

# Transmission ITP

## Monitoring of BES Equipment

PJM State & Member Training Dept.

Students will be able to:

- Describe the impacts of extended weather events on operations & equipment
- Identify conditions under which a BES line or transformer may need to be de-rated
- Determine one or more possible causes for an alarm and the potential corrective actions for a BES:
  - Transformer
  - Circuit Breaker
  - Reactive Resource
  - Substation

# Effects of Weather on Equipment Ratings

# Effects of Hot Weather on Equipment Ratings

- System equipment will be stressed
- Power transformers take longer to heat up, but also take longer to cool down
  - If a transformer is operating closer to its normal operating limit for several days, it will not have time to cool down
- Conductors can't dissipate heat as readily during hot weather and will tend to sag
  - Right of ways need to be maintained to prevent inadvertent contact with vegetation or other structures
- Generators may not be able to reach their max capacity
  - CTs power output may be decreased (air density)
  - Unit condensers may not operate efficiently

# Effects of Cold Weather on Equipment Ratings

- System equipment will be stressed
- Conductors may be weighted down with ice or snow
  - Right of ways need to be maintained to prevent inadvertent contact with vegetation or other structures
- Generator output may be affected
  - CTs may fail to start
  - Wet or frozen coal may reduce unit output
  - Fuel deliveries may be affected



# De-Rating Transmission Equipment

# De-Rating BES Transmission Equipment

- Lines



# De-Rating BES Transmission Equipment

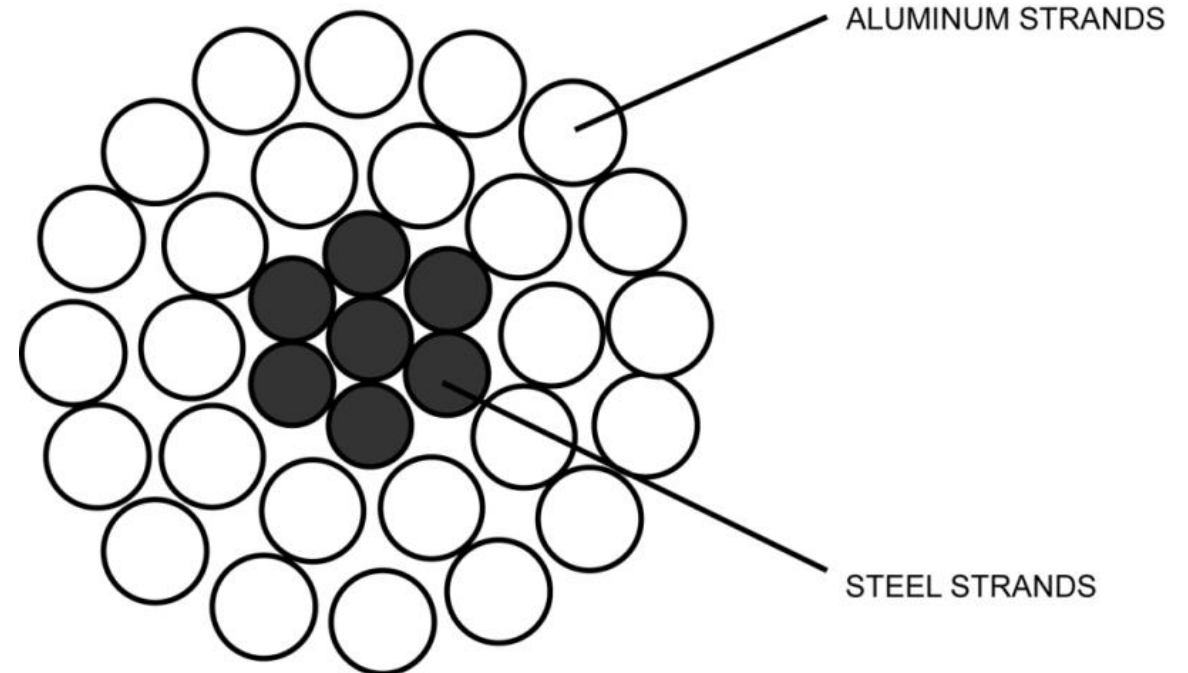
- The rating for a transmission line is determined by the most limiting piece of equipment installed to support its operation:
  - The conductor itself
  - Wave traps (if the line is protected by carrier relays)
  - Disconnect switches
  - Circuit breakers
  - Relay settings
- Every line has at least one “limitation”, as defined in Transmission Equipment Ratings Monitor (TERM)



# De-Rating BES Transmission Equipment

## Transmission Conductors:

- Overhead:
  - Aluminum Conductor, Steel Reinforced (ACSR)
  - Most popular type currently being used
  - Higher strength-to-weight ratio than other materials



# De-Rating BES Transmission Equipment

- As the loading on a line increases, the heat generated in the line increases with the *square* of the current ( $I^2R$  losses)
- If more heat is generated than can be dissipated to the surrounding air, the line begins to heat up and sag
- The sagging line has less room between it and the vegetation, structures, roads, or people beneath it
- To prevent inadvertent tripping because of potential flash-over, the transmission owner may chose to de-rate the line
  - Limiting the amount of current will reduce the heating and sag of the line, preserving the clearance necessary for safe operation
  - This de-rate may be permanent (or until the conductor is replaced) or temporary (until an encroaching object in the right-of-way is removed)

# De-Rating BES Transmission Equipment

- The conductor itself may not be the problem
  - People have started construction of buildings within the right-of-way that pose a risk of flash-over
  - Construction equipment (cranes, dump truck beds) can inadvertently encroach on safe line clearance distances

