Welcome to

Energy Production Systems Engineering

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UNIVERSITY OF SOUTH FLORIDA POLYTECHNIC

Session 6:
Electrical Systems

Spring 2012

Session 6: Electrical Systems

- **Electrical Systems**

Electrical Systems

Electrical Systems

Transformers

Construction
K-Factor
Winding configuration

Electrical Systems

Transformers & Transformer protection –
Oil filled transformer – dry type transformers

High efficiency

K rating – steal quality – core area to operate farther away from knee of saturation curve

Harmonics – positive / negative / zero sequence
Triplen harmonics

Electrical Systems

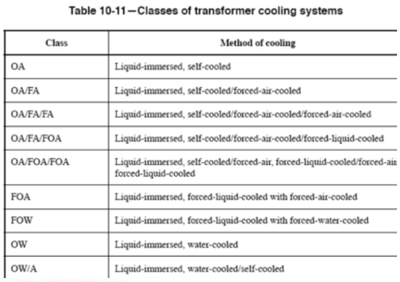
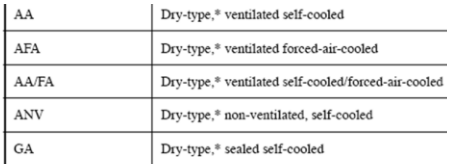


Table 10-11—Classes of transformer cooling systems

Class	Method of cooling
OA	Liquid-immersed, self-cooled
OA/FA	Liquid-immersed, self-cooled/forced-air-cooled
OA/FA/FA	Liquid-immersed, self-cooled/forced-air-cooled/forced-air-cooled
OA/FA/FOA	Liquid-immersed, self-cooled/forced-air-cooled/forced-liquid-cooled
OA/FOA/FOA	Liquid-immersed, self-cooled/forced-air, forced-liquid-cooled/forced-air forced-liquid-cooled
FOA	Liquid-immersed, forced-liquid-cooled with forced-air-cooled
FOW	Liquid-immersed, forced-liquid-cooled with forced-water-cooled
OW	Liquid-immersed, water-cooled
OW/A	Liquid-immersed, water-cooled/self-cooled

Electrical Systems

Dry type transformer cooling systems.

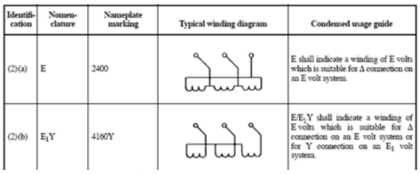


AA	Dry-type,* ventilated self-cooled
AFA	Dry-type,* ventilated forced-air-cooled
AA/FA	Dry-type,* ventilated self-cooled/forced-air-cooled
ANV	Dry-type,* non-ventilated, self-cooled
GA	Dry-type,* sealed self-cooled

Electrical Systems

Voltage designations

Table 10-12(b)—Designation of voltage ratings of three-phase windings (schematic representation)



Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(a)	E	2400		E shall indicate a winding of E volts which is suitable for Δ connection on an E volt system.
(2)(b)	E_1Y	4160Y		E/E_1Y shall indicate a winding of E volts which is suitable for Δ connection on an E volt system or for Y connection on an E_1 volt system.

Electrical Systems

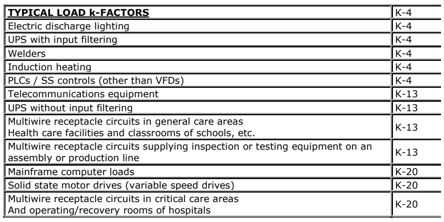
Transformer K factor

Defined in UL 1561
Ih = rms current value (pu) at harmonic h
Harmonic currents = additional heating
K-factor Xfmr > K-factor System

$$K = \sum_{h=1}^{h=h_{\max}} I_h^2 \cdot h^2$$

Electrical Systems

Recommended K factor for various applications



TYPICAL LOAD k-FACTORS	K-4
Electric discharge lighting	K-4
UPS with input filtering	K-4
Welders	K-4
Induction heating	K-4
PLCs / SS controls (other than VFDs)	K-4
Telecommunications equipment	K-13
UPS without input filtering	K-13
Multiwire receptacle circuits in general care areas Health care facilities and classrooms of schools, etc.	K-13
Multiwire receptacle circuits supplying inspection or testing equipment on an assembly or production line	K-13
Mainframe computer loads	K-20
Solid state motor drives (variable speed drives)	K-20
Multiwire receptacle circuits in critical care areas And operating/recovery rooms of hospitals	K-20

Electrical Systems

Magnetization current / over excitation.

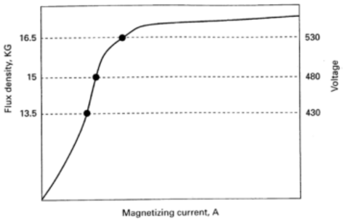


FIGURE 4.2.1 Magnetizing current in amperes.

