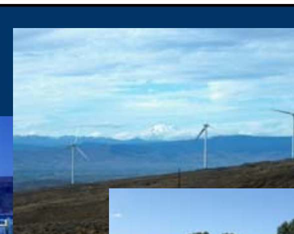
Eyjafjallajökull Volcano 21665_article_main_This Week.jpg

WSU EE 492

November 30, 2010



RENEWABLE ENERGY:

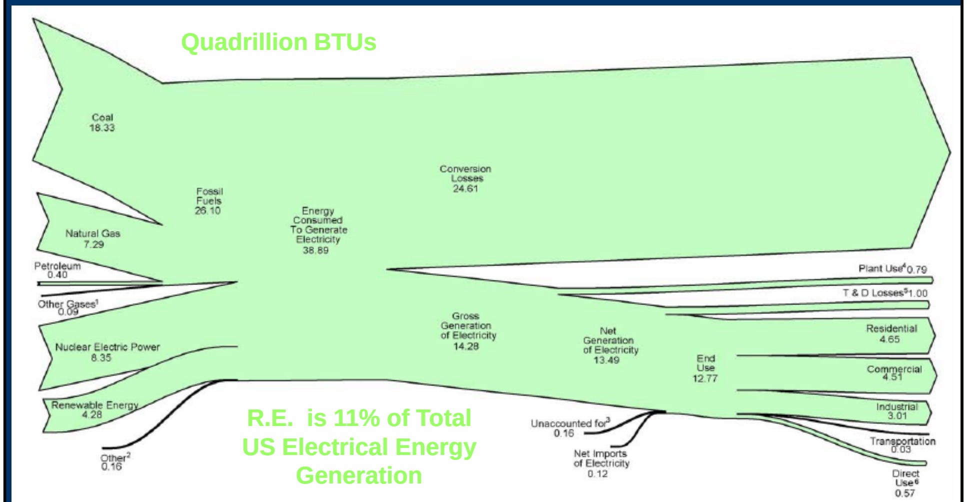
Perspective, Protection and PPE

RAI Relay Application Innovation, Inc.