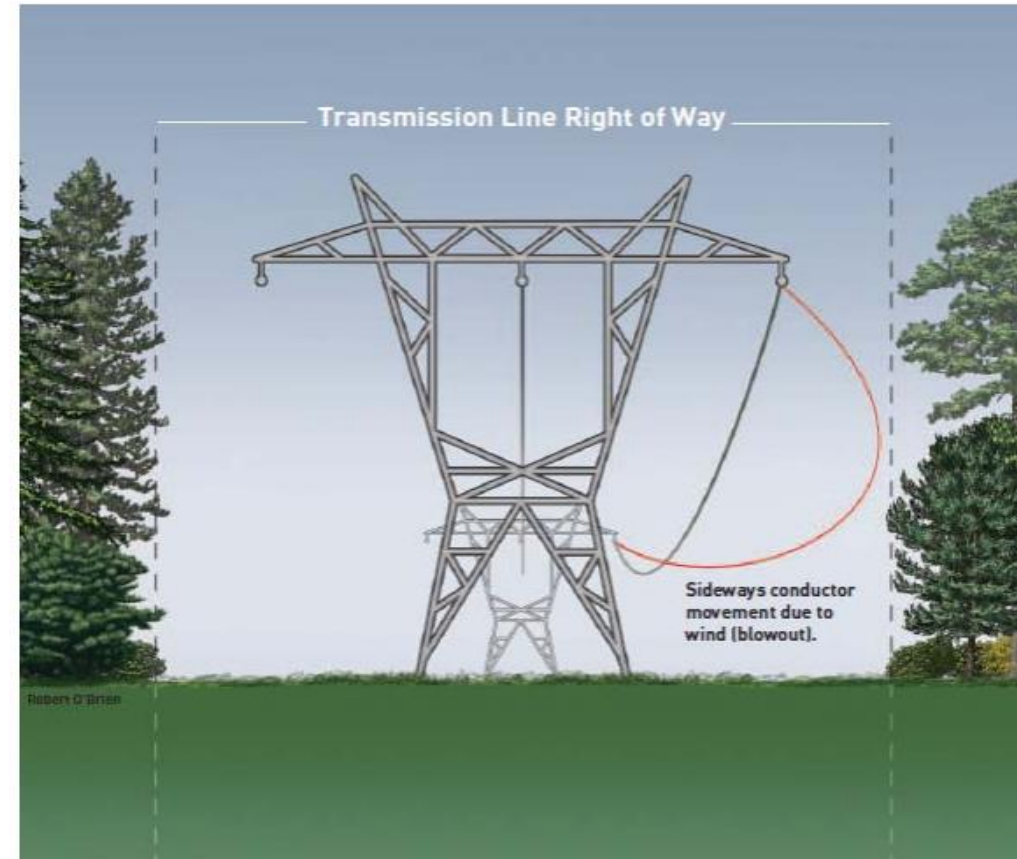
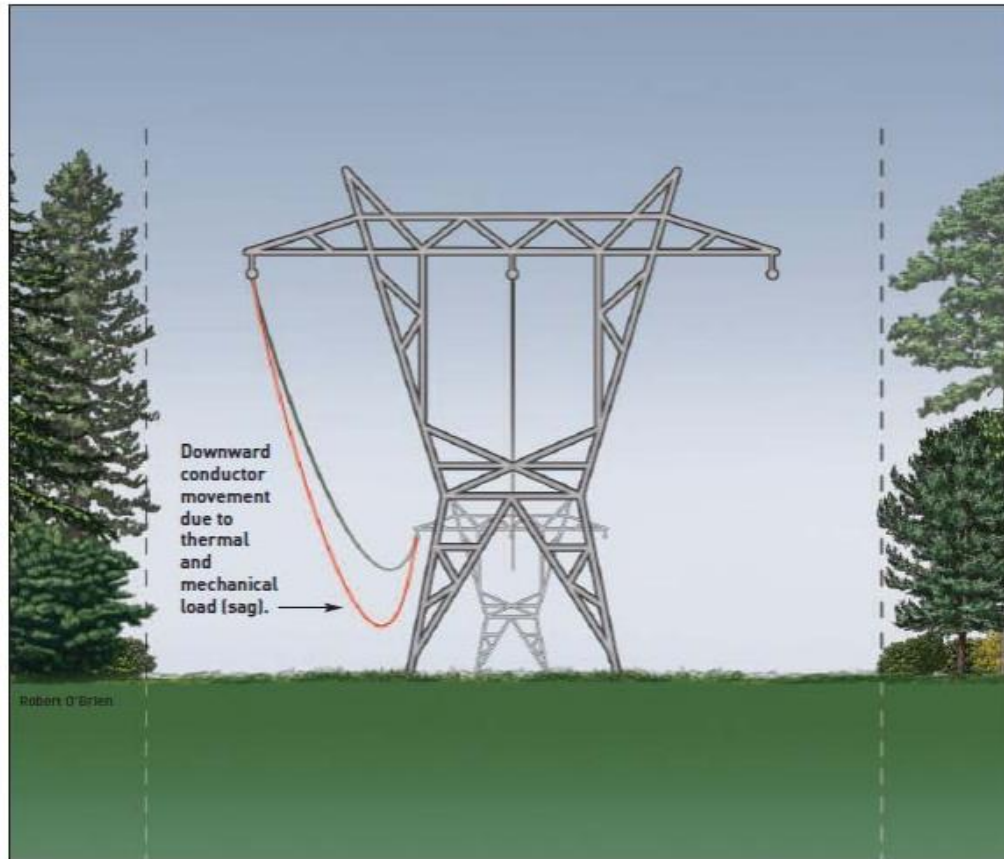


# De-Rating BES Transmission Equipment

- Outages caused by overgrown vegetation had FERC/NERC develop and enforce the Reliability Standards for Vegetation Management in transmission right-of-ways
  - NERC mandates that companies define and maintain C2 clearances, which specify the distance that must be kept between the conductors and any vegetation during “all operating conditions”
- In the event a right-of-way is leased, what happens if the property owner denies permission for the member company to cut vegetation
- Companies may temporarily de-rate the line, so that C2 clearances may be maintained until the vegetation issue can be taken care of

# De-Rating BES Transmission Equipment

## Understanding Conductor Position and Movement

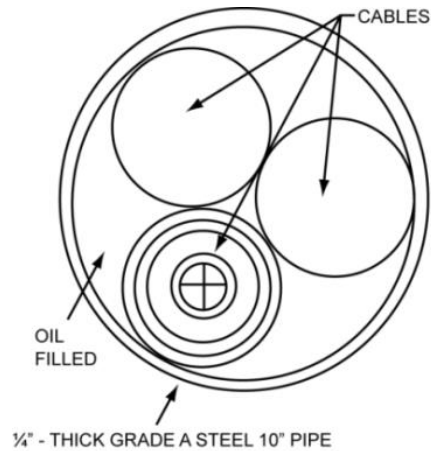


The conductor's position in space at any point in time is continuously changing as a reaction to a number of different loading variables. Changes in vertical and horizontal conductor positioning are the result of thermal and physical loads applied to the line

# De-Rating BES Transmission Equipment

- Underground/Underwater Cable
  - Virtually immune to environmental impacts (weather, trees)
  - Significantly more costly to install (2.5 to 15 X or more)
    - Cable itself is more expensive
    - Requires special equipment to install/maintain
  - In general, cables have a lower rating because they are less able to dissipate the heat caused in their operation