Electrical Systems

Transformer connections

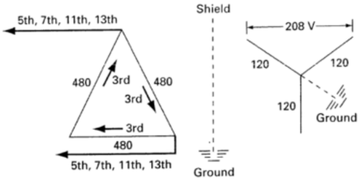


FIGURE 4.2.2 Schematic of delta-wye winding with electrostatic shield.

Electrical Systems

TENV dry transformers in dirty, dusty environment – also cast epoxy vs. VPI

Auto transformer – smaller adjust voltage – no isolation

Reactor – current limiting – reduced voltage start – with capacitor for tuned filter

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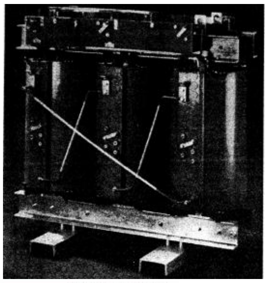
Electrical Systems



Dry type –
epoxy cast coil

Electrical Systems

Instrument transformer – PT & CT

Transformer polarity

PT vs. CT defined by application

PT circuits in parallel – CT circuits in series

Do not short PT circuit – Do not open CT circuit
Special shorting switch

120V / 5A (1A)

Electrical Systems

Accuracy – XXYZZZ
XX = max error at conditions
Y = C or T (calculated or tested)
ZZZ = volts secondary at 20X rated secondary current.

Example 7:
What is the max error at what voltage secondary for a;

10C200 current transformer

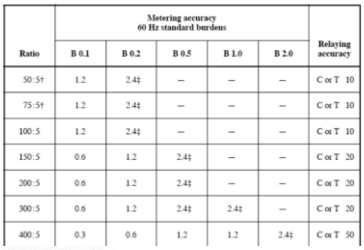
Electrical Systems

10C200 current transformer

Maximum error of 10% at 200 Volts on secondary side at 20 times current (100A for 5A secondary)

Electrical Systems

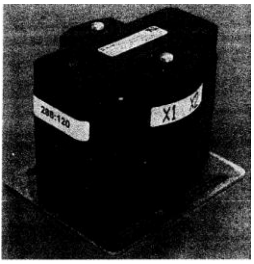
Table 10-7—Standard accuracy class ratings* current transformers in metal-clad switchgear



Ratio	Metering accuracy 60 Hz standard burdens					Relaying accuracy
	B 0.1	B 0.2	B 0.5	B 1.0	B 2.0	
50:5†	1.2	2.4‡	–	–	–	C or T 10
75:5†	1.2	2.4‡	–	–	–	C or T 10
100:5	1.2	2.4‡	–	–	–	C or T 10
150:5	0.6	1.2	2.4‡	–	–	C or T 20
200:5	0.6	1.2	2.4‡	–	–	C or T 20
300:5	0.6	1.2	2.4‡	2.4‡	–	C or T 20
400:5	0.3	0.6	1.2	1.2	2.4‡	C or T 50

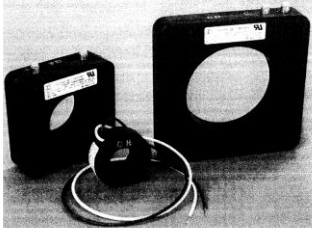
Electrical Systems

Potential
Transformer



Electrical Systems

Current
Transformer



Electrical Systems

Three parts of transformer –
Winding conductors, core material, insulation
Grain steel – M number (lower is lower loss)

Neutral terminal / conductor = twice size phase – maintain neutral to gnd voltage < 1 V. (solid grounded system)

Arrester 5 ft from transformer (vacuum switches and/or lighting exposure)

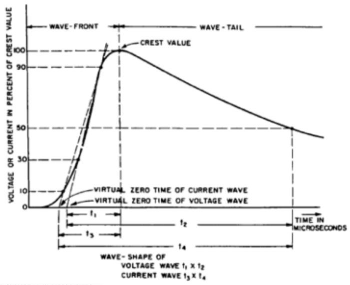
BIL ratings of transformers

Electrical Systems

Insulation Test

1 min, power-frequency high pot
Test
1.2/50 full-wave voltage impulse test

Electrical Systems



Electrical Systems

Full Wave vs. Chopped Wave test

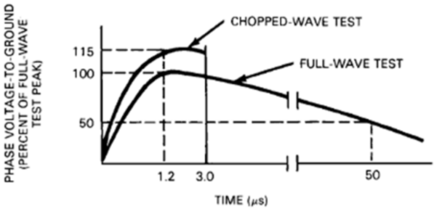
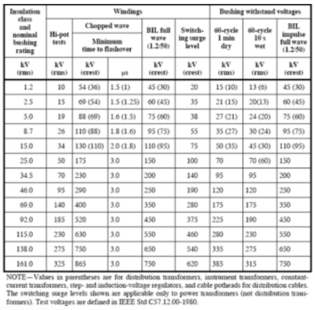


