Fundamentals of Transmission Operations

Monitoring of BES Equipment

PJM State & Member Training Dept.

Objectives

By the end of this presentation, the student will be able to:

- Describe the effects on operations and equipment based on extended weather events
- Identify conditions under which a BES line may need to be de-rated
- Identify conditions under which a BES Transformer may need to be de-rated
- Also;
- Given an EMS alarm from a BES Transformer, determine;
    - One or more possible causes for the alarm
    - Some potential corrective actions

Objectives

- Given an EMS alarm from BES Circuit Breaker, determine;
  - One or more possible causes for the alarm
  - Some potential corrective actions
- Given an EMS alarm from BES Reactive Resource, determine;
  - One or more possible causes for the alarm
  - Some potential corrective actions
- Given an general EMS alarm from a BES substation, determine;
  - One or more possible causes for the alarm
  - Some potential corrective actions

Agenda

- Effects of Weather on Equipment Ratings
- De-Rating Transmission Equipment
  - Lines
  - Transformers
- Basic Alarm Response from Bulk Electric System Equipment
  - BES Transformer Alarms
  - BES Circuit Breaker Alarms
  - BES Reactive Resource Alarms
  - BES Substation Alarms

Effects of Weather on Equipment Ratings

- Hot Weather
  - 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 never has 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
    - Unit condensers may not operate efficiently

Effects of Weather on Equipment Ratings

- Cold Weather
  - 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

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De-Rating BES Transmission Equipment

- Lines

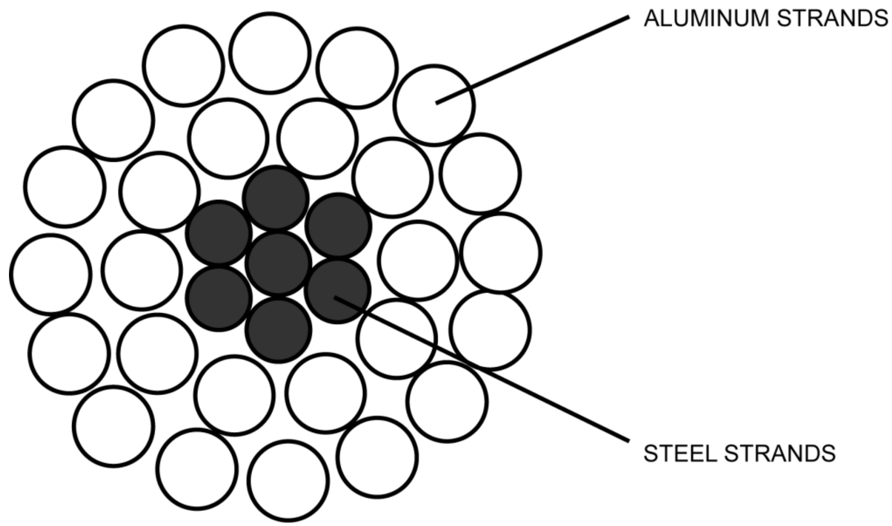
De-Rating BES Transmission Equipment

- 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 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

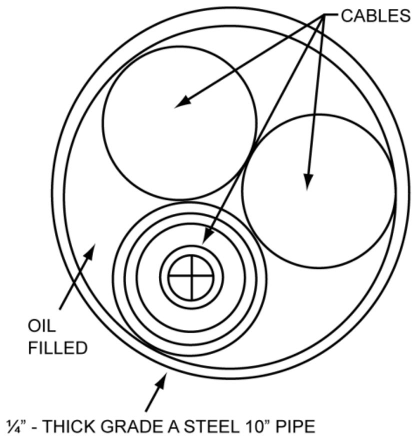
De-Rating BES Transmission Equipment

- Recent events have provoked FERC/NERC to rigorously enforce the Reliability Standards around Vegetation Management in transmission rights-of-way
  - 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”
  - How do utilities accurately determine the distances between the conductors and the vegetation under “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