# De-Rating BES Transmission Equipment

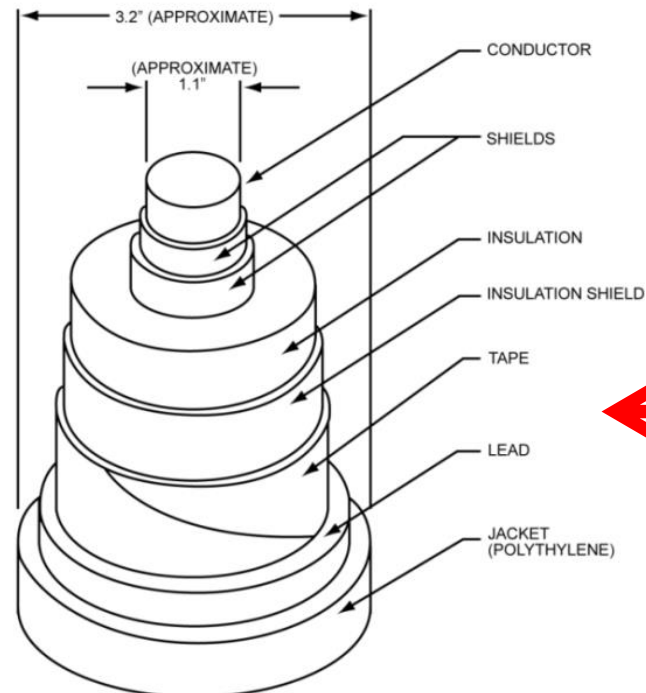


*Cross-Sectional View of 345kV Pipe-Type Cable*



- Some Cables are contained in a pipe which is filled with oil
- The oil is pumped through the cable to insulate the phases and aid in heat removal

*138 kV Solid Dielectric Cable*



- Other Cables simply dissipate their heat through the insulation and into the surrounding ground

# De-Rating BES Transmission Equipment

- If the oil pumping systems on the oil-filled cables become inoperative, the cable may need to be de-rated so that less heat is generated
  - If the pumps remain offline for an extended time, air pockets could build up in the pipes, which could cause phase-to-phase shorts in the cable if it was left energized
  - Faults in insulated cables can also occur. When the cable is repaired, it may be necessary to de-rate the cable so that the repaired section does not exceed its insulating capability and again short out the cable
  - Occasionally, the terminators, where the cables connect to overhead structures become the limiting current-carrying component and determine the rating of the cable



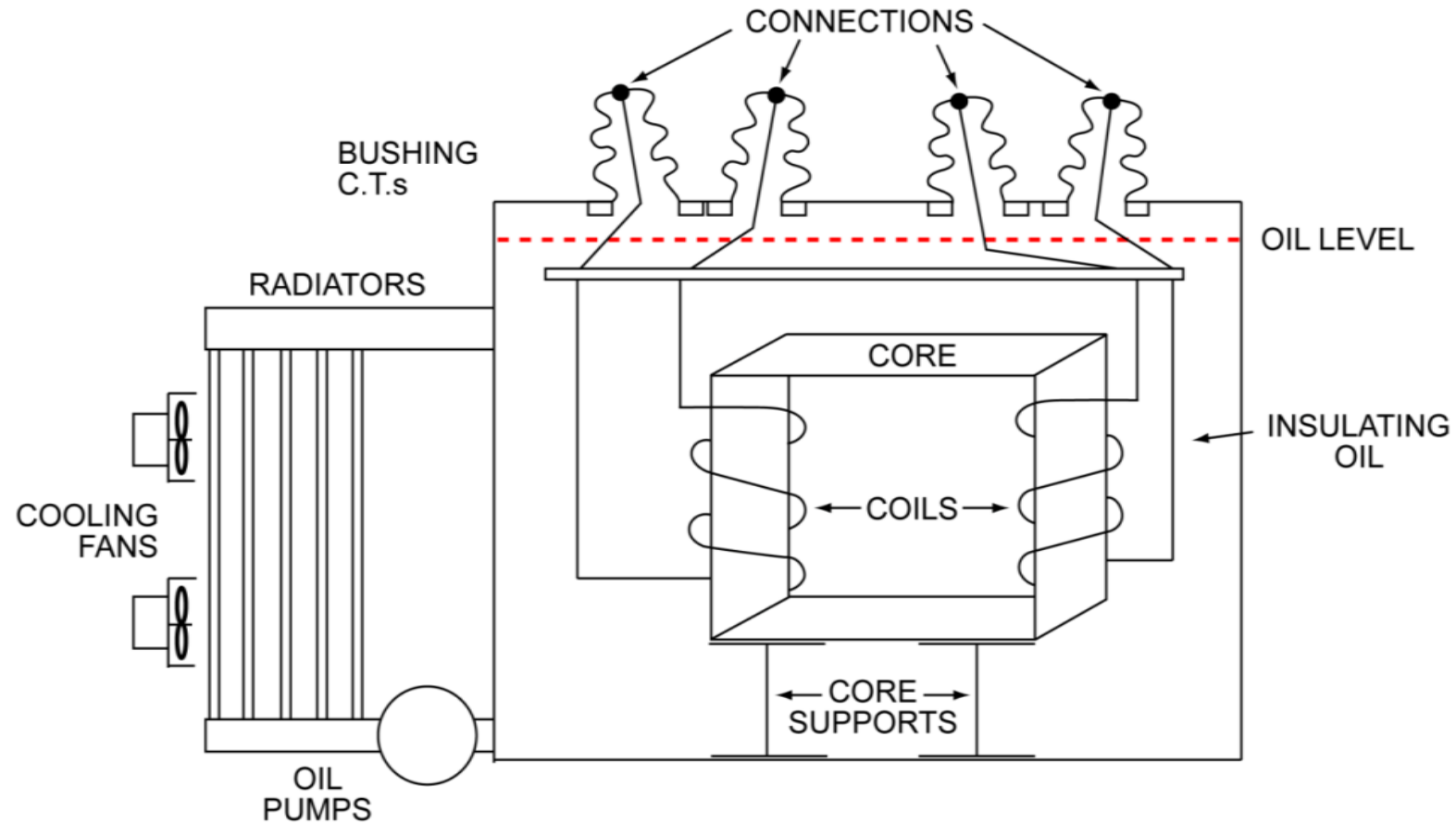
# De-Rating BES Transmission Equipment

- Transformers



# De-Rating BES Transformers

## Basic Schematic of a Power Transformer



# De-Rating BES Transformers

- Transformers are filled with oil
  - Acts to prevent arcing between the high and low voltage bushings,
  - Helps to cool the magnetic core, which becomes heated while the transformer is in service
- Transformer ratings are determined primarily by the manufacturer
  - Generally dictated by how well the transformer can disperse the heat generated by its operation