Figure 6-12—Standard impulse test waves



Insulation class and nominal bushing rating	Windings					Bushing withstand voltages		
	Hi-pot tests	Chopped wave Minimum time to flashover		BIL full wave (1.2/50)	Switching surge level	60-cycle 1 min dry	60-cycle 10 s wet	BIL impulse full wave (1.2/50)
kV (rms)	kV (rms)	kV (crest)	µs	kV (crest)	kV (crest)	kV (rms)	kV (rms)	kV (crest)
1.2	10	54 (36)	1.5 (1)	45 (30)	20	15 (10)	13 (6)	45 (30)
2.5	15	69 (54)	1.5 (1.25)	60 (45)	35	21 (15)	20(13)	60 (45)
5.0	19	88 (69)	1.6 (1.5)	75 (60)	38	27 (21)	24 (20)	75 (60)
8.7	26	110 (88)	1.8 (1.6)	95 (75)	55	35 (27)	30 (24)	95 (75)
15.0	34	130 (110)	2.0 (1.8)	110 (95)	75	50 (35)	45 (30)	110 (95)
25.0	50	175	3.0	150	100	70	70 (60)	150
34.5	70	230	3.0	200	140	95	95	200
46.0	95	290	3.0	250	190	120	120	250
69.0	140	400	3.0	350	280	175	175	350
92.0	185	520	3.0	450	375	225	190	450
115.0	230	630	3.0	550	460	280	230	550
138.0	275	750	3.0	650	540	335	275	650
161.0	325	865	3.0	750	620	385	315	750

NOTE—Values in parentheses are for distribution transformers, instrument transformers, constant-current transformers, step- and induction-voltage regulators, and cable potheads for distribution cables. The switching surge levels shown are applicable only to power transformers (not distribution transformers). Test voltages are defined in IEEE Std C57.12.00-1980.

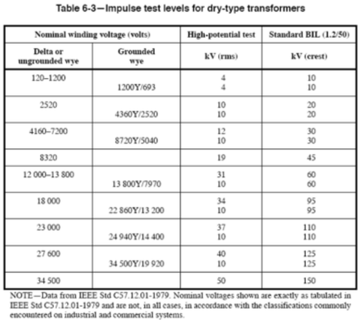


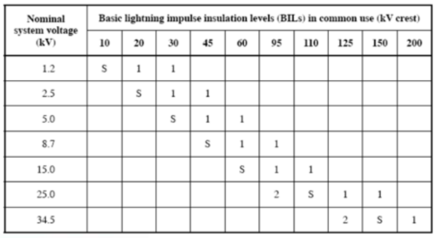
Table 6-3—Impulse test levels for dry-type transformers

Nominal winding voltage (volts)		High-potential test	Standard BIL (1.2/50)
Delta or ungrounded wye	Grounded wye	kV (rms)	kV (crest)
120–1200		4	10
	1200Y/693	4	10
2520		10	20
	4360Y/2520	10	20
4160–7200		12	30
	8720Y/5040	10	30
8320		19	45
12 000–13 800		31	60
	13 800Y/7970	10	60
18 000		34	95
	22 860Y/13 200	10	95
23 000		37	110
	24 940Y/14 400	10	110
27 600		40	125
	34 500Y/19 920	10	125
34 500		50	150

NOTE—Data from IEEE Std C57.12.01-1979. Nominal voltages shown are exactly as tabulated in IEEE Std C57.12.01-1979 and are not, in all cases, in accordance with the classifications commonly encountered on industrial and commercial systems.

Electrical Systems

Dry Type transformer BIL



Nominal system voltage (kV)	Basic lightning impulse insulation levels (BILs) in common use (kV crest)									
	10	20	30	45	60	95	110	125	150	200
1.2	S	1	1							
2.5		S	1	1						
5.0			S	1	1					
8.7				S	1	1				
15.0					S	1	1			
25.0						2	S	1	1	
34.5								2	S	1

Electrical Systems

Standard impedance < 500KVA = 3-5 %
>500 KVA = 5.75 %

Fan cooling dry type = 133% rating w/ fan

Caution, temperature of conductor connection

VPI – vacuum to draw moisture out, inject epoxy, pressure applied (inert gas) to push epoxy into winding – heat to cure epoxy

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Electrical Systems

Thermal insulation class (AMB 30C)

AVG TMP RISE C	HOT SPOT DIFF C	HIGHEST PERM RISE C	CLASS
55	10	105	A105
65	15	120	A120
80	30	150	B150
115	30	185	F185
150	30	220	H220

Electrical Systems

NEMA 1
NEMA 3R
NEMA 4
NEMA 12

Dry type reduced environmental requirements and fire protection compared with oil

Dry type available to about 15MVA

Electrical Systems

Circuit Breaker – switch to open under current

Driven by spring action both close and trip
DC power for charging motor
External relay trip on protection
Arc drawn –
Air / Vacuum / SF6 / Oil
Coordination – discussed later in relaying section

Electrical Systems

Table 6-2—Basic impulse insulation levels (BILs) of power circuit breakers, switchgear assemblies, and metal-enclosed buses