- 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

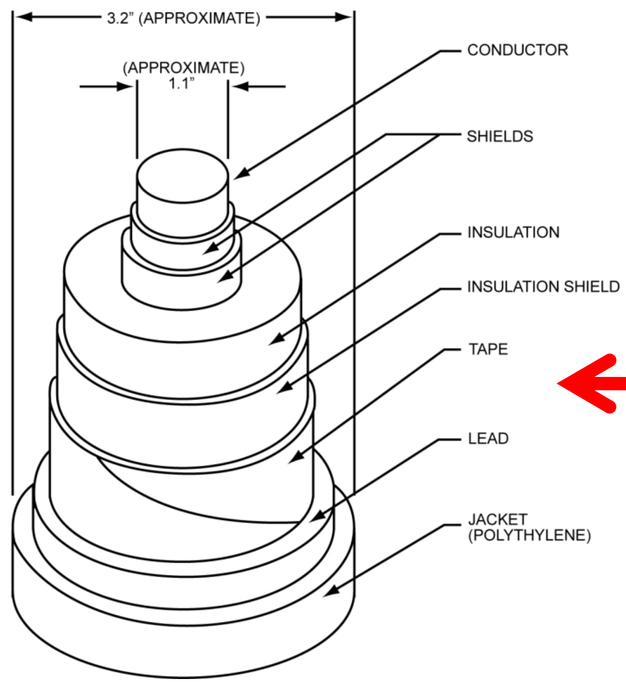
De-Rating BES Transmission Equipment



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

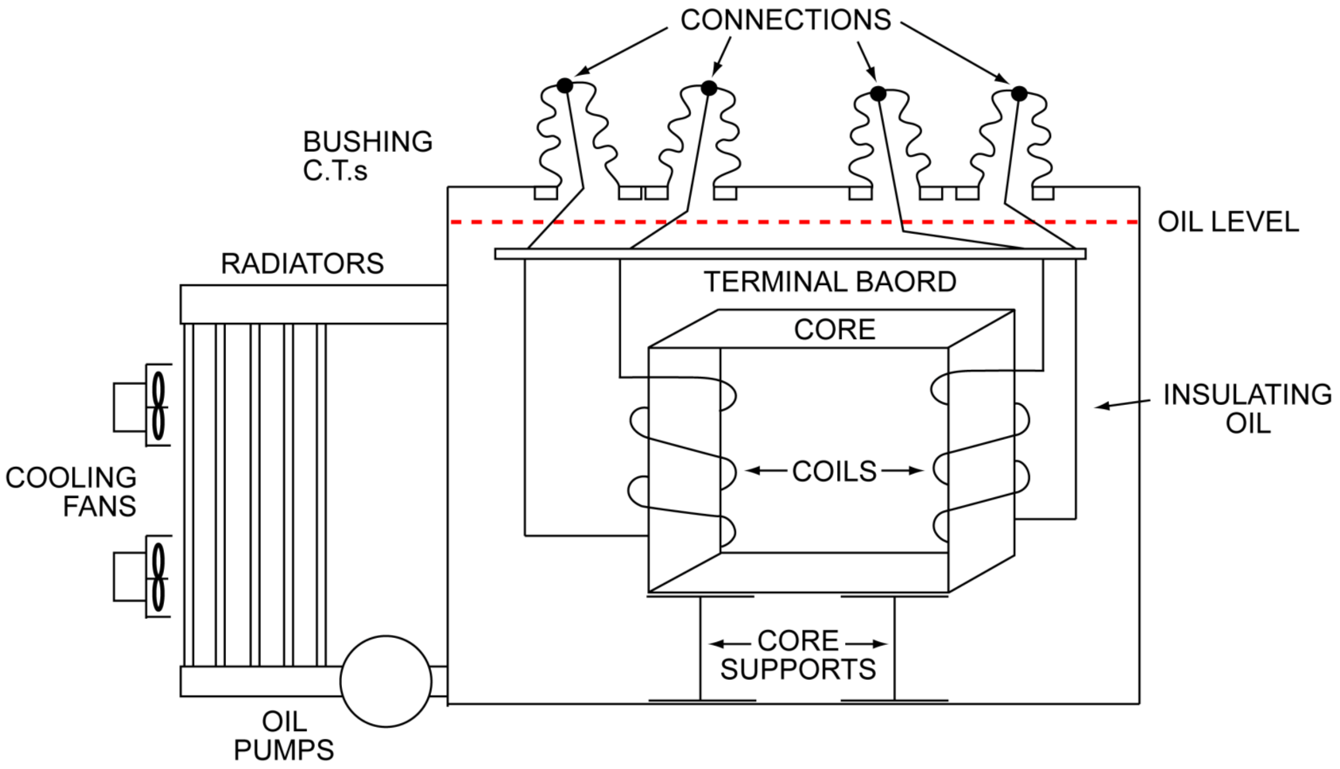
- If the oil pumping systems on the oil-filled cables become inoperative, the cable may need to be de-rated so that less heat is generated
  - If the pumps remain offline for an extended time, air pockets could build up in the pipes, which could cause phase-to-phase shorts in the cable if it was left 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 it’s 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



Power Transformer

De-Rating BES Transformers

- Transformers are filled with transformer oil, which acts to prevent arcing between the high and low voltage bushings, and helps to cool the magnetic core, which becomes heated while the transformer is in service

- Transformer ratings are determined primarily by the manufacturer, and are generally dictated by how well the transformer can disperse the heat generated by its operation