# De-Rating BES Transformers

- Sometimes equipped with a set of pumps
  - Used to circulate the oil through a set of radiators external to the transformer oil tank to cool it
- Most BES transformers also have one or more banks of fans
  - Force air onto the radiators to assist in the cooling process
  - Come on in stages, depending on the temperature of the oil



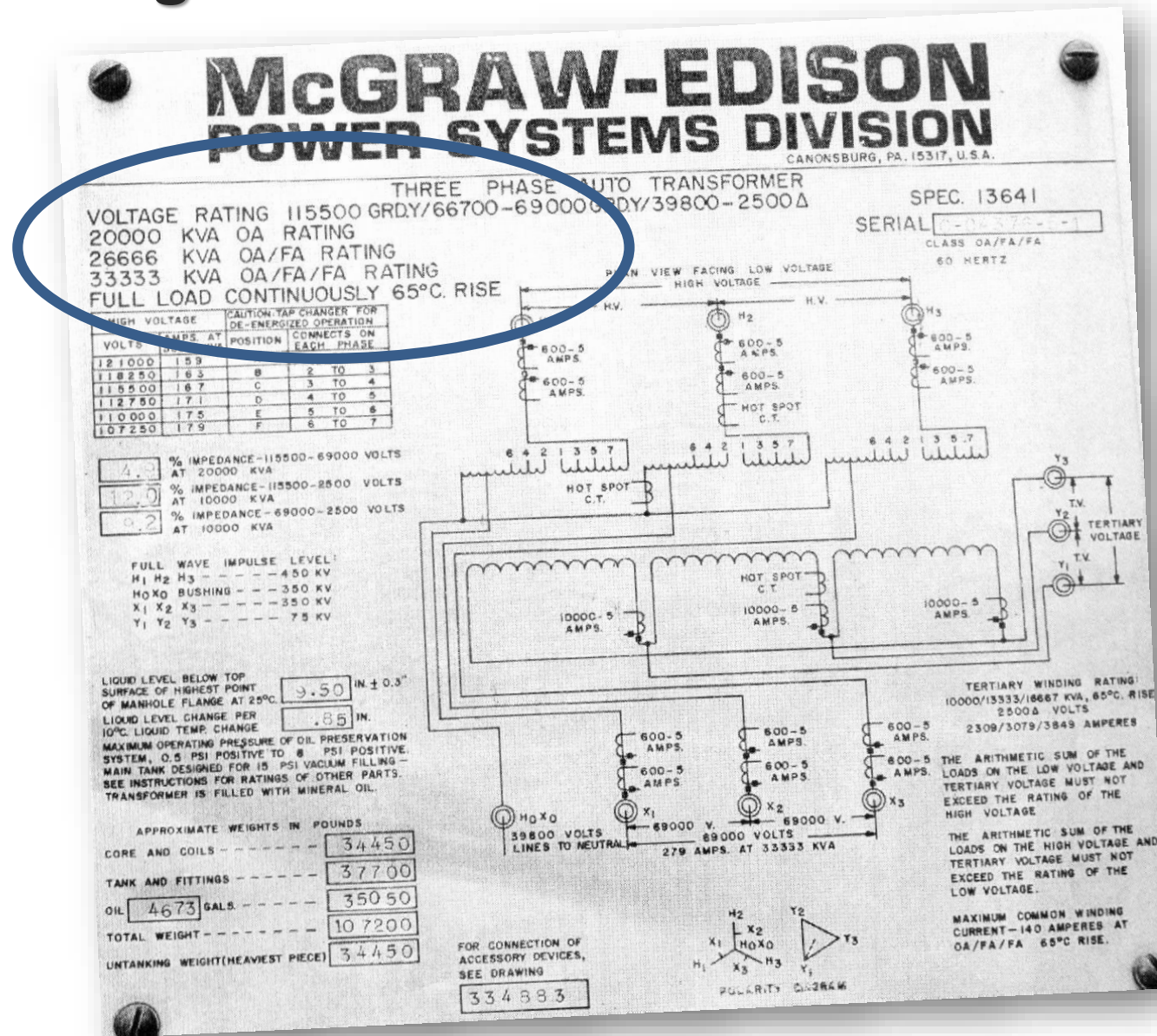
# De-Rating BES Transformers

- Transformer ratings are given in levels, depending on how many of these cooling mechanisms are in service



- OA (Oil/Air) - Natural circulation of oil through the radiators
- OA/FA - Natural circulation and one set of cooling fans in service
- OA/FA/FA - Natural circulation and both sets of cooling fans in service
- OA/FA/FOA - Oil pumps and cooling fans in service

# De-Rating BES Transformers



Transformer Name Plate, showing the ratings with various cooling systems in service

# De-Rating BES Transformers

- If a set of fans (or the pumps) becomes inoperative, the rating of the transformer may need to be decreased to prevent damage
- Transformer fans and pumps are generally supplied via Station Service Transformers
- Excessive heating of a transformer can lead to breakdown of the insulation, which can decrease the life of the transformer
- In excessive heat conditions, some companies have also been known to spray down their heavily loaded transformers with water to help with cooling

# Basic Alarm Response from BES Equipment



# Transformer Alarms

- Alarms from BES Transformers
  - Transformers have many auxiliary systems that are needed for proper operation
    - Circulating pumps move the oil through external radiator units to assist in cooling
    - As the oil temperature increases, one or more sets of auxiliary fans are switched into service to direct air across the radiator units

# Transformer Alarms

- Loss of one or more of these cooling systems will:
  - Generally cause an alarm via the EMS
    - Prompt actions should be taken to restore the lost equipment
- If the equipment cannot be restored, and the transformer temperature continues to increase, the transformer must be unloaded to prevent damage and possible failure
  - Transfer load to alternate sources if possible
  - Re-configure the transmission system to change flows on the equipment
  - Dump load as a last resort

# Transformer Alarms

- Transformers are equipped with gauges to monitor both:
  - Oil temperature, and
  - Temperature of the interior windings
- High oil temperatures can indicate loss of cooling systems, or excessive loading



