Protection Basics 101

What Are We Protecting?
Lightning Strikes Create Faults
Arcing Evidence on Pole Ground

Flashed C-Phase Insulator With Melted Balloon Material
Snake Causes Breaker to Fail

Flashed Insulators
When Primary Met Secondary

Extra Slack in CT Cable

Control Cabinet

Digital Relay

Junction Box Scorched
Arc Flash During Commissioning

Culprit Found!
Typical Short-Circuit Type Distribution

- Single-phase-to-ground: 70–80%
- Phase-to-phase-to-ground: 10–17%
- Phase-to-phase: 8–10%
- Three-phase: 2–3%

Power System Protection Requirements

- Reliability
- Selectivity
- Speed
- Simplicity
- Economics
Reiability

• Protection system will perform correctly
• Protection system will operate for in-zone problems (dependability)
• Protection system will not operate for out-of-zone problems (security)

Selectivity

• Ability of protection system to disconnect minimal amount of system
• Ability to isolate problem in shortest amount of time
Speed

- Hazards to humans, equipment damage, and stability problems are minimized when equipment is isolated faster.
- Speed and selectivity are frequently at odds – allowing for additional delay before tripping gives better selectivity.

Simplicity

Reliability increases when protection systems are kept simple.
Protection system should provide greatest amount of protection, commensurate with components being protected, for minimum total cost

Protection Performance Classification

- Correct performance
- Incorrect performance
  - Failure to trip
  - False tripping (misoperation)
Protective Devices

- Fuses
- Automatic reclosers
- Sectionalizers
- Circuit breakers
- Protective relays

Relay Classification

- Protective
- Regulating
- Reclosing and synchronism check
- Monitoring
- Auxiliary
IEEE C37.2 Device Numbers

51  Time-overcurrent relay  
50  Instantaneous overcurrent relay  
67  Directional overcurrent relay  
21  Distance relay  
87  Differential relay  
52  Circuit breaker  

Protective Relaying System
**Protection System Elements**

**Protective Relays**
- Monitor
- Detect
- Report
- Trigger

**Circuit Breakers**
- Interrupt
- Isolate from abnormal condition

**Instrument Transformers**

**CTs**
- Current scaling
- Isolation

**VTs**
- Voltage scaling
- Isolation
Why Does a CT Saturate?

Asymmetrical Saturation

Current

Time

a b c d e f g h i j
DC Tripping Circuit

Example Power System
Example Power System

Circuit Breakers

Dead-Tank Breaker

Live-Tank Breaker

Backup Protection

Breaker 5 Fails
Remote Backup

Breaker 5 Fails

Local Backup

Breaker 5 Fails

Remote Backup Trips

Local Backup Trips
Instantaneous (50) and Time-Overcurrent (51) Characteristics

Overcurrent Relay Coordination

Load or Fault Current

\[ I_{\text{Setting}} \approx \frac{E}{Z_{S1}} \]
Distance Relay

Relay designed to operate when \(|V_A| \leq (0.8)|Z_{L1}|I_A|\)

Mho Characteristic

Directional Impedance Relay Characteristic
Quadrilateral Characteristic

Distance Relay Timing and Coordination

Zone 1 is instantaneous
Why Is Distance Not Enough?

Typical Protection Pilot Schemes

- Direction comparison blocking (DCB)
- Permissive overreaching transfer trip (POTT)
- Directional comparison unblocking (DCUB)

- Direct underreaching transfer trip (DUTT)
- Permissive underreaching transfer trip (PUTT)
Communications Channels
Optical Fiber

- Advantages
  - High bandwidth
  - High reliability
  - Noise immunity
  - Safety

- Disadvantages
  - Cost (offset by shared use)
  - Rerouting (SONET)

Communications Channels
Microwave

- Advantages
  - Power line noise immunity
  - Not affected by faults

- Disadvantages
  - Placement
  - Weather
Communications Channels
Spread-Spectrum Radio

- Advantages
  - Low cost
  - Interference immunity
  - No license required
  - Not affected by faults

- Disadvantage – low bandwidth

Communications Channels
Power Line Carrier

- Advantage – reliable

- Disadvantages
  - Low bandwidth
  - Affected by power line noise
  - Affected by faults
Communications Channels
Telephone Lines