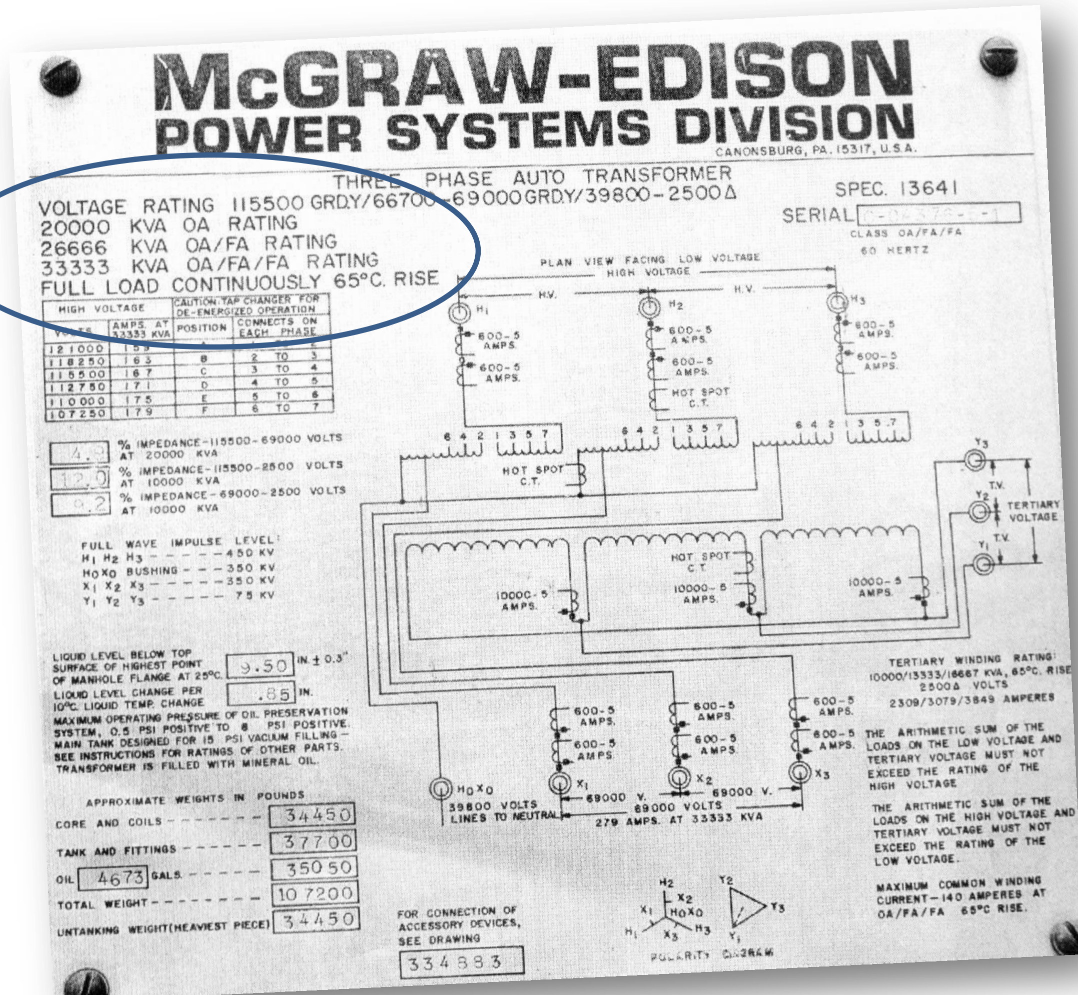
De-Rating BES Transformers

- To cool the oil, transformers are equipped with a set of pumps, which circulate the oil through a set of radiators external to the transformer oil tank. These radiators help to cool the oil
- Most BES transformers also have one or more banks of fans, which blow air onto the radiators to assist in the cooling process
    - These banks of fans 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 – The only cooling in service is natural circulation of oil through the radiators
    - OA/FA – The natural circulation and one set of cooling fans are in service
    - OA/FA/FA – The natural circulation and both sets of cooling fans are in service
    - OA/FA/FOA - The oil pumps and cooling fans are in service

De-Rating BES Transformers



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

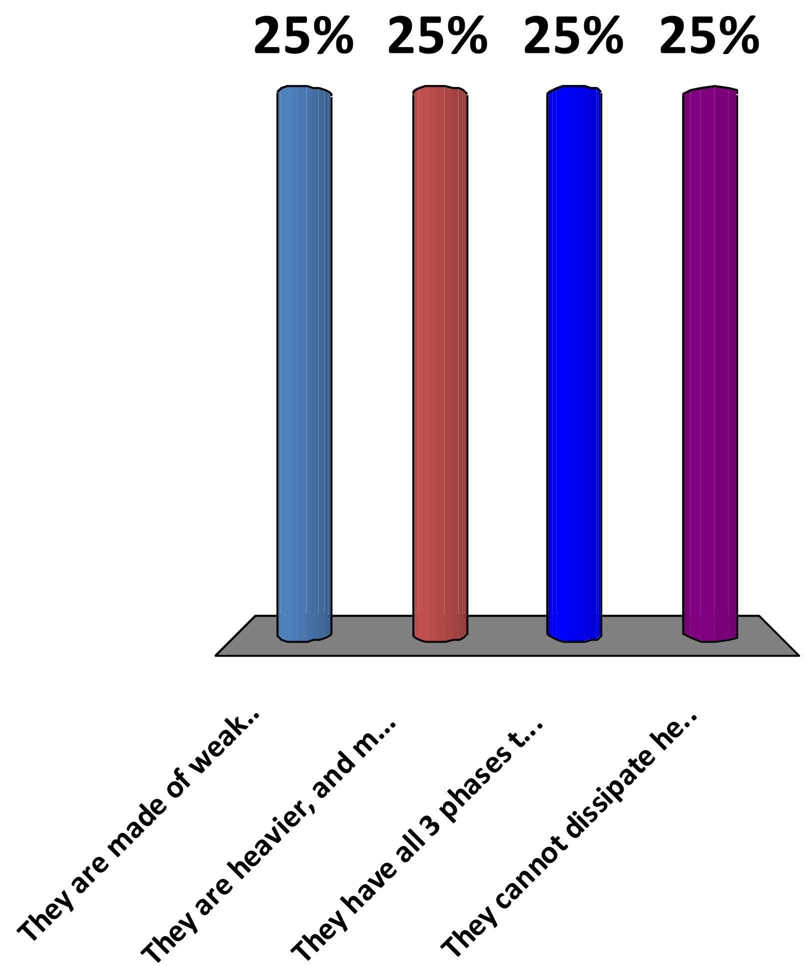
De-Rating BES Transformers

- 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 in cooling

Questions?

Transmission Cables generally have lower ratings than overhead lines because….

1. They are made of weaker materials
2. They are heavier, and more prone to “sag”
3. They have all 3 phases together in one structure
4. They cannot dissipate heat as well



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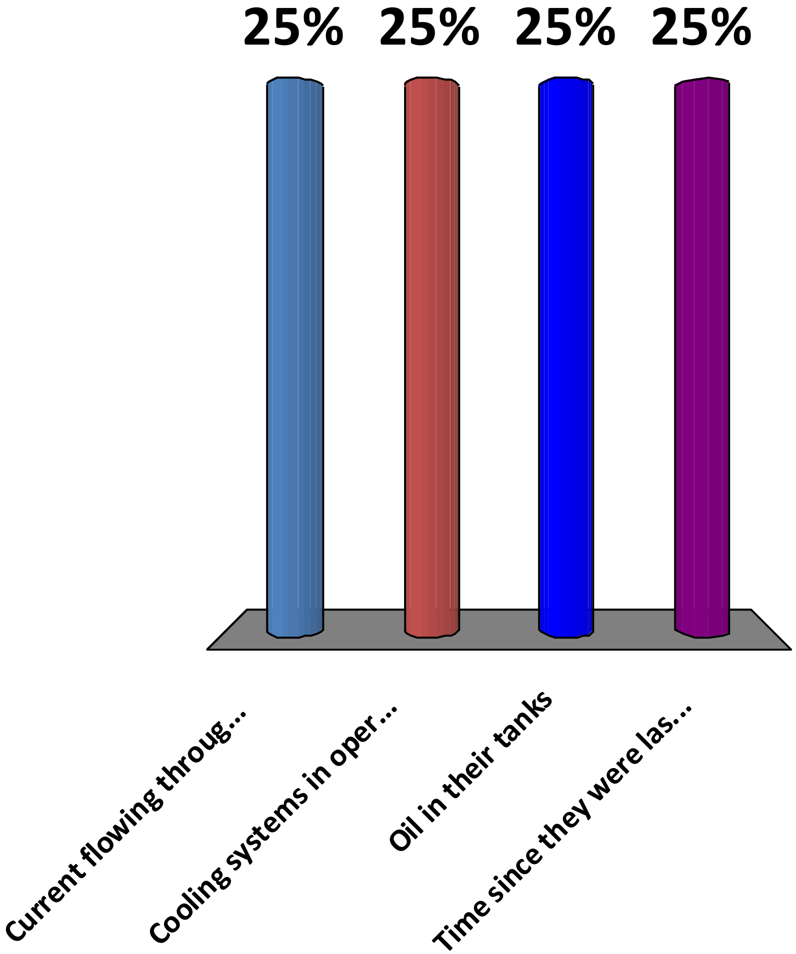
Transformers can have multiple ratings, based on the amount of…..

