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The widest range of products for power systems protection, control, measurement and supervision. Interoperable and future-proof solutions designed to implement the core values of the IEC 61850 standard. ABB’s leading-edge technology, global application knowledge and experienced support network ensures complete confidence that your system performs reliably - in any situation.
ABB is pleased to provide you with technical information regarding protective relays. The material included is not intended to be a complete presentation of all potential problems and solutions related to this topic. The content is generic and may not be applicable for circumstances or equipment at any specific facility. By participating in ABB’s web-based Protective Relay School, you agree that ABB is providing this information to you on an informational basis only and makes no warranties, representations or guarantees as to the efficacy or commercial utility of the information for any specific application or purpose, and ABB is not responsible for any action taken in reliance on the information contained herein. ABB consultants and service representatives are available to study specific operations and make recommendations on improving safety, efficiency and profitability. Contact an ABB sales representative for further information.
Mike is a Senior Engineer, Product Specialist for the Relion family 670 and 650 product series. He is located in Raleigh, North Carolina. Mike has been part of the NAM SA Products team for 9 months. Prior to this he worked as a Senior Applications Specialist / Senior Regional Technical Manager for 12 years at the SA Product factory in Västerås, Sweden.

Prior to joining ABB SAP in Sweden in 2000, Mike was Chief Consultant, Protection (Transmission) at Eskom (national power utility, South Africa). Mike joined Eskom as a training engineer in 1983.

Mike graduated from the University of Cape Town with BSc (electrical engineering) degree (with honors) in 1980.
Learning objectives

- Power Generation fundamentals
- Generator Faults
- Generator Abnormal Conditions
- Typical Generator Protections
Power station is the most complex part of the power system
Typical Parts of a Power Plant

- Busbar in HV Substation
- HV - Breaker
- Main Transformer
- Generator Breaker
- Turbine valve
- Turbine - Generator
- Earthing System

HV Substation
Power plant
Auxiliary Transformer
Excitation Transformer
Excitation System
Field Circuit Breaker
Different power plants electrical equipment layouts
Damage to the stator core in case of earth-fault

- Practically all unit connected generators are high-impedance earthed
- Only industrial generators may be low-impedance earthed
Stator winding earthing practices

- **Resistive Grounded**: $\sim 1k\Omega$
- **Grounding Transformer (Neutral)**: $\sim 0.5\Omega$
- **Grounding Transformer (Terminal)**: $\sim 3.0\Omega$
- **Isolated**
Possible faults

- Stator Earth Faults
- Rotor Earth Faults
- Stator Short Circuits
- Stator/Rotor Interturn faults
- Unit transformer faults
- External faults
Abnormal operating condition

- overcurrent/overload
- unbalanced load
- overtemperature
- over- and undervoltage
- over- and underexcitation
- over- and underfrequency
- over-fluxing
- asynchronous running
- out of step
- generator motoring
- failures in the machine control system (i.e. AVR or governor failure)
- failures in the machine cooling system
- failures in the primary equipment (i.e. breaker head flashover)
- open phase
Allocation of protection functions

32 Reverse power
81O/U Frequency

46 Unbalance
40 Loss of excitation
78 Pole slipping
64R Earth fault rotor
49R Rotor overload

87G/87O Differential
59 Over-voltage
24V/Hz over-fluxing
49S Stator over-load
21/51V Voltage/over-current
64S Earth fault stator
Inter-turn
50AE Accidental energizing

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### Function allocations with older generation relays