Larry D. Elliott, PE
Project Engineer

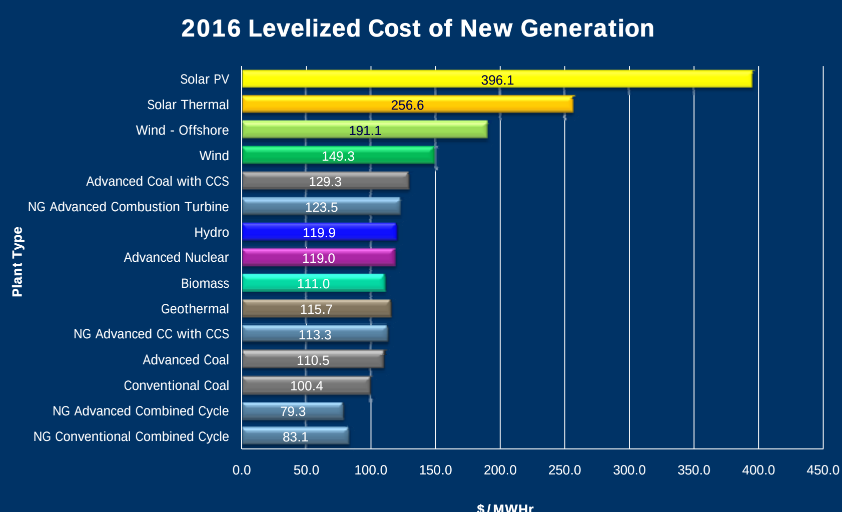
Carla E. Heathman
Associate Engineer

ENERGY USE IN CONTEXT

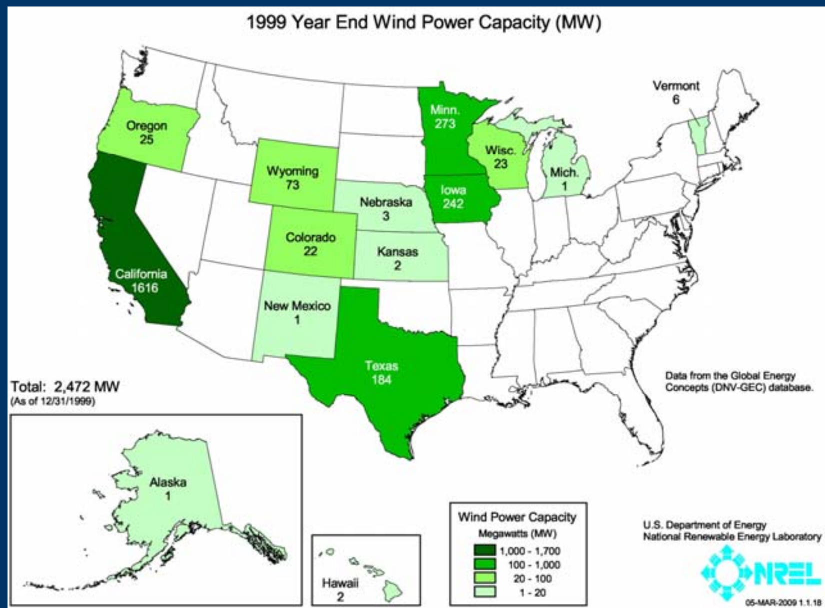


U.S. Energy Information Administration, Annual Energy Review 2009

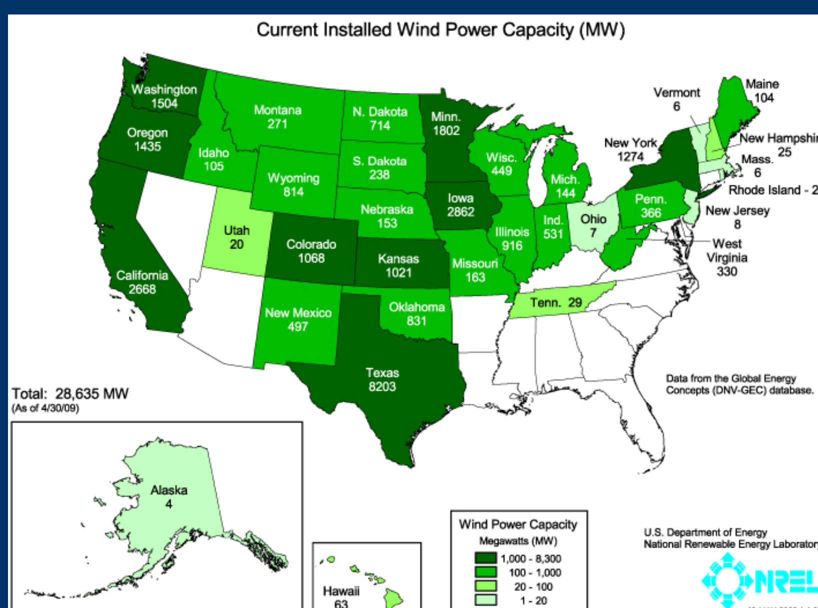
ENERGY COST IN CONTEXT



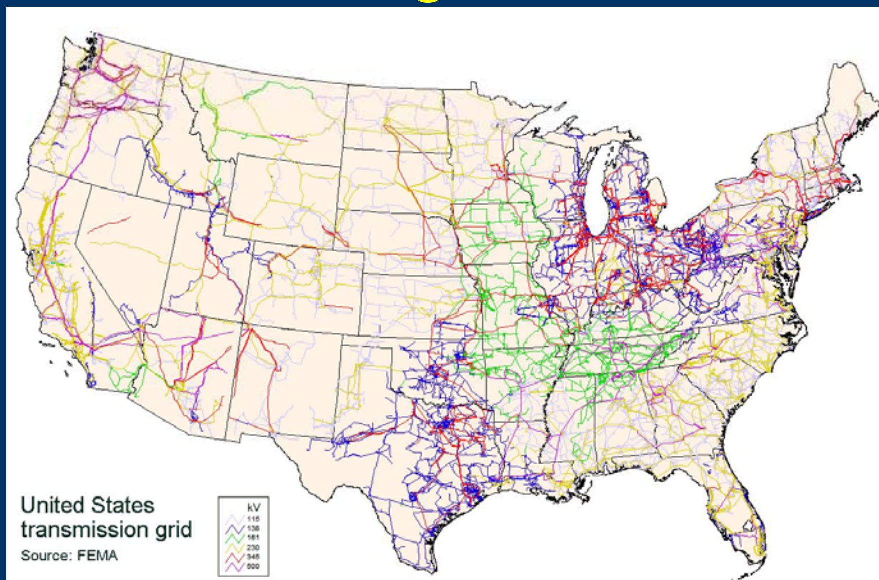
1999 Wind Energy △=+2.5 GW



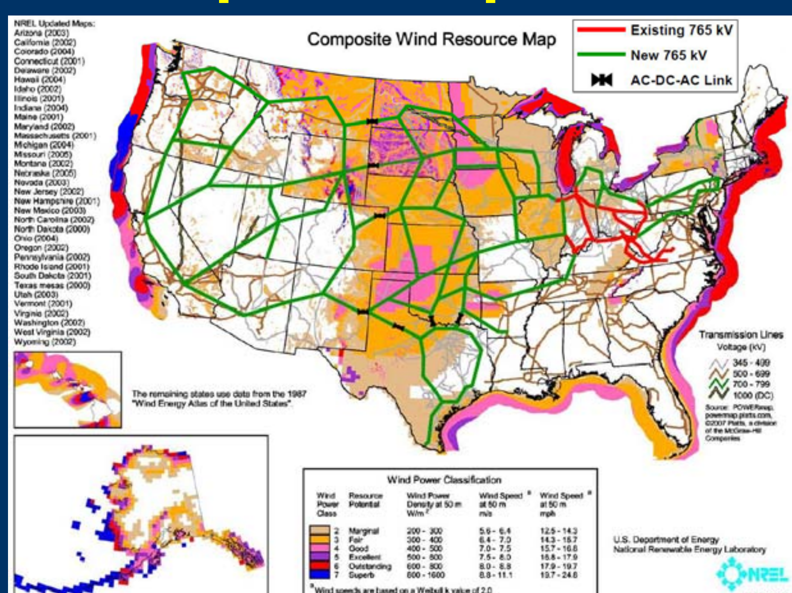
2009 Wind Energy △=+28.6 GW



Existing US Grid



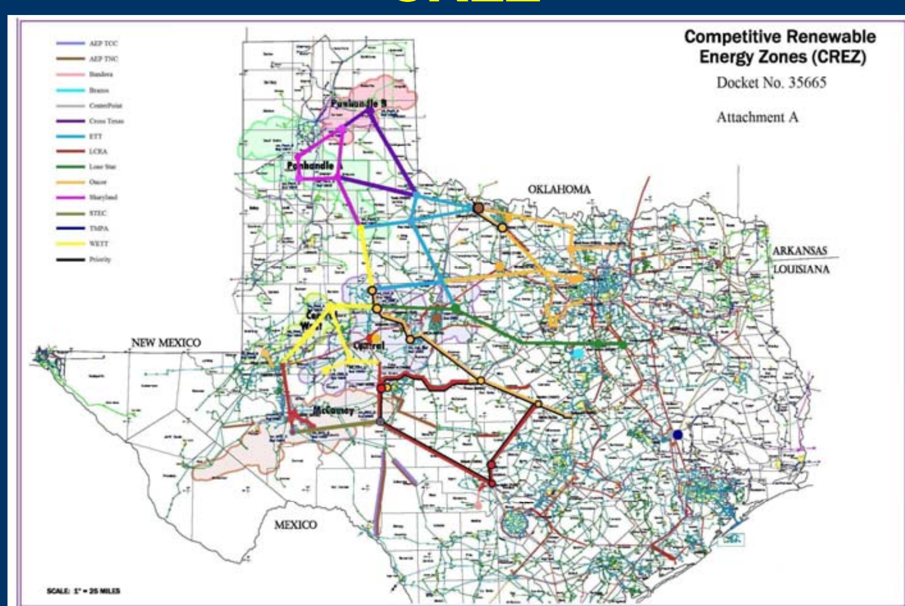
Proposed Super Grid



Interactive US Grid Map

http://www.npr.org/templates/story/story.php?storyId=110997398

CREZ



Solar Capacity of the Sahara

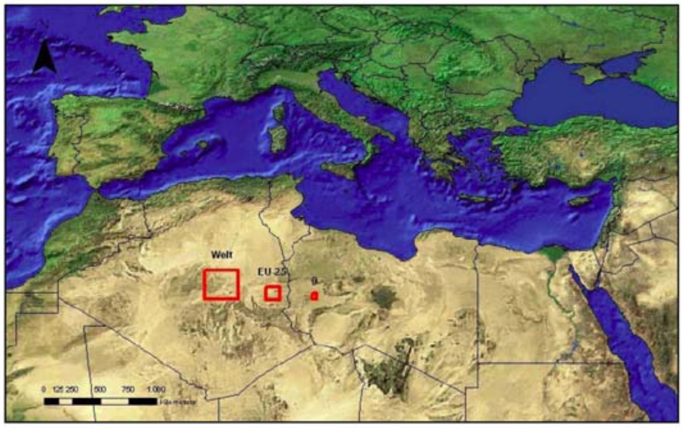


Fig. 12: Theoretical space requirement to meet the electricity demand of the world, Europe (EU-25) and Germany (Data from DLR, 2005).

