Medium Voltage Switchgear & Circuit Breaker Ratings and Application

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Aramco

How Circuit Breakers Work Seminar

IEEE

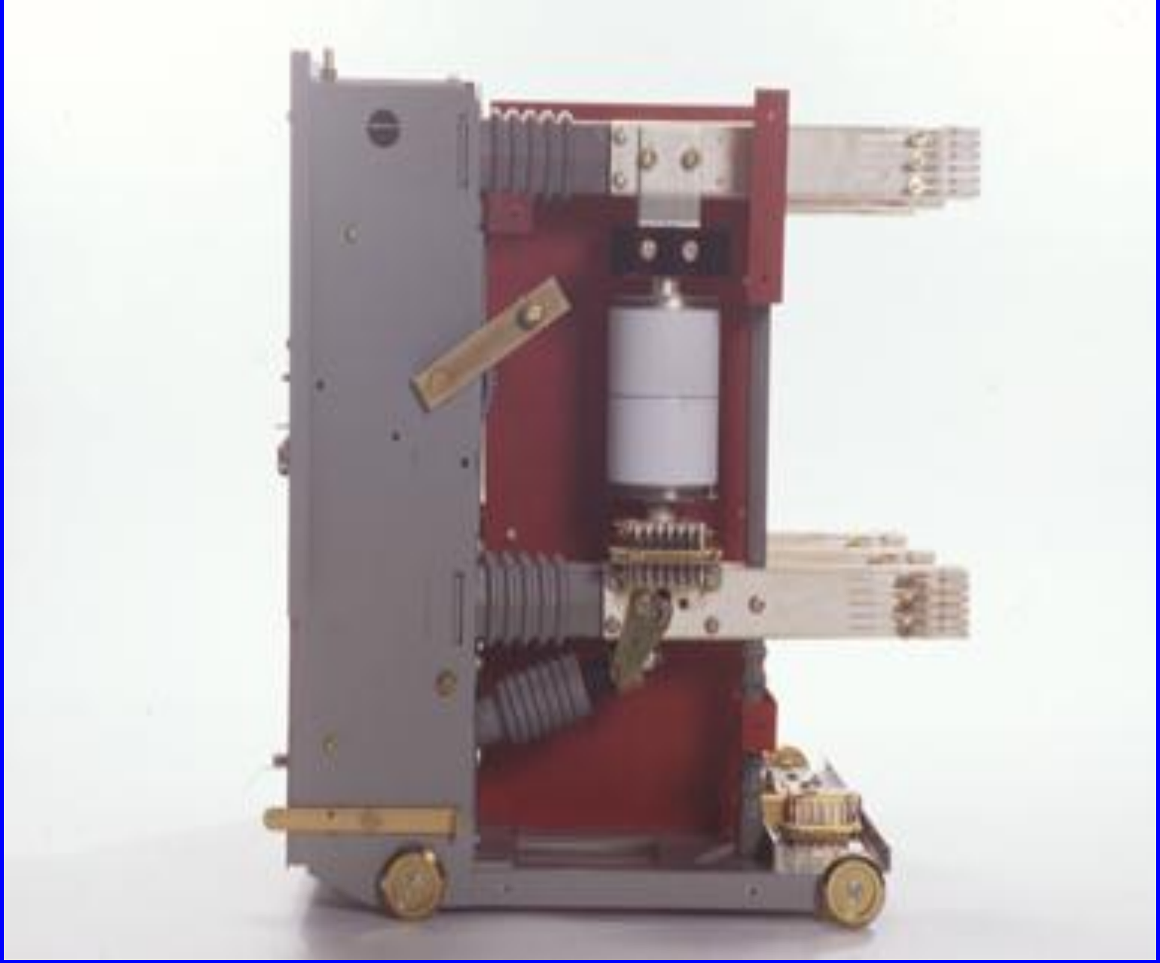
continuing education

by Jim Bowen

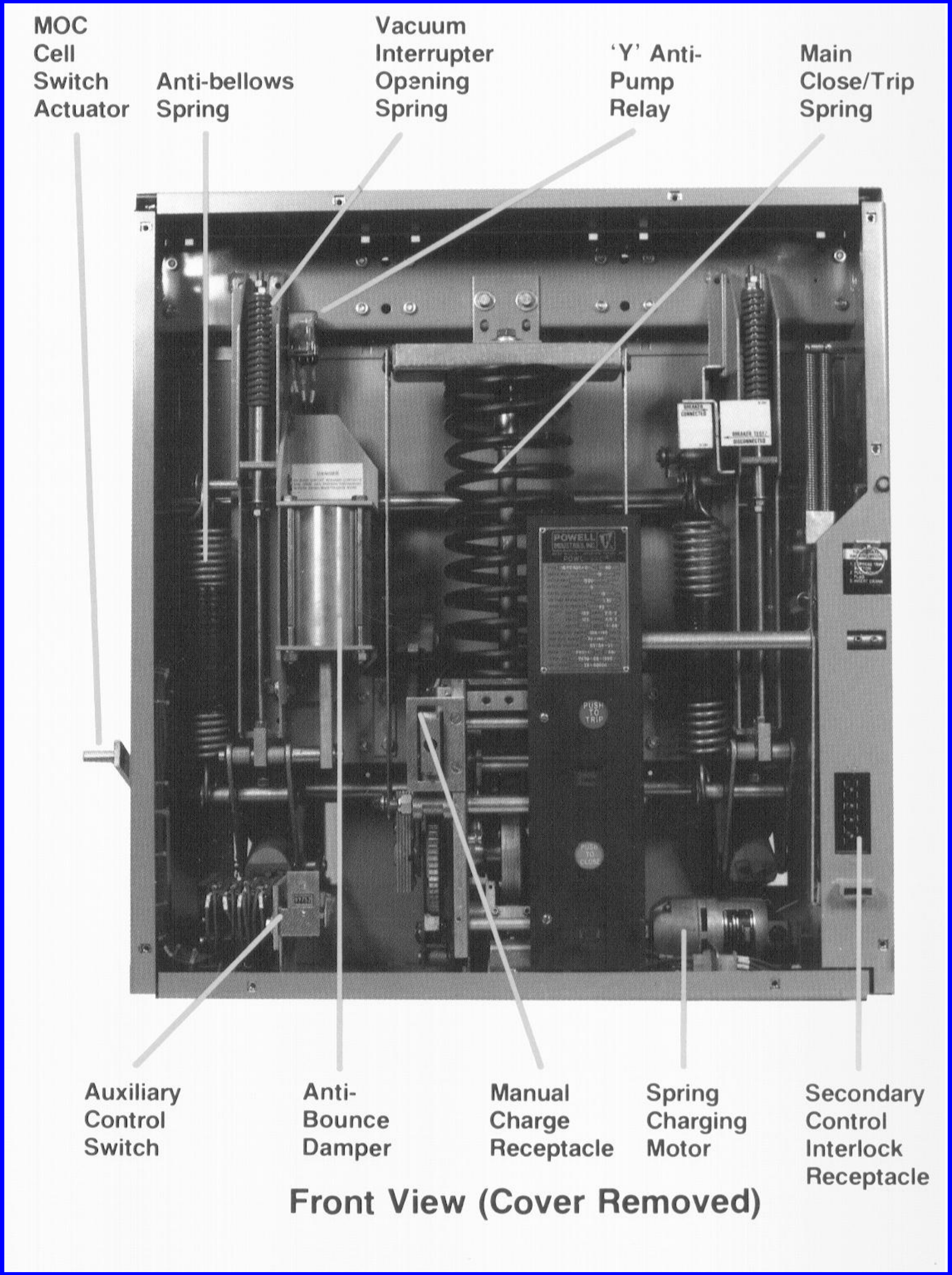
Aramco

Circuit Breaker Parts

- Current Path & Insulators
- Interrupter
- Push Rod
- Mechanism



Circuit Breaker Mechanism



Front View (Cover Removed)

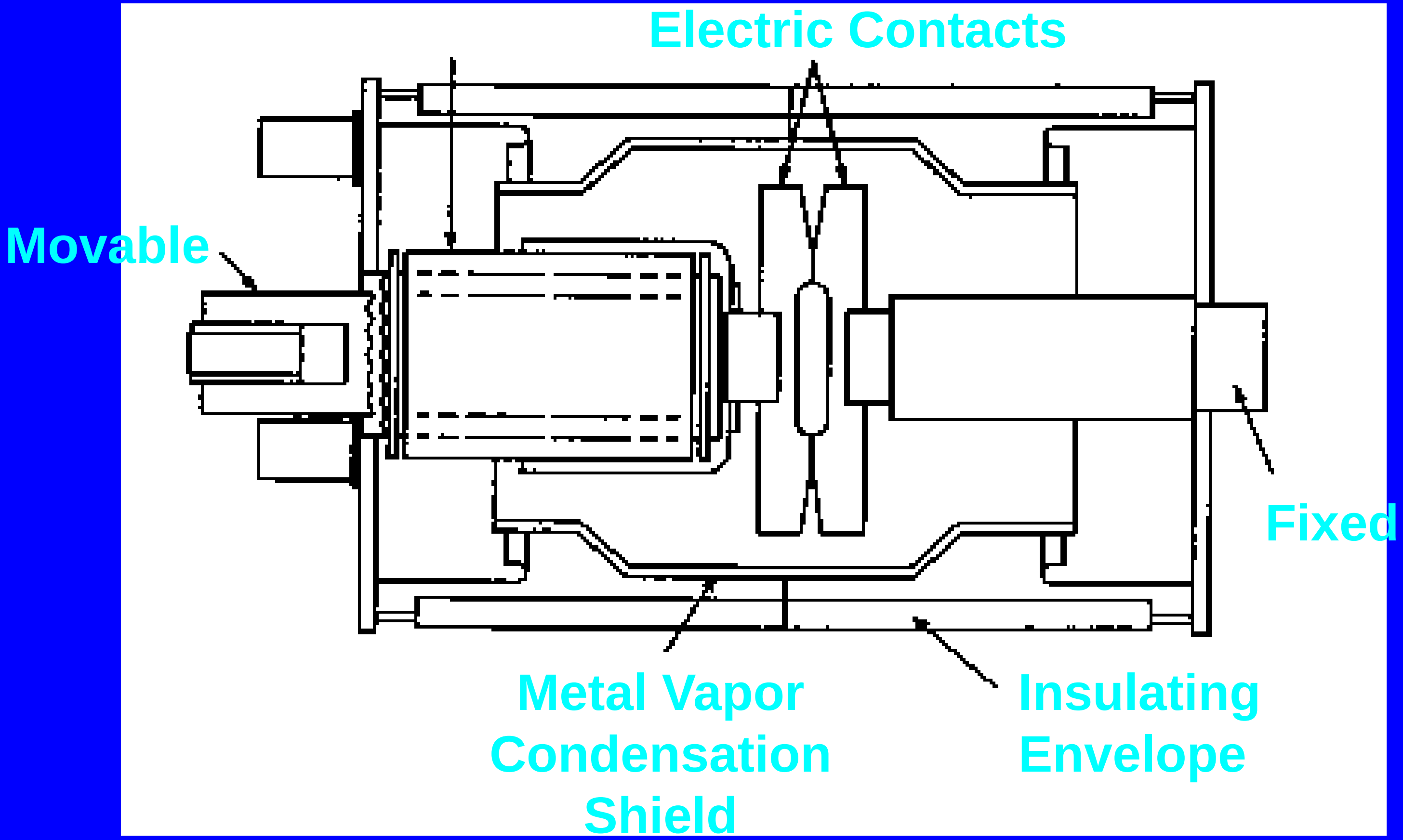
Circuit Breaker Technology

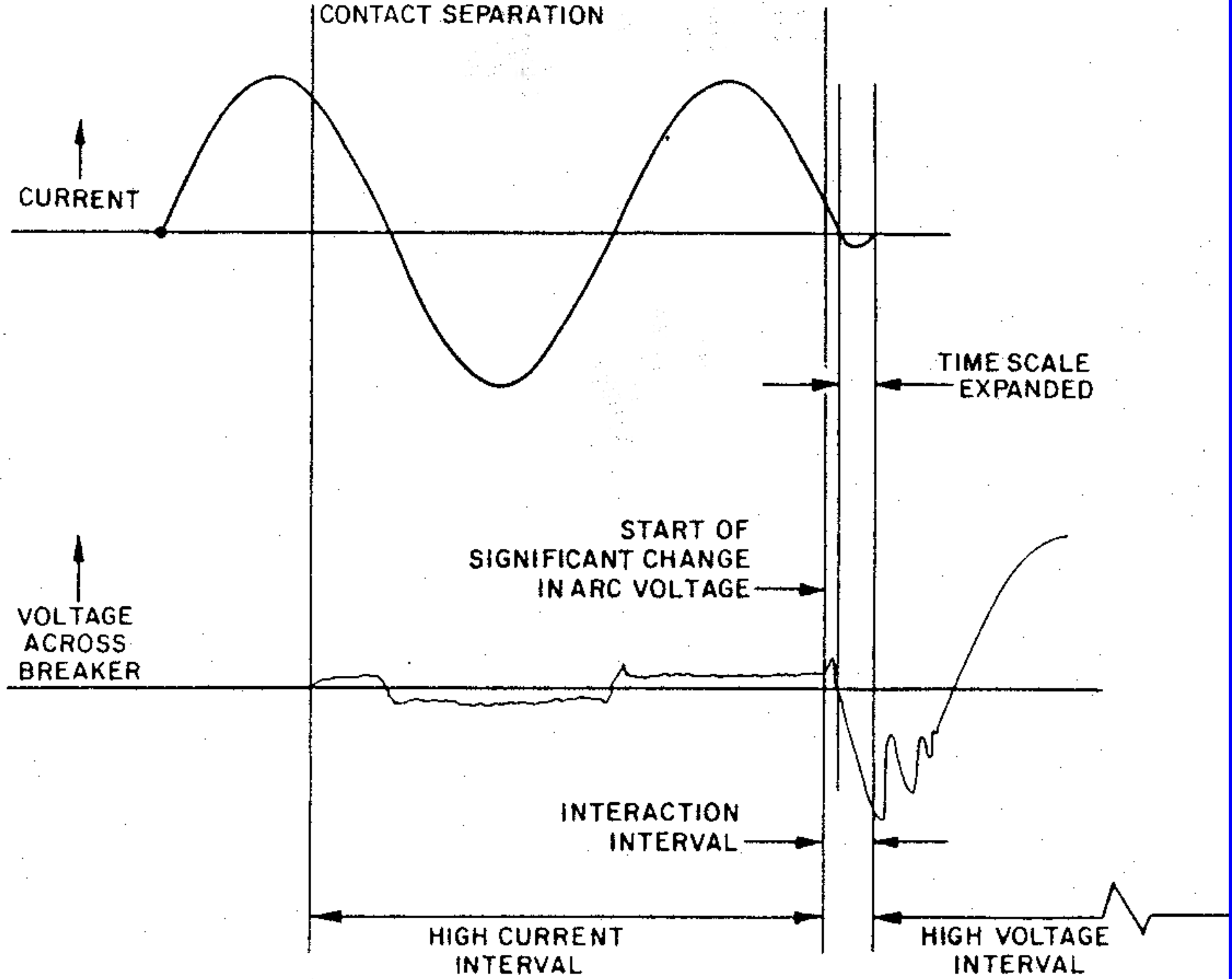
- Vacuum: *480 Vac -- 38 kV.*
- SF6: *69kV & above in ANSI.*
- Bulk Oil: *5 kV & above (obsolete)*
- Air Magnetic: *600 Vac & below.*
- Solid state: *active current limiter 15kV <*

Vacuum Circuit Breakers

- Arc forms between the main contacts
- Arc plasma is controlled by the geometry to maintain a diffused arc column
- Interruption of current flow occurs at zero crossing
- Dielectric build up of contact gap exceeds pole to pole voltages

Vacuum Interrupter Design For High Voltage



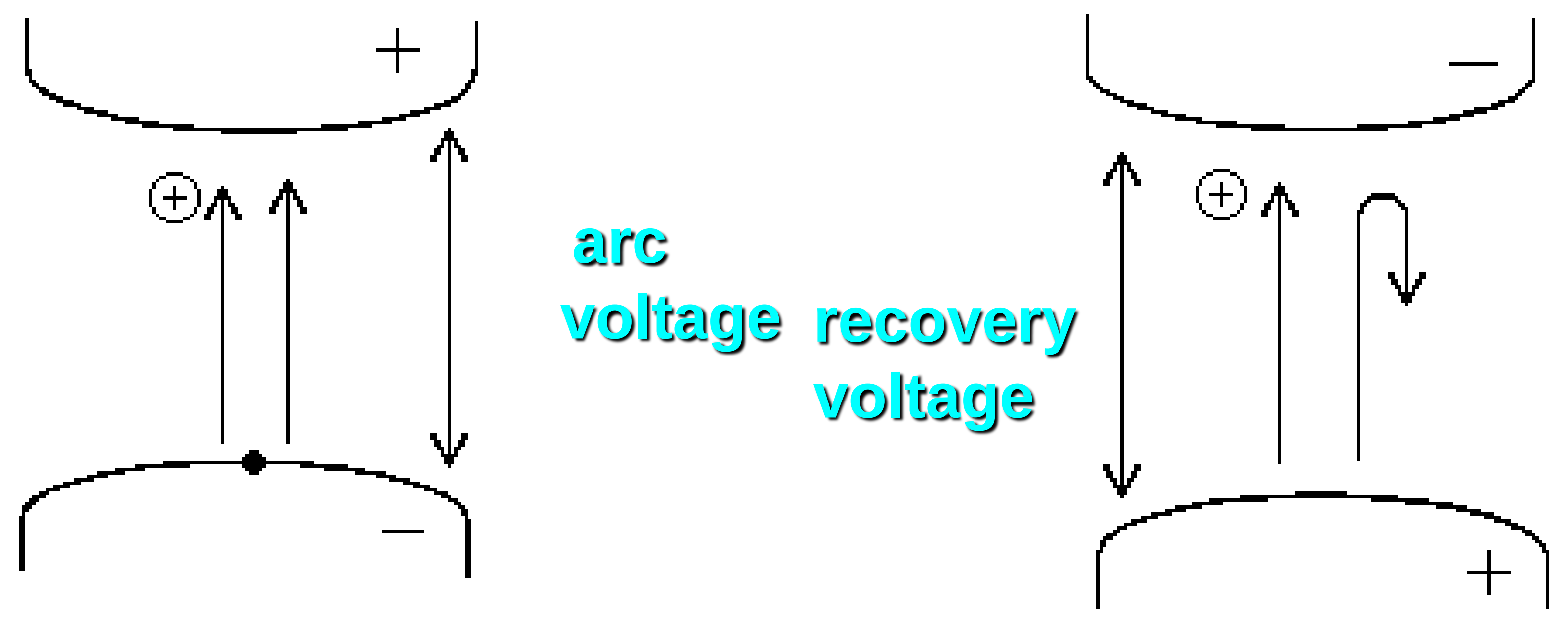

CONTACT SEPARATION
CURRENT
TIME SCALE EXPANDED
START OF SIGNIFICANT CHANGE IN ARC VOLTAGE
VOLTAGE ACROSS BREAKER
INTERACTION INTERVAL
HIGH CURRENT INTERVAL
HIGH VOLTAGE INTERVAL

Arcing in a VI

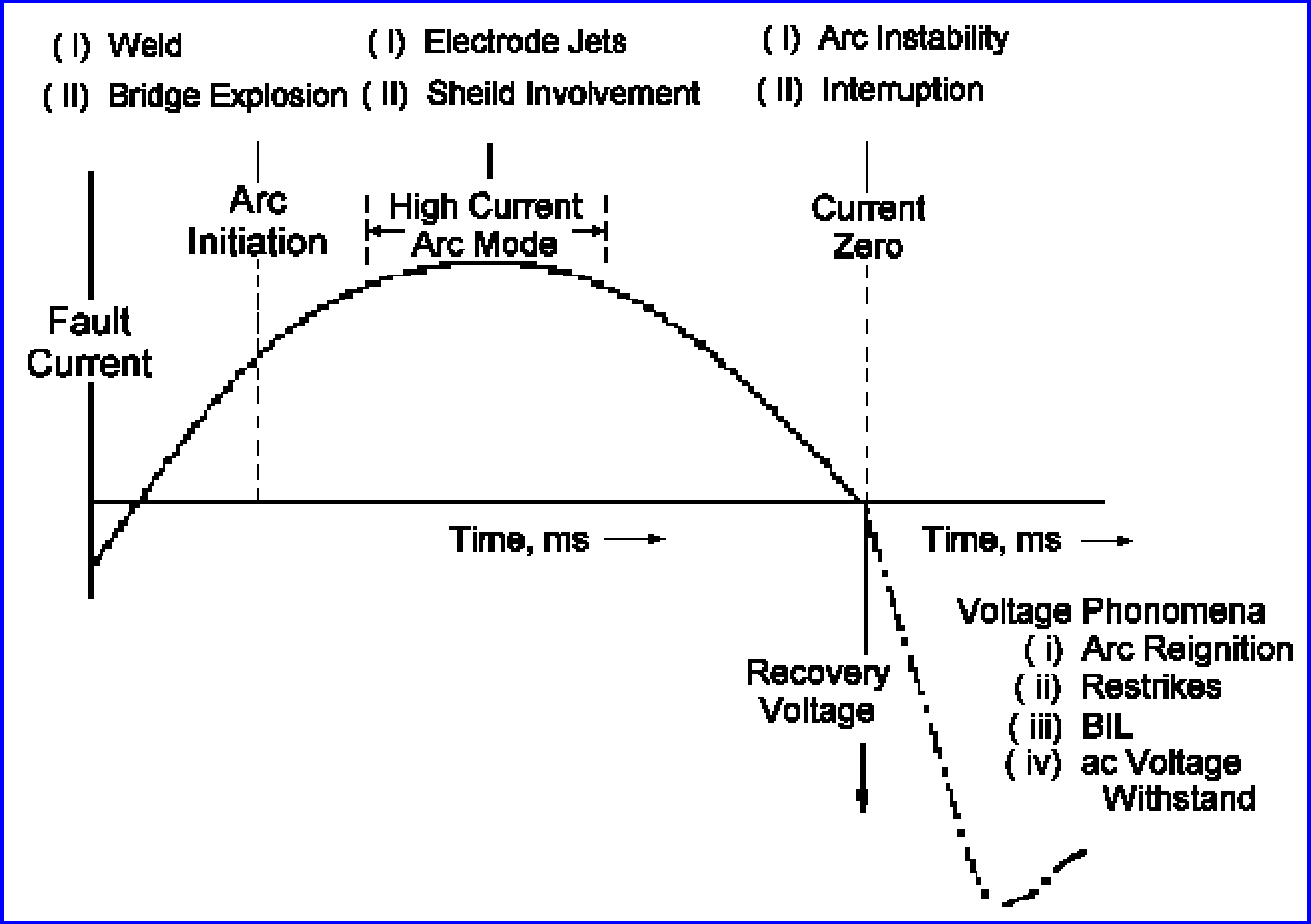
Current Interruption at Ion Level

JUST BEFORE I=0

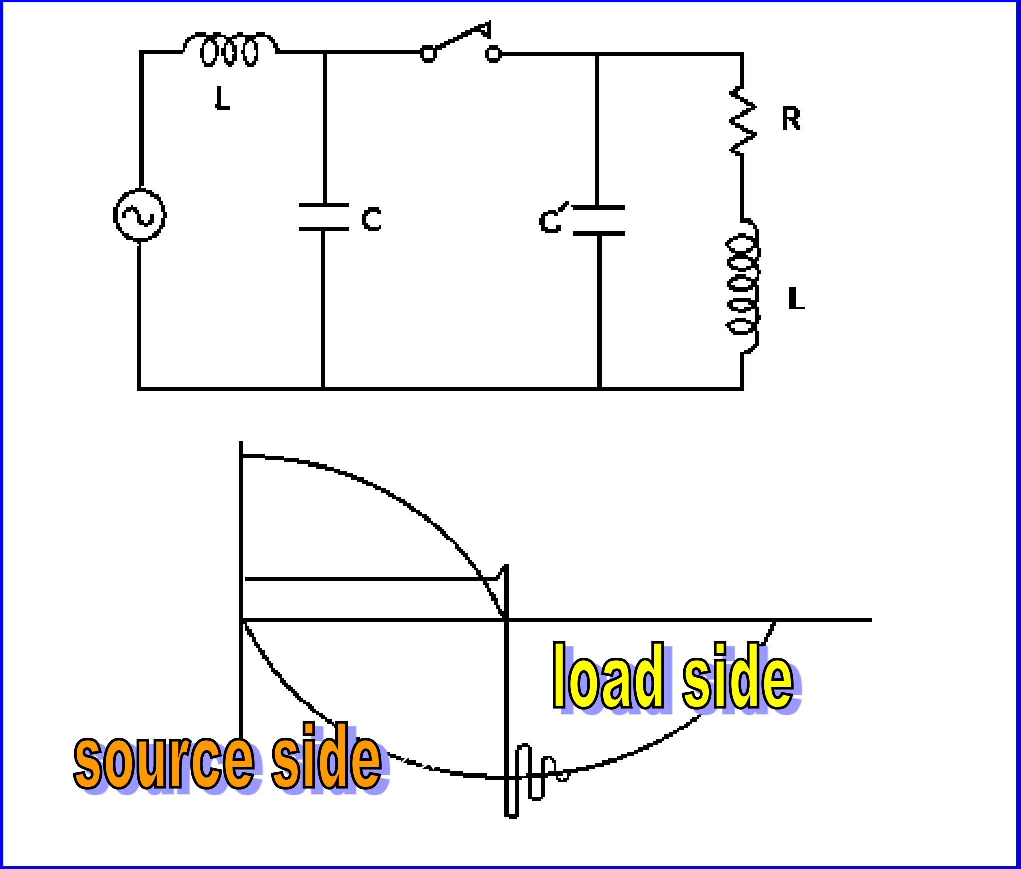
JUST AFTER I=0

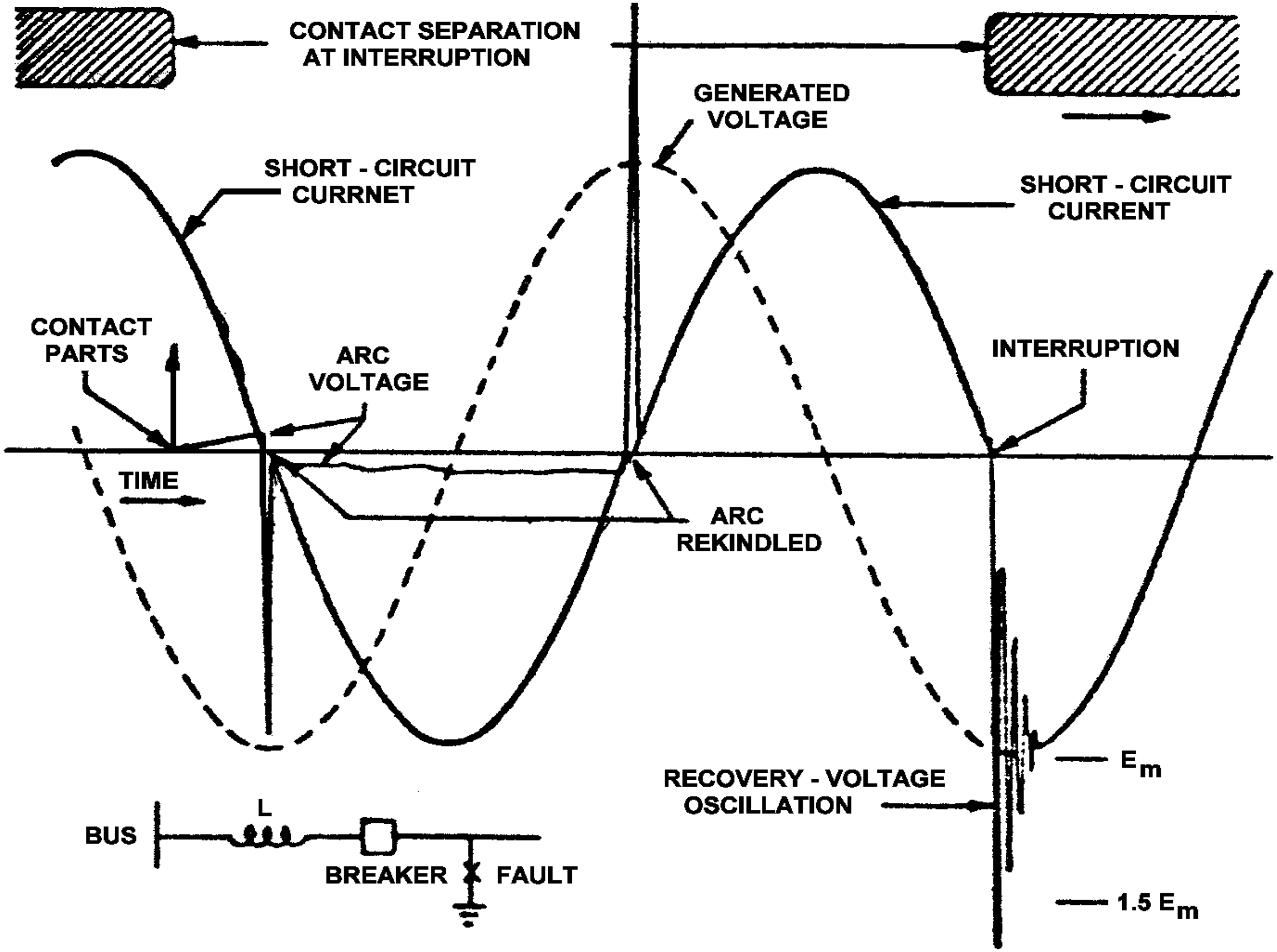


Ac arcing and interruption phenomena in vacuum

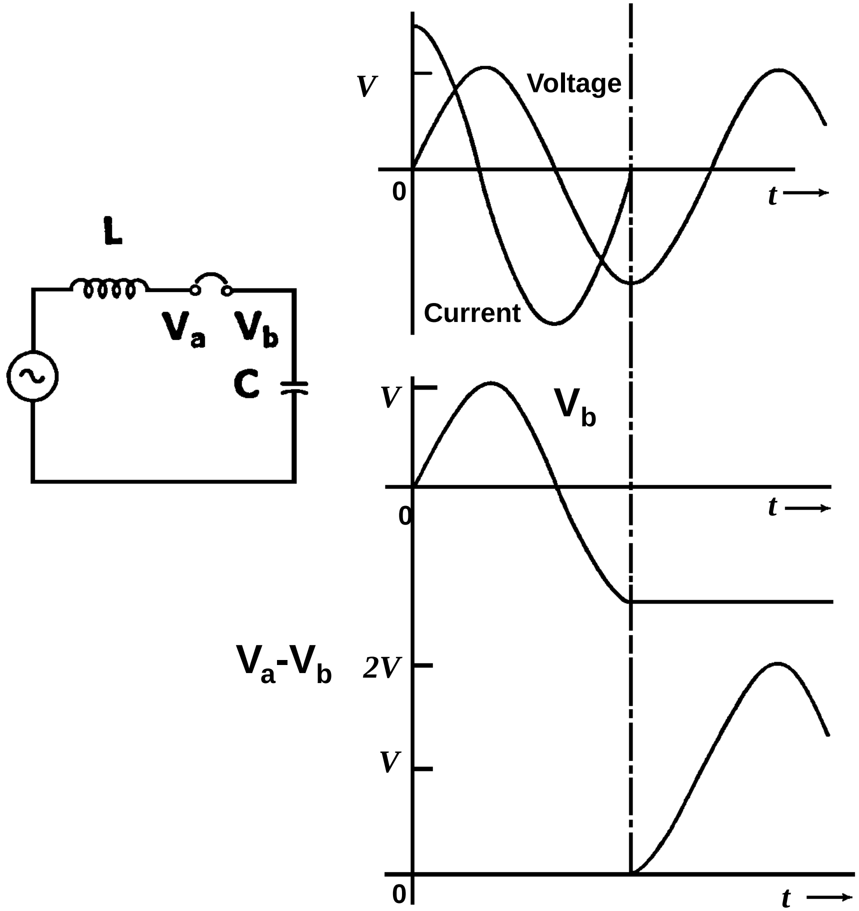


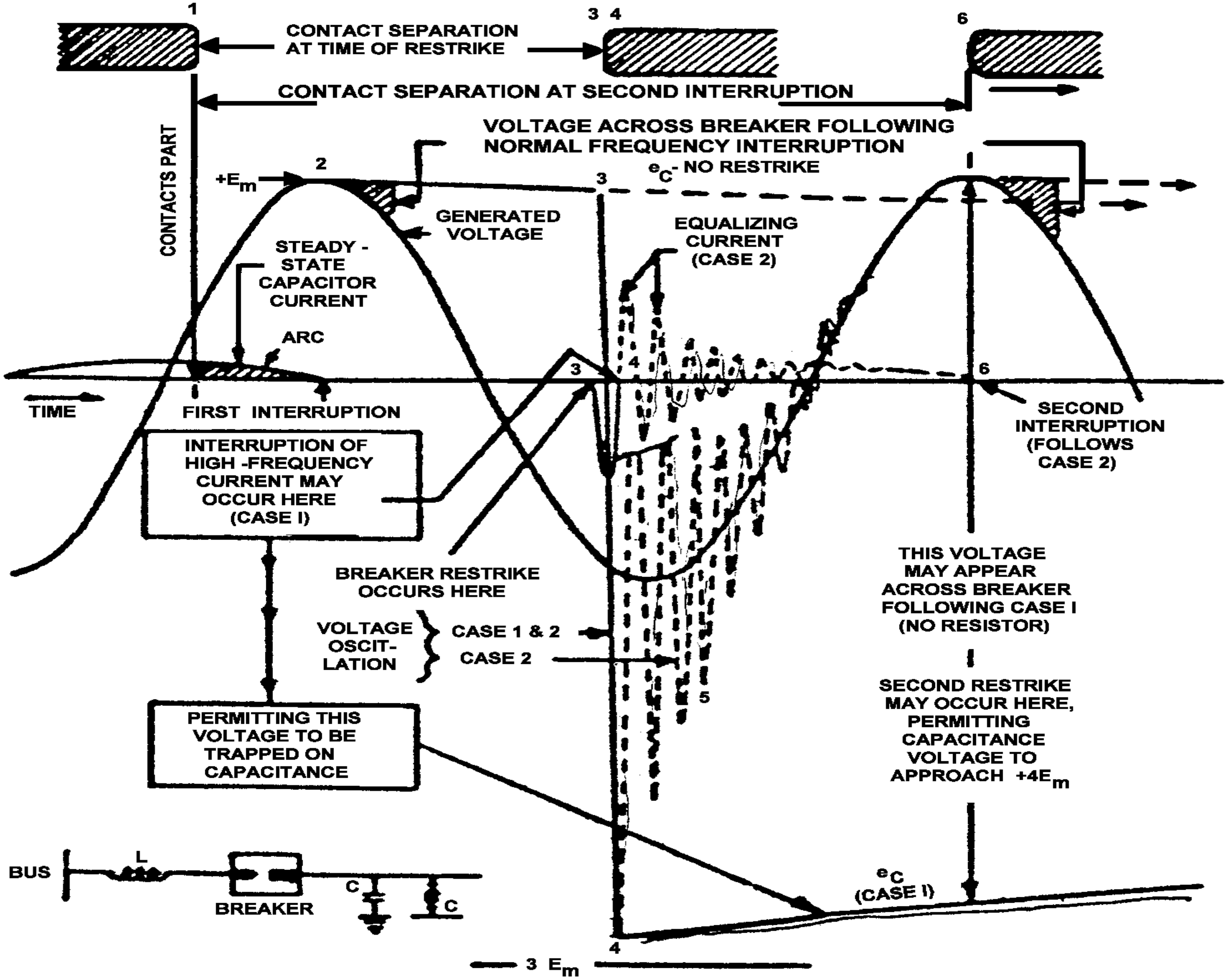
AC Circuit



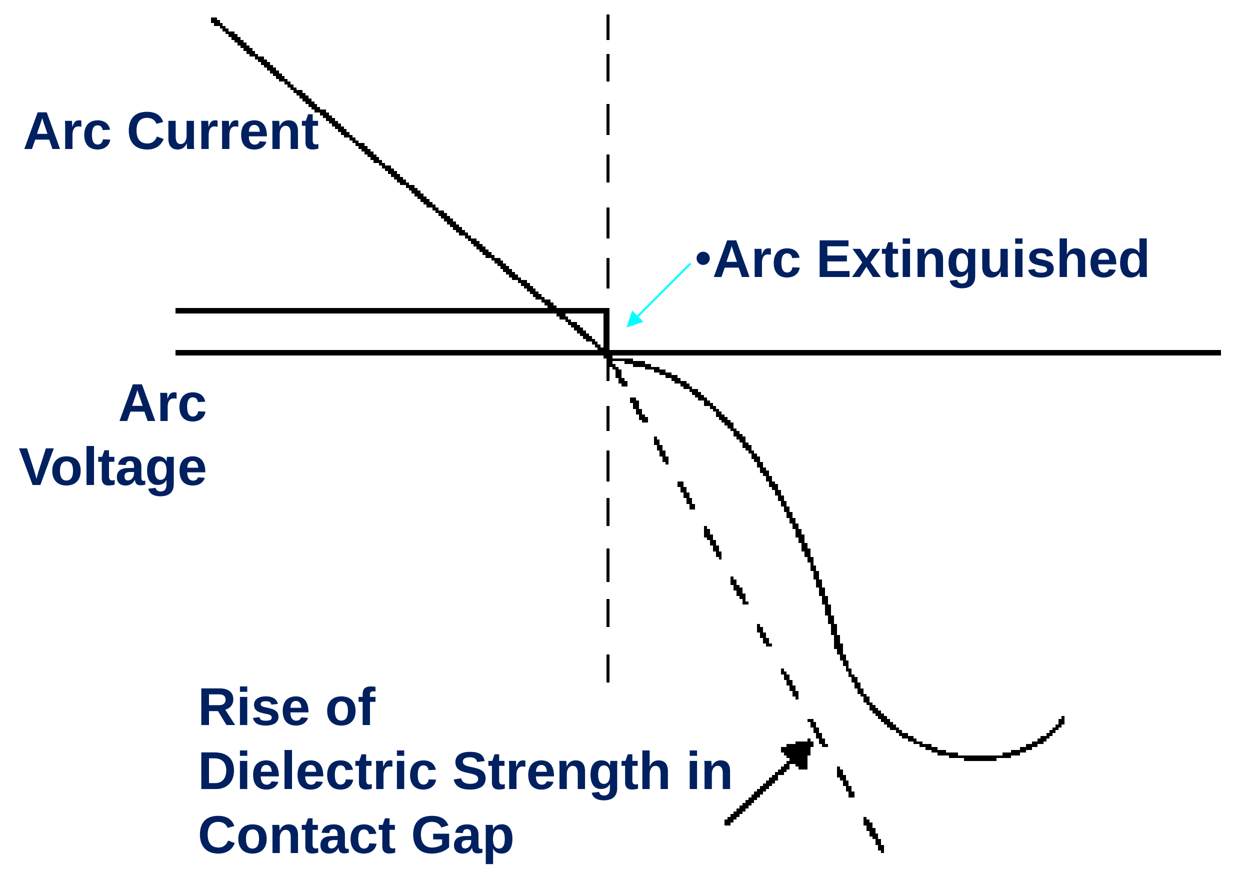

CONTACT SEPARATION
AT INTERRUPTION
GENERATED
VOLTAGE
SHORT - CIRCUIT
CURRNET
SHORT - CIRCUIT
CURRENT
CONTACT
PARTS
ARC
VOLTAGE
INTERRUPTION
TIME
ARC
REKINDLED
RECOVERY - VOLTAGE
OSCILLATION
E_m
$1.5\ E_m$
BUS
L
BREAKER
FAULT

Interrupting A Capacitive Circuit




1
CONTACT SEPARATION
AT TIME OF RESTRIKE
3 4
6
CONTACT SEPARATION AT SECOND INTERRUPTION
CONTACTS PART
VOLTAGE ACROSS BREAKER FOLLOWING
NORMAL FREQUENCY INTERRUPTION
e_C- NO RESTRIKE
2
$+E_m$
3
GENERATED
VOLTAGE
STEADY -
STATE
CAPACITOR
CURRENT
EQUALIZING
CURRENT
(CASE 2)
ARC
3
4
6
TIME
FIRST INTERRUPTION
SECOND
INTERRUPTION
(FOLLOWS
CASE 2)
INTERRUPTION OF
HIGH -FREQUENCY
CURRENT MAY
OCCUR HERE
(CASE I)
BREAKER RESTRIKE
OCCURS HERE
THIS VOLTAGE
MAY APPEAR
ACROSS BREAKER
FOLLOWING CASE I
(NO RESISTOR)
VOLTAGE
OSCIT-
LATION
CASE 1 & 2
CASE 2
5
SECOND RESTRIKE
MAY OCCUR HERE,
PERMITTING
CAPACITANCE
VOLTAGE TO
APPROACH $+4E_m$
PERMITTING THIS
VOLTAGE TO BE
TRAPPED ON
CAPACITANCE
BUS
L
BREAKER
C
C
e_C
(CASE I)
4
3 E_m

Short Circuit Interruption - Success



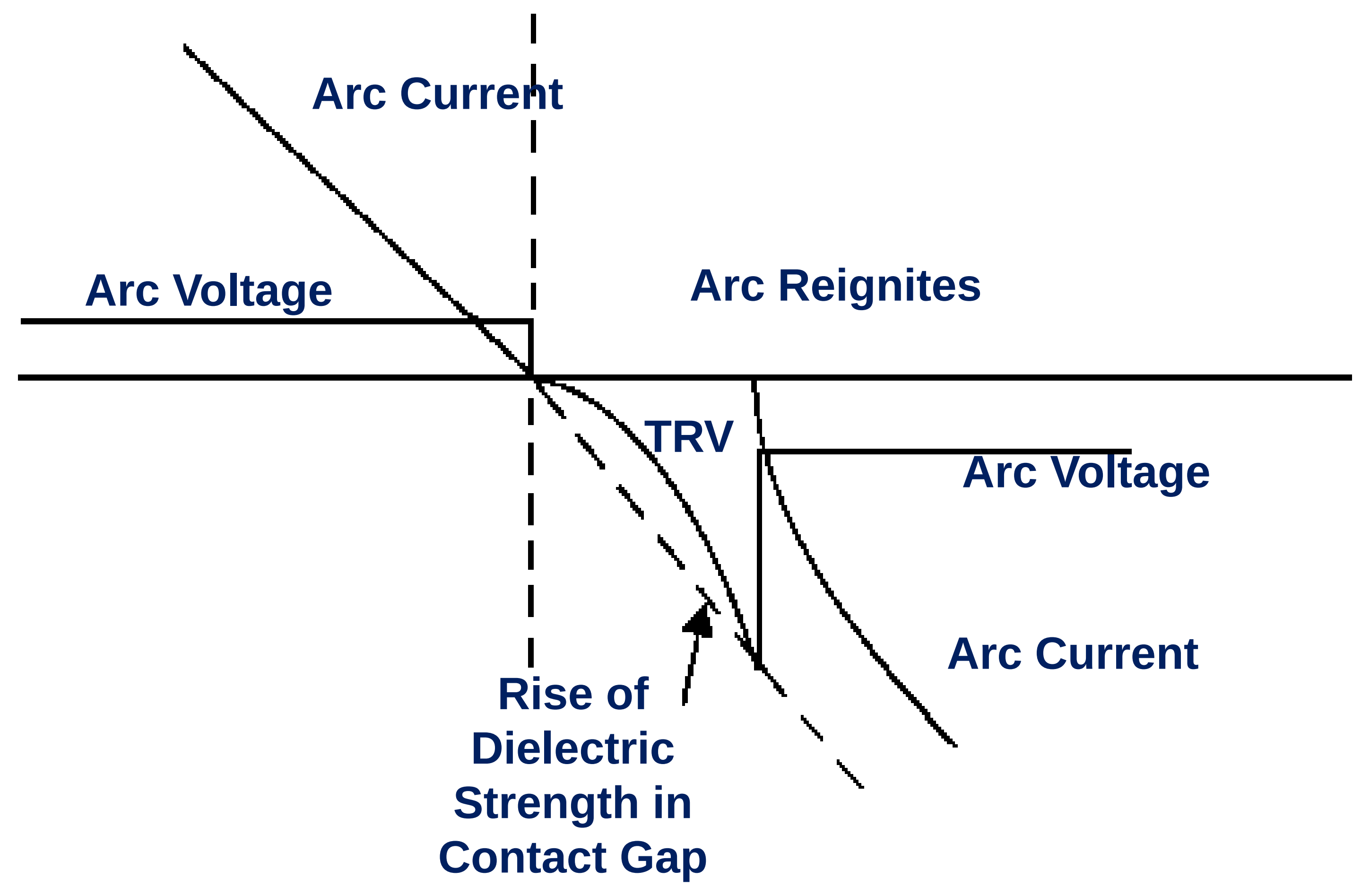
Arc Current

- Arc Extinguished

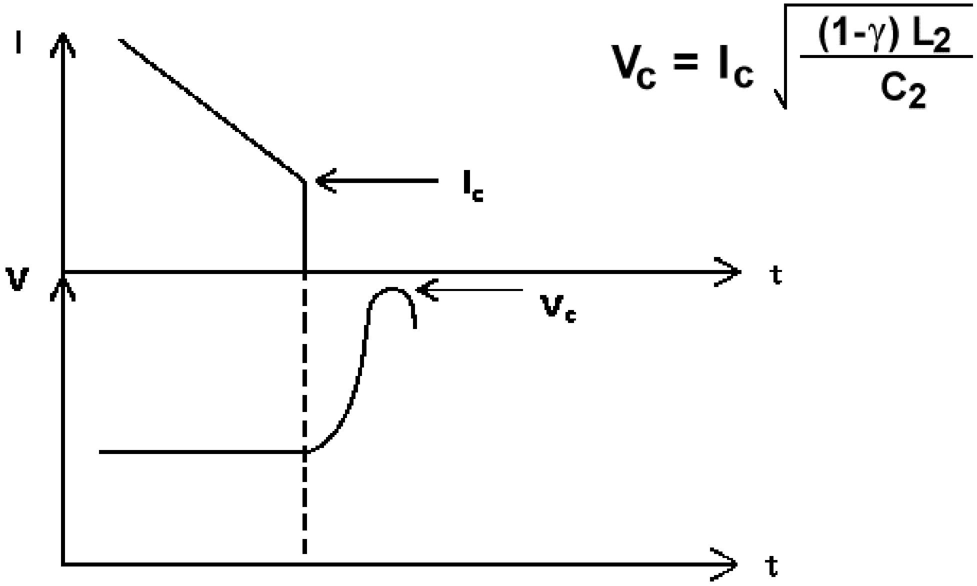
Arc Voltage

Rise of Dielectric Strength in Contact Gap

Short Circuit Interruption Dielectric Failure (RESTRIKES)

