O&M of Protection System and Relay Coordination

Over View of Power System Protection

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## Detailed Schedule

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<th>Time/Date</th>
<th>Monday 21-Jan-2013</th>
<th>Tuesday 22-Jan-2013</th>
<th>Wednesday 23-Jan-2013</th>
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<td><strong>Week 1</strong></td>
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<td>09:00-10:00</td>
<td>Opening Ceremony</td>
<td>Relay Input</td>
<td>General Protection</td>
<td>General Concepts</td>
<td>Numerical Relays &amp; Advanced Concepts</td>
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<td>10:00 - 10:30</td>
<td>Tea Break</td>
<td>Tea Break</td>
<td>Tea Break</td>
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<tr>
<td>10:30-12:00</td>
<td>Over View of Power System &amp; Protection</td>
<td>Fault Analysis</td>
<td>General Protection</td>
<td>Relay Coordination Tutorial</td>
<td>Protection SCADA</td>
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<td>12:00-13:30</td>
<td>Lunch Break</td>
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<tr>
<td>13:30-14:45</td>
<td>Relay Type &amp; Applications</td>
<td>Fault Analysis Simulation / Case Studies</td>
<td>General Protection</td>
<td>Relay Testing &amp; Lab</td>
<td>Smart Grid/Microgrid</td>
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<td>14:45 - 15:15</td>
<td>Tea Break</td>
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<td>Tea Break</td>
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<tr>
<td>15:15-16:15</td>
<td>Protection Movies</td>
<td>Case Studies</td>
<td>Fault Analysis Simulation / Case Studies</td>
<td>Al Based relaying</td>
<td>Concluding Ceremony</td>
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Generation - typically at 4-20kV

Transmission - typically at 230-765kV

Receives power from transmission system and transforms into subtransmission level

Subtransmission - typically at 69-161kV

Receives power from subtransmission system and transforms into primary feeder voltage

Distribution network - typically 2.4-69kV

Low voltage (service) - typically 120-600V
Introduction

Sub Station Transformer Explosion
Introduction
Winding Damage-1
Winding Damage-2
Transformer Winding Damage
Factors Affecting the Protection System

- Economics
- Personality
- Location of Disconnecting and Input Devices
- Available Fault Indicators
Protective Relay

- **Relay**: An electric device that is designed to respond to input conditions in a prescribed manner and, after specified conditions are met, to cause contact operation or similar abrupt change in associated electric control circuits. (IEEE)

- **Protective Relay**: A relay whose function is to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action. (IEEE)
Typical Protective Relays
Classification of Relays

- Protective Relays
- Regulating Relays
- Reclosing, Synchronism Check, and Synchronizing Relays
- Monitoring Relays
- Auxiliary Relays
- Others
Protective Relay Performance

Since many relays near the trouble area may begin to operate for any given fault, it is difficult to completely evaluate an individual relay’s performance.

Performance can be categorized as follows:

- **Correct:** (a) As planned or (b) Not as planned or expected.
- **Incorrect:** (a) Fail to trip or (b) False tripping
- No conclusion
The power system is divided into protection zones defined by the equipment and available circuit breakers.

**Six possible protection zones** are listed below:

1. Generators and generator-transformer units
2. Transformers
3. Buses
4. Lines (Transmission, sub transmission, and distribution)
5. Utilization equipment
6. Capacitor or reactor banks
Protection Zones

1. Generator or Generator-Transformer Units
2. Transformers
3. Buses
4. Lines (transmission and distribution)
5. Utilization equipment (motors, static loads, etc.)
6. Capacitor or reactor (when separately protected)
Desirable Protection Attributes

1. **Reliability:** System operate properly
   - **Security:** Don’t trip when you shouldn’t
   - **Dependability:** Trip when you should

2. **Selectivity:** Trip the minimal amount to clear the fault or abnormal operating condition

3. **Speed:** Usually the faster the better in terms of minimizing equipment damage and maintaining system integrity

4. **Simplicity:**

5. **Economics:** Don’t break the bank
Selection of protective relays requires compromises:

- Maximum and Reliable protection at minimum equipment cost
- High Sensitivity to faults and insensitivity to maximum load currents
- High-speed fault clearance with correct selectivity
- Selectivity in isolating small faulty area.
- Ability to operate correctly under all predictable power system conditions
• Cost of protective relays should be balanced against risks involved if protection is not sufficient and not enough redundancy.