Voltage rating (kV)	BIL (kv)	Voltage rating (kV)	BIL (kV)	Voltage rating (kV)	BIL (kV)
2.4	45	23	150	115	550
4.16	60	34.5	200	138	650
7.2	75*	46	250	161	750
13.8	95	69	350	230	900
14.4	110	92	450	345	1300

*95 for metal-clad switchgear with power circuit breakers

Electrical Systems

Special considerations:
Need DC to trip / close – battery fed
Synchronizing
Dead bus transfer
Motor bus transfer – reclosing

Electrical Systems

Grounding –
Ungrounded / low impedance / high impedance / solid grounded

Advantages / disadvantages

Ungrounded – reliable – first GF no trip
High transient voltage
Difficult to locate ground
Ground detection via open delta transformer (DRAW)

Electrical Systems

Grounding –
High impedance ground (10A) – low damage, can alarm on ground increase reliability,
Need sensitive relay to detect and locate ground
Transient less than ungrounded but higher than low impedance ground.

Electrical Systems

Grounding –
Low impedance ground (400A) – easily detected, higher damage, easily located, transients less, trip on fault, reduced security

Solid grounded – most damage, easily detected, easily located, transients minimum, trip on fault, reduced security

Electrical Systems

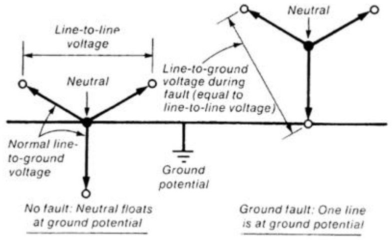

FIGURE 4.3.2 No fault versus ground fault for a three-phase power system.

Electrical Systems

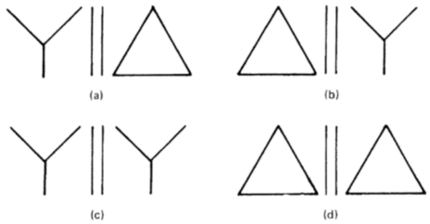

FIGURE 4.3.3 Transformers may be connected (*a*) wye-delta, (*b*) delta-wye, (*c*) wye-wye, and (*d*) delta-delta.

Electrical Systems

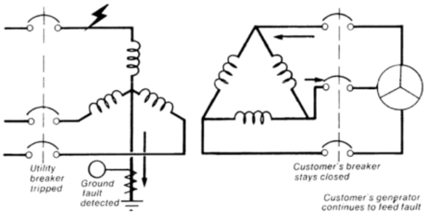

FIGURE 4.3.4 Wye-delta connection is best for most installations, but if the customer's generator is large, it may continue to feed a fault on the utility side of the transformer.

Electrical Systems

Differential protection on delta wye may need wye delta connected CTs to compensate for 30 degree phase shift.

Electrical Systems

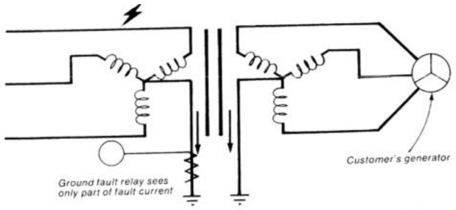

FIGURE 4.3.5 Wye-wye connection is least desirable because ground fault current is divided between two grounding legs.

Electrical Systems

Can add grounding transformer to ground a delta fed system

Electrical Systems

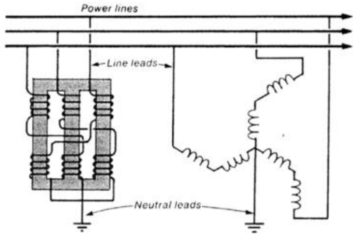

FIGURE 4.3.7 Zigzag grounding transformer has primary and secondary windings connected as shown, with the secondary neutral point grounded.

Electrical Systems

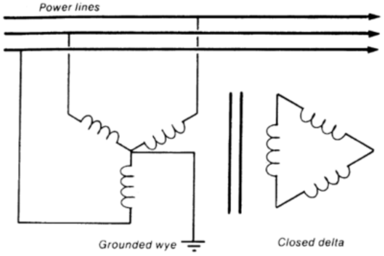

FIGURE 4.3.6 Any transformer will double as a grounding device if its primary is wye-connected and its secondary is a closed delta.

Electrical Systems

System-grounding design considerations –
Three levels of conductor insulation for MV cables: 100, 133, and 173% levels.
The solidly grounded system permits the use of 100% insulation level.
If fault cleared within 1 hour, 133% insulation level should be specified
If fault cleared more than 1 hour, 173% voltage level insulation should be used

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Electrical Systems

Grounding –
Adequate ground-return conductors to minimize the inherent **step-and-touch potentials** w/ solidly grounded systems Instantaneous ground fault relaying to minimize the fault duration.

See the NEC NESC and IEEE Std 80

Electrical Systems

All non-current-carrying metallic structures are interconnected and grounded.