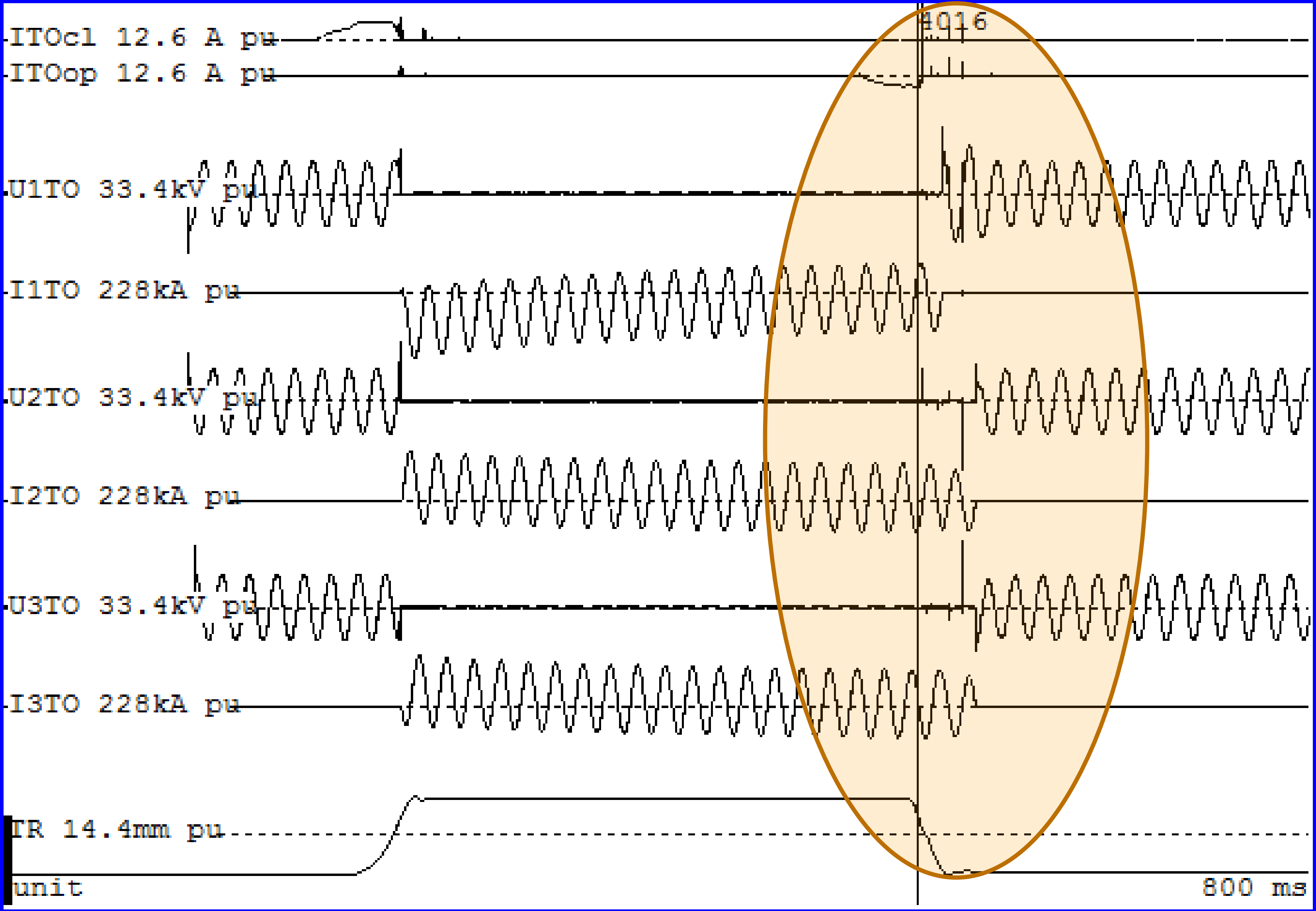


Current Chop

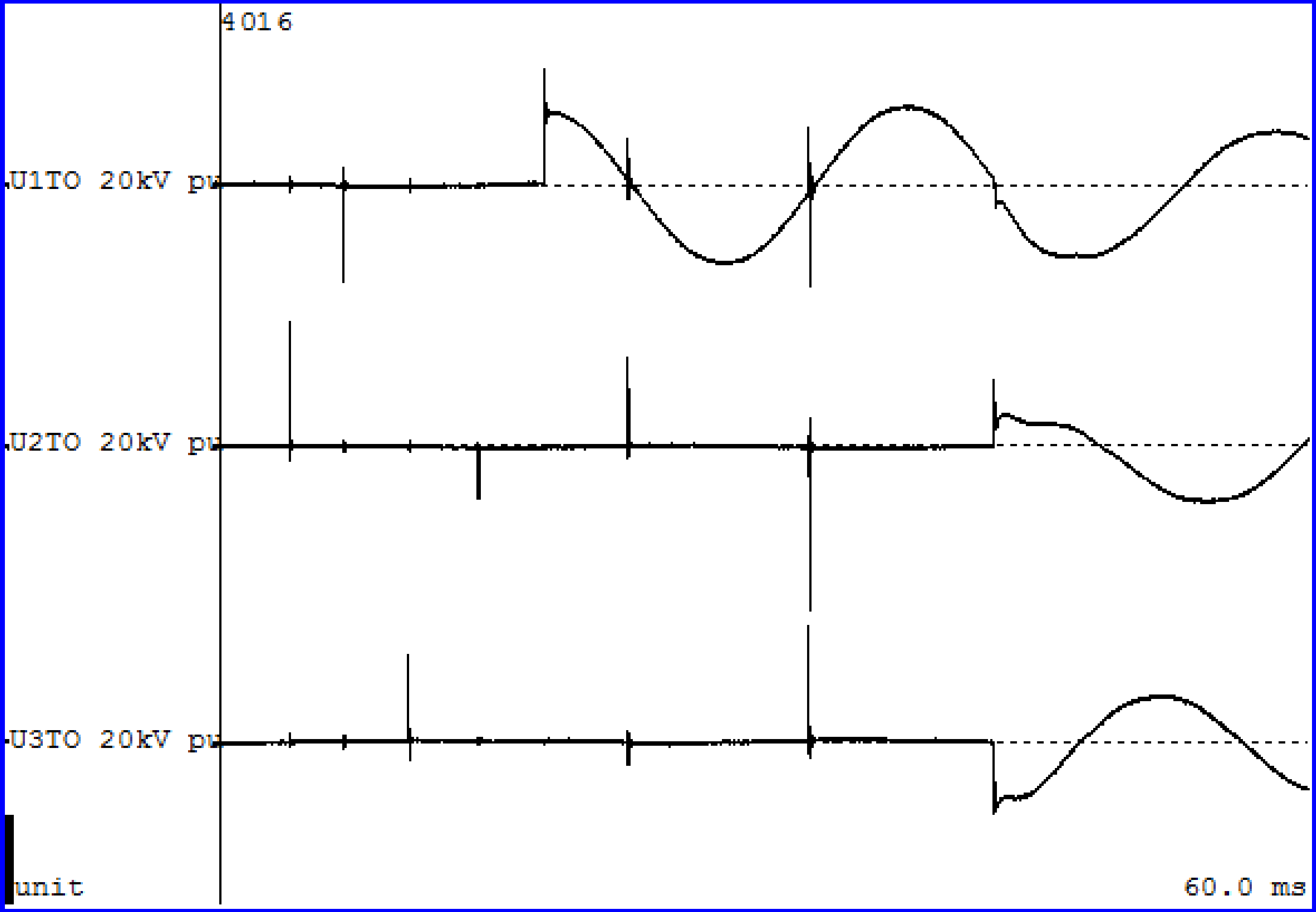


$$V_C = I_C \sqrt{\frac{(1-\gamma)\, L_2}{C_2}}$$

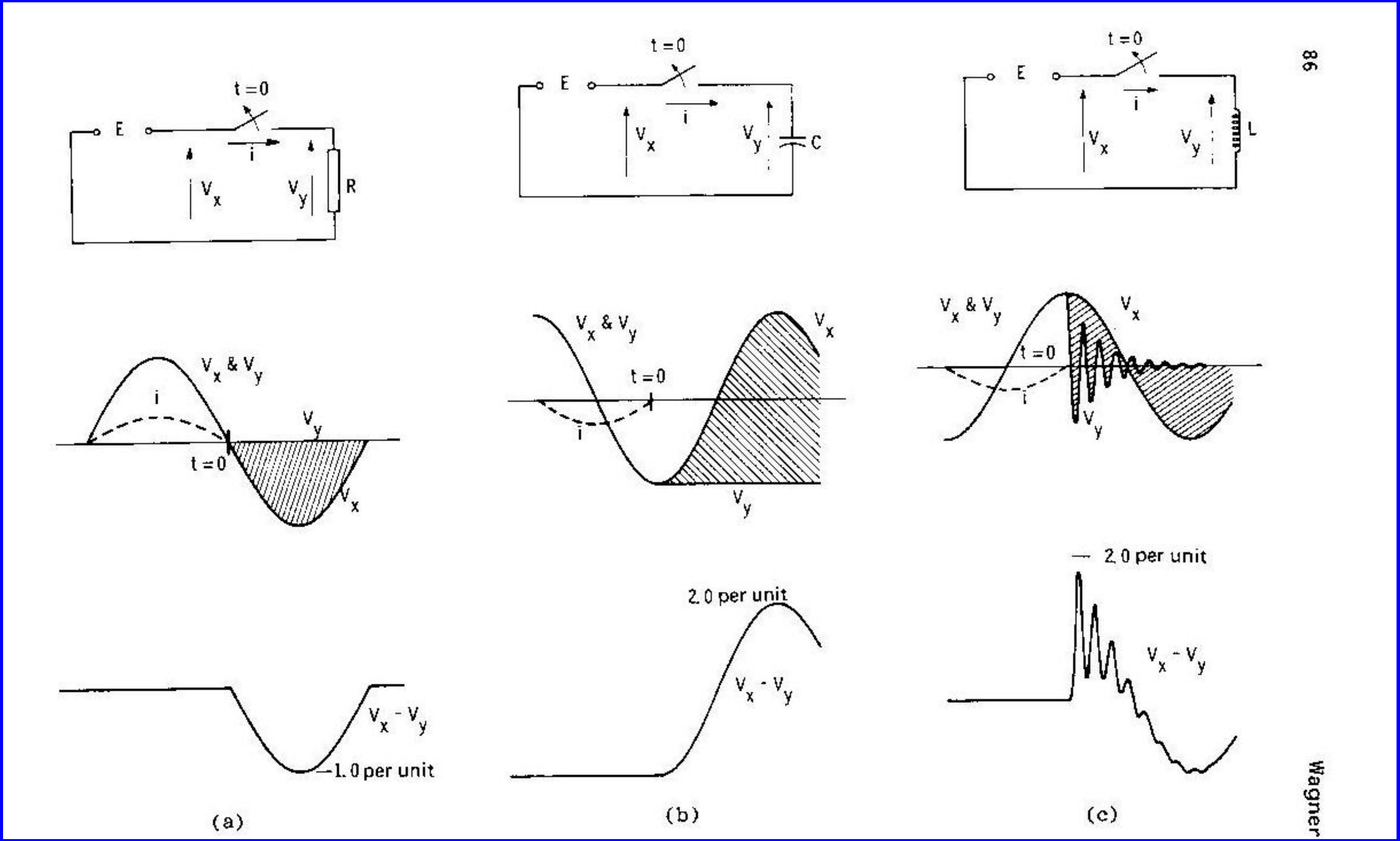
Restrikes at zero crossings



Restrikes



Various Circuit TRV’s



Wagner

Circuit Breaker Ratings

PowlVac Breaker Type	Max Voltage (kV)	Interrupting Symmetrical (kA rms) Note (1)	Obsolete MVA Class	Continuous Current (A)	Cubicle width (In.)	Power Frequency Withstand (kV)	BIL crest (kV)	Close and Latch (10cycle) Momentary (kA, crest)	%DC Interrupting Current (%)	Rated Interrupting Time (3) (cycle/msec)	Short Time Current (3 sec.)	Back to Back Cap Switching (Amps) (4)
05PV36SND	4.76	36	250	1200, 2000	26	19	60	97	50	3 / 50	36	
05PV36STD	↓	36	250	1200, 2000, 3000, 4000(2)	36	↓	↓	97	↓	↓	36	
05PV50SND	↓	50	350	1200, 2000	26	↓	↓	135	↓	↓	50	
05PV50STD	↓	50	350	1200, 2000, 3000, 4000(2)	36	↓	↓	135	↓	↓	50	
05PV63STD	↓	63	500	1200, 2000, 3000, 4000(2)	36	↓	↓	170	↓	↓	63	1640
15PV25STD	15	25	500	1200, 2000, 3000, 4000(2)	36	36	95	67	50	3 / 50	25	1640
15PV36STD	↓	36	750	1200, 2000, 3000, 4000(2)	↓	↓	↓	97	↓	↓	36	1640
15PV50STD	↓	50	1200	1200, 2000, 3000, 4000(2)	↓	↓	↓	135	↓	↓	50	1640
15PV63STD	↓	63	1500	1200, 2000, 3000, 4000(2)	↓	↓	↓	170	↓	↓	63	1640

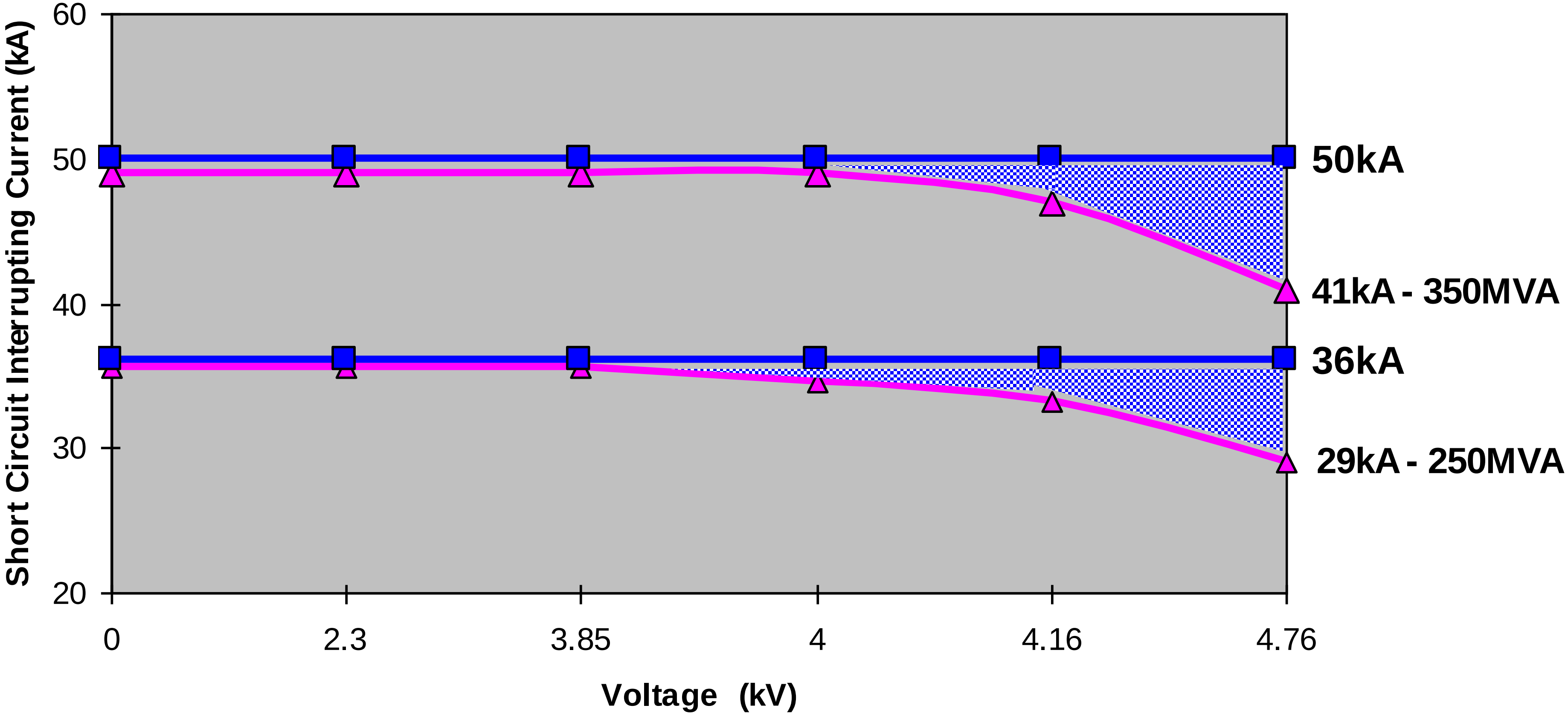
Notes:

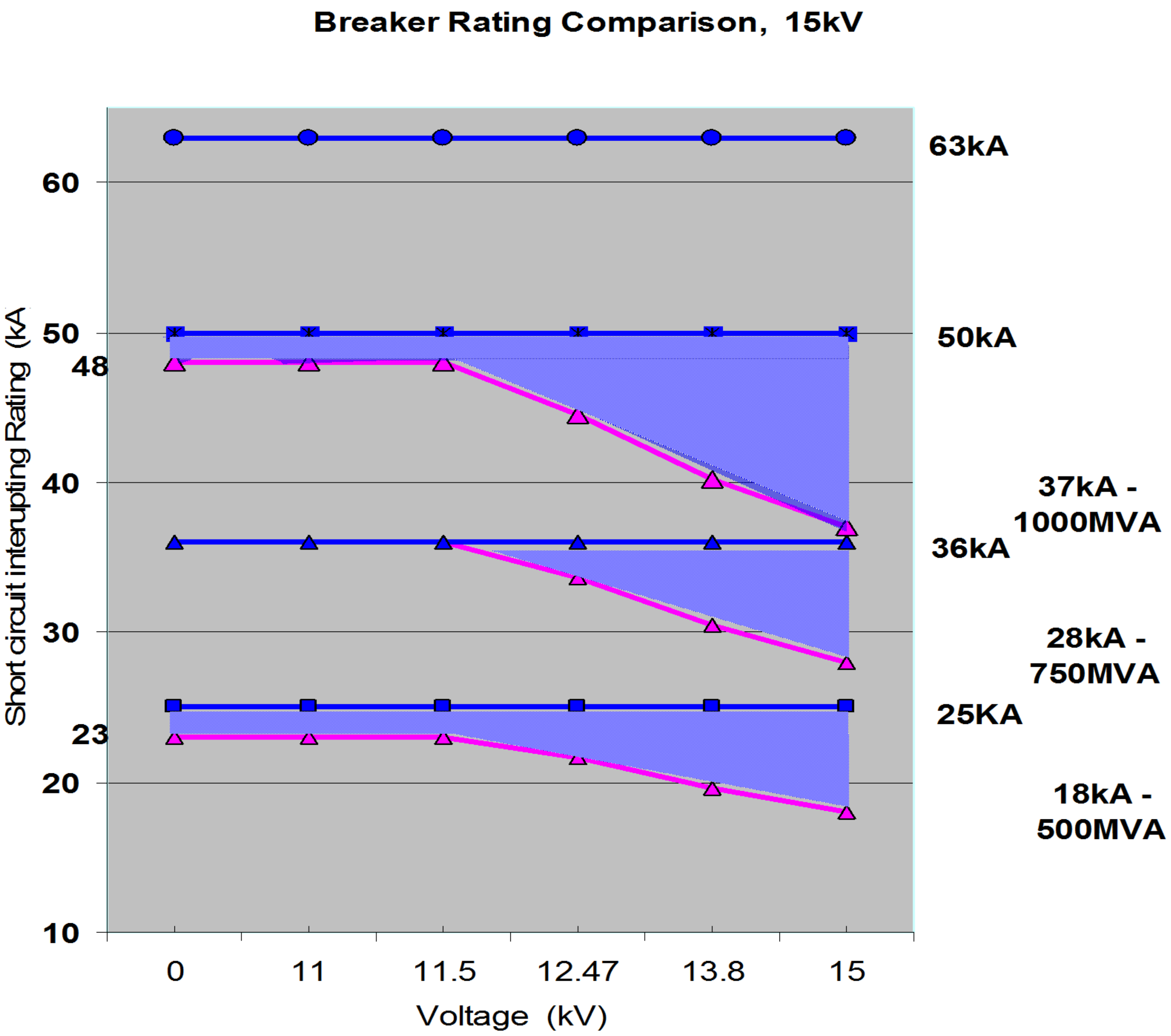
(1) Interrupting current constant for all voltages less than the maximum voltage. Rated voltage range factor k=1.
(2) Forced Air Cooling fans required for current in excess of 3000 amps.
(3) 5 cycle breakers available at the same %dc ratings
(4) Back to back capacitor switching rating is good for 1200, 2000, 3000, and 4000 continuous current ratings.
(5) Maximum tripping delay is 2 seconds for all circuit breaker as per the ANSI standards.

Breaker Comparison, 5kV

Purple Lines -- Old Ratings

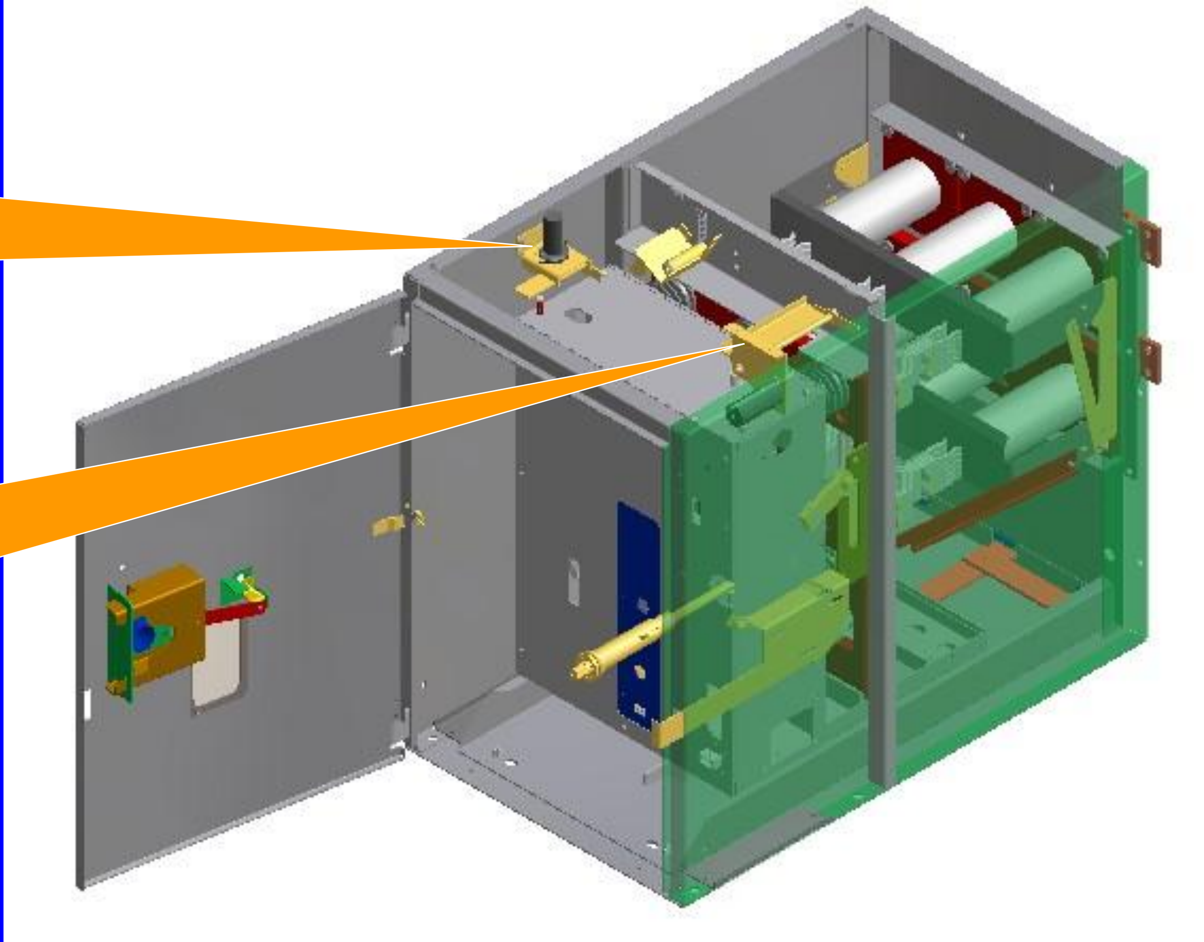
Blue Lines -- New Ratings




Breaker Rating Comparison, 15kV
63kA
50kA
37kA - 1000MVA
36kA
28kA - 750MVA
25KA
18kA - 500MVA
60
50
48
40
30
23
20
10
Short circuit interupting Rating (kA)
0
11
11.5
12.47
13.8
15
Voltage (kV)

Medium Voltage Switchgear

Breaker Compartment



TOC
(Truck
Operated
Contacts)

MOC
(Mech
Operated
Contacts)

Metal - Clad Barriers

- Compartment for each main switching device
- Separate compartment for feeder and incoming power
- Internal main bus compartment barrier
- Shutters

Metal - Clad Safety Interlocking

- Prevent racking in/out of a closed breaker
- Prevent closing during the racking operation
- Control circuit completed before closing in the operating position

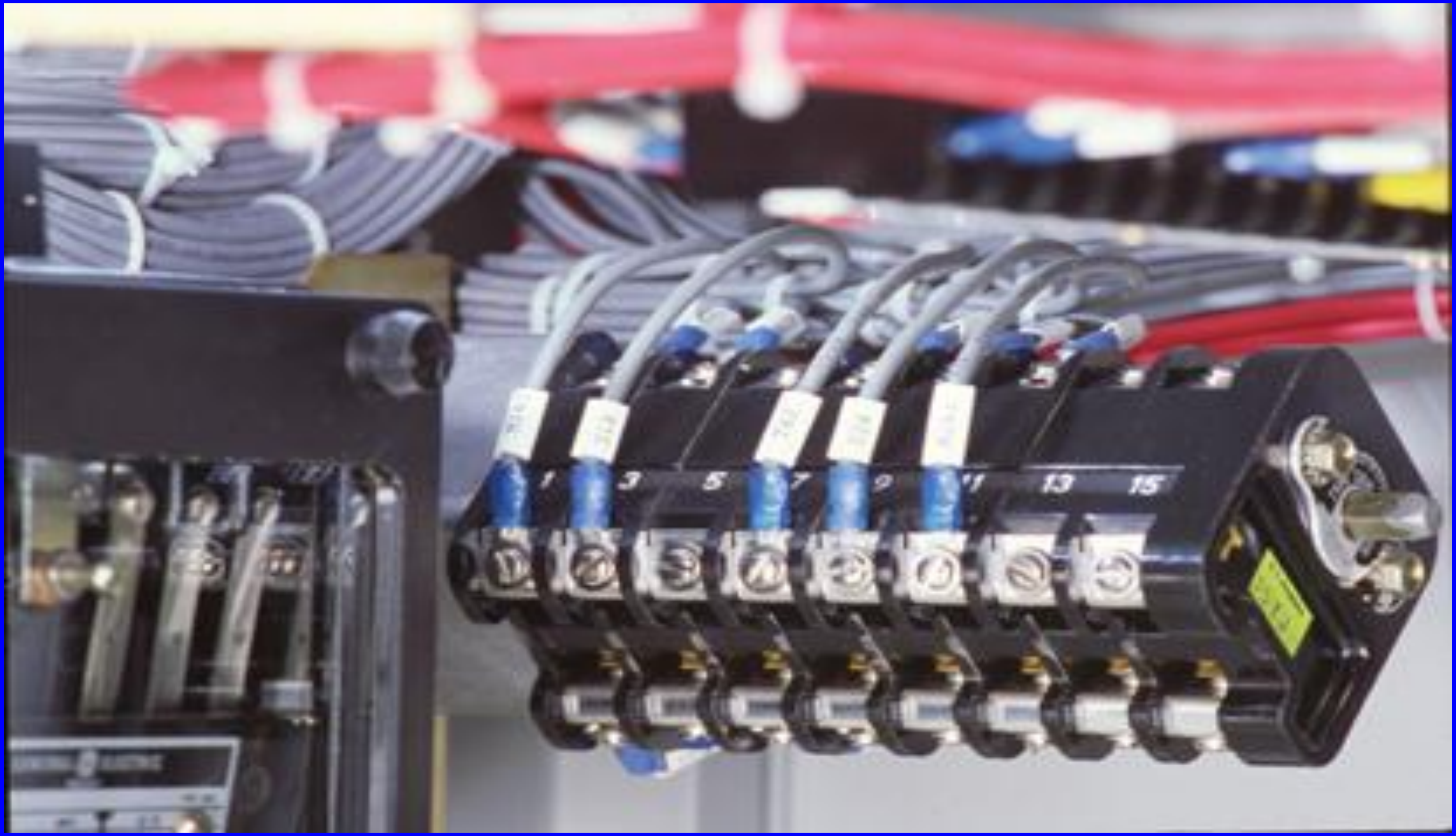
Metal - Clad Safety Interlocking (Cont)

- Hold breaker in place in all positions
- Prevent disconnecting CPT primary fuses unless secondary circuit open
- locking means for lock and tagout
- Prevent release of stored energy to close breaker unless fully charged

Switchgear

- Ground Bus
- Shutters
- Lockout means
- Breaker rating interference
- Current transformer

Mechanism Operated Cell (MOC) switch changes state as breaker opens and closes.



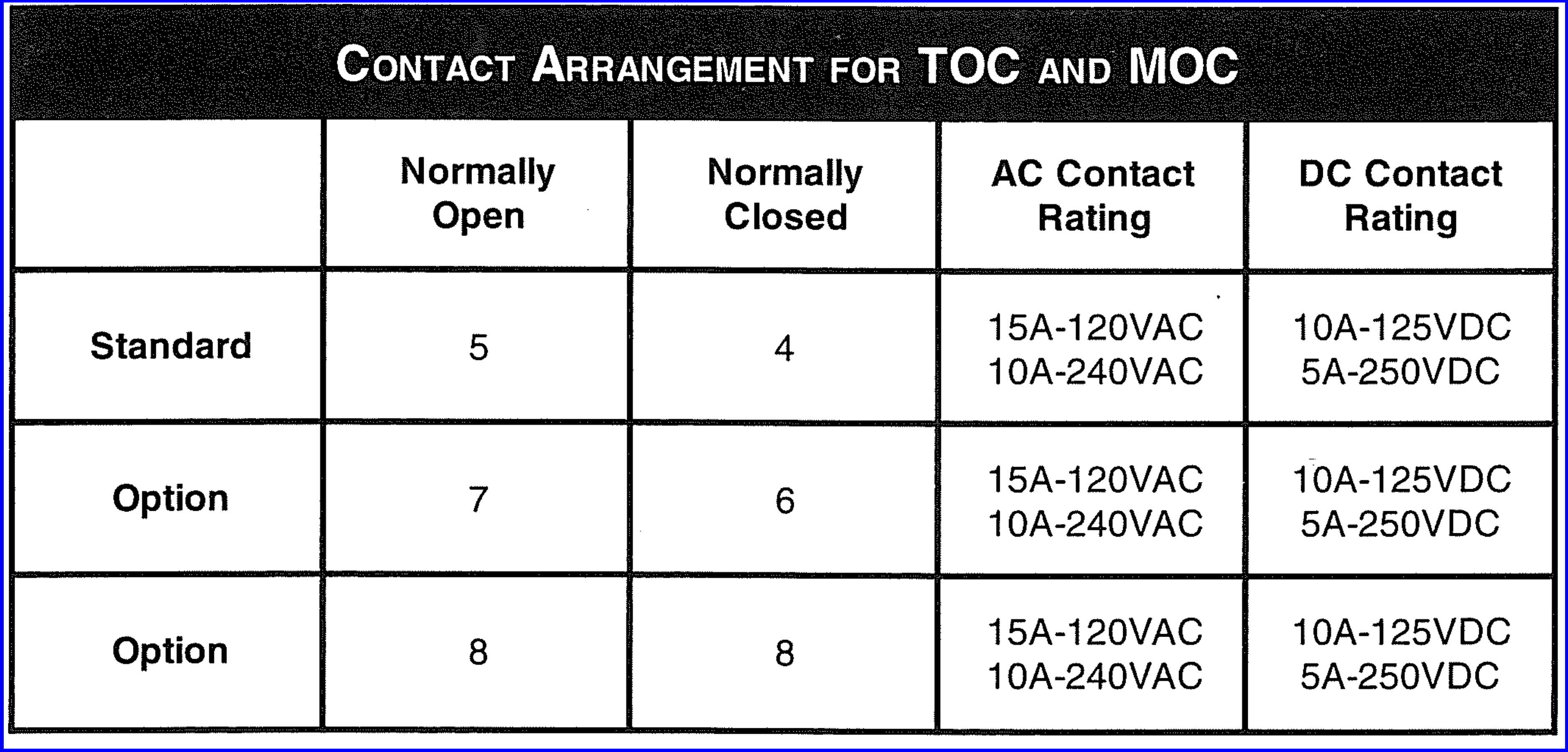
One or two voltage transformer roll-out assemblies will fit in the same space as one circuit breaker.

When withdrawn the roll-out assembly positively grounds the primary fuses.

Truck Operated Cell (TOC)

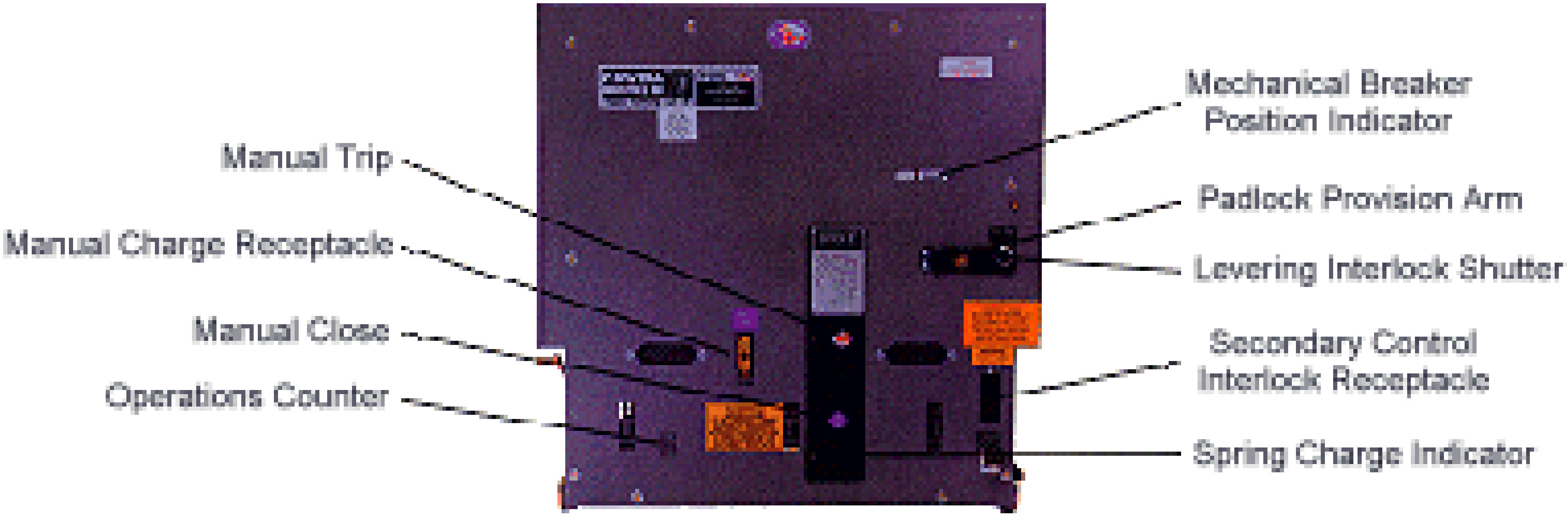
Switch changes state with movement of the breaker in and out of the cell.

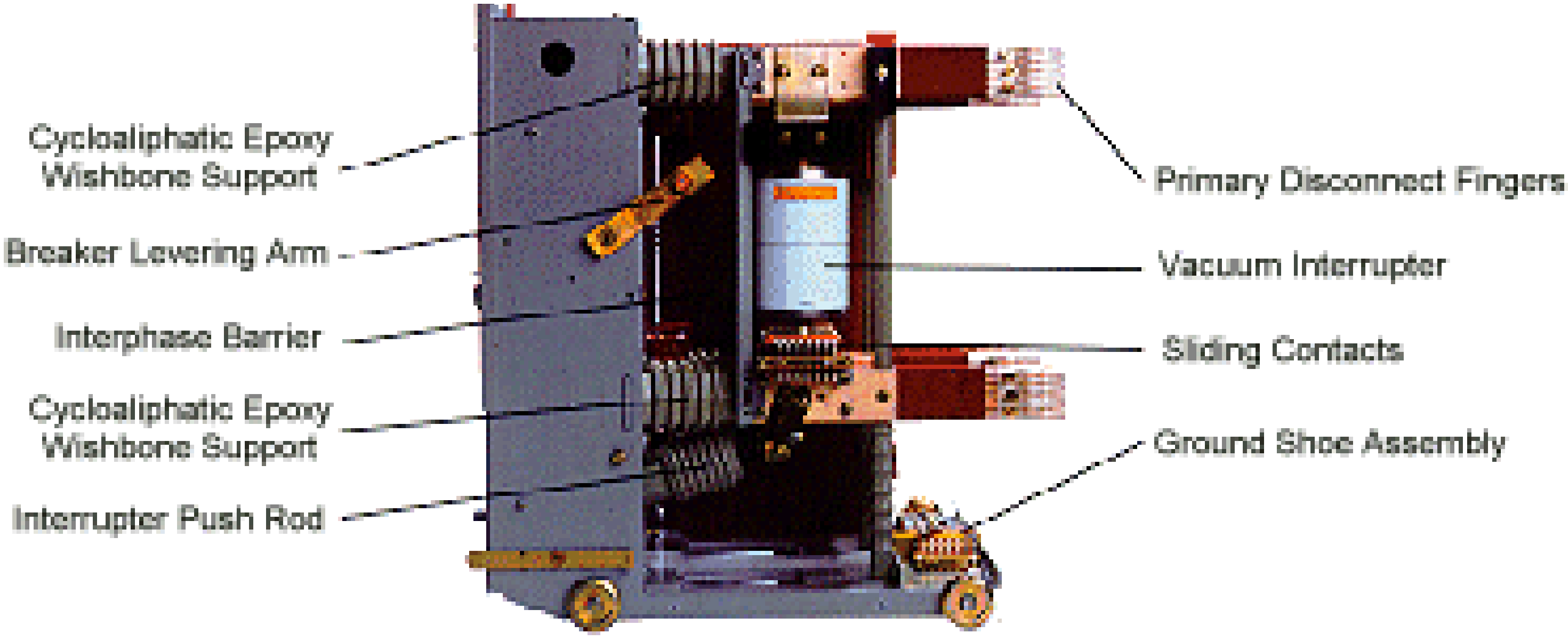
Toc and MOC



Contact Arrangement for TOC and MOC

	Normally Open	Normally Closed	AC Contact Rating	DC Contact Rating
Standard	5	4	15A-120VAC 10A-240VAC	10A-125VDC 5A-250VDC
Option	7	6	15A-120VAC 10A-240VAC	10A-125VDC 5A-250VDC
Option	8	8	15A-120VAC 10A-240VAC	10A-125VDC 5A-250VDC

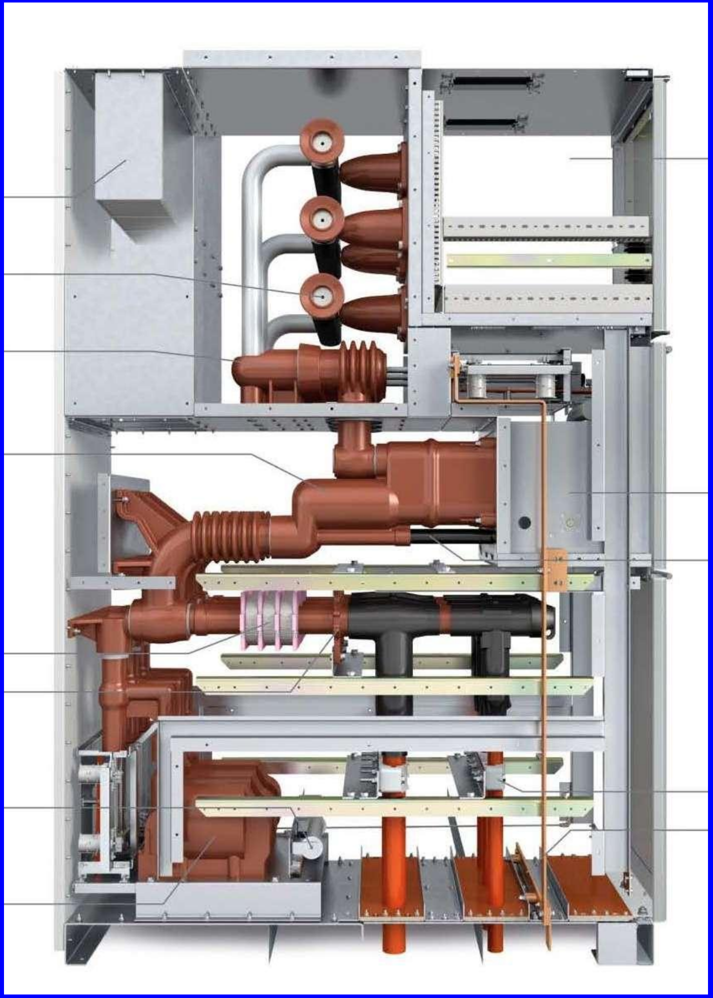

Manual Trip
Manual Charge Receptacle
Manual Close
Operations Counter
Mechanical Breaker Position Indicator
Padlock Provision Arm
Levering Interlock Shutter
Secondary Control Interlock Receptacle
Spring Charge Indicator


Cycloaliphatic Epoxy Wishbone Support
Breaker Levering Arm
Interphase Barrier
Cycloaliphatic Epoxy Wishbone Support
Interrupter Push Rod
Primary Disconnect Fingers
Vacuum Interrupter
Sliding Contacts
Ground Shoe Assembly