- **Older type of design:**
  - M1 and M2 with different function allocations

#### Table 3: Example on relay functions divided into two function groups

<table>
<thead>
<tr>
<th>Type of fault</th>
<th>ANSI</th>
<th>Protection function</th>
<th>System</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generator stator</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Short circuit</td>
<td>87G</td>
<td>Generator differential</td>
<td>A</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Minimum impedance or alternatively</td>
<td>B</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>51/27</td>
<td>Overcurrent/undervoltage for thyristor magnetisation</td>
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<td></td>
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<tr>
<td></td>
<td>51</td>
<td>Overcurrent</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Dissymmetry</td>
<td>46</td>
<td>Negative sequence overcurrent</td>
<td>A</td>
<td>X</td>
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<tr>
<td>Stator overload</td>
<td>49</td>
<td>Thermal overload</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stator earth fault</td>
<td>50</td>
<td>95% stator earth fault</td>
<td>A</td>
<td>X</td>
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<tr>
<td>Loss of excitation</td>
<td>40</td>
<td>Reactive current and phase angle</td>
<td></td>
<td>X</td>
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<tr>
<td>Motoring</td>
<td>32</td>
<td>Reverse power Redundant protection used for large generators</td>
<td></td>
<td>X</td>
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<tr>
<td>Overspeed</td>
<td>81</td>
<td>Max. frequency</td>
<td></td>
<td>X</td>
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<tr>
<td>Turbine blade fatigue</td>
<td>81</td>
<td>Min. frequency</td>
<td></td>
<td>X</td>
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<tr>
<td>Interruption fault</td>
<td>50 or 51N</td>
<td></td>
<td></td>
<td>(X)</td>
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<tr>
<td>Overvoltage</td>
<td>59</td>
<td>Overvoltage</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Over magnetization</td>
<td>24</td>
<td>V/Hz</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Low voltage</td>
<td>27</td>
<td>Undervoltage</td>
<td></td>
<td>X</td>
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<tr>
<td>Inadvertent breaker closing</td>
<td>50/27</td>
<td>Overcurrent with low voltage</td>
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<td>X</td>
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<tr>
<td>Shaft current</td>
<td>-</td>
<td>Overcurrent, fixed time</td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Generator rotor</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotor overload</td>
<td>49</td>
<td>Thermal overload</td>
<td>A</td>
<td>X</td>
</tr>
<tr>
<td>Rotor earth fault</td>
<td>64R</td>
<td>Injected AC</td>
<td></td>
<td>X</td>
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<tr>
<td></td>
<td></td>
<td>Injected DC</td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Step-up (Block) transformer</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Short circuit/earth fault</td>
<td>87T</td>
<td>Differential protection</td>
<td>A</td>
<td>X</td>
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<tr>
<td>Overcurrent</td>
<td>50/51</td>
<td>Time overcurrent with instantaneous function</td>
<td></td>
<td>X</td>
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<tr>
<td>Breker failure protection</td>
<td>50BFR</td>
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<td>X</td>
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<td>Earth fault differential prot.</td>
<td>87D</td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Over magnetization prot.</td>
<td>24</td>
<td>V/Hz</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Generator protection with modern IEDs

- Generator/transformer protection with integrated IEDs
- Mainly function duplication used
  - Most functions duplicated
- Duplication not used for small machines only
Generator protection

Other functions available from the function library

<table>
<thead>
<tr>
<th>Function</th>
<th>Alternative</th>
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<tbody>
<tr>
<td>25</td>
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<td>31/&gt;</td>
<td>51/27</td>
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<tr>
<td>U&lt;/I&gt;</td>
<td>32N</td>
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<tr>
<td>P&lt;/&gt;</td>
<td>64S</td>
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<tr>
<td>R&lt;/E&lt;&gt;</td>
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<tr>
<td>SES RSYN</td>
<td>PH PIOC</td>
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<tr>
<td>CV GAPC</td>
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<tr>
<td>SDE PSDE</td>
<td></td>
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<tr>
<td>STTI PHIZ</td>
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<td>52PD</td>
<td>51/67</td>
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<tr>
<td>31/&gt;</td>
<td>51V</td>
</tr>
<tr>
<td>1&gt;/U</td>
<td>87CT</td>
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<tr>
<td>12d/I</td>
<td>64R</td>
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<tr>
<td>R&lt;/E&lt;&gt;</td>
<td></td>
</tr>
<tr>
<td>CCS RPLD</td>
<td>OC4 PTOC</td>
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<td>CV GAPC</td>
<td></td>
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<tr>
<td>ROTI PHIZ</td>
<td></td>
</tr>
<tr>
<td>87T</td>
<td>31d/I</td>
</tr>
<tr>
<td>87</td>
<td>1dN</td>
</tr>
<tr>
<td>T2W PDIFF</td>
<td>HZ PDIFF</td>
</tr>
</tbody>
</table>
Generator protection with 87HZ

- Fast and sensitive differential protection against short-circuits
- Requires dedicated and identical CT cores on both sides of the generator
- Requires external resistor and metrosil

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Generator protection with 87T
Complete Protection Scheme