Global Vision

http://en.wikipedia.org/wiki/Desertec

Sahara Solar Project

http://www.saharasolarproject.com/

PSEG Solar Source LLC / juwi Solar Inc. MARS Solar Project Hackettstown NJ, 2009

Who is PSEG Solar Source LLC?

- **Subsidiary of Public Service Enterprise Group (PSEG):** ***Publicly traded energy company headquartered in New Jersey and one of the ten largest electric companies in the U.S.***
- **Total assets:** ***$29 billion***
- **Total annual revenues:** ***$13.3 billion***
- **Employees:** ***Approximately 10,500***
- **Reliability:** ***In 2009 PSE&G was named for the fourth time as America's most reliable electric utility, by receiving the prestigious National Reliability Excellence Award from the industry benchmarking group, PA Consulting.***

Who is juwi?

Founded by Fred Jung and Matthias Willenbacher in 1996

Headquarters in Wörrstadt, Germany

juwi Growth & Operations

1996 · First wind turbine in Germany
1999 · Entry into photovoltaic (PV) sector
2001 · Entry into the bio energy sector
2002 · Enter North and South America
2005 · Enter Spain and the Czech Republic
2006 · Enter Italy
2007 · Largest PV plant of it's tim
40 MW, Brandis, Germany
2008 · Enter Greece and Costa Ri
2009 · Agreements signed for larg
US wind and solar farms; Construct
Germany's largest solar park, 53
MW;
Entry geothermal and hydropower
business arenas

Growth -
employees:
2000: approx. 30
2005: approx. 100
2010: approx.

MARS, Inc.

- Worldwide manufacturer
- $21 billion in annual sales in 2008
- 6th largest privately-held company in the United States
- Headquartered in McLean, unincorporated Fairfax County, Virginia, USA
- Six business segments in the U.S.:

1. *Chocolate, Hackettstown, NJ*
2. *Petcare , Franklin, TN*
3. *Wrigley Gum and Confections , Chicago, IL*
4. *Food , Los Angeles, CA*
5. *Drinks , West Chester, PA*
6. *Symbioscience , Gaithersburg, MD*

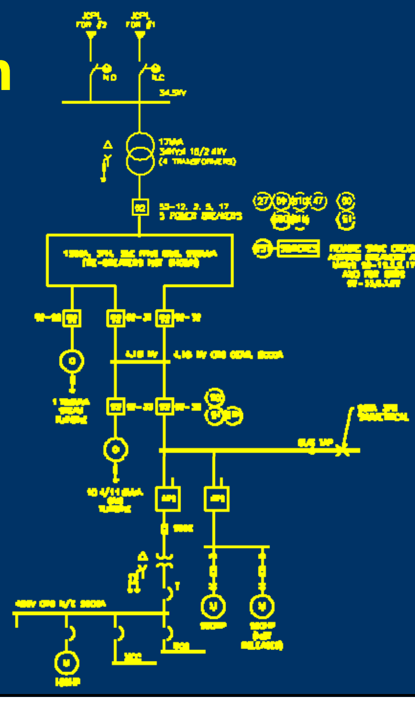
MARS, Hackettstown NJ

PV Panel Installation

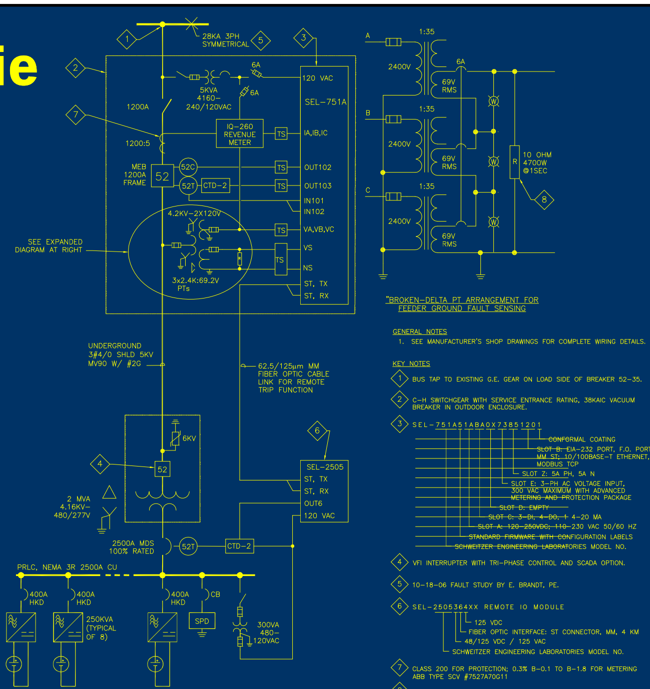
The PV "Garden"

PV Panel String

MARS System

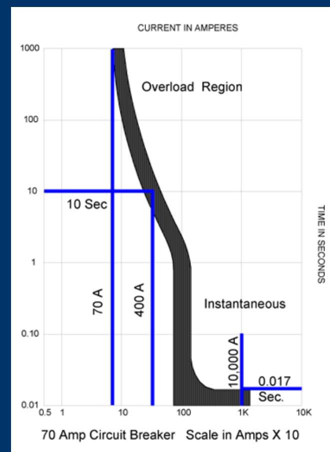


Intertie



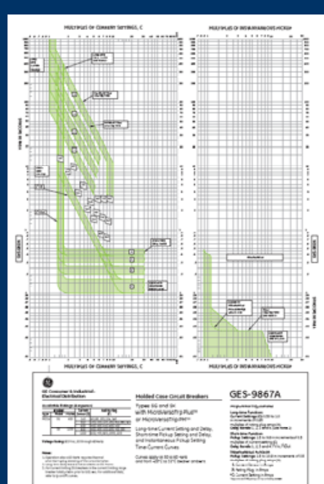
Overcurrent Protection

- LOAD CURRENTS
- FAULT CURRENTS

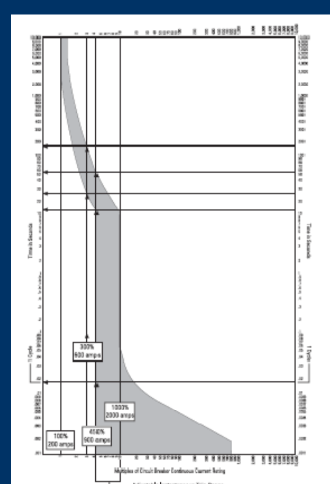


www.brainfiller.com/articles/TimeCurrentCurves.php

Typical TCC's



www.geindustrial.com/publibrary/checkout/Time%20Current %20Curves|GES-9867|generic