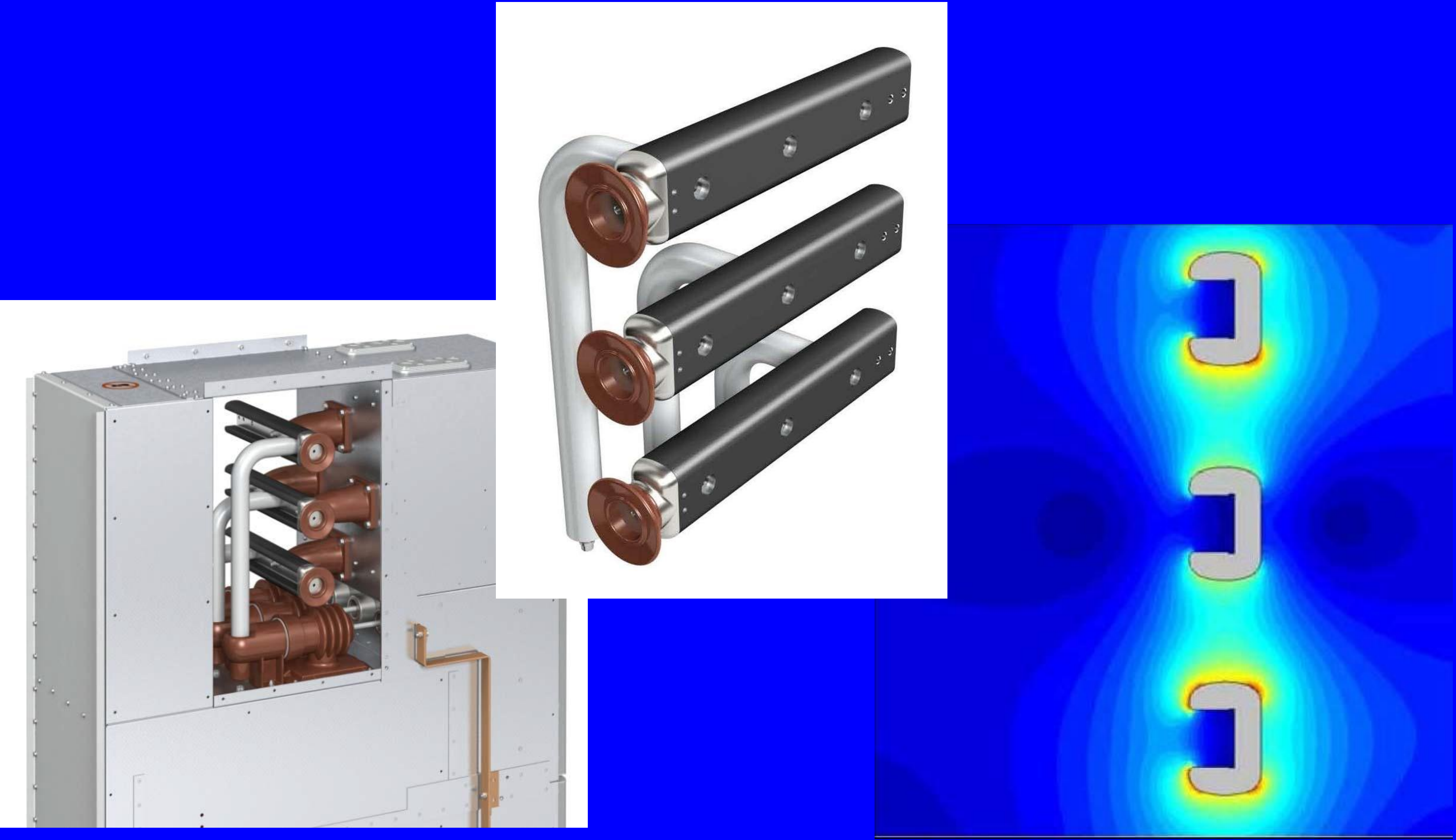
Plug and play vertical sections

- Only a 630A, 20kA device at this time

Minimized bare copper helps prevent arcing fault



Managing the E Field

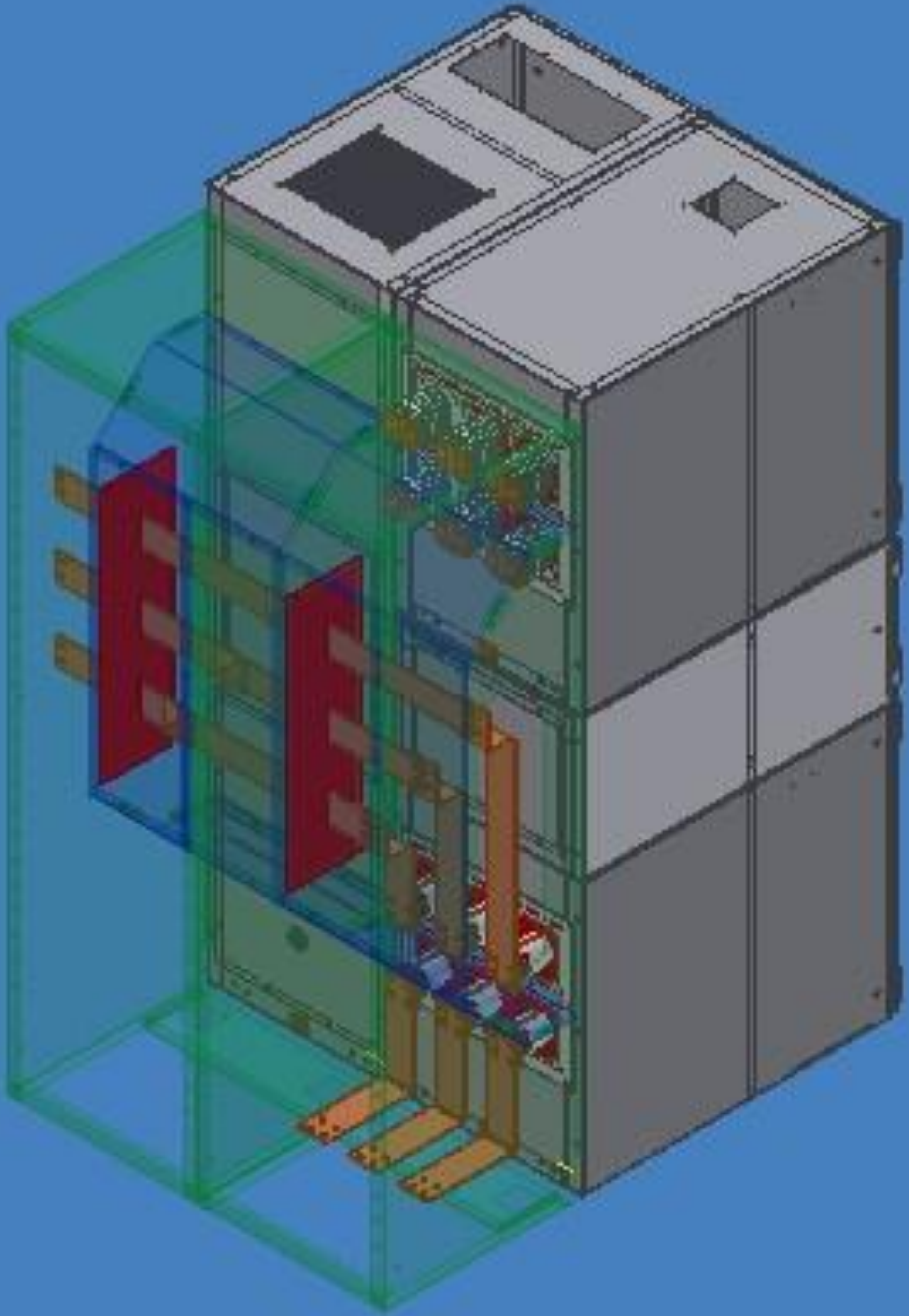


Rating Structure Standards

- **C37.04, C37.06 & C37.09 - MV Breakers**
- **C37.20.2 - Metal-Clad Switchgear**
- **C37.20.7 – Arc Resistant Switchgear**
- **C37.20.3 - MV Load Interrupter Swgr.**
- **C37.13, C37.16 & C37.17 - LV Breakers**
- **C37.20.1 - Low Voltage Switchgear**
- **NEMA ICS 1, ICS 2, ICS 3, and ICS 6 - Low and Medium Voltage MCC's**

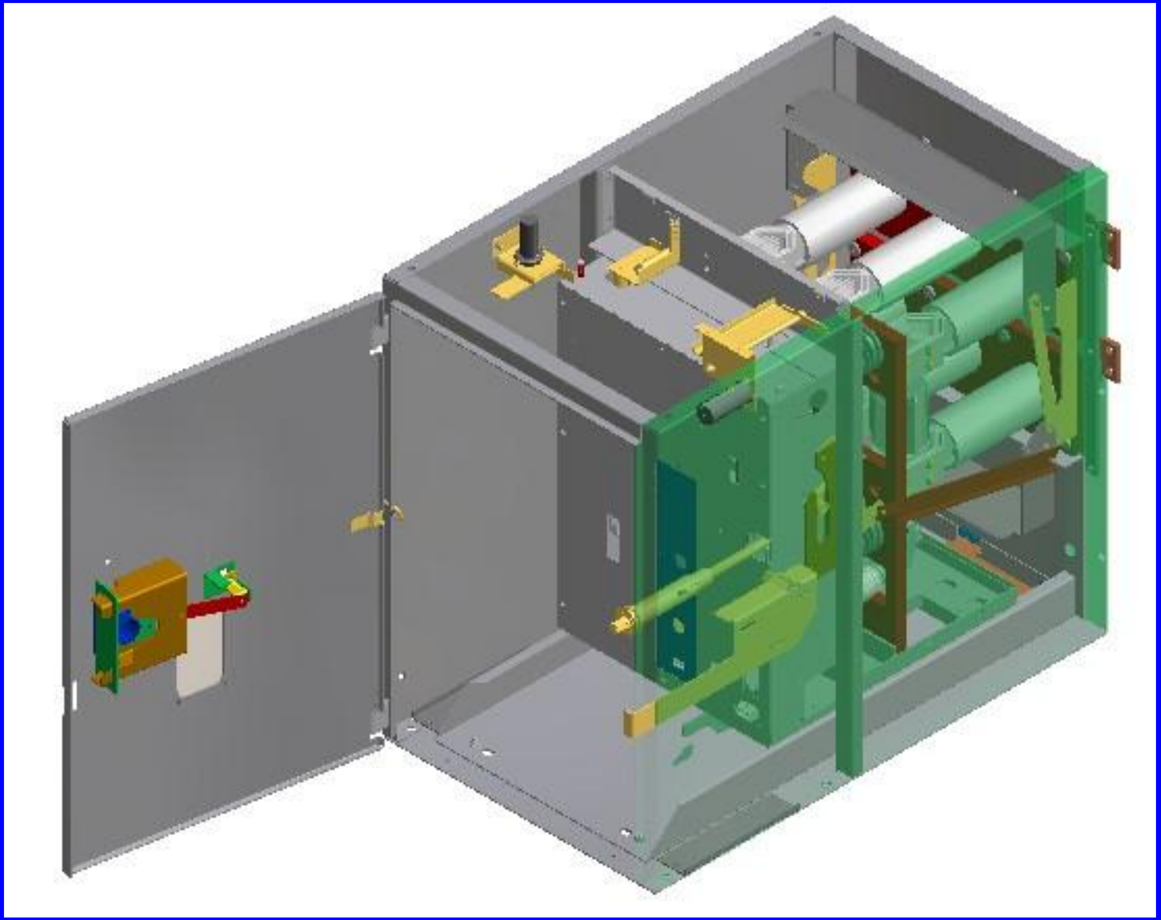
Switchgear and Circuit Breakers

- Dielectric tests
- Continuous current
- Short time and momentary
- Racking endurance



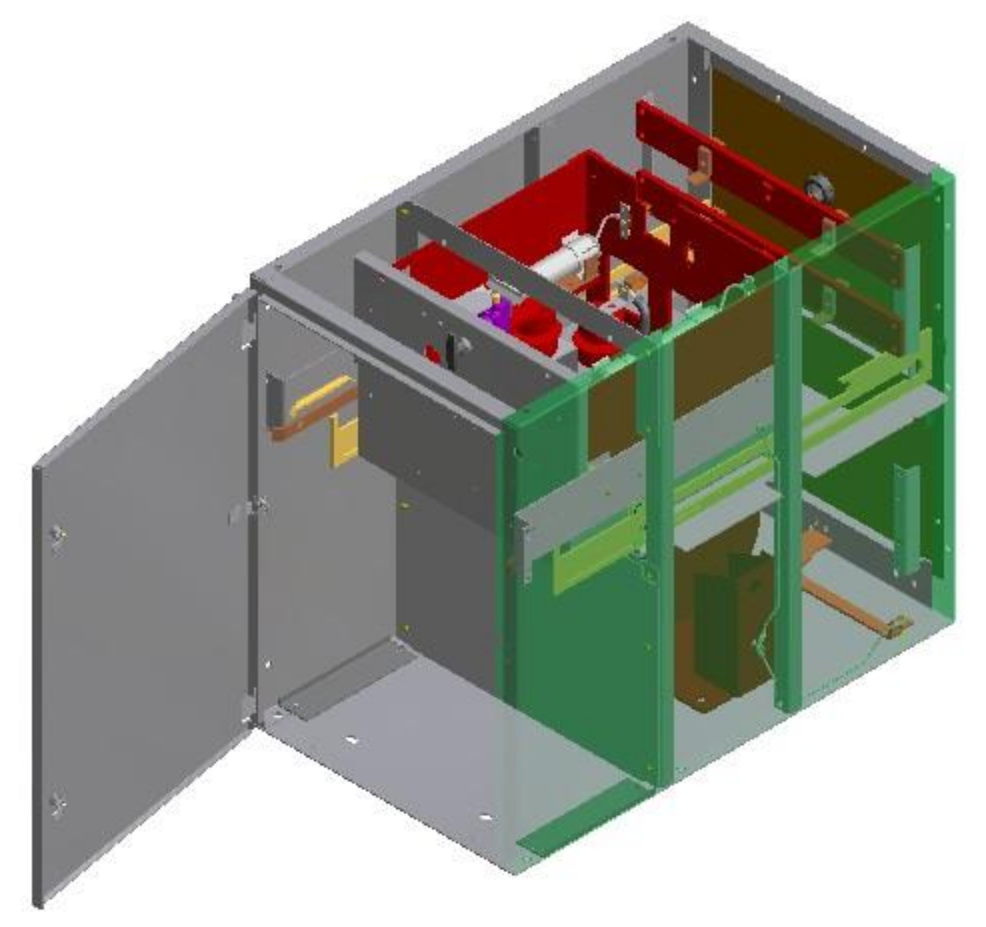
Breaker

- Short Circuit Interrupting
- Mechanical Endurance
- Load Current
- Definite purpose -- Cap Switching



New Rollout Design with CPT

- Blown Fuse



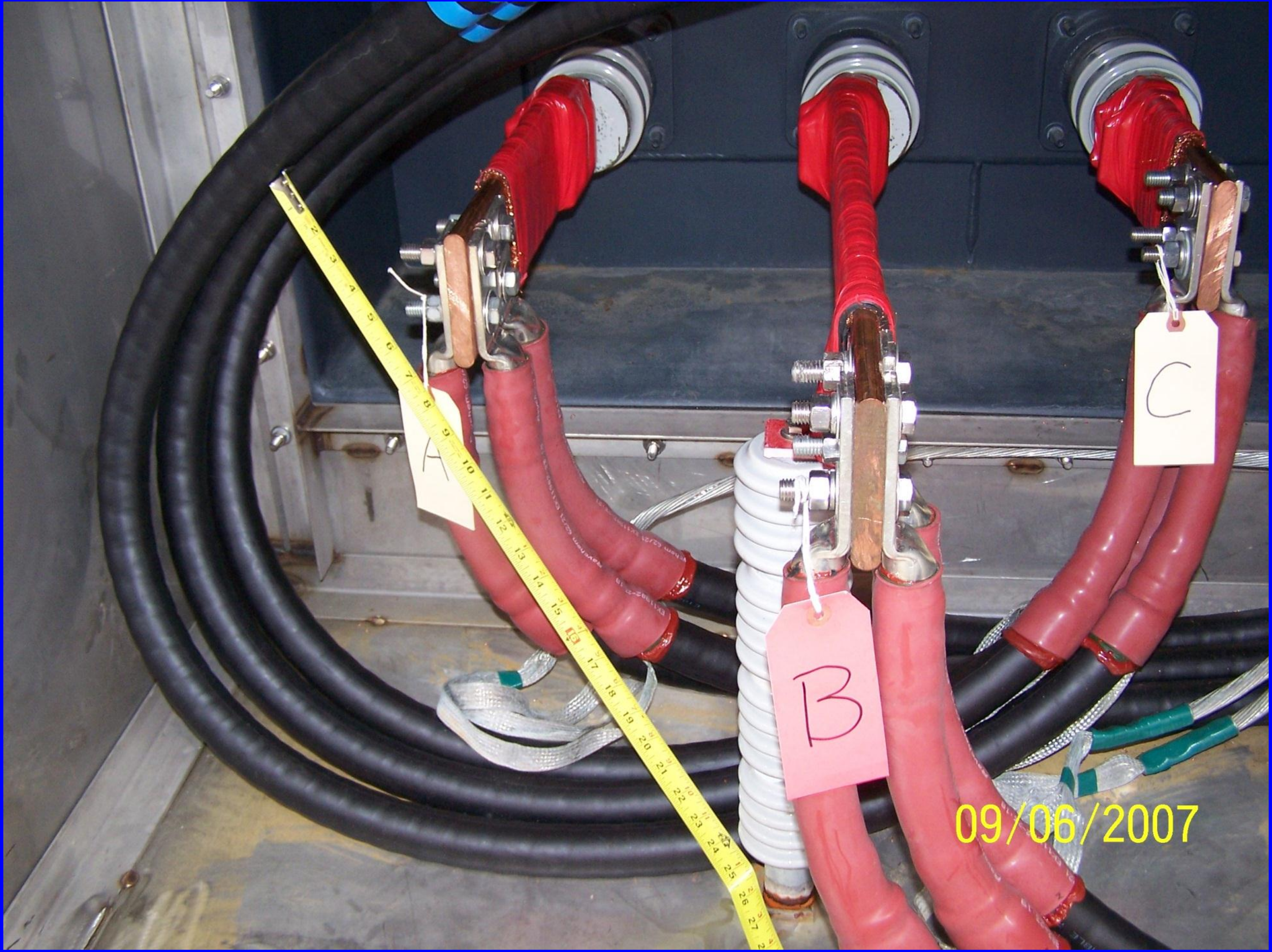
Voltage Ratings

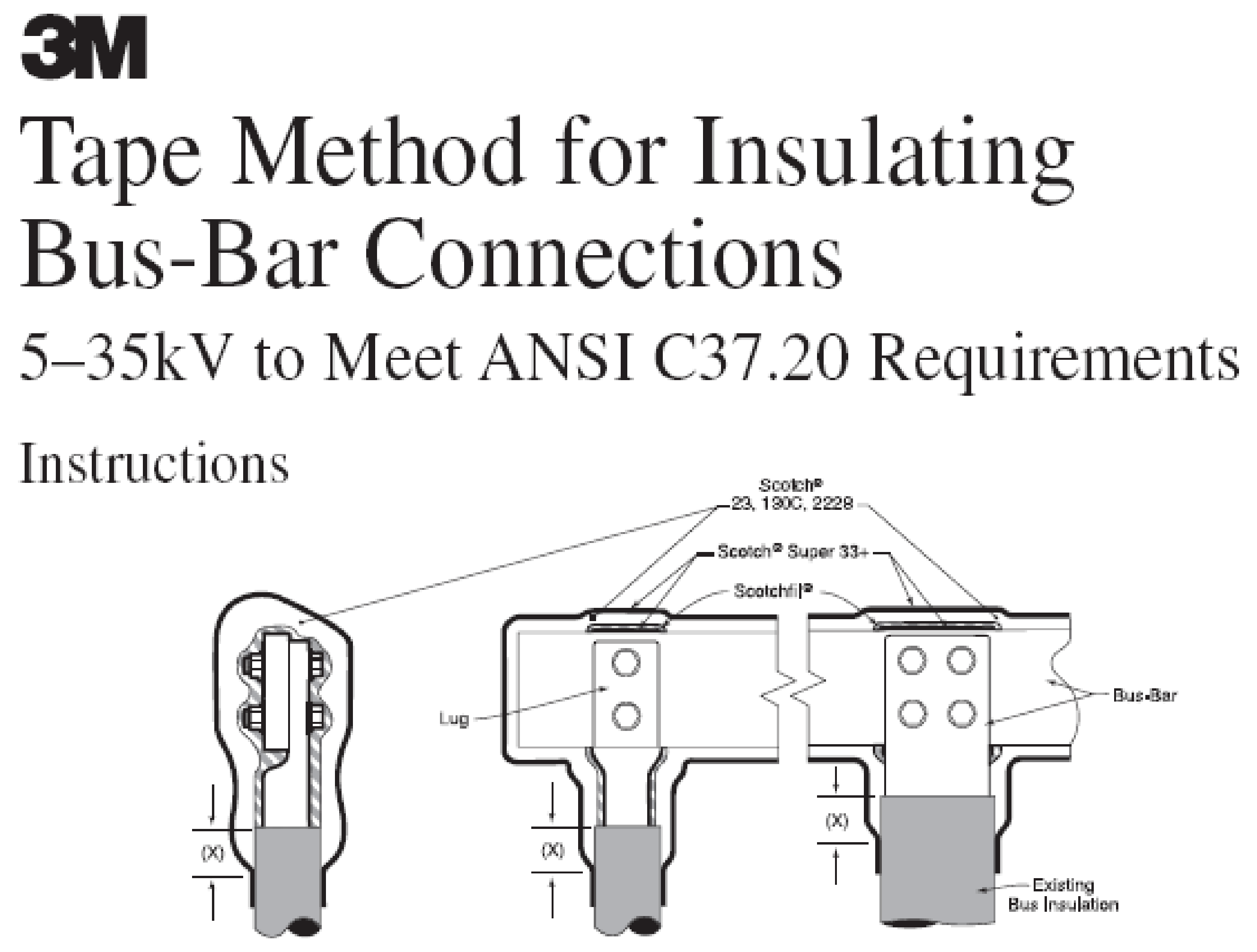
- Rated Voltage (Rated Maximum Voltage): highest rms voltage
- Power frequency withstand (Hipot): indicates health of dielectric system under ideal condition
- B.I.L.: Basic impulse voltage (1.2 x 50 microsecond wave) for coordination
- Foil Test: Test of the withstand capability of bus insulation
- Partial Discharge indication of level of deterioration within dielectric (not required)
- Chopped for outdoor bkr and switching impulse for 362kV

Bus Spacing Function of BIL and MFR

Voltage	**Air Clearance**		**Surface Clearance**	
	Insulated	Bare	Insulated	Bare
635V	N/A	1”	N/A	2”
4.76kV	2”	3 1/2”	3”	5”
15kV	3”	6”	5”	7”
27kV	6”	9”	9”	14”
38kV	7 ½”	10 ½”	11”	17”

why Insulate lugs??


A
B
C
09/06/2007



3M

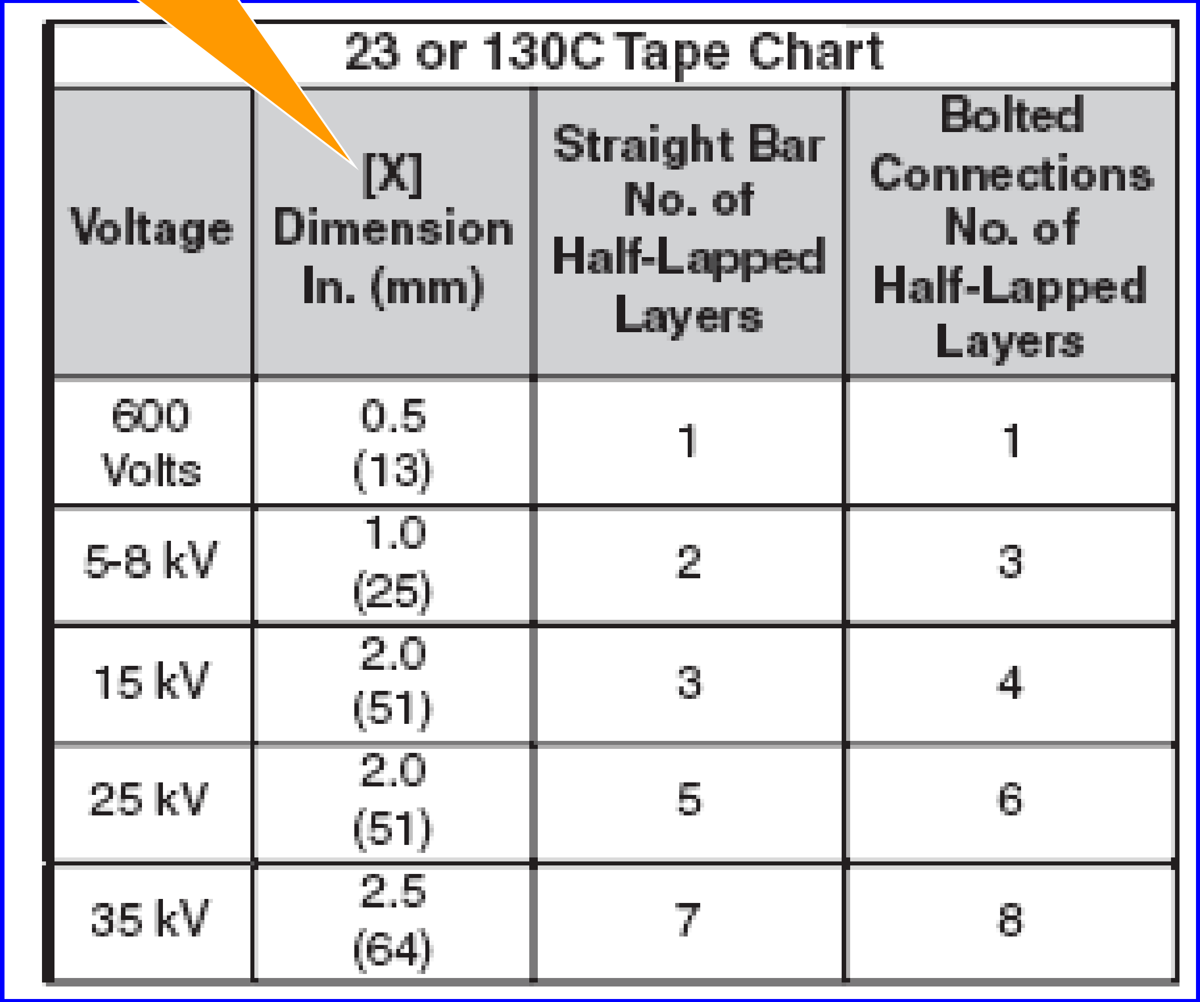
Tape Method for Insulating Bus-Bar Connections

5–35kV to Meet ANSI C37.20 Requirements

Instructions

Tape Details

Insulation Overlap



23 or 130C Tape Chart

Voltage	[X] Dimension In. (mm)	Straight Bar No. of Half-Lapped Layers	Bolted Connections No. of Half-Lapped Layers
600 Volts	0.5 (13)	1	1
5-8 kV	1.0 (25)	2	3
15 kV	2.0 (51)	3	4
25 kV	2.0 (51)	5	6
35 kV	2.5 (64)	7	8

Rated Dielectric Strength

	Rated Maximum Voltage (kV rms)	Insulation Levels (kV)		
		Normal Frequency Withstand (rms) 1min	Impulse Withstand	Reference dc Withstand
MC Switchgear	4.76	19	60	27
	8.25	36	95	50
	15.0	36	95	50
	27.0	60	125	❄
	38.0	80	150	❄

Altitude De-rating Factors

Low Voltage

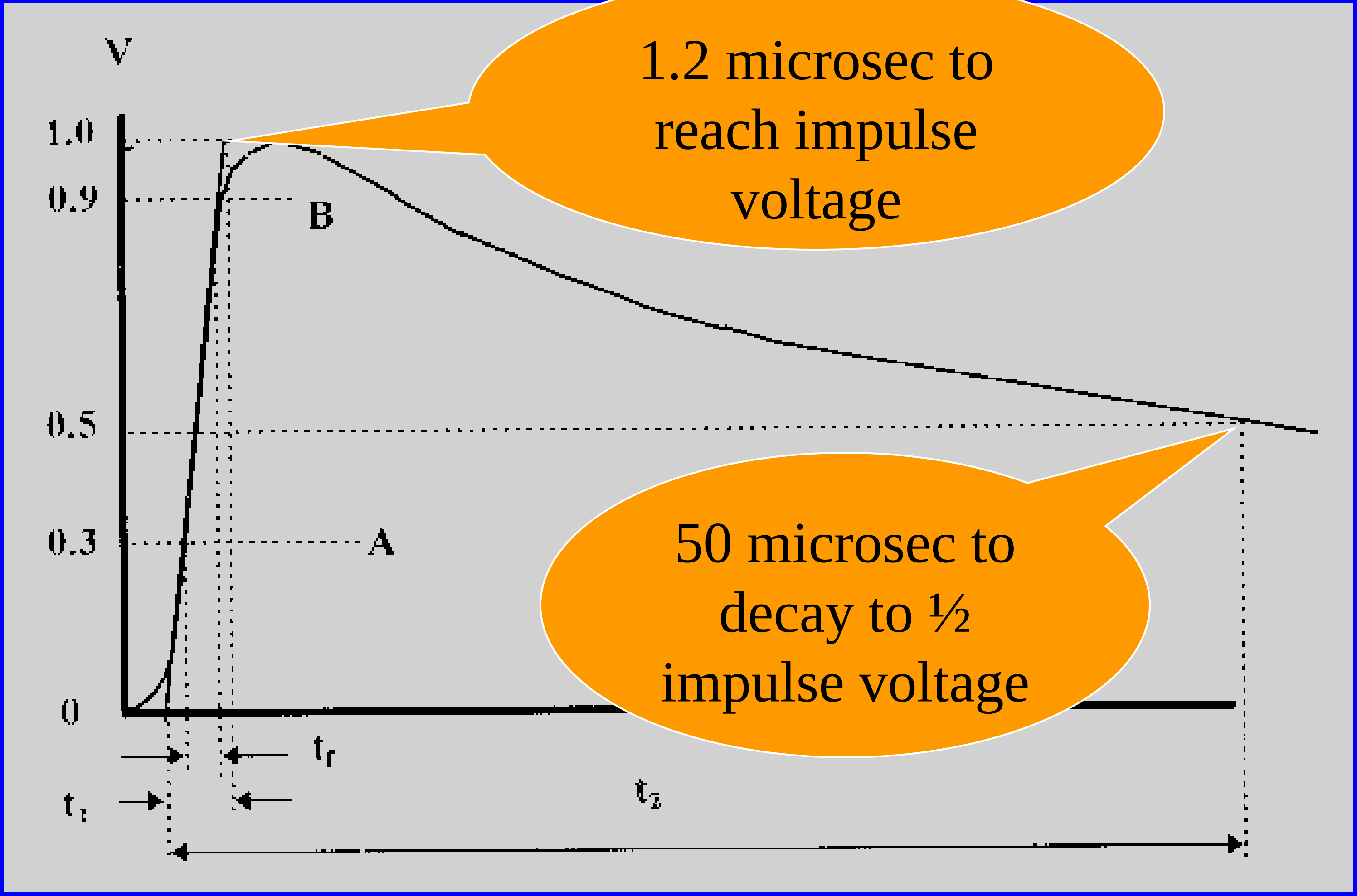
Altitude	Voltage	Current
<6,600ft (2000m)	1.00	1.00
8,500ft (2600m)	0.95	0.99
13,000ft (3900m)	0.80	0.96

Medium Voltage

Altitude	Voltage	Current
<3,300ft (1000m)	1.00	1.00
5,000ft (1500m)	0.95	0.99
10,000ft (3000m)	0.80	0.96

Typical Test Set-up

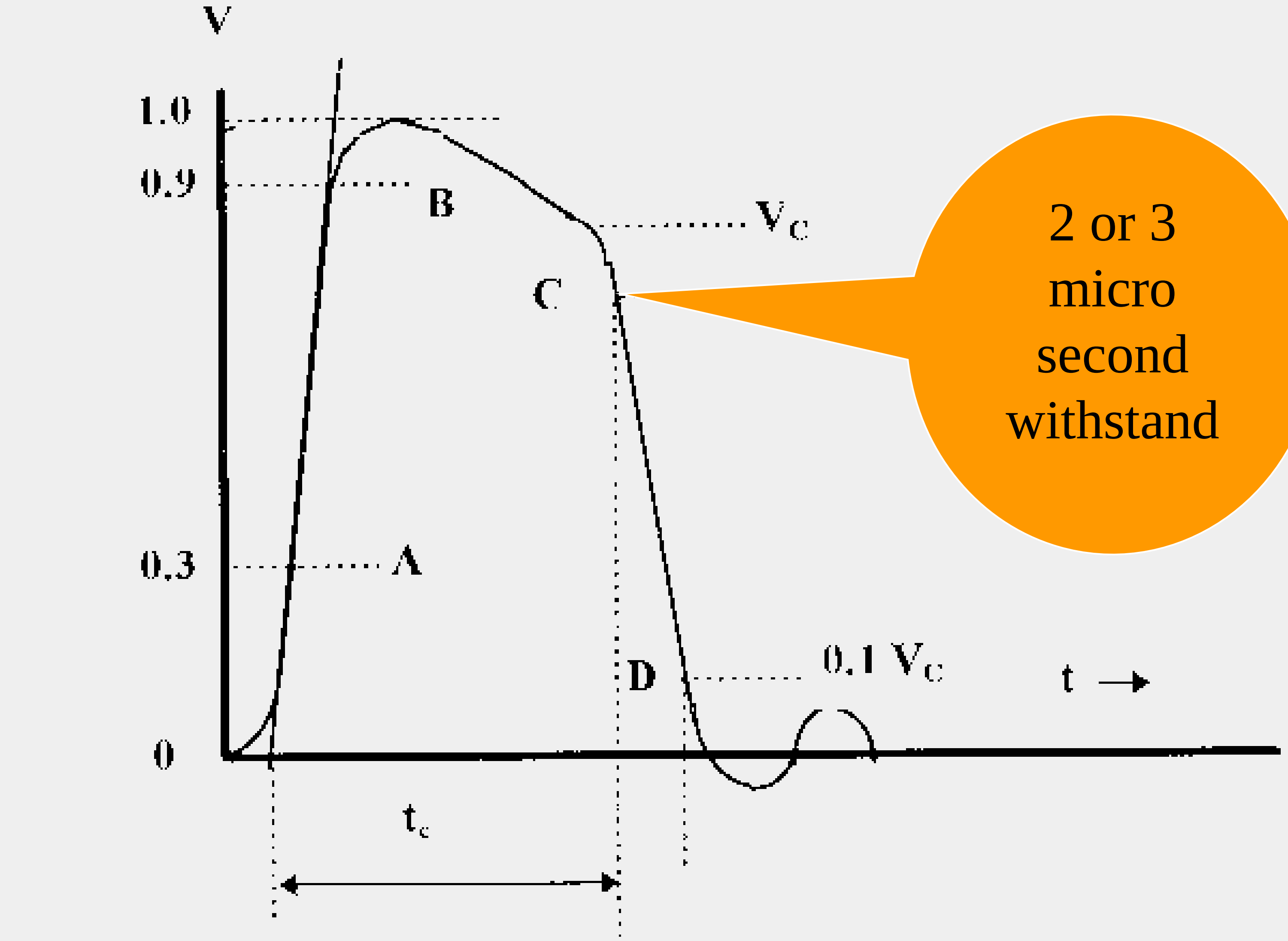
1.2 X 50 Voltage Impulse Wave



1.2 microsec to reach impulse voltage

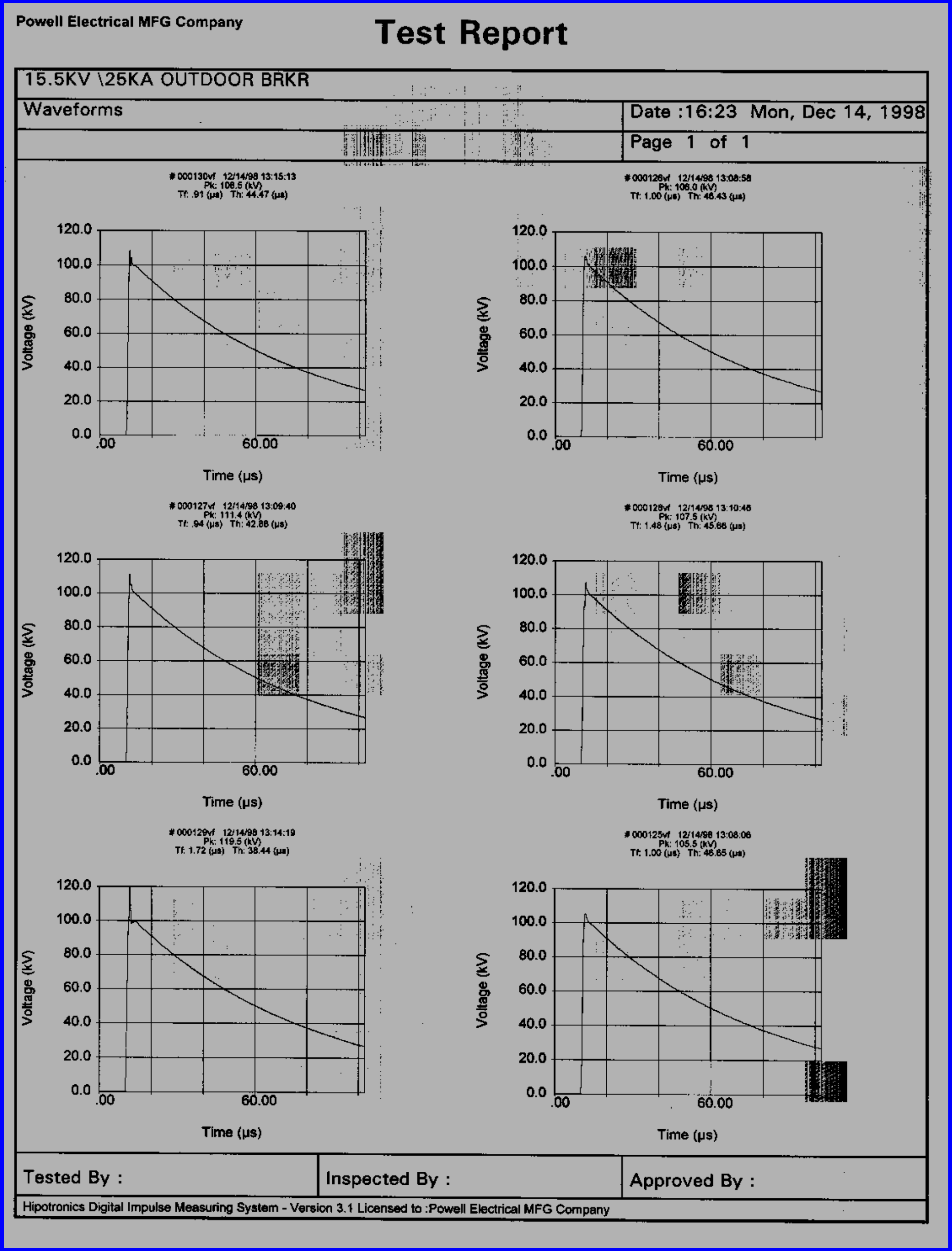
50 microsec to decay to ½ impulse voltage

Chopped Wave



2 or 3 micro second withstand

BIL Test Report 3 x 9



Powell Electrical MFG Company

Test Report

15.5KV \25KA OUTDOOR BRKR

Waveforms

Date :16:23 Mon, Dec 14, 1998

Page 1 of 1

000130vf 12/14/98 13:15:13
Pk: 108.5 (kV)
Tf: .91 (µs) Th: 44.47 (µs)

000126vf 12/14/98 13:08:58
Pk: 106.0 (kV)
Tf: 1.00 (µs) Th: 46.43 (µs)

000127vf 12/14/98 13:09:40
Pk: 111.4 (kV)
Tf: .94 (µs) Th: 42.88 (µs)

000128vf 12/14/98 13:10:46
Pk: 107.5 (kV)
Tf: 1.48 (µs) Th: 45.66 (µs)

000129vf 12/14/98 13:14:19
Pk: 119.5 (kV)
Tf: 1.72 (µs) Th: 38.44 (µs)

000125vf 12/14/98 13:08:06
Pk: 105.5 (kV)
Tf: 1.00 (µs) Th: 46.65 (µs)

Tested By :

Inspected By :

Approved By :

Hipotronics Digital Impulse Measuring System - Version 3.1 Licensed to :Powell Electrical MFG Company

Current Ratings

- Rated continuous current: maximum current in rms amperes at rated frequency which can be carried continuously without exceeding specified temperature rise.

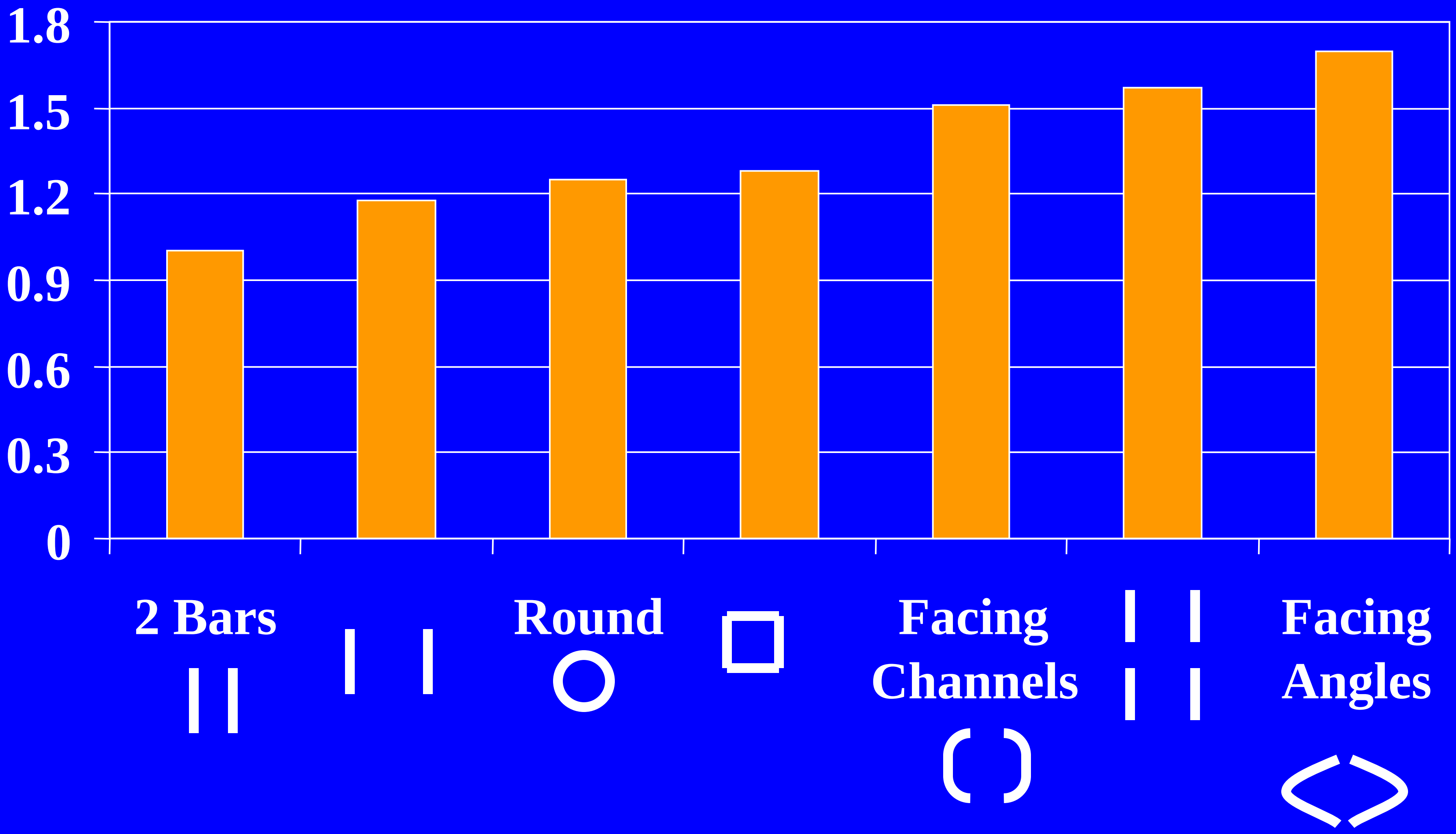
- 65 C rise with a 40 C ambient for tinned and silver plate joints per ANSI

Conductor Temperature Limits

Type of bus or connection	Limit of hottest spot temperature rise (°C)	Limit of hottest spot total temperature (°C)
Buses and connections with unplated copper to copper	30	70
Buses and connections silver surfaced or tin surfaced	65	105
Connection to insulated cables unplated copper to copper	30	70
Connections to insulated cables silver surfaced or tin surfaced	45	85

Note: All aluminum buses shall have silver surfaced, tin surfaced, or equivalent connecting joints. Welded bus connections are not considered connecting joints.