- Generator M1 & M2 protection
  - Two identical IEDs with 87G (low/high impedance based)

- Complete Unit Protection for Smaller Machines
  - One with 87G
  - One with 87T or 87O
Generator protection & optional transformer protection

Other functions available from the function library

<table>
<thead>
<tr>
<th>25</th>
<th>50</th>
<th>3l&gt;</th>
<th>51/27</th>
<th>U&lt;l/b&gt;</th>
<th>64S</th>
<th>RSE&lt;</th>
<th>87T</th>
<th>3kd/l</th>
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</thead>
<tbody>
<tr>
<td>SES RSYN</td>
<td>PH PIOC</td>
<td>CV GAPC</td>
<td>STTI PHIZ</td>
<td>T2W PDIF</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>52PD</td>
<td>PD</td>
<td>87CT</td>
<td>12d/l</td>
<td>51V</td>
<td>b/U</td>
<td>64R</td>
<td>RRe&lt;</td>
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<td>CC RPLD</td>
<td>CCS RDIF</td>
<td>CV GAPC</td>
<td>ROTI PHIZ</td>
<td>SDE PSDE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Complete generator-transformer unit protection
Stator short circuit

- Consequence of stator short circuit
  - Insulation, windings and stator core can be damaged
  - Large forces, caused by large fault currents, can give damage to other components in the plant
  - Risk of explosion and fire
  - Mechanical stress on generator- and turbine shafts
Detection of stator short circuits

- Protection functions
  - Generator differential protection
  - Block (unit) differential protection
  - Directional negative sequence overcurrent protection
  - Under impedance protection
  - Phase overcurrent protection
  - Voltage dependent phase overcurrent protection
  - Under voltage protection
  - Phase overcurrent protection of the block transformer
Phase to phase fault in the stator winding

- **Endangering condition**
  - Overcurrent
- **Protected object**
  - Stator winding
- **Consequences**
  - Heating
  - Forces
  - Smelted stator core

Main Protection Function

Reserve Protection Function
Generator differential protection

- Unstabilized differential protection level
- Stabilized differential protection level
  - Harmonic blocking
- Negative sequence unrestrained
  - Combination: bias differential and negative sequence internal/external discriminator; increases speed and security
- Negative sequence sensitive differential protection
Differential protection characteristics

The restrained characteristic is defined by the settings:

1. IdMin
2. EndSection1
3. EndSection2
4. SlopeSection2
5. SlopeSection3

\[ \text{D}_{\text{operate}} \frac{\text{operate current}}{\text{gen. rated curr.}} = \frac{\text{slope}}{100\%} = \frac{\text{D}_{\text{restrain}} \text{restrain current}}{\text{gen. rated curr.}} \]

Operate unconditionally

Operate conditionally

UnrestrainedLimit

Section 1
Section 2
Section 3

IdMin

Restrain
Generator differential protection

- Shall trip
  - Turbine: close down active power
  - Generator breaker: if available
  - Field breaker
  - Unit breaker: If no generator breaker
  - Fire protection
Different differential protection functions can be used
Overall or transformer differential protection (87O/87T)

The diagram illustrates the concept of differential protection with three sections:

- **Section 1**: The initial section with a linear slope up to the end of Section 1.
- **Section 2**: The intermediate section with a steeper slope up to the end of Section 2.
- **Section 3**: The final section with the steepest slope.

The current equation is:

\[ I_{\text{diff}} = I_{\text{bias}} - I_{\text{dunre}} - I_{\text{min}} \]

Where:
- \( I_{\text{diff}} \) is the differential current.
- \( I_{\text{bias}} \) is the bias current.
- \( I_{\text{dunre}} \) is the unrestrained current.
- \( I_{\text{min}} \) is the minimum current.