www.enm.com/eandm/training/siemenscourses/ep_9.pdf

4kV Cable Shield Duty

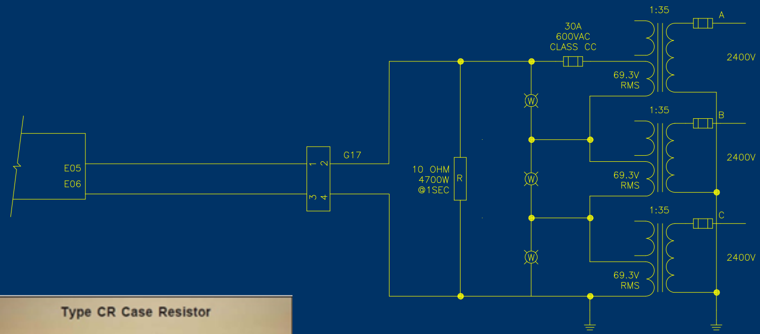
EPR/5mil Cu tape shield 25% lap, MV-90, 100% Insulation Level

	4/0	AWG	
	280	Amperes	Conduit in Air, NEC Table 310.73 90 deg.C
	290	Amperes	UG Duct, NEC Table 310.77 90 deg.C, Detail 1
Cond_Dia	0.516	In.	Nom. Cond. Dia.
Ins_Dia_Max	0.765	In.	Insul. Dia., Max.
Ins_Dia_Min	0.765	In.	Insul. Dia., Min.
Jkt_thk	0.080	In.	Nom.Jacket
Cbl_Dia	1.055	In.	Nom. Cable Dia.
Shld_th	5	mils	Shield thickness
Shld_Mean_Dia	845	mils	Shield Mean Diameter
T_w		mils	Tape width
T_l		mils	Tape lap
A_OL_tape_50	16900	CM	Shield Area 50% overlap=4*Shld_th*Shld_Mean_Dia
A_OL_tape_25	13816	CM	Shield Area 25% overlap=3.27*Shld_th*Shld_Mean_Dia
A_OL_tape_20	13351	CM	Shield Area 20% overlap=3.16*Shld_th*Shld_Mean_Dia
A_OL_tape_12	12760	CM	Shield Area 12.5% overlap=3.02*Shld_th*Shld_Mean_Dia
N	3	Integer	Number of cycles (time of fault current, 60=1 sec)
T1	65	Deg.C	Initial Temp
T2	200	Deg.C	Max Temp

		T2max	Cu	Al	Pb
K	0.288	150	0.193	0.083	0.0063
		200	0.288	0.123	0.0094
		250	0.372	0.159	0.0121
		350	0.517	0.221	NA

I	4281	Amperes	Shield Short Circuit Current=A_OL_tape_25/SQRT(N/K)

