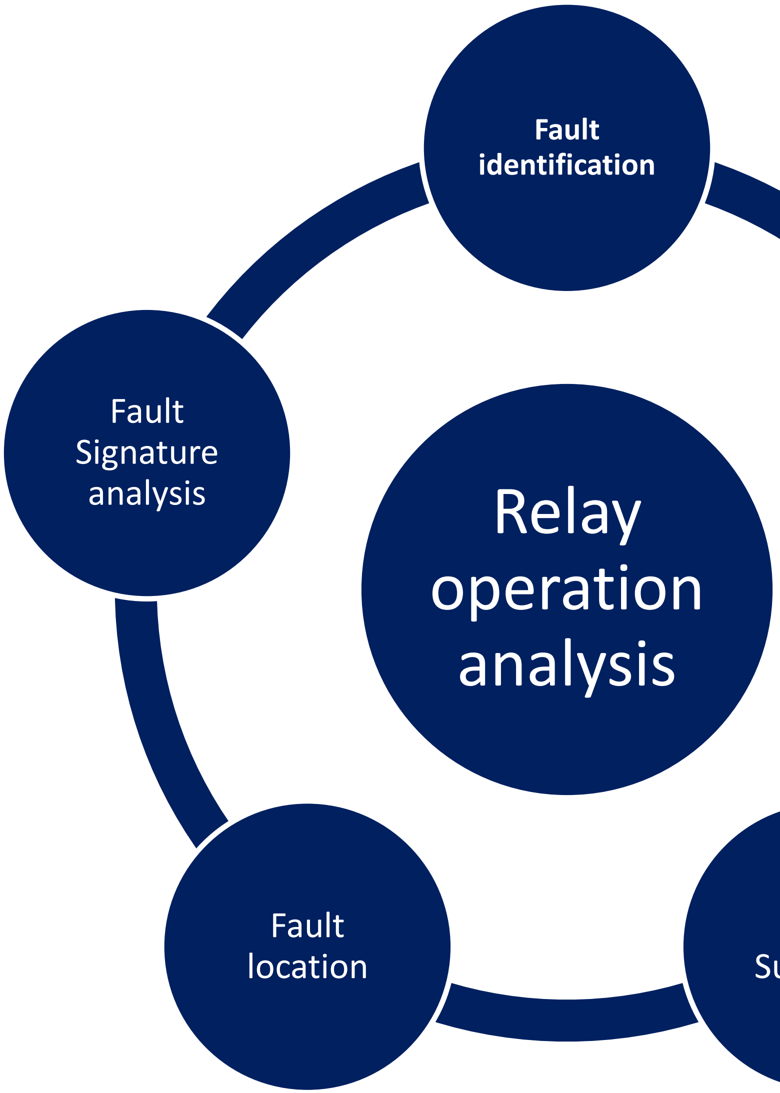
Functionality of AFAS

- Identification of faults
- Distinguish from various phenomenon such as power swing, voltage instability
- Evaluating relay operation
- Condition assessment of switch gears

Levels of Analysis



Major types of analysis



Where the problem lies

????????????   !!!!!!!!!!!!!!!!

Coordination among all stake holders

1. Equipment Supplier and End user

2. CPP and Industry Electrical system

3. Industry and Utility

4. STU & CTU

5. STU & IPP

6. CTU & IPP

Conclusions

The various issues in the protection are discussed

It is concluded that close co-ordination for protection department with other departments are required.

The adaptive relaying and special protection schemes will help the system

Automated fault analysis system will help in understanding the relay tripping incidences better.

Close coordination and cooperation among all stake holders

Discussions

Thank You