1. Current flowing through them
2. Cooling systems in operation
3. Oil in their tanks
4. Time since they were last overloaded



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What is the PJM eSuite application you would use to inform PJM of reduced equipment ratings?

1. eDATA
2. eDART
3. TERM
4. SSR

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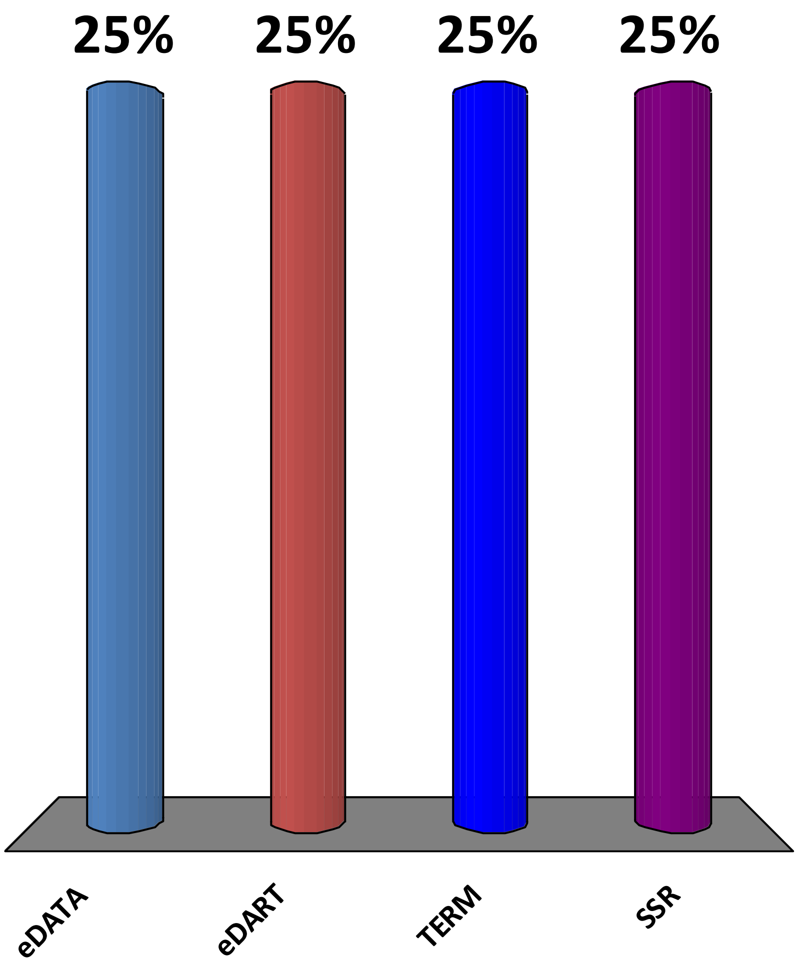

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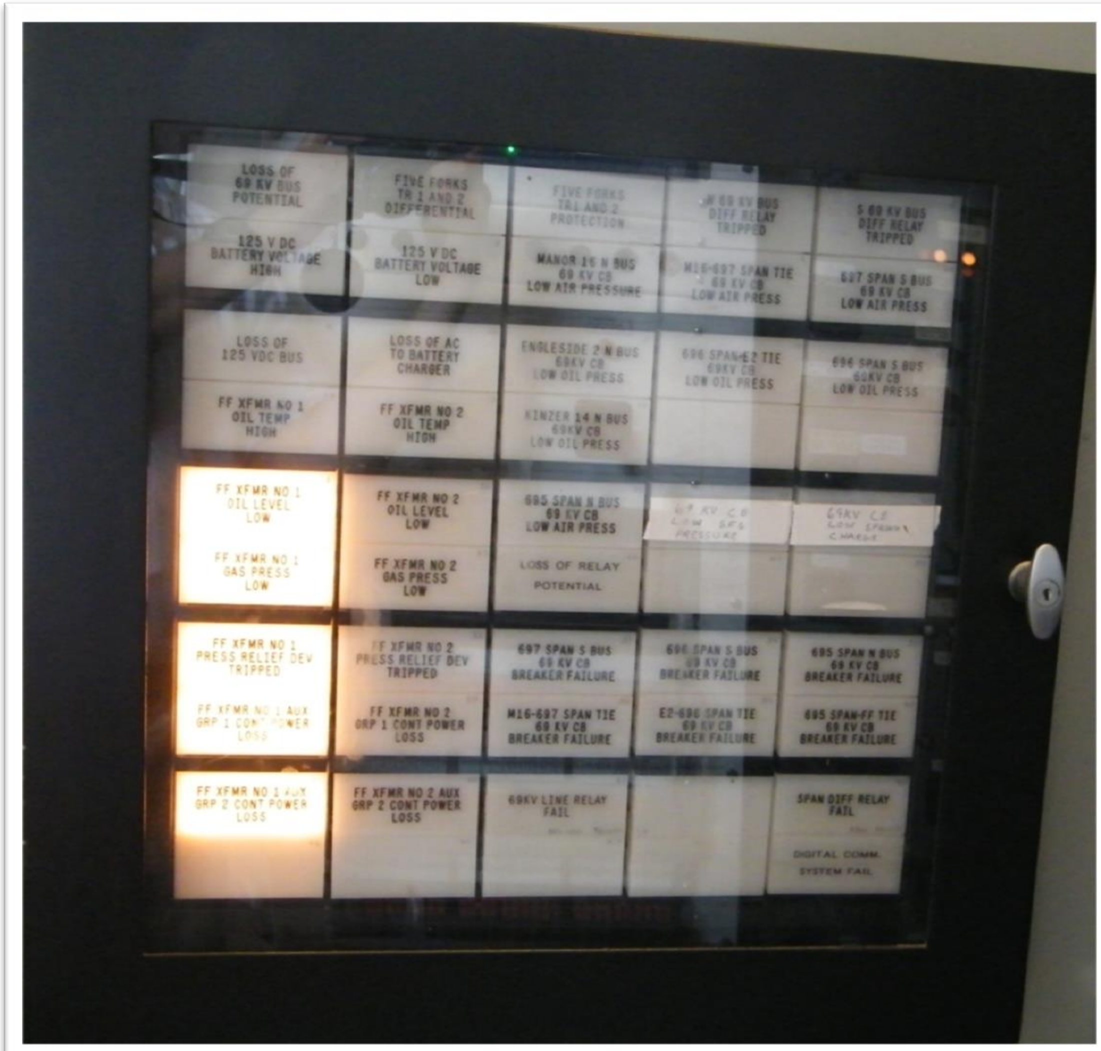
Basic Alarm Response from Bulk Electric System Equipment