Purpose:

Minimize potential difference between metallic members

Minimizing the risk of electric shocks to personnel

Improve protective device performance

d) To avoid fires in combustible atmospheres

Electrical Systems

Inductance of ground path

$L = 4 \times 10^{-7} \ln (D / r')$ *H/m*

Therefore, L increases as D increases

<u>VD increases as D increases &</u>
<u>Current tends to flow in closest cond.</u>

Electrical Systems

Two or more rods suggested

Distance between rods must be Lr1 + Lr2

Example two 8 ft rods, should be 16ft distance

(Numerous books and articles show the distance between two standard length 8 or 10 ft rods to be 3 m (10 ft), which is incorrect.)

Electrical Systems

Impedance depended on IEEE 80 Calc.

Larger substations and generating stations < 1Ω

Smaller substations and for industrial plants < 5Ω

NEC, Article 250, approves the use of a single electrode, if < 25Ω

Electrical Systems

Protective relaying & coordination:

Two functions – Protection of equipment (secondary)
Security of system (primary)

Trip when faulty condition present AND don't trip when faulty condition not present

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Electrical Systems

Balance of following concepts:

Reliability – Relay system trip when fault exists in protective zone

Security – Relay system trip only when fault exists in protective zone

Selectivity – Relay system should trip minimum equipment to remove fault

Speed – Relay system remove fault fast to minimize damage and arc flash incident energy.

Simplicity – minimum amount of equipment – maximize reliability

Economics – Reasonable cost

Electrical Systems

Most common – 50, 51, 27, 59, 81O, 81U, 87

PTs and CTs feed relays

Electrical Systems

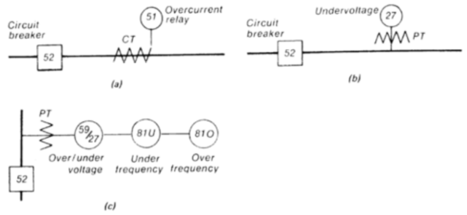
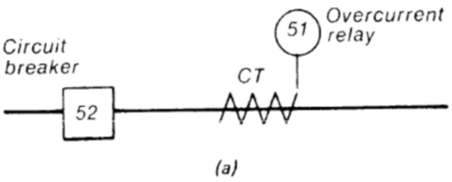
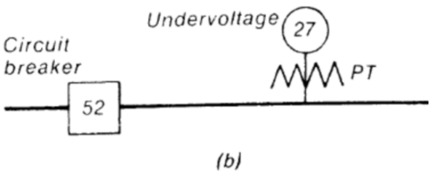


FIGURE 4.3.10 Instrument transformers may be (*a*) current (CT) or (*b*, *c*) potential (PT).

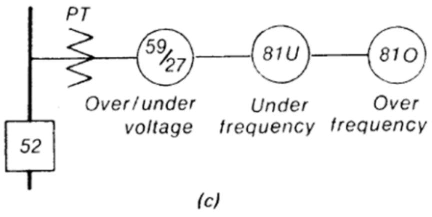
Electrical Systems



Electrical Systems



Electrical Systems



Electrical Systems

Ground fault –
Unbalanced current – not easily detected by phase relay, use sensitive ground fault relay
For grounded system, use 50G or 51G as shown below. For ungrounded system use broken delta with 59 relay.

Electrical Systems

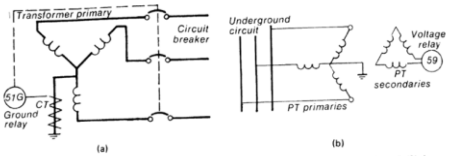


FIGURE 4.3.11 Ground fault (*a*) on one phase of a grounded three-phase circuit and (*b*) in an ungrounded circuit.

Electrical Systems

Phase Faults:
Line to Line, Line to Ground (solid system), and 3 phase fault detection. 50 and/or 51 detect.

Overvoltage (59) – typically used on neutral or ground detection systems

Frequency (81O & 81U) – indication of system transient. Protection during “Islanding”

Electrical Systems

Differential relay (87) –
Detect internal fault quickly – ignore external fault reliably
May be more than just 2 winding device (i.e. 6 CT inputs)

Overcurrent (50/51) both phase and ground detection – 51 device to allow for coordination between elements

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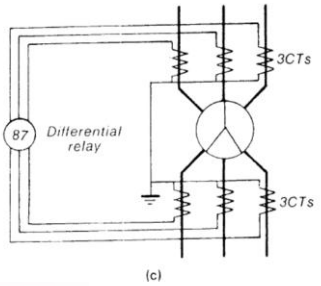
Electrical Systems

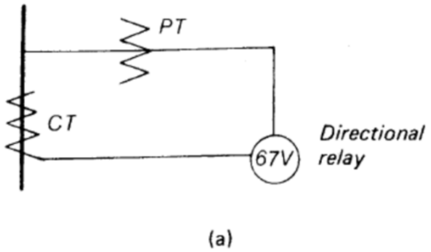


Electrical Systems

Directional overcurrent (67) –
Control flow of power – prevent motoring of generator
Need VT & CT to polarize relay

Distance relay (21), trip if fault in zone 1, backup for zone 2, 3. Needs VT & CT input. Common application is looking back into generator impedance (quick trip of breaker for gen fault).