Ampacity for same square inches

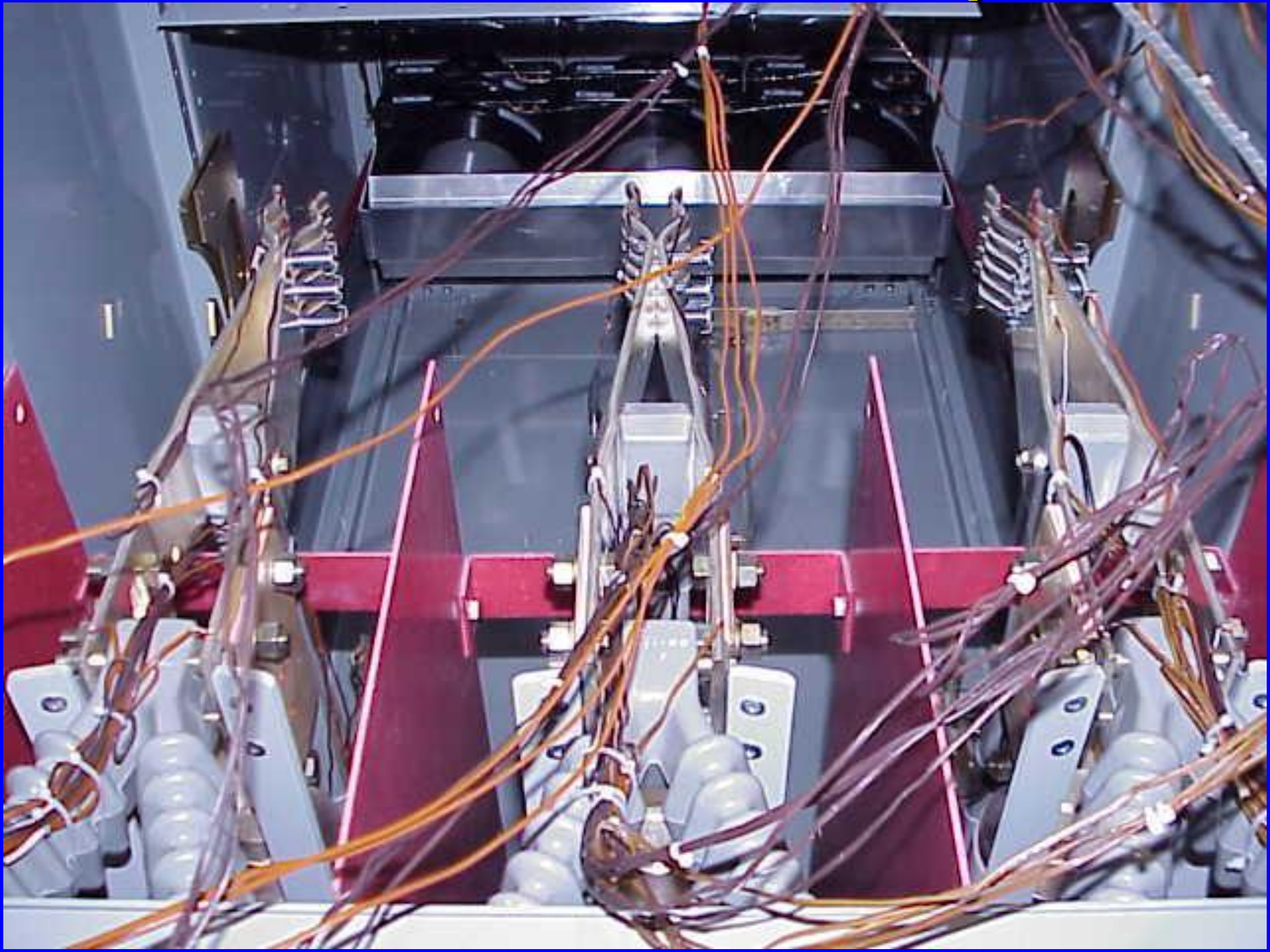


Varying Ambient Temps

- De-rating is applied for various ambient
- Equipment design does not change only a second nameplate
- Emergency load current capability 4h = 1.12
- Requires inspection

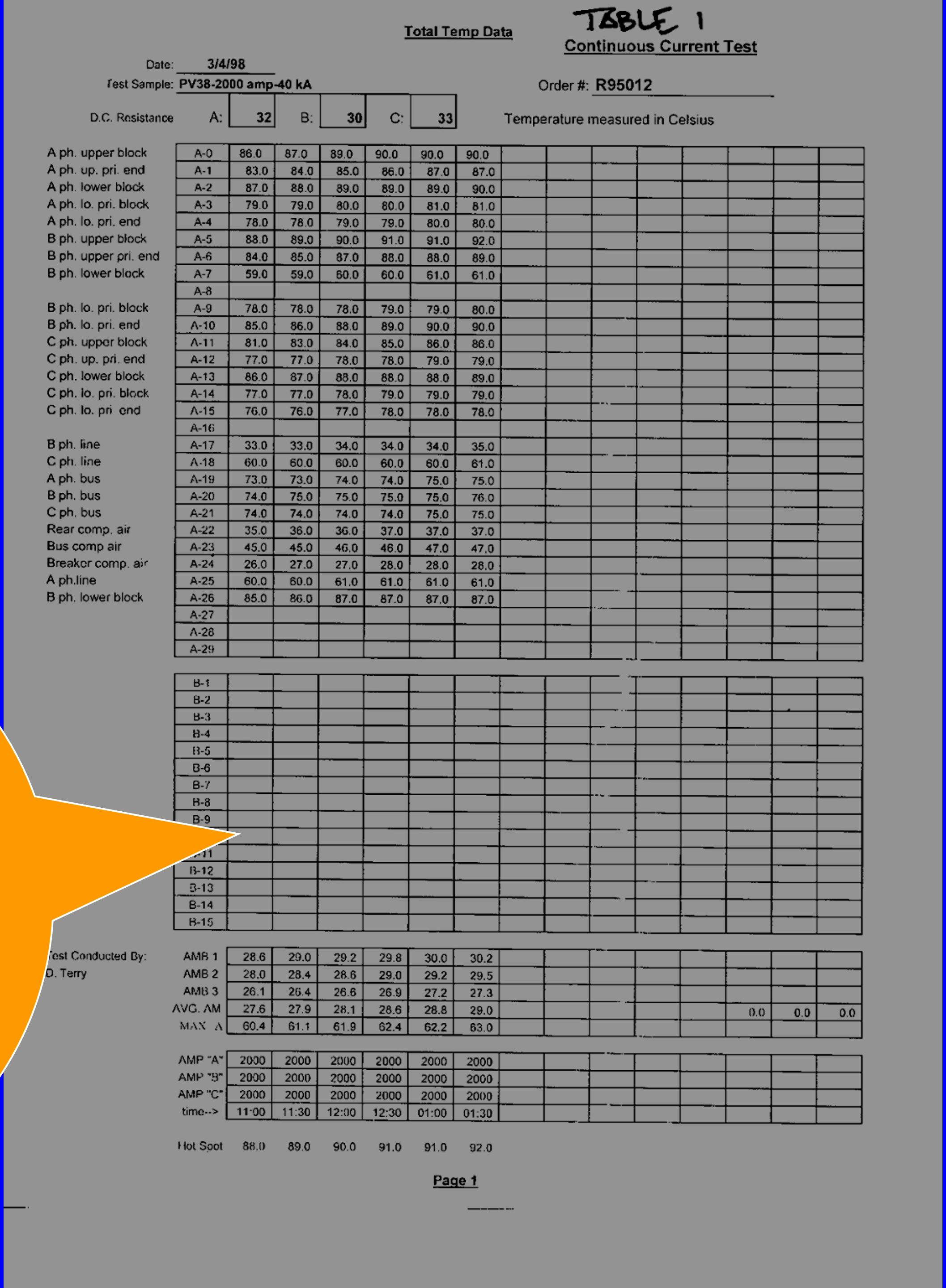
Max Ambient	De-rating factor
60	.81
50	.91
40	1.0
30	1.08

Breaker Thermocouples



Continuous Current Certification

Heat Run Results



Total Temp Data

TABLE 1

Continuous Current Test

Date: 3/4/98

Test Sample: PV38-2000 amp-40 kA

Order #: R95012

D.C. Resistance A: 32 B: 30 C: 33

Temperature measured in Celsius

A ph. upper block	A-0	86.0	87.0	89.0	90.0	90.0	90.0								
A ph. up. pri. end	A-1	83.0	84.0	85.0	86.0	87.0	87.0								
A ph. lower block	A-2	87.0	88.0	89.0	89.0	89.0	90.0								
A ph. lo. pri. block	A-3	79.0	79.0	80.0	80.0	81.0	81.0								
A ph. lo. pri. end	A-4	78.0	78.0	79.0	79.0	80.0	80.0								
B ph. upper block	A-5	88.0	89.0	90.0	91.0	91.0	92.0								
B ph. upper pri. end	A-6	84.0	85.0	87.0	88.0	88.0	89.0								
B ph. lower block	A-7	59.0	59.0	60.0	60.0	61.0	61.0								
	A-8														
B ph. lo. pri. block	A-9	78.0	78.0	78.0	79.0	79.0	80.0								
B ph. lo. pri. end	A-10	85.0	86.0	88.0	89.0	90.0	90.0								
C ph. upper block	A-11	81.0	83.0	84.0	85.0	86.0	86.0								
C ph. up. pri. end	A-12	77.0	77.0	78.0	78.0	79.0	79.0								
C ph. lower block	A-13	86.0	87.0	88.0	88.0	88.0	89.0								
C ph. lo. pri. block	A-14	77.0	77.0	78.0	79.0	79.0	79.0								
C ph. lo. pri end	A-15	76.0	76.0	77.0	78.0	78.0	78.0								
	A-16														
B ph. line	A-17	33.0	33.0	34.0	34.0	34.0	35.0								
C ph. line	A-18	60.0	60.0	60.0	60.0	60.0	61.0								
A ph. bus	A-19	73.0	73.0	74.0	74.0	75.0	75.0								
B ph. bus	A-20	74.0	75.0	75.0	75.0	75.0	76.0								
C ph. bus	A-21	74.0	74.0	74.0	74.0	75.0	75.0								
Rear comp. air	A-22	35.0	36.0	36.0	37.0	37.0	37.0								
Bus comp air	A-23	45.0	45.0	46.0	46.0	47.0	47.0								
Breaker comp. air	A-24	26.0	27.0	27.0	28.0	28.0	28.0								
A ph.line	A-25	60.0	60.0	61.0	61.0	61.0	61.0								
B ph. lower block	A-26	85.0	86.0	87.0	87.0	87.0	87.0								
	A-27														
	A-28														
	A-29														

B-1														
B-2														
B-3														
B-4														
B-5														
B-6														
B-7														
B-8														
B-9														
11														
B-12														
B-13														
B-14														
B-15														

Test Conducted By:
D. Terry

AMB 1	28.6	29.0	29.2	29.8	30.0	30.2								
AMB 2	28.0	28.4	28.6	29.0	29.2	29.5								
AMB 3	26.1	26.4	26.6	26.9	27.2	27.3								
AVG. AM	27.6	27.9	28.1	28.6	28.8	29.0						0.0	0.0	0.0
MAX A	60.4	61.1	61.9	62.4	62.2	63.0								

AMP "A"	2000	2000	2000	2000	2000	2000								
AMP "B"	2000	2000	2000	2000	2000	2000								
AMP "C"	2000	2000	2000	2000	2000	2000								
time-->	11:00	11:30	12:00	12:30	01:00	01:30								
Hot Spot	88.0	89.0	90.0	91.0	91.0	92.0								

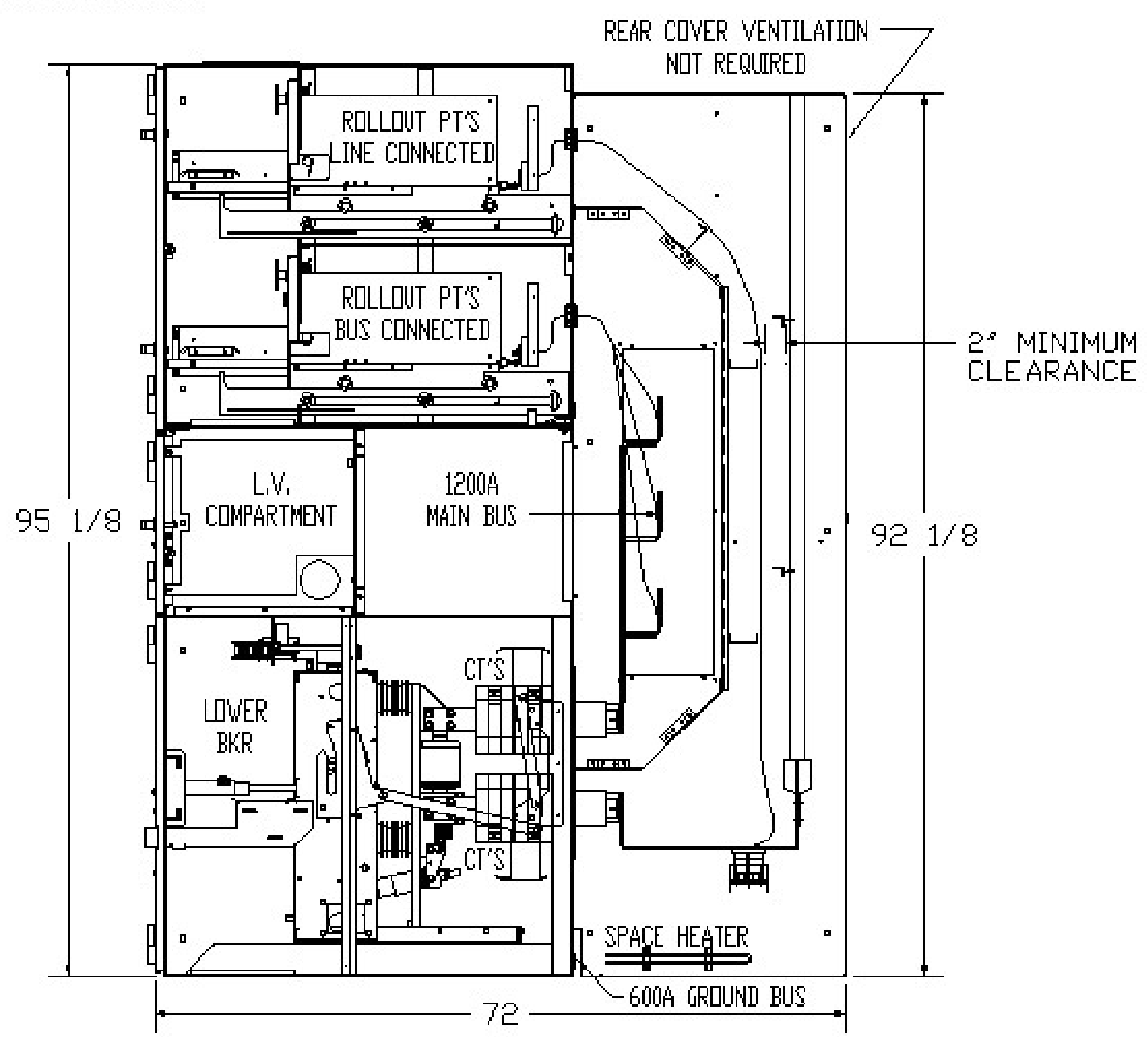
Page 1

Three sets of readings at 30 min intervals with no more than a 1 degree change to indicate thermal stability

Equipment Selection

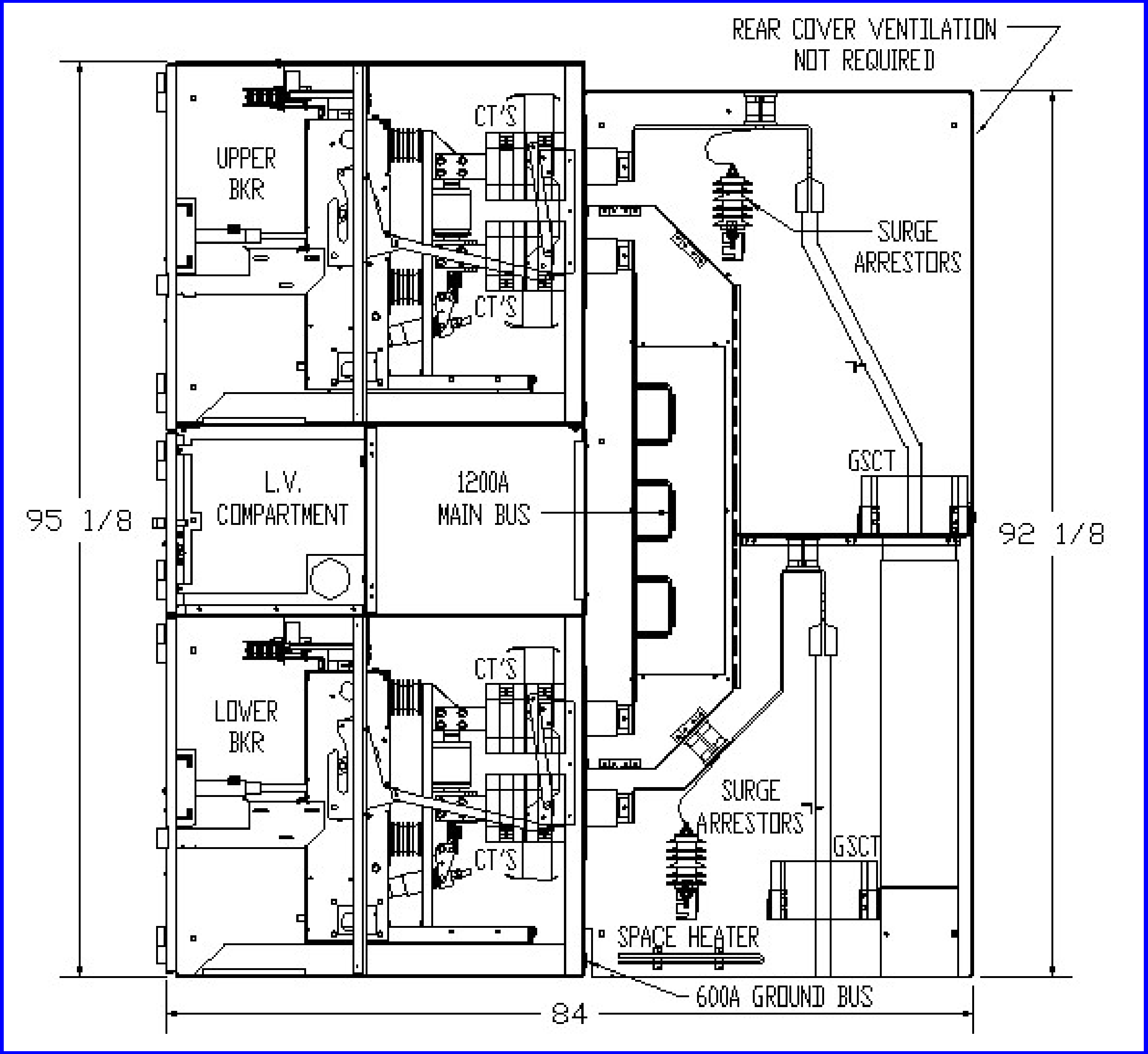
One High with rollouts

- 1200 and 2000 A
- All PT hook-ups available

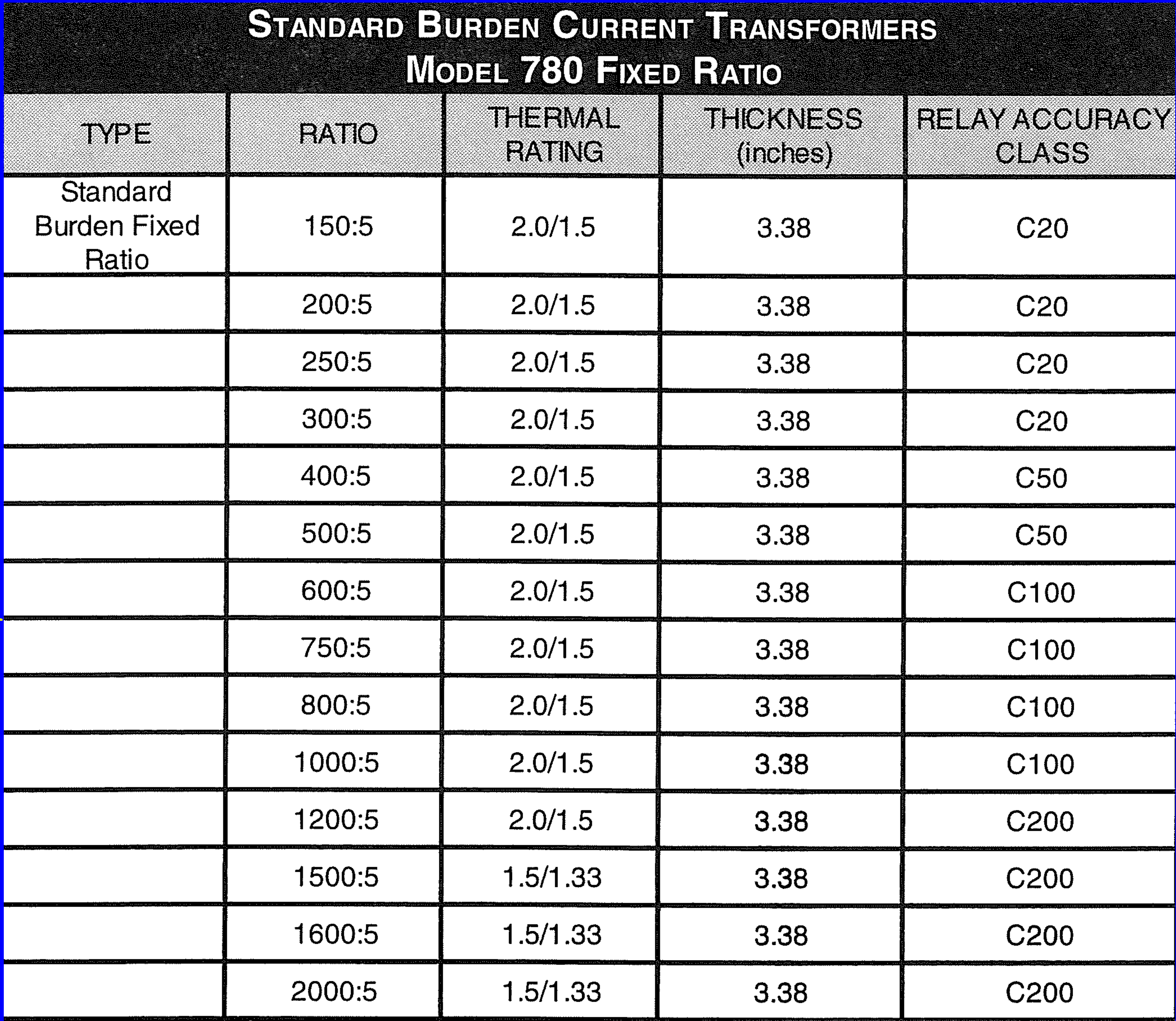


Two High

- 1200 A
- Limited cable compartment
- MOV's in all classes
- Zero sequence ct



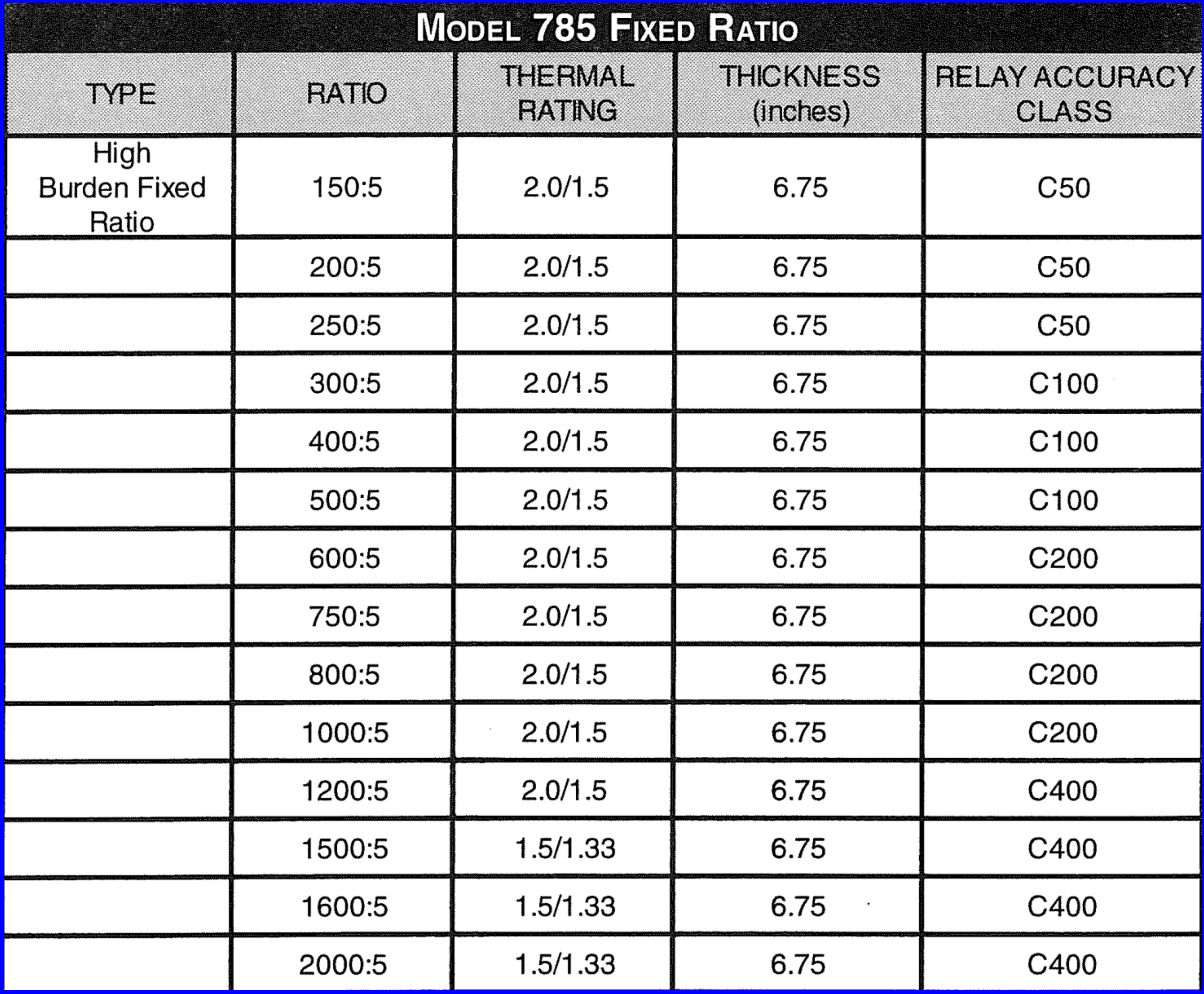
CT size std. Burden CTs



STANDARD BURDEN CURRENT TRANSFORMERS
MODEL 780 FIXED RATIO

TYPE	RATIO	THERMAL RATING	THICKNESS (inches)	RELAY ACCURACY CLASS
Standard Burden Fixed Ratio	150:5	2.0/1.5	3.38	C20
	200:5	2.0/1.5	3.38	C20
	250:5	2.0/1.5	3.38	C20
	300:5	2.0/1.5	3.38	C20
	400:5	2.0/1.5	3.38	C50
	500:5	2.0/1.5	3.38	C50
	600:5	2.0/1.5	3.38	C100
	750:5	2.0/1.5	3.38	C100
	800:5	2.0/1.5	3.38	C100
	1000:5	2.0/1.5	3.38	C100
	1200:5	2.0/1.5	3.38	C200
	1500:5	1.5/1.33	3.38	C200
	1600:5	1.5/1.33	3.38	C200
	2000:5	1.5/1.33	3.38	C200

CT size High Burden CTs

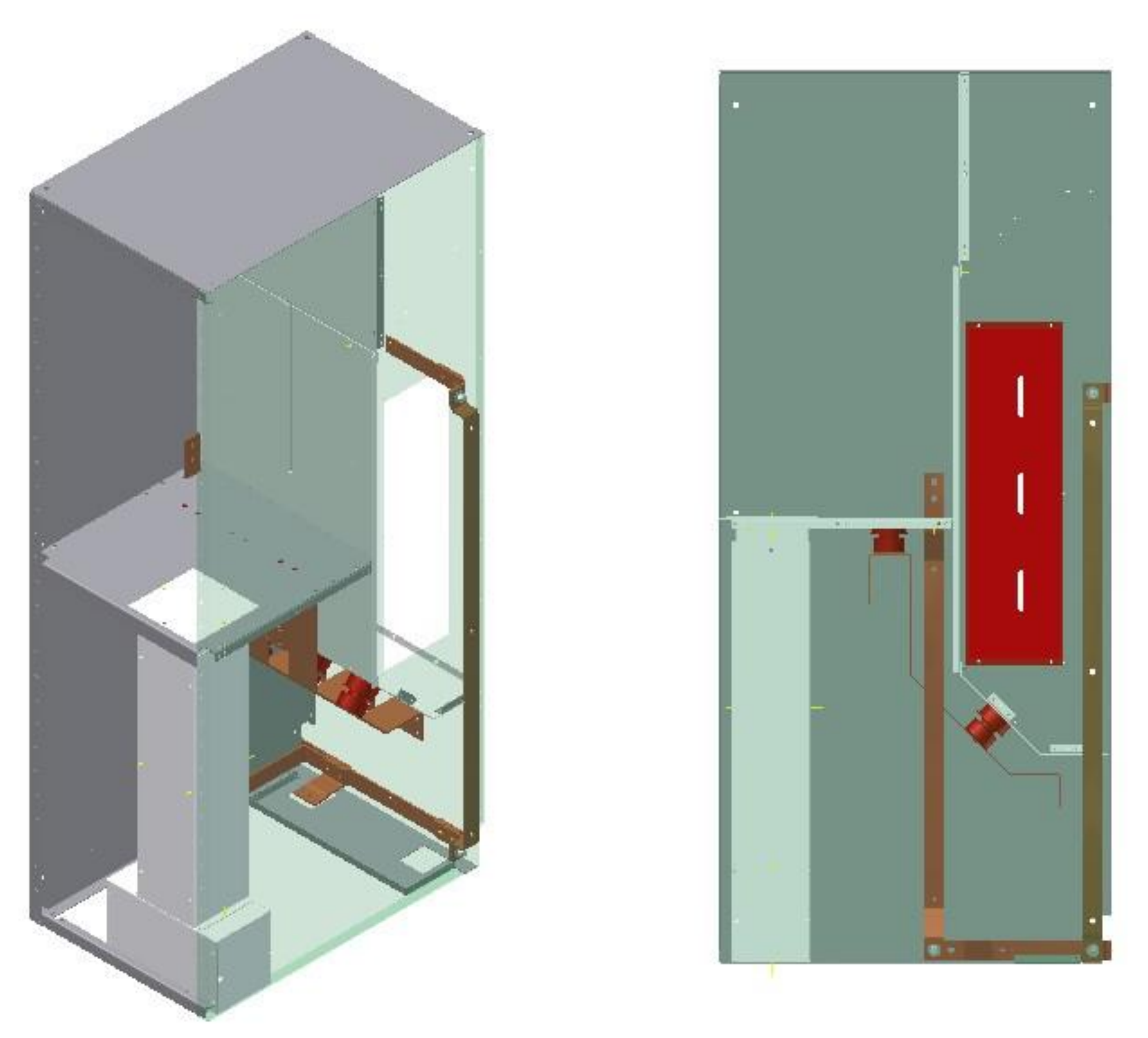


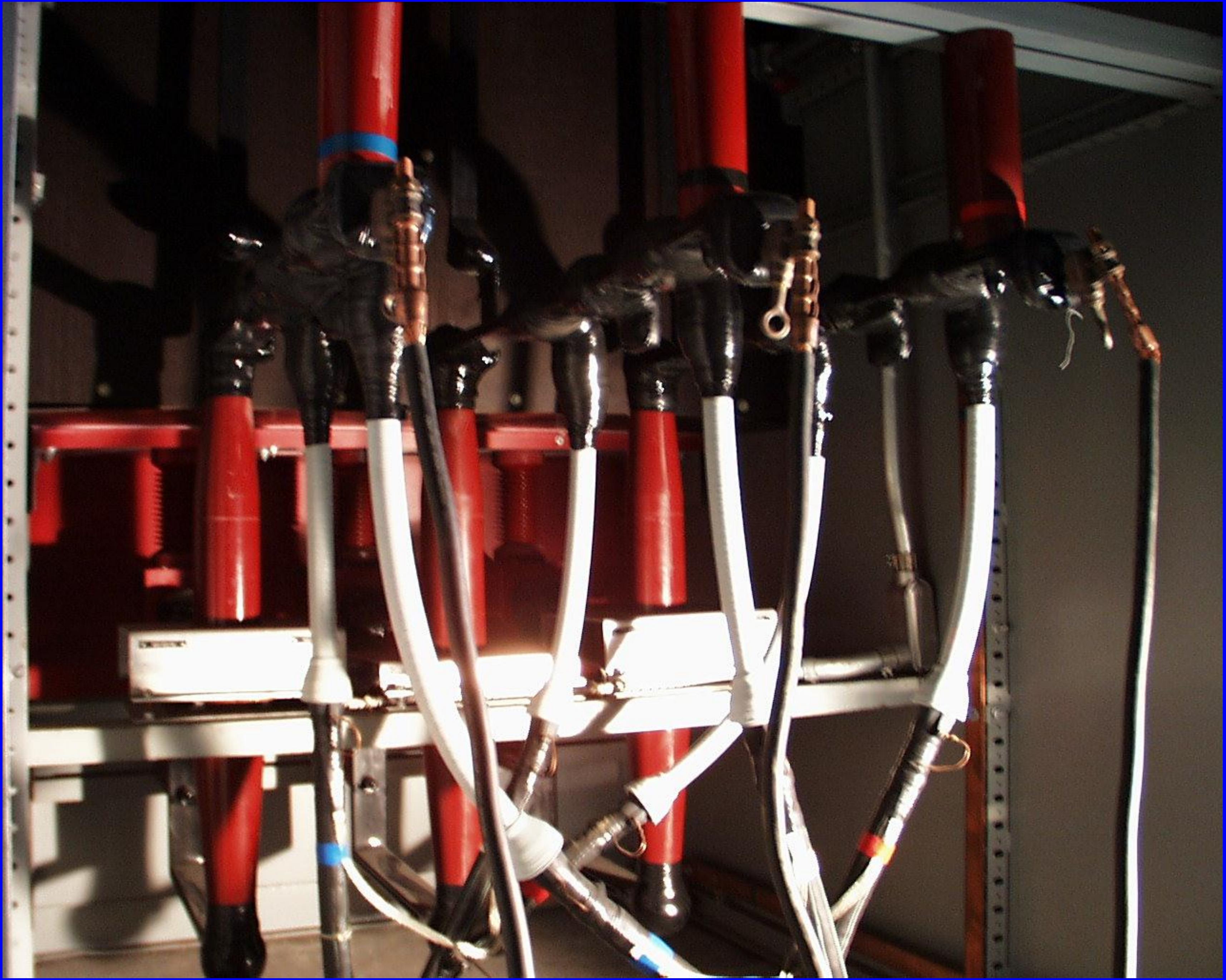
MODEL 785 FIXED RATIO

TYPE	RATIO	THERMAL RATING	THICKNESS (inches)	RELAY ACCURACY CLASS
High Burden Fixed Ratio	150:5	2.0/1.5	6.75	C50
	200:5	2.0/1.5	6.75	C50
	250:5	2.0/1.5	6.75	C50
	300:5	2.0/1.5	6.75	C100
	400:5	2.0/1.5	6.75	C100
	500:5	2.0/1.5	6.75	C100
	600:5	2.0/1.5	6.75	C200
	750:5	2.0/1.5	6.75	C200
	800:5	2.0/1.5	6.75	C200
	1000:5	2.0/1.5	6.75	C200
	1200:5	2.0/1.5	6.75	C400
	1500:5	1.5/1.33	6.75	C400
	1600:5	1.5/1.33	6.75	C400
	2000:5	1.5/1.33	6.75	C400

Rear Compartment w/ Power Trough

- 40% Fill
  - 3-500MCM
  - 2-750MCM
- *ND* deep – 84”
- ND shallow – 72”
  - One High cable
  - 2 High (bottom cell out bottom) (top cell out top)





Cable Ampacity by Size

This data is based upon 15kV Okonite EPR 90°C cable with a 133% insulation level, a tape shield, and a polyethylene jacket.

Table J

CABLE AMPACITY BY SIZE

Cable Size (kcmil)	Current Capacity in Conduit in Open Air[1] (Amps)	Current Capacity in Underground Duct[1] (Amps)	Current Capacity in Cable Tray[1] (Amps)	Current Capacity within Swgr Assembly[2] (Amps)
350	440	415	460	431
500	535	500	575	537
750	655	610	745	693
1000	755	690	890	831

Notes: 1) Data from published Okonite cable specifications.

2) Data from ANSI.

Cable Fills

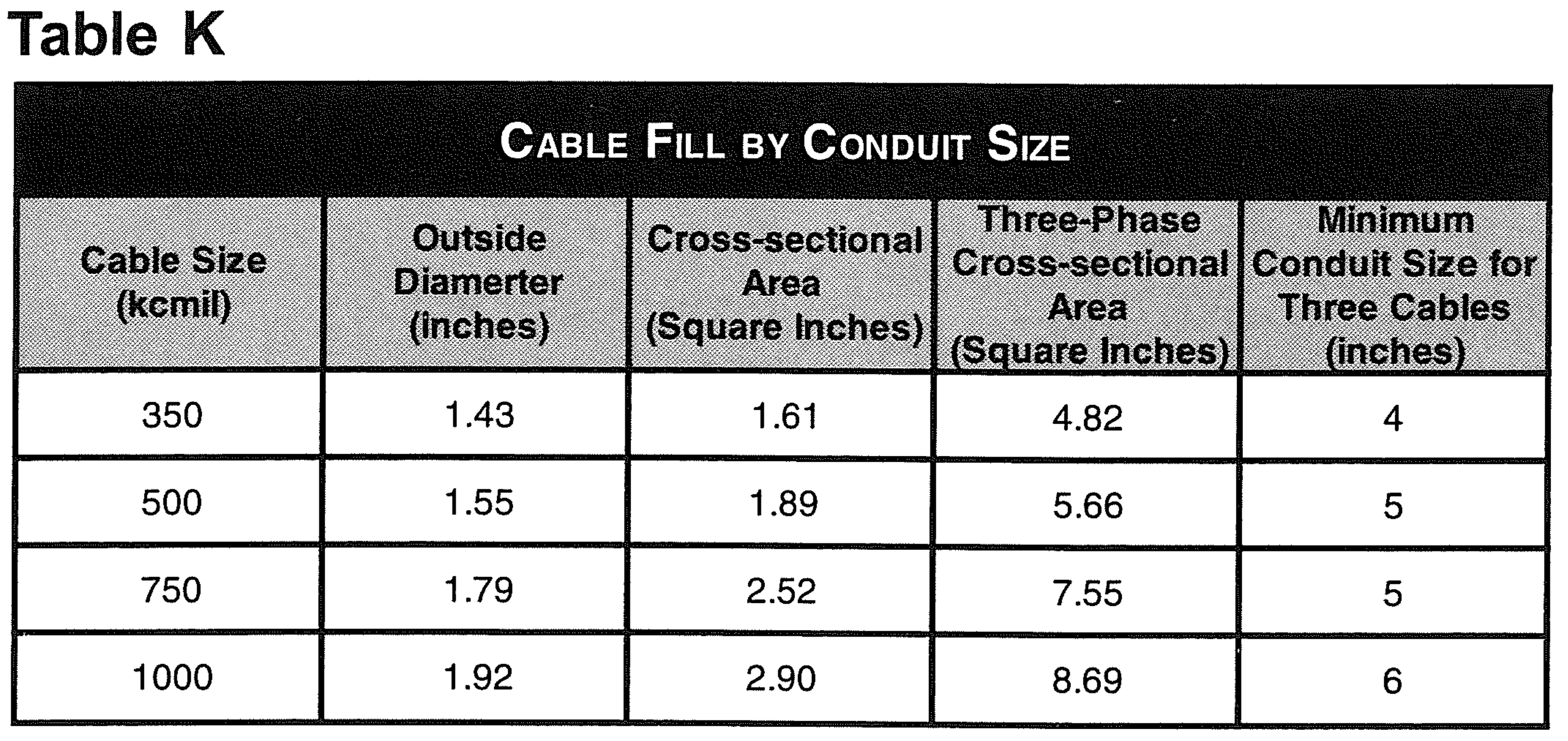
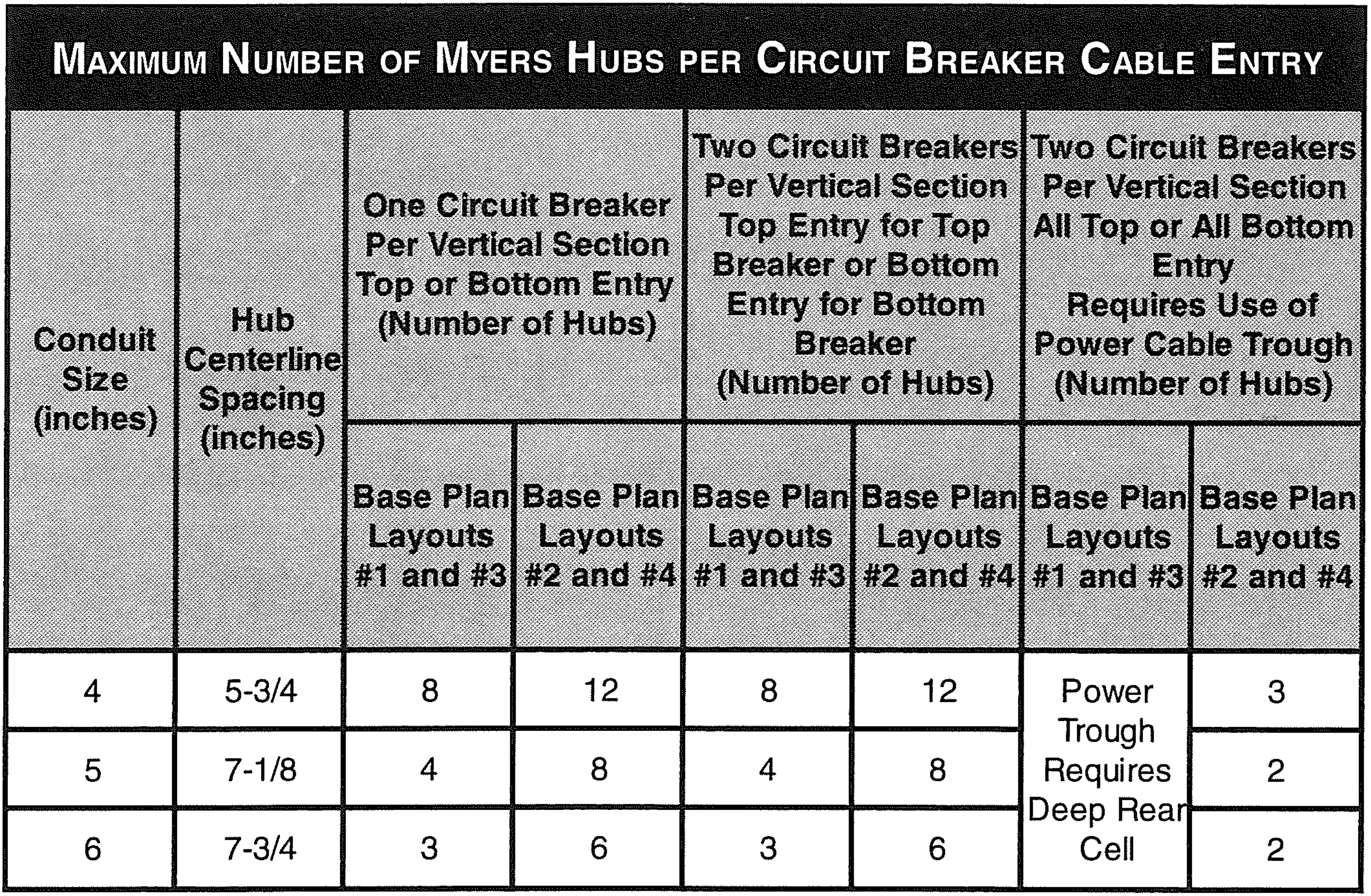


Table K

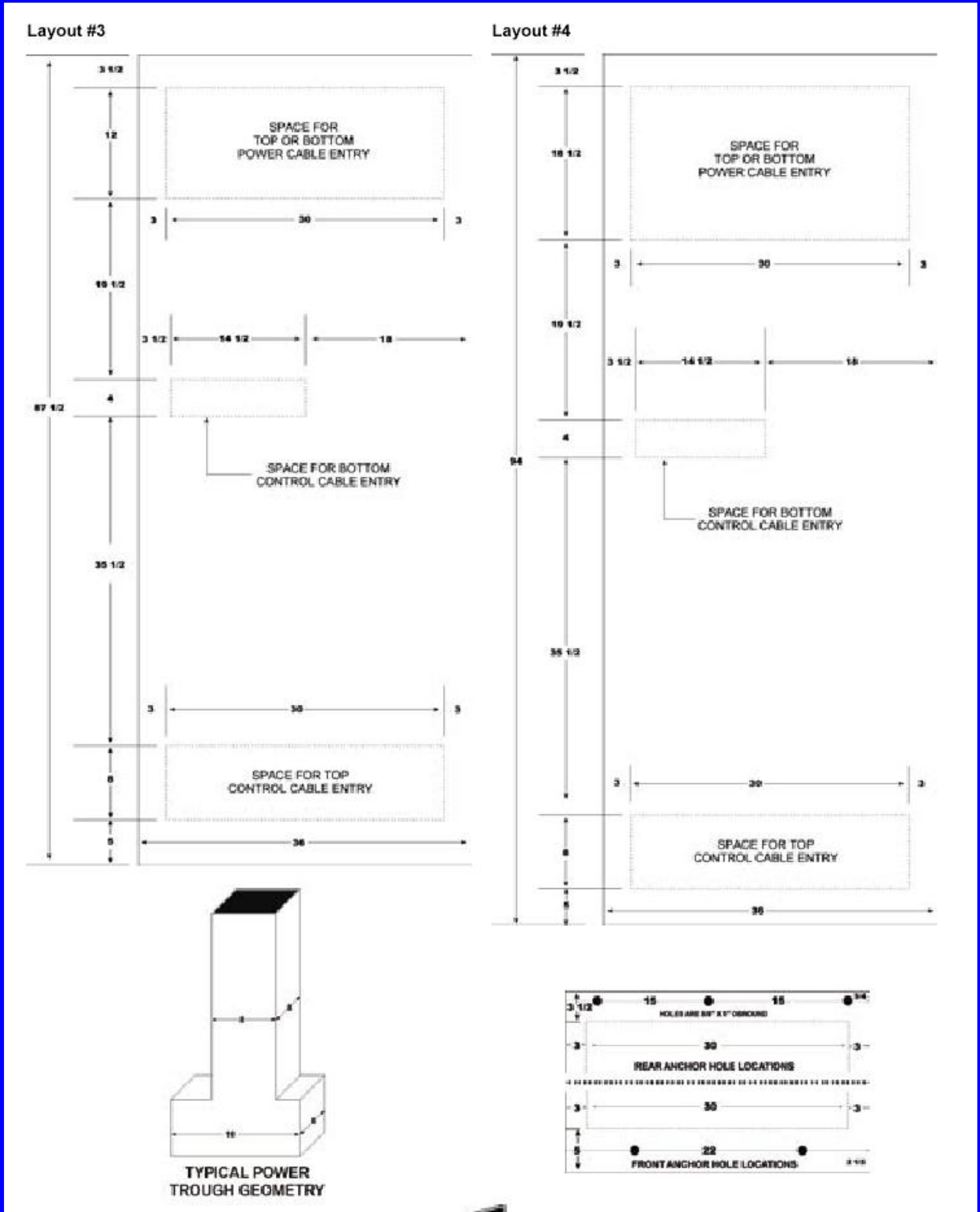
CABLE FILL BY CONDUIT SIZE				
Cable Size (kcmil)	**Outside Diamerter (inches)**	**Cross-sectional Area (Square Inches)**	**Three-Phase Cross-sectional Area (Square Inches)**	**Minimum Conduit Size for Three Cables (inches)**
350	1.43	1.61	4.82	4
500	1.55	1.89	5.66	5
750	1.79	2.52	7.55	5
1000	1.92	2.90	8.69	6



MAXIMUM NUMBER OF MYERS HUBS PER CIRCUIT BREAKER CABLE ENTRY

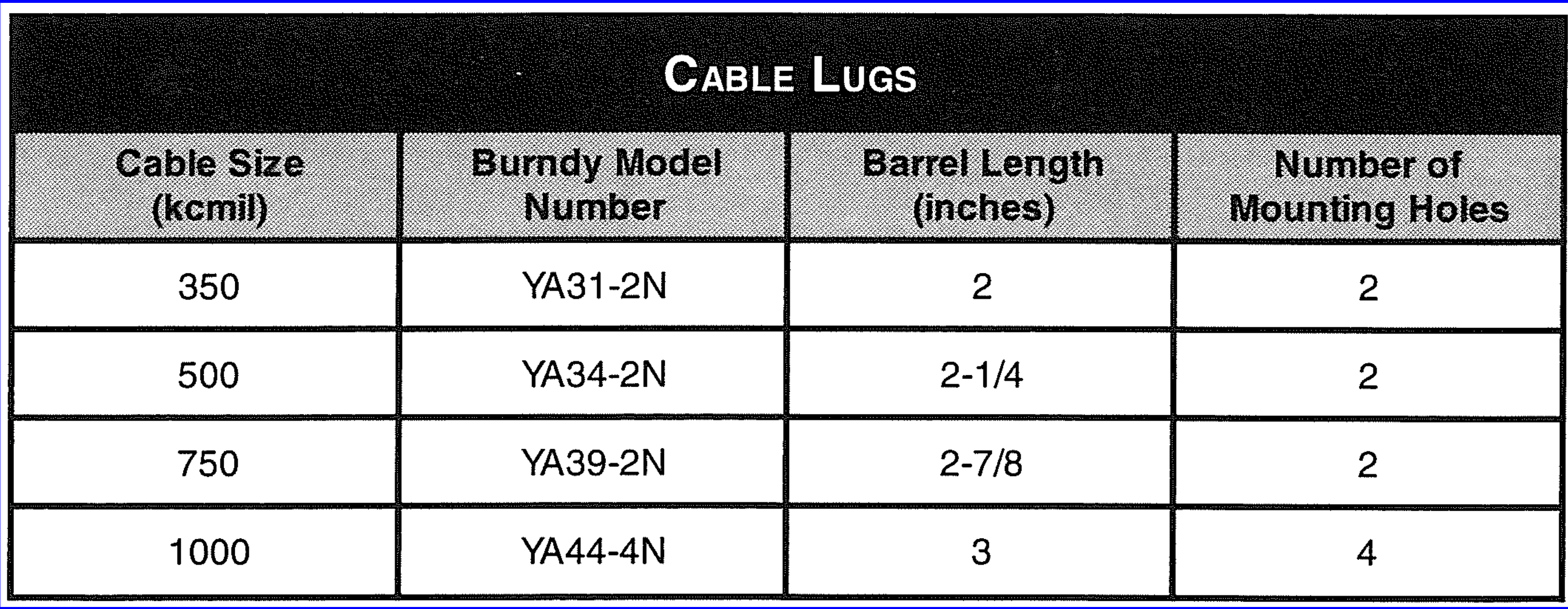
Conduit Size (inches)	Hub Centerline Spacing (inches)	One Circuit Breaker Per Vertical Section Top or Bottom Entry (Number of Hubs)		Two Circuit Breakers Per Vertical Section Top Entry for Top Breaker or Bottom Entry for Bottom Breaker (Number of Hubs)		Two Circuit Breakers Per Vertical Section All Top or All Bottom Entry Requires Use of Power Cable Trough (Number of Hubs)	
		Base Plan Layouts #1 and #3	Base Plan Layouts #2 and #4	Base Plan Layouts #1 and #3	Base Plan Layouts #2 and #4	Base Plan Layouts #1 and #3	Base Plan Layouts #2 and #4
4	5-3/4	8	12	8	12	Power Trough Requires Deep Rear Cell	3
5	7-1/8	4	8	4	8		2
6	7-3/4	3	6	3	6		2

Stub up space



Simple installations

Lug Dimensions



CABLE LUGS

Cable Size (kcmil)	Burndy Model Number	Barrel Length (inches)	Number of Mounting Holes
350	YA31-2N	2	2
500	YA34-2N	2-1/4	2
750	YA39-2N	2-7/8	2
1000	YA44-4N	3	4

No one hole lugs !!