Basic Alarm Response from Bulk Electric System Equipment

- It is important for System Operators to know the types of alarms that may result from equipment problems in substations, as well as be prepared with a course of action to respond
- Properly informed and prepared System Operators can only enhance BES safety and reliability
- We will cover some general alarms and responses here. **For specific responses, on your own equipment, make sure you follow your company's policies !!!!!!**

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 dispatch a repairman to the station and attempt 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 the oil temperature as well as the 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
  - 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
- In the event a 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
- Don’t let this happen to you: http://www.youtube.com/watch?v=YZipeaAkuC0

Transformer Alarms

- Stuck Tap Alarms
  - Transformers with LTCs are also usually equipped with “Stuck Tap” alarms. These alarms are received via the EMS when the LTC is unable to successfully complete a change between 2 taps, leaving 2 taps energized in the “bridging position”
  - This creates a low-level short circuit in the windings, and creates the potential for excessive heating as well as a catastrophic internal fault
  - It 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)

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 Brake or MOD’s can be safely opened to isolate the transformer, and the transmission line can be returned to service

- http://www.youtube.com/watch?v=QAmP-CnBT9k&feature=related

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 2 alarm points for these conditions. One to warn you that the pressure is below desired levels, a second to warn you that the pressure is too low to allow the CB to open

Circuit Breaker Alarms

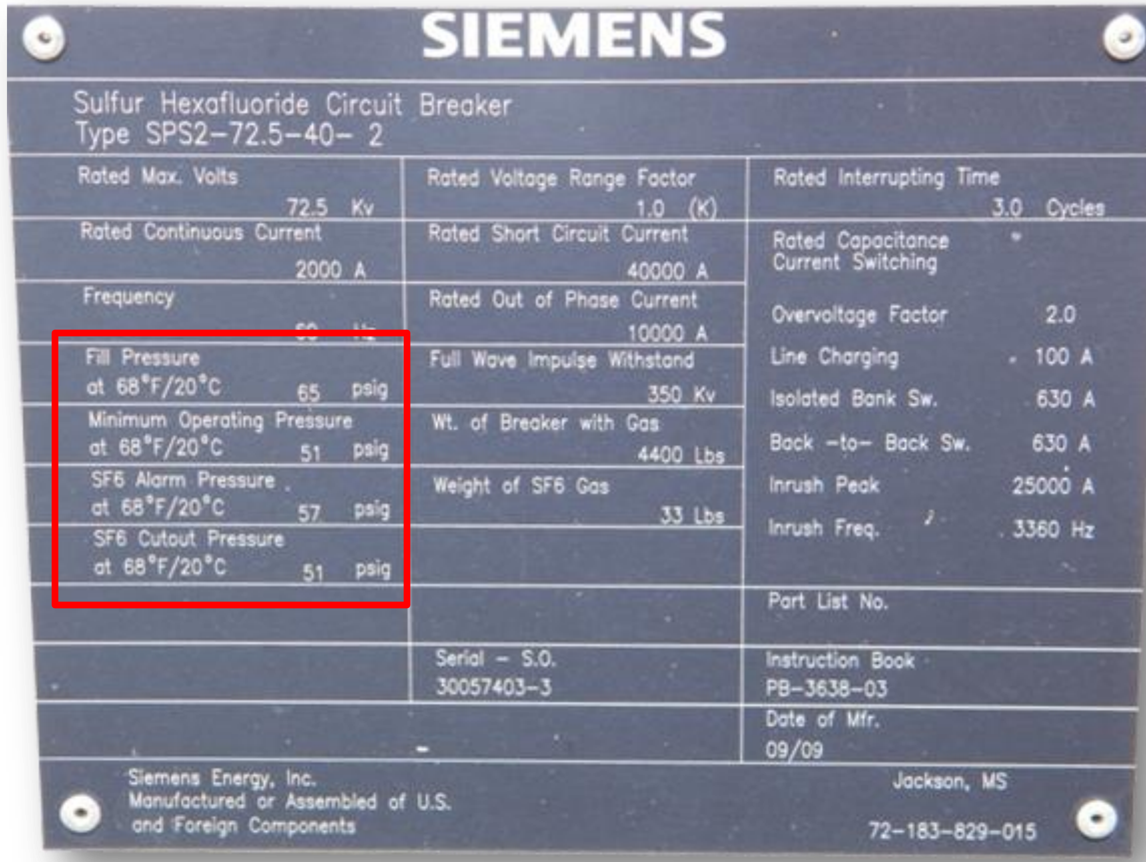
- Depending on how the Breaker is installed, one of 2 things can happen as pressures approach the second setpoint
  - The CB will trip while it is still able to extinguish the arc. Automatic disconnects on either side of the CB will isolate it from the system
  - The CB will "lockout" to prevent operation 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



Circuit Breaker Alarms

- Another type of pressure alarm may be received from pneumatically operated CBs
  - This low pressure alarm does not indicate a problem with the breaker's ability to interrupt the circuit, but rather with its ability to re-charge it's closing mechanism
    - If the pressure is too low, the breaker will still trip, but will be unable to reclose on its own
    - 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 2 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