This diagram is used to protect transformers by detecting and isolating faults within the system.
Generator unit (overall) differential protection

- Identical to transformer differential protection
  - Zero sequence current elimination
  - Vector group compensation
  - Transformer ratio compensation
  - Unstabilized differential protection
  - Stabilized differential protection
    - Harmonic blocking
    - Waveform blocking
  - Negative sequence unrestrained
    - Combination: bias differential and negative sequence internal/external discriminator
- Negative sequence sensitive differential protection
Transformer (overall) differential protection

- Shall trip
  - Turbine: close down active power
  - Generator breaker: if available
  - Field breaker
  - Unit breaker
Phase to phase fault in the transformer winding

- Endangering condition
  - Overcurrent
- Protected object
  - Transformer windings
- Consequences
  - Heating
  - Forces
  - Smelted trafo core

Main Protection Function

Reserve Protection Function
Phase to phase fault at the generator buswork 1

- Endangering condition
  - Overcurrent
- Protected object
  - Buswork, other equipment
- Consequences
  - Heating
  - Forces
  - Mechanical damages

Main Protection Function

Reserve Protection Function
Phase to phase fault at the generator buswork 2

- Endangering condition
  - Overcurrent

- Protected object
  - Buswork, other equipment

- Consequences
  - Heating
  - Forces
  - Mechanical damages

Main Protection Function

Reserve Protection Function
Short circuit protection: Differential protection (87)

- Aux. Transformer Differential 87SST
- Unit Transformer Differential 87T
- Generator Diff 87G

Transformer differential prot. 87T
Differential protection for service station transformer 87SST
Generator differential prot. 87G

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Under-impedance protection

- Backup protection for internal short circuits in the generator or the unit transformer
- Backup or main protection for fault at the busbar where the plant is connected to the power system
- Backup protection for line-faults at lines out from the power plant
- Up to 3-zones with offset mho characteristic

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Under-impedance protection (21)

- Offset mho characteristic with up to three zones (two zones shown only)
  - Zone 1: Generator and trafo back up
  - Zone 2: External faults back up
Phase overcurrent protection

- Backup protection for internal short circuits in the generator or the unit transformer
- Backup or main protection for fault at the busbar where the plant is connected to the power system
- Backup protection for line-faults at lines out from the power plant
Generator short circuit current

- The fault current from the generator change during fault sequence
  - Change of generator reactance $X_d'' \rightarrow X_d' \rightarrow X_d$
  - Dependent of the excitation system
Voltage dependent phase overcurrent protection
External short circuit

Before Fault
First period of Fault
After 0.4 s
I >

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Voltage controlled phase overcurrent protection
External phase-to-phase fault

- Endangering condition
  - Overcurrent

- Protected object
  - External power system parts.

- Consequences
  - Heating
  - Forces
  - Mechanical damages

Main Protection Function

Reserve Protection Function
External earth fault

- Endangering condition
  - Overcurrent
- Protected object
  - External power system parts.

- Consequences
  - Heating
  - Forces
  - Mechanical damages

Main Protection Function
Reserve Protection Function
Stator earth fault

- Damages on the stator iron
- Increased voltage on “healthy phases”
- Small fault currents
- Sensitivity requirements on fault clearance
- The fault resistance is normally low at stator earth fault
- The residual voltage and earth fault current is highly dependent on fault location in the generator
Voltage based 95 % stator earth fault protection

Neutral point voltage transformer used to measure Uo voltage

Voltage Uo has the following primary value for the solid Ph-Gnd fault at generator HV terminals

$$Uo = \frac{U_{Gen\_Ph-Ph}}{\sqrt{3}}$$
Current based 95 % stator earth fault protection

Neutral point current measurement
Why 95 % and 100% stator ground fault protection?

- Protected zone is approximately 95%
- Last 5% is NOT protected

Over voltage function
95% stator ground fault 59GN
U = 0.05 Un
T = 0.5 s
Possible 100 % stator earth fault protection solutions

- Measurement of the "natural" third harmonic voltage induced in the generator can be used to protect against EF close to the generator neutral point (i.e. 3rd harmonic based principle; 59THD)

- Neutral point voltage injection where the injected voltage has non-harmonic frequency (i.e. injection principle; 64S)
3rd harmonic voltages

\[ U_{3N} \]

\[ U_3 \]

\[ U_{3T,L1} \]

\[ U_{3T,L2} \]

\[ U_{3T,L3} \]
3rd harmonic 100% stator ground fault

- Simplest approach:
  - 3rd harmonic under-voltage in the neutral (i.e. $U_{3N}<)$
  - 3rd harmonic over-voltage at generator terminals (i.e. $U_{3T}>$)
- Possible problems:
  - Generator start-up
  - Generator shut-down
  - Different generator loading
- $3^{rd}$ harmonic differential principle

$$|U_{N3} + U_{T3}| \geq Beta \cdot |U_{N3}|$$
3rd harmonic based 100% stator earth-fault