# Transformer Alarms

- Excessive winding temperature is usually the result of either a short circuit in the windings, or a ground in the winding
- These types of faults may occur gradually or suddenly
  - Gradual, low-current faults will generally raise the winding temperature and trigger an alarm
  - They may also trigger relaying to automatically isolate the transformer

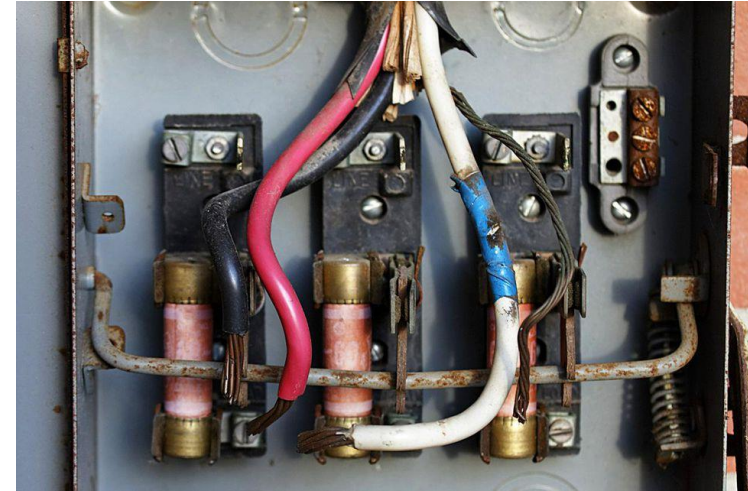
# Transformer Alarms

- More sudden faults can causing arcing in the transformer, and can be identified by a sudden increase in internal tank pressure
- “Sudden Pressure” relays will act to isolate the transformer in this event



# Transformer Alarms

- In the event that a temperature alarm is received, a repairman should be dispatched to confirm that the local temperature indication matches the EMS alarm
- If the transformer isolates itself due to relay action, a repairman should also be sent to determine the extent of the problem
  - Some internal faults can literally compromise the integrity of the transformer tank and allow the oil to leak out
  - It is important to identify and correct this situation as soon as possible



# Transformer Alarms

- External events such as bushing failures, animal contacts, or flashover events may also cause the transformer to isolate itself on relay action
- Again, the only true indication of the extent of damage is to have the equipment checked by a qualified repairman

[https://www.youtube.com/watch?feature=player\\_embedded&v=YZipeaAkuC0](https://www.youtube.com/watch?feature=player_embedded&v=YZipeaAkuC0)

# Transformer Alarms: Stuck Tap Alarms

- Transformers with LTCs are also usually equipped with “Stuck Tap” alarms
  - Received via the EMS when LTC is unable to successfully complete a change between 2 taps, leaving 2 taps energized in the “bridging position”
- Creates a low-level short circuit in the windings,
  - Potential for excessive heating as well as a catastrophic internal fault
  - May not be advisable to wait until a repairman can reach the station and manually change the tap position (If this can even be done)

[https://www.youtube.com/watch?v=1f4P8LAXkT0&list=PL2EK64GVS\\_aJm8nKVQQ3UkSrQ71092yAz&feature=player\\_embedded](https://www.youtube.com/watch?v=1f4P8LAXkT0&list=PL2EK64GVS_aJm8nKVQQ3UkSrQ71092yAz&feature=player_embedded)



# Transformer Alarms

- The System Operator needs to understand that it may be necessary to de-energize the transformer under these conditions
  - Opening the low side CB will **not** be sufficient
  - The high side must be isolated to prevent the short circuit from continuing to arc
  - **HOWEVER it is important** – that under these conditions – the transformer be de-energized using a device that is capable of breaking fault current (a circuit switcher or similar device)
    - Attempting to de-energize the transformer using a standard air break or MOD will draw an arc that may damage the components, and may not be safely extinguished, compounding your problem

# Transformer Alarms

- If necessary, the incoming transmission line to the transformer should be de-energized, then the Air Break or MOD's can be safely opened to isolate the transformer, and the transmission line can be returned to service

[https://www.youtube.com/watch?feature=player\\_embedded&v=QAmP-CnBT9k](https://www.youtube.com/watch?feature=player_embedded&v=QAmP-CnBT9k)

# Circuit Breaker Alarms

- Alarms from BES Circuit Breakers
  - Most alarms coming from Circuit Breakers warn of either compromised relaying, or of a situation in which the Circuit Breaker cannot trip to isolate a fault
    - Loss of air pressure in air blast CBs
    - Loss of gas pressure in SF-6 CBs
  - Most breakers have two alarm points for these conditions
    - One to warn you that the pressure is below desired levels
    - Second to warn you that the pressure is too low to allow the CB to open

# Circuit Breaker Alarms

- Depending on how Breaker is installed, one of two things can happen as pressures approach the second setpoint:
  - The CB will trip while it is still able to extinguish the arc
    - Automatic disconnects on either side of the CB will isolate it from the system
  - The CB will “lockout” to prevent operation at the reduced pressure
    - The CB will have to be de-energized via other devices, then isolated from the system

# Circuit Breaker Alarms

- Air (or gas) should be added to the breaker in question as soon as possible to return the equipment to its full functionality
  - If the pressures are too low, the breaker may need to be de-energized to safely add gas (to prevent internal flash-over from stirring up tank debris)
  - The breaker may need to be disconnected using load-break devices to prevent arcing
    - This may require some system re-configuration

# Circuit Breaker Alarms

**SF-6 Breaker rating nameplate, showing critical pressure limits**

SIEMENS		
Sulfur Hexafluoride Circuit Breaker Type SPS2-72.5-40- 2		
Rated Max. Volts 72.5 Kv	Rated Voltage Range Factor 1.0 (K)	Rated Interrupting Time 3.0 Cycles
Rated Continuous Current 2000 A	Rated Short Circuit Current 40000 A	Rated Capacitance Current Switching *
Frequency 60 Hz	Rated Out of Phase Current 10000 A	Overtoltage Factor 2.0
Fill Pressure at 68°F/20°C 65 psig	Full Wave Impulse Withstand 350 Kv	Line Charging 100 A
Minimum Operating Pressure at 68°F/20°C 51 psig	Wt. of Breaker with Gas 4400 Lbs	Isolated Bank Sw. 630 A
SF6 Alarm Pressure at 68°F/20°C 57 psig	Weight of SF6 Gas 33 Lbs	Back -to- Back Sw. 630 A
SF6 Cutout Pressure at 68°F/20°C 51 psig		Inrush Peak 25000 A
		Inrush Freq. 3360 Hz
		Part List No.
	Serial - S.O. 30057403-3	Instruction Book PB-3638-03
		Date of Mfr. 09/09
Siemens Energy, Inc. Manufactured or Assembled of U.S. and Foreign Components		Jackson, MS 72-183-829-015