Electrical Systems



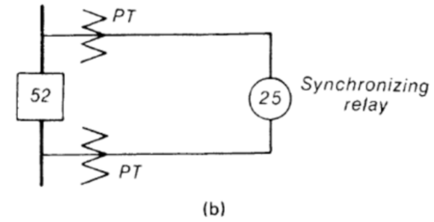
Electrical Systems

Synchronizing relay (25) -

Both Synchronizing and Synch check

Magnitude, angle, rotation, frequency

Electrical Systems



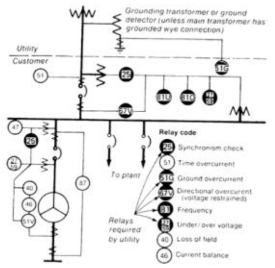


FIGURE 4.3.13 Basic protection scheme suggested by Southern California Edison Co. for total generation greater than 200 kVA. (*Courtesy Southern California Edison Co.*).

Electrical Systems

Typical Relay
& Protection
One-line
Diagram

Electrical Systems

Short Circuit Current Calculations

Purpose
- Present considerations of short-circuit current calculations;
- Illustrate common methods for calculations;
- Furnish typical data used in calculations.

Electrical Systems

Rotating Machine Equivalent Circuit

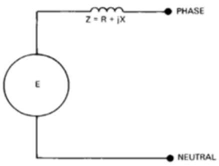


Figure 4-1—Equivalent circuit for generators and motors
E = (driving voltage, X varies with time)

Electrical Systems

Xd’ ’ - subtransient reactance – (0 < t < 0.1s)
Xd’ - transient reactance – (0.1 < t < 0.5 to 2.0s)
Xd - synchronous reactance – (0.5 to 2.0s < t) Steady State

When given ***Xdv’ ’*** – (at rated voltage, saturated, smaller) and ***Xdi’ ’*** – (at rated current unsaturated, larger), use ***Xdv ’ ’***

Electrical Systems

Xd' ' - subtransient reactance – (0 < t < 0.1s)
No Value for ***Xd'*** and ***Xd*** *as motor only contributes SCA for initial cycles.*

Electrical Systems

Utility normally shown with as infinite bus with fixed impedance.
For MV & HV systems, R usually ignored
For LV system R included
Arc Resistance not zero

Electrical Systems

Select location for purpose of calculation
- Establish simple model
 Recognize restraints of model
 Adjust model if assumptions too restraining

Electrical Systems

Step 1: Prepare system diagrams
Step 2: Collect and convert impedance data
Step 3: Combine impedances
Step 4: Calculate short-circuit current

Electrical Systems

Wye Delta Conversion

$$A = \frac{b \cdot c}{a} + b + c$$

$$B = \frac{a \cdot c}{b} + a + c$$

$$C = \frac{a \cdot b}{c} + a + b$$

Electrical Systems

Delta Wye Conversion

$$a = \frac{B \cdot C}{A + B + C}$$

$$b = \frac{A \cdot C}{A + B + C}$$

$$c = \frac{A \cdot B}{A + B + C}$$

Electrical Systems

Per Unit Calculations

$$\text{base current (amperes)} = \frac{\text{base kVA (1000)}}{\sqrt{3}\ \text{(base V)}} = \frac{\text{base kVA}}{\sqrt{3}\ \text{(base kV)}}$$

$$= \frac{\text{base MVA } 10^6}{\sqrt{3}\ \text{(base V)}} = \frac{\text{base MVA (1000)}}{\sqrt{3}\ \text{(base kV)}}$$

$$\text{base impedance (ohms)} = \frac{\text{base V}}{\sqrt{3}\ \text{(base A)}} = \frac{(\text{base V})^2}{\text{base kVA (1000)}}$$

$$= \frac{(\text{base kV})^2(1000)}{\text{base kVA}} = \frac{(\text{base kV})^2}{\text{base MVA}}$$

Electrical Systems

Per Unit Calculations

$$Z_{pu} = \frac{\text{actual impedance in ohms ((base MVA)}}{(\text{base kV})^2}$$

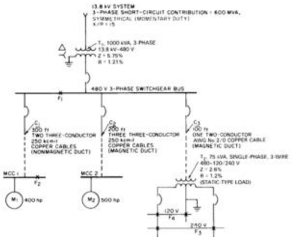
$$= \frac{\text{actual impedance in ohms (base kVA)}}{(\text{base kV})^2(1000)}$$

