Applying Intelligent Fast Load Shed Using IEC 61850 GOOSE

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• Introduction/Types of Load Shedding Solutions
• IEC 61850 Fast Load Shed Architecture
• Case Study Fast Load Shed Architecture
• Dynamic Source/Load Power Balancing
• Contingency Operation
• Fast Speed
• Lessons Learned
• Enhancements over Existing Systems
• HMI and DCS Involvement
• Conclusions
Introduction/Types of Load Shed

- Industrial facilities with co-generation experience large frequency decay if source lost (power-balance disrupted)
- Can cascade – whole local system lost
- Conventional load shedding schemes (>250ms)
  Underfrequency and dF/dt
  Undervoltage
- Traditional contingency based load shedding schemes (160 – 400ms)
  PLC or PC based (centralized)
- Fast load shedding schemes (<150ms)
  IED or EMS/SCADA based
  Source/load power balance calculated
IEC 61850 Fast Load Shed Architecture

• What is a power-balanced Fast Load Shed (FLS) system?
  One controller
  Aggregators (0 to multiple)
  IEC 61850-capable Ethernet network
  IEC 61850-8-1 capable end devices (IEDs)

• Controller supports up to 64 end devices (IEDs)

• Aggregator extends system by 64 Loads

• Controller: 32 sources & 32 loads/load groups

• Each load group has settable priority
IEC 61850 Fast Load Shed Architecture

32 Infeed Powers
32 Reserve Powers
32 Load Group Powers
Load Group Priorities/Trip Masks

External Computer
HMI/DCS (Optional)

Ethernet Switch

Fast Load Shed Controller (FLSC)

Fast Load Shed Aggregator (FLSA)

MTR Relay
FDR Relay
Main Relay

Eth Switch

MTR Relay
FDR Relay
Main Relay

Eth Switch

Main Relay
Gen Relay
Trfr Relay

Eth Switch

Main Relay
FDR Relay
MTR Relay

Loads

Loads, Infeeds

Loads

Modbus over TCP/IP

Goose

Aggregator Data Message (32 Ld Groups)
Load Data Units, analog/offline stat GOOSE
Shed commands, digital
GOOSE message
Infeed data units (power, offline)
Case Study Fast Load Shed Architecture

- 38 Data Units
- 11 Infeeds Power/Status
- 18 Load Group Powers/Status
- Load Group Priorities

External Computer HMI

Ethernet Switch

Fast Load Shed Controller (FLSC)

Main Relay

Loads, Infeeds

Loads
Goal: re-establish source/load power balance when source power is lost

Fast Load Shed Controller (FLSC) receives source/load powers once per second

FLSC calculates power balance

Checks if generation/source lost exceeds reserve

Send GOOSE messages to shed Loads per pre-defined priorities above reserve

FLSC recalculates power balance after contingency time
Contingency Operation

- FLS trigger: when source power is lost
- Case study system: when utility supply is lost
- FLS calculate loads on lowest priority
- Shed loads at Subs 1, 2 and Power Plant
- Reserves set to 0kW
- Keeps all power values fixed until shedding done – contingency timer
- Priorities changed via HMI
Simplified Source-Load Example

- Total system load: \( P_{\text{Grp} 1} + P_{\text{Grp} 2} + P_{\text{Grp} 3} + P_{\text{Grp} 4} + P_{\text{Grp} 5} \)
- Total source/gen: \( P_{\text{G} 1} + P_{\text{G} 2} + P_{\text{M} A} + P_{\text{M} B} \)
- Load group priorities set from HMI
• Load group prioritization (32 load groups; 128 priorities)
• Set by user
• Higher numbers mean lower priority loads
• 9MW source loss above reserve, FLSC will shed groups 3 and 5 (i.e. 10MW)

<table>
<thead>
<tr>
<th>Asset</th>
<th>Value</th>
<th>Priority/Status (user set)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>10 MW</td>
<td>1 (highest priority)</td>
</tr>
<tr>
<td>Group 2</td>
<td>10 MW</td>
<td>0 (do not shed)</td>
</tr>
<tr>
<td>Group 3</td>
<td>5 MW</td>
<td>128 (lowest priority)</td>
</tr>
<tr>
<td>Group 4</td>
<td>20 MW</td>
<td>2</td>
</tr>
<tr>
<td>Group 5</td>
<td>5 MW</td>
<td>3</td>
</tr>
</tbody>
</table>
Fast Speed

- Fast load shedding including internal processing or execution time

<table>
<thead>
<tr>
<th>Execution Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>t = 0</td>
<td>End device (Source or Gen Prot) detects trip/breaker operation</td>
</tr>
<tr>
<td>3000 μs</td>
<td>GOOSE message with change of online state sent by end device</td>
</tr>
<tr>
<td>200 μs</td>
<td>GOOSE message passed through multiple LAN Ethernet switches</td>
</tr>
<tr>
<td>3000 μs</td>
<td>FLSC processing and calculations from received GOOSE message</td>
</tr>
<tr>
<td>1000 μs</td>
<td>Shed command GOOSE message composed by FLSC</td>
</tr>
<tr>
<td>500 μs</td>
<td>FLSC GOOSE message is sent through LAN Ethernet switches (20)</td>
</tr>
<tr>
<td>3000 μs</td>
<td>Shed command GOOSE message parsed by end load devices</td>
</tr>
<tr>
<td>4000 μs</td>
<td>End load device calculations and processing</td>
</tr>
<tr>
<td>2000 μs</td>
<td>Trip contact output closes on end load devices</td>
</tr>
<tr>
<td>16.7 ms</td>
<td>Total FLS execution time</td>
</tr>
<tr>
<td>67-100 ms</td>
<td>End device load breakers open (3-5 cycle breaker)</td>
</tr>
</tbody>
</table>
Fast load shedding including internal processing or execution time