Cable Termination Spacing

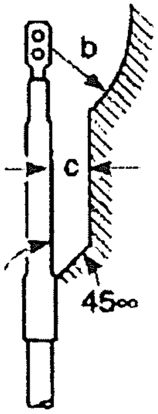


Figure 1
Phase to Ground

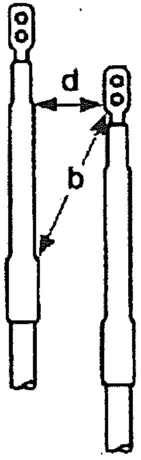


Figure 2
Same Phase

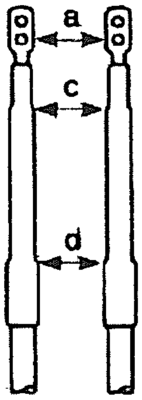


Figure 3
Between Phases

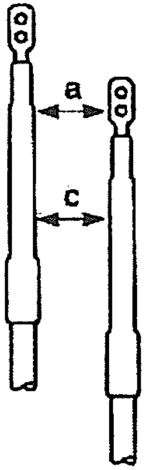


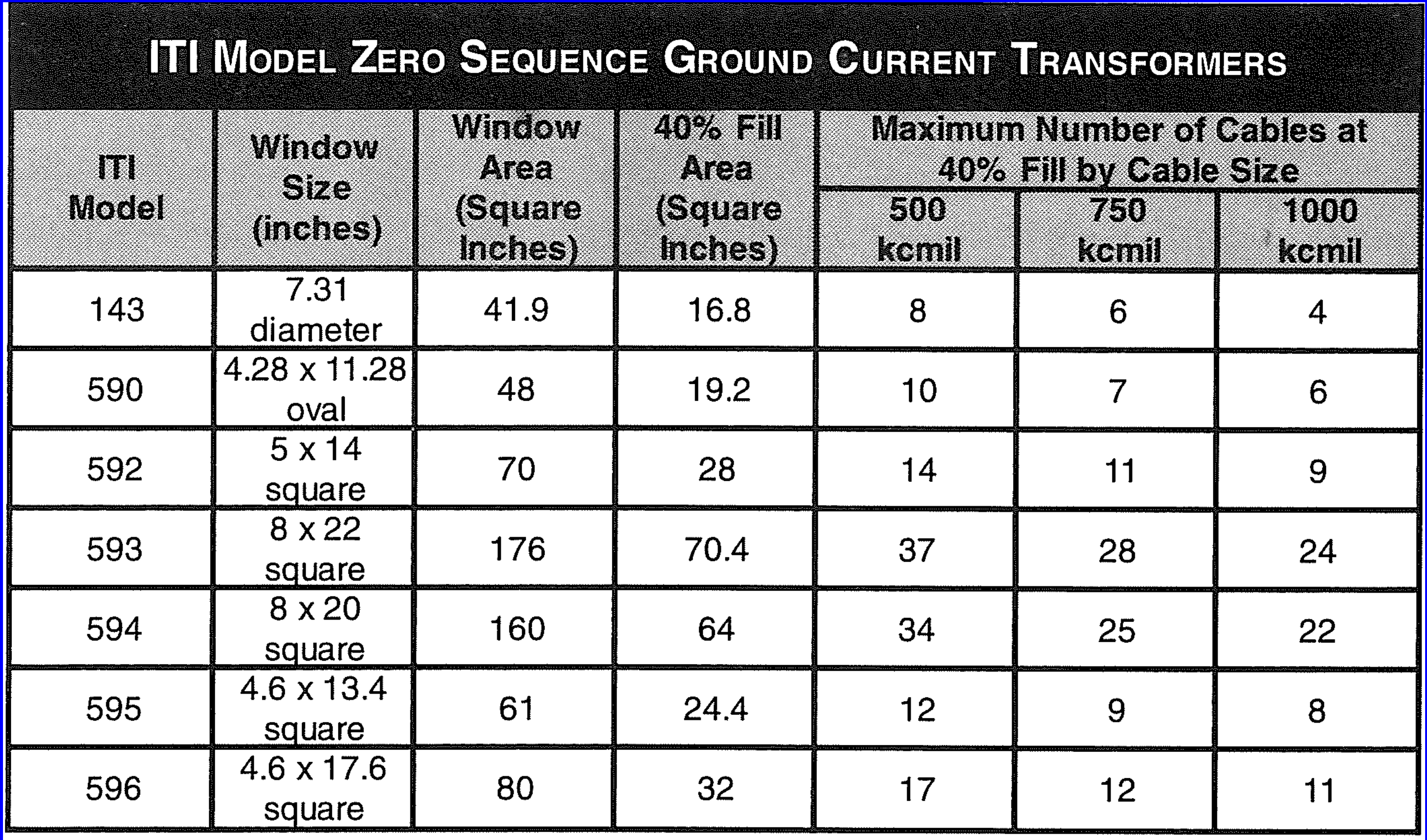
Figure 4
Between Phases

Table N

MINIMUM CABLE CLEARANCE				
Basic Insulation Level (kV)	**a (inches**	**b (inches)**	**c^2 (inches)**	**d (inches)**
60	3.5	2.0	0.8	0.8
95	6.5	3.5	1.2	0.8

Note: The (a) and (b) dimensions for insulated cables and lugs are 2" for 60kV BIL and 3" for 95kV BIL.

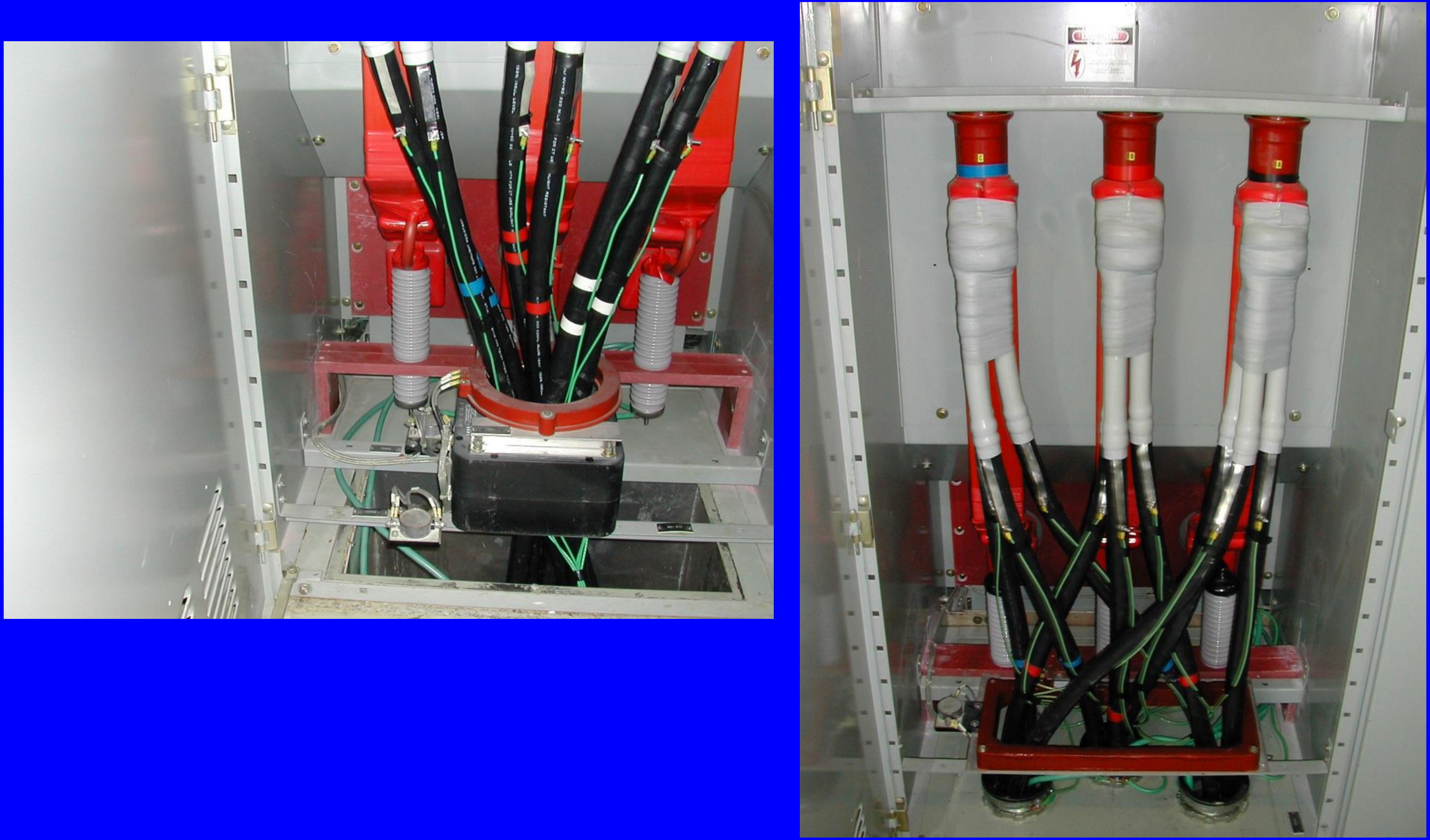
Zero Sequence Sizing



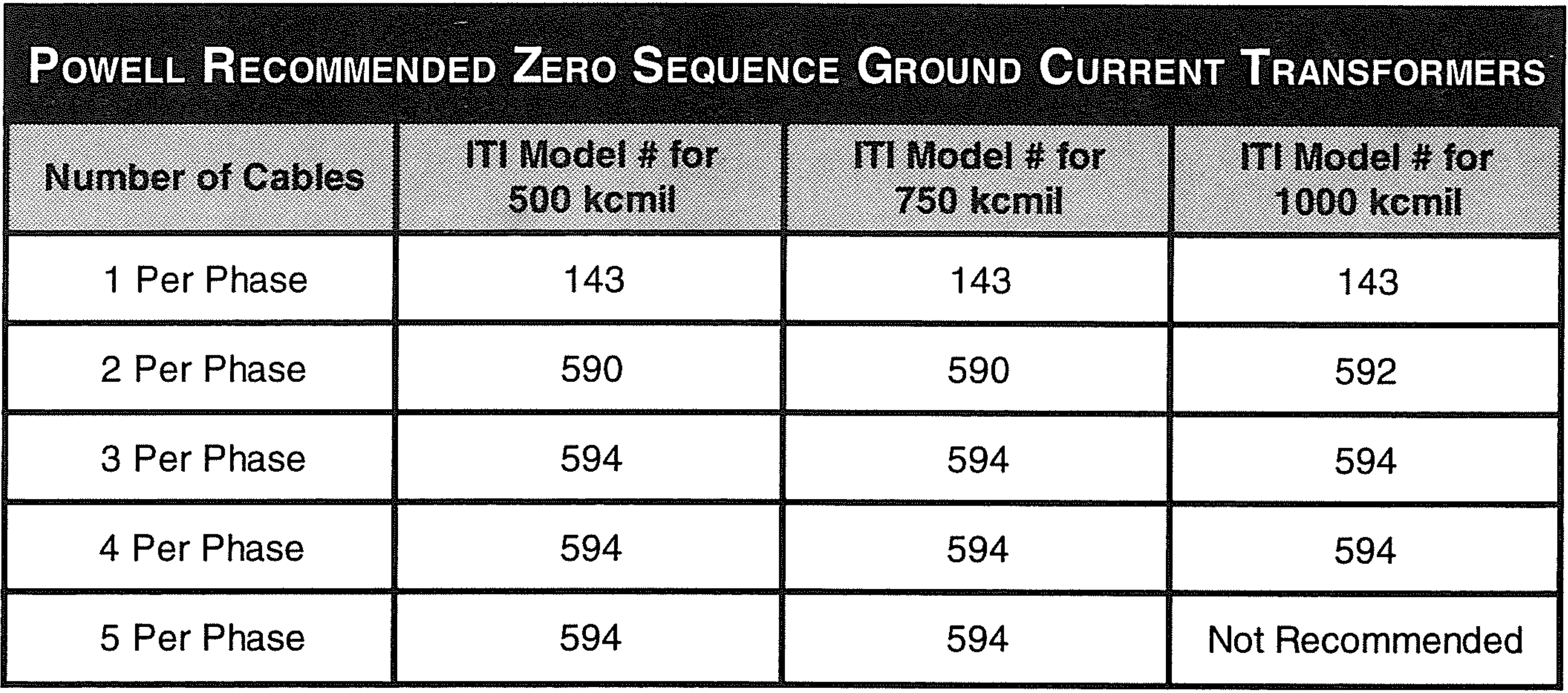
ITI MODEL ZERO SEQUENCE GROUND CURRENT TRANSFORMERS

ITI Model	Window Size (inches)	Window Area (Square Inches)	40% Fill Area (Square Inches)	Maximum Number of Cables at 40% Fill by Cable Size		
				500 kcmil	750 kcmil	1000 kcmil
143	7.31 diameter	41.9	16.8	8	6	4
590	4.28 x 11.28 oval	48	19.2	10	7	6
592	5 x 14 square	70	28	14	11	9
593	8 x 22 square	176	70.4	37	28	24
594	8 x 20 square	160	64	34	25	22
595	4.6 x 13.4 square	61	24.4	12	9	8
596	4.6 x 17.6 square	80	32	17	12	11

Zero Sequence CT’s



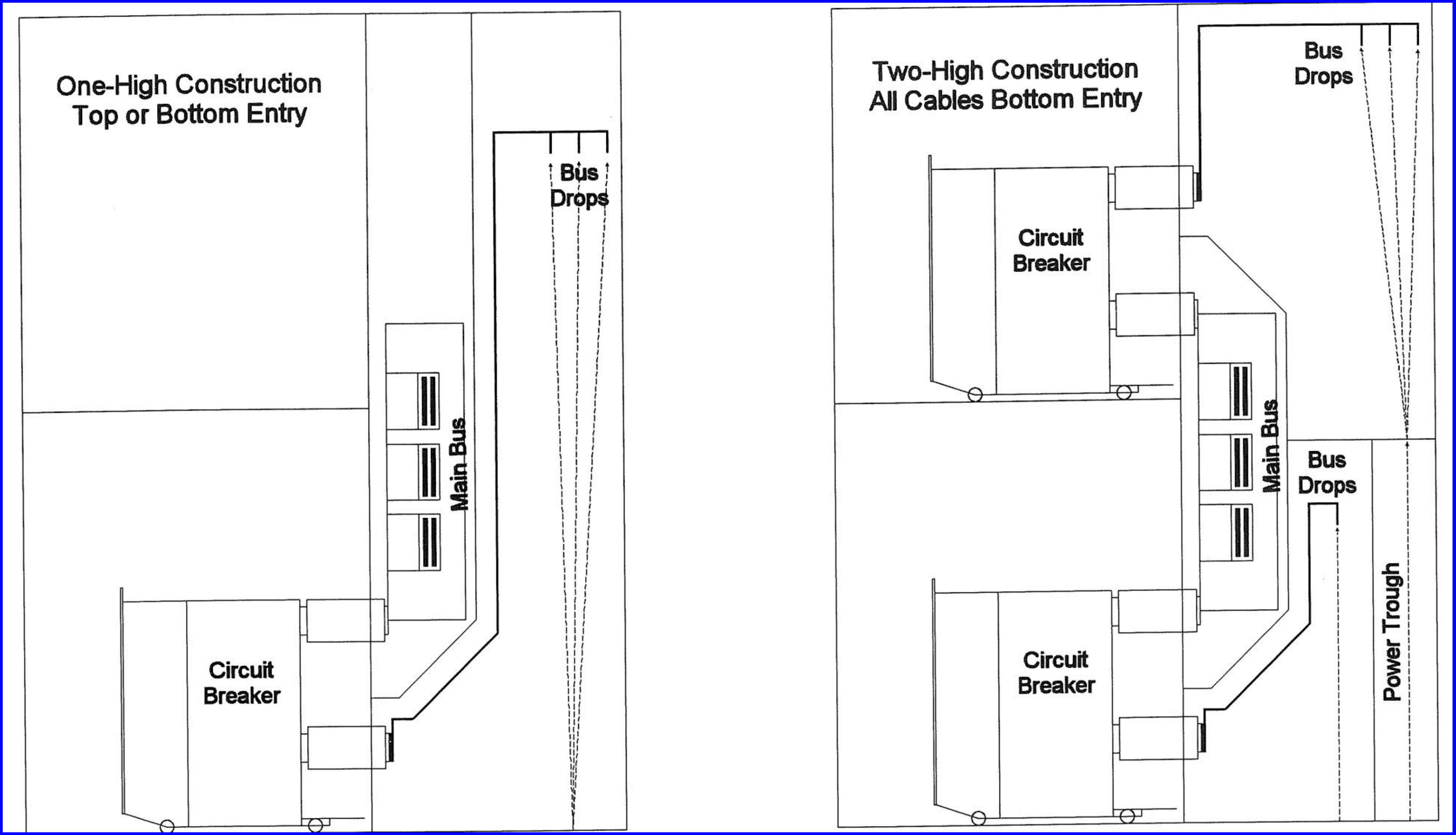
Physical sizing of Zero Sequence Ct



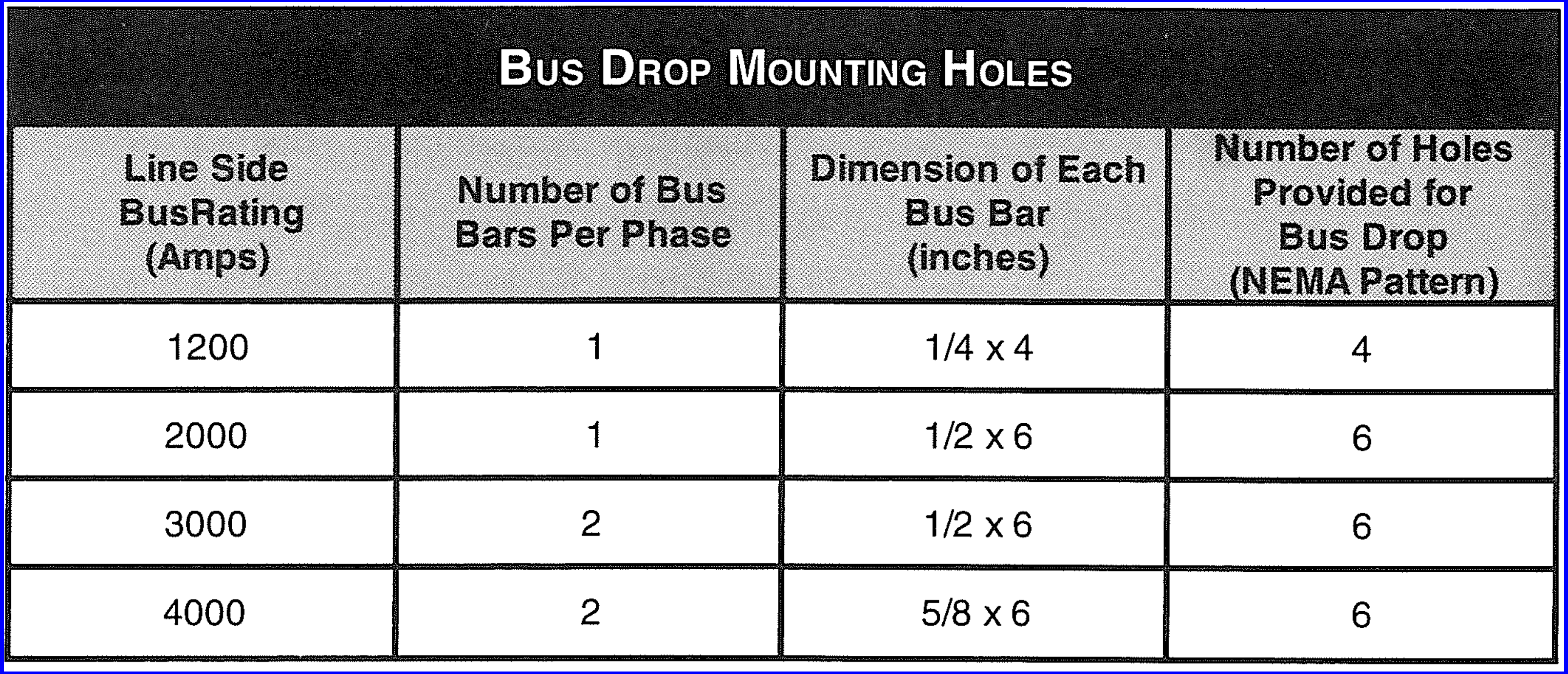
POWELL RECOMMENDED ZERO SEQUENCE GROUND CURRENT TRANSFORMERS

Number of Cables	ITI Model # for 500 kcmil	ITI Model # for 750 kcmil	ITI Model # for 1000 kcmil
1 Per Phase	143	143	143
2 Per Phase	590	590	592
3 Per Phase	594	594	594
4 Per Phase	594	594	594
5 Per Phase	594	594	Not Recommended

Cutaway View



Bus Drops Hole Pattern



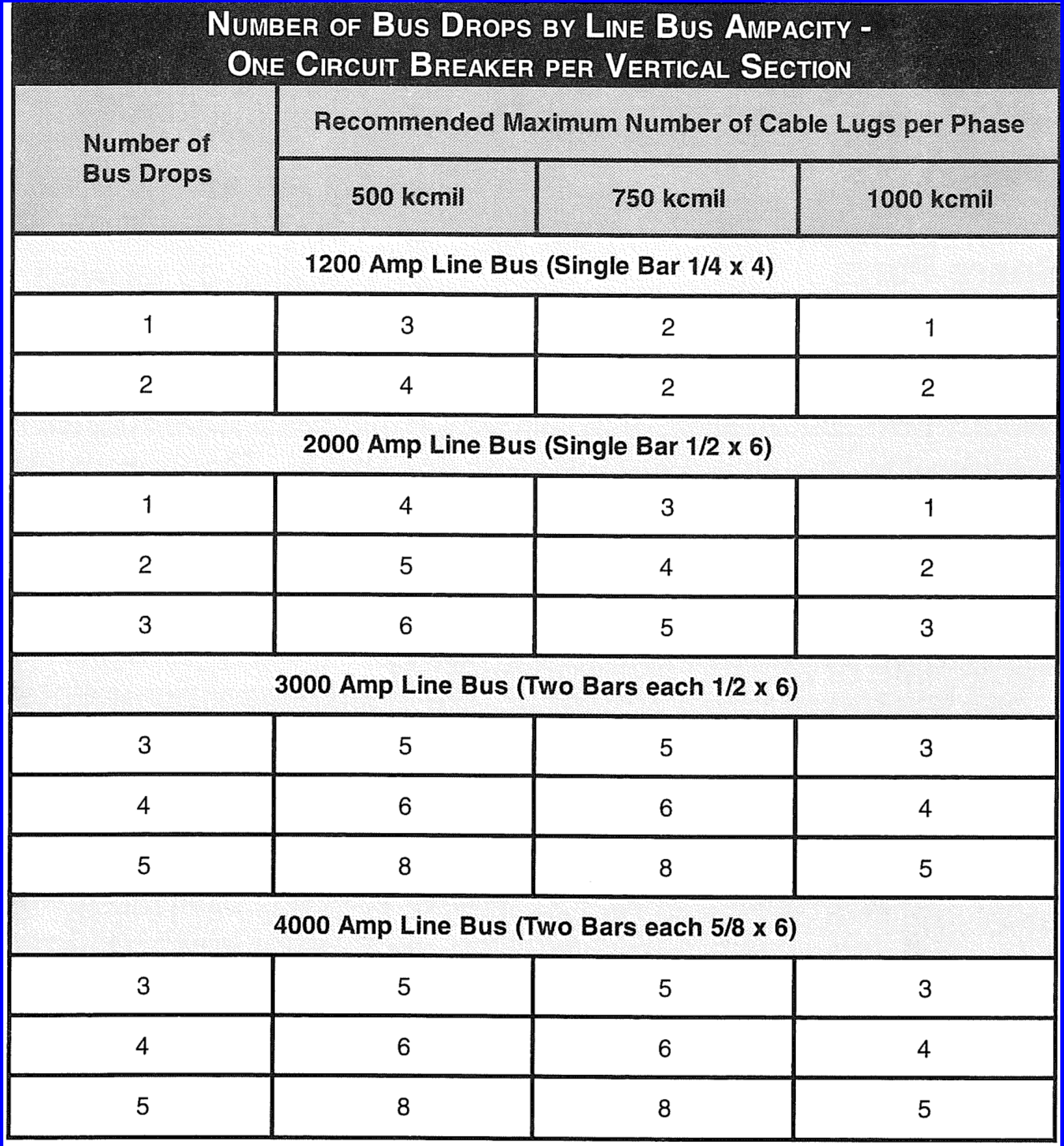
Bus Drop Mounting Holes

Line Side BusRating (Amps)	Number of Bus Bars Per Phase	Dimension of Each Bus Bar (inches)	Number of Holes Provided for Bus Drop (NEMA Pattern)
1200	1	1/4 x 4	4
2000	1	1/2 x 6	6
3000	2	1/2 x 6	6
4000	2	5/8 x 6	6

How many lugs can we land on a drop

BIL is left unbooted

Number of lugs per drop for one high swgr



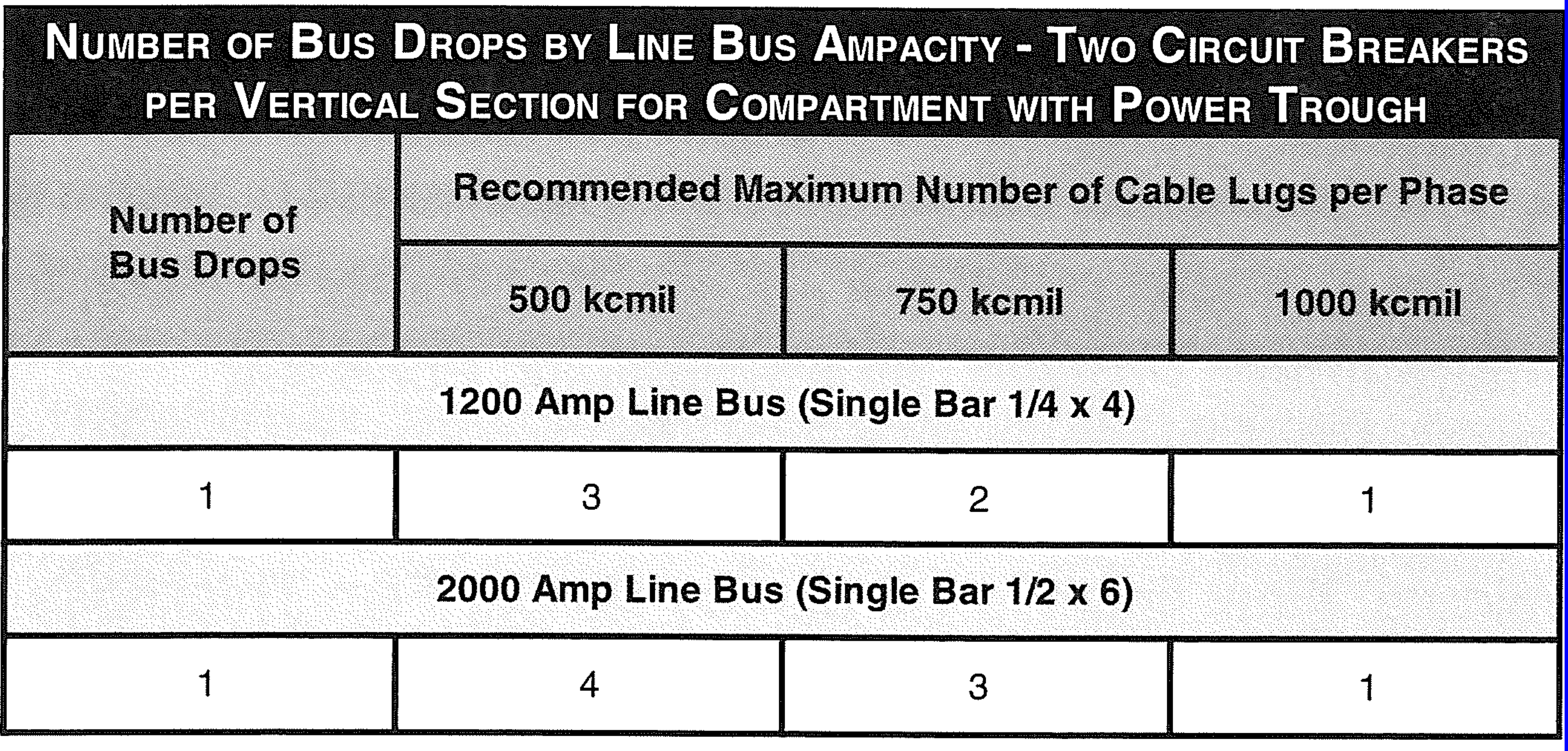
NUMBER OF BUS DROPS BY LINE BUS AMPACITY -
ONE CIRCUIT BREAKER PER VERTICAL SECTION

Number of Bus Drops	Recommended Maximum Number of Cable Lugs per Phase		
	500 kcmil	750 kcmil	1000 kcmil
1200 Amp Line Bus (Single Bar 1/4 x 4)			
1	3	2	1
2	4	2	2
2000 Amp Line Bus (Single Bar 1/2 x 6)			
1	4	3	1
2	5	4	2
3	6	5	3
3000 Amp Line Bus (Two Bars each 1/2 x 6)			
3	5	5	3
4	6	6	4
5	8	8	5
4000 Amp Line Bus (Two Bars each 5/8 x 6)			
3	5	5	3
4	6	6	4
5	8	8	5

Lugs per drop

Cable trough And Surge arrestors

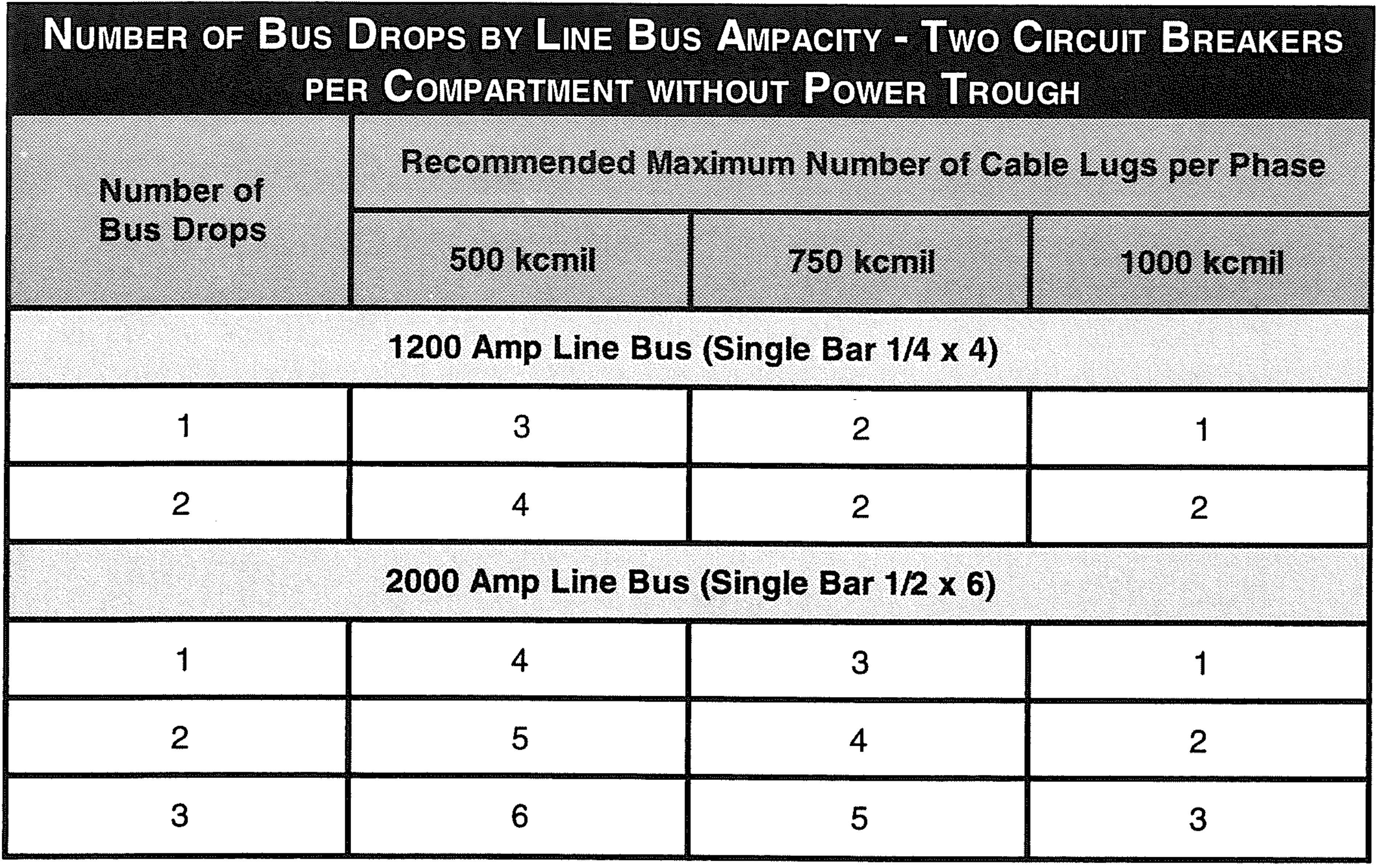
Lugs per drop for two high swgr



Number of Bus Drops by Line Bus Ampacity - Two Circuit Breakers per Vertical Section for Compartment with Power Trough

Number of Bus Drops	Recommended Maximum Number of Cable Lugs per Phase		
	500 kcmil	750 kcmil	1000 kcmil
1200 Amp Line Bus (Single Bar 1/4 x 4)			
1	3	2	1
2000 Amp Line Bus (Single Bar 1/2 x 6)			
1	4	3	1

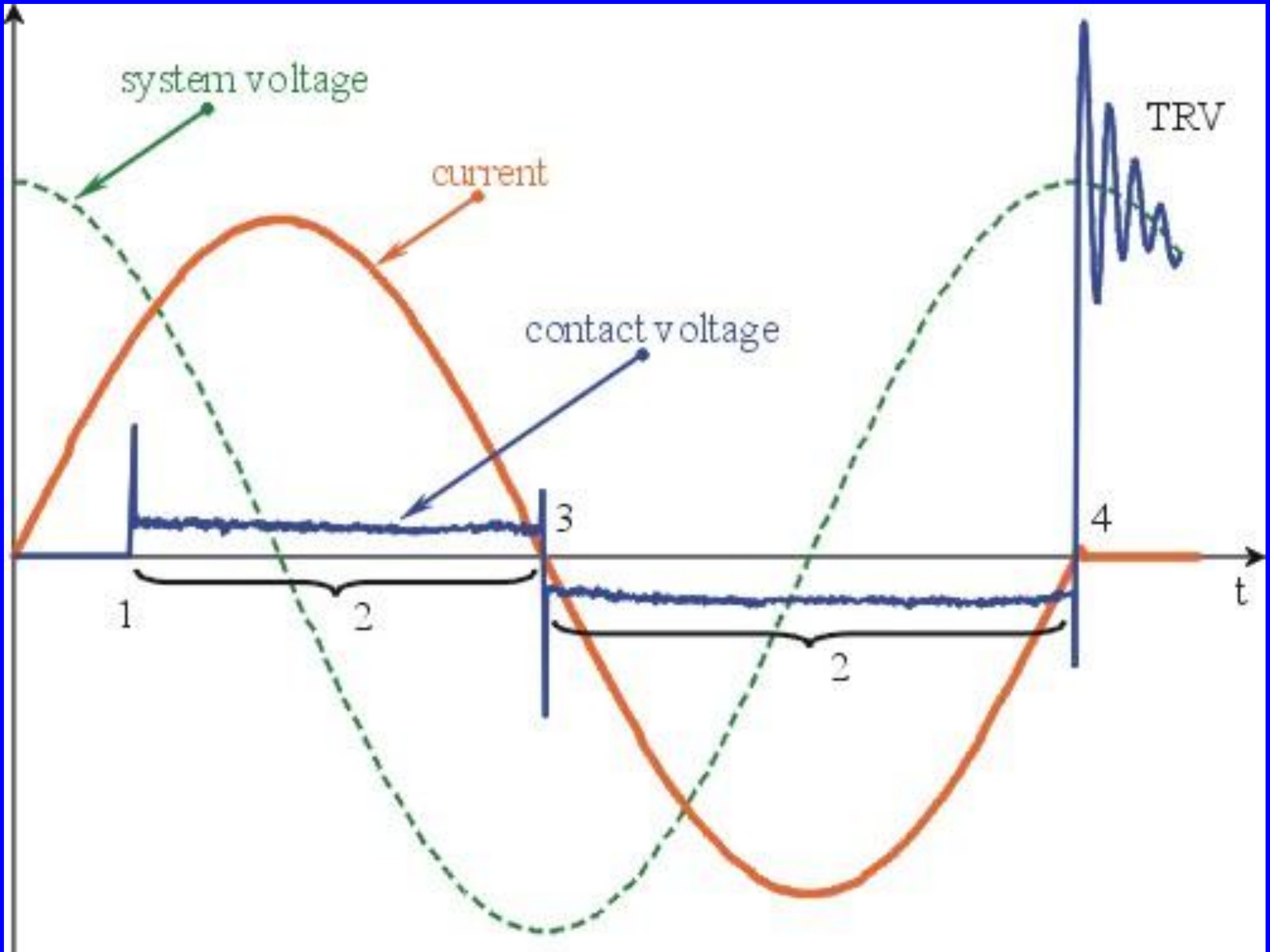
Lugs per Drop 2 High No Trough



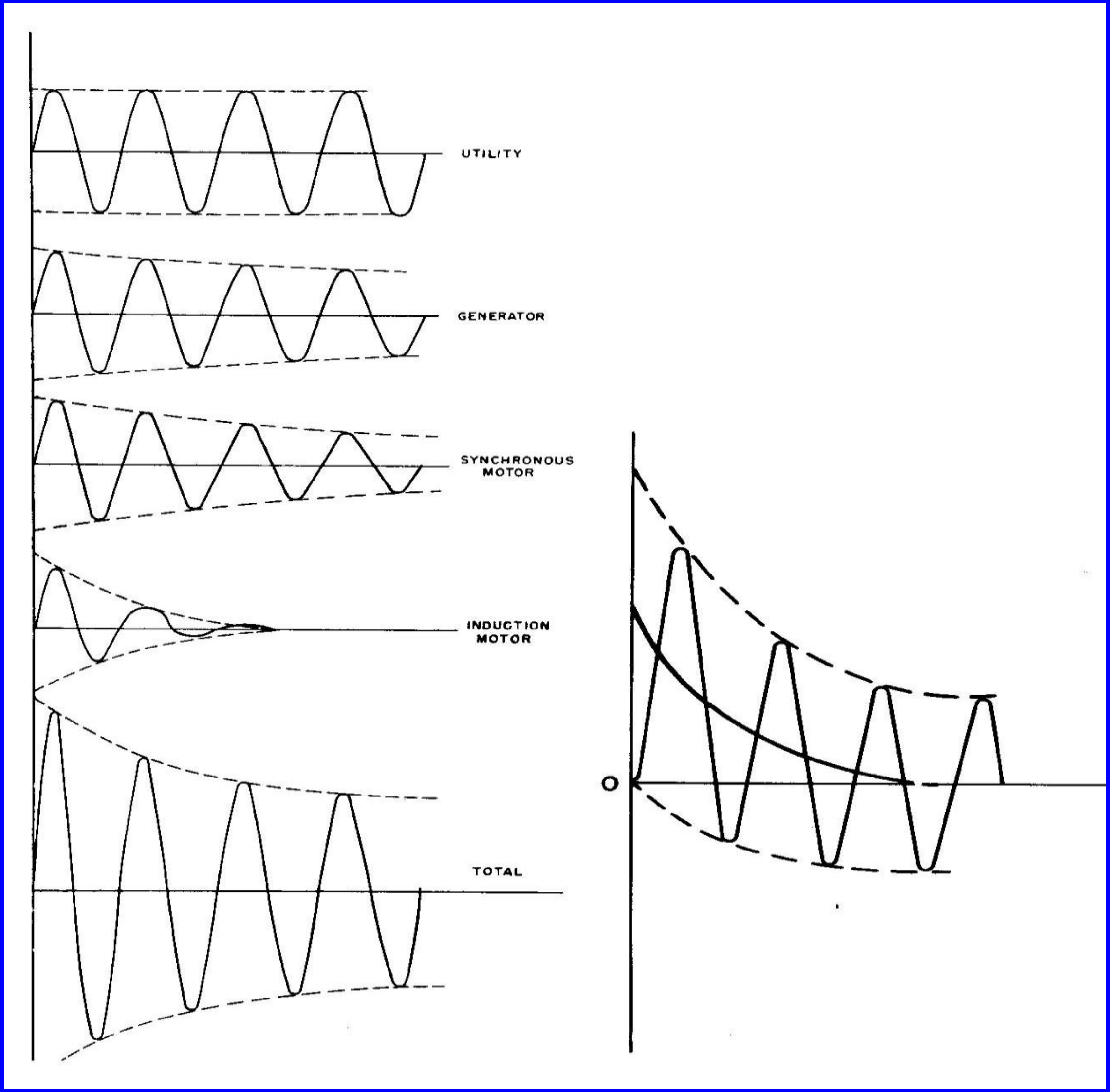
NUMBER OF BUS DROPS BY LINE BUS AMPACITY - TWO CIRCUIT BREAKERS PER COMPARTMENT WITHOUT POWER TROUGH