$$Z_{pu} = \frac{\text{percent impedance (base kVA)}}{\text{kVA rating (100)}}$$

$$= \frac{\text{percent impedance (10) (base MVA)}}{\text{kVA rating}}$$

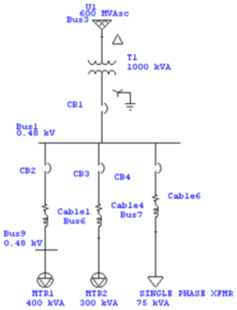
Electrical Systems

example



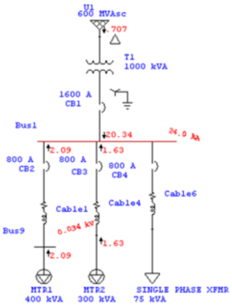
Electrical Systems

Software Model



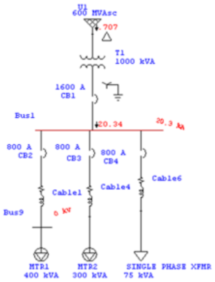
Electrical Systems

Subtransient
Result



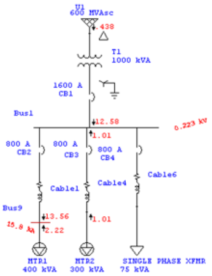
Electrical Systems

Steady state result



Electrical Systems

Fault at MCC1



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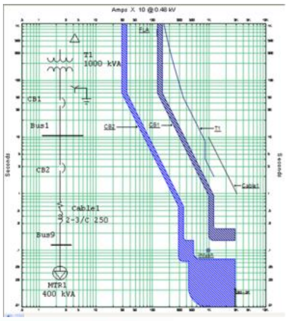
Electrical Systems

Correct Phase TCC



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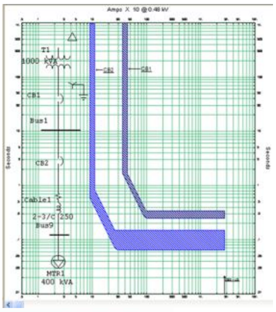
Correct Ground
TCC



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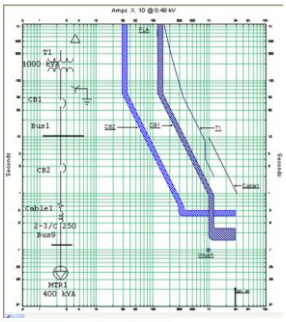
Electrical Systems

Incorrect Phase
TCC



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Electrical Systems

In-Plant Electrical Distribution System
Ensure reliability of system
Either higher spinning reserve – high failure rate
Low spinning reserve – low failure rate

Without reliable distribution system, plant operation can not be reliable.

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Electrical Systems

Distribution system design standards:
IEEE Color Books

EMERALD BOOK IEEE Std 1100-1999 IEEE Recommended Practice for Powering and Grounding Electronic Equipment

RED BOOK IEEE Std 141-1993 IEEE Recommended Practice for Electric Power Distribution for Industrial Plants

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Electrical Systems

Distribution system design standards:
IEEE Color Books

GREEN BOOK IEEE Std 142-1991 IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

BUFF BOOK IEEE Std 242-2001 IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

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Electrical Systems

IEEE Color Books

BROWN BOOK IEEE Std 399-1997 IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis

ORANGE BOOK IEEE Std 446-1995 IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications

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Electrical Systems

IEEE Color Books

GOLD BOOK IEEE Std 493-1997 IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems

BRONZE BOOK IEEE Std 739-1995 IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities

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Electrical Systems

NFPA HFPE and Society of Fire Protection Engineers SFPE Handbook of Fire Protection Engineering
NFPA 101H, Life Safety Code Handbook
NFPA 20, Centrifugal Fire Pumps
NFPA 70, National Electrical Code
NFPA 70B, Electrical Equipment Maintenance
NFPA 70E, Electrical Safety Requirements for Employee Workplaces
NFPA 72, National Fire Alarm Code
NFPA 75, Protection of Electronic Computer/Data Processing Equipment

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Electrical Systems

Difference between
- Code (Stand alone)
- Standard (Shall)
- Recommended Practice (Should)
- Guide (May)

Electrical Systems

System Planning.

a) Load development & schedule
    1) Peak load requirements
    2) Temporary power
    3) Timing
b) Load variations – load growth.

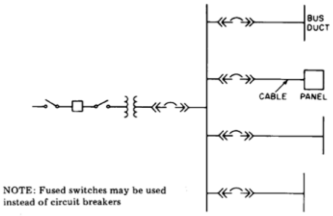
Electrical Systems

c) Nature of load in terms of its occurrence
  1) Continuous
  2) Intermittent
  3) Cyclical
  4) Special or unusual loads
  5) Combination of above
d) Expected power factor

Electrical Systems

Cost vs. Reliability
- Radial system
- Primary-selective system
 Secondary selective system
- Simple spot network system
- Secondary-network system

Electrical Systems



NOTE: Fused switches may be used instead of circuit breakers

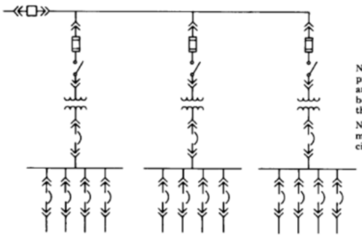
Figure 2-1—Simple radial system

Electrical Systems

Simple Radial System

- Fault in device = power outage
- Maintenance difficult
 Operation simple
Low capital cost
Larger installations where outage time not critical

Electrical Systems



NOTE: If non-draw-out primary fused switches are used, the fuse should be on the load side of the switch.