<table>
<thead>
<tr>
<th>Execution Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>t = 0</td>
<td>Utility breaker opened by protection</td>
</tr>
<tr>
<td>2 ms</td>
<td>Breaker status open after de-bounced, island detected (1.05MW under generation), priorities 32, 18, 17, 16, 15, 14 and 12 load group shed sent by FLSC (1.148MW)</td>
</tr>
<tr>
<td>13 ms</td>
<td>Shed command message received at load devices</td>
</tr>
<tr>
<td>15 ms</td>
<td>Trip coils energized</td>
</tr>
<tr>
<td>46 ms</td>
<td>Shed breaker open – load disconnected (Breaker time 31ms) by FLS scheme</td>
</tr>
<tr>
<td>64 ms</td>
<td>ROCOF (df/dt) trigger (typical)</td>
</tr>
<tr>
<td>106 ms</td>
<td>Under frequency load shed trigger (typical)</td>
</tr>
</tbody>
</table>
During FAT/SAT/Commissioning and system operations, following changes/improvements implemented:

Testing: FAT/SAT not all IED or settings available. Live system testing performed – over and under generated Island. All contingencies tested live. Detailed test plan used.

Scheme Initialization: During active monitoring of FLS, tripping of a DG initiated FLS with undesired load shedding. FLS initialization changed to be only Loss of Utility.

Post FLS operation and Challenges:
1) Event report analysis: FLSC triggered and captured report and SOE. End device IEDs did capture SOE but not all waveforms. Some events not captured (contact inputs/outputs) all needed info i.e. when breakers tripped/closed. Not all waveform captures and triggers configured correctly (i.e. some powers missing). All SOE and waveforms should be used during testing.
Case Study System: Lessons Learned 2

Post FLS operation and Challenges:

2) Time synchronization: All IEDs synchronized via SNTP (10ms), but some DST not configured correctly. Better choice is Irig-B (1ms) or PTP.

3) Disable/reset of FLS: initially enable/disable only from HMI – problem if comms lost. Local control pushbutton implemented (FLSC close proximity to HMI). Each FLS trip implemented as Latch in end devices (to maintain trip if comms lost), reset one-by-one from HMI. Global reset function implemented.

4) Local generator protection coordination: some system faults on longer than 0.6s before feeder breaker tripped islanding system. Gas turbine protection also tripped as FLS operated – system lost. Proper feeder/generator protection coordination needed. Some feeder faults trip only on 27P (undervoltage) at PCC – only occurs if gens trip too. One event 59N operated; FLS was successful. Transfer tripping from utility explored.
Case Study System: Lessons Learned 3

- Post FLS operation and Challenges:
  5) Use of Synchrophasors: during a FLS event, dynamic changes of local system (Voltages and Frequency) observed at update rate of IEDs. PMUs can be used to observe/analyze fast dynamic system changes during FLS events.
An aggressive GOOSE retransmission scheme within a FLS controller, aggregator, or end device is used.

<table>
<thead>
<tr>
<th>Sequence Number</th>
<th>Time From The Event</th>
<th>Time Between Messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 ms</td>
<td>0 ms</td>
</tr>
<tr>
<td>1</td>
<td>4 ms</td>
<td>4 ms</td>
</tr>
<tr>
<td>2</td>
<td>8 ms</td>
<td>4 ms</td>
</tr>
<tr>
<td>3</td>
<td>16 ms</td>
<td>8 ms</td>
</tr>
<tr>
<td>4</td>
<td>Heartbeat</td>
<td>Heartbeat</td>
</tr>
<tr>
<td>5</td>
<td>Heartbeat</td>
<td>Heartbeat</td>
</tr>
</tbody>
</table>
**Device Interoperability/Interchangeability**

- End devices (IEDs) send power & receive shed commands via IEC 61850 GOOSE.
- IEC 61850 GOOSE is an open standard, i.e. any IED compliant to IEC 61850-8-1 can be used.
- Use of IEC 61850 increases system longevity – replacing or adding IEDs supported.
- Publisher/subscriber architecture makes future IED changes much easier.
- Minimal changes to FLSC or FLSA needed for system expansion.
Enhancements Over Existing LS Systems

• Speed – much faster than PLC/SCADA/PC
• Future proof – based on IEC 61850 architecture
• Programming based on communications – not logic in PLC
• System changes and expansions much simpler
• Reduction of end devices (hardware & wiring)
• Utilization of existing IEDs and networks
• System can be much larger – up to 2500 IEDs
• Optimal load shedding achieved – no Under/Over
HMI and DCS Involvement

• Load group shed priorities: fixed or dynamic
• HMI, DCS or SCADA to change priorities
  Process priorities can change – time-of-day; time-of-year or process importance/materials etc.
• Load groups blocked from load shed
Conclusions

• Fast Load Shed is essential for industrials with co-gen for system stability
• Prevents loss of complete system if gen/source is lost
• Fast Load Shed system is proven: Case Study
• Several advantages over existing systems
• Large and complex systems and expansions more manageable
Thank You

Questions?