Number of Bus Drops	Recommended Maximum Number of Cable Lugs per Phase		
	500 kcmil	750 kcmil	1000 kcmil
1200 Amp Line Bus (Single Bar 1/4 x 4)			
1	3	2	1
2	4	2	2
2000 Amp Line Bus (Single Bar 1/2 x 6)			
1	4	3	1
2	5	4	2
3	6	5	3

Circuit Breaker Selection



Short Circuit Current Contribution



Utility

Generator

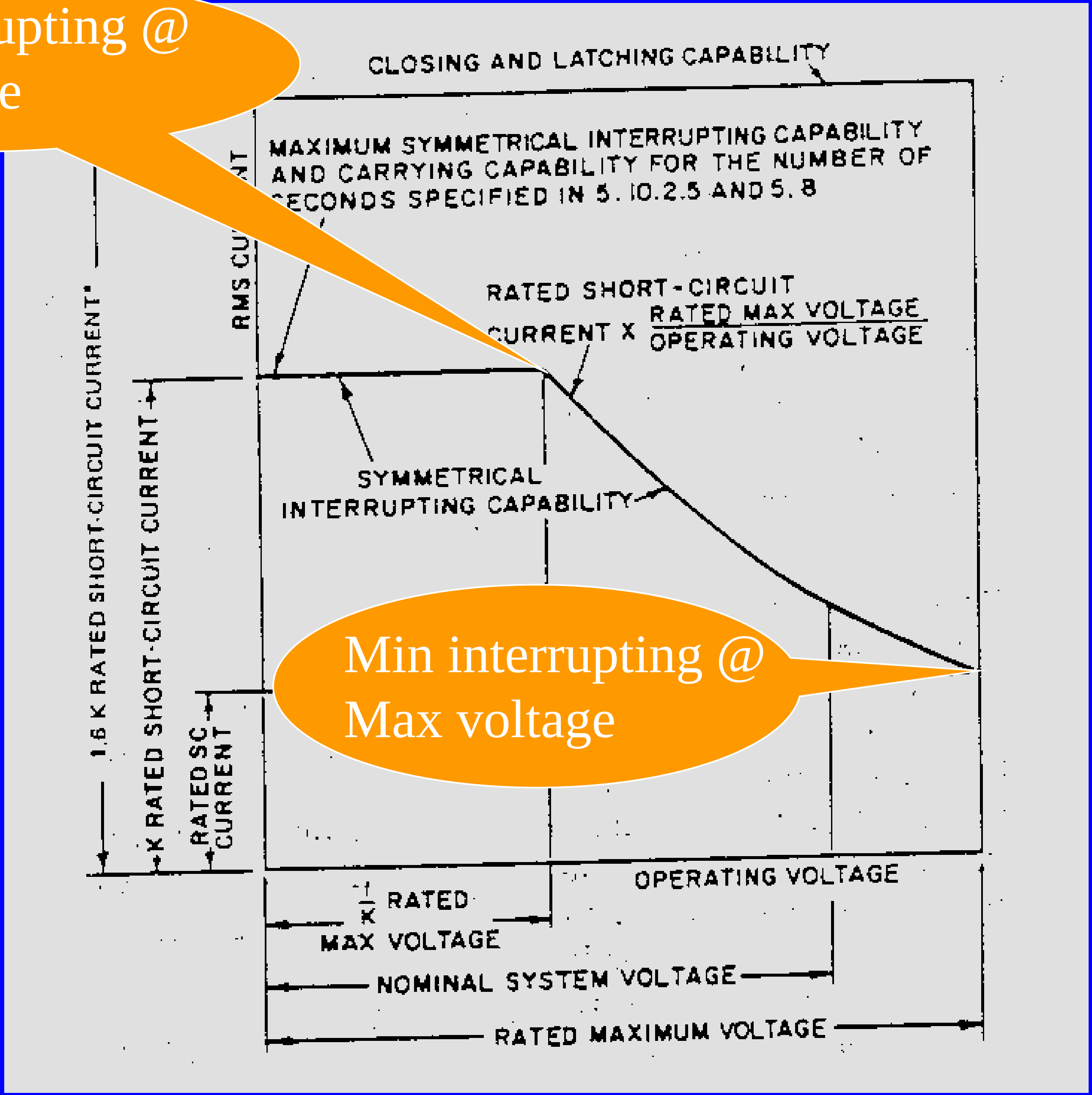
Synchronous Motor

Induction Motor

Total Fault Current

Symmetrical Asymmetrical

Old MVA Short Circuit Rating



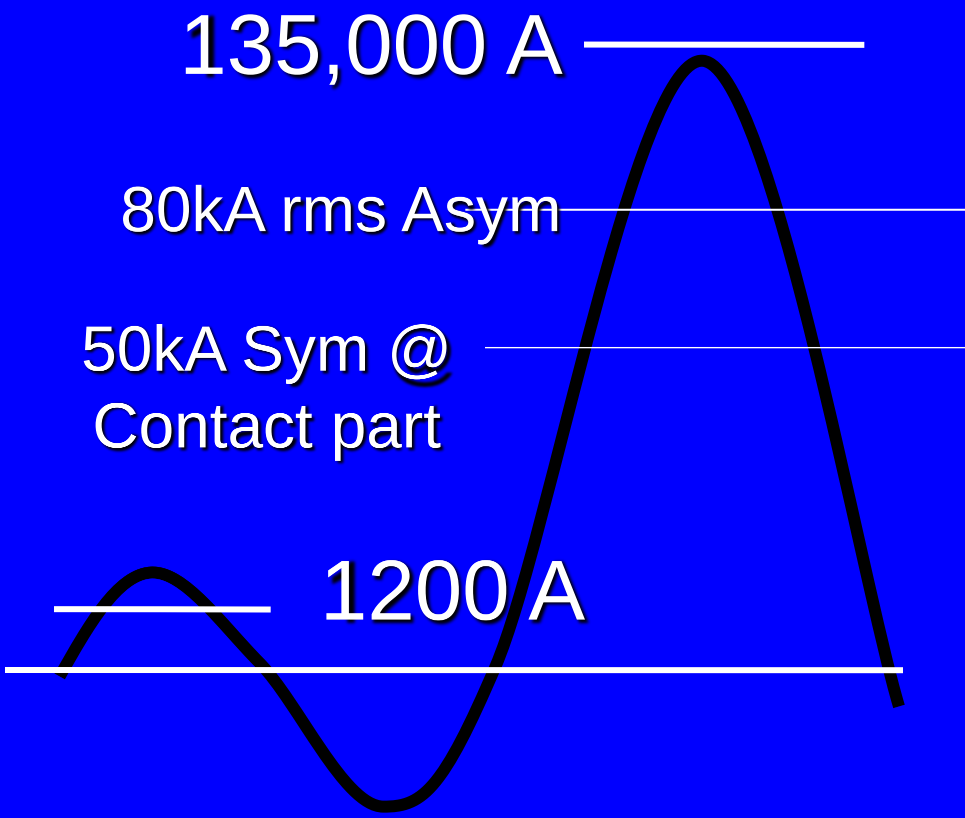
Max interrupting @ Min voltage

Min interrupting @ Max voltage

System Capability	*Equipment Rating*
Short Circuit at Contact part	Interrupting rating
X/R	%dc at contact part
Possible asymmetrical current	
Back-up clearing time	Short time rating
Momentary current	Latch & Close of Breaker
	Momentary & Short Time of Switchgear

SC Latch & Close Ratings

- Rated Momentary Current: The maximum total current the switchgear shall be required to withstand; peak of the maximum cycle
- Max current breaker can latch and stay closed
- New standard - in crest amperes
- Asymmetrical clearing time can be 0.2 cycles longer



135,000 A

80kA rms Asym

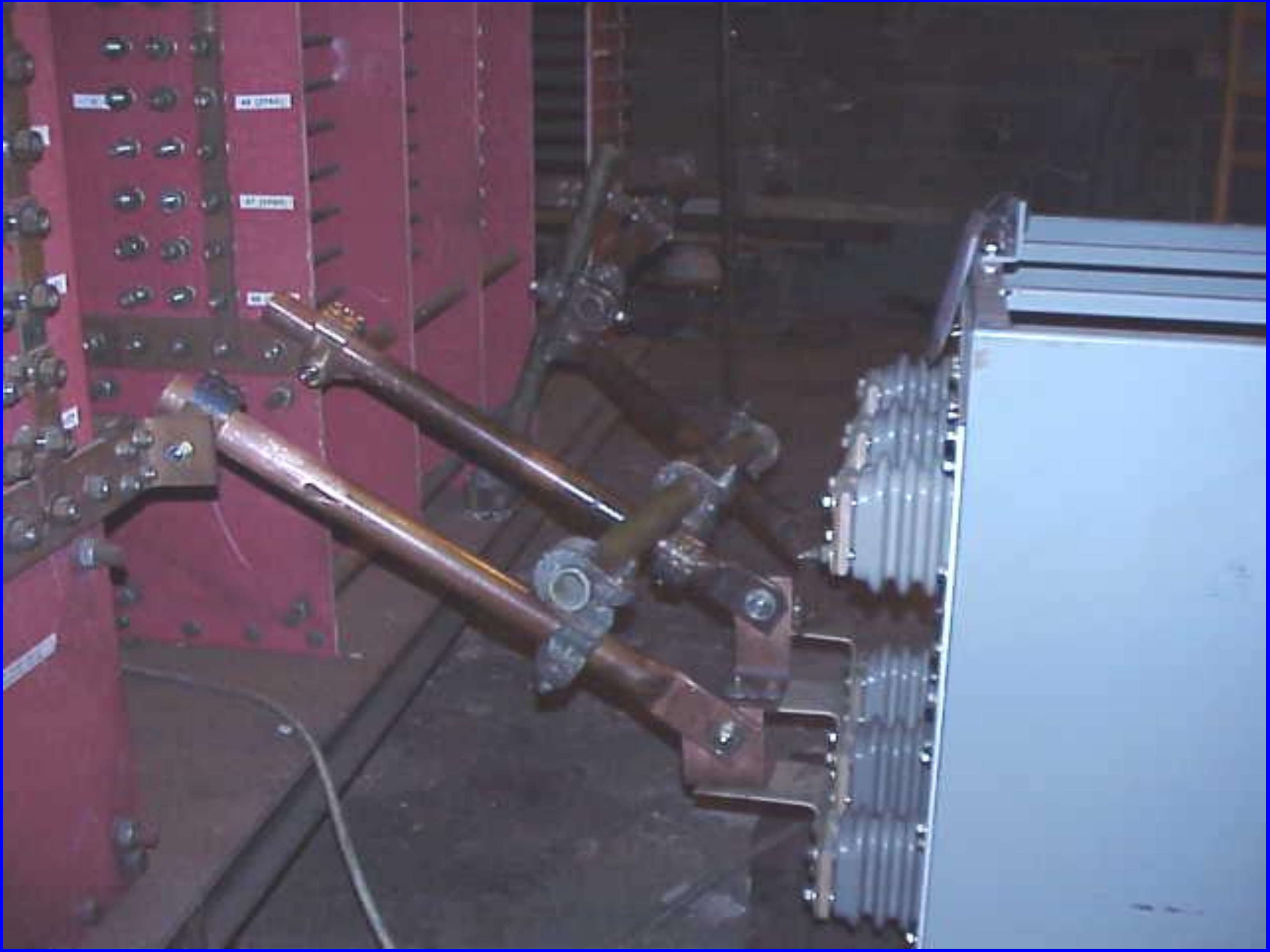
50kA Sym @
Contact part

1200 A

SC Interrupting Ratings

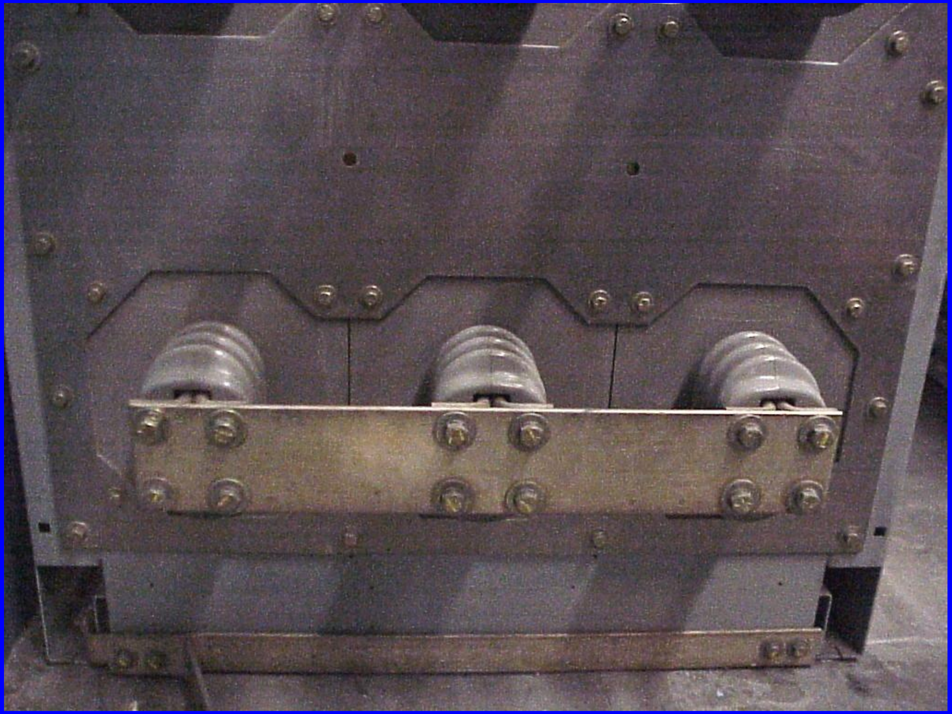
- Symmetrical current in rms amperes breaker interrupt through out voltage range
- Rating is based on current at time of contacts part
- Test assumes a min. relay time of ½ cycle
- Max relay tripping delay up to 2 sec

Breaker Short Circuit



Bolted Fault vs. Arcing Fault in Medium-Voltage Switchgear

- Bolted Faults
  - **Current I^2t**
  - **Mechanical forces**
- Testing
  - Interrupting capability
  - Thermal capacity of bus
  - Mechanical bracing of bus



Bus bracing failure

3000A Main bus at 63kA sym / 135kA crest

Max force from fault

$$F = 43.2kI^2 \frac{L}{s} x10^{-7}$$

F = force at crest for single phase fault
k = Shape factor
I = current per conductor in amps
L = length of conductor in feet
S = distance between conductor centers in inches

S Factor Chart

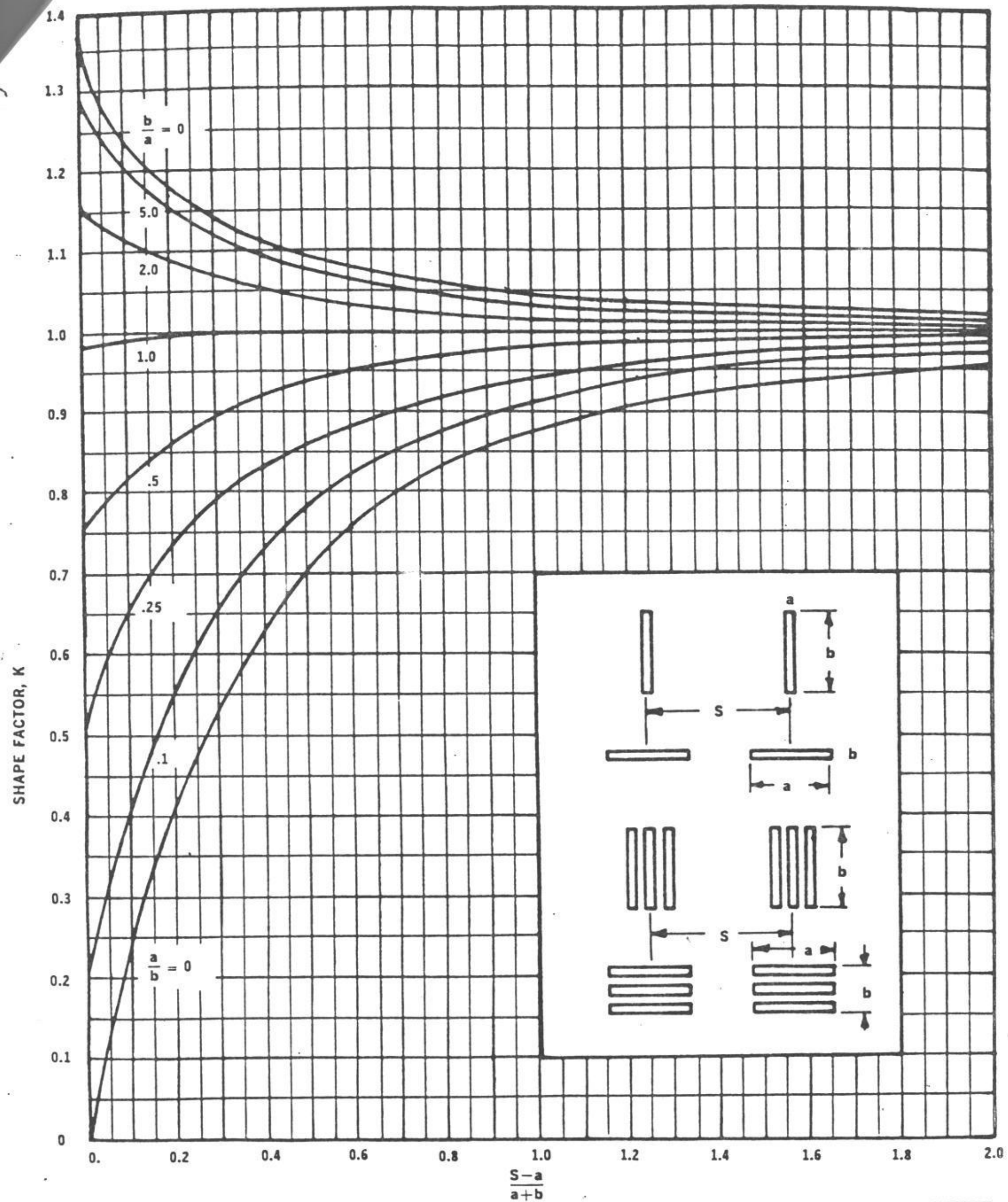
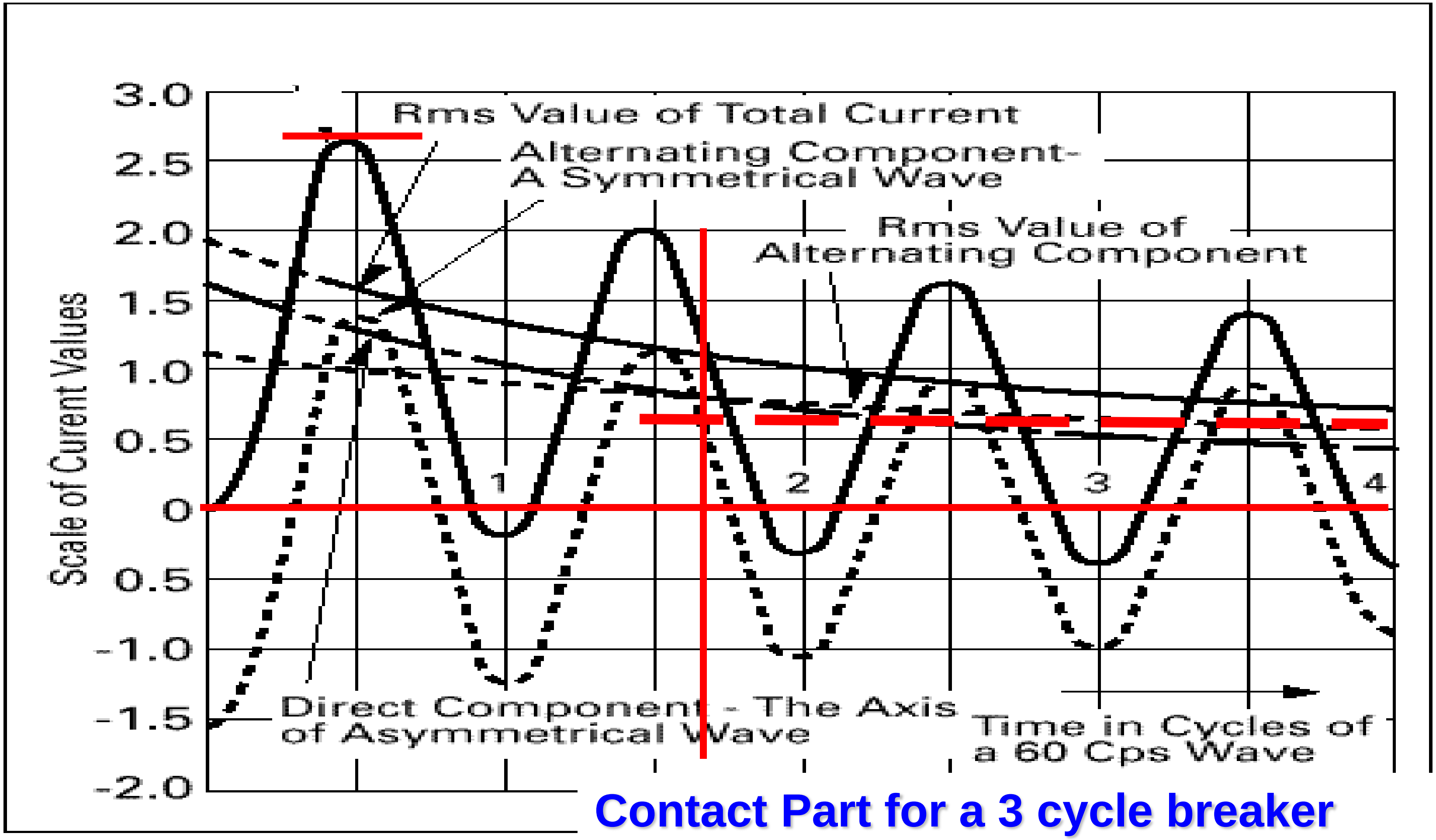


FIGURE 20 Shape factor, K, for rectangular conductors in various positions and arrangements.

REF. 5

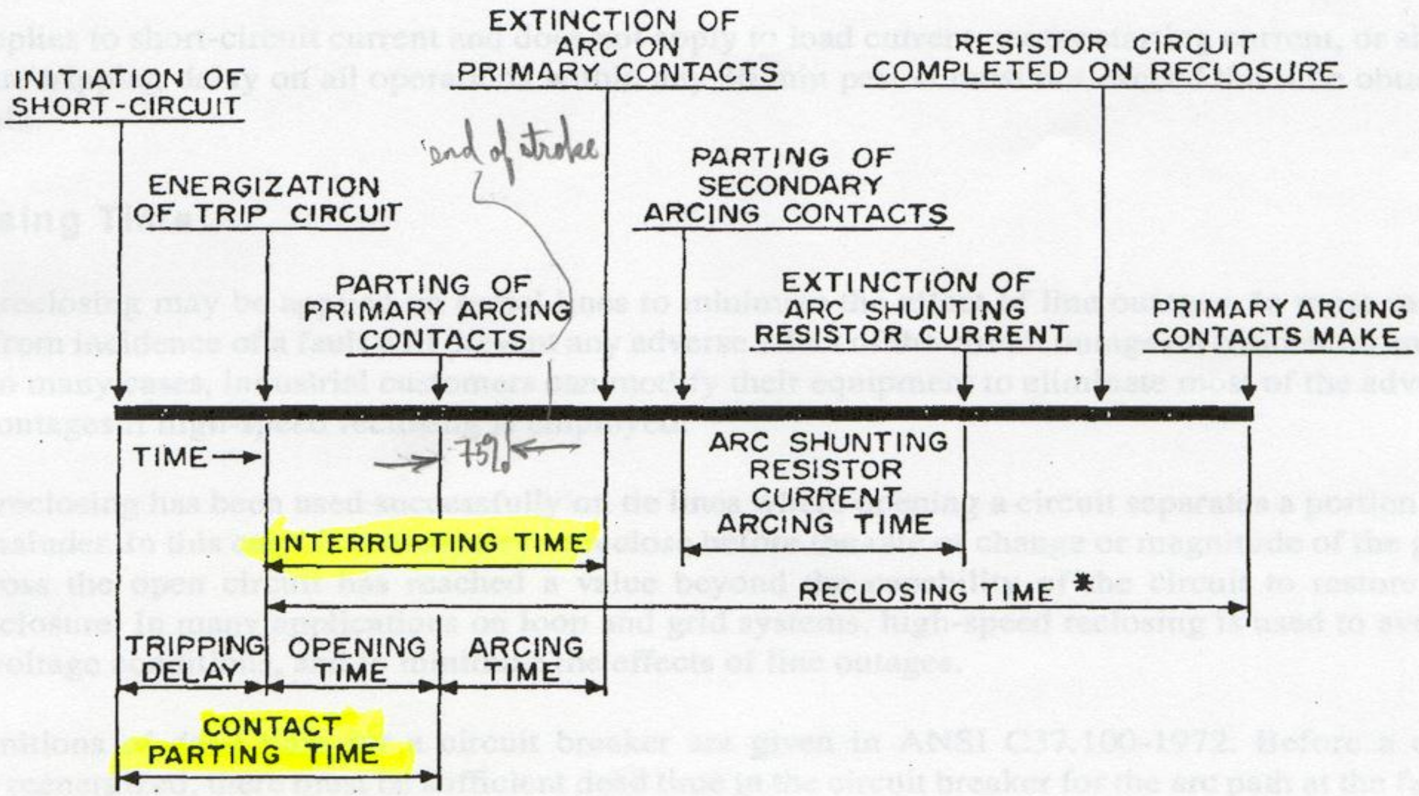
Short Circuit Current



Contact Part for a 3 cycle breaker

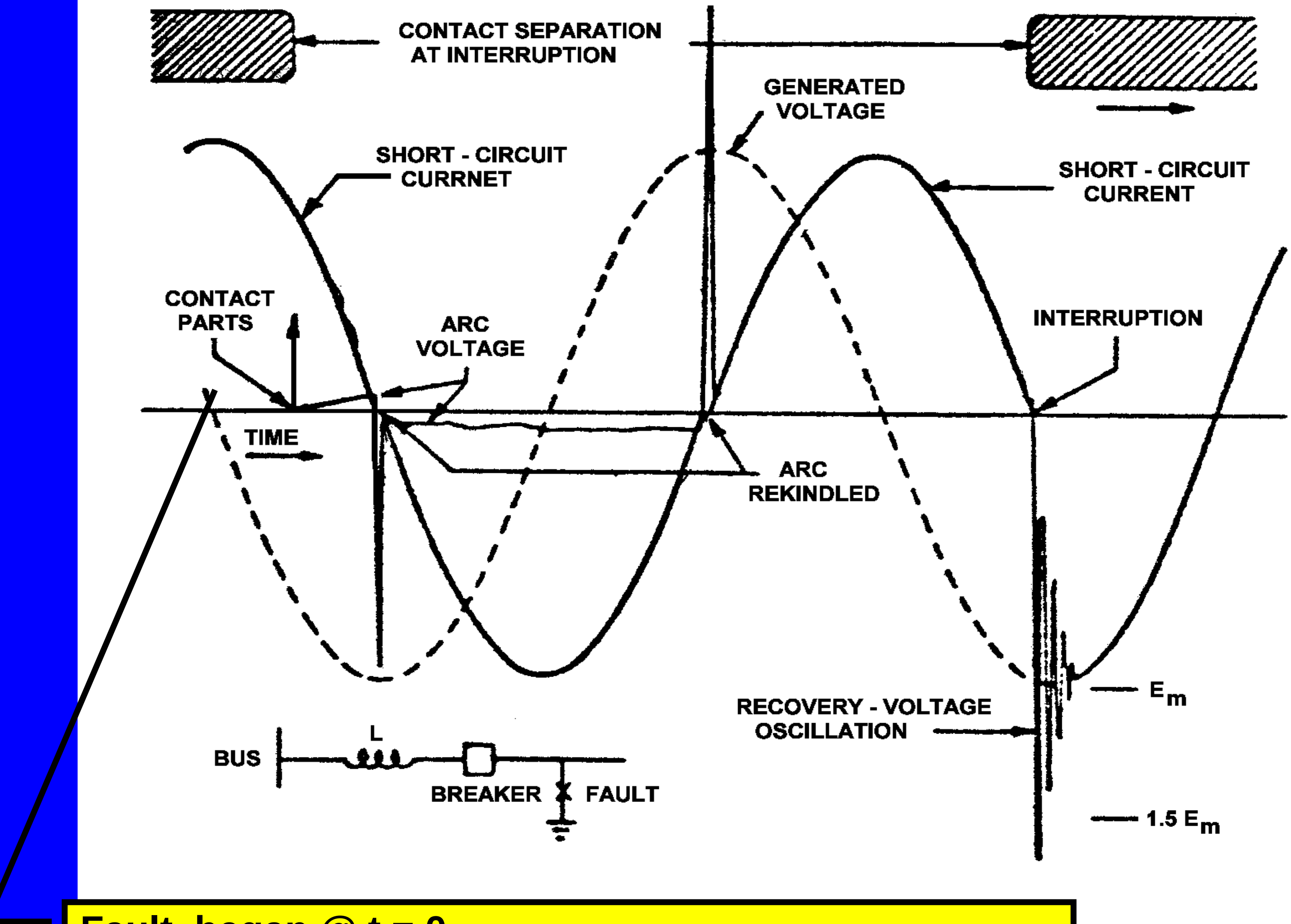
Structure of an Asymmetrical Current Wave

Circuit Breaker Timing



(*) RECLOSING TIME IS THE TIME INTERVAL BETWEEN ENERGIZATION OF THE TRIP CIRCUIT AND MAKING OF THE PRIMARY ARCING CONTACTS. WHERE LOW OHMIC RESISTORS ARE USED, MAKING OF THE RESISTOR CONTACT ON RECLOSURE MAY BE MORE SIGNIFICANT.

Figure 2— Operating Time



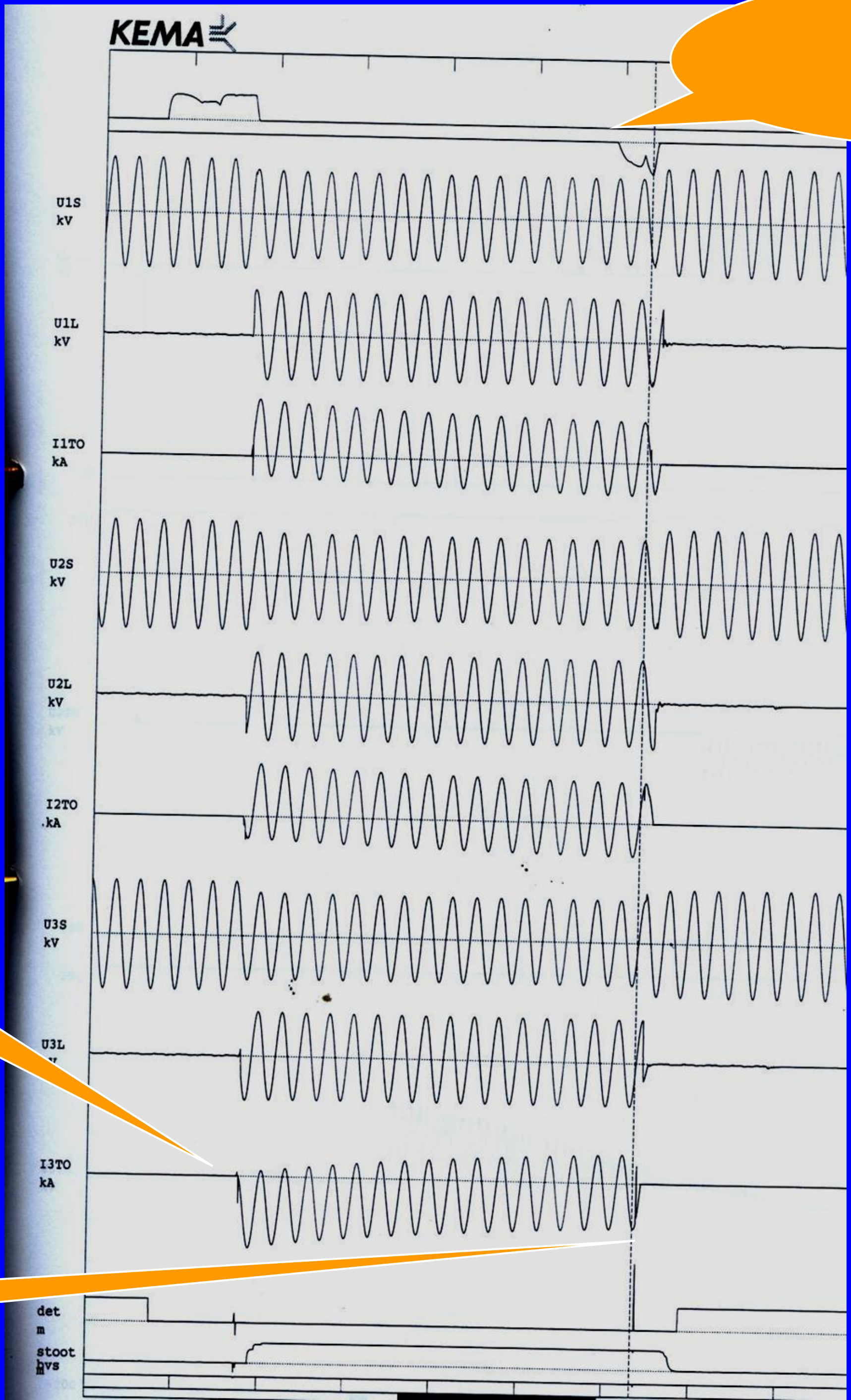
Fault began @ t = 0
Relay tells breaker to open @ t= ½ cycle
3 cycle breaker takes 11/2 cycles before contact part

Typical Circuit Breaker Timing

Opening time (cycles)	**Rated interrupting time**
1.0	2 cycle
1.5 (25ms)	3 cycle
2.5 (42ms)	5 cycle
3.5	8 cycle

Contact part = opening time + ½ cycle for minimum relay time

3 phase fault current



Trip coil energized

Gen Ph A

Ph A current

Gen Ph B

Ph B current

Gen Ph C

Ph C current

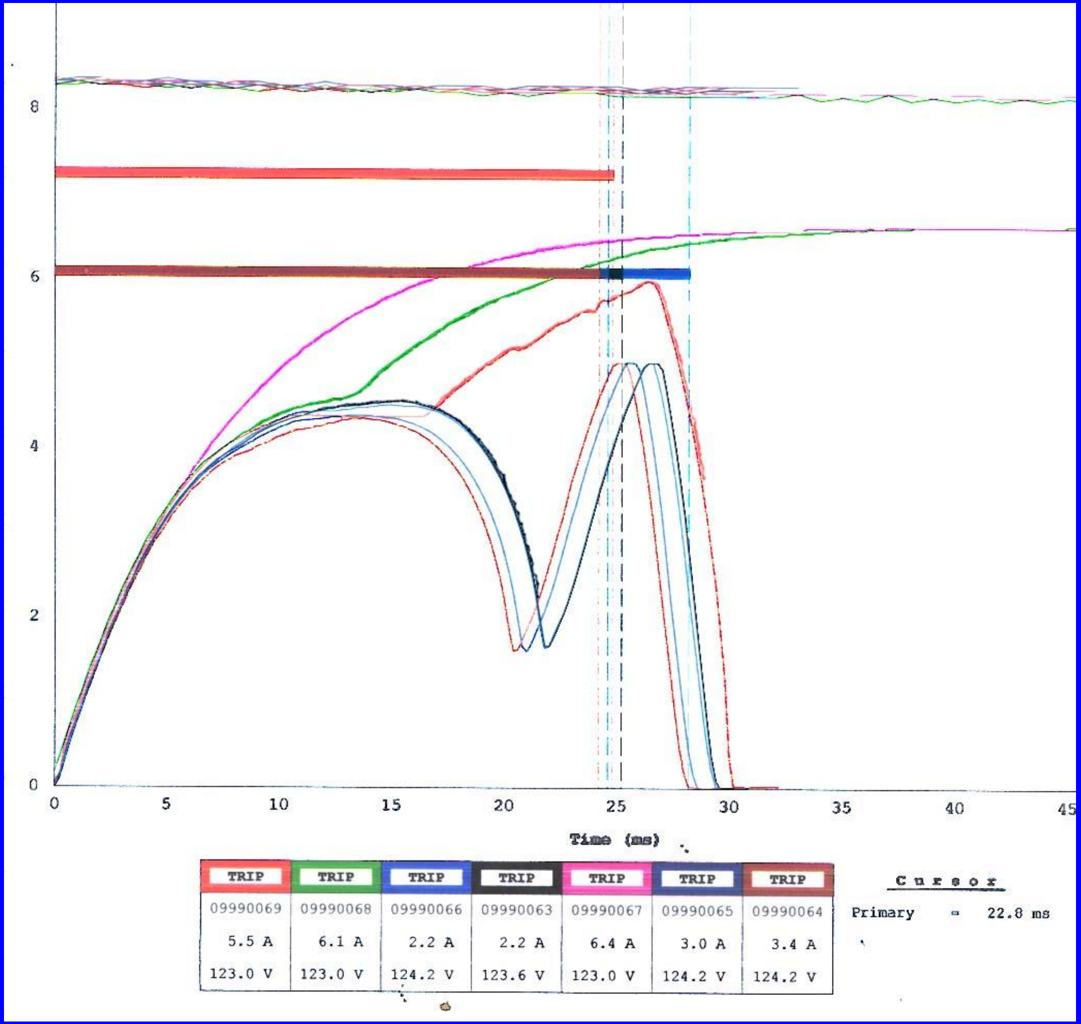
Asymmetrical current

TRV

Mechanism Speed

- Breaker Timing
  - First time operation
  - Latch operation
  - Speed
- Breaker Trip

Current vs voltage



TRIP	TRIP	TRIP	TRIP	TRIP	TRIP	TRIP
09990069	09990068	09990066	09990063	09990067	09990065	09990064
5.5 A	6.1 A	2.2 A	2.2 A	6.4 A	3.0 A	3.4 A
123.0 V	123.0 V	124.2 V	123.6 V	123.0 V	124.2 V	124.2 V

Cursor

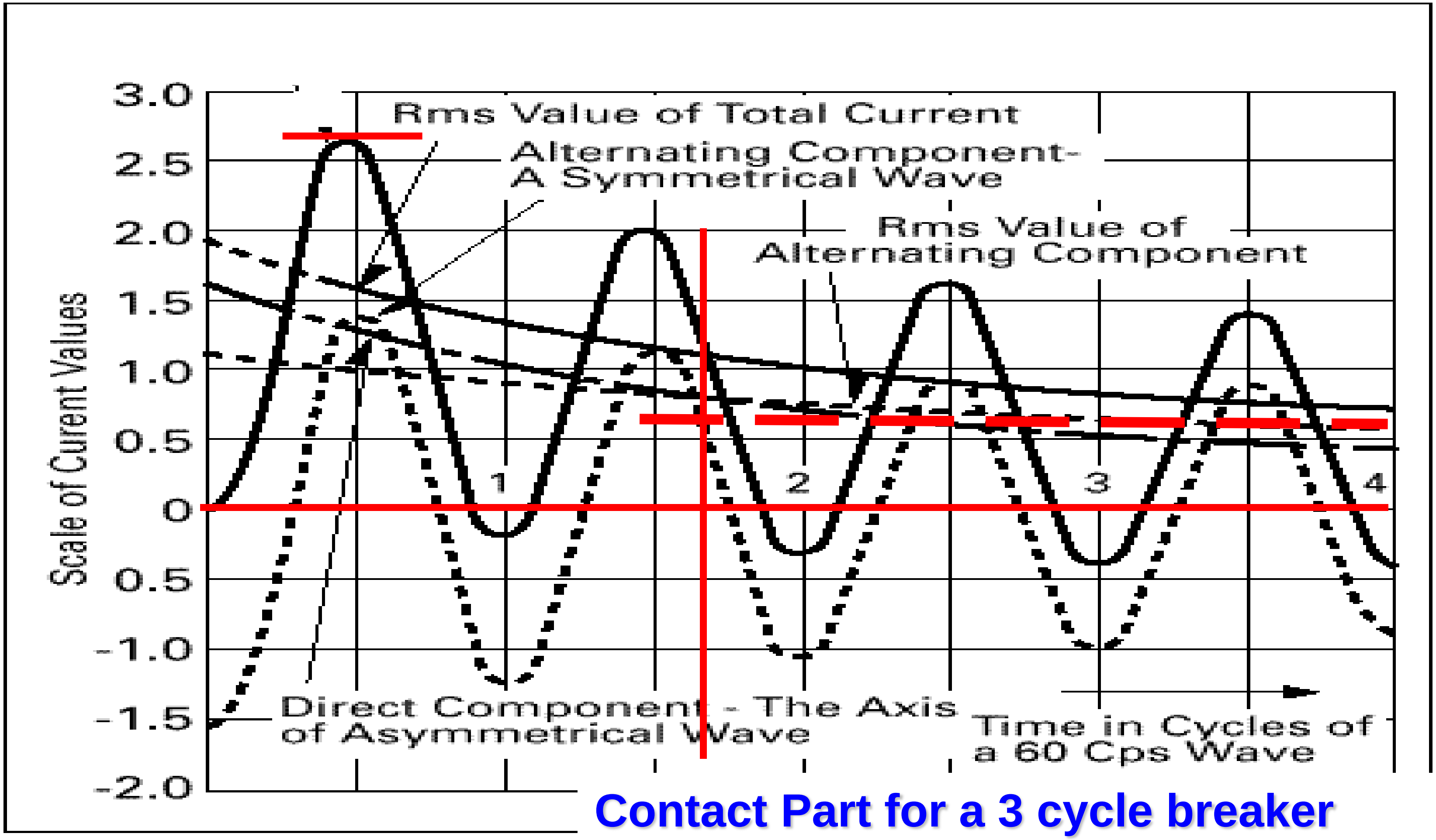
Primary = 22.8 ms

Asymmetrical Capability

- Based on X/R of 17 @ 60 Hz and 14 @ 50 Hz
- Breaker ability fixed at contact part time
- Asymmetrical capability is constant for entire time up to max tripping delay of 2 seconds
- Old S factors and new %DC

$$I_{TOTAL} = I_{symetrical}\sqrt{1+2\left(\frac{\%dc}{100}\right)^2}$$

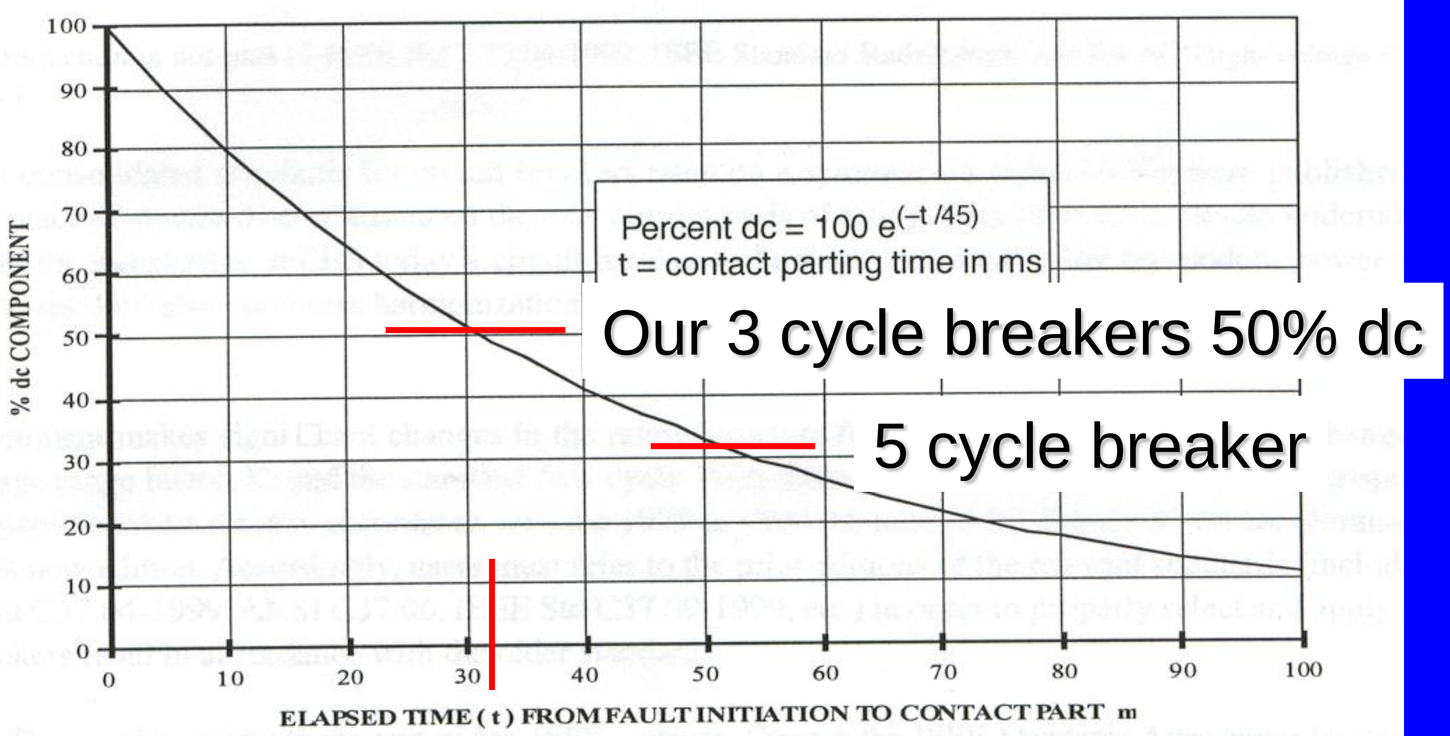
Short Circuit Current



Contact Part for a 3 cycle breaker

Structure of an Asymmetrical Current Wave

New Capability Curve



Percent dc = $100\ e^{(-t/45)}$

t = contact parting time in ms

Our 3 cycle breakers 50% dc

5 cycle breaker

Figure 1—Percent dc component of asymmetric current as a function of contact parting time