Samples of the neutral voltage from which the fundamental- and 3rd harmonic voltages are filtered out

Samples of the terminal voltage from which the 3rd harmonic voltage is filtered out

Neutral point fundamental frequency over- voltage protection 10 – 100 %

Differential 0 – 30 %
Stator injection

Generator Protection Cubicle

PCM600 2.3

ICT

PC

REG670

PCM600 2.3

ICT

REX060
(Injection Unit)
ALWAYS required

REG670

ICT

REX060
(Shunt Resistor Unit)
SOMETIMES required

PC

ICT

STATOR

Generator Protection Cubicle

Generator

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Earth fault in the stator winding

- **Endangering condition**
  - Overvoltage in two healthy phases
  - Voltage in the star point
  - Relatively small earth fault current

- **Protected object**
  - Stator winding

- **Consequences**
  - Damage to the stator core
  - Risk of second earth fault

**Main Protection Function**

**Reserve Protection Function**
Earth fault in the stator winding close to the star point

- **Endangering condition**
  - None
- **Protected object**
  - Stator star point
- **Consequences**
  - Damage to the stator core
  - Risk of second earth fault

Main Protection Function

Reserve Protection Function
Earth fault in transformer HV winding

- **Endangering condition**
  - Overcurrent

- **Protected object**
  - Transformer windings

- **Consequences**
  - Heating
  - Forces
  - Smelted trafo core

**Main Protection Function**

**Reserve Protection Function**
Earth fault in transformer LV winding

- **Endangering condition**
  - Overvoltage in two healthy phases
  - Voltage in the star point
  - Relatively small earth fault current

- **Protected object**
  - Transformer winding

- **Consequences**
  - Small possibility to damage trafo core
  - Risk of second earth fault

**Main Protection Function**

**Reserve Protection Function**

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Earth fault at the generator buswork 2

- Endangering condition
  - Overvoltage in two healthy phases
  - Voltage in the star point
  - Relatively small earth fault current

- Protected object
  - Buswork, other equipment

- Consequences
  - Risk of second earth fault

Main Protection Function
Reserve Protection Function
Turn to turn fault in the stator winding

- **Endangering condition**
  - Circulating currents
  - Asymmetrical phase currents

- **Protected object**
  - Stator winding

- **Consequences**
  - Damage to the stator core
  - Risk of evolving into earth fault

*59N will detect this fault when it develops into an earth fault*

**Main Protection Function**

**Reserve Protection Function**
Turn to turn fault in the stator winding

- Generator with split stator phase winding can have dedicated turn-to-turn fault protection as shown in the figure

Main Protection Function
Reserve Protection Function
Rotor earth fault

- The field circuit of the generator is normally isolated from earth
- With a single earth fault in the rotor circuit it is possible to have continuous operation without generator damages
- There is however a risk of a second rotor earth fault. In such a case there will be large current and risk of severe damages.
- The requirement of fast fault clearance is moderate
Rotor injection

**Generator Protection Cubicle**

**PCM600 2.3**

**ICT**

**REX060**

*(Injection Unit)*

**ALWAYS required**

**REG670**

**RIM**

**SIM**

**PSM**

**STATOR**

**ROTOR**

**Generator**

**REX061**

*(Coupling Capacitor Unit)*

**ALWAYS required**

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Earth fault in the rotor winding

- **Endangering condition**
  - None

- **Protected object**
  - Rotor winding

- **Consequences**
  - Risk of evolving into double earth fault

**Main Protection Function**

**Reserve Protection Function**
Turn to turn fault in the rotor winding

- **Endangering condition**
  - None

- **Protected object**
  - Rotor winding

- **Consequences**
  - Damage to the rotor core
  - Risk of evolving into earth fault

*64R will detect this fault when it develops into an earth fault*

**Main Protection Function**

**Reserve Protection Function**
Synchronous machine operating in a parallel with a large power system can:

- supply active power to the system (operates as generator)
- receive active power from the system (operates as motor)
- supply reactive power to the system (overexcited machine; operates as shunt capacitor)
- receive reactive power from the system (underexcited machine; operates as shunt reactor)
- Note: machine shall have fixed rotating speed at all times
Different protection operating planes

