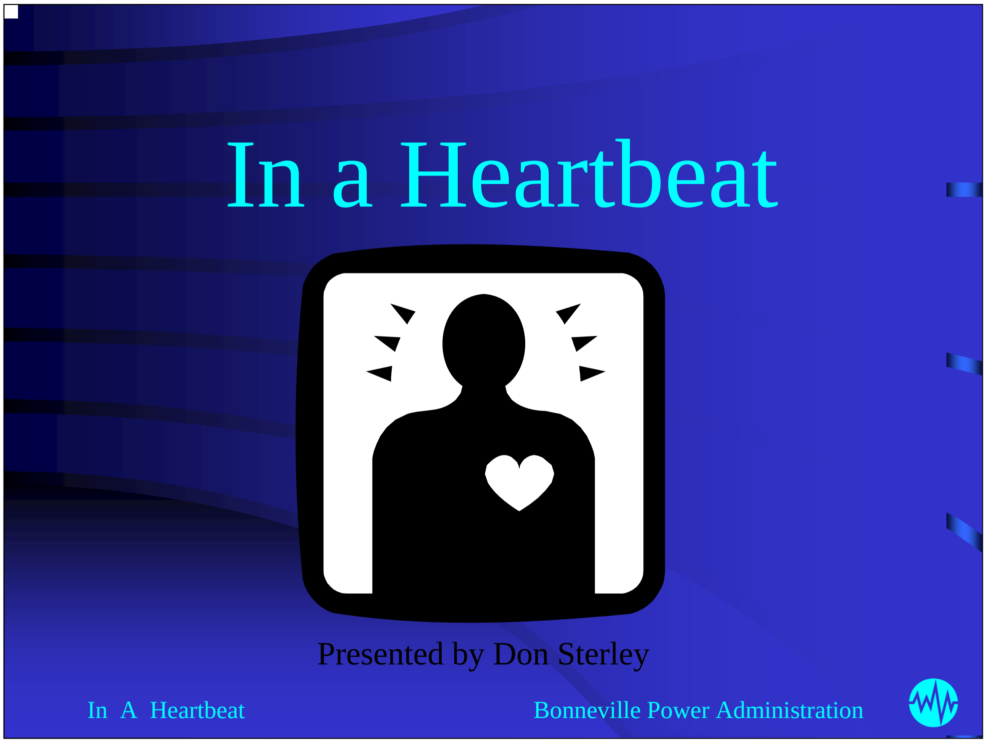
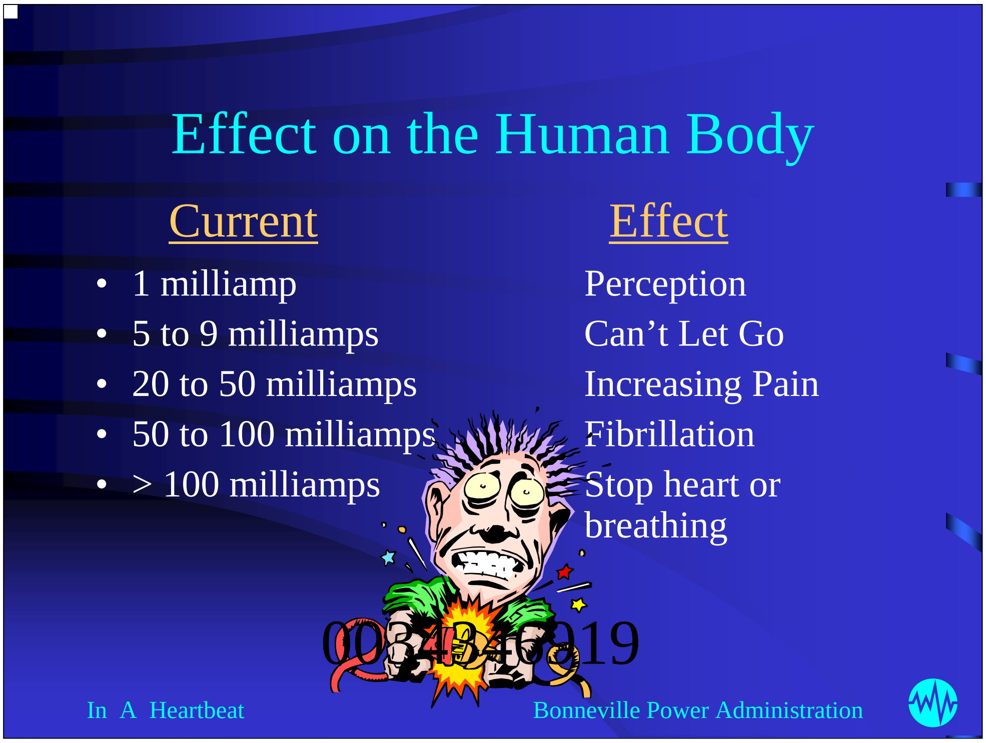


In a Heartbeat

- It is my desire and your management's desire that all of you are safe while at work and that you are able to go home to your family every night. There are very real hazards as a result of step & touch potential as well as capacitive and inductive coupling. It only takes a moment, a heartbeat, for you or I to get into trouble and not go home to our family this night.

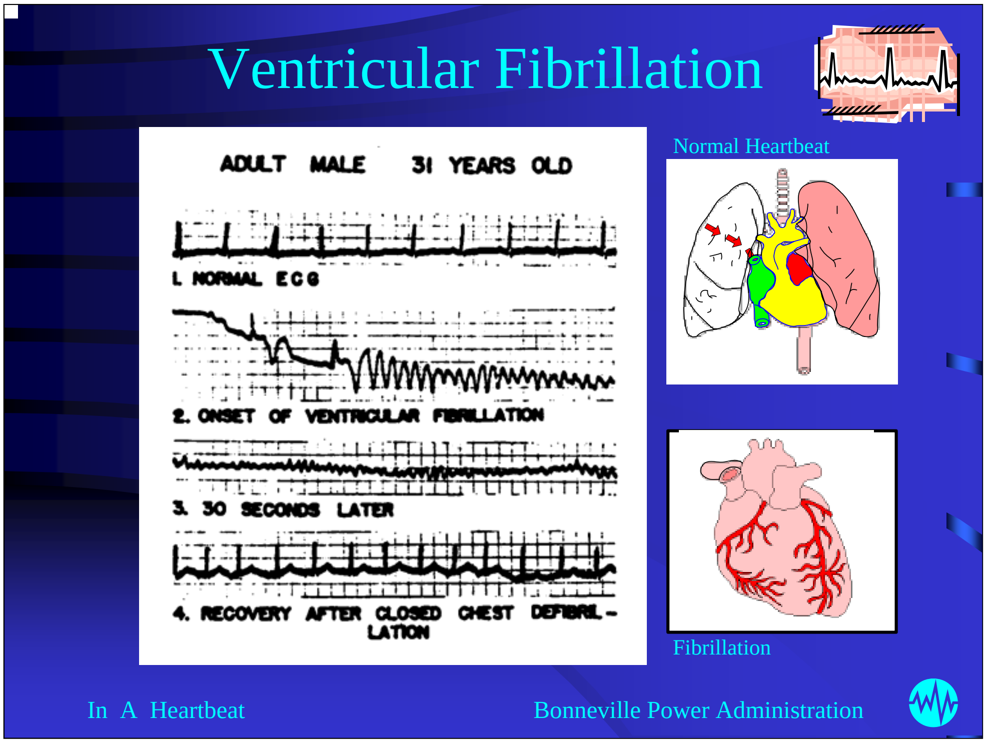
What are We Going to Talk About?

- Ventricular Fibrillation
- Step & Touch Potential
- Ground Grid Design
- Fatal Accidents on the BPA System
- Magnetic & Capacitive Coupling from Transmission Lines



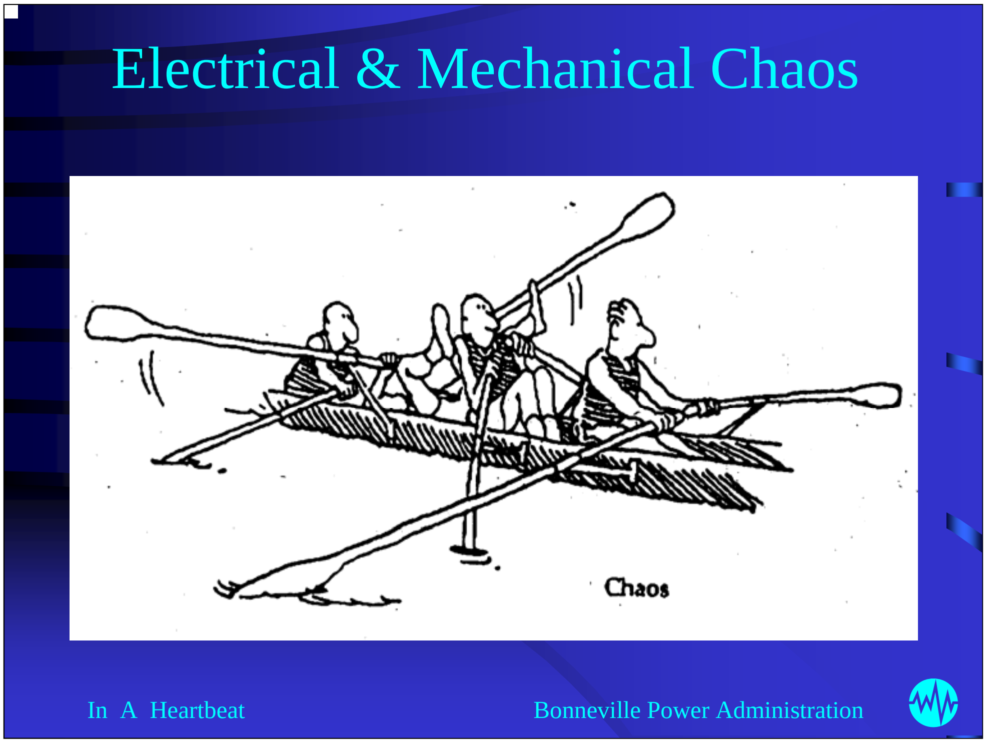
Effect of current through the heart region

- Man's perception occurs at just 1 milliamp. This is the point at which an individual can feel a tingling sensation.
- The "can't let go" value occurs at about 9 milliamps. If you reach out and grasped something hot, you probably would not be able to let go because your hand muscles would have contracted around the object.
- The effect of currents up to about 50 milliamps are temporary in nature. Upon removal of contact the body resumes normal function without any lasting effects. (Assuming the duration is reasonably short.)
- The point at which ventricular fibrillation occurs is critical. Ventricular fibrillation occurs between 50 to 100 milliamps.
- Currents greater than 100 milliamps can:
  - completely stop the heart
  - inhibit breathing in two ways:
    - by causing the chest muscles to contract, preventing the lungs from expanding
    - by blocking the nerve center of the brain that controls the breathing function
- The above values are true for a 155# adult. The value at which these effects occur is dependent upon body weight. For a woman or child the values would be smaller.



Ventricular Fibrillation Waveform

- This slide presents one of those extremely rare instances where ventricular fibrillation occurs during cardiac catheterization. The cardiogram shows the patient's normal heart record, the onset of fibrillation, its characteristic pattern, and the recovery of normal heart action after defibrillation. The defibrillating shock was given some 80 seconds after the onset of the emergency. The patient went home the next day.
- *Field Treatment in Electric Shock Cases-II*, Kouwehoven, Knickerbocker, Milnor, Jude, April 1960, p.20.



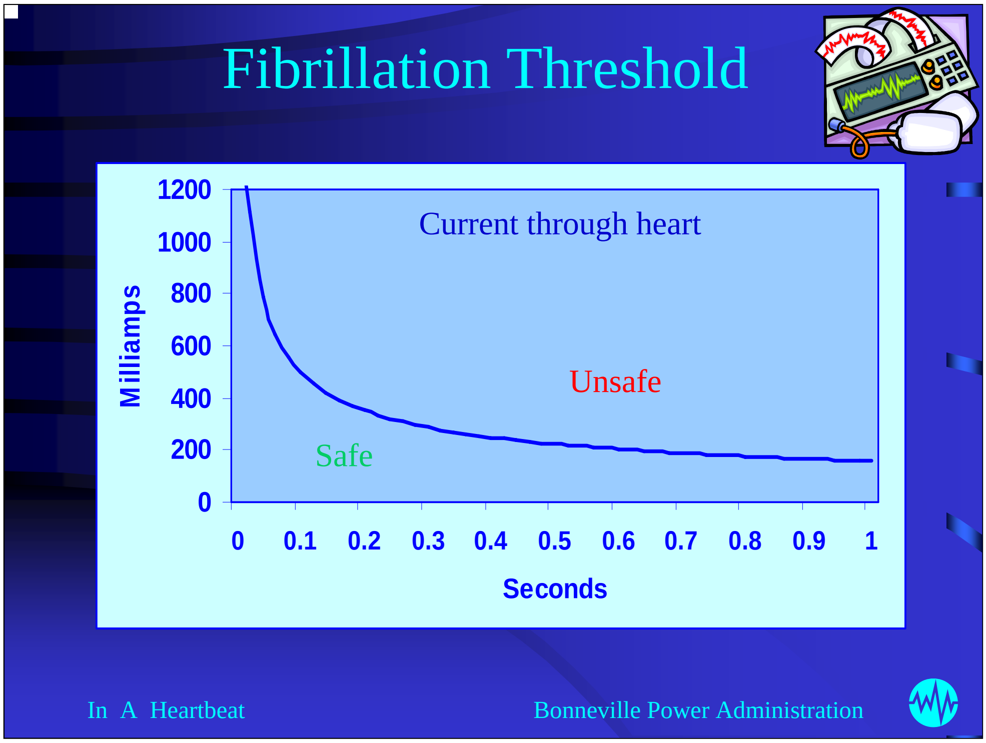
Electrical and Mechanical Chaos

- **Definition:** Ventricular Fibrillation is a potentially fatal arrhythmia characterized by electrical and mechanical chaos. It is most commonly associated with coronary disease and myocardial infarction, but it may also occur in electric shock, drug overdoses and sensitivities, or drownings.

- In other words,

  fibrillation is the ineffectual and uncoordinated spasm of the heart.