# Circuit Breaker Alarms

- Another type of pressure alarm may be received from pneumatically or hydraulic operated CBs
  - If the pressure is too low, the breaker may still trip, but will be unable to reclose on its own or not be able to trip at all
    - This may have some impacts to system reliability

# Reactive Resource Alarms

## Alarms from BES Capacitors, Reactors, and SVCs

- Capacitors
  - Capacitors have relatively few alarms connected to them
  - Individual can failures will blow the connected fuse, and isolate the problem
  - The arrangement and number of capacitor cans in a bank are calculated in part to ensure that the primary voltage divides across them without subjecting any one can to more than its rated voltage
  - When a capacitor can in a group fails and blows its fuse, the overall impedance of that group increases because an open circuit effectively replaces the blown can
  - This increase in the group's impedance in turn raises the total impedance of the phase containing that group



# Reactive Resource Alarms

The increase in impedance has two effects:

1. Less current flows in the phase with the failed can due to its higher overall impedance
  - Normally, all three phases of a capacitor bank are balanced such that the bank neutral current is negligible.
  - However, the phase with the failed can draws less current than the other “good” phases, creating an unbalance among the phase currents.
  - This unbalance is reflected in the flow of neutral current

# Reactive Resource Alarms

2. Loss of a can reduces the number of cans available to divide up the primary voltage, resulting in a higher voltage drop across the remaining cans



- This stresses the remaining cans and increases their potential for failure.
- If another can fails, the remaining cans are subjected to an even higher voltage
- Ultimately, as more cans fail from the stress of higher voltage, failures of the remaining cans could cascade until the bank was seriously damaged

# Reactive Resource Alarms

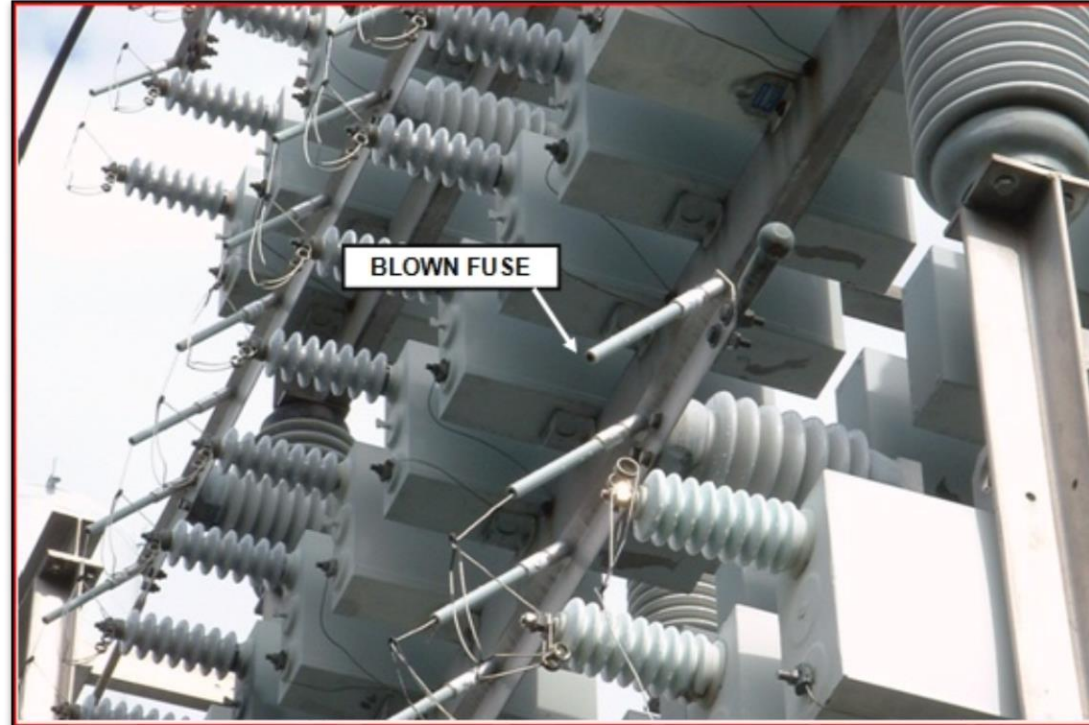
- Because these 2 effects are linked
  - Unbalanced neutral current in a capacitor bank can be measured
    - A relay is set to trip the bank when enough cans blow that the resulting voltages on the bank are high enough to cause unacceptable stress on the remaining cans
    - A lockout relay is also triggered to stop the operator from trying to reenergize the capacitor bank
- So one potential cause of capacitor bank tripping is the operation of the unbalanced neutral relay

# Equipment Alarms

- In EHV capacitors, the voltages are already so high that the blowing of a single fuse may be enough to trip the capacitor bank
- A repairman will need to be called to investigate the cause of a capacitor bank trip
- If the bank contains blown fuses, the cause of the unbalanced neutral operation is obvious
  - Failed cans and the associated fuses must be replaced before the bank can be restored to service
  - *This may be easier said than done*

# Reactive Resource Alarms

The blown fuse is indicated by the bayonet being displaced from the bottom of the housing



# Reactive Resource Alarms

The fuse may be easy to find in a small installation...