Broken Delta



Broken Delta Input to SEL-751A

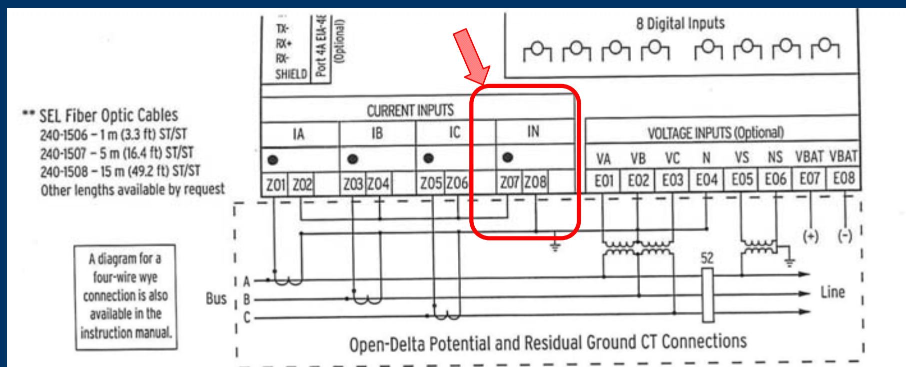


Figure 12 Wiring Diagram SEL-751A

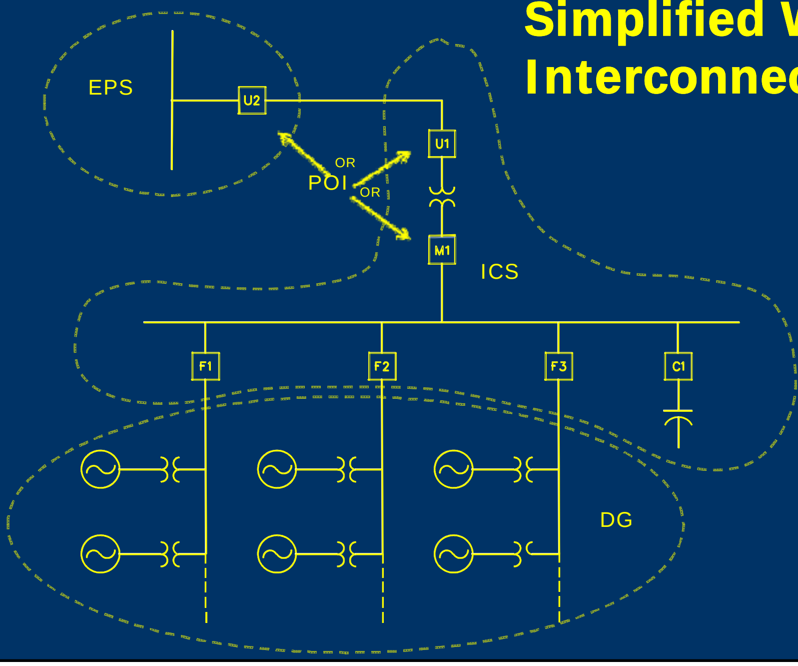
4kv Gear

SEL-751A Relay

The Happy Client

Next Solar Project

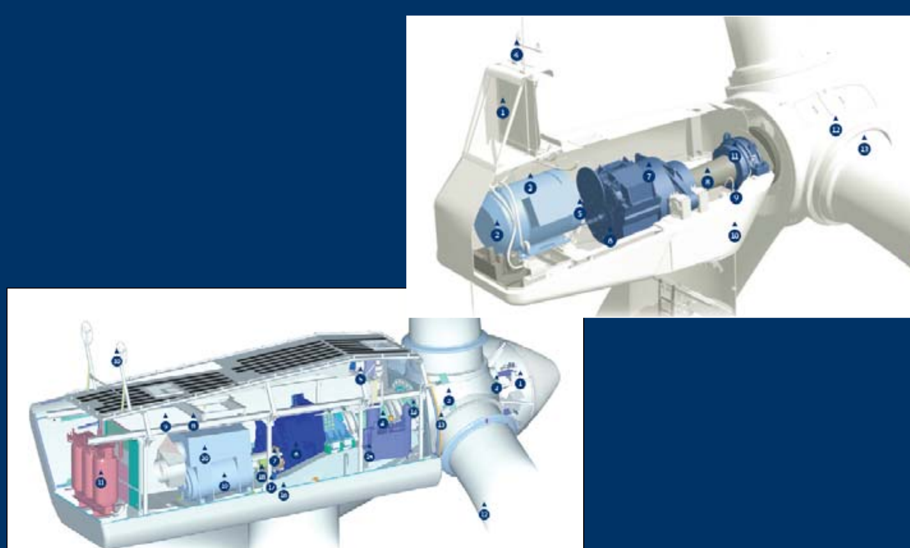
Simplified Wind Interconnection



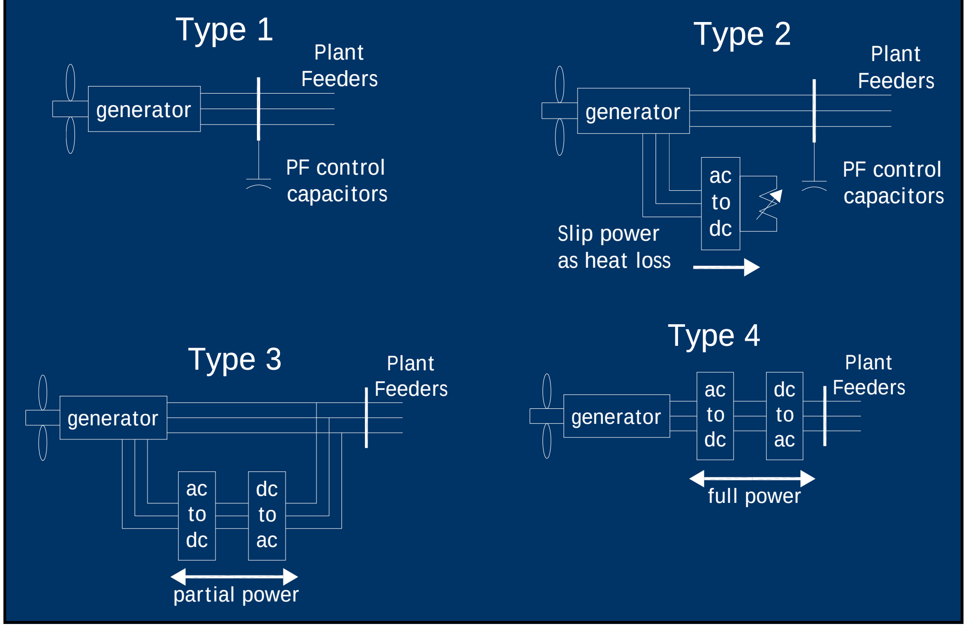
Basic Protection

- Line Protection
- Interconnection Protection
- High Side Bus Protection
- Transformer Protection
- Low Side Bus Protection
- Collector Circuit Protection
- Breaker Failure Protection
- Generator Step Up (GSU) Protection
- Turbine Protection

Turbines



Turbine Types



Cable Selection

Thermal Considerations for 34 kV Cables
- Source of Heat I^2R
- Dielectric Losses are Constant Based on Voltage

Heat Transfer is Characterized by Fourier's Law of Heat Conduction

Where
- P is heat loss in Watts
- ρ_T is Thermal Resistivity
- Δd is Thickness
- S is Surface Area

$$\Delta\Theta = P \cdot \rho_T \left(\frac{\Delta d}{S} \right)$$

Trefoil Cable External Thermal Resistance

One Example to Calculate Thermal Resistance

$$T = \frac{1.5}{\pi} \cdot \rho_T [\ln(2u) - 0.63]$$

$$u = \frac{2 \cdot L}{D_e}$$

Where

- ρ_T is thermal resistivity of the soil
- L is millimeters from Trefoil center to ground surface
- D_e is external diameter of one cable in millimeters
- IEC 60287-2-1, 1994

Detecting Ground Faults

Ground Fault

- short circuit from the power conductor to the cable shield
- cable shield is connected to ground

High Impedance Ground Path = Lower Ground Current

May Not Detect Low Current Fault

Engineering Trade-Offs

Large Concentric Neutrals
- Improve Ground Fault Detection (lower ground fault impedance)
- Increases Losses (heating)
- Standard Model for Calculations

Small Concentric Neutral
- Poor Ground Fault Detection (higher impedance)
- Less Losses
- Lower cable costs

Engineering Trade-Offs (cont.)