• Primary objectives is to have faulted zone’s primary protection operate first, but if there are protective relays failures, some form of backup protection is provided.

• Backup protection is local (if local primary protection fails to clear fault) and remote (if remote protection fails to operate to clear fault)
Transformers - to step up or step down voltage level

Breakers - to energize equipment and interrupt fault current to isolate faulted equipment

Insulators - to insulate equipment from ground and other phases

Isolators (switches) - to create a visible and permanent isolation of primary equipment for maintenance purposes and route power flow over certain buses.

Bus - to allow multiple connections (feeders) to the same source of power (transformer).
Primary Equipment & Components

• **Grounding** - to operate and maintain equipment safely

• **Arrester** - to protect primary equipment of sudden overvoltage (lightning strike).

• **Switchgear** – integrated components to switch, protect, meter and control power flow

• **Reactors** - to limit fault current (series) or compensate for charge current (shunt)

• **VT and CT** - to measure primary current and voltage and supply scaled down values to P&C, metering, SCADA, etc.

• **Regulators** - voltage, current, VAR, phase angle, etc.
Types of Protection

**Overcurrent**

- Uses current to determine magnitude of fault
- Simple
- May employ definite time or inverse time curves
- May be slow
- Selectivity at the cost of speed (coordination stacks)
- Inexpensive
- May use various polarizing voltages or ground current for directionality
- Communication aided schemes make more selective.
Time Overcurrent Protection (TOC)

- Selection of the curves uses what is termed as a “time multiplier” or “time dial” to effectively shift the curve up or down on the time axis.

- Operate region lies above selected curve, while no-operate region lies below it.

- Inverse curves can approximate fuse curve shapes.
## ANSI Reference Numbers

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<th>Description</th>
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<td>51N</td>
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<tr>
<td>52b</td>
<td>Auxiliary Switch - Normally Closed</td>
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Protective Device function Nos.
Transformer Protection Scheme - Example
Time Overcurrent Protection
(51, 51N, 51G)
Un Restricted & Restricted Protection

**Unrestricted**

- No Specific Point downstream up to which protection will protect.
  - Will Operate for faults on the protection equipment.
  - May also operate for faults on downstream equipment which has its own protection.
  - Need for discrimination with downstream protection usually by means of time grading.

**Restricted**

Has an accurately defined zone of protection.
- An item of power plant is protected as a unit
- Will not operate for out of zone faults thus no back up protection for downstream faults
Types of Protection

Differential

- current in = current out
- Simple
- Very fast
- Very defined clearing area
- Expensive
- Practical distance limitations
  - Line differential systems overcome this using digital communications
Types of Protection

Voltage

- Uses voltage to infer fault or abnormal condition
- May employ definite time or inverse time curves
- May also be used for under voltage load shedding
  - Simple
  - May be slow
  - Selectivity at the cost of speed (coordination stacks)
  - Inexpensive.
Types of Protection

Frequency

- Uses frequency of voltage to detect power balance condition
- May employ definite time or inverse time curves
- Used for load shedding & machinery under/over speed protection
  - Simple
  - May be slow
  - Selectivity at the cost of speed can be expensive
Types of Protection

Power

- Uses voltage and current to determine power flow magnitude and direction
- Typically definite time
  - Complex
  - May be slow
  - Accuracy important for many applications
  - Can be expensive
Types of Protection

**Distance (Impedance)**
- Uses voltage and current to determine impedance of fault
- Set on impedance [R-X] plane
- Uses definite time
- Impedance related to distance from relay
- Complicated
- Fast
- Somewhat defined clearing area with reasonable accuracy
- Expensive
- Communication aided schemes make more selective
Impedance

- Relay in Zone 1 operates first
- Time between Zones is called CTI
1. Overlap is accomplished by the locations of CTs, the key source for protective relays.

2. In some cases a fault might involve a CT or a circuit breaker itself, which means it can not be cleared until adjacent breakers (local or remote) are opened.