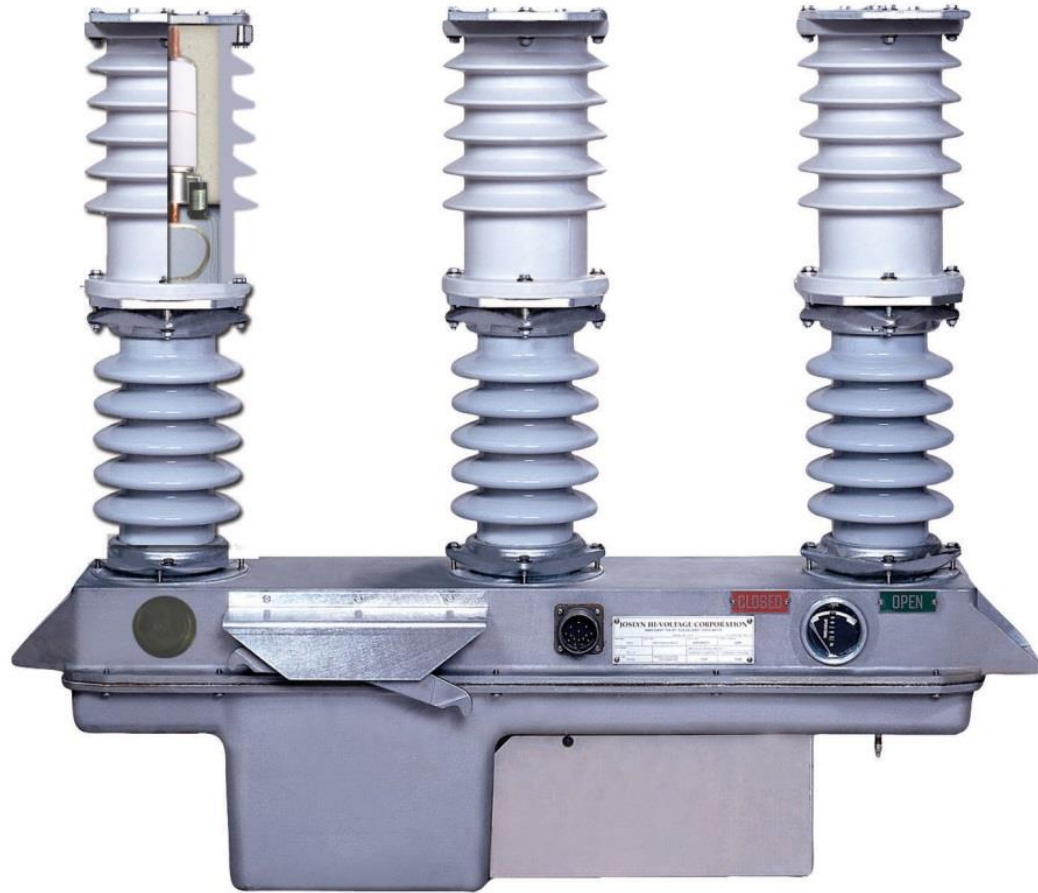
But what about one that looks like this???



# Reactive Resource Alarms

- If there is no sign of a blown fuse, there are other possible causes that should be investigated
- The switches that connect some capacitor banks to the power system are *independent pole* devices, meaning that the interrupting unit on each phase can operate independently of the other phases
- Unfortunately, these independent poles don't always operate together, or at all
  - If one or more poles of the vacuum switch fail to operate, it means that only one or two phases of the capacitor bank are energized
  - The resulting neutral current flow would be sufficient to operate the unbalanced neutral relay

# Reactive Resource Alarms





# Reactive Resource Alarms

- If this kind of operation occurs, **do not** reset the unbalanced neutral lockout relay and try again to close the capacitor bank
  - Isolate the capacitor bank and have the switch checked
- In some areas, the earth upon which the substation is placed is prone to Geo-Magnetically Induced Current (GIC)
  - During periods of Geo-Magnetic Disturbances (GMDs), ground currents could be created that can be seen by the neutral relay, and cause the capacitor bank to trip due to an *unbalanced neutral* relay operation
  - If no other problem is indicated, and GMD activity was noted, this may be a potential cause

# Reactive Resource Alarms

## Reactors

- Because oil-cooled reactors have basically the same construction as transformers, they have the same variety of monitoring, alarming, and relaying that transformers have
  - System Operators should respond to these alarms in a similar manner
- Air-cooled reactors have far less monitoring equipment
  - A failure of the reactor would generally be seen only as a trip on the associated circuit breaker
- A repairman would be needed to investigate the cause of the trip

# Reactive Resource Alarms

## SVCs

- Because they are composed of reactors and capacitors, the alarms associated with each of these components can be associated with the SVC units
- In addition, the voltage monitoring and control components may fail, and cause additional EMS alarms
- The unit components may be able to be used in manual mode, or the entire SVC may be out of service until repairs are made, depending on the nature of the failure

# Reactive Resource Alarms

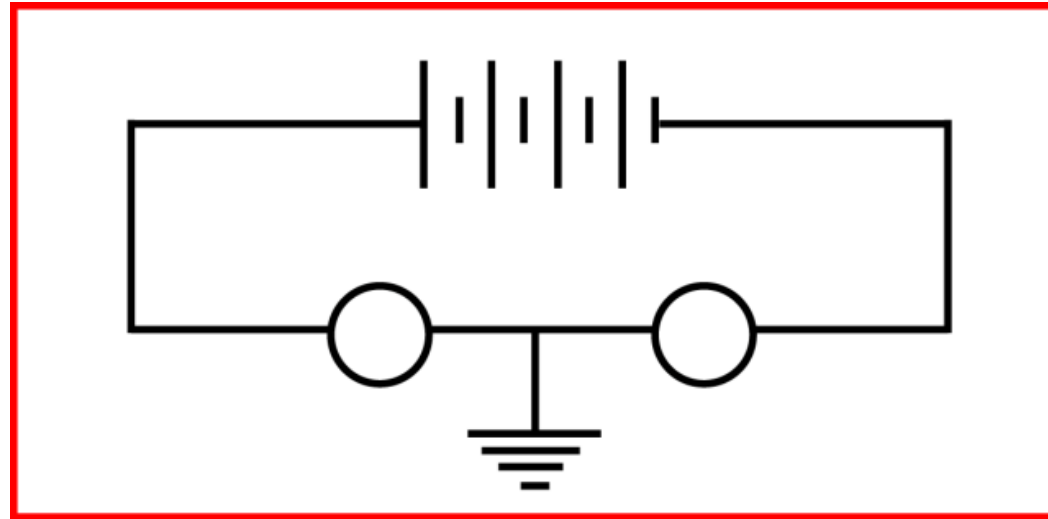
- General notes for reactive control device problems:
  - Make sure you consult your company's specific operating instructions for the site in question
  - Follow the approved alarm response guidelines
  - PJM will most likely request that repairs to any EHV reactive resource be made as soon as possible, to ensure the integrity of the BES
    - This is especially true during high load periods, or when a heavy load voltage schedule is expected to be implemented

# Other Substation Alarms

- Alarms from Other BES Substation Components
  - DC Ground alarms:
    - Relay and control circuits are individually fused to guard against disruption of the entire DC system for problems on a particular branch circuit
    - In larger stations, primary and back-up DC buses are usually established to serve completely separate, redundant, relay and control circuits, although in all but a few cases both these buses are fed from the same battery bank
    - With a few special exceptions, all substation DC systems operate ungrounded
    - Most transmission, and some distribution, stations are equipped with battery ground indicating lamps to alert personnel to inadvertent grounds on the DC system