AB: Field current limit
BC: Stator current limit
CD: End region heating limit of stator, due to leakage flux
BH: Possible active power limit due to turbine output power limitation
EF: Steady-state limit without AVR
X_s: Source impedance of connected power system

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Loss of/under excitation 40

Causes
- open field circuit
- field short circuit
- accidental tripping of the field breaker
- AVR failure
- loss of field at the main exciter

Consequence
- Machine speed higher than synchronous speed
- Asynchronous running of a synchronous machine without excitation
- Stator end-core heating
- Induced rotor currents

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RMS values of U & I during loss of field
Generator apparent power $S$ during loss of excitation

Loss of/under excitation 40
Loss of/under excitation 40

- Loss of/under excitation is based on under-impedance measurement (offset Mho)

- Main features:
  - Two zones Z1 and Z2, with independent block and trip
  - Directional element for additional zone restriction
Loss of/Under excitation 40

- Endangering condition
  - Stator reactive current component
- Protected object
  - Rotor and stator winding
- Consequences
  - Thermal damage of rotor and stator end regions
  - Asynchronous machine operation
  - Voltage and current variations

Main Protection Function

Reserve Protection Function
Generator shall produce active power (i.e. $P>0$)

When it starts to receive the active power it acts as a motor (i.e. $P<0$)

Not dangerous operating condition for machine but it may be dangerous for the turbine
Generator motoring protection 32/37

- **Causes**
  - loss of prime-mover
  - low water flow (hydro)
  - load variations / problems

- **Effects**
  - steam units → overheating of turbine and turbine blades
  - hydro units → cavitation of the blades

- **Demands**
  - accurate active power measurement (i.e. P~0 & Q=30-60%)
Directional power protection 32/37

- Reverse power, low forward, active and reactive power

Overpower (e.g. 32)

Underpower (e.g. 37)
Reverse power protection

- Set desired pickup (0.5 to 3%)
- Set time delay 5-30 s
- Sequential tripping logic
Low forward power protection

- Set desired pickup (1 to 10%)
- Set time delay 5-30 s
- Sequential tripping logic
- Blocked by external signal when generator is not loaded
Reverse Power Protection (32R)

- Endangering condition
  - Motor operation
- Protected object
  - Turbine
- Consequences
  - Excessive heating of turbine blades (steam units)
  - Mechanical damages to thrust bearing (Francis turbines)
  - Explosion risk for diesel units

Main Protection Function

Reserve Protection Function
Negative sequence overcurrent (46)

From asymmetric currents, a negative sequence current component $I_2$, is filtered out.

Negative sequence stator currents rotate in a opposite direction from the rotor and consequently induce a 100Hz current component into the rotor. As a consequence rotor ends can over-heat.

\[ I_2^2 \times t = k \]
Negative phase sequence (46)

Causes

- unbalanced loads
- untransposed transmission circuits
- unbalanced system faults
- series faults
- CB pole discrepancy
- open circuits

Features

- Characteristic adjustable to $I_2^2 t=k$
Broken stator winding

- Endangering condition
  - Unsymmetrical currents
- Protected object
  - Stator windings
  - Rotor
- Consequences
  - Rotor overheating
  - Vibrations

Main Protection Function

Reserve Protection Function

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Broken transformer winding

- **Endangering condition**
  - Unsymmetrical currents

- **Protected object**
  - Stator windings
  - Rotor

- **Consequences**
  - Rotor overheating
  - Vibrations

**Main Protection Function**

**Reserve Protection Function**
Pole slip / out of step protection (78)

- Asynchronous running of a synchronous machine with the rest of the system but **with excitation intact**
- Characterized by power (P & Q) oscillation
- Manifests as impedance movement in R & X plane
- Big mechanical impact on turbine and shaft
- Pole Slip typically caused by:
  - Long fault clearance time (especially close by 3Ph faults are critical)
  - Inadvertent tripping of a transmission line (increase of transmission impedance between generator and load)
  - Loss of large generator unit
Pole slip / out of step protection (78)

- Endangering condition
  - High stator current
  - Possible system blackout
- Protected object
  - Rotor shaft and stator winding
- Consequences
  - Mechanical damages to shaft
  - Asynchronous machine operation (with field intact)
  - Voltage and current variations

Main Protection Function

Reserve Protection Function
Frequency protection (81U/O)