CTs are located at both sides of CB-fault between CTs is cleared from both remote sides

CTs are located at one side of CB-fault between CTs is sensed by both relays, remote right side operate only.
What Info is Required to Apply Protection

1. One-line diagram of the system or area involved
2. Impedances and connections of power equipment, system frequency, voltage level and phase sequence
3. Existing schemes
4. Operating procedures and practices affecting protection
5. Importance of protection required and maximum allowed clearance times
6. System fault studies
7. Maximum load and system swing limits
8. CTs and VTs locations, connections and ratios
9. Future expansion expectance
10. Any special considerations for application.
Current Transformers

- Current transformers are used to step primary system currents to values usable by relays, meters, SCADA, transducers, etc.
- CT ratios are expressed as primary to secondary; 2000:5, 1200:5, 600:5, 300:5
- A 2000:5 CT has a “CTR” of 400
Important Considerations When Applying Protection

- **Current and Voltage Transformers**

  - These are an essential part of the protection scheme to reduce primary current and volts to a low level suitable to input to relay.
  - They must be suitably specified to meet the requirements of the protective relays.
  - Correct connection of CTs and VTs to the protection is important, in particular for directional, distance, phase comparison and differential protections.
  - VTs may be electromagnetic or capacitor types.
  - Busbar VTs: Special consideration needed when used for line protection.
Instrument Transformer Circuits

Never open circuit a CT secondary circuit, so:

- **Never** fuse CT circuits;
- VTs must be fused or protected by MCB.
- **Do** wire test blocks in circuit (both VT and CT) to allow commissioning and periodic injection testing of relays.
- Earth CT and VT circuits at one point only;

*Wire gauge ≥ 2.5mm² recommended for mechanical strength.*
Auxiliary Supplies

Required for:

- TRIPPING CIRCUIT BREAKERS
- CLOSING CIRCUIT BREAKERS
- PROTECTION and TRIP RELAYS

- AC AUXILIARY SUPPLIES are only used on LV and MV systems.
- DC AUXILIARY SUPPLIES are more secure than AC supplies.
- SEPARATELY FUSED SUPPLIES used for each protection.
- DUPLICATE BATTERIES are occasionally provided for extra security.
- MODERN PROTECTION RELAYS need a continuous auxiliary supply.
- During un operated (healthy) conditions, they draw a small ‘QUIESCENT’ load to keep relay circuits energised.
- During operation, they draw a larger current which increases due to operation of output elements.
Voltage Transformers

- Voltage (potential) transformers are used to isolate and step down and accurately reproduce the scaled voltage for the protective device or relay.

- VT ratios are typically expressed as primary to secondary: 14400:120, 7200:120

- A 4160:120 VT has a “VTR” of 34.66
Typical CT/VT Circuits

Courtesy of Blackburn, Protective Relay: Principles and Applications
System Grounding

- Limits over voltages
- Limits difference in electric potential through local area conducting objects
- Several methods
  - Ungrounded
  - Reactance Coil Grounded
  - High Z Grounded
  - Low Z Grounded
  - Solidly Grounded

Equipment Grounding

- Prevents shock exposure of personnel
- Provides current carrying capability for the ground-fault current
- Grounding includes design and construction of substation ground mat and CT and VT safety grounding
1. Ungrounded: There is no intentional ground applied to the system, however it’s grounded through natural capacitance. Found in 2.4 - 15kV systems.

2. Reactance Grounded: Total system capacitance is cancelled by equal inductance. This decreases the current at the fault and limits voltage across the arc at the fault to decrease damage.

\[ X_0 \leq 10 \times X_1 \]
System Grounding

3. High Resistance Grounded: Limits ground fault current to 10A-20A. Used to limit transient overvoltages due to arcing ground faults.

\[ R_0 \leq \frac{X_{0C}}{3}, \quad X_{0C} \text{ is capacitive zero sequence reactance} \]

4. Low Resistance Grounded: To limit current to 25-400A

\[ R_0 \geq 2X_0 \]
5. Solidly Grounded: There is a connection of transformer or generator neutral directly to station ground.

Effectively Grounded: $R_0 \leq X_1$, $X_0 \leq 3X_1$, where $R$ is the system fault resistance
Substation Types

- Single Supply
- Multiple Supply
- Mobile Substations for emergencies
- Types are defined by number of transformers, buses, breakers to provide adequate service for application
Industrial Substation Arrangements

(Typical)
Industrial Substation Arrangements

(Typical)

SECONDARY SELECTIVE
(DOUBLE-ENDED SUBSTATION)

MAIN

TIE
N.O.