Small Concentric Neutrals with Extra Ground Conductor
- Improve Ground Fault Detection
- Low Losses
- Non-standard Model for Calculations
- Measured the Impedance

Feeder

- Outdoor
  - Vacuum Breakers
- Indoor
  - Vacuum Switchgear
- Typical 34 kV
  - Rated for 1200/2000/3000A

Capacitor Breaker and VAr Compensation

- Breaker (Sometimes w/ special purpose rating)
- Multiple Switches (may Control Multiple Banks)
- Reactor (may be added)
  - Limit Current or
  - Tune Impedance for Harmonics
- Auto / Manual Control

Main Breaker

- Similar to Feeder Breaker
- Indoor
  - Vacuum Switchgear
- Typical 34 kV
  - Rated for Bus Load/Gen

Power Transformer

- 60-200 MVA
- Typically Three Ratings
  - OA (Oil Air), ONAN
  - FA (Forced), ONAF
  - FOA, OFAF

i.e. 100/133/167
  - OA / FA / FA

High Voltage Breaker

- Nomenclature
PCB = Power Circuit Breaker
GCB = Gas Circuit Breaker
OCB = Oil Circuit Breaker

- Typically SF6
  - Gas Dielectric
  - Self monitoring and alarms
  - 2000 or 3000 A rating

- Connects to Bus or Line

Transmission Line

- Various Voltages
  - 69 kV
  - 115 kV
  - 138 kV
  - 230 kV
  - 345 kV
- Typically have OPGW
  - Optical Ground Wire

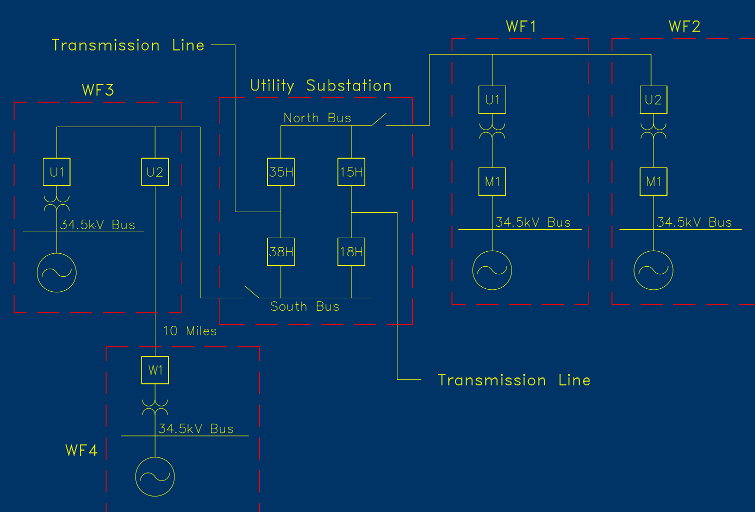
Substation

- A part of a generation, transmission or distribution system where voltage is stepped up or down using a transformer

230 kV Breaker

230-13.8 kV Transformer

Switching Station Interconnection

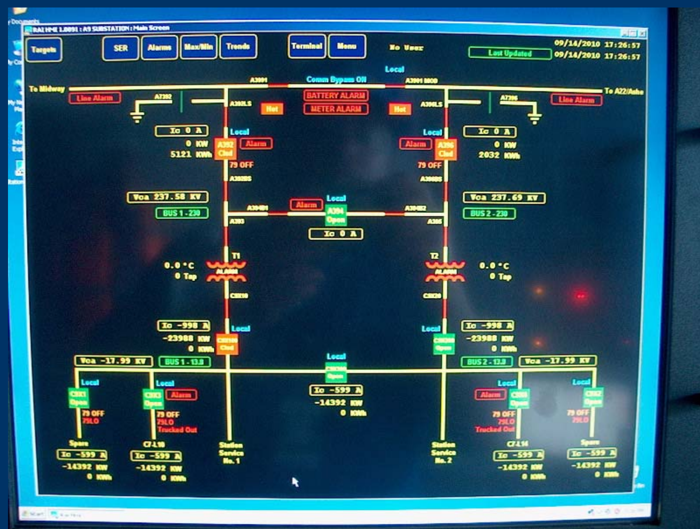


Control Building

- All Substation Controls
  - Protection, Auto-VAr, Auto-Restoration, Batteries, Auto Transfer for Station Service
- Sometimes HV Equipment
  - 34 kV Bus, Breakers, Voltage Transformer (Switchgear)

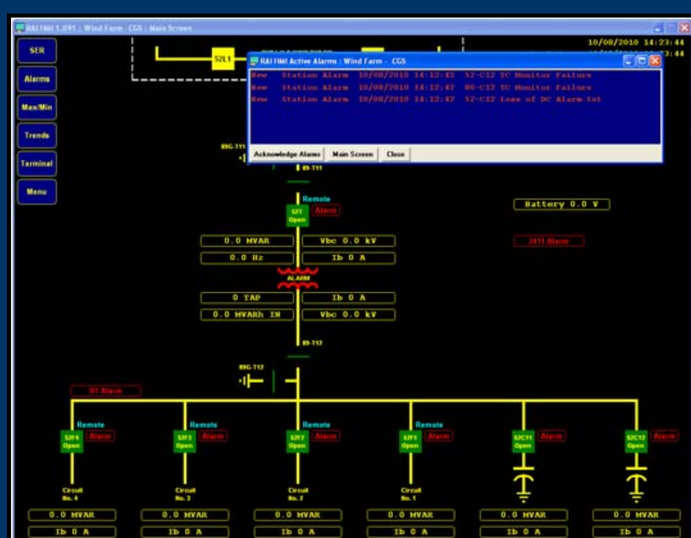
Protection & Control Panels

Monitoring the System



HMI at a De-energized Station

HMI



General HMI with Alarm Window

Control Through HMI

Pro:
- Control Remotely
- Convenience

Con:
- Security
- Safety

230 kV Breaker

Getting Power to the Grid

- Transmission Line vs Switching Station
- Power Factor Control
- Voltage Control
- Line Capacity
- Low Voltage Ride-through
- Load/Generation Shedding

Protection System Challenges

- Generation may exceed lowest fault current
  - End-of-line fault creates 500 A of current
  - Generators produce 600 A of current
  - Relay must be set at about 250 A to detect fault
  - Solution: Directional element control based on V vs I angle
- Generator Swings Angle and Trips Breaker during Generation
  - Solution: timing and angle limits

Protection System Challenges (cont.)

- Wind Farm is Weak Phase Source
  - Traditional communication schemes get complicated
- Typical Distribution Transformers Create Transmission Overvoltages (Delta-Wye)
  Solution: Use Wye-Delta-Wye Transformer
- Ground Current is Strong Source
  - Traditional impedance based schemes can get complicated

  Solution: Current Differential Relays

Control System Challenges

- Turbine Control Systems
  - Generation
  - Discrete Capacitors or Dynamic VAr Support
  - Equipment Protection
- Typical Substation Control Systems
  - Discrete Capacitors or Dynamic VAr Support
  - Equipment Protection
- Harmonics (IEEE 519)
- Voltage vs VAr Control (Grid Expectations)
- Coordinating Control Systems

Advanced Systems Automation

- Dynamic Protection
  - Capacitors vs Reactors
  - With or Without Communications
- Generation Curtailment (Centralized Controller)
- Auto-Restoration

Uninterrupted Transformer Fault

http://205.243.100.155/frames/longarc.htm

ELECTRICAL SAFETY

- PERSONS
- PROPERTY

Underwriters Laboratories Inc.

