Substation Engineering: Safety Standards and Regulations (Part 1 of 2)

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Safety Standards and Regulations (Part 1 of 2)

- Substation Engineering
- Lecture 31
- Unit 5: Substation Safety and Regulations

Agenda

- Introduction to Substation Safety
- Primary Safety Hazards
- Regulatory Bodies and Standards Overview
- National Electrical Safety Code (NESC)
- IEEE Std 80: Safety in AC Substation Grounding
- Step and Touch Potentials
- Human Body Resistance Model

Introduction to Substation Safety

- Substations are inherently dangerous environments due to high voltage equipment
- Safety must be integrated into the design phase, not just operation
- Primary goal: Protect personnel (utility workers) and the public
- Secondary goal: Protect equipment from damage during faults
- Compliance with safety standards is mandatory and legally enforced

Primary Safety Hazards in Substations

- Electric Shock: Contact with energized parts or unacceptable ground potentials
- Arc Flash: Explosive release of energy due to an electrical arcing fault
- Magnetic and Electric Fields (EMF): Exposure limits for personnel
- Fire and Explosions: From oil-filled equipment like transformers
- Trips and Falls: Uneven terrain, trenches, and elevated work

Regulatory Bodies and Standards Overview

- Safety is governed by a combination of national codes and industry standards
- Codes provide the 'what' (legal minimum requirements)
- Standards provide the 'how' (engineering practices to meet the codes)
- Major organizations: IEEE, ANSI, NEMA, OSHA, NFPA
- Local jurisdictions may have additional specific requirements

Key Substation Safety Standards

IEEE 80	Guide for Safety in AC Substation Grounding
NESC (IEEE C2)	National Electrical Safety Code
NFPA 70E	Standard for Electrical Safety in the Workplace
IEEE 979	Guide for Substation Fire Protection
OSHA 1910.269	Electric Power Generation, Transmission, and Distribution

National Electrical Safety Code (NESC)

- Published by IEEE, updated every 5 years
- Sets ground rules for practical safeguarding of persons during installation, operation, and maintenance
- Covers supply and communication lines, and associated equipment
- Adopted as law by most US states and Public Utility Commissions
- Part 1 specifically covers Rules for the Installation and Maintenance of Electric Supply Stations

NESC Rules for Substations (Part 1)

- Rule 110: General Requirements (Enclosure of equipment, rooms, and spaces)
- Rule 111: Illumination requirements under normal and emergency conditions
- Rule 112: Floor, floor openings, passageways, and stairs
- Rule 124: Guarding live parts (clearance from live parts)
- Fences must be minimum 7 feet high (often 6 ft fabric + 1 ft barbed wire)

IEEE 80: Guide for Substation Grounding

- Primary standard for designing safe grounding systems in AC substations
- Objective 1: Provide means to carry electric currents into the earth under normal and fault conditions
- Objective 2: Assure that a person in the vicinity is not exposed to danger of critical electric shock
- Establishes safe limits for potential differences during a fault
- Provides mathematical models for calculating grounding grid resistance

Step and Touch Potential Concept

Fault current flows into the ground grid, causing a Ground Potential Rise (GPR)
Step Potential: Voltage difference between a person's two feet (1 meter apart)
Touch Potential: Voltage difference between a person's hand touching a grounded structure and their feet
Mesh Potential: Maximum touch voltage within a mesh of a ground grid
Current through the heart is the fatal mechanism (fibrillation)

Touch Voltage Limits

- Most critical safety criteria in substation design
- Assumes a person is standing on the ground and touching a grounded structure
- Current path is from hand to both feet
- Calculated touch voltage must be less than the 'Tolerable Touch Voltage'
- Addition of crushed rock on the surface increases contact resistance to shoes

Step Voltage Limits

- Voltage between two points on the earth surface 1 meter apart
- Current path is from one foot, through the legs, to the other foot
- Does not usually pass directly through the heart, making it slightly less lethal
- Tolerable step voltage is much higher than tolerable touch voltage
- Calculated step voltage must be less than 'Tolerable Step Voltage'

Human Body Resistance Model

- IEEE 80 models the human body resistance (Rb) as 1000 Ohms
- This value represents hand-to-feet or foot-to-foot resistance
- Skin resistance is ignored because high voltage breaks it down instantly
- Fibrillation current thresholds are based on body weight (50 kg and 70 kg models)
- Formula for permissible body current: Ib = k / sqrt(ts)

Tolerable Body Current (IEEE 80)

Body Weight	Formula for Fibrillation Limit
50 kg person	Ib = 0.116 / sqrt(ts)
70 kg person	Ib = 0.157 / sqrt(ts)
ts (Fault Time)	Typically 0.5 seconds for backup clearing
Note: 70 kg allows slightly higher current	

Fault Current and Clearing Time

- The safety limits are heavily dependent on time (ts)
- Faster relay operation and circuit breaker clearing = higher tolerable voltages
- Typical fault durations used for safety calculation: 0.25 to 0.5 seconds
- Backup clearing time must be considered in case primary protection fails
- Ground grid must be designed for the maximum expected future fault current

Safe Grounding Grid Requirements

- If Actual Mesh Voltage ¡ Tolerable Touch Voltage, design is safe
- If Actual Step Voltage ¡ Tolerable Step Voltage, design is safe
- If criteria are not met: add more conductors, use ground rods, or increase surface rock layer
- Software tools like CDEGS or ETAP are used for complex 3D grid modeling
- Final design must be validated by field testing after construction

Summary

- Substation safety is governed by strict codes (NESC) and standards (IEEE 80)
- NESC dictates physical requirements like fences and guarding
- IEEE 80 provides the engineering foundation for safe ground grids
- Step and Touch potentials are the primary metrics for shock hazard
- Tolerable limits depend on human body weight and fault clearing time

Next Lecture Preview

- Safety Standards and Regulations (Part 2 of 2)
- Electrical clearance distances in detail
- Fire protection and oil containment
- Personal Protective Equipment (PPE) for arc flash
- Lockout/Tagout (LOTO) procedures