Modern Protective Relay Enables Generator Operating at Wide Range of Frequencies and Different Phase Rotation

Umar Khan—GE
Carlos Aguilar - GE
Fabio Bianchi—Baker Hughes
Alessio Tobaldi—Baker Hughes

2019 Texas A&M Protective Relaying Conference
Agenda

• Introduction - Bi-directional Generator Application and Test Modes
• A Typical Modern Generator Protection Relay
• Discussion on the Protection Challenges
  • Off-nominal frequency operation
  • Tailoring the protection scheme for each test mode
• Conclusions

Takeaways...
Challenges and capability of the generator protection relay and its performance when applied to the non-conventional system
Nova LT16 GT is a two-shaft gas turbine designed for mechanical drive and power generation applications.

- As part of the NPI (R&D) program there is a need to test it throughout a wide range of speeds and loads. A generator is chosen to provide the load for the turbine.
Introduction

- Nova LT16 GT is a two-shaft gas turbine designed for mechanical drive and power generation applications.
- The gas turbine is connected to a generator that delivers energy to a resistor load bank or the national grid.
Nova LT16 GT is a two-shaft gas turbine designed for mechanical drive and power generation applications.

The gas turbine is connected to a generator that delivers energy to a resistor load bank or the national grid.

To speedup R&D cycle, two twin turbines are connected to a bidirectional generator, only one turbine runs at a time.
**Introduction**

Generator:
- 4 Poles Machine
- Rated output of 22 MVA
- Static excitation system
- Cooled by water

Load system:
- Resistor Load bank packs
- Grid for endurance tests
Generator Protection

- Modern generator protection relay is used to prevent the generator from electrical failure or if not possible, the mitigation of that electrical failure.

- Modern protection relay provides protection against the short circuit conditions as well as control and monitoring solutions.

- Generator protection devices provides:
  - Primary protective elements
  - Protection against generator abnormal operating conditions
  - Back-up protection
Generator Protection

• Modern generator protection relay is used to prevent the generator from electrical failure or if not possible, the mitigation of that electrical failure.

• Modern protection relay provides protection against the short circuit conditions as well as control and monitoring solutions.

• Generator protection devices provides:
  • Primary protective elements
  • Protection against generator abnormal operating conditions
  • Back-up protection

What are the Performance Challenges to protection relay when applied to the such non-conventional systems
A Typical Modern Generator Protection Relay

Diagram of a generator protection relay, showing connections and components.
A Typical Modern Generator Protection Relay

<table>
<thead>
<tr>
<th>Codes of generator protection elements</th>
<th>Description of protection elements in a typical generator protection IED</th>
</tr>
</thead>
<tbody>
<tr>
<td>21P</td>
<td>Phase distance backup</td>
</tr>
<tr>
<td>24</td>
<td>Volts per hertz</td>
</tr>
<tr>
<td>25</td>
<td>Synchro-check</td>
</tr>
<tr>
<td>27P</td>
<td>Phase under-voltage</td>
</tr>
<tr>
<td>27TN</td>
<td>Third harmonic neutral under-voltage</td>
</tr>
<tr>
<td>27X</td>
<td>Auxiliary under-voltage</td>
</tr>
<tr>
<td>32</td>
<td>Sensitive directional power</td>
</tr>
<tr>
<td>40</td>
<td>Loss of excitation</td>
</tr>
<tr>
<td>46</td>
<td>Generator unbalance</td>
</tr>
<tr>
<td>49</td>
<td>Thermal overload (RTD)</td>
</tr>
<tr>
<td>50G</td>
<td>Ground instantaneous overcurrent</td>
</tr>
<tr>
<td>50N</td>
<td>Neutral instantaneous overcurrent</td>
</tr>
<tr>
<td>50P</td>
<td>Phase instantaneous overcurrent</td>
</tr>
<tr>
<td>50SP</td>
<td>Split phase protection</td>
</tr>
<tr>
<td>50/27</td>
<td>Accidental energization</td>
</tr>
<tr>
<td>51G</td>
<td>Ground time overcurrent</td>
</tr>
<tr>
<td>51P</td>
<td>Phase time overcurrent</td>
</tr>
<tr>
<td>59N</td>
<td>Neutral overvoltage</td>
</tr>
<tr>
<td>59P</td>
<td>Phase overvoltage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Codes of generator protection elements</th>
<th>Description of protection elements in a typical generator protection IED</th>
</tr>
</thead>
<tbody>
<tr>
<td>59_2</td>
<td>Negative-sequence overvoltage</td>
</tr>
<tr>
<td>64F</td>
<td>Field ground protection (low-freq. injection based)</td>
</tr>
<tr>
<td>64S</td>
<td>Sub-harmonic injection - 100% stator ground</td>
</tr>
<tr>
<td>64TN</td>
<td>100% stator ground third harmonic neutral voltage</td>
</tr>
<tr>
<td>67_2</td>
<td>Negative-sequence directional overcurrent</td>
</tr>
<tr>
<td>67N</td>
<td>Neutral directional overcurrent</td>
</tr>
<tr>
<td>67P</td>
<td>Phase directional overcurrent</td>
</tr>
<tr>
<td>68/78</td>
<td>Power swing detection</td>
</tr>
<tr>
<td>81A</td>
<td>Frequency out-of-band accumulation</td>
</tr>
<tr>
<td>81O</td>
<td>Over-frequency</td>
</tr>
<tr>
<td>81R</td>
<td>Rate of change of frequency</td>
</tr>
<tr>
<td>81U</td>
<td>Under-frequency</td>
</tr>
<tr>
<td>87G (RGF)</td>
<td>Restricted ground fault protection</td>
</tr>
<tr>
<td>87S</td>
<td>Stator differential</td>
</tr>
</tbody>
</table>
## Operation Modes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connection</strong></td>
<td>Resistor Load</td>
<td>national grid</td>
<td>Resistor Load</td>
<td>Resistor Load</td>
<td>Resistor Load</td>
</tr>
<tr>
<td><strong>Voltage test range</strong></td>
<td>0 – 10.5 kV</td>
<td>10.5 kV</td>
<td>0 – 13.8 kV</td>
<td>0 – 10.5 kV</td>
<td>0 – 2.2 kV</td>
</tr>
<tr>
<td><strong>Frequency test range</strong></td>
<td>25 to 65 Hz</td>
<td>50 Hz</td>
<td>25 to 65 Hz</td>
<td>25 to 65 Hz</td>
<td>10 Hz</td>
</tr>
<tr>
<td><strong>Generator Phase rotation system</strong></td>
<td>Counter Clock Wise ACB</td>
<td>Counter Clock Wise ACB</td>
<td>Clock Wise ABC</td>
<td>Clock Wise ABC</td>
<td>Counter Clock Wise ACB</td>
</tr>
<tr>
<td><strong>Generator moved by</strong></td>
<td>Turbine Nova LT16 FETT at OGTL</td>
<td>Turbine Nova LT16 FETT at OGTL</td>
<td>Turbine Nova LT16 SETT at SAPO</td>
<td>Turbine Nova LT16 SETT at SAPO</td>
<td>Turbine Nova LT16 FETT at OGTL</td>
</tr>
</tbody>
</table>
Discussion on the Protection Challenges
Protection Scheme Used