Changes in X/R

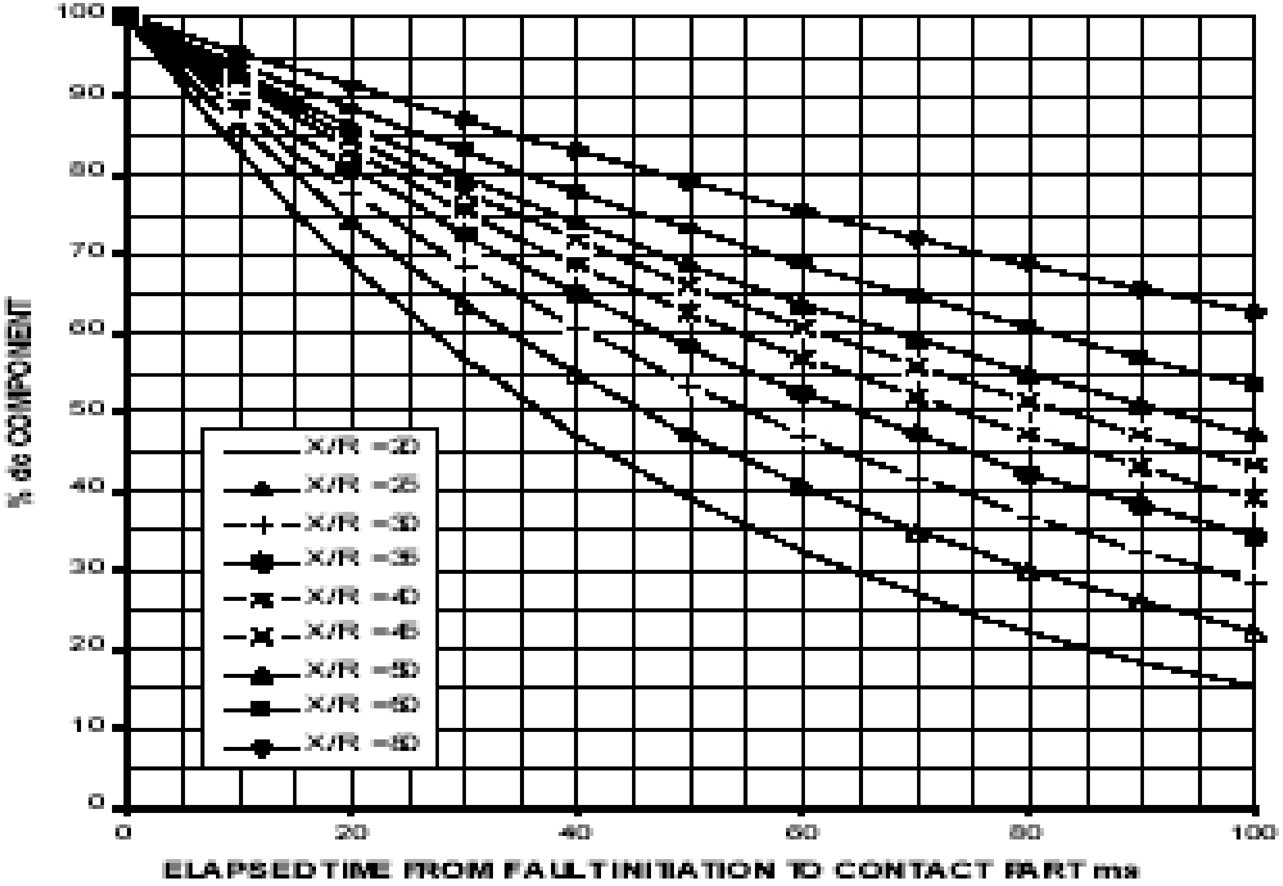
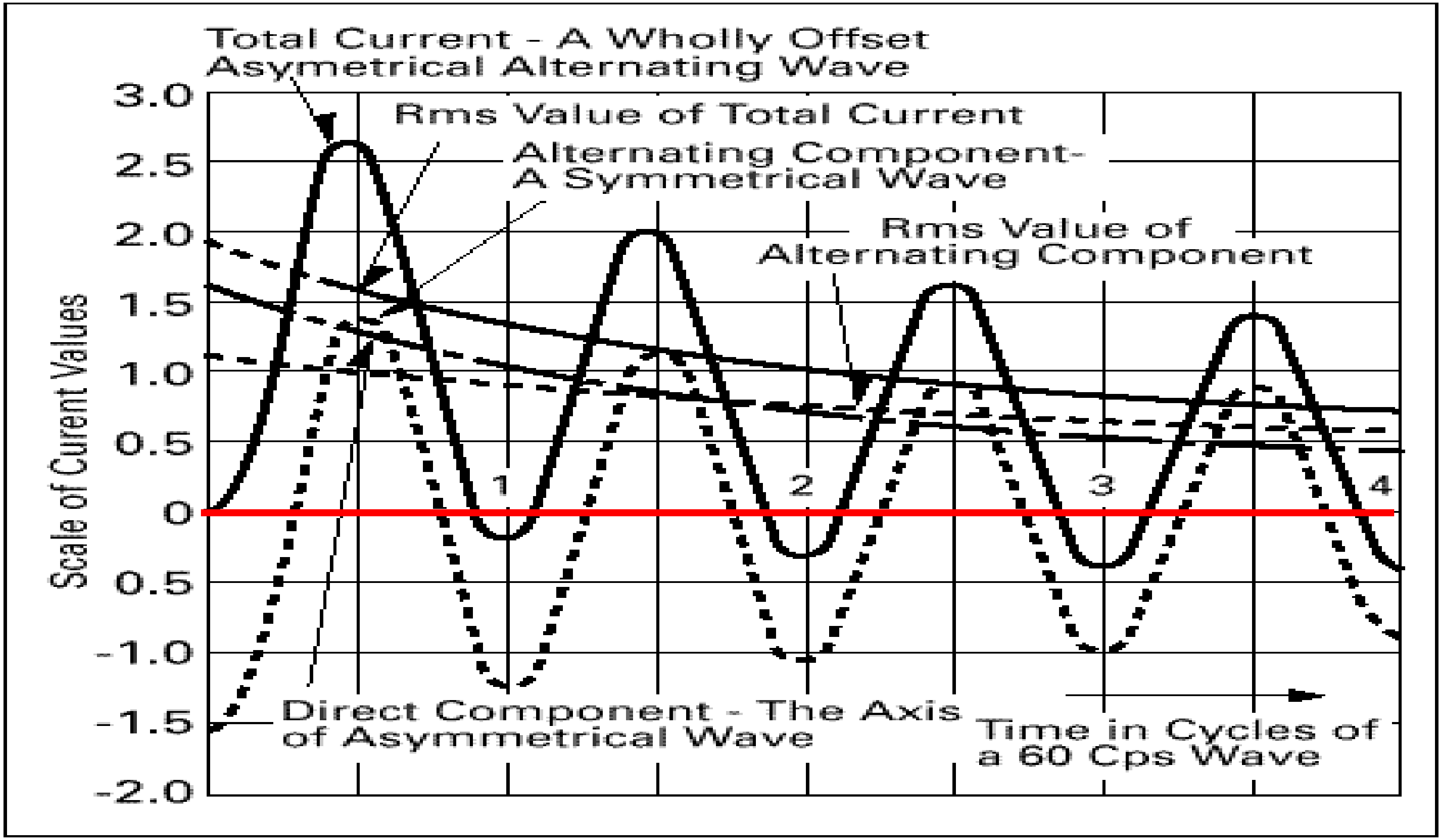


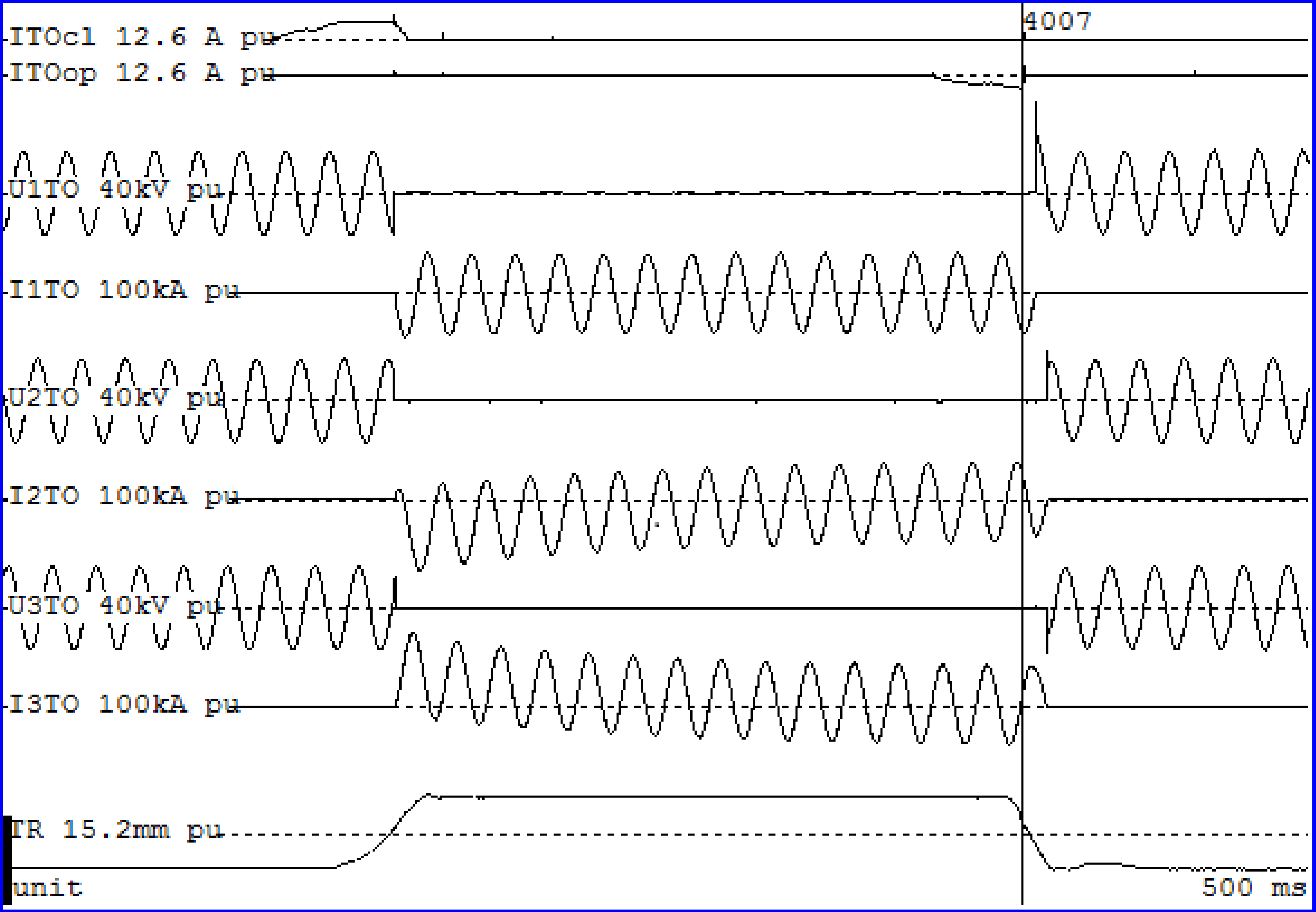
Figure 2—Percent dc required at contact part for asymmetrical tests (values based on a range of X/R factors at 60 Hz)

Short Circuit Current

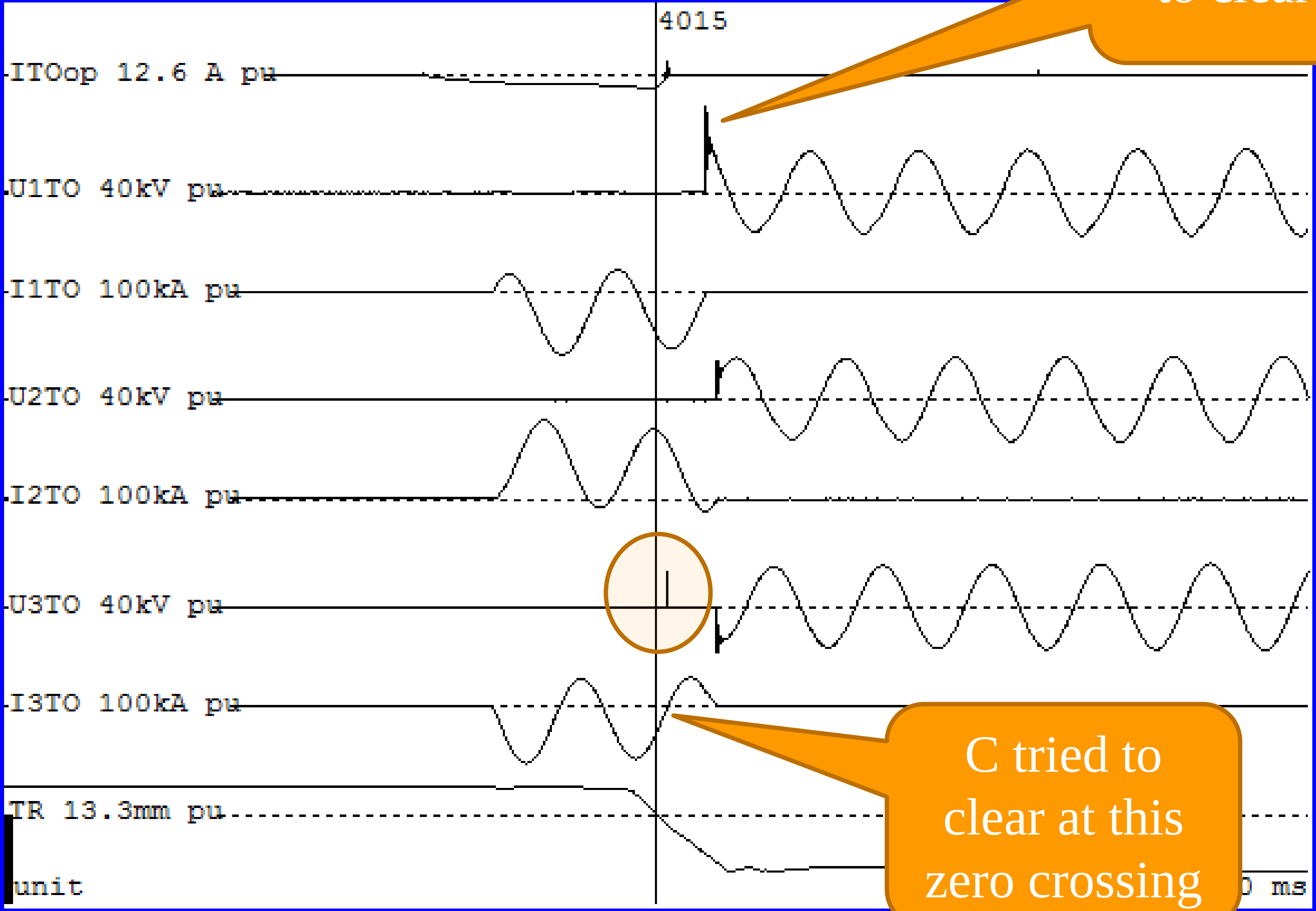


Structure of an Asymmetrical Current Wave

Gen Bkr Close and Trip



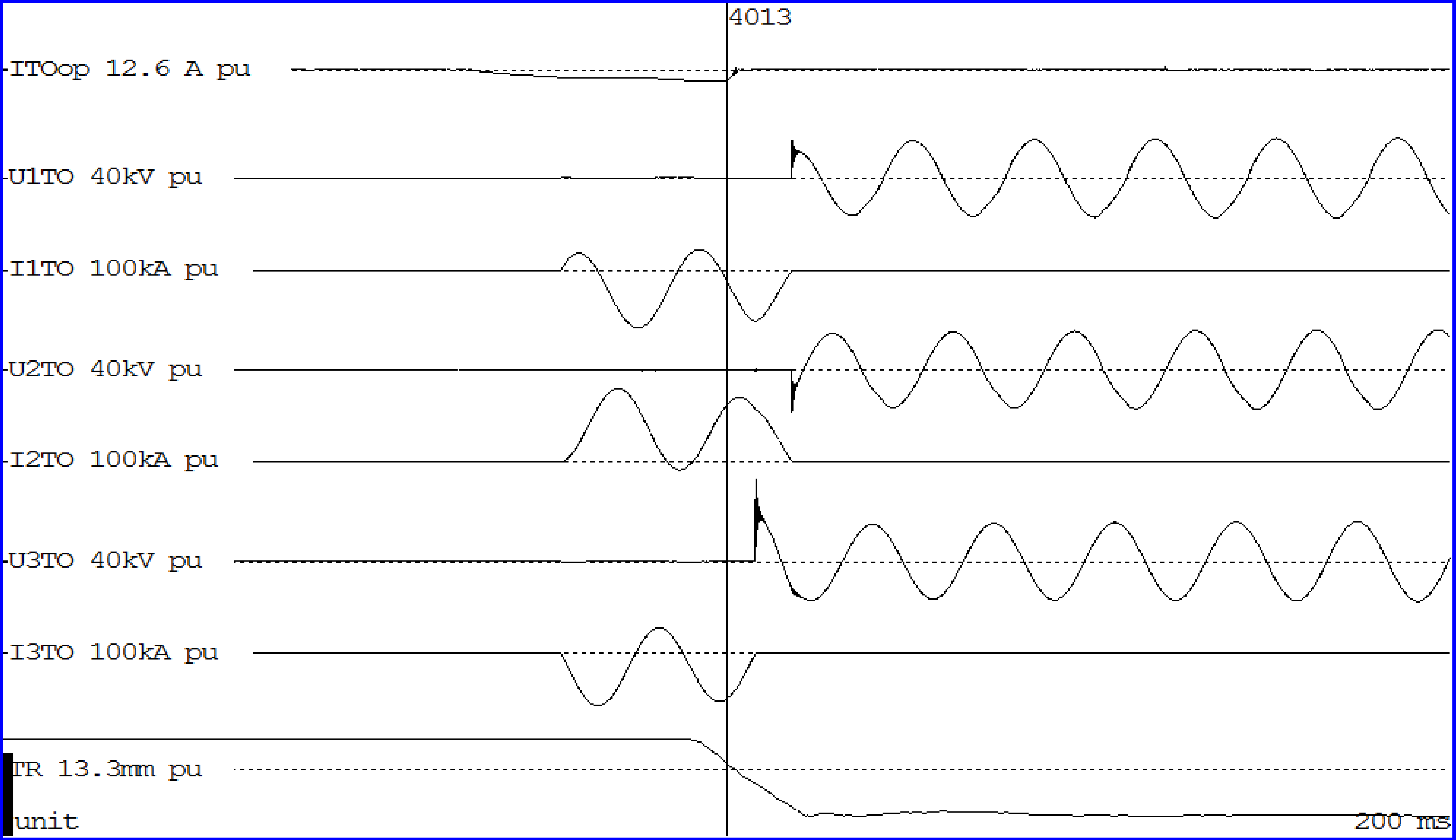
Generator Breaker



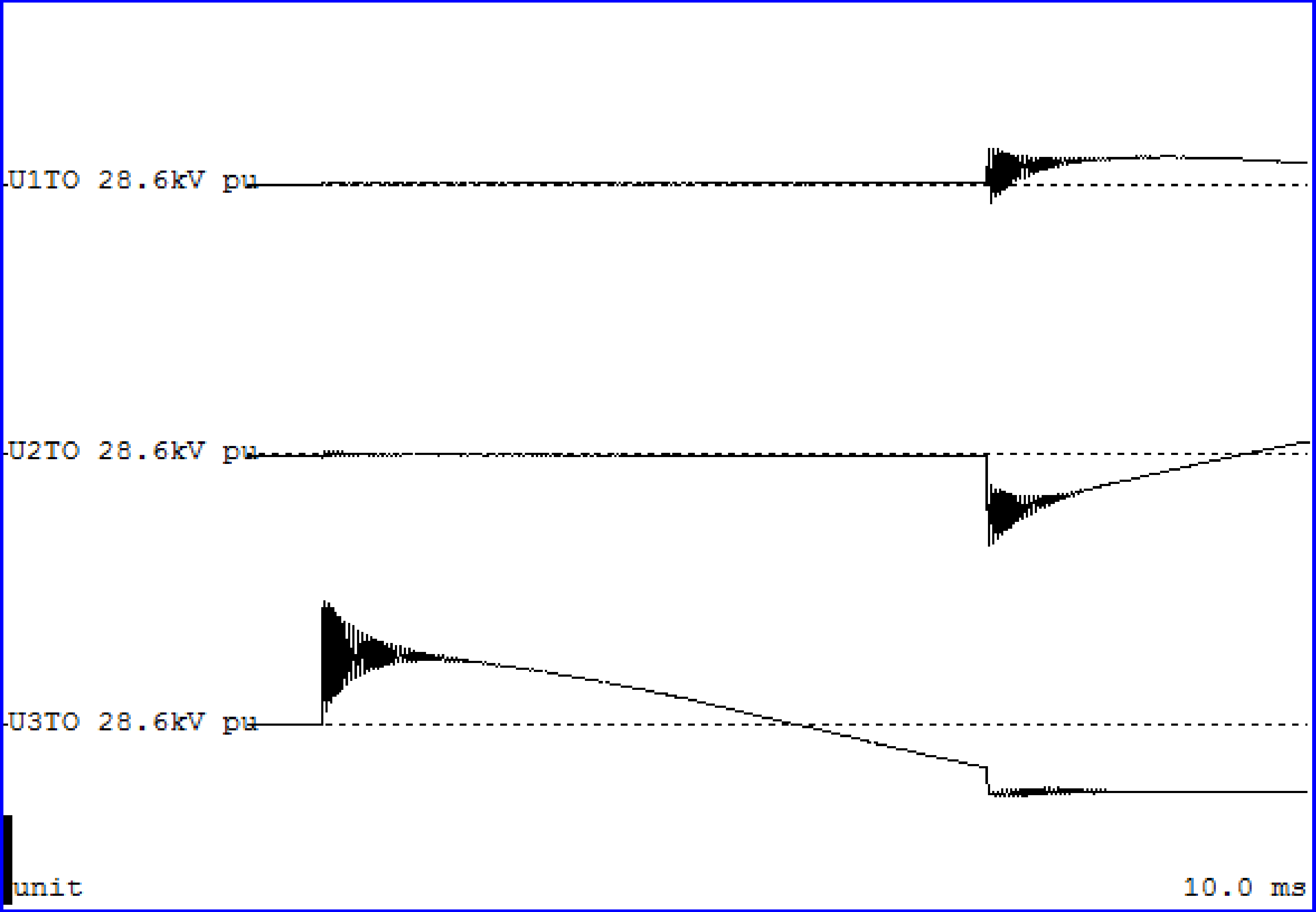
A 1st pole to clear

C tried to clear at this zero crossing

Generator Bkr Interruption



Recovery Voltage



Circuit Breaker Ratings

PowlVac Breaker Type	Max Voltage (kV)	Interrupting Symmetrical (kA rms) Note (1)	Obsolete MVA Class	Continuous Current (A)	Cubicle width (In.)	Power Frequency Withstand (kV)	BIL crest (kV)	Close and Latch (10cycle) Momentary (kA, crest)	%DC Interrupting Current (%)	Rated Interrupting Time (3) (cycle/msec)	Short Time Current (3 sec.)	Back to Back Cap Switching (Amps) (4)
05PV36SND	4.76	36	250	1200, 2000	26	19	60	97	50	3 / 50	36	
05PV36STD	↓	36	250	1200, 2000, 3000, 4000(2)	36	↓	↓	97	↓	↓	36	
05PV50SND	↓	50	350	1200, 2000	26	↓	↓	135	↓	↓	50	
05PV50STD	↓	50	350	1200, 2000, 3000, 4000(2)	36	↓	↓	135	↓	↓	50	
05PV63STD	↓	63	500	1200, 2000, 3000, 4000(2)	36	↓	↓	170	↓	↓	63	1640
15PV25STD	15	25	500	1200, 2000, 3000, 4000(2)	36	36	95	67	50	3 / 50	25	1640
15PV36STD	↓	36	750	1200, 2000, 3000, 4000(2)	↓	↓	↓	97	↓	↓	36	1640
15PV50STD	↓	50	1200	1200, 2000, 3000, 4000(2)	↓	↓	↓	135	↓	↓	50	1640
15PV63STD	↓	63	1500	1200, 2000, 3000, 4000(2)	↓	↓	↓	170	↓	↓	63	1640

Notes:

(1) Interrupting current constant for all voltages less than the maximum voltage. Rated voltage range factor k=1.

(2) Forced Air Cooling fans required for current in excess of 3000 amps.

(3) 5 cycle breakers available at the same %dc ratings

(4) Back to back capacitor switching rating is good for 1200, 2000, 3000, and 4000 continuous current ratings.

(5) Maximum tripping delay is 2 seconds for all circuit breaker as per the ANSI standards.

Circuit Breaker Timing

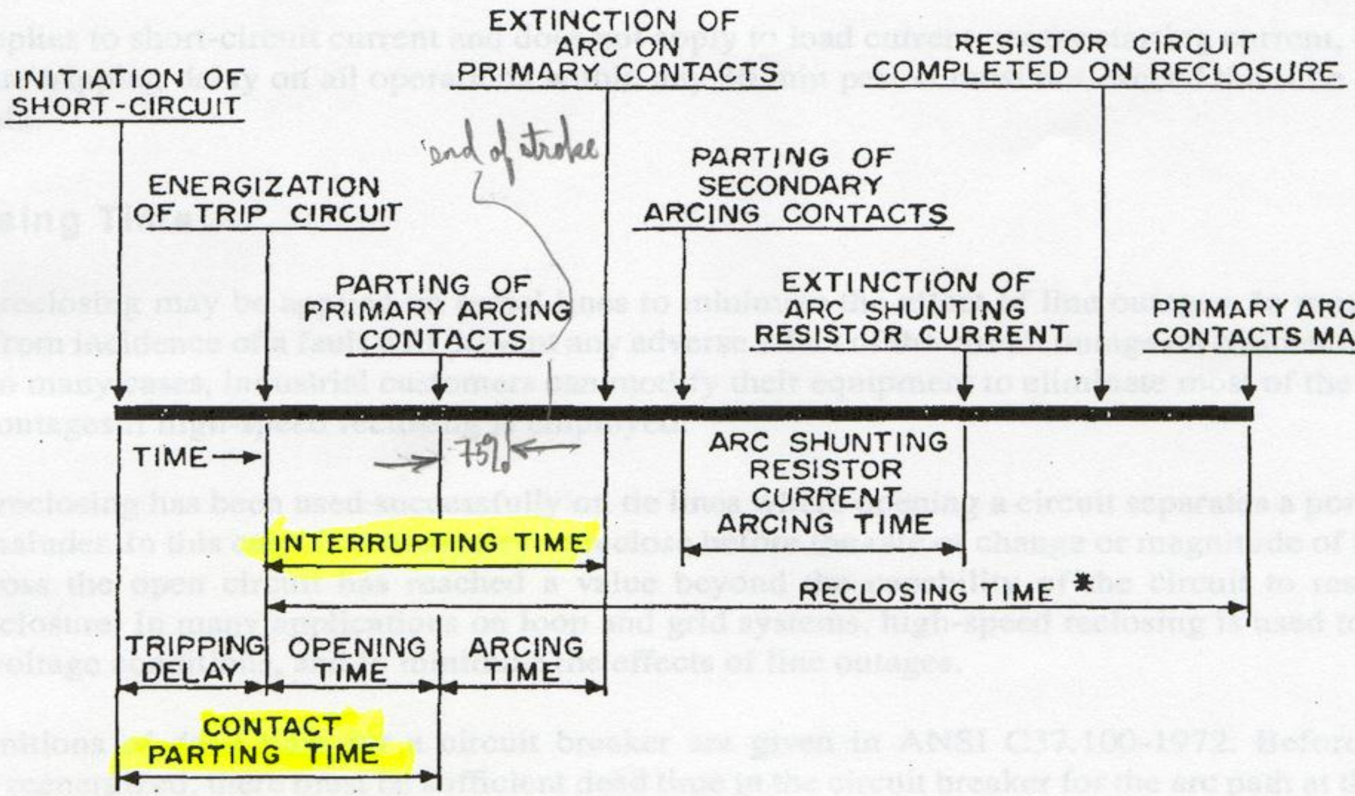


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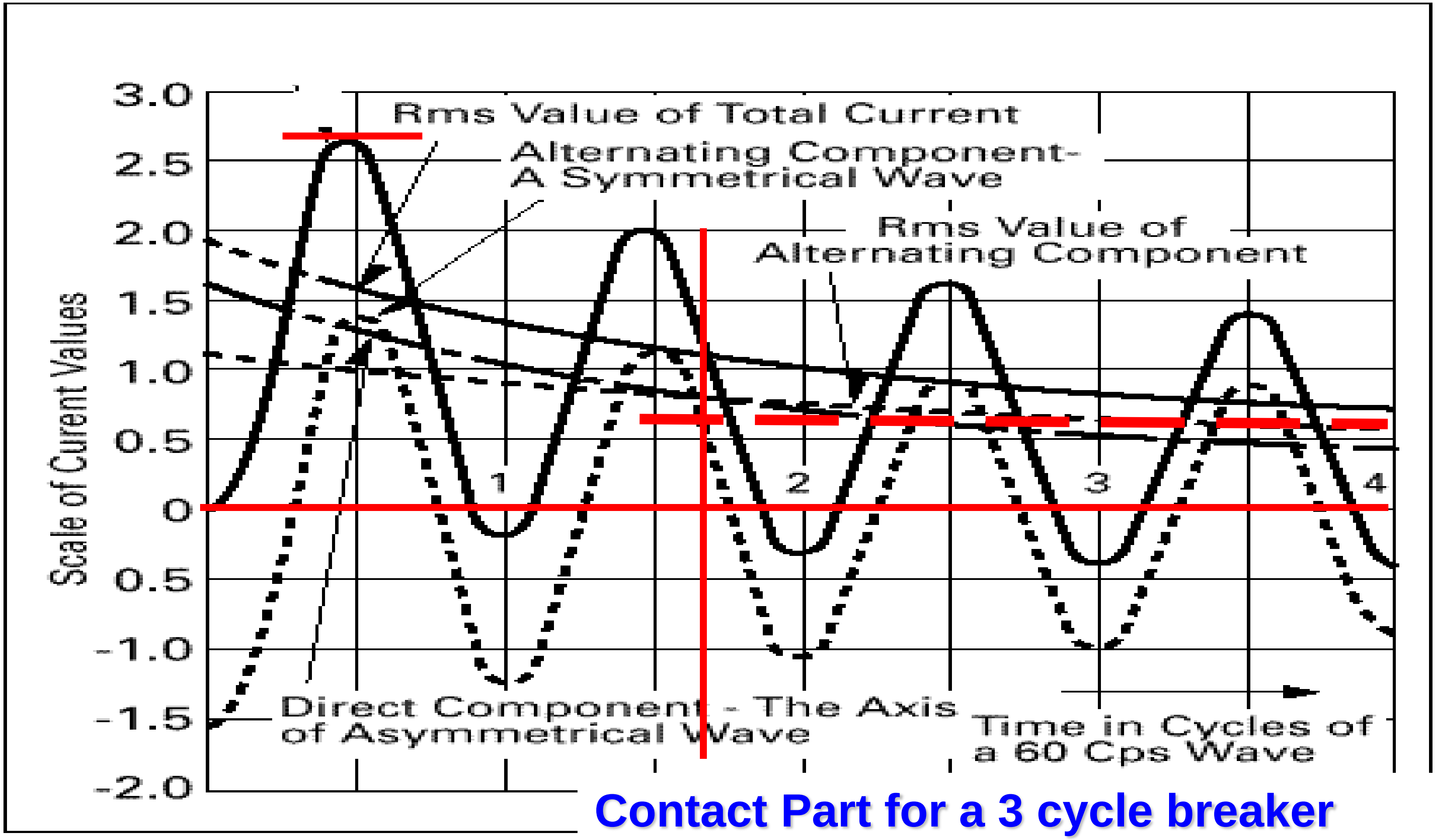
Figure 2— Operating Time

Asymmetrical Capability

- Based on X/R of 17 @ 60 Hz and 14 @ 50 Hz
- Breaker ability fixed at contact part time
- Asymmetrical capability is constant for entire time up to max tripping delay of 2 seconds
- Old S factors and new %DC

$$I_{TOTAL} = I_{symetrical}\sqrt{1+2\left(\frac{\%dc}{100}\right)^2}$$

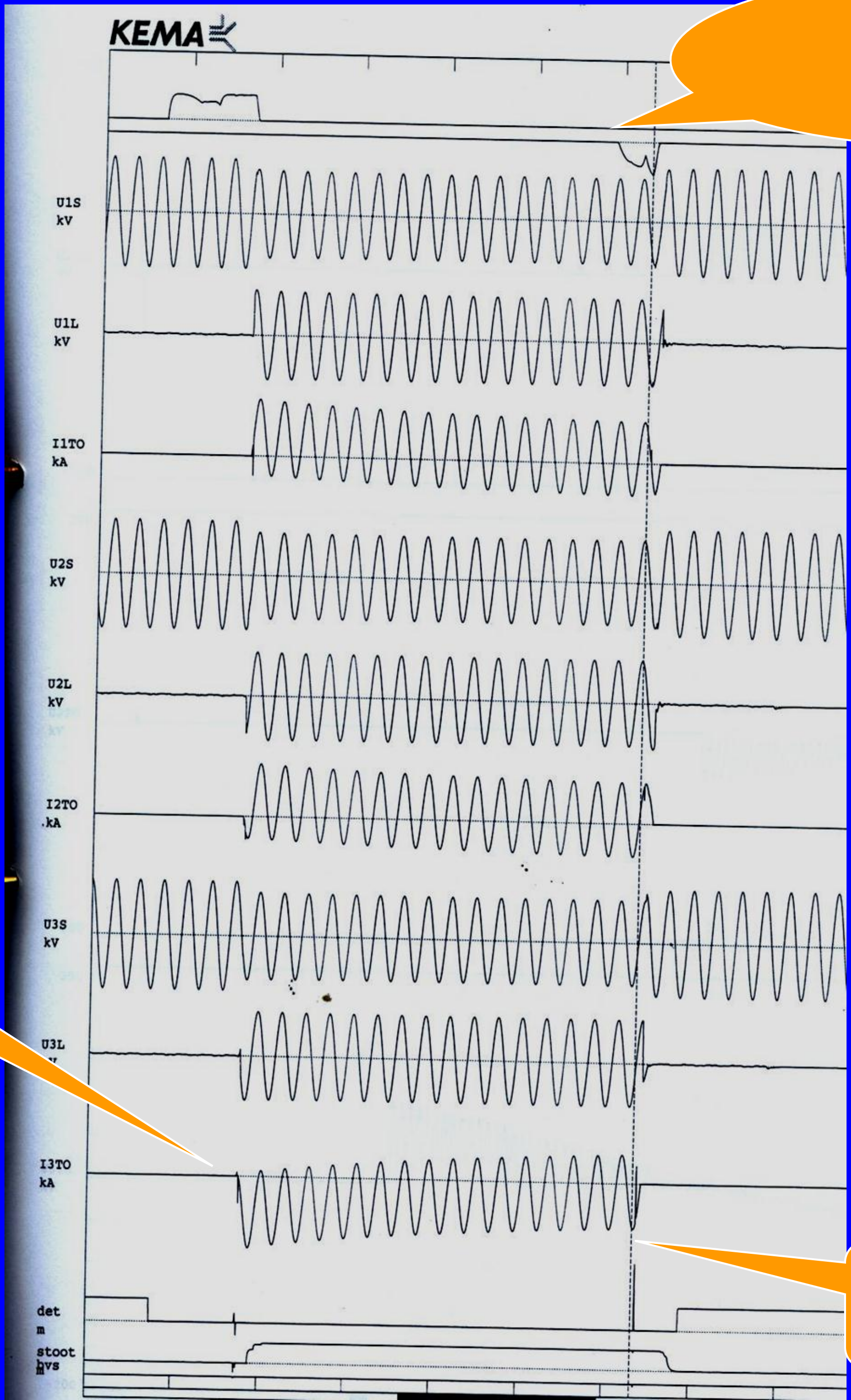
Short Circuit Current



Contact Part for a 3 cycle breaker

Structure of an Asymmetrical Current Wave

3 phase fault current



Trip coil energized

Gen Ph A

Ph A current

Gen Ph B

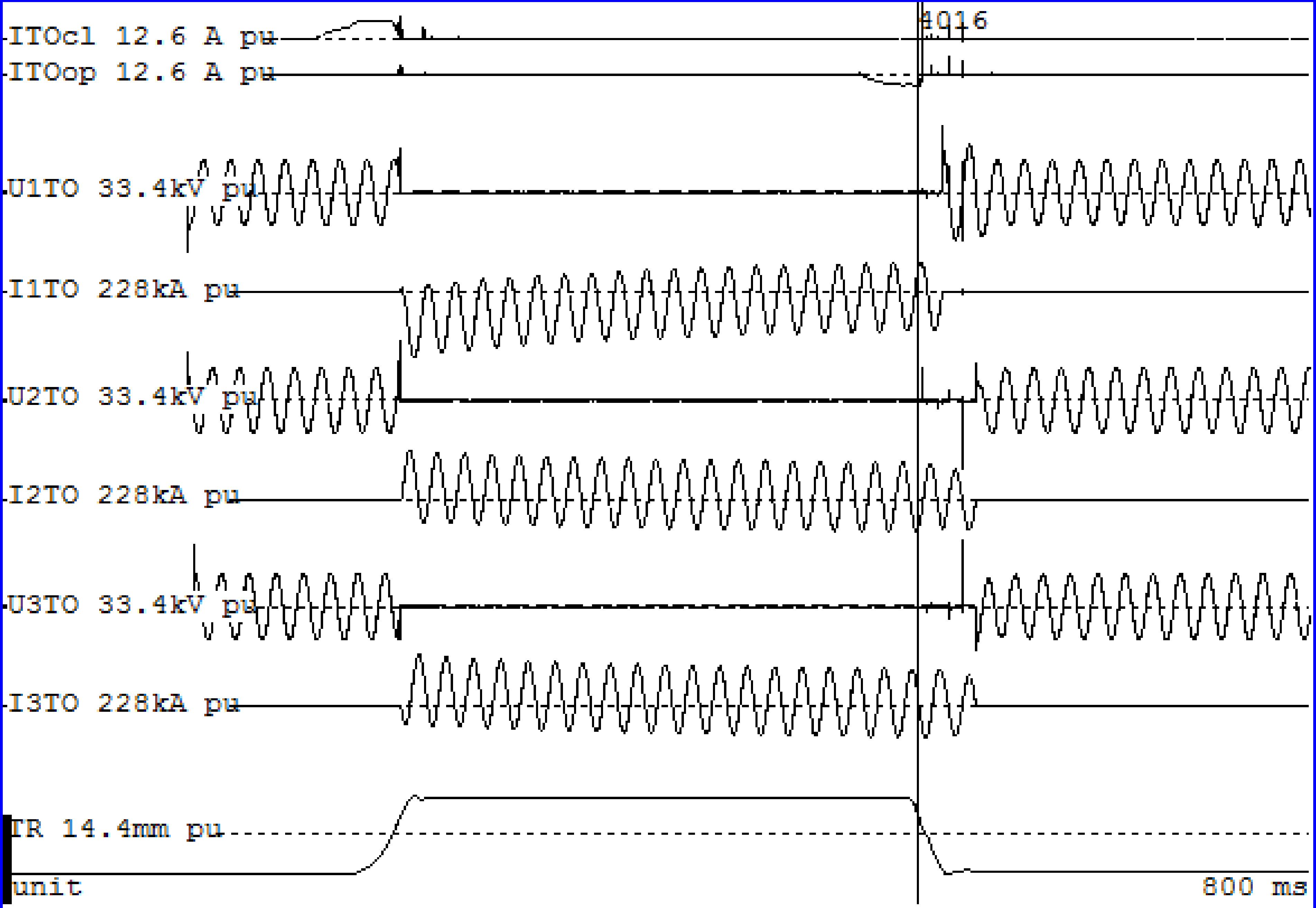
Ph B current

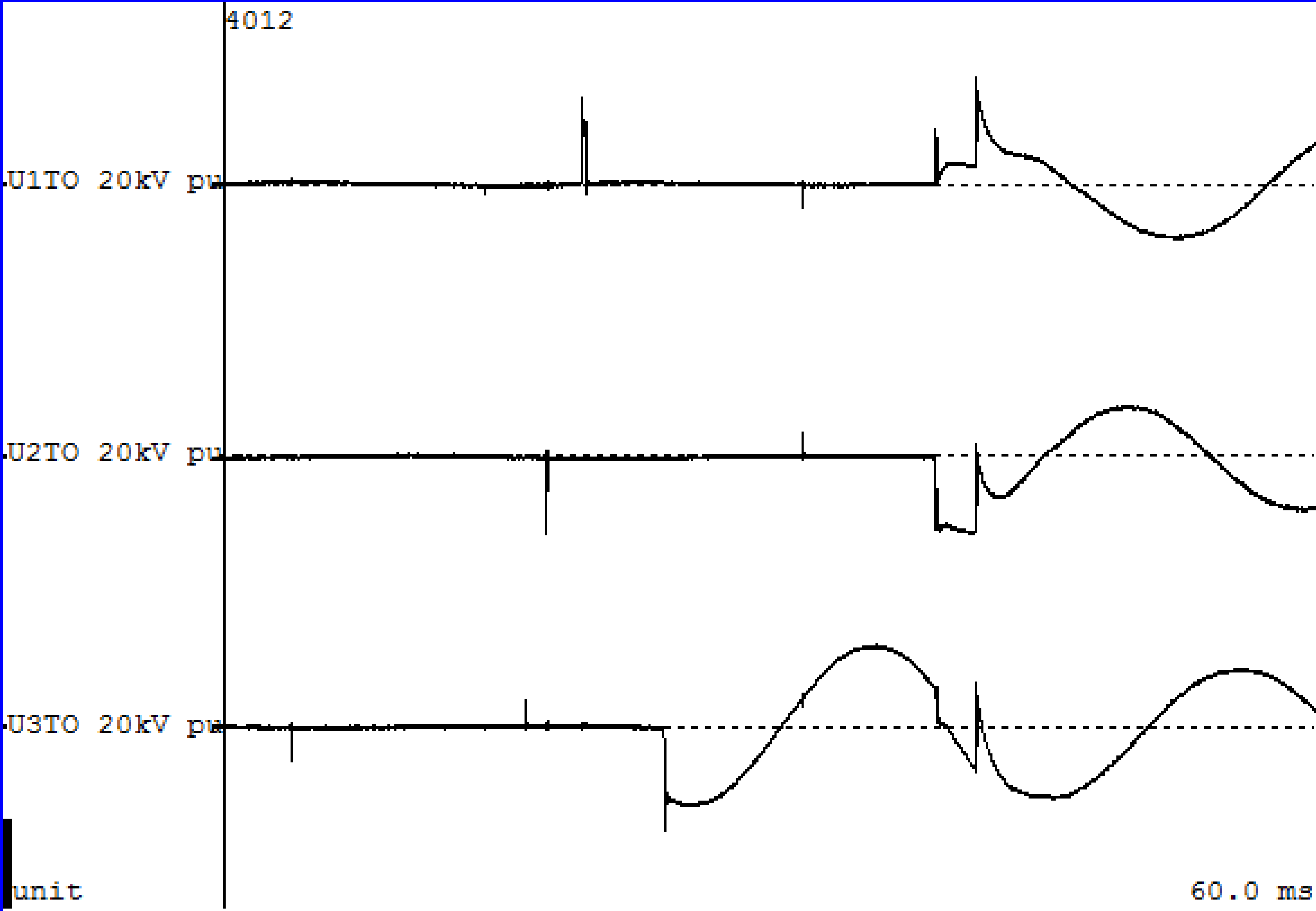
Gen Ph C

Ph C current

Asymmetrical current

TRV


4016
ITOcl 12.6 A pu
ITOop 12.6 A pu
U1TO 33.4kV pu
I1TO 228kA pu
U2TO 33.4kV pu
I2TO 228kA pu
U3TO 33.4kV pu
I3TO 228kA pu
TR 14.4mm pu
unit
800 ms


4012
U1TO 20kV pu
U2TO 20kV pu
U3TO 20kV pu
unit
60.0 ms

Information for Choosing an MV Circuit Breaker

- System operating voltage & frequency
- Continuous current of circuit
- Short-circuit current
  - Close-and-latch (crest) current
  - Interrupting current (rms) at contact part
- System X/R ratio
- Service conditions: altitude, ambient temperature, solar radiation, seismic, etc...