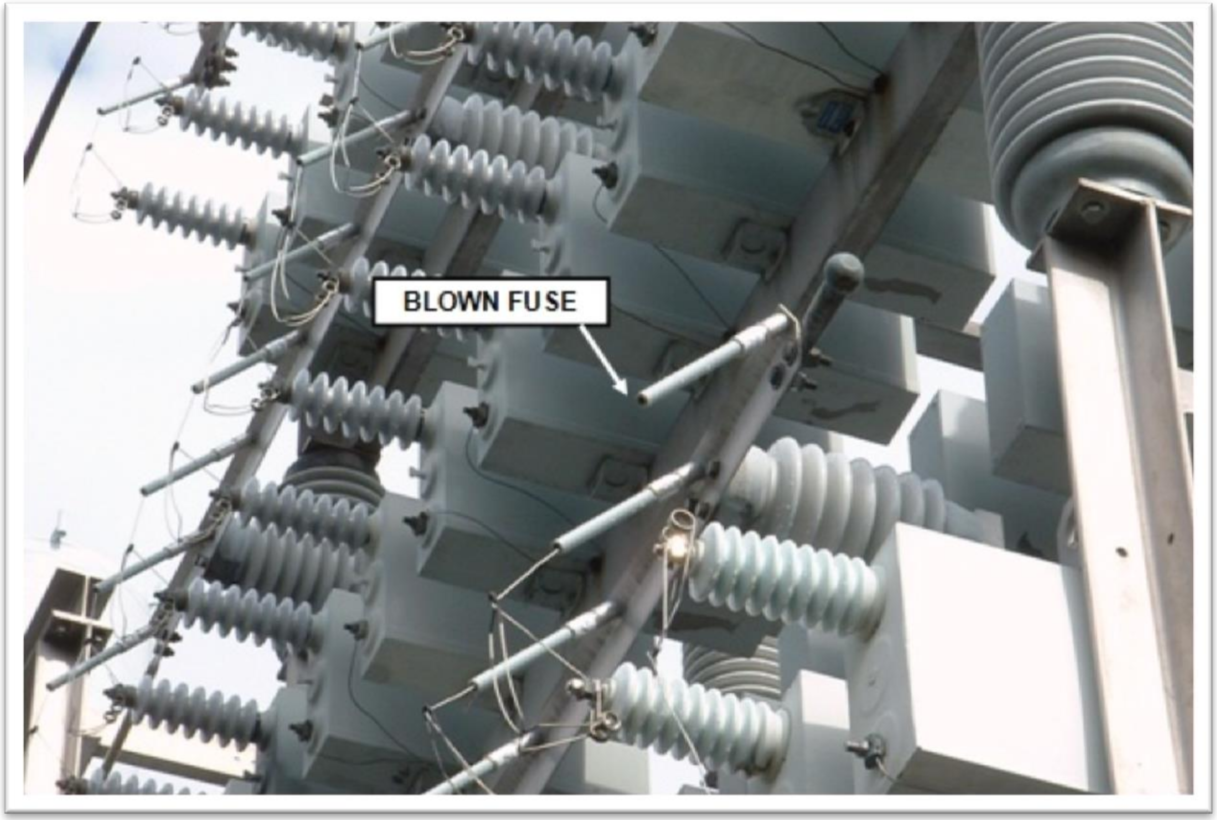
- Because these 2 effects are linked, we can measure the unbalanced neutral current in a capacitor bank, and set a relay to trip the bank when enough cans blow that the resulting voltages on the bank are high enough to cause unacceptable stress on the remaining cans. A lockout relay is also triggered 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 vacuum 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

- 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 vacuum switch checked.
- In some areas, the earth upon which the substation is placed is prone to GIC (Geo-Magnetically Induced Current).   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

- One other potential cause for capacitor bank tripping
  - Capacitor bank controls and vacuum switches operate on AC, rather than DC, control voltage. If the station service AC voltage deteriorated for some reason, the vacuum switch might not be able to open to clear a problem before serious damage occurred
  - A special relay scheme monitors the AC station service and, if the voltage falls below a preset limit, will initiate a ***fast trip*** of the vacuum switch to make sure the capacitor bank is de-energized. The fast trip scheme discharges large capacitors to pulse the vacuum switch trip solenoids
  - These capacitors are interlocked with the vacuum switch closing circuit such that the switch can't close unless the capacitors are charged enough to energize the trip solenoids
  - The fast trip scheme does not operate the lock out relay and thus requires no manual reset

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

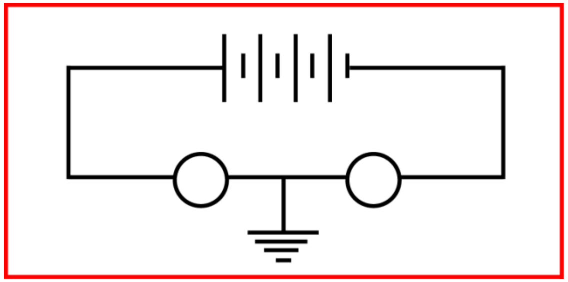
- General notes for reactive control device problems;
  - Make sure you consult your company's specific operating instructions for the site in question.
    Follow the approved alarm response guidelines
  - PJM will most likely request that repairs to any EHV reactive resource be made as soon as possible, 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;

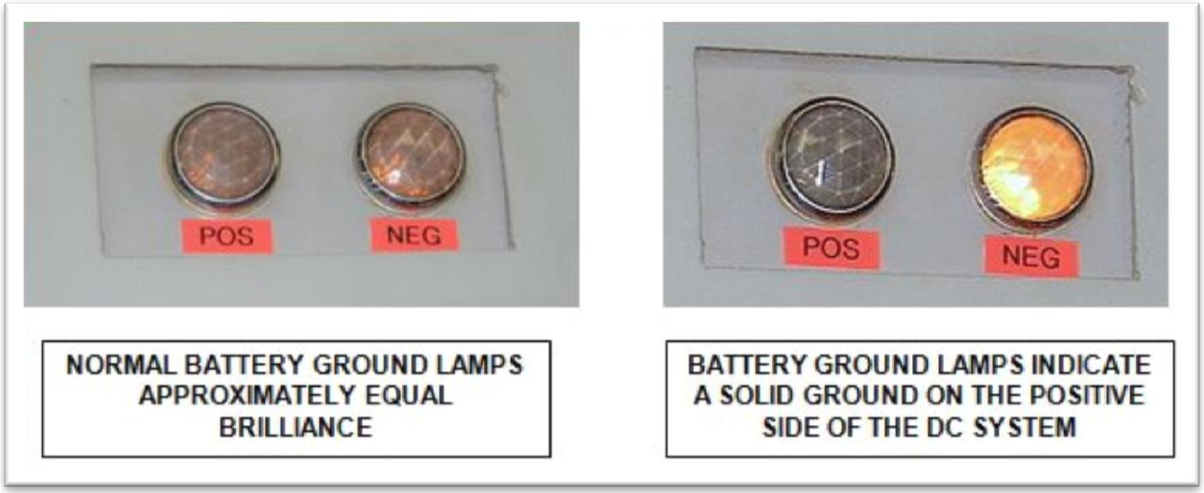


- With no grounds on the system, one-half the total battery voltage drops across each lamp, and they glow with equal brilliance