- Advantages
  - Low installation cost
  - Dedicated channel

- Disadvantages
  - Ongoing cost
  - Low reliability
  - Short range

Modulation Techniques

- Proprietary
- On / off
- Frequency shift keying (FSK)
**DUTT Logic**

- Underreaching Zone 1 elements send tripping signal
  - Limited fault resistance coverage
  - Immunity to current reversals

**DUTT Scheme**

- Scheme trips without supervision – susceptible to misoperation with noisy channels
PUTT Logic

PUTT Scheme

- Underreaching Zone 1 elements send tripping signal
  - Limited fault resistance coverage
  - Immunity to current reversals
- Overreaching Zone 2 elements trip on receipt of signal, making PUTT scheme more secure than DUTT scheme
**POTT Logic**

**DCB Logic**
Differential Overcurrent

[Diagram of electrical circuit]

Differential Overcurrent
External Fault

[Diagram of electrical circuit with external fault indicated]
Differential Overcurrent
Internal Fault

Effect of CT Saturation
Percentage Differential Protection Principle

![Diagram of Percentage Differential Protection Principle]

\[
\text{IOP} = |I_1 + I_2|
\]
\[
\text{IRT} = 0.5 \cdot (|I_1| + |I_2|)
\]

Percentage Restraint Characteristic

![Diagram of Percentage Restraint Characteristic]

\[
\text{IOP} = |I_1 + I_2|
\]
\[
\text{IRT} = k \cdot (|I_1| + |I_2|)
\]
Adaptive Slope

I_{OP}

Operate

Slope 2
External Fault

Slope 1
Internal Fault

I_{RST}

Restrain

High-Impedance Differential Protection

87P
Trip Alarm
OUT1
OUT2
86
Trip and Short
87 Input
How Many Relays for One Line?

3 phase + 3 ground + auxiliaries

1 relay has it all, and much more!

Microprocessor-Based Relay Advantages

• Multifunction devices
• Negative-sequence element
• Low-burden devices
• Programmable logic; very flexible
• Automatic self-tests
• Greater sensitivity due to high-accuracy metering
The Good Old Days?

I wonder where the problem is...

Root Cause Found!
Digital Relay I/O Scheme

- Auxiliary Inputs (ac or dc)
- Analog Inputs
- Discrete Inputs
- Computer-Based Relay (digital)
- Dry Contact Outputs (trip and alarm)
- "Live" Outputs
- Computer Communications

Digital Relay Architecture

- Analog Input Subsystem
- Discrete Input Subsystem
- Analog-to-Digital (A/D) Conversion
- Microprocessor
- Discrete Output Subsystem
- Operation Signaling
- Communications Ports
- RAM
- ROM / PROM
- EEPROM
- Tripping Outputs
Signal Path for Microprocessor-Based Relays

- Analog Low-Pass Filter
- A/D Conversion
- Digital Cosine Filter and Phasor
- Magnitude and Impedance

A/D Conversion

- Input
- A/D
- Output

Analog Signal

- 00000001
- 00000101
- 00001001
- 00100100
- 10010000
- ...

Digital Signal
**Digital Filtering**

Nonfiltered Signal (samples) → Digital Filtering → Filtered Signal (samples)

**Phasor Calculation**

Filtered Signal (samples) → Phasor Calculation → Phasor Samples: Magnitude and Angle Versus Reference
**Programmable Logic**

\[ E = A \text{ AND } B \text{ OR } C \text{ OR NOT } D \]

**Digital Relay Algorithm**

1. Read Present Sample \( k \)
2. Digital Filtering
3. Phasor Calculation
4. Protection Methods
5. Relay Logic
6. Trip Order

Modify if Required

No Trip
It Takes a Cycle to Catch a Cycle

- Phasors depend on sinusoidal steady state
- Faults change the network
- We want to determine where … fast!
- We want to determine sinusoidal steady state and filter out everything else
- Shorter windows make us faster but less accurate
Traveling Waves Bring Information Fast
Traveling Waves Bring Information Fast

Internal Phase Fault (100 km, 400 kV)

BC fault at 50 km
TW32 0.1 ms
TD3 2.1 ms
TD21 3.7 ms
TW87 0.9 ms
Fault Location = 49.993 km
One-Microsecond Power System View!

This Is Only the Beginning

We’ll all learn more about the power system!