- Over-frequency 81O: protects in case of turbine over-speed
- Under-frequency 81U: protection of the steam turbine at the "critical speed"
Low network frequency (81U)

- Endangering condition
  - Under-frequency
- Protected object
  - Transformer
  - Steam turbine
- Consequences
  - Over-excitation
  - Steam turbine vibrations

Main Protection Function

Reserve Protection Function
High Network Frequency (810)

- Endangering condition
  - Over-frequency
- Protected object
  - Turbine
  - Rotor
- Consequences
  - Mechanical stresses
  - Turbine vibrations

Main Protection Function

Reserve Protection Function
With faulty AVR overvoltage can cause over excitation of the generator-transformer block.

$V$ can sharply increase after load rejection followed by machine runaway.
Over-voltage protection (59)

- Endangering condition
  - Over-voltage
  - Improper voltage regulation
- Protected object
  - Electrical circuits
- Consequences
  - Increased risk for earth-faults
  - Over-excitation

Main Protection Function

Reserve Protection Function
Over-fluxing (excessive V/Hz), 24

- Overfluxing protects generator and transformer magnetic core against overheating
- Specially critical during start-up and shut-down
- Wide frequency operation of the relay important for generator protection

\[ \Phi = const \cdot \frac{E}{f} \approx const \cdot \frac{U}{f} \]
Incorrect turbine control (24, 81O/U)

- Endangering condition
  - Under-frequency
- Protected object
  - Transformer
- Consequences
  - Over-excitation

Main Protection Function

Reserve Protection Function
Thermal overload, 49

\[ \Theta = \Theta_F \cdot (1 - e^{\frac{t}{T}}) \]

\( \Theta \) = Winding temperature increase

\( \Theta_F \) = final temperature with present current

\( T \) = Winding thermal time constant

\[ t = \tau x \ln \left( \frac{l^2 - I_p^2}{l^2 - (k x I_b)^2} \right) \]
Stator thermal overload (49S)

- Endangering condition
  - Stator overcurrent

- Protected object
  - Electrical circuits

- Consequences
  - Stator overheating

Main Protection Function

Reserve Protection Function

* In case of severe overload (setting dependent)
Rotor thermal overload (49R)

- Endangering condition
  - Rotor overcurrent
- Protected object
  - Rotor winding
- Consequences
  - Rotor overheating

Main Protection Function

Reserve Protection Function
Accidental energizing, 50AE

- Operates when generator is energized by a mistake
- In principle voltage controlled OC function
Accidental energizing (50AE)

- Endangering condition
  - Stator overcurrent or unsymmetrical currents
- Protected object
  - Bearings
  - Rotor
- Consequences
  - Bearing damages due to low oil pressure
  - Rotor overheating
  - Stator overheating

Main Protection Function

Reserve Protection Function

*3Z< is a delayed reserve protection
Breaker-failure protection (50BF)

- Issues a back-up trip of adjacent breaker in case of failure of the circuit breaker of the protected object to open (i.e. to interrupt the primary circuit)
- Its operation in most cases trips only local breakers
- Commonly uses the bus bar protection disconnector replica logic to route its tripping command to adjacent breakers
- Re-trip (t1), Backup trip / bus-strip (t2), Second back-up trip timer (t3)
- Short reset time (15ms)
- Known CB faulty (bypass t2)
- Operating mode
  - Current / Contact / Current & Contact
Breaker fails to open the circuit (50BF)

- **Endangering condition**
  - Stator overcurrent or unsymmetrical currents
- **Protected object**
  - Electrical circuits
  - Rotor
- **Consequences**
  - Rotor overheating
  - Stator overheating
  - Prolonged damages caused by the fault current

**Main Protection Function**

**Reserve Protection Function**
Destroyed bearing insulation (38)

- Endangering condition
  - Shaft (bearing) current

- Protected object
  - Bearing

- Consequences
  - Bearing damages
  - Stator/rotor damages

Damage to the bearings occurs if the current through the shaft exceeds 1 A

The induced EMF is about: 0.5 - 1 V for turbo-machines; 10 - 30 V for hydro-machines
Conclusion

- Stator earth faults
- Rotor earth faults
- Stator short circuits
- Stator/rotor interturn faults
- External faults
- Abnormal operation
Thank you for your participation

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