Do We Have to Balance Speed and Security?
Security Enables Speed – And Speed *Can* Improve Security
Let’s Talk Security

Inrush
Through Fault
Saturation
Wiring Error
Relay Failure
Cyber Security
Transformer Construction is Changing

• Lower Losses Specified
• Low Noise Specified
• Laser Etched
• Amorphous
• Improved Stacks
• Super Conductor?
Actual False Trip Event
Harmonics at Energization and Trip
### Blocking Early, Unblocking Later

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Status</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>00501</td>
<td>Relay PICKUP</td>
<td>ON</td>
<td>0 ms</td>
</tr>
<tr>
<td>05631</td>
<td>87 Differential protection picked up</td>
<td>ON</td>
<td>0 ms</td>
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<tr>
<td>05657</td>
<td>87 Crossblock by 2.Harmonic</td>
<td>OFF</td>
<td>67 ms</td>
</tr>
<tr>
<td>05644</td>
<td>87 Blocked by 2.Harmon. A</td>
<td>ON</td>
<td>15 ms</td>
</tr>
<tr>
<td>05646</td>
<td>87 Blocked by 2.Harmon. C</td>
<td>ON</td>
<td>15 ms</td>
</tr>
<tr>
<td>05682</td>
<td>87-1 Phase B (without Tdelay)</td>
<td>ON</td>
<td>66 ms</td>
</tr>
<tr>
<td>00511</td>
<td>Relay GENERAL TRIP command</td>
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<tr>
<td>05691</td>
<td>87 TRIP by 87-1</td>
<td>ON</td>
<td>67 ms</td>
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<tr>
<td>05701</td>
<td>Diff. curr. Ph. A at trip without Tdelay</td>
<td>1.34 l/InO</td>
<td>67 ms</td>
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<td>05704</td>
<td>Restr.curr. Ph. A at trip without Tdelay</td>
<td>1.63 l/InO</td>
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<td>Diff. curr. Ph. C at trip without Tdelay</td>
<td>0.83 l/InO</td>
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<td>Restr.curr. Ph. C at trip without Tdelay</td>
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<tr>
<td>05645</td>
<td>87 Blocked by 2.Harmon. B</td>
<td>ON</td>
<td>108 ms</td>
</tr>
<tr>
<td>05682</td>
<td>87-1 Phase B (without Tdelay)</td>
<td>OFF</td>
<td>108 ms</td>
</tr>
<tr>
<td>05644</td>
<td>87 Blocked by 2.Harmon. A</td>
<td>OFF</td>
<td>191 ms</td>
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</tbody>
</table>
Replay with Current Waveform Analysis (CWA)

CWA blocks before Harmonic
Block Removed
Lessons Learned

- Inrush is Difficult to Predict
- Inrush is not Consistent
- Changes in Transformer Design and Construction Change Inrush
- Multiple Blocking Principles Increase Security and Speed
How Does Increased Security Increase Speed?
Relay Operating Characteristics are Changing

- Trajectory Based
- Improved Quantities
- Error Detection/Correction

$$I_{diff} - I_{Stab} - Trip \ Area$$

Add-on Stabilization

$$CT = ?$$

$$I_{MP1} - I_{MP2}$$
Restrained current due to CT saturation

- relay measures a distorted current signal (red curve)
- relay calculates the fundamental frequency component (blue curve)
- deviation between both curves (green area) is a criteria for signal distortion
- relay determines restrained current depending this signal deviation
Application of Multiple Algorithms

N=1 (1st half-wave): 1-of-1 measurement
N=2 (2nd half-wave): 2-of-2 measurement
N=3 (3rd half-wave): Filtered Algorithm

1. Output is high, if tripping characteristic (A and B) is exceeded; trip follows according to the 2-of-2 algorithm (N=2)

2. If additionally the gradient criteria dI/dt is fulfilled and no blocking (block input gate 5) is pending, a trip according to the 1-of-1 algorithm (N=1) is issued

3. With a high external fault (gate 1 is not high, but dI/dt is fulfilled), gate 3 is high and blocks the fast 1-of-1 algorithm and the filtered algorithm for 150 ms (timer 4) in order to maintain stability throughout CT saturation

4. Output is high, if tripping characteristic (E and F) is exceeded, a trip according to filter algorithm (N=3) is issued, if no blocking (block input gate 5) is pending
Rate of Rise of Stabilizing Quantity

Each Measurement is the average of 8 samples
Internal Short Circuit with Transformer Saturation
Di/dt

External Short Circuit with Transformer Saturation
Trajectory Based Restraint – External Fault with Saturation
Multiple A/D Crosscheck Adds Security
Bad Things Can Happen When Tanks Rupture
Case Study
Case Study

Single Phase Fault by Low Side Bushing

30,000 gal spilled

No Fire
Fault Record Combines with Physical Examination
Combine Voltage, Current, Time and Location

53,900 Amps
78 kV (at fault location)

= 70,000 kJ per cycle
Could Tripping Have Been Faster?

Fault Playback through a test set into a more modern relay provides options.
Could Tripping Have Been Faster?

• Tripping in 4-20 ms vs 28 ms

• Clearing ½ – 1 ½ cycle earlier (depends on test set)

• 35,000 – 105,000 kJ energy reduction

• Tank saved?
Questions
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