A Technicians Approach to Generator Protection
Moderator

Ron Spataro
AVO Training Institute Marketing Manager
Send us your questions and comments during the presentation.
Today’s Presenter: Ralph Parrett
AVO Training Institute, Training Specialist

A Technicians Approach to Generator Protection
What We Are Protecting Against!

• Further Damage to the Power System
  • Thermal Damage
  • Mechanical Damage
• System Disturbances
Overview Of Generator Protection
What Do We Want To Do?

- Protect the Generating Unit from thermal and mechanical damage.
- Keep the Generating Unit on line if at all possible.
  - Limit grid wide impact (Watt capability)
- Protect the power delivery system from unwanted disturbances.
- Provide safe and reliable power to customers.
Generator Component Fundamentals

- Generator Components that require protection
  - Rotor
  - Stator
  - Exciter
  - Core
  - Prime Mover
  - Loads
What Are The Protective Functions We Are Interested In?

- Volts per Hertz (24) Gen and Transformer core
- Under and Overvoltage (27/59) System stability
- Reverse Power (32) Prime mover
- Loss of Excitation (40) Stator and Rotor
- Negative Sequence (46) Rotor
- Voltage Controlled Overcurrent (51V) Phase faults
- Blown Fuse (60) Inadvertent Trips
- 100% Stator (64) Stator
- Out of Step (78) Generator and Transformer
- Frequency (81) Turbine vibration, system disruption
- Generator Differential (87G) Stator Windings
Types Of Generators For Our Discussion

Synchronous Generators

- Steam Turbines
- Gas Turbines
- Hydro Units
- Diesel Units

Induction Generators

- Wind Turbines
Testing Techniques

- NETA, OSHA, NFPA70B, IEEE, etc.
  - Always refer to the manufacturers manual for proper testing and calibration techniques.
  - Approved test methods provided by your company or the customer.
  - The methods discussed will be according to NETA standards.
  - Best Practices
    - Understand the Relay/Element you are testing.
    - Prove the **Operation** of the relay/element
      - Going from a Normal Condition to Faulted Condition.
    - Be the least intrusive as possible (limit your current when you can)
Volts per Hertz (24)

Purpose

• Protect generator and unit transformer cores from over heating caused by over-excitation.
• Occurs when the generator terminal voltage is increased or operating frequency is decreased.
• Truly a percentage relationship between system Voltage and Frequency.

Relay Examples

• GE STV
• ABB Circuit Shield 59F
• Microprocessor Based Relays

Basic Testing Fundamentals

• Connect test voltage to relay
• Determine pickup frequency at rated voltage
• Determine pickup frequency at a second voltage
• Perform timing tests as Definite Time or Inverse Curve functions
Under/Over Voltage (27/59)

Purpose
• Protect the generator from prolonged under-voltage and overvoltage conditions

Relay Examples
• GE IAV. Westinghouse CV
• ABB Circuit Shield 27/59
• Microprocessor Based Relays (27/59 Elements)

Basic Testing Fundamentals
• Connect single phase or three phase test voltage as required
• Determine Drop Out for Undervoltage Units
• Determine Pickup for Overvoltage Units
• Perform timing tests as required (Definite Time or Inverse Curve)
Reverse Power (32)

- **Purpose**
  - Protect the prime mover from thermal and mechanical damage

- **Relay Examples**
  - GE ICW, GGP, Westinghouse CW, CRN-1
  - ABB Circuit Shield 32R
  - Microprocessor Based Relays (32 Elements)

- **Basic Testing Fundamentals**
  - Relay requires both current and voltage
    - Single phase current and voltage for ICW, CW, CRN-1
    - Three phase current and voltage for GGP
    - Three phase current and voltage for microprocessor based relays
    - This function is not a fault detecting function so the test voltage is nominal
    - The test current is calculated from the reverse power wattage setting of the relay
    - Test current is usually very low (less than 1 amp) Be precise when testing!
    - Microprocessor based relays may have two 32 elements. One for alarm and one for tripping.
Reverse Power (32)

- $I \text{ lags } V$
  - $W = -$  
  - $\text{VAR} = +$
  - $\text{PF} = \text{LEAD}$

- $I \text{ lags } V$
  - $W = +$
  - $\text{VAR} = +$
  - $\text{PF} = \text{LAG}$

- $I \text{ leads } V$
  - $W = -$
  - $\text{VAR} = -$
  - $\text{PF} = \text{LAG}$

- $I \text{ leads } V$
  - $W = +$
  - $\text{VAR} = -$
  - $\text{PF} = \text{LEAD}$

Direction of Positive Real Power

Source Bus

Generator

32
Reverse Power (32)

Reverse Power

Power Threshold

TRIP

Load

-1.0 PU

1.0 PU

Pickup

Forward Power Flow
Loss of Field (40)

Purpose

- Protect the rotor and stator from overheating due to loss of excitation.