NAFFA INTERNATIONAL

National Fire Protection Association
The authority on fire, electrical, and building safety

OSHA

OSHA's mission is to assure the safety and health of America's workers by setting and enforcing standards; providing training, outreach, and education; establishing partnerships; and encouraging continual improvement in workplace safety and health.

Demystifying Codes and Standards

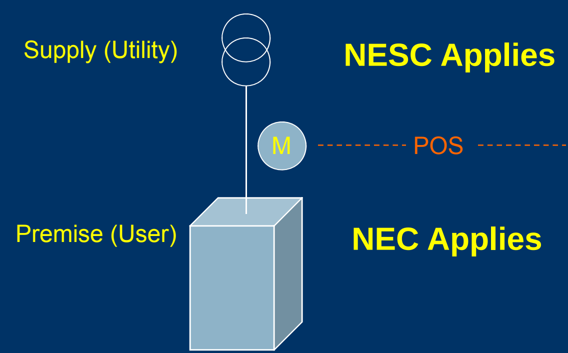
- Standards are necessary for interchangeability and compatibility
- Codes are regulatory for safety
- Codes rely on standards to achieve enforceability
- Insurance companies rely on codes to provide a level of assurance of profitability

Two Important Codes

- **NESC – National Electric Safety Code (IEEE)**
- **NEC – National Electric Code (NFPA-70)**

POS / PCC / POI

- POS = Point-of-Service
- PCC = Point-of-Common Coupling
- POI = Point-of-Interconnect



NESC Distinctions

- Published exclusively by the IEEE, the National Electrical Safety Code (NESC®) sets the ground rules for practical safeguarding of persons during the installation, operation, or maintenance of electric supply and communication lines and associated equipment. The NESC contains the basic provisions that are considered necessary for the safety of employees and the public under the specified conditions.

NEC Distinctions

1. Installations of electric conductors and equipment within or on public and private buildings or other structures, including mobile homes, recreational vehicles, and floating buildings; and other premises such as yards, carnivals, parking lots, and industrial substations.
2. Installations of conductors and equipment that connect to the supply of electricity.
3. Installations of other outside conductors and equipment on the premises.

NEC Distinctions, Cont'd.

4. Installations of optical fiber cable.
5. Installations in buildings used by the electric utility, such as office buildings, warehouses, garages, machine shops, and recreational buildings that are not an integral part of a generating plant, substation, or control center.

Wind Farm Regulations

Objective	Considerations
Interconnection of Plant	• Voltage ride-through • Power factor • SCADA capability • Metering and Protection
Meeting Regulations	Check with: • NEC and NESC (comparable Canadian codes) • IEC and IEEE • ISO's • Local codes and standards • State • Utility requirements • Manufacturer requirements & standards

Mortenson construction

Wind Farm Application

NESC and NEC

Location	Rules that Apply
Wind Turbine	NESC provides guidance for the Generation Plant and NEC provides guidance and rules for the wind turbine, LV electrical circuits and controls, as well as industrial requirements.
Collector System	NESC rules apply; grounding, overhead conductor clearances and loadings, underground clearances.
Arc Flash	NESC from Section 410 – collector system, NFPA 70E for inside tower.
Safety Practices	Part 4 of NESC in NFPA OSHA State Occupational safety rules - For working in a tower of on power lines.

Safety Disconnects

- Rated in Current and Horsepower
- Lock-out and Tag required for safety

NEC AND OTHER AGENCIES

- **LISTING AGENCIES**
- **COMPONENT RECOGNITION**
- **FIELD CERTIFICATION**

Underwriter's Laboratories

- Underwriters Laboratories (UL) is an independent testing organization created in 1893, when William Henry Merrill was called in to find out why the Palace of Electricity at the Columbian Exposition in Chicago kept catching on fire (which is not the best way to tout the wonders of electricity). After making the exhibit safe, he realized he had a business model on his hands. Eventually, if your electrical equipment wasn't UL certified, you couldn't get insurance.

http://www.schneier.com/essay-024.html

U.L Terms

- **LISTING** (evaluated relative to life and property hazards)
- **CLASSIFICATION** (evaluated to specific hazards and conditions)
- **CERTIFICATE** (evaluated field-installed systems)
- **RECOGNITION** (evaluated system component)

Other Listing Agencies

- CSA
- Factory Mutual

Note:

- CE Mark is not a listing, but a European quality mark

NFPA Standards

- **NFPA 820** - Standard for Fire Protection in Wastewater Treatment and Collection Facilities
- **NFPA 70E** - Standard for Electrical Safety in the Work Place

NFPA 70E – Standard for Electrical Safety in the Work Place

- ARC FLASH AND BLAST
- PPE

High Voltage Arcing

http://205.243.100.155/frames/longarc.htm

480V 3-Ph Arc Blast

http://205.243.100.155/frames/longarc.htm

Electric Arc Hazards

Arc Flash Hazards

- Temperatures up to 35000 F
- Brilliant flash
- Loud noise
- Spreading hot gases
- Molten metal
- Flying objects

Jefferson Lab — Thomas Jefferson National Accelerator Facility — Page 3 — Office of Science U.S. DEPARTMENT OF ENERGY

Operated by the Southeastern Universities Research Association for the U.S. Department of Energy

The Dangers

- Burns
- Blast
- Blindness
- Shock

Injuries

- 1992 to 2001: 44,363 electrical related injuries [Cawley and Homace of the CDC/NIOSH]
- Construction Shock/Burn Ratio: 5,884/5,990

OSHA, NFPA, NEC

- OSHA 29 Code of Federal Regulations 1910
- NFPA 70E Standard for Electrical Safety in the Workplace
- NFPA 70-NEC Section 110.16

W.A.C.

WAC 296-24-975

Selection and use of work practices.

(1) General. Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits which are or may be energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards.