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. At the same time, the 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, by introducing transients and alternate current paths that can damage equipment or cause control schemes to misoperate
- The greatest danger is that a second ground will occur on the opposite polarity side of the DC system, essentially shorting out the battery through a ground path. Fortunately, 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, providing an unintended path for DC current flow. Conductive paths formed by the urine and feces deposits that accompany field mouse infestation 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. Some substations, primarily distribution stations, have no means at all of battery ground detection. Some stations have only indicating lamps with no alarms to the EMS, others have external ground detection devices that may or may not be connected to alarm remotely, and some stations have ground detection integral with the PLC SCADA RTU

Other Substation Alarms

- Battery grounds often accompany heavy rains, and often will clear on their own when given a chance to dry out. The fact that a ground appears at all is cause for investigation and repair, but a ground that clears on its own is not an emergency
- 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 the least likelihood of causing an operational problem when they’re de-energized

Other Substation Alarms

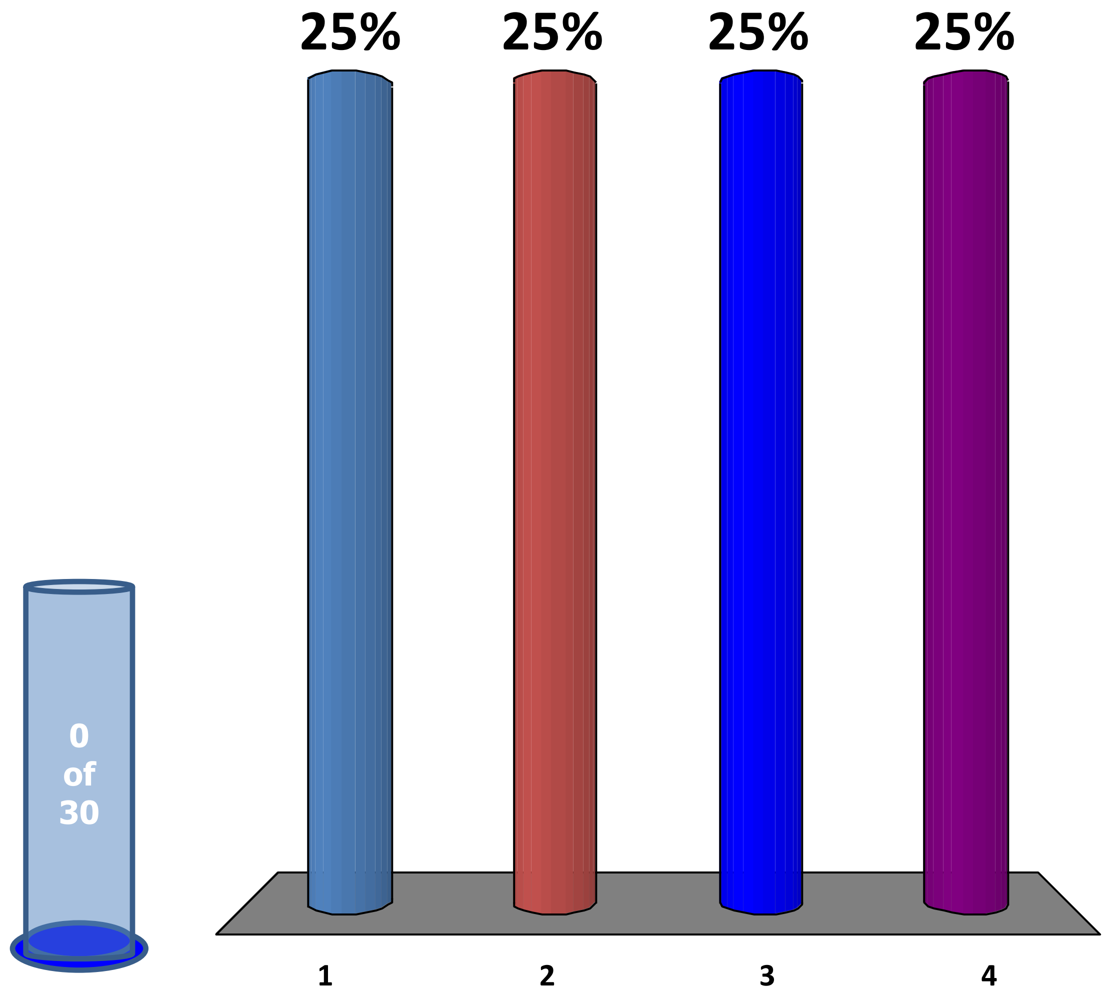
- There are risks associated with de-energizing DC circuits
  - Equipment could trip, or fail to trip
  - EMS indications may not be valid
- Communication with field crews is important as they work to isolate and correct DC grounds

Questions?

From which type of equipment might you expect to receive an alarm for high winding temperature?