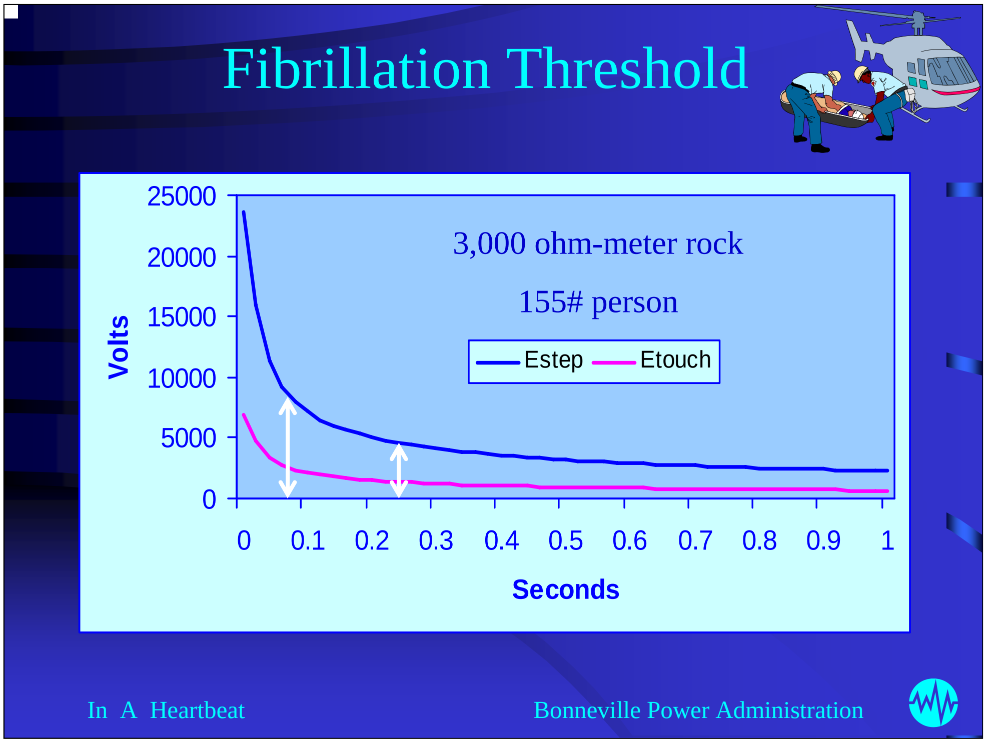
  This spasm does not contribute to blood flow and therefore can be fatal if normal heart function is not soon restored.



Fibrillation Threshold for a 155# person

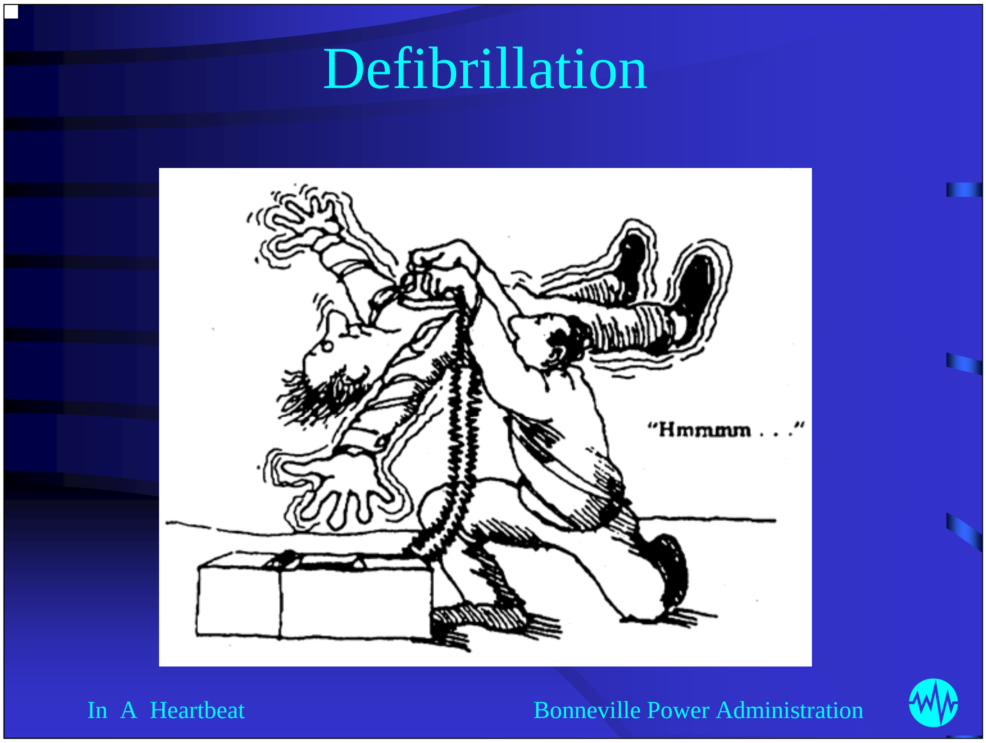
- This slide illustrates the fibrillation threshold for a 155# adult using Dalziel's formula I_{body}=0.157/sqr(time in seconds). This formula is applicable to 99.5% of persons weighing 155#. This formula is based on tests limited to a 0.03-3.0 second range, and is not valid for very short or long times.

- ANSI/IEEE Std 80-1986 p. 31 & 32.



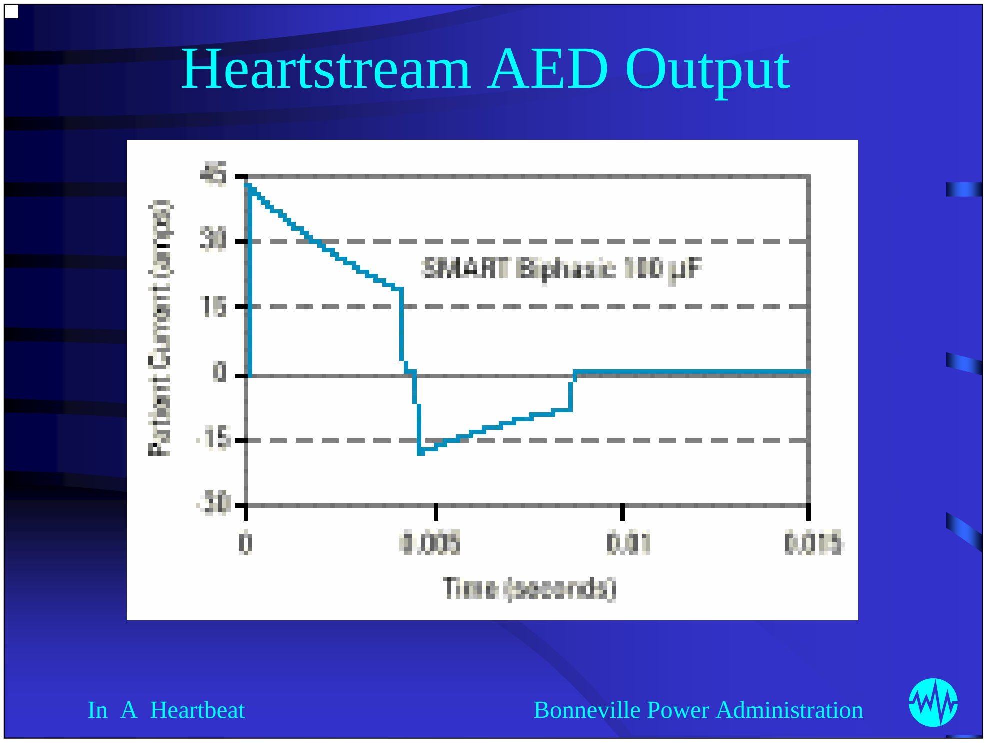
Step & Touch Potential

- As we know, it is the current through the heart region that produces ventricular fibrillation. We saw on the previous slide the level of body current required to put the heart into fibrillation. Because it is much easier to work with the step and touch voltages, the following formulas have been derived to help us determine the voltage necessary to induce ventricular fibrillation in a 155# person.
- E_{touch}=[157+0.23*(surface soil resistivity)]/[square root(time in seconds)]
- E_{step}=[157+0.94*(surface soil resistivity)]/[square root(time in seconds)]
- This slide illustrates the Estep and Etouch for a 155# person on 3,000 ohm-meter rock. (BPA specifies a minimum of 3,000 ohm-meter rock fractured on three sides and three inches thick for use in its substations.)



Defibrillation

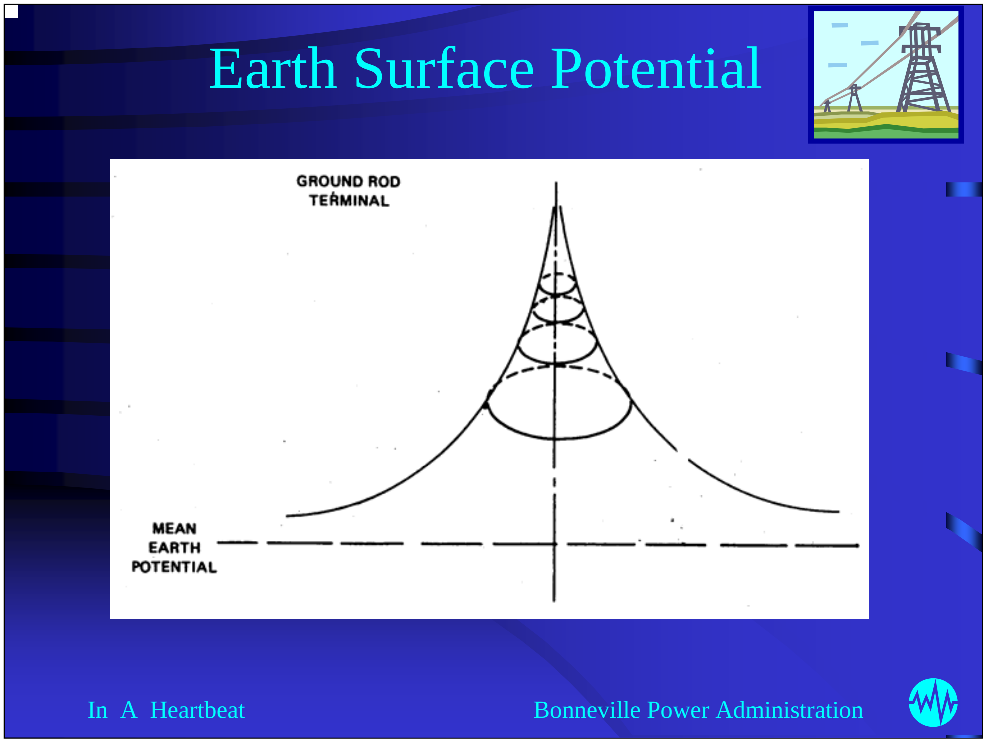
- This slide is a picture from a recent BPA training session.
- **Defibrillation is the delivery of electric current to the heart through the chest to terminate ventricular fibrillation.**
- The only reliable effective method of stopping ventricular fibrillation is to send sufficient electric current through the heart to contract it and bring its twitching fibers to rest. The hearts natural regulator (pacemaker) then takes over and restores regular heartbeat.
- CPR is essential to keep the victim viable until a defibrillator arrives. If defibrillation is attempted within one minute, there exists a 90% chance of survival. The odds for survival decrease approximately 10% per minute.
- Each year about 60,000 people in the USA suffer a short-circuit of the heart that can be reversed by a shock from a defibrillator. In recent years, easy-to-use AEDs have saved thousands of lives. The critical factor is time. New studies show the chances of surviving a cardiac arrest nearly quadruple if fast-acting laypeople perform CPR and more than triple if a shock from a defibrillator is delivered within eight minutes.
- Approximately 80% of the time Sudden Cardiac Arrest (SCA) drops into ventricular fibrillation.
- CPR by itself, without intervention by medical personnel, will recover a heart 0.3% of the time. The addition of emergency medical personnel using CPR and medications raises this to 14.8%.
- *Defibrillation, What You Should Know,* Physio-Control, p. 2, 3 & 10.
- *USA Today, August 12, 2004, as reported in the New England Journal of Medicine.*



Heartstream Output

- This is the Agilent Technologies Heartstream FR2 Automatic External Defibrillator (AED). It outputs a Bi-phasic low energy (150 Joules) pulse. The output pulse is a peak current of about 45 amperes with a pulse duration of less then 10 milliseconds.
- Bystanders performing CPR and using automated external defibrillators (AEDs) save as many cardiac arrest victims as highly trained paramedics-and send more of them home with normal brain function. Because paramedics often arrive relatively late, the research found the people they save are more likely to suffer brain damage: 78% of those saved by bystanders without paramedics survived with excellent brain function vs. 68% of those treated by paramedics.
- But the best outcomes occur when bystanders intervene immediately instead of waiting for paramedics. When bystanders manage to shock a person with an AED before emergency crews arrive, survival rates double according to a second study published today.
- Roger White, Mayo Clinic Researcher and medical director of the early defibrillation program in Rochester, Minnesota, maintains that his data show that victims shocked within six minutes almost always live; those shocked after six minutes almost always die.
- We must be prepared to use AEDs. A study published in 2003 indicated defibrillators were used only slightly more than a third of the time by rescuers in places where the devices were nearby. About four out of five non-health workers couldn't use them properly when training on mannequins, according to the December issue of the Journal of Dental Education. Patients who receive CPR and a defibrillator shock within three minutes of going into cardiac arrest survive 75% of the time. Just two minutes longer and the survival odds drop to 40%.

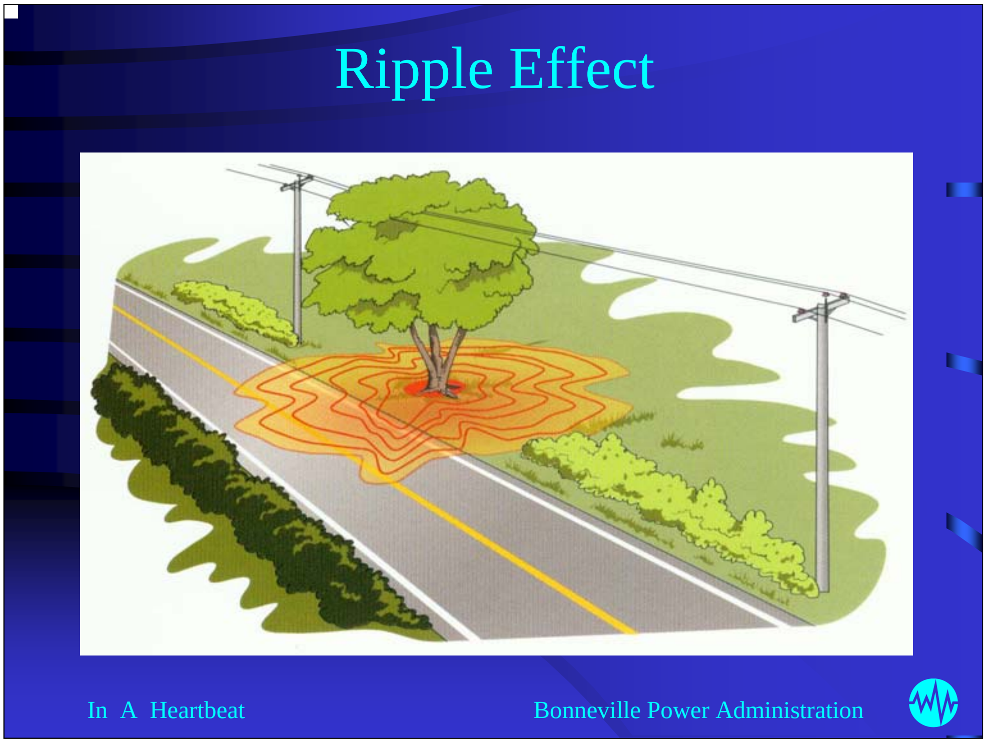
- *Agilent Technologies Webpage.*
- *Defibrillation, What You Should Know*, Physio-Control, p. 2, 3 & 10.
- *USA Today, August 12, 2004, as reported in the New England Journal of Medicine.*
- *Everett Herald, September 13, 2004.*



Earth Surface Potential at a Ground Rod

- This slide illustrates the voltage gradient around the point of contact for current flow to earth. This could be for a fault or simply for any ground rod out on the right-of-way. Note the steep shape of the waveform close to the point of contact. This slide demonstrates that the dangerous voltages are typically confined close to the point of contact location. This distance depends on the voltage, current, soil conditions and the presence of fencing or piping in the area.