• A single protection IED is used to protect the generator: G60
• K-SET2 operation mode does not differ from a standard generator protection scheme
• K-SET1, K-SET3 and K-SET4 differ from standards one as those provided by IEEE C37.102.
• There is no much relevant effect on application of IEEE C37.101
• Stator differential protection, generator unbalance and 100% stator ground protection share the same settings.
Protection Scheme Used

K-SET1, K-SET3 and K-SET4 modes:

- Connected to resistor load banks, so NO Importing active power, NO Importing reactive power, NO Power Swing, NO Accidental Energization
- Loss of excitation, reverse power, accidental energization and phase under voltage remain disabled
- Internal logic to reverse phase sequence rotation
- Phase distance is active in K-SET2, but K-SET1, K-SET3 and K-SET4 use an instantaneous overcurrent
- Neutral overvoltage, phase overvoltage, overexcitation protection and frequency protection elements are set depending on each voltage and frequency ranges at each group.
Off-nominal Frequency Operation

There are special concerns when off-nominal frequencies are addressed from a strict protection perspective:

- Low frequencies
- High frequencies
- Frequency rate of change

No Risk because of higher frequencies and frequency rate of change

- Maximum test frequency was set to 65 Hz
- The tests did not require great rates of change

Low frequencies posed several challenges
Off-nominal Frequency Operation

Impact on

- Relay Current Magnetics
- Magnitude and Phase Measurements
- Protection Performance
Impact of Low Frequency Operation

Current Transformer Performance

The current transformer knee point voltage is reduced as frequency is reduced.

Excitation voltage significantly reduces as the frequency is decrease from nominal to maintain V/Hz.

CT capability to withstand saturation at such low frequencies is reduced significantly.
Impact of Low Frequency Operation

Relay Current Magnetics Performance

Magentics used in the relay as current transducers are also current transformers.

Therefore, performance of relay current transducers at low operating frequencies is important to analyze.

Generator operation at 10Hz frequency (test mode “K-Set 1”) didn’t pose any risk to relay magnetics.

Results from laboratory test performed. 2Hz frequency signal input to relay terminals (ideal) vs actual signal measured by the relay.
Impact of Low Frequency Operation

On Phasor Measurements and Metering

- Typically, RMS- or DFT-type estimators are used to calculate phasors.
- Protection functions that use DFT-type phasors to detect the presence of higher levels of fault currents will be affected.
- Using RMS-type estimator complemented with a peak sample detector to detect the maximum fault current level, but such estimator accuracy will not be great.
Impact of Low Frequency Operation

Protection Performance

- For example, over-current protection typically uses fundamental currents (DFT-type) to detect short circuit.
- Performance of the overcurrent protection can be impacted at the low frequency operation.

This problem can be solved by 
(1) proper selection of current transformer (2) lower setting of the overcurrent pickup level.
Impact of Low Frequency Operation

Protection Performance

• Differential protection performance during an external fault:
  • Single- or dual-slope characteristic and higher pickup are typically used to prevent mal-operation of the differential protection in the event of an external fault with CT saturation.

However, it won’t impact the differential operation because both ends CTs see the same low frequency currents resulting in zero or very small false differential current measurement.
Conclusions

• Frequency tracking feature can accommodate actual frequency to the phasor estimator and eliminate phasor estimation oscillation.
• An unavoidable transient will occur during the adapting time so frequency change rate is also a factor to consider
• Saturation issue because of de-rated CT capability at low frequencies as well as operation times because of saturation and 10 Hz wave period deviates from standard settings and so these factors have been included in the pick-up levels and time delays.
• Pick-up levels and delay times were set conservative and bordering the “control” or specific test operational ranges enhancing dependability.
Thank You

Questions?