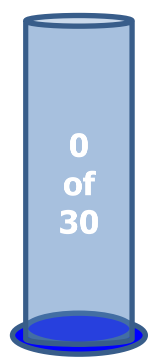
A. Transformer
B. Capacitor
C. PAR
D. Circuit Breaker

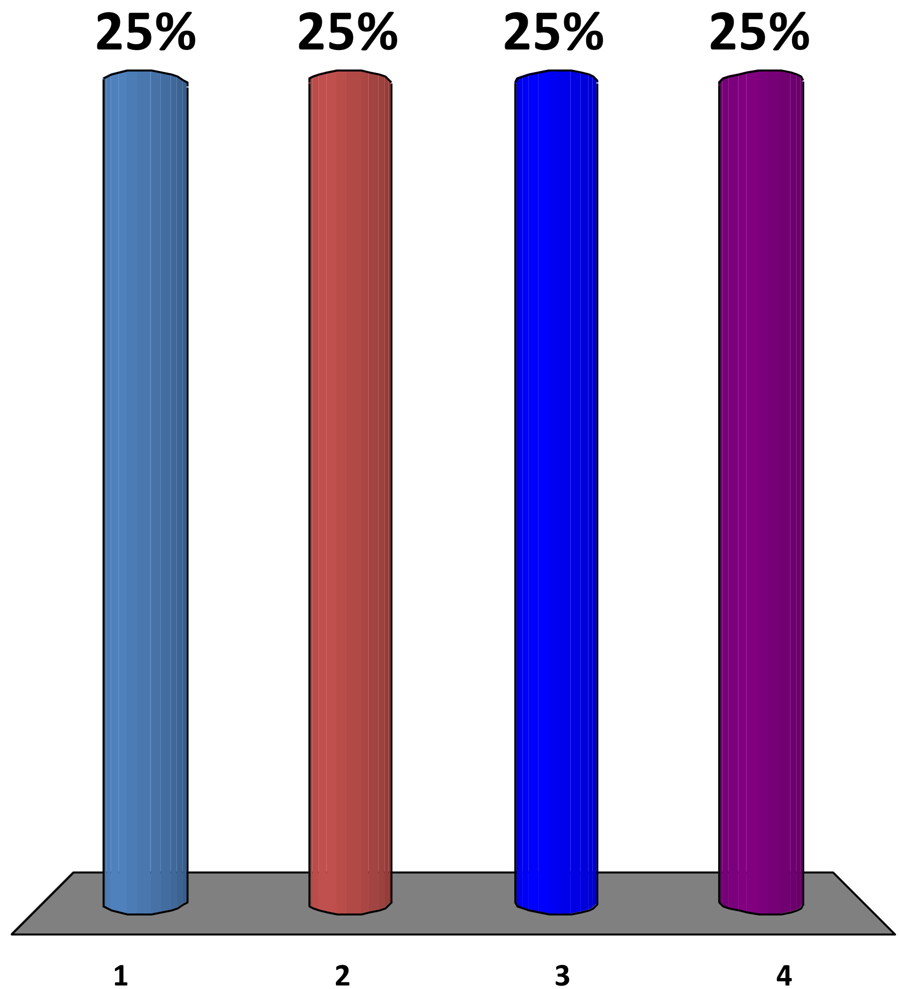
1. A only
2. A & C
3. B & C
4. A, B & D



Which of the following is ***not*** a potential cause for an unbalanced neutral trip of a capacitor bank?

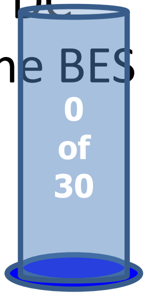
1. Blown fuse(s) on Capacitor cans
2. Geomagnetically induced currents
3. Low station service voltage
4. Problems with the capacitor circuit switcher

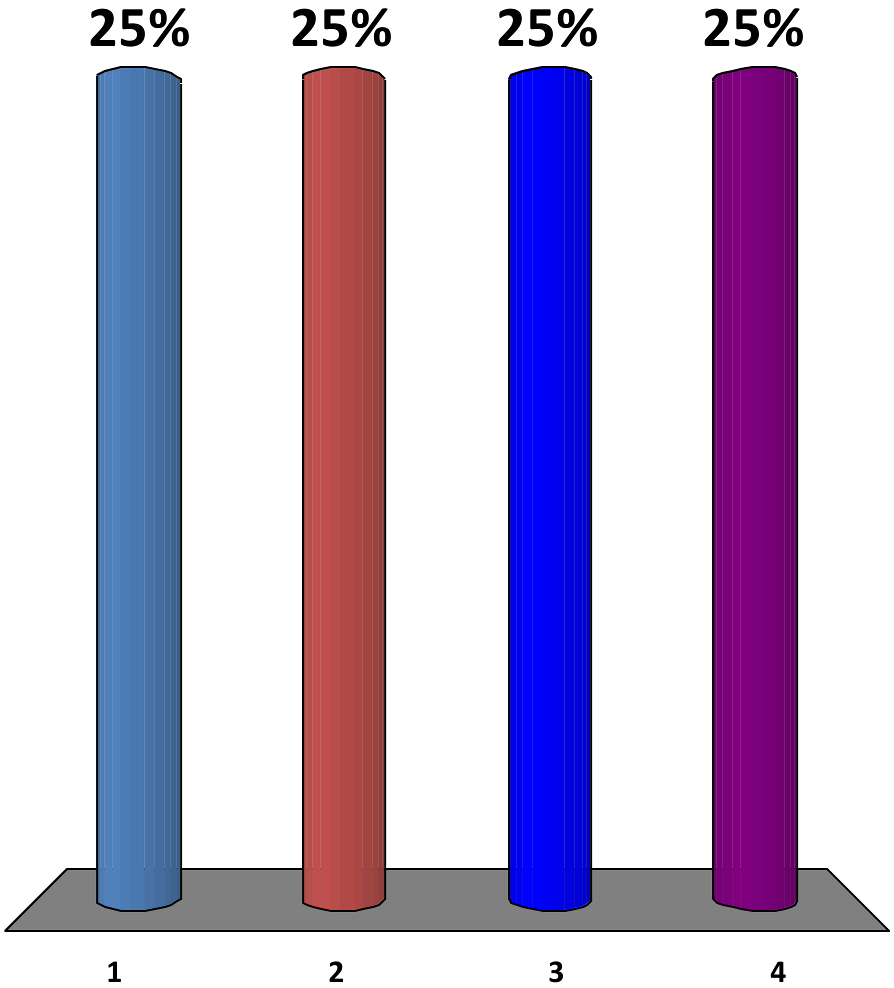




Which of the following is ***true*** concerning substation DC grounds?

1. A DC ground is an emergency condition that my require load shedding
2. DC grounds can cause relay mis-operations
3. There is no way to detect a DC ground in a substation control circuit
4. Field crews looking for a DC ground pose no risk to the BES





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