- IEEE Std. 142-1982 page 62.



Ripple Effect

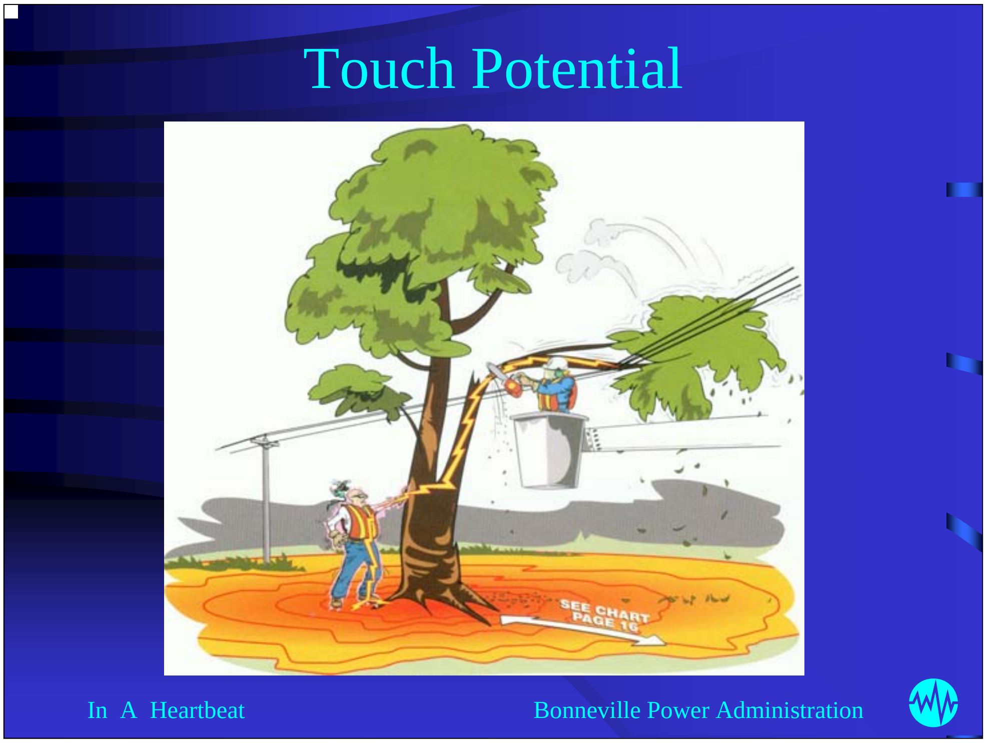
- This slide shows the voltage gradient developed in the earth as a tree contacts the line. The voltage manifests itself in concentric circles.

- *Utility Tree Workers Safety Guide*, BC Hydro, December 2001, p.15

Step Potential

- This slide shows the step potential developed due to the voltage gradient in the earth as a tree contacts a line. Note the current flow is up one leg and down the other leg.

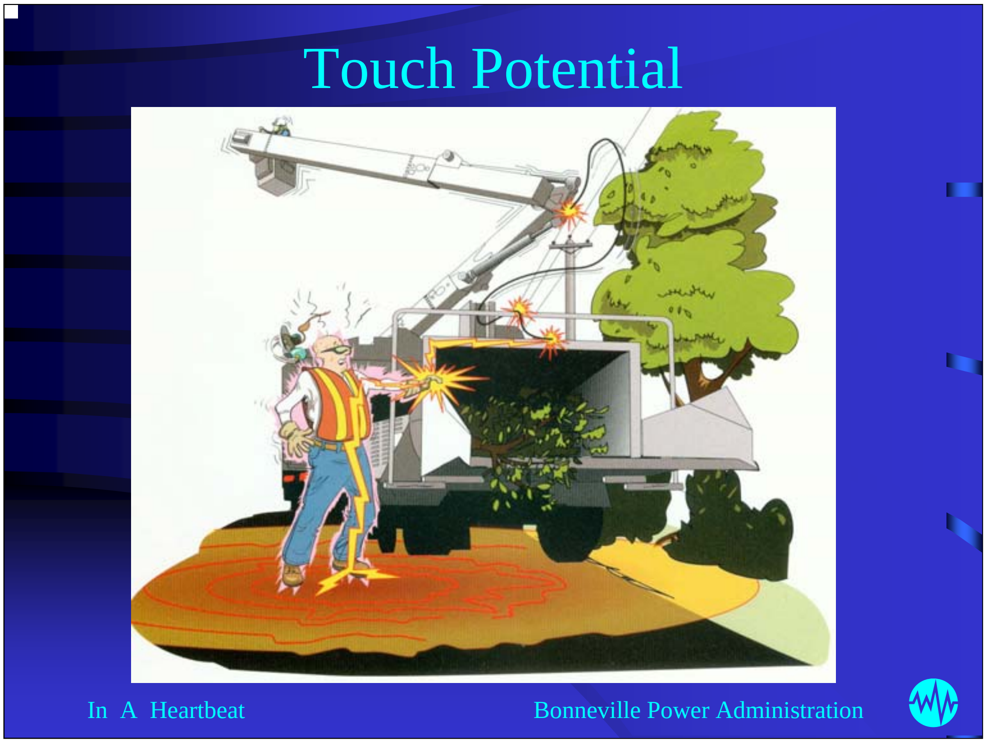
- *Utility Tree Workers Safety Guide*, BC Hydro, December 2001, p.17



Touch Potential

- This slide shows the touch potential developed as the worker stands on the earth and touches the tree making contact with the line. The earth is no longer at ground potential but has been raised to some voltage due to the current flowing in it. Note that with touch potential, current flow is up one arm and down the leg(s). Current flow is through the vital organs (specifically the heart).

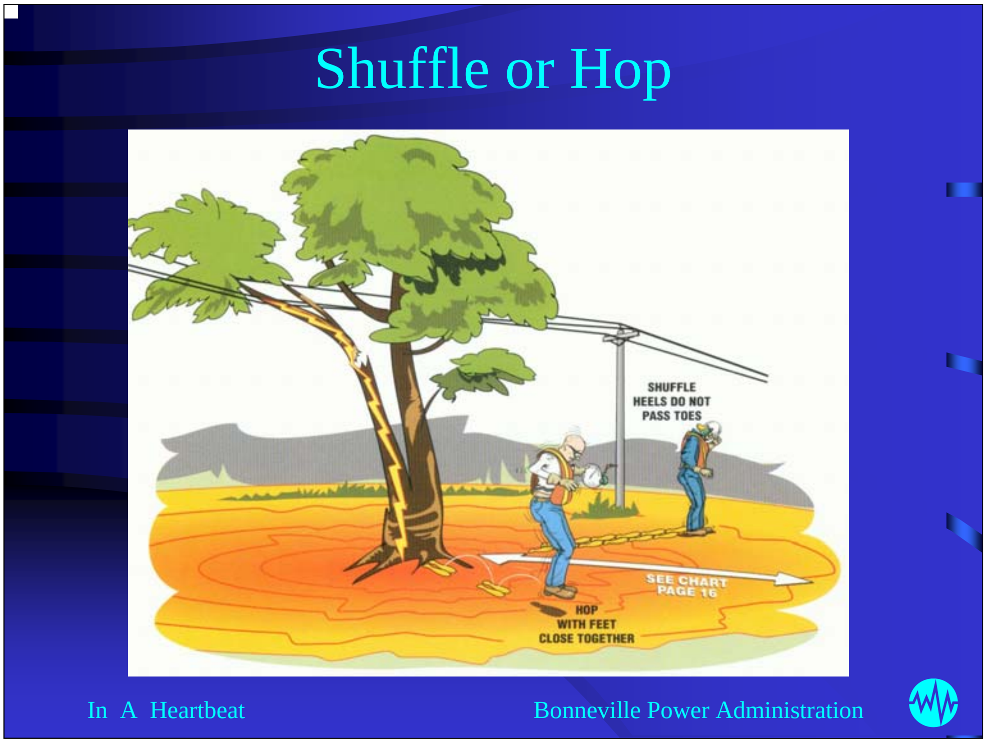
- *Utility Tree Workers Safety Guide*, BC Hydro, December 2001, p.18



Touch Potential

- This slide shows the touch potential developed as the worker stands on the earth and touches the man lift making contact with the line. Previous to the human contact the tires on the man lift may prevent current flow to earth. Note the center of the concentric circles lies at the point at which current enters the earth.

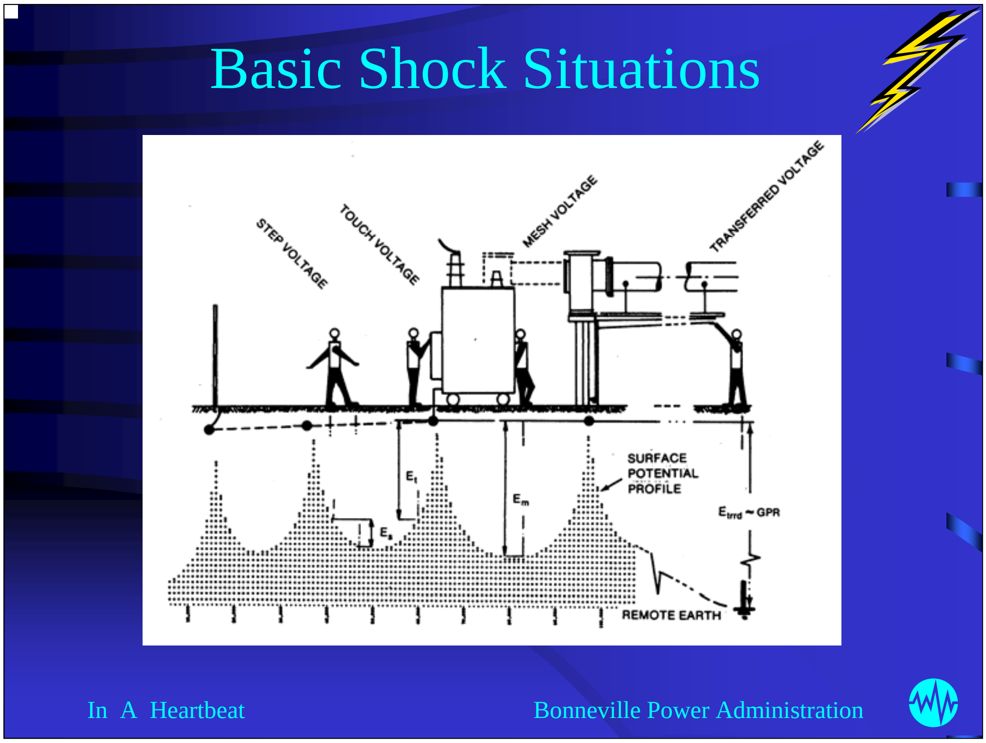
- *Utility Tree Workers Safety Guide*, BC Hydro, December 2001, p.19



Shuffle or Hop

- This slide shows two ways to safely exit a dangerous situation by minimizing your exposure to step potential. If you hop, keeping your feet together, you virtually eliminate the voltage gradient developed between your feet. Another recommended procedure is to shuffle your feet. Slide your feet on the ground without allowing the heel of one foot to get beyond the toe of the other.

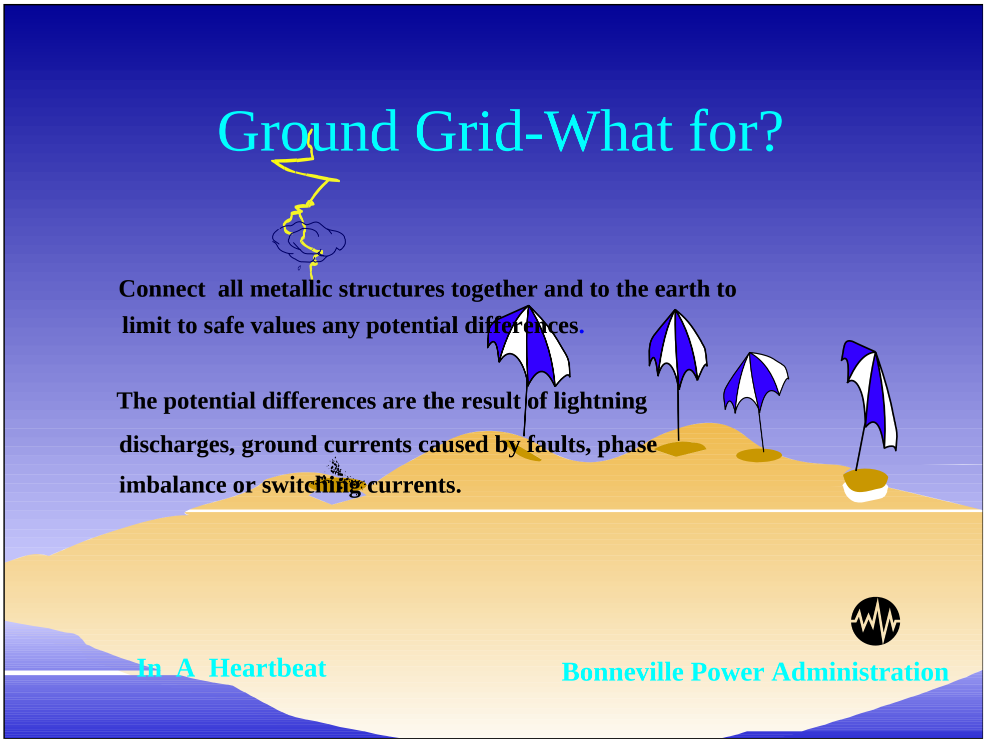
- *Utility Tree Workers Safety Guide*, BC Hydro, December 2001, p.20



Basic Shock Situations

- This slide illustrates the four basic shock situations. The ground grid designer must evaluate the performance of each grid design based on these basic shock situations. Note the degree of hazard each situation presents. Starting with the most hazardous we have:
- Transferred Potential
- Mesh Potential
- Touch Potential
- Step Potential

- ANSI/IEEE STD 80-1986 page 44.