NOTE: Fused switches may be used instead of circuit breakers.

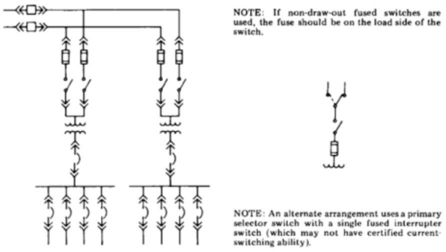
Figure 2-2—Expanded radial system

Electrical Systems

Expanded Radial System –

Fault in main feed = power outage
Fault in xfmr = reduced outage
- Maintenance difficult
 Operation simple
Low capital cost

Electrical Systems



NOTE: If non-draw-out fused switches are used, the fuse should be on the load side of the switch.

NOTE: An alternate arrangement uses a primary selector switch with a single fused interrupter switch (which may not have certified current-switching ability).

Figure 2-3—Primary selective system

Electrical Systems

Primary Selective System –

-Protection against loss of primary feed
-Still Xfmr Dependent
-Primary source Maintenance easier
-Slightly higher capital cost

Electrical Systems

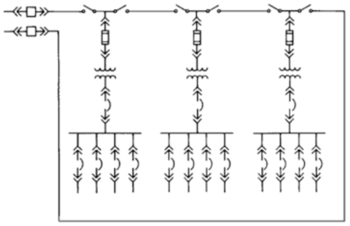
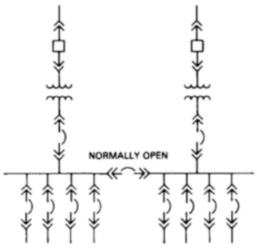


Figure 2-4—Primary loop system

Electrical Systems

Protection against loss of primary feed
Still Xfmr Dependent
Slightly higher capital cost
Operation slightly more difficult
Open loop operation
More reliable with loop closed and directional protection but two devices to isolate fault

Electrical Systems

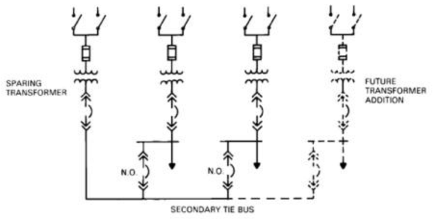


(a) Secondary selective system

Electrical Systems

Protection against loss of primary feed and primary xfmr
Maintenance of xfmr
Higher capital cost
Operation more difficult
Size xfmr & breaker for full load

Electrical Systems



(b) Sparing transformer scheme

Electrical Systems

Similar to secondary selective system
Xfmr sized for only one bus
N+1 transformer needed
Operation difficult – interlock so xfmr only feed one bus at a time
Possible retrofit

Electrical Systems

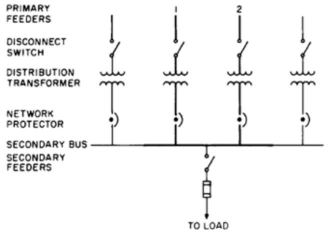


Figure 2-6—Secondary spot network

Electrical Systems

Requires Network Projector
Trip on reverse power
High reliability
High cost

Electrical Systems

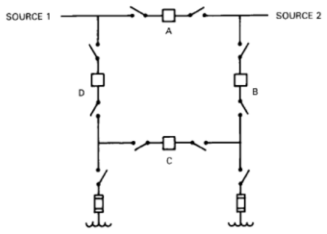


Figure 2-7—Ring bus system

Electrical Systems

Two devices to isolate fault
Trip on reverse power
High reliability
Higher cost

Electrical Systems

Expected daily and annual load factor:

$$\text{Daily} \quad \frac{\text{kWh for 24 h/24 h}}{\text{peak kW during the 24 h}} = \frac{\text{avg. kW}}{\text{peak kW}}$$

$$\text{Annual} \quad \frac{\text{kWh for 8670 h/8670 h}}{\text{peak kW during the 8670 h}} = \frac{\text{avg. kW}}{\text{peak kW}}$$

Electrical Systems

Large motor-starting requirements
- 1) HP, FLA, LRA
- 2) synchronous - induction
- 3) Voltage
- 4) Starting requirements

Special or unusual loads such as
- 1) Welding
- 2) Induction heating or melting
- 3) Portable (Crane)

Electrical Systems

Harmonic-generating loads
- 1) VFDs
- 2) Arc discharge lighting
- 3) Arc furnaces
- 4) SCR controlled loads

Special power quality requirements for sensitive or critical loads
- 1) Data processing operations
- 2) Special machines (Semiconductor process)
- 3) Continuous process loads

Electrical Systems

To be continued …

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**End of Session 6:
Electrical Systems**

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