MAIN

FEEDERS

NETWORKS

NETWORK PROTECTORS
Utility Substation Arrangements

1. Single Bus, 1 Tx, Dual supply
2. Single Bus, 2 Tx, Dual Supply
3. 2-sections Bus with HS Tie-Breaker, 2 Tx, Dual Supply

(Typical)
Utility Substation Arrangements

(Typical)

Bus 1

Bus 2

**Breaker-and-a-half** – allows reduction of equipment cost by using 3 breakers for each 2 circuits. For load transfer and operation is simple, but relaying is complex as middle breaker is responsible to both circuits

**Ring bus** – advantage that one breaker per circuit. Also each outgoing circuit (Tx) has 2 sources of supply. Any breaker can be taken from service without disrupting others.
Utility Substation Arrangements

(Typical)

Main bus
Aux. bus
Bus 1
Bus 2

Double Bus: Upper Main and Transfer, bottom Double Main bus

Main-Reserved and Transfer Bus: Allows maintenance of any bus and any breaker
Switchgear Defined

- Assemblies containing electrical switching, protection, metering and management devices
- Used in three-phase, high-power industrial, commercial and utility applications
- Covers a variety of actual uses, including motor control, distribution panels and outdoor switchyards
- The term "switchgear" is plural, even when referring to a single switchgear assembly (never say, "switchgears")
- May be described in terms of use:
  - "the generator switchgear"
  - "the stamping line switchgear"
Switchgear Examples

- Air insulated, 2-high drawout Vacuum Switchgear
- Air insulated, fused load-interrupter Switchgear
- Air insulated, load-interrupter Padmounted Switchgear
- SF6 insulated, vacuum interrupter Switchgear
A Good Day in System Protection......

- CTs and VTs bring electrical info to relays
- Relays sense current and voltage and declare fault
- Relays send signals through control circuits to circuit breakers
- Circuit breaker(s) correctly trip

What Could Go Wrong Here????
A Bad Day in System Protection......

- CTs or VTs are shorted, opened, or their wiring is
- Relays do not declare fault due to setting errors, faulty relay, CT saturation
- Control wires cut or batteries dead so no signal is sent from relay to circuit breaker
- Circuit breakers do not have power, burnt trip coil or otherwise fail to trip

Protection Systems Typically are Designed for N-1
Contribution to Faults
Fault Types (Shunt)

THREE PHASE

LINE-TO LINE

LINE-TO GROUND

TWO LINES TO GROUND
FAULTS IN UNDERGROUND CABLES

Underground Cables

- Diggers
- Overloading
- Oil Leakage
- Ageing
Faults in Overhead Lines

Overhead Lines

- Lightning
- Kites
- Trees
- Moisture
- Salt
- Birds
- Broken Conductors
Faults in Machines

Machines

Mechanical Damage

Unbalanced Load
Type of Fault

\[ \emptyset/E \]

\[ \emptyset/\emptyset/E \]

\[ \emptyset/\emptyset \]

\[ 3\emptyset \]

\[ 3\emptyset/E \]
Type of Faults

CROSS COUNTRY FAULT

Diagram showing different types of faults.
Type of Fault
Type of Cable Faults

CHANGING FAULT IN CABLES

Diagram showing the sequence of a changing fault in cables.
AC & DC Current Components of Fault Current

When DC becomes zero, then AC will be balanced around zero axis.
Establish two base quantities:

- **Standard practice is to define**
  - Base power – 3 phase
  - Base voltage – line to line
- **Other quantities derived with basic power equations**

### Per-Unit System | Base Values

- Select base kVA and base volts
- Calculate base amps and base ohms

\[
\text{BASE AMPS} = \frac{\text{BASE kVA} \times 1000}{\text{BASE VOLTS} \times \sqrt{3}}
\]

\[
\text{BASE OHMS} = \frac{\text{BASE VOLTS}}{\text{BASE AMPS} \times \sqrt{3}}
\]

**KVA is three-phase**
**Volts is line-to-line**
**Ohms is line-to-neutral**
Short Circuit Calculations
Per Unit System

Per Unit Value = \frac{Actual Quantity}{Base Quantity}

V_{pu} = \frac{V_{actual}}{V_{base}}

I_{pu} = \frac{I_{actual}}{I_{base}}

Z_{pu} = \frac{Z_{actual}}{Z_{base}}
A Study of a Fault......

Total Clearing Time

Relaying (2 Cycles)  Mech Time (1 Cycle)  Arcing Time (2 Cycles)

ARC Extinguished in Five Cycles

SHORT CIRCUIT OCCURS HERE
Co-ordinate protection so that relay nearest to fault operates first – minimises amount of system disconnection.
Regards,

YBL Systems and Solutions
(Electrical Power System Research Consultants)
www.sasidharan.webs.com