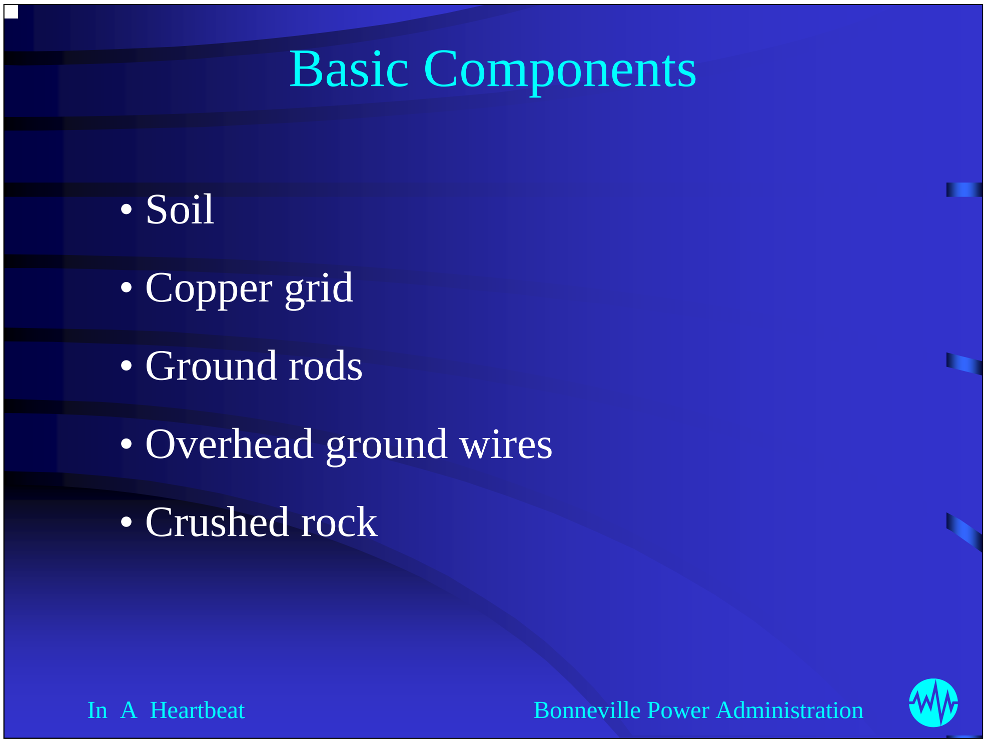
Ground Grid-Design Intent

•In all types of substations, it is necessary to install a system for effectively connecting all metallic structures and non-energized parts of the power system equipment together and to earth in order to limit to safe values any potential differences between them.

•The potential differences are the result of lightning discharges, ground currents caused by fault conditions, phase imbalance, or switching or inrush currents caused by normal system operations. The passage of these currents through the soil and metallic conductors causes high voltages which, if not properly controlled, can be dangerous to human life, and can cause damage to, and malfunction of, system equipment.

•The grounding system shall be designed and installed to provide a means to safely discharge lightning strokes to earth, reduce step and touch potentials to safe levels, and confine dangerous soil currents to inaccessible areas. It shall also allow the detection of ground fault currents by protective relaying system, provide low impedance paths through the earth for load and ground currents, and provide a common ground reference which assists in the coordination of insulation throughout the power system.

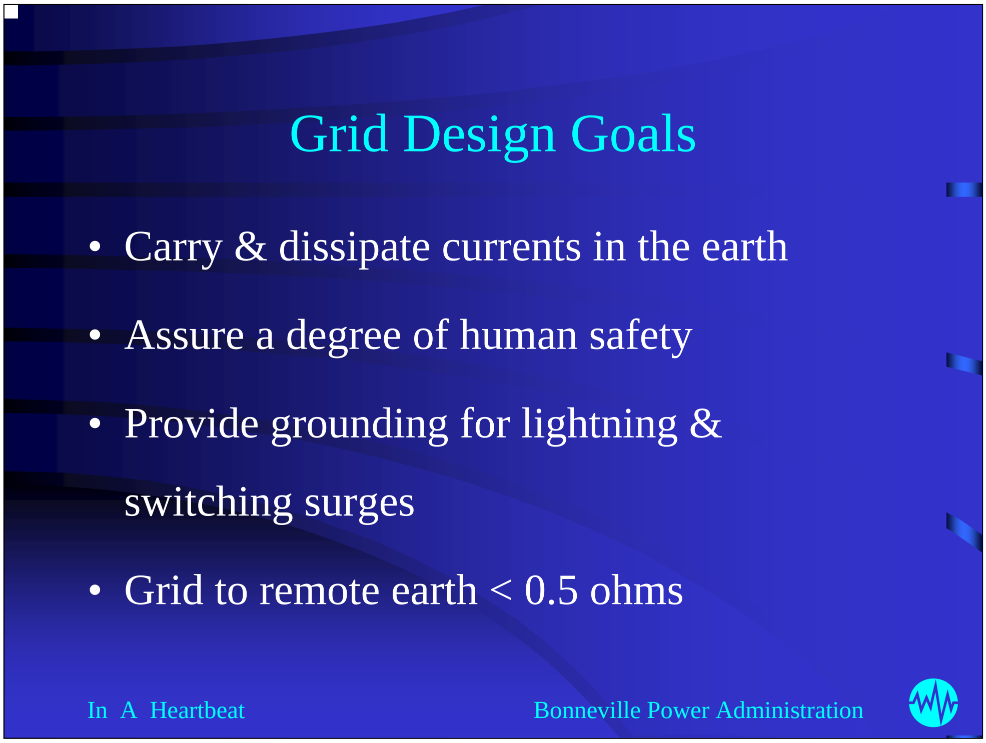
•BPA Substation & Control Engineering Criteria & Standards, Book 1, Chapter 7, Section 8, page 1.



Basic Components of a Ground Grid

- The soil beneath and around the substation site.
- The ground grid which is a network of bare, interconnected, conductive cables buried beneath the surface of the soil, and which interconnects all grounded equipment and structures.
- Ground rods or other electrodes connected to the grid, and installed vertically near and/or beneath the site, usually reaching lower resistivity soil.
- Overhead ground wires and masts for lightning protection.
- The crushed rock surfacing covering the site.

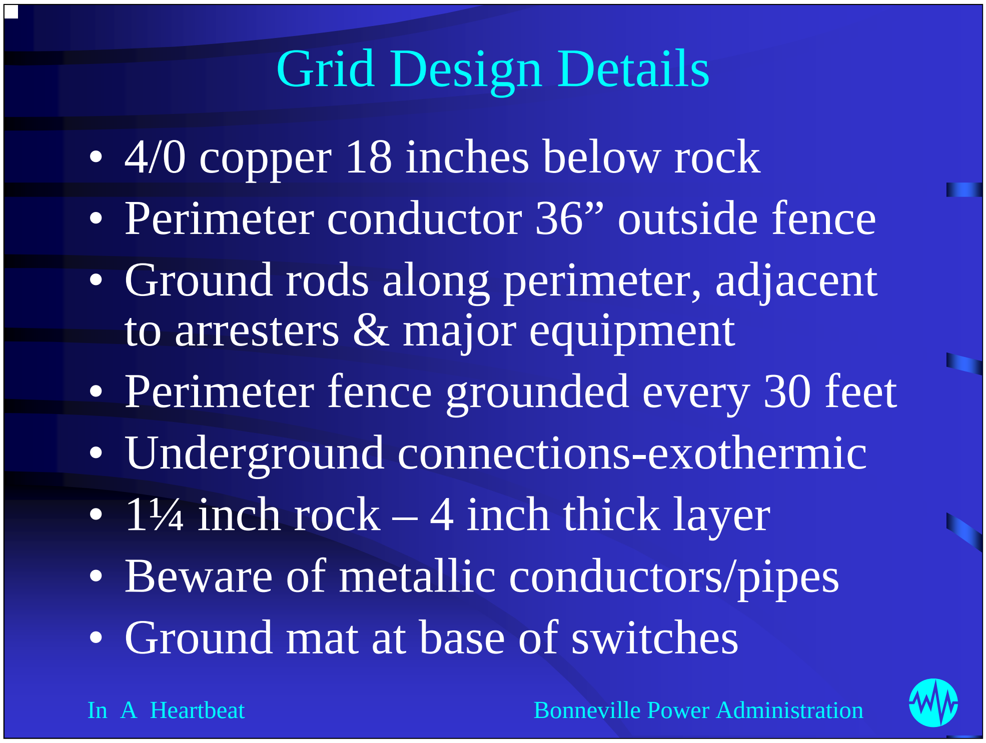
- BPA Substation & Control Engineering Criteria & Standards, Book 1, Chapter 7 Section 8, page 3.



Snohomish County PUD Ground Grid Design Goals

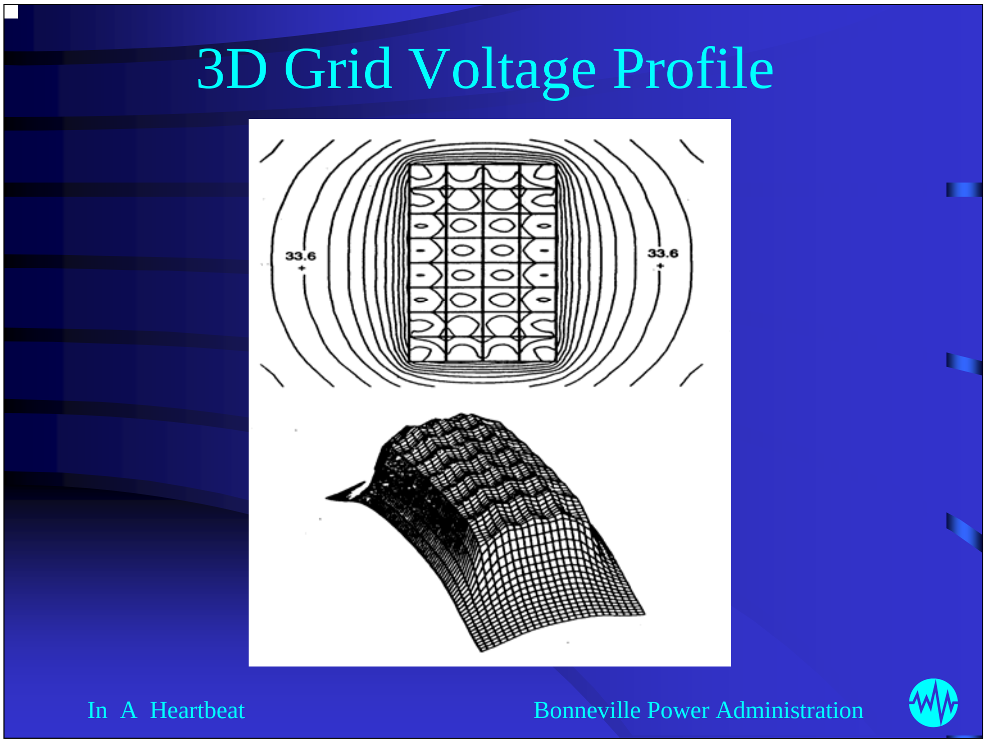
- Each element of a grounding system shall be so designed that for the expected design life of the installation each element will:
    - Have sufficient conductivity so that it will not contribute substantially to local voltage differences.
    - Resist fusing and mechanical deterioration under the most adverse combination of a fault current magnitude and duration.
    - Be mechanically reliable and rugged to a high degree, especially on locations exposed to corrosion or physical abuse.
- Reasonably low resistance between the grid and remote earth, preferably 0.5 ohms or less.
- Include an appropriate factor of safety for both initial conditions and for the projected lifetime of the grid.
- Provide a means for protective relays to clear ground faults.

- *Snohomish County PUD, Substation Design Standard, Substation Grounding Design, SD-20-0001, March 6, 1995.*



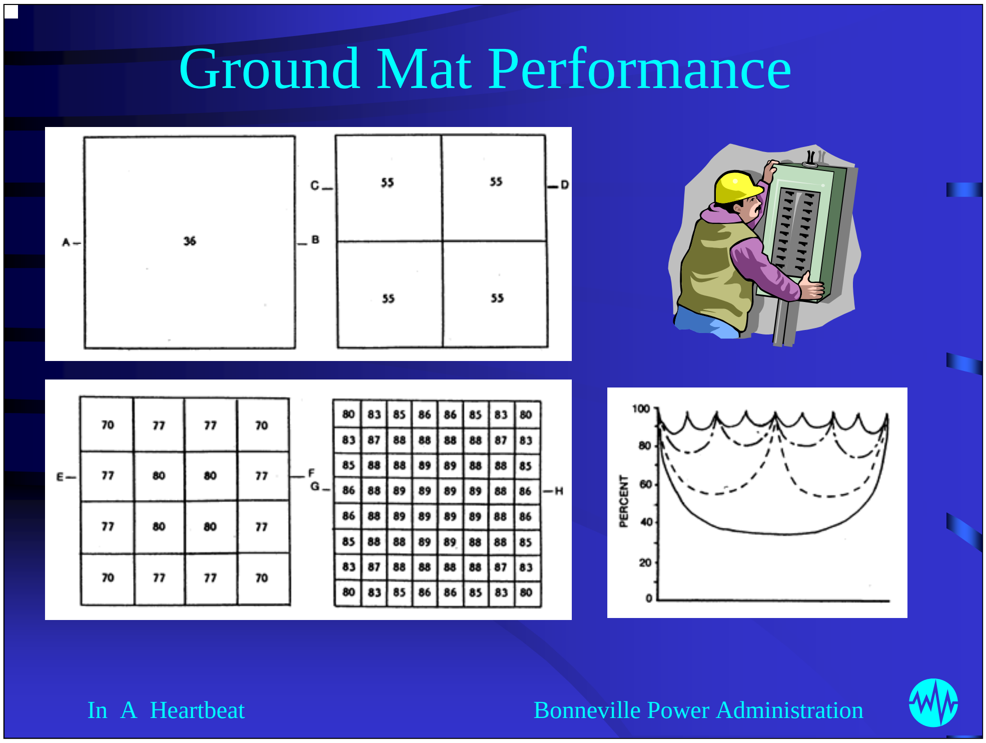
Grid Design Details

- At the District, 4/0 copper conductor is selected as the standard ground grid conductor because it has properties that will cover longer fault clearing times due to relay malfunctions or human errors; it will cover the ultimate requirements of future growth.
- Place perimeter cable around outer edge of fence if possible. (Suggested dimension is 3 feet outside of fence.)
- Place conductors parallel to both the East-West sides and the North-South sides. Interconnect the conductors to make up the grounding grid. As a start this grid should consist of a minimum number of meshes to facilitate equipment grounding. Additional conductor will be added if required when the grounding system does not yield desirable system resistance.
- Place some grid pigtail conductors to facilitate connections to fence, structures and equipment. The fence pigtails are usually placed at the fence corners, at the gate posts and every 30 ft along straight fence lines.
- Add ground rods on the outer edge. The minimum distance between ground rods shall be greater than the ground rod length (suggested: 30 ft minimum between rods.)
- Add ground rods inside the ground grid, near the lightning arresters and major equipment.
- Add protective ground mats at the base of switch operating handles.
- Metallic conductors or pipes which enter or leave the station ground grid can produce dangerous voltages as a result of the transferred potential.