# Other Substation Alarms

General diagram of a DC ground lamp circuit:

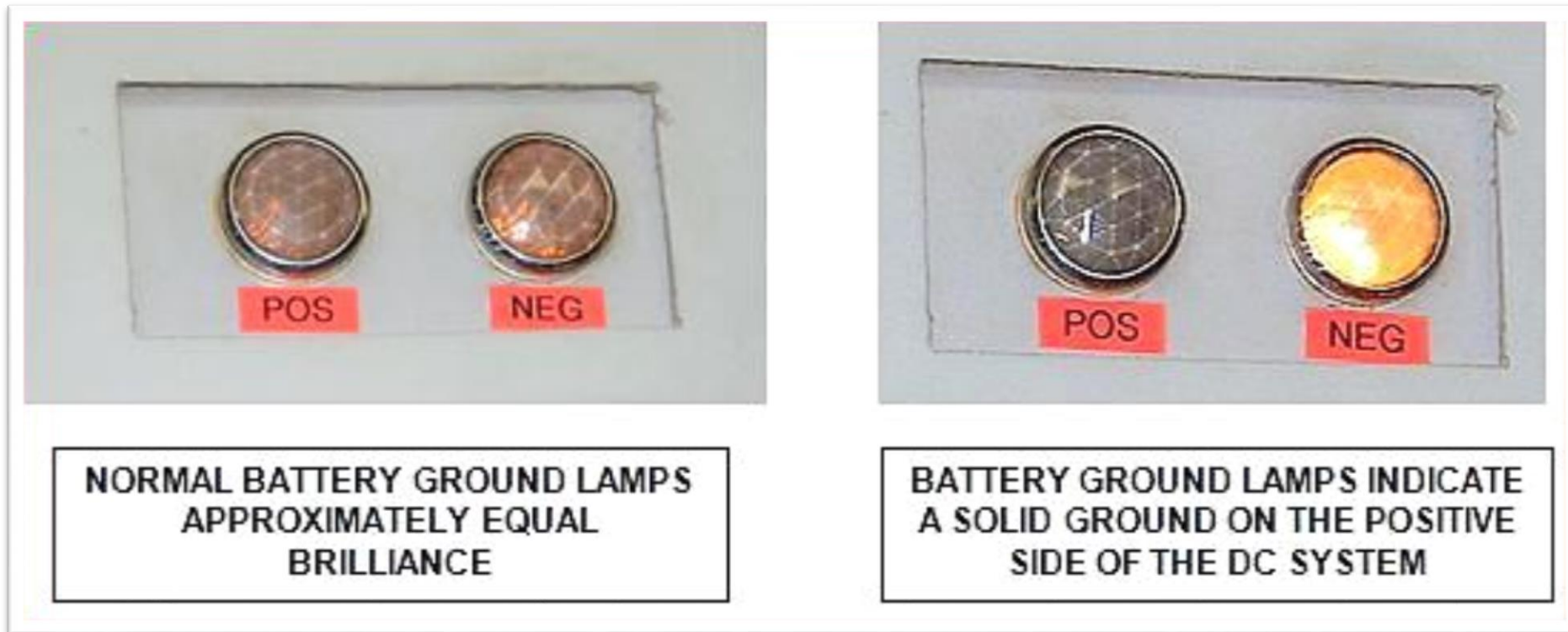


With no grounds on the system, one-half the total battery voltage drops across each lamp, and they glow with equal brilliance

# Other Substation Alarms

- A high impedance ground on the positive side of the DC system:
  - Decreases the voltage dropped across the positive-side lamp, causing it to dim perceptibly
  - Lamp connected to the negative side of the battery becomes brighter as the voltage between the negative terminal and ground becomes closer to full battery voltage
- For a dead short between positive DC and ground, the positive-side lamp will go out completely and the negative-side lamp, now exposed to full battery voltage, will glow with full brilliance

# Other Substation Alarms



This same principal of DC ground detection is used in more sophisticated devices that provide a contact alarm instead of only a visual indication



# Other Substation Alarms

- DC grounds, particularly multiple grounds
  - Can create havoc with relay and control circuits
    - Particularly with solid state digital equipment and can damage equipment or cause control schemes to mis-operate
- The greatest danger is that a second ground will occur on the opposite polarity side of the DC system:
  - Shorting out the battery through a ground path
    - Unless these grounds occur on the main battery cables or the directly connected buses in the DC distribution panel, fuses on the DC branch circuits should prevent major permanent damage

# Other Substation Alarms

- Substation battery grounds are not uncommon
  - Rain and moisture are the usual culprits
  - Conductive paths, formed by the urine and feces deposits that accompany field mouse infestations, are other common causes of DC grounds
- While it is important to correct a battery ground as soon as possible after it's identified, there's no reason to panic

# Other Substation Alarms

- Battery grounds often accompany heavy rains
  - May clear on their own when given a chance to dry out
  - Field personnel commonly isolate DC grounds by turning off branch circuits one at a time
    - When the grounded circuit is de-energized or disconnected from the battery, the ground disappears
  - Typically, the DC circuits interrupted first would be
    - Those with the highest likelihood of being grounded and,
    - Having the least likelihood of causing an operational problem when they're de-energized

# Other Substation Alarms

- There are risks associated with de-energizing DC circuits:
  - Equipment could trip, or fail to trip
  - EMS indications may not be valid
- Communication with field crews and PJM is important as they work to isolate and correct DC grounds

# Questions?

**PJM Client Management & Services**

**Telephone: (610) 666-8980**

**Toll Free Telephone: (866) 400-8980**

**Website: [www.pjm.com](http://www.pjm.com)**



The Member Community is PJM's self-service portal for members to search for answers to their questions or to track and/or open cases with Client Management & Services

# Resources & References



Guignet, D. (2004). *HMI – Human Machine Interface*.

Laganosky, T. (2003). *What does it mean when... And what can I do about it? When bad things happen to good operators*.

PPL Training Module LNM 014 (2001). *Identifying T&D Line Hardware*.

PPL Training Module ERO 040 (2005). *Substation Design & Operating Characteristics*.

PPL Training Module ERO 230 (2005). *Installing & Maintaining Substation Switches*.

PPL Training Module GTD 260 (2000). *Orientation to Substations*.

Rustebakke, H. (1983). *Electric Utility Systems and Practices* (4 ed.). Wiley-Interscience.