Relay Examples

- GE CEH, Westinghouse KLF
- ABB Circuit Shield 40
- Microprocessor Based Relays (40 elements)

Basic Testing Fundamentals

- Voltage and Current inputs required
- Characteristic of relay is an Mho circle
- Maximum Torque Angle is 90 degrees current leading voltage.
- Relays can have 1 or 2 Mho circles, used for an alarm and the other for tripping
- Test maximum reach, offset reach, MTA, and characteristic circle
Loss of Field (40)

Testing Fundamentals

• **Reach Test**
  - Nominal voltage (name plate voltage or nominal voltage)
  - Current angle leads nominal voltage by 90 degrees
  - Ramp current up until impedance unit operates
  - Volts / Amps = Reach (Don’t forget any “k” factors such as 2 or 1.5)

• **MTA Test**
  - Apply Voltage and Current to simulate System impedance to be inside of the circle.
  - Swing the current angle in one direction until the relay contacts open, then swing the current in the other direction until the contacts again open
  - \( \frac{( Opening \ Angle \ 1 + Opening \ Angle \ 2)}{2} = MTA \)

• **Offset Test**
  - Same as reach test except top of circle is tested.
    - To test the offset you may need to decrease your test voltage in order to limit the amount of current required to give the relay the correct Impedance.
    - Ramp current up or down to find pickup point
Loss of Field (40)
Current Balance or Negative Sequence (46)

Purpose
• Used to detect phase imbalance in the generator. Excessive phase imbalance will result in overheating of the generator rotor. Negative sequence is used to calculate the intensity of the phase imbalance.

Relay Examples
• GE INC, SGC, Westinghouse COQ, SOQ
• ABB Circuit Shield 46Q
• Microprocessor Based Relays (46 elements)

Basic Testing Fundamentals
• Most electromechanical are built for ABC rotation, and would have the CT’s for two of the phases swapped. Otherwise normal system rotation (ACB) would result in the relay producing 100% operating torque.
• Pickup is percent of tap (per unit)
• Timing is an inverse curve in percent of tap (per unit)
• Microprocessor based relays will have two levels – Alarm and Trip
  o Alarm time will be definite time, Trip will be inverse time
Current Balance or Negative Sequence (46)

ABC

ACB
Negative Sequence (46)
Time Overcurrent Relay (51V)

Purpose
• Protect stator from phase faults
• Can be Voltage Controlled or Voltage Restrained
  • Depending on Model or Settings

Relay Examples
• Westinghouse (COV)
• GE IJCV (IFCV)
• Microprocessor Based Relay (51V Element)

Basic Testing Fundamentals
• Current and Voltage must be applied
• Pickup changes as voltage changes
Time Overcurrent Relay (51V)

Voltage Control

Voltage

Inhibit

Adjustable 40-120V

Enable

Voltage Restrain

51V Pickup (per unit of 51VP setting)

Selected Phase-Phase Voltage (per unit of VNOM)
Blown Fuse (60)

Purpose

• Protect the generator from inadvertent trip due to loss of potential (blown fuse) on relays that use both voltage and potential for operation.

Relay Examples

• GE CFVB
• ABB Circuit Shield 60
• Microprocessor Based Relays (60 Element)

Basic Testing Fundamentals

• Mechanical Relay require 6 voltages to effectively test relay
  o Uses two PT inputs.
  o If one set is normal and the other set sees a voltage drop, blown fuse is assumed
• Microprocessor based relays use negative sequence voltage and current to determine if a fuse is blown.
  o If negative sequence voltage is seen with no corresponding negative sequence current rise, a blown fuse is assumed.
• Operation of some relay elements will be blocked if loss of potential is detected.
100% Stator Ground (64)

Purpose

• Provide 100% stator protection against ground faults by:
  o Detecting 60 Hz overvoltage on the neutral voltage inputs of the relay. (This covers the middle and upper portions of the stator and is designated as zone 1)
  o Detecting 3\textsuperscript{rd} harmonic under-voltage on the neutral voltage inputs of the relay. (This covers the upper and lower portions of the stator and is designated as zone 2)
  o Detecting the 3\textsuperscript{rd} harmonic ratio difference between phase voltage 3\textsuperscript{rd} harmonics and neutral voltage 3\textsuperscript{rd} harmonics.