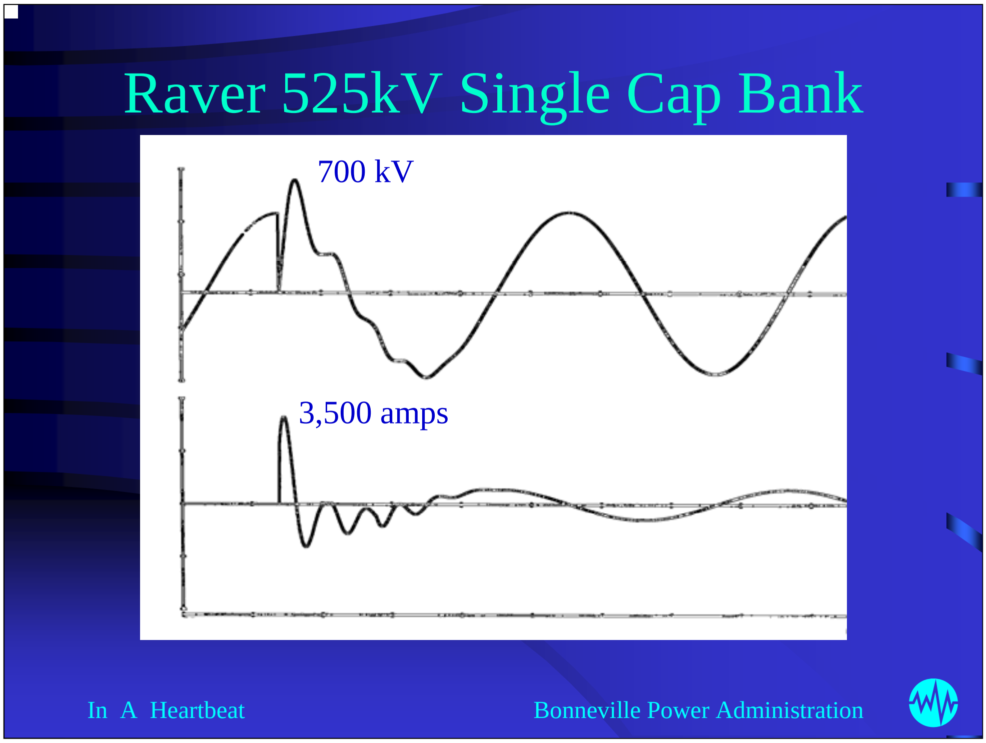
3 Dimensional Grid Voltage Profile

- This slide illustrates in 3D the contour of a substation ground grid during a ground fault. Note how the voltage on the entire substation ground grid rises as one entity and resembles a plateau that ends at the perimeter ground just outside the perimeter fence.
- ANSI/IEEE STD 80-1996 page 25.



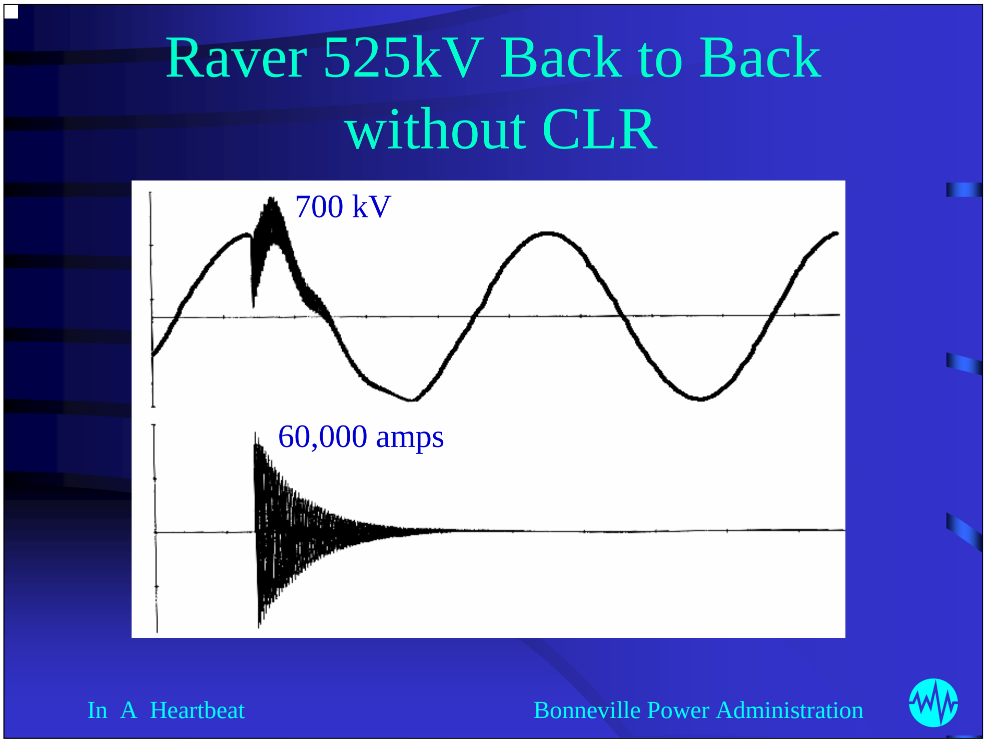
Ground Mat Performance

- This slide illustrates the performance of four different designs for a typical substation ground grid. Each successive design has finer and finer mesh. The values shown are the center of mesh voltages expressed as a per cent of total grid voltage rise above remote ground. The voltage profile in the lower right corner graphically illustrates the effectiveness of each design.
- ANSI/IEEE STD 80-1986 page 350-351.



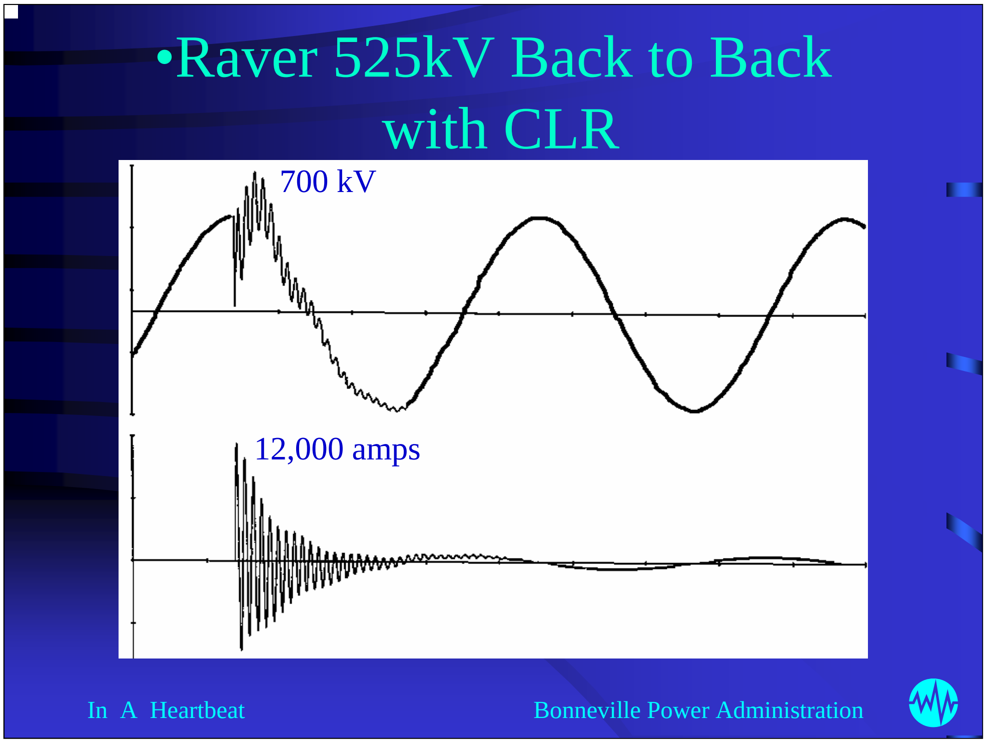
Switching a Single Capacitor Bank

- This slide shows switching of a 525kV 342MVAR Capacitor Group at Raver with no other capacitors in-service. Please note the overvoltage which is a result of system overshoot . Also, note the medium charging current (3,500 amps.) associated with energizing a single capacitor group. The higher frequencies are a result of the capacitance of the capacitor group reacting with the reactance of the power system. This value of current can easily be handled by the substation ground grid.



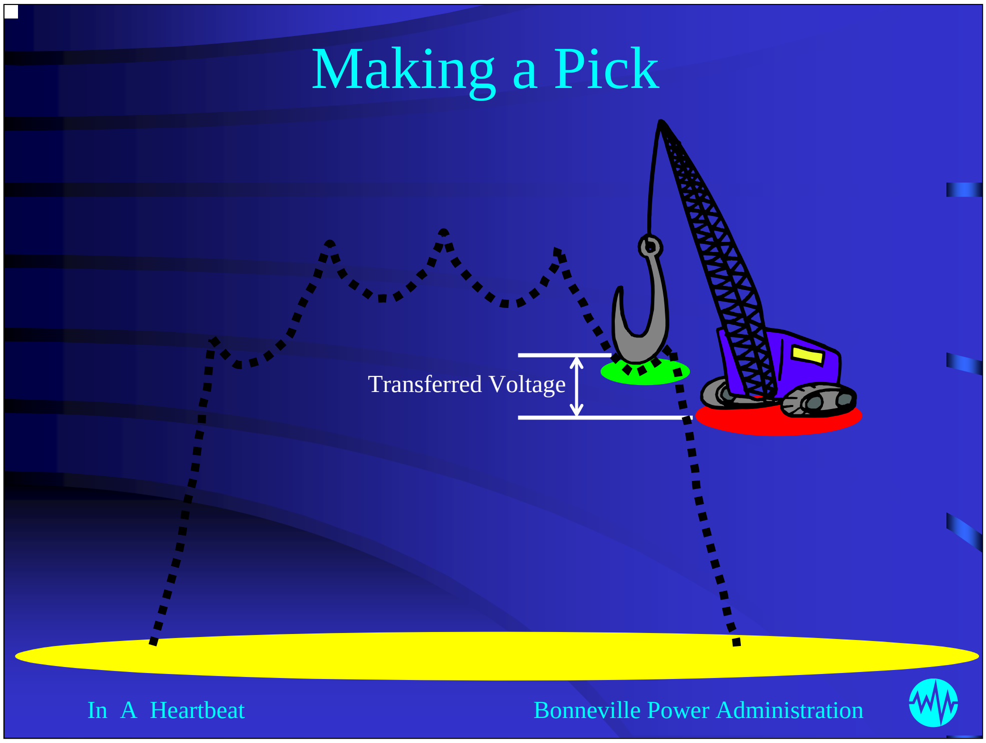
Back to Back Capacitor Switching

- This slide shows the extremely high current that flows during back to back switching of capacitor groups at the same voltage level. Back to back switching is the insertion of a capacitor group with another capacitor group already in-service. When the second capacitor group is inserted, the in-service capacitor group discharges into the just inserted capacitor group. Any unbalance current flows through the ground mat from one capacitor group to the other. This extremely high current flowing in the ground mat produces very high voltages, but for just a very short time as seen from the slide.
- Therefore, for any worker out in the yard, especially those working on the ground mat, back to back capacitor switching is a specific situation requiring special consideration. When making connection from a new fence or ground mat to an existing fence or ground mat it is very important that no switching occurs in the substation. Have the operator take the station on local control!



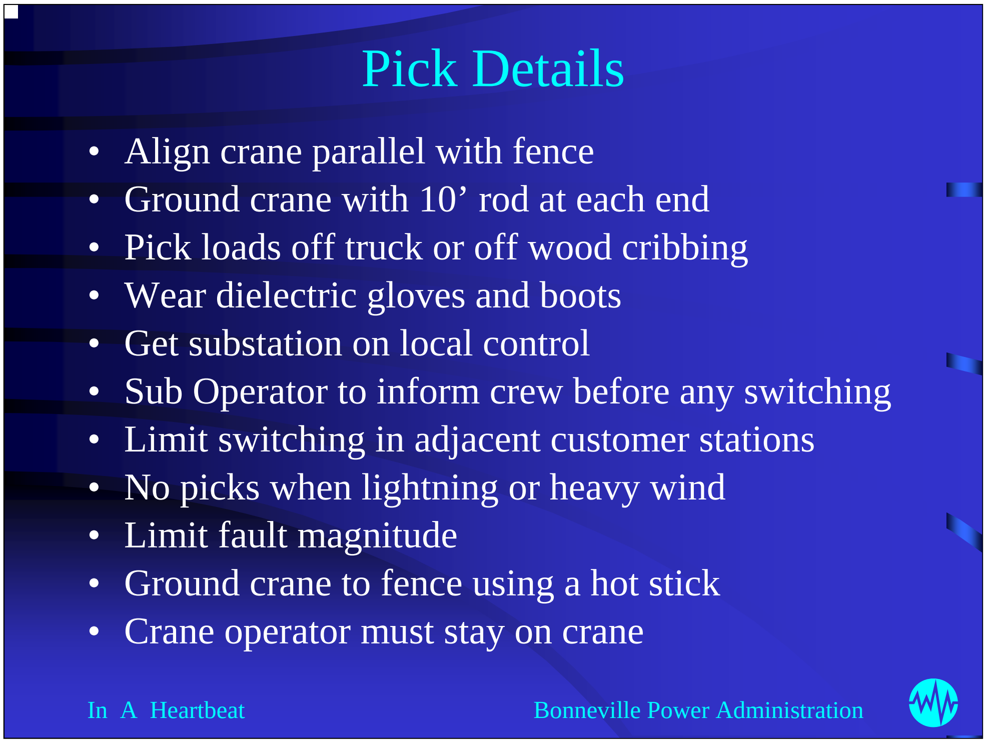
Back to Back Cap. Switching with a Current Limiting Reactor

- BPA now installs current limiting reactors to limit the amount of current inrush to the newly energized capacitors.
- This slide shows the huge reduction in current flow during back to back switching of capacitor groups when current limiting reactors are added (from 60,000 amps. to just 12,000 amps.).
- To further reduce switching currents BPA now installs Breaker Failure Relays or Synchronous Close Units (SCU) with controlled closing capability. Capacitor inrush current is maximum when the capacitor breaker or switcher closes at a voltage peak. These devices are programmed to close the breaker at a voltage zero crossing. This dramatically reduces the amount of current inrush.
- When the new 525kV, 386MVAR Capacitor Group #3 with current limiting reactor and a controlled closing Breaker Failure Relay at Monroe was first energized on December 22, 2000, the capacitor inrush was just 800 amperes.
- Recent efforts by BPA to reduce capacitor switching currents have been extremely successful, greatly reducing exposure to BPA personnel working in the substation yard.