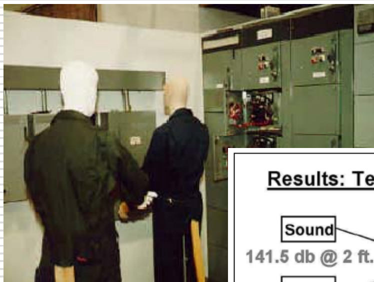
(a) Deenergized parts. Live parts to which an employee may be exposed shall be deenergized before the employee works on or near them, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Live parts that operate at less than 50 volts to ground need not be deenergized if there will be no increased exposure to electrical burns or to explosion due to electric arcs.

Lock-out & Tag

Staged Testing

- IEEE Transactions on Industry Applications, Vol. 36, No. 2 March April 2000
- Ray Jones, Danny Liggett, Mary Capelli-Schellpfeffer, Terry Macalady, Lyn Aunders, Robert Downey, Bruce McClung, Arthur Smith, Shahid Jamil and Vincent Saporita

Testing is Basis for NFPA Standard



r photo of test No. 4 during test

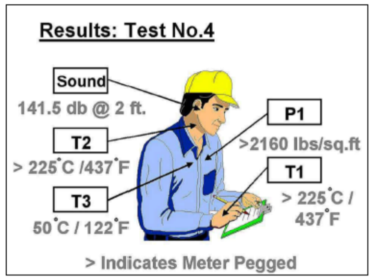


Fig. 5 - Results of Test No. 4

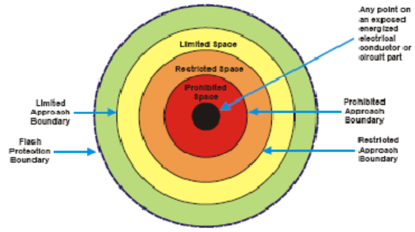
Unified Facilities Criteria (UFC) 3-560-02, Electrical Safety

John Peltz, PE
NAVFAC Atlantic, CIEE

Eddie Davis, PE
Edan Engineering Corporation

Approach Boundaries

- Limited Approach
- Restricted Approach
- Prohibited Approach



- All of these are based solely on voltage
- Flash protection boundary is different

Flame Resistant (FR) Clothing

Hazard/Risk Category	General Clothing Description	Required Minimum PPE Arc Rating (cal/cm^2)
0	Non-melting, flammable materials	N/A
1	Flame-resistant (FR) shirt and FR pants, or FR coverall over Category 0 clothing	4
2	Category 1 clothing, including cotton underwear (conventional short sleeve t-shirt and brief/shorts)	8
3	Category 2 clothing with an extra set of coveralls (FR shirt and pants with cotton underwear plus FR coverall, or cotton underwear plus two FR coveralls)	25
4	FR shirt and pants with cotton underwear plus multilayer flash suit	40



11.2 ATPV Label

Arc Flash Hood

Arc Flash Protective Hood

“Moon Suit”

Arc Flash Hazard Analysis

- Determines flash protection boundary and PPE requirements as a function of location and work activity
- Typically requires electrical analysis software to do an effective arc flash hazard analysis
- UFC will provide tables for various tasks if the arc flash hazard analysis tools are not available

Abbreviations

- SCCR: Short Circuit Current Rating
- IR: Interrupting Rating
- IC: Interrupting Capacity
- SYM: Symmetrical
- ASYM: Asymmetrical

SCCR Labeling

- Industrial Control Panels (UL 508A)
- Conversion Equipment (UL 508C)
- HVAC Equipment
- Lighting Contactors
- SPD (Surge Protective Devices)

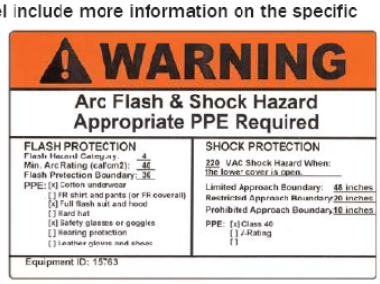
DATA REQUIRED TO BE ON THE NEW ARC FLASH WARNING LABELS

NFPA 70-NEC Section 110.16 only requires the label to state the existence of an arc flash hazard.

It is suggested that the party responsible for the label include more information on the specific parameters of the hazard including:

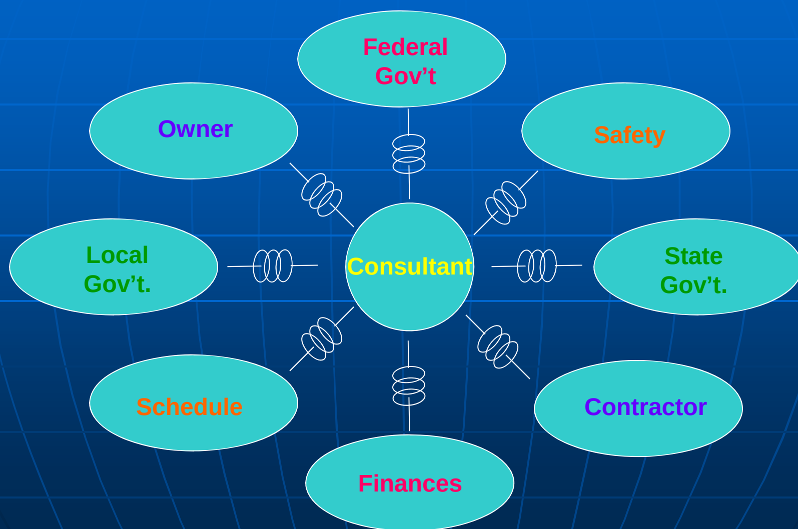
- **Boundaries**
  The limited, restricted and prohibited approach boundaries are determined using NFPA Table 2-1.3.4 (2000 edition).

- **Flash protection boundary**
  This boundary is the closest that anyone may approach without the use of PPE. The available short circuit current, predicted fault duration and the voltage are all needed to determine the flash protection boundary. This boundary is the distance from the arc source where there is a potential heat energy of 1.2 calories/cm2 falling on the surface of the skin for 0.1 seconds. According to NFPA 70E, there are three ways in which this boundary can be calculated:
  - Simplified Table 220.2 (B) (2), 220.6 (B) (9)
  - Analysis based on NFPA 70E Annex B
  - Analysis based on IEEE 1584



- **PPE required**
  The Personal Protective Equipment required is dependent on the incident energy at every point a person may perform work on energized equipment. An electrical engineer or other qualified person should perform the calculations that determine the incident energy. The appropriate PPE should cover all parts of the body that may be exposed to an arc flash. This could include shoes, gloves, flame resistant clothing, safety glasses, etc.

Key Player in Construction



Questions and Comments

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Thanks for your attention!