Power System Protection

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Week 1
Philosophy of Protective Relaying

Readings-Mason Chapter 1
• Relay function
• What exactly is a relay?
• CT’s and PT’s
• Abnormal conditions-faults
• Desirable relay characteristics
• Zones of protection
  – Primary and backup protection
Relay function

• Causes fast disconnection of equipment from power system during abnormal conditions
  – Minimizes damage
  – Minimizes effects on the system operation
  – Maximizes power transfer
Relay function

- Power transfer (from C.R. Mason page 13)

Fig. 4. Curves illustrating the relation between relay-plus-breaker time and the maximum amount of power that can be transmitted over one particular system without loss of synchronism when various faults occur.
What exactly is a relay?

• **Measuring device**-receives a signal from the Power System (PS) & determines if the condition is abnormal

• **Control device**-for abnormal conditions, it signals Circuit Breakers (CB) to disconnect equipment
  – It kind of “relays” a signal from the PS to the CB
  – Relay & CB is a system protection team
  – Fuses are simpler system
What exactly is a relay?
What exactly is a CB?
What exactly is a relay?

- **Power System**
- **Voltage Current Xmer**
- **Relay**
- **Circuit Breaker**

Decides if abnormal condition

Change high voltage and currents to relay levels

Abnormal condition, signal is sent to open CB
Current Transformers (CT’s)

• Device that produces current proportional to current in the power system conductor

• Ideal CT has current of:

\[ I_{CT} = \frac{I_{SYS}}{N_{CT}} \]

• Rated \( I_{CT} \) is aprox. 5A, typically (called CT secondary current)
Current Transformers (CT’s)

Common ratios

<table>
<thead>
<tr>
<th>Current</th>
<th>Turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>50:5</td>
<td>10</td>
</tr>
<tr>
<td>100:5</td>
<td>20</td>
</tr>
<tr>
<td>200:5</td>
<td>40</td>
</tr>
<tr>
<td>400:5</td>
<td>80</td>
</tr>
<tr>
<td>600:5</td>
<td>120</td>
</tr>
<tr>
<td>1000:5</td>
<td>200</td>
</tr>
<tr>
<td>2000:5</td>
<td>400</td>
</tr>
</tbody>
</table>

Polarity dot convention
Potential Transformers (PT’s)

- Device that produces voltage proportional to voltage in the power system bus
- Ideal PT has voltage of:
  \[ V_{PT} = V_{SYS} \frac{N_2}{N_1} \]
- Rated \( V_{PT} \) is aprox. 120V, typically (called PT secondary voltage)
Relaying Diagram
Simple Contacts Diagram

- Short hand notation for the trip circuit
- Control Relaying & Instrumentation Diagram (CR&I)
Relay Contacts

• “a” Contact
  – Open when relay that controls it is not picked up, or when CB that controls it is open
  – Closed when relay that controls it is picked up, or when CB that controls it is closed

• “b” Contact
  – Closed when relay that controls it is not picked up, or when CB that controls it is open
  – Open when relay that controls it is picked up, or when CB that controls it closed
Contacts

• A relay is said to be picked up when its:
  – Its “a” contacts are closed
  or
  – Its “b” contacts are open
Faults (Short Circuits)

- Most common type of abnormal condition
- Often Abnormally high currents flow $I_F >> I_L$
- Flow of current in a path not intended for it
- To interrupt $I_F$, circuit must be opened
- Relays often set based on calculated $I_F$

\[
\begin{align*}
\text{Relay Setting} & \quad I_L (\text{continuous}) \\
\end{align*}
\]
Faults (Short Circuits)

• Cause high current
  – mechanical stress
• Cause high temperature arcs
  – destroy equipment, cause fires
• Alter system voltage
• Cause system unbalance
• Block the flow of power
• Cause generator overspeed
  – Instability, loss of synchronism
Fault Current Interruption

- No current flow when breakers open
Desirable Relay Characteristics

• Speed (time to make decision 1/60sec)
  – Minimizes damage from current
  – Maximizes power transfer and stability

• Security
  – Relay should not cause CB to open during normal conditions

• Dependability (reliability)
  – Relay should cause CB to open during abnormal operation
Desirable Relay Characteristics

- **Sensitivity**
  - Ability to detect all faults for the expected limiting system and fault conditions

- **Selectivity**
  - Ability to discriminate between faults internal and external to its intended zone of protection

![Diagram of protection zones]
Primary & Backup Protection

- Relays, CB’s, CT’s & PT’s located at substations
- Substation is a point of
  - Interconnection
  - Switching
  - Voltage transformation
Primary & Backup Protection

- Every equipment should be protected by at least two independent protection systems
  - **Equipment**
    - Lines, busses, transformers, generators
  - **Protection system**
    - Primary and backup
Primary Protection

• **Primary**
  – To do it, zones are drawn on the system’s one-line diagram
  – Zones are defined by CT location and include equipment & CB’s that isolate equipment
Primary Protection

- **Primary protective zones**
  - CB’s located in connection to each PS equipment
  - Zones configured so the fault within the zone causes all CB’s in the zone to open
  - CB’s open simultaneously & instantaneously (no intentional delay)
  - If primary zone is successful, minimum effect on the system (power transfer ability)
Primary Protection

- **Primary protective zones**
  - Zones defined by the CT’s located in the bushings of the CB’s
  - Zones overlap to avoid uncovered areas and CB failure
Primary & Backup Protection

Causes of Relay Failure

- CT’s and circuits
- PT’s and circuits
- Loss of DC supply
  - Short circuit
  - Open circuit
  - Failure of auxiliary switches
- Relay failure
Primary & Backup Protection

Causes of CB failure

- Loss of DC supply
- Open trip coil
- Short circuit trip coil
- Mechanical failure
- Failure of main contacts
Backup Protection

• Provided in case of:
  – Primary relay failure
  – Circuit breaker failure

• Ideally primary & backup must be independent
  – Relay, CB’s, CT’s, PT’s
  – However, duplicity of CB’s is not practical & causes other problems

• Backup is slower than primary
• Opens more CB’s than necessary to clear a fault
• Provides primary protection when primary equipment is out of service
Backup Protection

Types of backup protection

• Remote backup
  – Clears fault one substation away from where the failure has occurred

• Local backup
  – Clears fault in the same substation where the fault has occurred
Remote Backup

- CB’s P and O opens
- CB M stay closed
- Then B, C and I has to open
- Load is lost in this case
Remote Backup

• Trips more system than necessary to clear the fault
• Long backup times from 50-60 cycles (0.8-1.0 sec)
• Difficult to set remote relays
• Initially, more economical
• In the long run is more expensive
Local Backup

- Primary relay op. & energizes timer
- If CB relays remain picked up & timer times out
  - Opens all CB’s on the bus (trips all CB’s)
Local Backup

- J opens
- H closed
- G and I opens
- Load is operating
Local Backup

- P and O open
- M closed
- G and I opens
- L trips locally
- I tripped by communicated signal (Transfer Trip)
- A special kind of backup keeps Z closed
Local Backup

When a CB does not work

- Trips least amount of system in clearing a fault
- Fastest backup times are 9-20 cycles (0.15-0.33 sec)
- Simple relay settings
- Initially has a higher cost
Remote vs. Local Backup

- Remote

- Local
Remote vs. Local Backup

- Remote

- Local