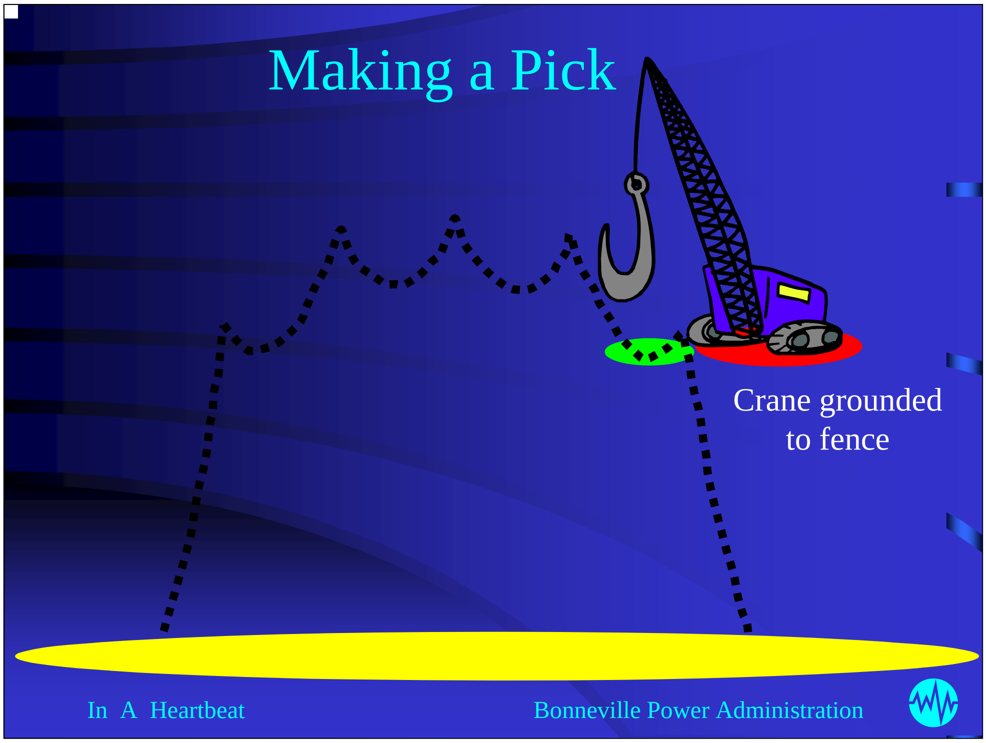
Making a Pick

- This slide attempts to illustrate the dangerous potentials that can occur when a pick is being made from outside the substation. As can be seen from the voltage profile, the most dangerous place is just outside the perimeter fence where the voltage gradient is greatest. This slide shows a pick where the lifting equipment is outside the substation and off the ground mat, picking material which is inside the substation and on the ground mat. Therefore, to make this pick safely you must limit your exposure to voltage gradients by positioning the lift equipment as close as possible to the fence such that it is above the substation perimeter ground. Please see the next slide for a fuller explanation of how to make this pick safely.



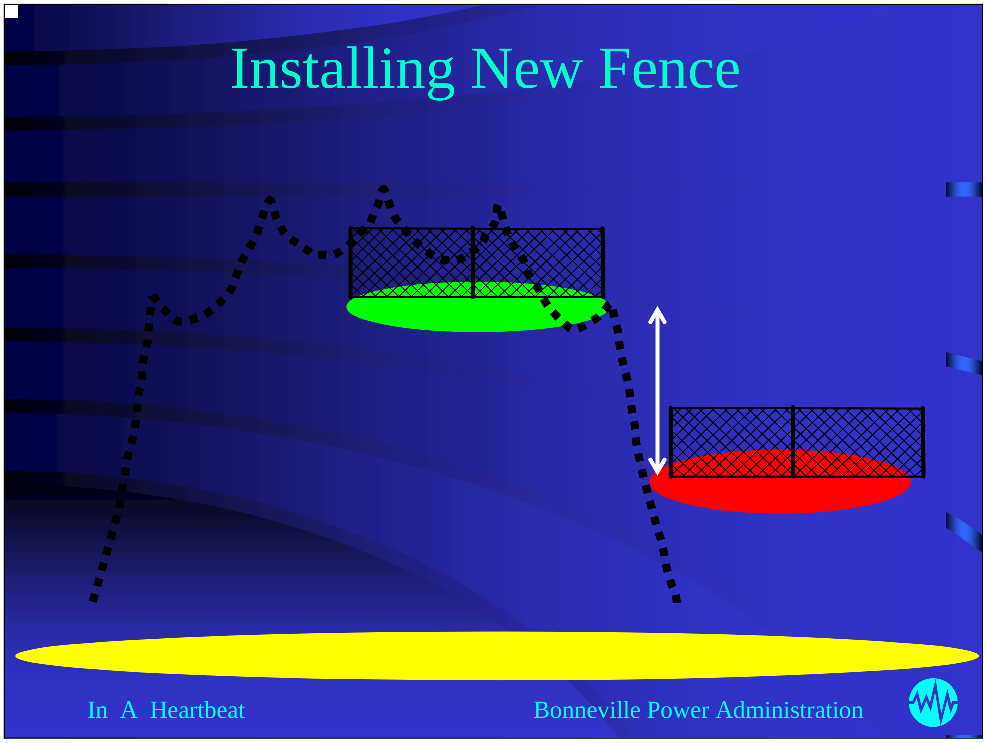
Pick Details

- It is strongly recommended that picks not be made outside the substation (off the ground mat) with the overhead lift equipment inside the substation OR do not make picks inside the substation with the crane outside the substation. There can be very dangerous step and transfer potentials between where the crane is grounded and the crane’s hook when switching surges or faults occur. If this type of pick must be made you must follow the above procedures.
- Also, locate the crane where it is not possible to get into any overhead lines or de-energize the overhead line.
- You may limit fault magnitude by opening bus sectionalizing breakers, by opening loop-fed lines, or by opening lines in the vicinity of the pick.
- Substation Maintenance Procedure, Grounding-Grounding Work Equipment and Vehicles, PS18-GND-14, 5/15/97.



Making a Pick

- This slide attempts to illustrate the reduction in potential when you follow the previously outlined guidelines. This method attempts to place the crane and the equipment being picked at the same potential, thereby limiting personnel exposure to dangerous voltages.



Constructing a Yard Addition

- This slide attempts to illustrate the dangerous potentials that can occur near the edge of an existing ground grid. It is mandatory that when constructing a yard addition, that the new fence and the new ground grid be electrically isolated from the existing yard fence and ground grid. When the new construction is complete then the new fence and new grid can be electrically connected to the existing fence and grid at the same time. This procedure is necessary to insure safe working conditions for construction personnel.
- A 20 foot gap is necessary between the existing and new fence to protect personnel and make certain there is no possibility of accidentally making contact between the new equipment and the existing equipment.
- Please see the next slide for the details regarding the construction of a yard addition.

Installation Steps

- This slide describes the preferred way to install new perimeter fence for a new addition. The 20 foot electrical gap between the new and the old yard provides the most protection. In the Substation Maintenance SPIF noted below there is an alternative method of installing the new perimeter fence with slightly reduced protection.
- The principles underlying this sequence are:

  •to minimize exposure to construction personnel who are completing the final fence and ground connections in the 20 foot gap area, and

  •to electrically isolate the addition where construction personnel will be working over long periods of time.
- PPG=Portable protective ground-2/0 copper

- BPA Substation Maintenance Procedure, Grounding-Adding to and Expanding Substation Ground Grids, PS18-GND-16, p. 1-2, 8/30/98.
- BPA Substation and Control, Engineering Criteria & Standards, Book 1, Chapter 7, Section 8, p.18-19.

Dead Cows

- On January 30, 1985, a logger fell a tree into the Mason County PUD #1 34.5kV transmission line, fed from BPA's Potlatch Substation. The BPA breaker at Potlatch failed to operate because of a failed trip coil. The conductor parted six miles from Potlatch and fell to the ground. Eleven cows were killed due to step potential.
- This is the tower at which the conductor parted. It fell to the ground and burned for about 1/2 hour until the PUD opened a disconnect to isolate it. The fault turned the soil into glass for about six inches around the full length of the downed conductor.
- This slide shows the relationship of the cows to the downed conductor. Apparently, the cows walked up to the fault, one by one, to investigate. The cows range from about 10 to 15 feet away from the conductor.

More Dead Cows

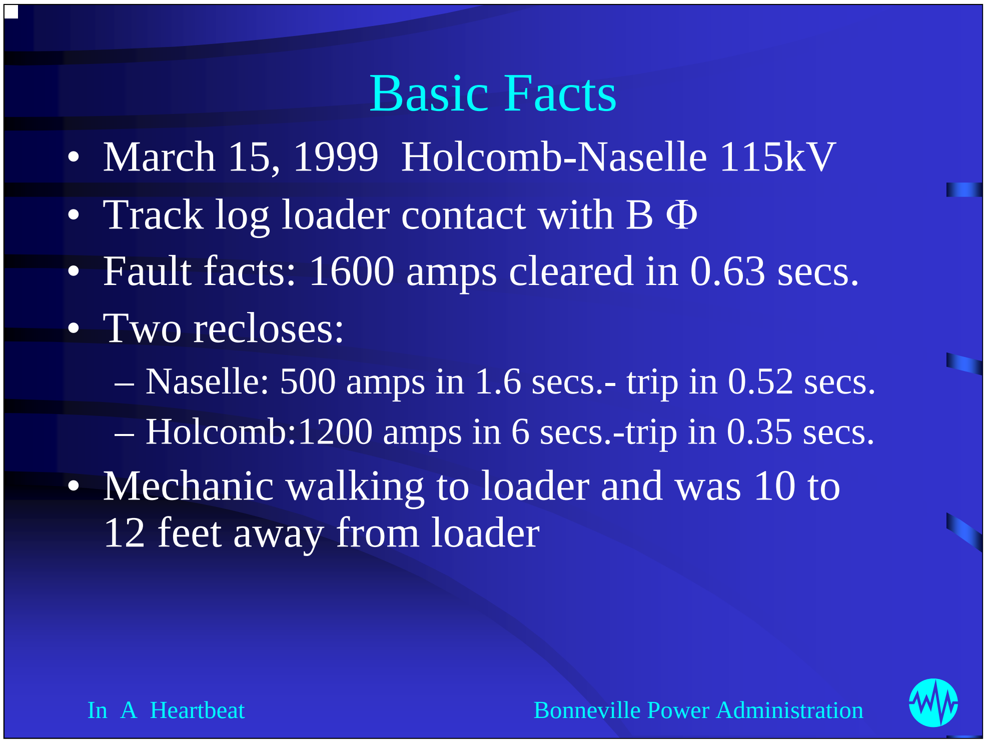
- Serious damage was done to these cows. These cows were subjected to touch potential for such a long time that tremendous amounts of heat and gases built up. This caused the cows to explode sending flesh and hide hundreds of feet away. We have learned that touch potential is a more dangerous situation than step potential. This slide demonstrates what could if someone is shocked with step potential such that they fall to the ground. What started out as a step potential situation then turns into a touch potential case.
- In this case, the fault persisted for approximately 1/2 hour. Fault current was recorded at 840 amps.

Wear Your Waders

- When the PUD crews pulled up they found a man standing next to these cows. Apparently, the man was on his way fishing because he was wearing hip length waders. The PUD crews knew the fault had not been cleared so they did not get out of there trucks. What is significant is that this man was oblivious that anything was still wrong. His waders provided him with enough contact resistance to give him adequate protection.
- Why was the man unharmed while the cows experienced a deadly voltage?
  - A cow has 1/5 the body resistance of a man
  - A cow gets much better ground contact
  - A man’s shoes provide a resistance of typically 4,000 to 5,000 ohms.
  - A cow spans 2 to 3 times the distance of a man’s stride.
  - A cow experiences touch voltage.

Mechanic Fatality

- This slide illustrates the relative position of the mechanic vehicle and the log loader underneath the 115kV Holcomb-Naselle line.



• **Basic Facts**

•On March 15, 1999 at approximately 11:52 A.M. a mechanic was fatally injured when the equipment he was preparing to work on contacted the Holcomb-Naselle 115kV transmission line. Two mechanics were summoned to a location under the transmission line to repair a large track mounted log loader.

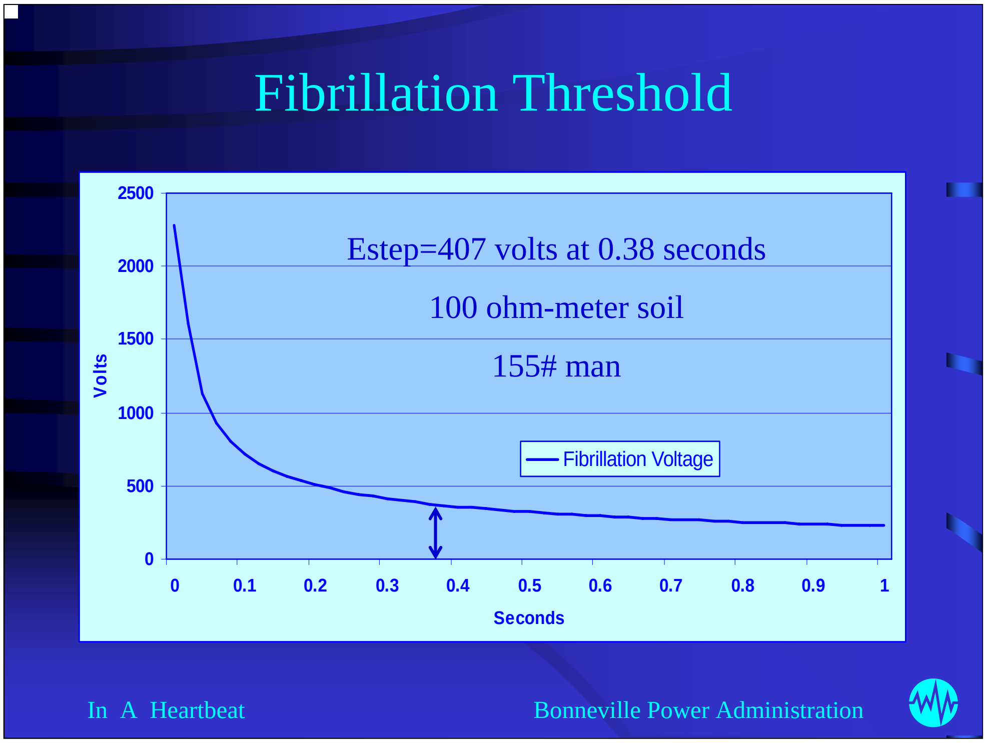
•As the mechanics were gathering equipment to work on the loader, the loader operator decided to relocate the grapple boom for repairs and in doing so the elbow of the boom contacted or came within flash distance of the B phase conductor.

•Mechanic #1 was knocked to the ground and complained about not being able to feel his legs. The power line was de-energized by protective relay operations at Holcomb in 0.38 seconds and at Naselle in 0.63 seconds. The power line was re-energized in 1.6 seconds by automatic reclosing at Naselle and relayed again in 0.52 seconds. Six seconds later the line was again re-energized, but this time from Holcomb. By this time Mechanic #2 had gone to assist Mechanic #1 and was knocked to the ground. The Holcomb terminal tripped for the last time in 0.35 seconds.

•*Holcomb-Naselle 115kV Electrical Contact Accident*, Gary LaRonge, June 29, 1999.