Example Relays

• Microprocessor Based Relays (64G Elements)

Basic Testing Fundamentals

• Zone 1 pickup looks for a 60 Hz overvoltage condition applied to the relay neutral voltage inputs. Start with voltage less than Zone 1 setting and ramp up.
• Zone 2 pickup looks for a 3\textsuperscript{rd} harmonic under-voltage condition applied to the relay neutral voltage input. Start with voltage greater than Zone 2 setting and ramp down.
100% Stator Ground 64G

Zone 1
- OV Fundamental Frequency

Zone 2
- UV 3rd Harmonic
- (180 Hertz)
Out of Step (78)

Purpose
• Protect against out-of-step conditions between two or more generators. Out-of-Step conditions cause high peak currents, winding stress and rotor torque stress.

Example Relays
• GE GSY-CEX
• Microprocessor Based Relays (78 Elements)

Basic Testing Fundamentals
• Requires both current and voltage
• Characteristic is a Mho circle and two “blinders”
• Calculate voltage and current so that impedance lies just outside circle at unity power factor
• Swing impedance through characteristic by changing current angle.
Out of Step 78
Over/ Under Frequency 81

Purpose

- Protect the generator from excessive vibration, keep system devices efficient, and assist in synchronizing functions.

- **Example Relays**
  - GE SFF, Westinghouse KF, MDF
  - ABB Circuit Shield 81
  - Microprocessor Based Relay (81 Element)
  - Basler BE1-81

- **Basic Testing Fundamentals**
  - Single phase voltage (SFF, KF, MDF, ABB 81, Basler 81) or three phase voltage (Microprocessor Based) is required
  - Apply nominal voltage and ramp frequency down for under-frequency testing
  - Ramp frequency up for over-frequency testing
  - Perform timing test by stepping frequency from normal to greater than setting for over-frequency and less than setting for under-frequency.
Over/Under Frequency 81
Differential 87G

Purpose
• Protect against internal generator faults

Example Relays
• GE CFD, Westinghouse SA-1, CA
• ABB 87M, Basler 87G
• Microprocessor Based Relays (87G Element)

Basic Testing Fundamentals
• Requires two current inputs
• Test relay pickup on each winding
• Test slope using current in each winding
  • For Electromechanical and Solid State Relays the two test currents must be 180 degrees out of phase
  • Consult Microprocessor settings for any compensation for Angle shifts due to a Delta-Y or Y-Delta transformer with Y-Y CT’s.
  • This type of shift is corrected by the relay where before the CT configuration would HAVE to externally correct any angle shifts.
Differential 87G
Differential Operating Principles

- Operate if difference current exceeds setting.
- Restrain on through current
- Operate instantaneously on in zone faults
Summary

1. Protective relays are an integral part of the power delivery system.

2. Protective relays are designed to detect system abnormalities and take the appropriate action to remove the abnormality from the power system.

3. Protective relays allow the system to be restored back to normal after an abnormal event.

4. In combination with breaker and switch reclosers
Offering Many Protective Relay Courses

Protective Relay Maintenance, Basic - Certification Course
Protective Relay Maintenance, Advanced - Certification Course
Protective Relay Maintenance, Solid-State - Certification Course
Protective Relay Maintenance, Generation - Certification Course
Microprocessor-Based Relay Testing, Distribution/Feeder
Microprocessor-Based Relay Testing, Generation
Advanced Visual Testing Software
Join Us For Our Next Webinar

The Importance of Battery Maintenance and Testing Lead Acid Technology

Monday, February 19
1: PM – 2:00 PM CDT
After more than 50 years, AVO Training remains a global leader in safety and maintenance training for the electrical industry. We deliver an engaging, hands-on experience for our clients in a professional, real-world environment.

We strive to provide industry relevant courses in a practical and flexible learning environment through an ongoing commitment to quality service, integrity, instruction, and client satisfaction.

Our goal is to convey practical job skills and career development for our clients and students by saving lives through a world-class learning experience.