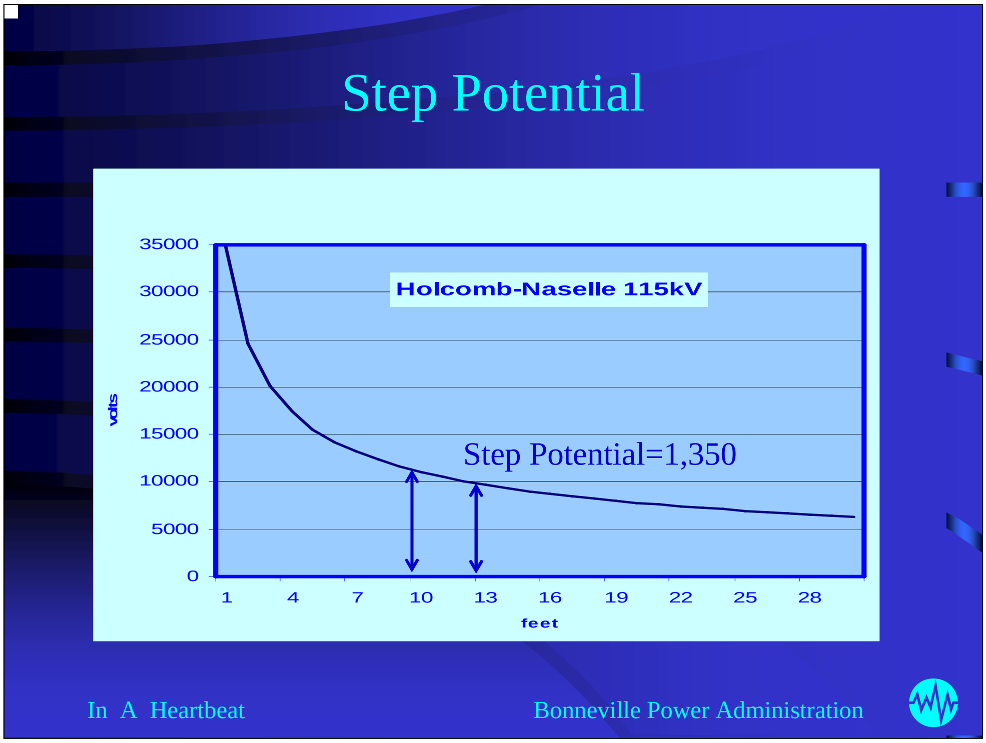
Mechanic Fatality

- This slide gives a good perspective of the path of victim from his work vehicle to the log loader as well as the location of the overhead conductor.



Fibrillation Threshold for the Holcomb-Naselle Contact

- This graph illustrates the voltage threshold to induce fibrillation in a 155# man on 100 ohm-meter soil using the following formula:
- Estep=[157+0.94*(soil resistivity)]/[square root(time in seconds)]
- For a fault duration of 0.38 seconds under these conditions a 155# man could withstand a step voltage of up to 407 volts before fibrillation would be induced.
- CPR was immediately started on the mechanic and continued for 40 minutes until the EMTs arrived. The EMTs continued CPR for approximately 10 minutes until instructed to cease by a doctor via the telephone.

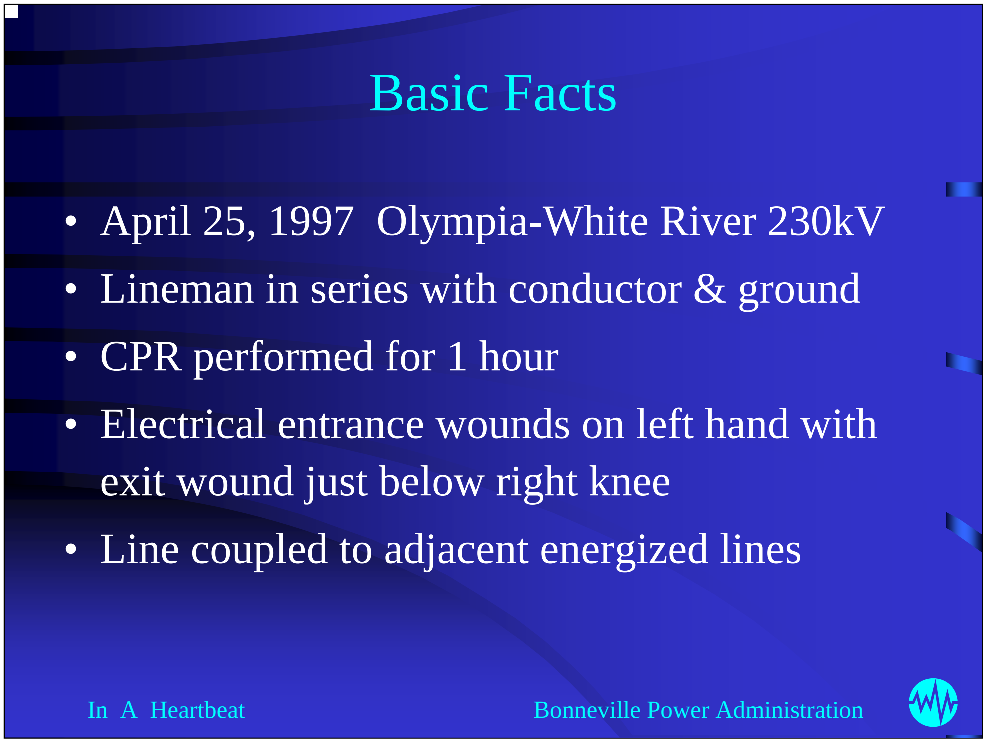


Step Potential

- This slide illustrates the estimated voltage profile from the log loader outwards. From this curve it is estimated the mechanic experienced a step voltage of approximately 1,350 volts. Clearly, with a fibrillation threshold of approximately 407 volts, the mechanic's heart was subjected to a lethal voltage (and current).

Contractor Fatality on the Olympia-White River 230kV Line

- This slide gives an good view of the accident location. The contractor lineman was working for a company who was reconductoring this line. The victim was working from the bucket of the near boom truck.

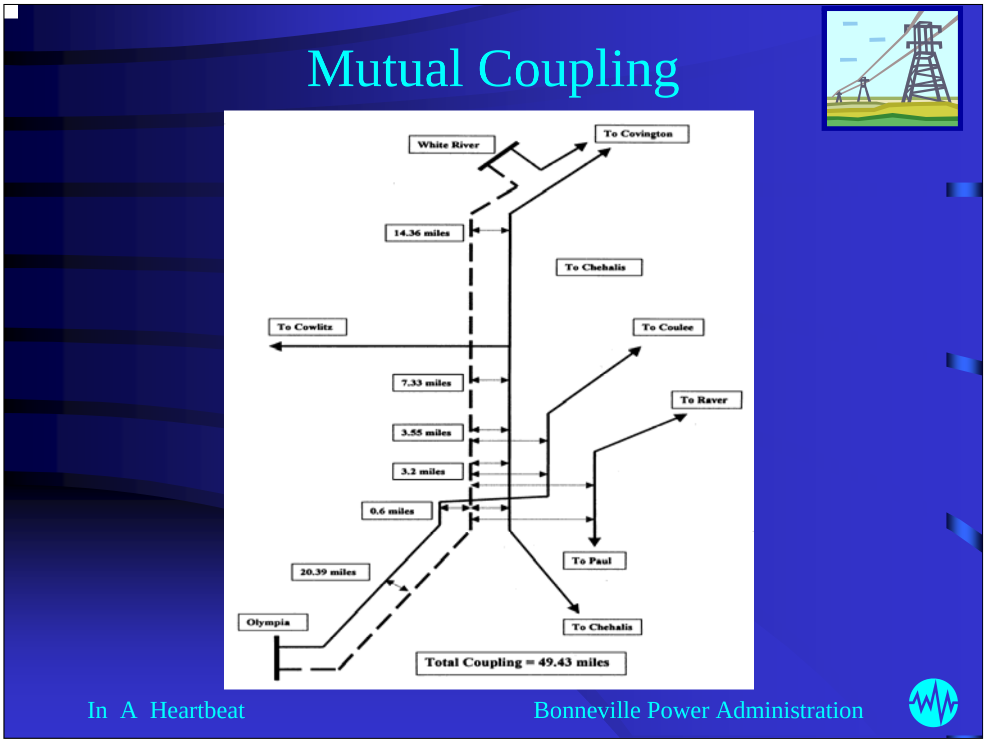


Basic Facts for the Olympia-White River #1 230kV Fatality

- An employee of Great Southwestern Construction inadvertently placed himself in series with the A phase conductor line and ground. The crew performed CPR until relieved. CPR was performed for over one hour. Electrical entrance wounds were found on the left index finger, left thumb, and left palm. An electrical exit wound was found just below the right knee.
- *Type A Accident Investigation Board Report of the April 25, 1997 Contractor Fatality on the Olympia-White River #1 230kV Line.*

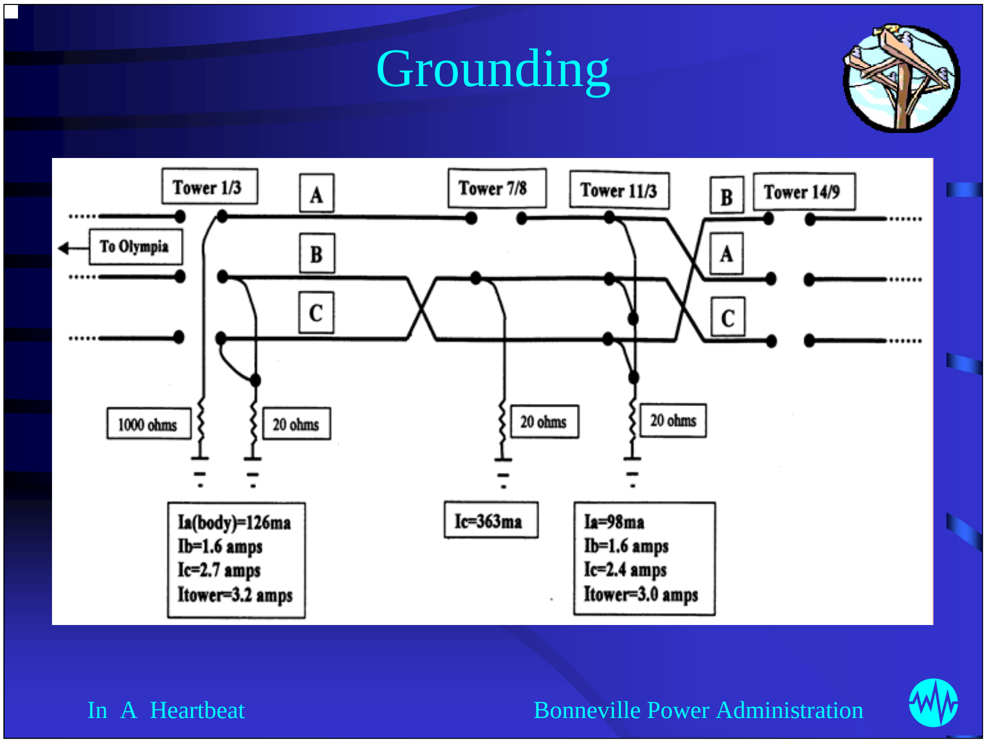
Basic Facts for the Contractor Fatality

- A ground rod was driven 4 feet into the ground and connected to the vehicle frame, via a portable ground, to serve as a grounding path. The victim and coworker, both linemen equipped with fall protection gear, were raised in the basket by the crane boom to the work area on the A phase conductor. According to crew statements, the victim connected a personal protective ground to the conductor by hand, within the work area, but was not observed tightening the ground clamp onto the conductor. (The other end of the PPG was connected to the basket. The boom truck was being used as part of the grounding circuit.)
- At the time of the electrical contact, the coworker was attempting to remove the grip from the conductor by hand. The victim assisted his coworker and somehow during the process placed himself in series with the A phase conductor and ground. The coworker observed smoke rising from the victim's glove. The boom was retracted but it took sometime before the victim was eventually freed from his hold on the grip.
- It is believed that the hand tightened PPG did not provide an effective ground on the A phase conductor.
- *Type A Accident Investigation Board Report of the April 25, 1997 Contractor Fatality on the Olympia-White River #1 230kV Line.*



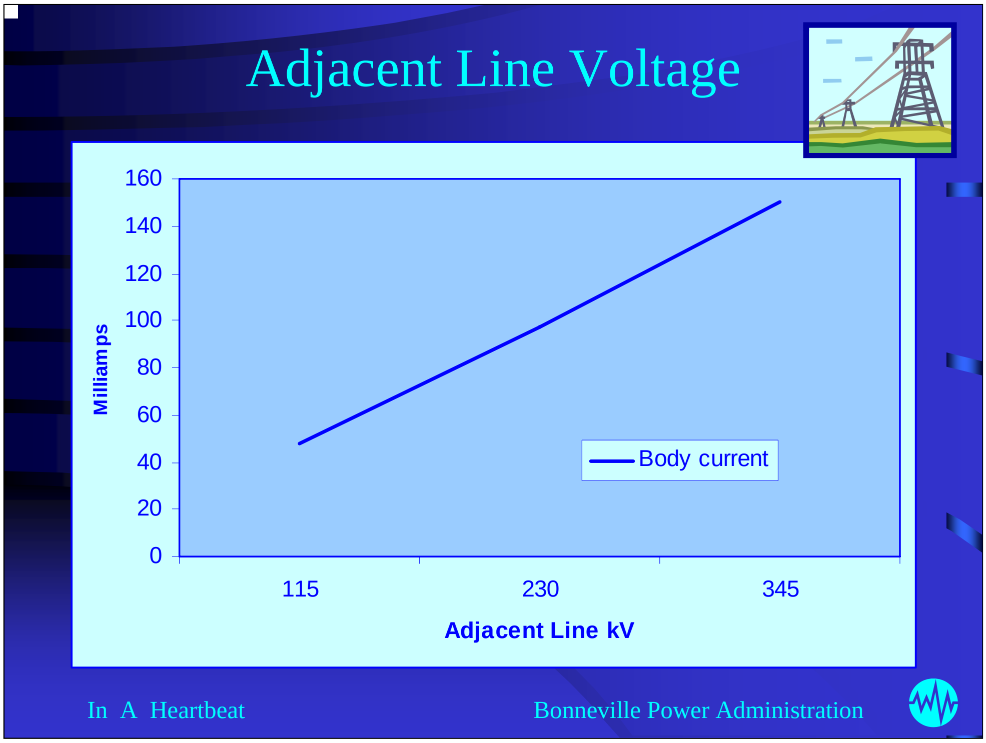
Mutual Coupling for the Olympia-White River 230kV #1 Line

- This is the mutual impedance coupling diagram for the Olympia-White River 230 kV #1 line. Observe that it is coupled to three different lines for 49.43 miles. These lines include the Grand Coulee-Olympia 300kV, the Covington-Cowlitz-Chehalis 230kV, and the Raver-Paul 500kV line.
- *System Electrical Data of Bonneville Power Administration and Interconnected Northwest Systems*, mutual drawings M-188 & M-195.



Grounding on April 25, 1997

- Because the line was being reconductored, the Olympia-White River 230kV #1 line was separated at several different locations. Therefore, because of the removed jumper at tower 7/9, A phase of the Olympia-White River line was actually coupled for only six miles to the Grand Coulee-Olympia 300kV line.
- The separation between the two lines is 125 feet.
- Body current was calculated to be 126 milliamperes.



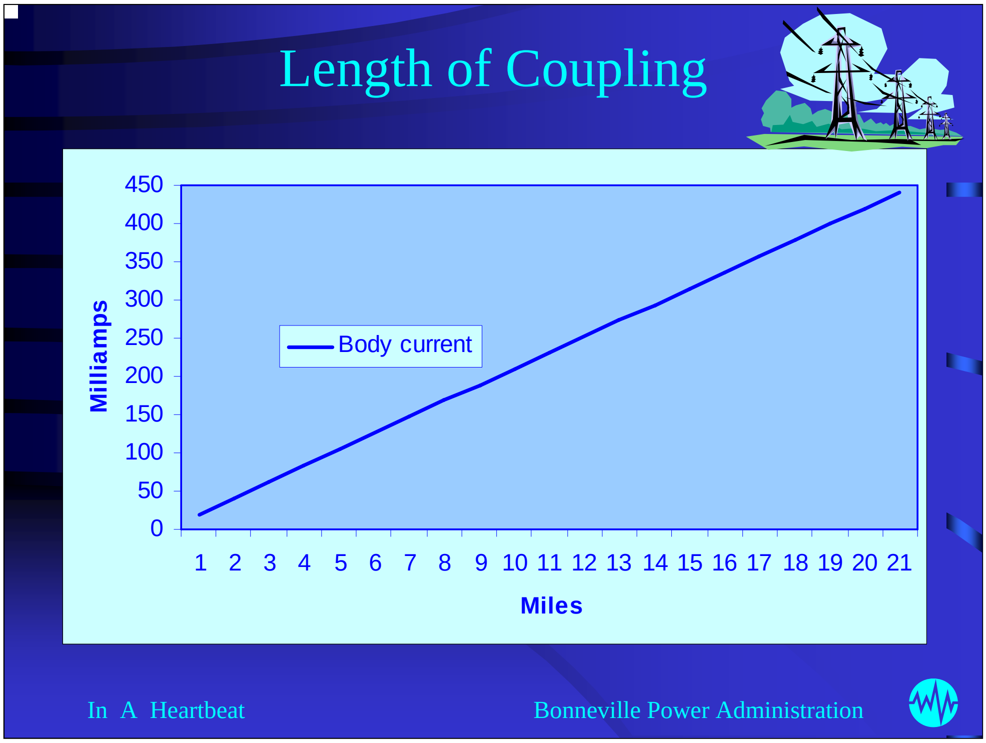
Coupling as a function of adjacent energized line voltage

- Observe the change in body current as the voltage of the adjacent energized line is changed.

- At 115kV--body current=48 milliamps
- At 230kV--body current=97 milliamps
- At 287kV--body current=126 milliamps

- (Assume coupled for 6 miles to the Grand Coulee-Olympia 300kV line.)
- (Assume a body resistance of 1000 ohms and a tower footing resistance of 20 ohms.)

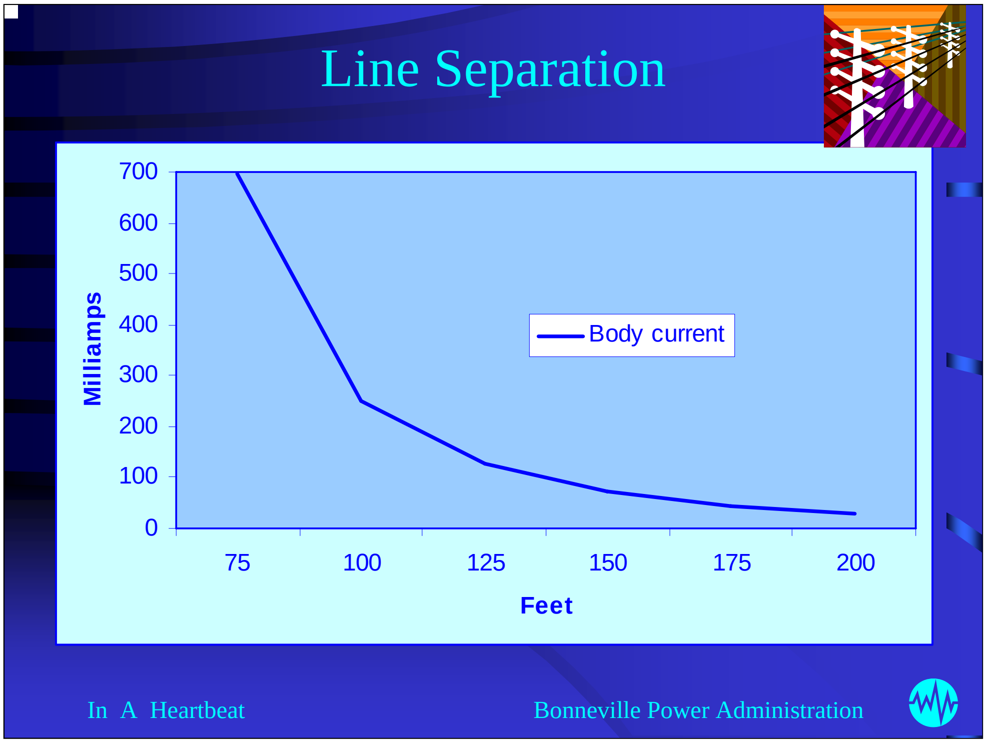
- Data supplied by Monty Tuominen TNLD-TPP-3, BPA Electrical Effects.



Body current vs. miles of coupling to adjacent energized line

- Observe the change in body current as the length of coupling to the adjacent energized line is increased. Also, note that as the length of coupling increases, the body current increases in a linear fashion.
- (Assume coupled to the Grand Coulee-Olympia 300kV line.)
- (Assume a body resistance of 1000 ohms and a tower footing resistance of 20 ohms.)

- Data supplied by Monty Tuominen TNLD-TPP-3, BPA Electrical Effects.

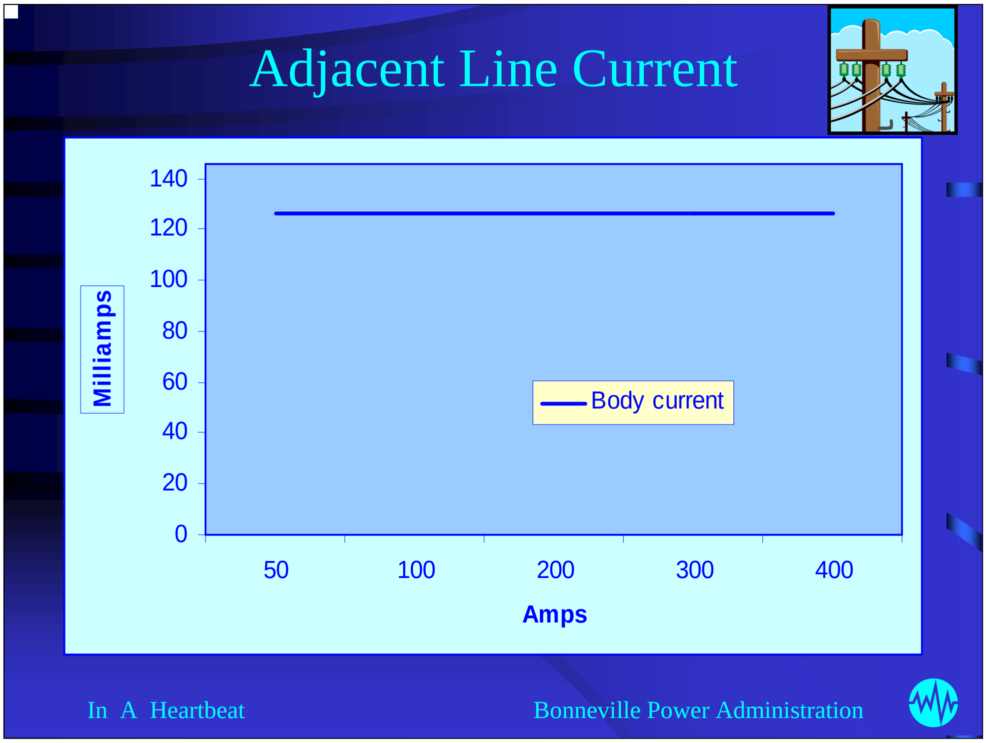


Body current as a function of separation between adjacent lines

- Observe the change in body current as the distance between the de-energized line and the adjacent energized line is varied.

Feet	Milliamps
• 75	696
• 100	249
• 125	126
• 150	71
• 175	43
• 200	28

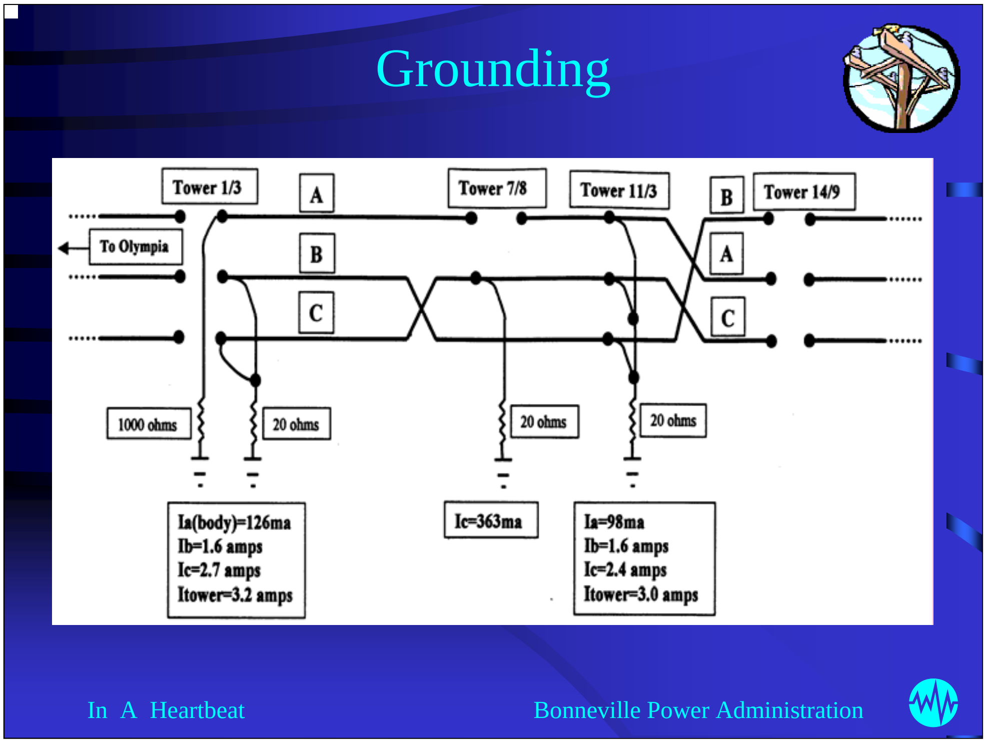
- (Assume coupled for 6 miles to the Grand Coulee-Olympia 300kV line.)
- (Assume a body resistance of 1000 ohms and a tower footing resistance of 20 ohms.)
- Data supplied by Monty Tuominen TNLD-TPP-3, BPA Electrical Effects.



Body current as a function of load flow in adjacent line

- Observe there is no change in body current as a function of the current flowing in the adjacent energized line. Why is this? From an earlier slide we observed there was only one ground path (victim) on A phase for the line section under consideration. The current flow on an adjacent energized line will induce a voltage in the de-energized line (magnetic coupling), but current will flow only if there is a loop (complete path usually involving earth). Without at least two paths to ground a loop is not formed and current cannot flow.
- The body current in this slide and the previous three slides is due to the capacitive coupling between two lines. A single ground path will discharge this capacitively coupled voltage.
- **Therefore, it was the capacitive coupling from the Grand Coulee-Olympia 300kV line that was responsible for the current in this fatality accident.**
- (Assume coupled for 6 miles to the Grand Coulee-Olympia 300kV line.)
- (Assume body resistance of 1000 ohms and a tower footing resistance of 20 ohms.)

- Data supplied by Monty Tuominen TNLD-TPP-3, BPA Electrical Effects.



Grounding on April 25, 1997

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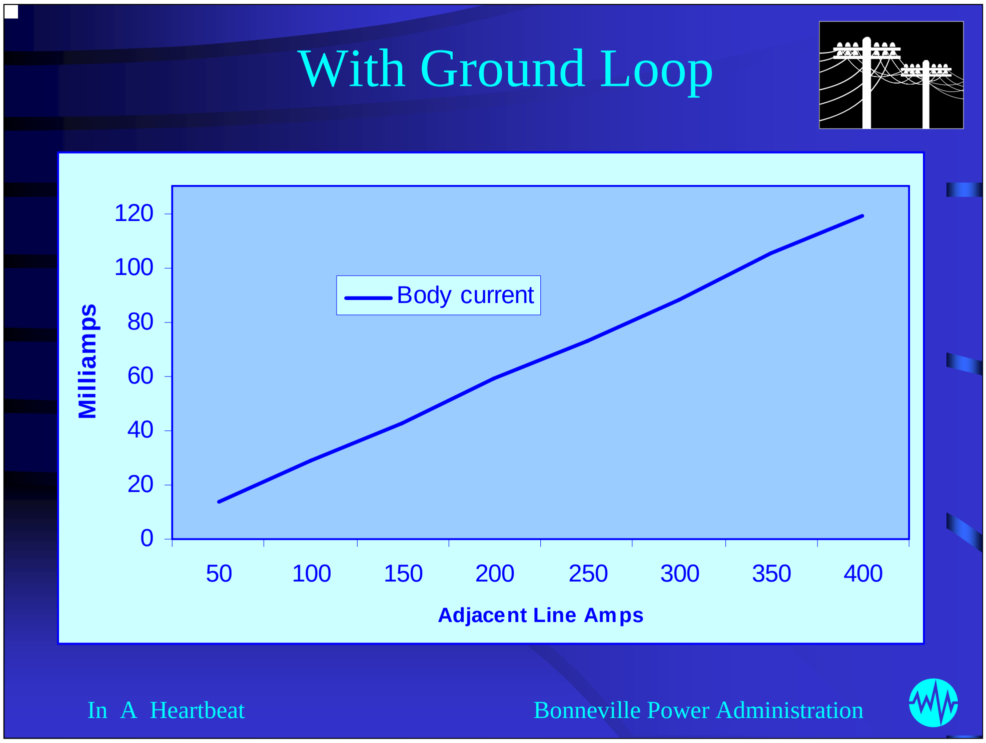
- The separation between the two lines is 125 feet.
- Body current was calculated to be 126 milliamperes.



Body current as a function of load flow in adjacent line with two grounds on A phase

- Observe that unlike the previous slide, that as we add a second ground path, the body current now changes in a linear fashion proportional to the load flow in the adjacent energized line. This occurs because with the addition of a second ground path a ground loop is formed, allowing the current induced by the magnetic coupling from the adjacent line to flow.
- (Assume coupled for 6 miles to the Grand Coulee-Olympia 300kV line.)
- (Assume body resistance of 1000 ohms and a tower footing resistance of 20 ohms.)

- Data supplied by Monty Tuominen TNLD-TPP-3, BPA Electrical Effects.

Final Thoughts

- Current thru heart causes vent. fibrillation
- CPR critical to keep victim viable
- Clearing times limit fault duration
- Step, touch, & transferred potential as well as magnetic & capacitive coupling are real hazards in the substation & on ROW
- Power system designed to minimize exposure
- Adherence to grounding procedures will keep you safe

Thank You

In A Heartbeat

Bonneville Power Administration