Choosing an MV CB

Rated Voltage

- Rated voltage of circuit breaker must equal or exceed maximum voltage at which system will operate
- Standard ratings are 4.76 kV, 8.25 kV, 15 kV, and 38 kV
- Higher voltage breaker may be used at lower voltage

Choosing an MV CB
Rated B. I. L.

- B.I.L. rating of circuit breaker should equal or exceed system insulation coordination.
- Standard ratings are 60 kV for 4.76 kV breakers, 95 kV for 8.25 kV and 15 kV breakers, and 150 kV for 38 kV breakers
- Properly applied surge arresters will protect switchgear against surges above B.I.L. rating

Choosing an MV CB
Rated Frequency

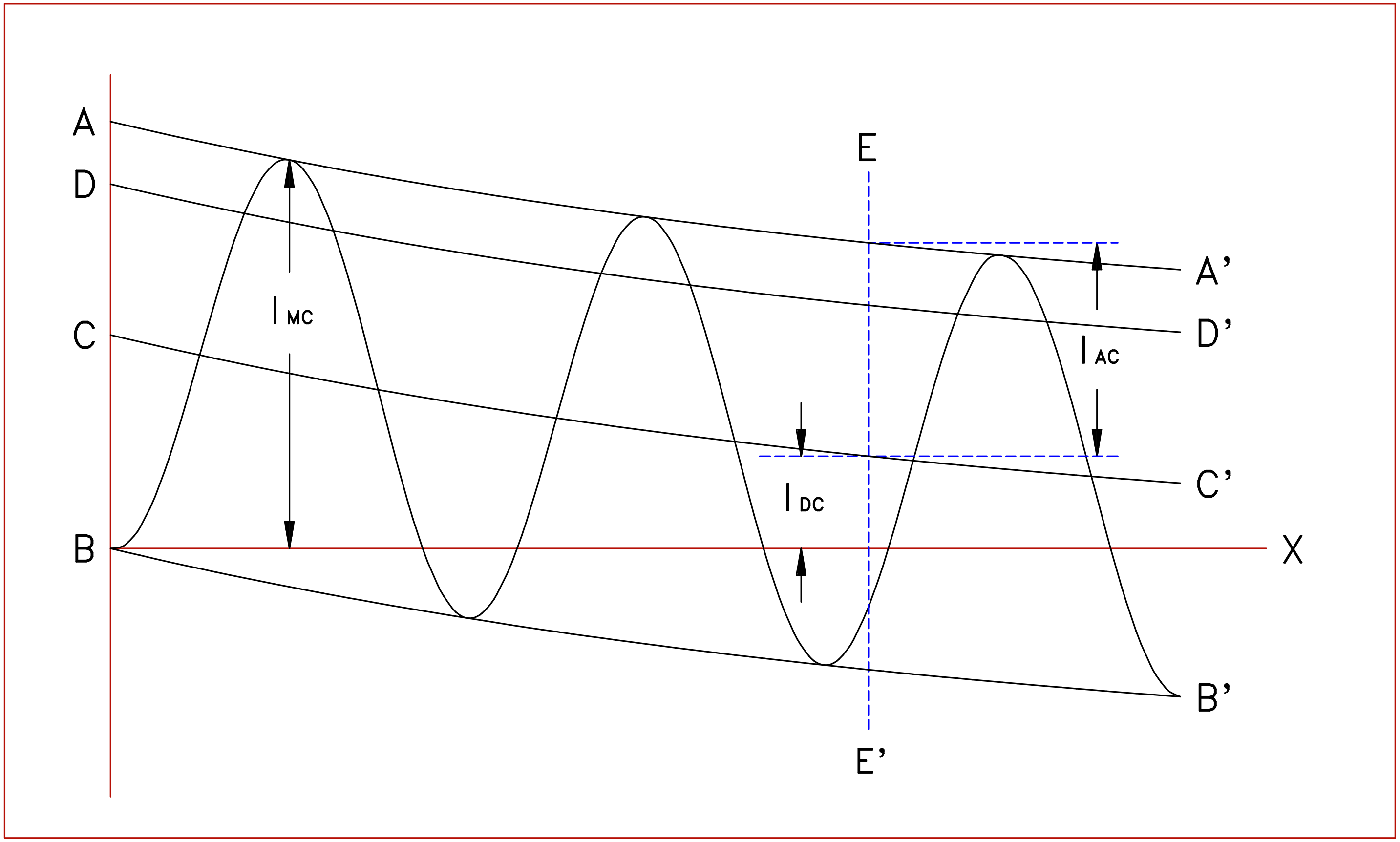
- ANSI/IEEE standards specify rated frequency of 60 Hertz
- ANSI/IEEE standards allow 60 Hz tests to qualify breaker for 50 Hz use
- Use at other frequencies requires special engineering consideration
  - Long arcing time for low frequencies
  - Overheating for higher frequencies

Choosing an MV CB Continuous Current

- Continuous current rating of circuit breaker must equal or exceed maximum continuous current of circuit
- Standard ratings are 1200 A, 2000 A, and 3000 A
- For currents over 3000 A:
  - Redesign system
  - Force cool breaker
  - Parallel breakers

Choosing an MV CB

Short-Circuit Current



Back of the Envelope
Short Circuit Calculations

Choosing an MV Circuit Breaker

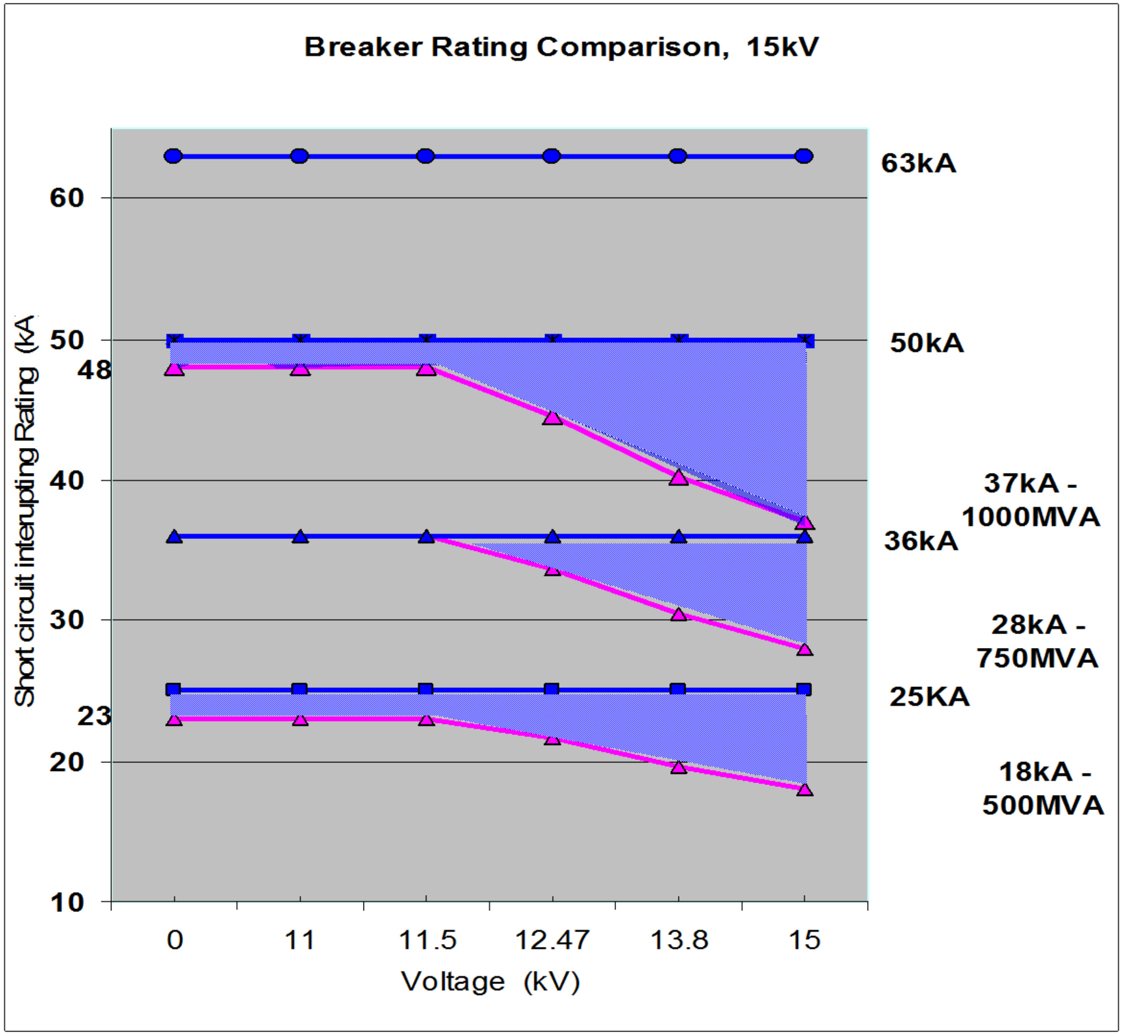
Short-Circuit Current

- Forget MVA! Breakers are rated in kA
- Breaker rated short-circuit current, in kA_{rms}, must equal or exceed available fault current at breaker rated interrupting time (3 cycle/5 cycle, or 50ms/83.3ms, per standards).
- Use *K* factor on older breakers.
  - Newer designs all have *K* of 1.
- Consider X/R Ratio

K=1 Circuit Breakers

- Old k factor breaker’s interrupting rating increased as voltage went down

- K=1 breakers are constant interrupting breakers



Choosing an MV Circuit Breaker

X/R Considerations

- Simplified E/X method - up to 100% of breaker rating if X/R does not exceed 15
- Simplified E/X method - up to 80% of breaker rating for any X/R
- For currents over 80% and X/R over 15, more exact short circuit calculations are required

Choosing an MV Circuit Breaker

Short Time Current

- Per ANSI Standards, rated short-time current equals maximum symmetrical interrupting capability
- Time is 2 seconds for metal-clad switchgear and 3 seconds for breakers
- Relaying needs to ensure that backup breaker is tripped before front-line breaker exceeds its short-time rating

Choosing an MV Circuit Breaker

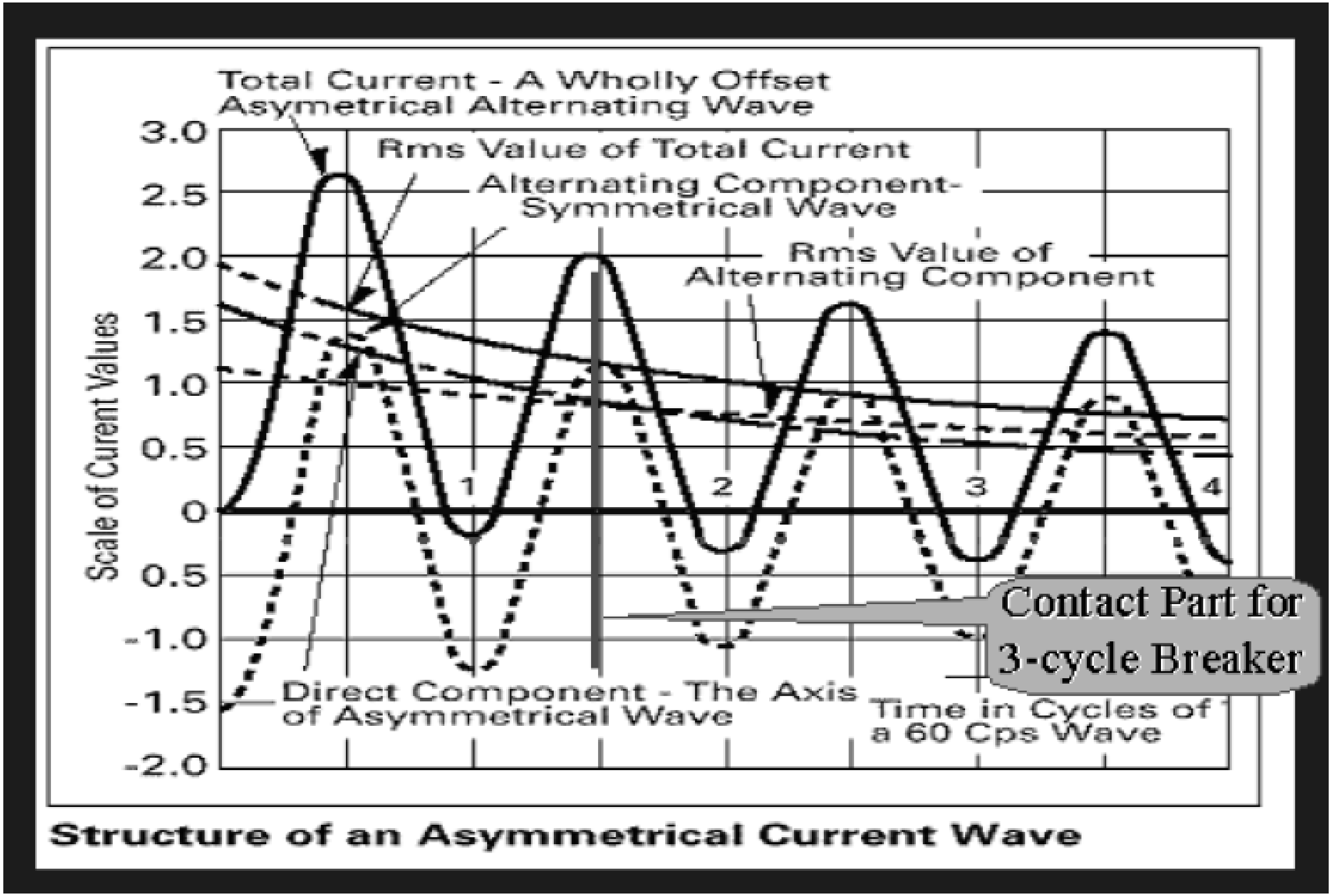
Momentary Current

- Momentary current equals close-and-latch current of circuit breaker
- This rated current must exceed maximum available on system

- Now stated as crest (peak) current or as rms asymmetrical current
- Be sure that you compare currents stated in same terms

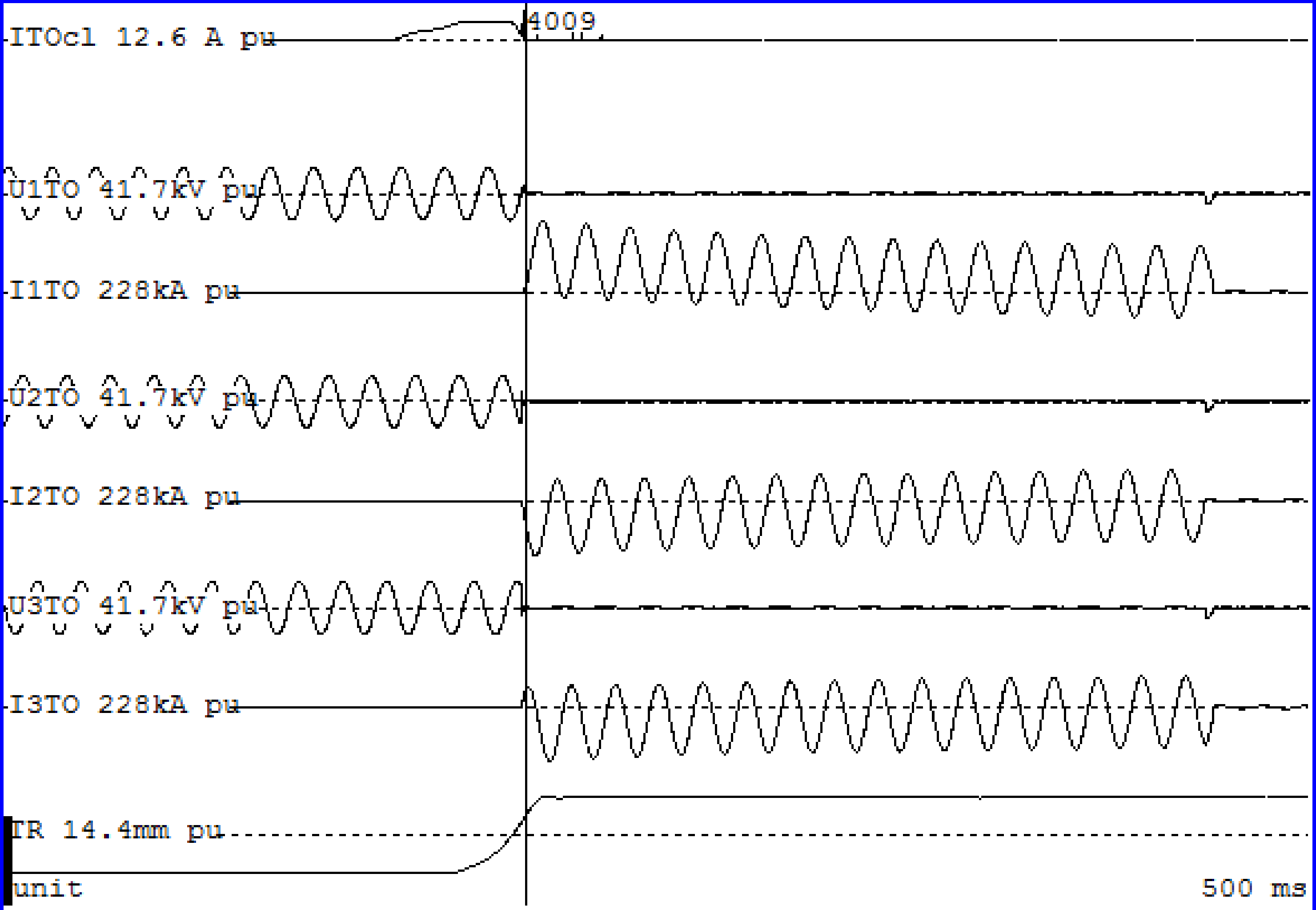
- For ANSI ratings,
  - 1.6X = tested asymmetrical rms
  - 2.7X = tested crest

Short Circuit Current



Structure of an Asymmetrical Current Wave

Latch and Close



C37.010-1999 – Figure 2

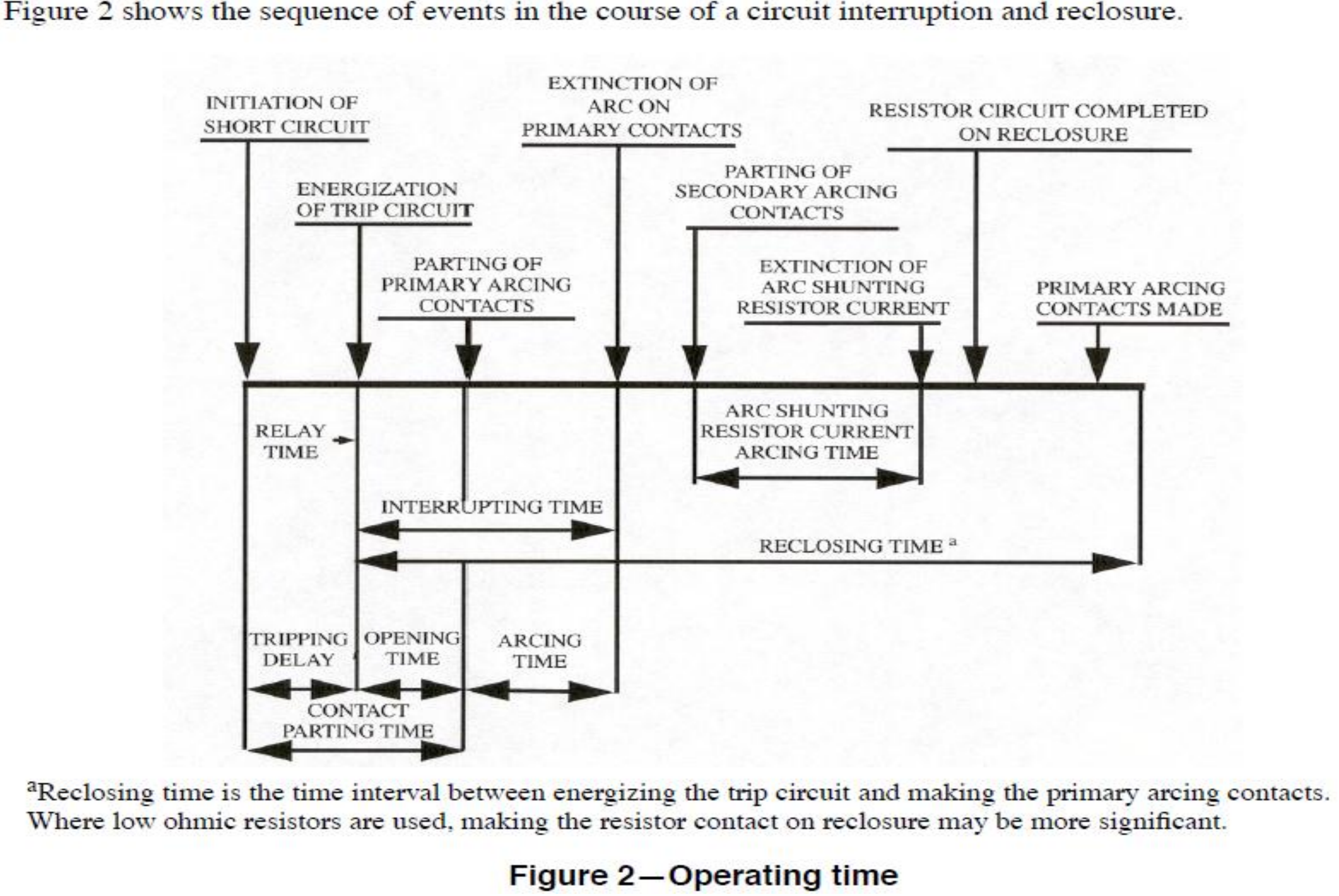
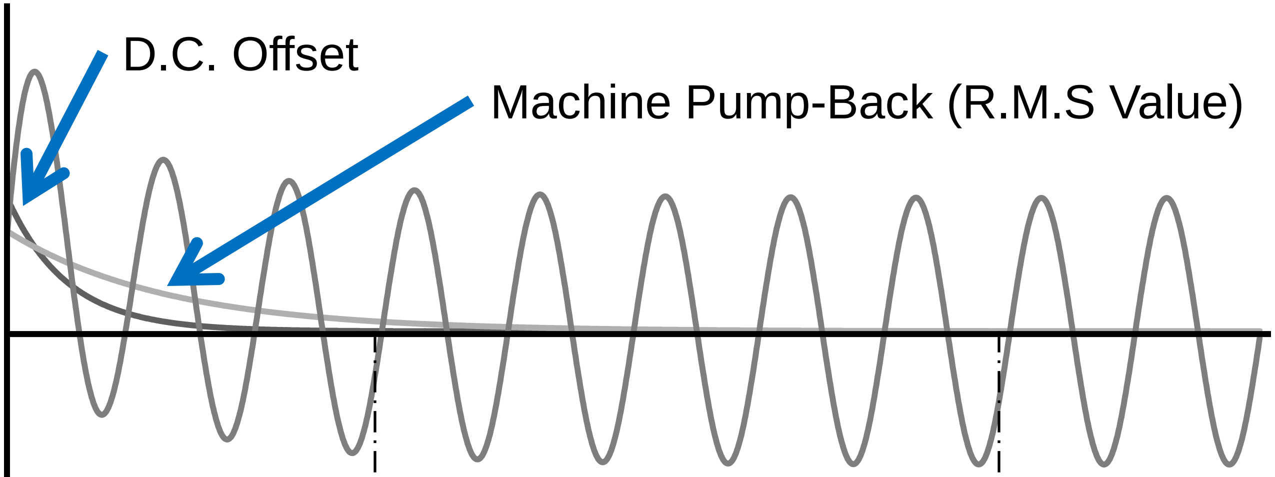


Figure 2 shows the sequence of events in the course of a circuit interruption and reclosure.

[a] Reclosing time is the time interval between energizing the trip circuit and making the primary arcing contacts. Where low ohmic resistors are used, making the resistor contact on reclosure may be more significant.

Figure 2—Operating time

Short Circuit Terminology



Short Circuit Duty Name	Momentary or “1st Cycle”	Interrupting	-
Reactance or (Impedance) Symbol	$X''_d \quad (Z''_d)$	$X'_d \quad (Z'_d)$	$X_d \quad (Z_d)$
Short Circuit Current Symbol	I'' Symmetrical	I' Symmetrical	I
Machine Reactance Name	Subtransient	Transient	Synchronous
	Fuses & LV Breakers		

Commonly Used Per Unit Formulae

(1) $$\text{p.u.X} = \text{OHMS} \times \frac{\text{MVA BASE}}{(\text{kV})^2}$$

Line and Conductor Values

(2) $$\text{NEW p.u.X} = \text{OLD p.u.X} \times \frac{\text{NEW MVA BASE}}{\text{OLD MVA BASE}}$$

Transformer and Machine Values

(3) $$\text{MVA s/c} = \frac{\text{MVA BASE}}{\text{p.u.X}}$$

Short Circuit MVA

(4) $$\text{p.u.X} = \frac{\text{MVA BASE}}{\text{MVA s/c}}$$

Equivalent p.u.X from known MVA s/c value

(5) $$\text{I s/c} = \frac{\text{MVA s/c}}{\text{kV} \times \sqrt{3}} \times 1000$$

Short Circuit Current (A)

When Necessary Use:

(6) $$\text{NEW p.u.X} = \text{OLD p.u.X} \times \frac{(\text{OLD kV})^2}{(\text{NEW kV})^2}$$

New p.u.X based on voltage rating of equipment being different from study base voltage

C37.010-1999 – Table 6

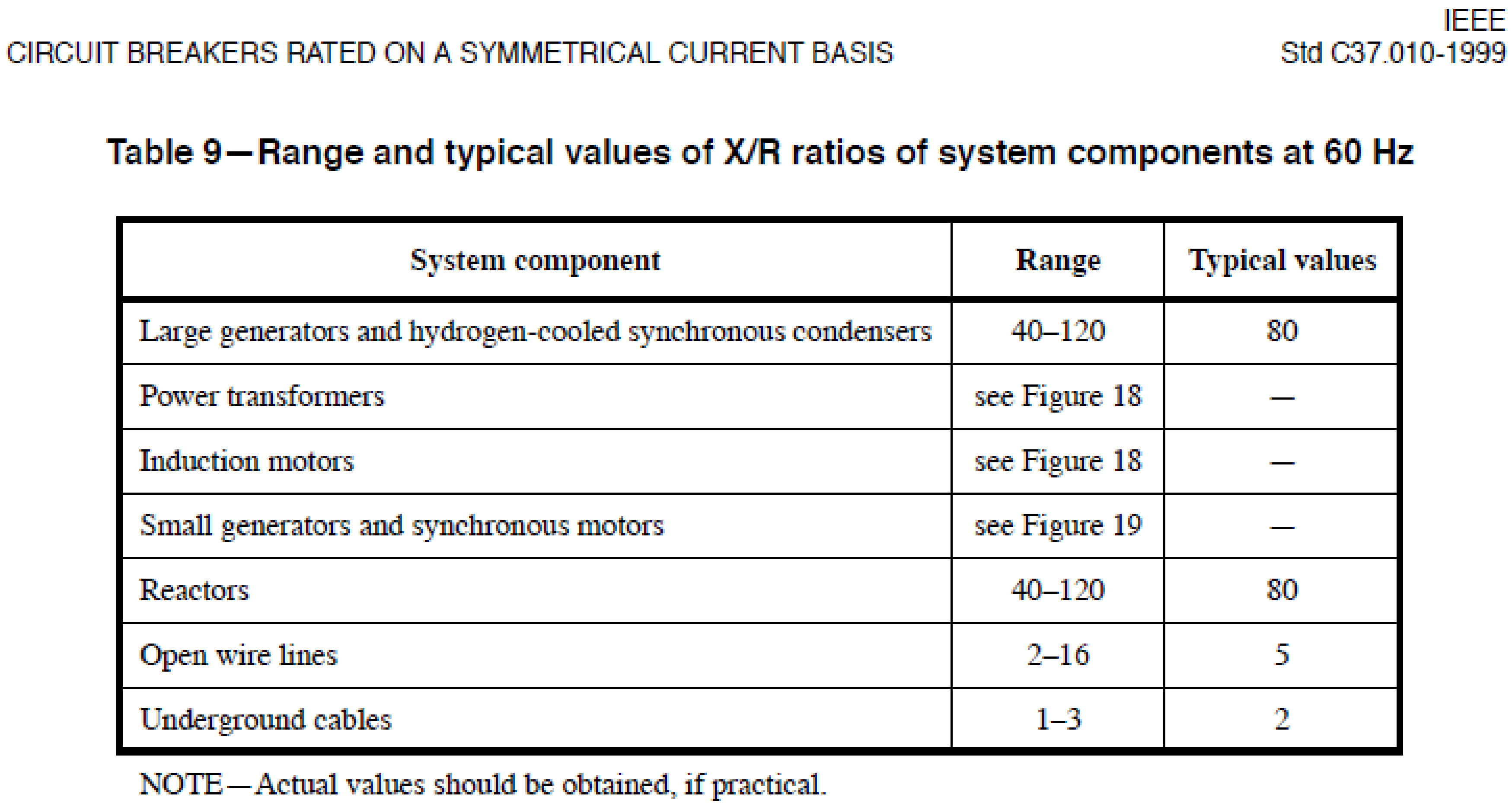
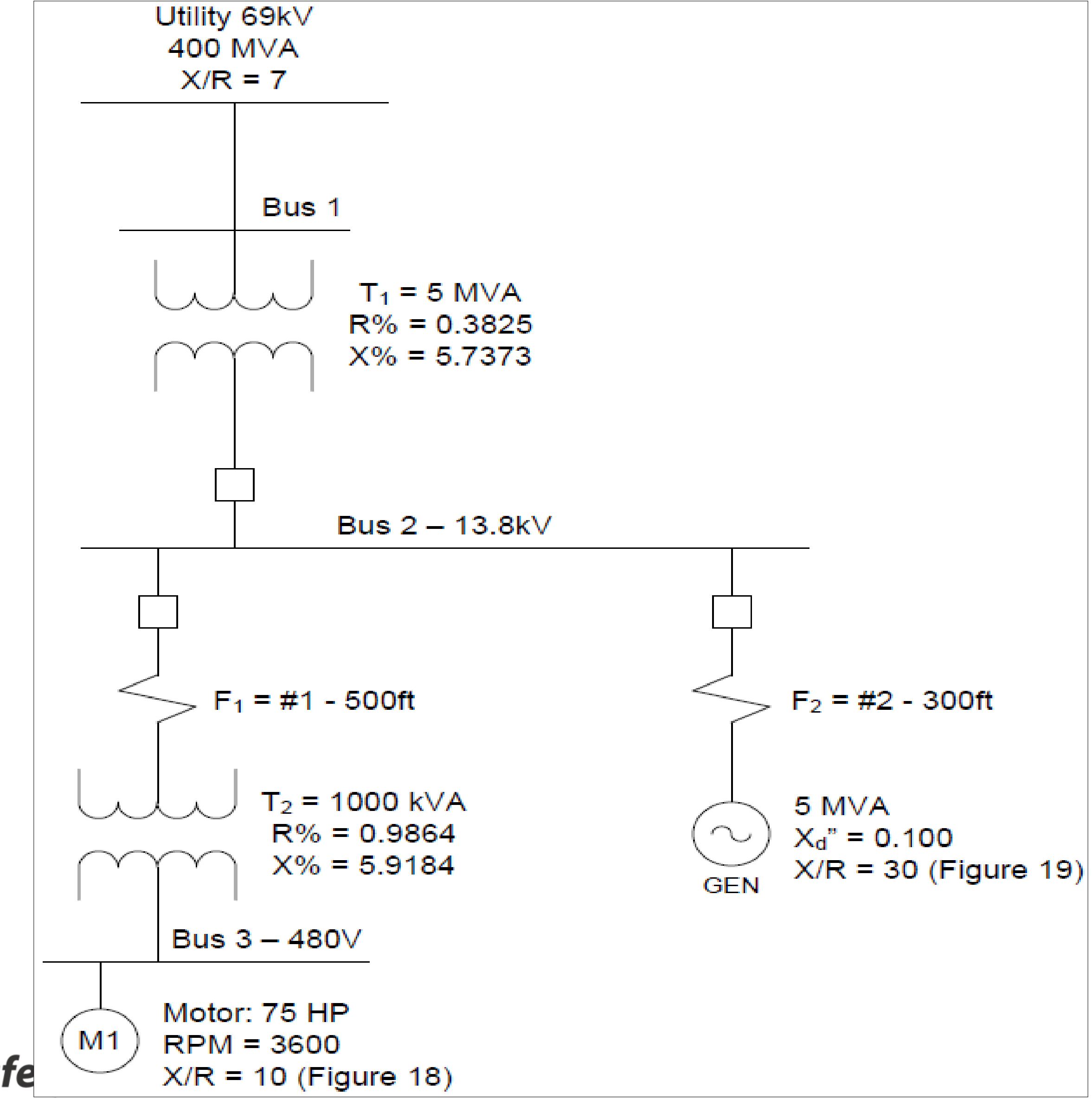


Table 9—Range and typical values of X/R ratios of system components at 60 Hz

System component	Range	Typical values
Large generators and hydrogen-cooled synchronous condensers	40–120	80
Power transformers	see Figure 18	—
Induction motors	see Figure 18	—
Small generators and synchronous motors	see Figure 19	—
Reactors	40–120	80
Open wire lines	2–16	5
Underground cables	1–3	2

NOTE—Actual values should be obtained, if practical.

Example System - Single Line Diagram



Find Utility X_{pu} & R_{pu}

$$\text{Assume Base of } \underline{100\text{MVA}}$$

$$\text{Convert Everything to } X_{pu} \;\&\; R_{pu}$$

$$Z_{Utility} = \frac{MVA_{BASE}}{MVA_{Utility}} = \underline{0.25}$$

Given

$$\Theta_{Utility} = \arctan\frac{X}{R} = \arctan(7) = \underline{81.87^\circ}$$

$$X_{pu} = (Z_{Utility})(\sin\Theta) = 0.25\sin(81.87^\circ) = \underline{0.2475}$$

$$R_{pu} = (Z_{Utility})(\cos\Theta) = 0.25\cos(81.87^\circ) = \underline{0.0354}$$

C37.010-1999 – Figure 18

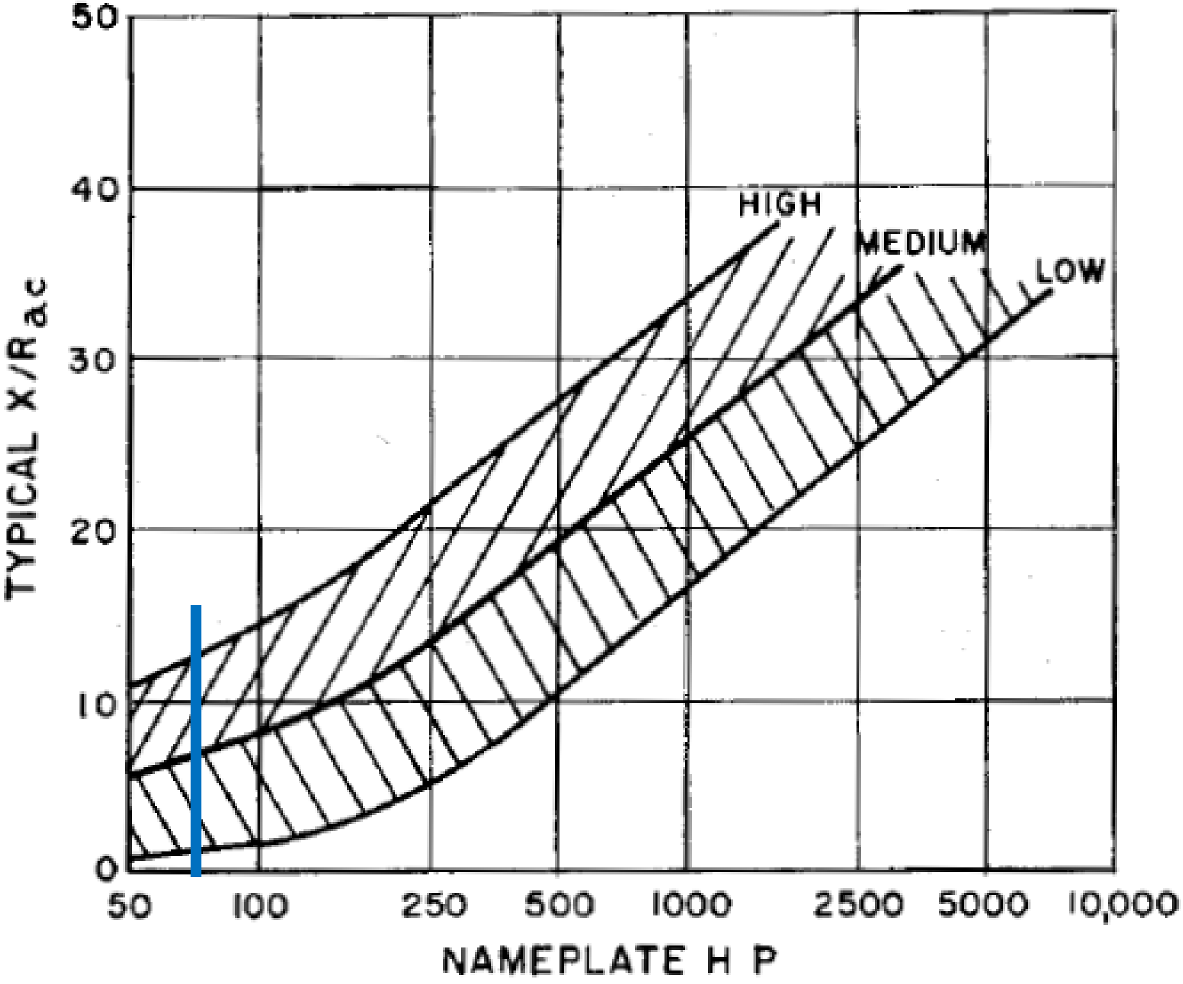


Figure 18—X/R range for three-phase induction motors at 60 Hz

Find Motor X_{pu} & R_{pu}

$$Z_{Motor,pu} = Z_M \frac{MVA_{BASE}}{MVA_{Motor}}$$

For $480V_{AC}$ assume $\underline{1HP = 1kVA}$

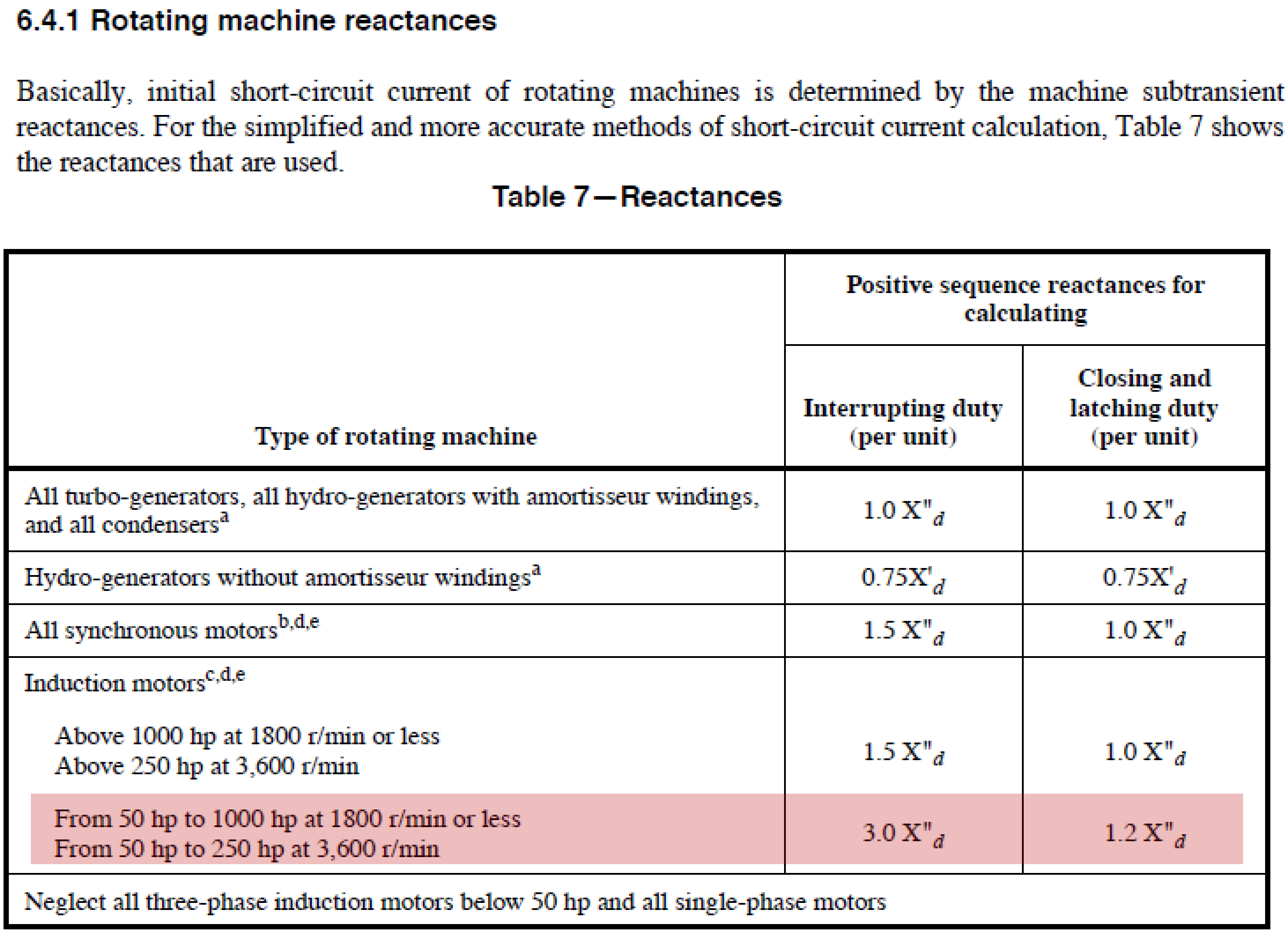
From $\underline{6.4.1}$, $\underline{\text{foot note c}}$, $X''_d = \frac{1}{LRA_{pu}}$

To calculate the interrupting duty in per unit, use $3.0X''_d$ (Table 7)

$$X_{pu} = 3\frac{1}{LRA_{pu}}\frac{MVA_{BASE}}{MVA_{Motor}} = 3\frac{1}{6}\frac{100}{0.075} = \underline{666.67}$$

$$R_{pu} = \frac{X_{pu}}{X/R} = \frac{666.67}{10} = \underline{66.67}$$

C37.010-1999 – Table 7



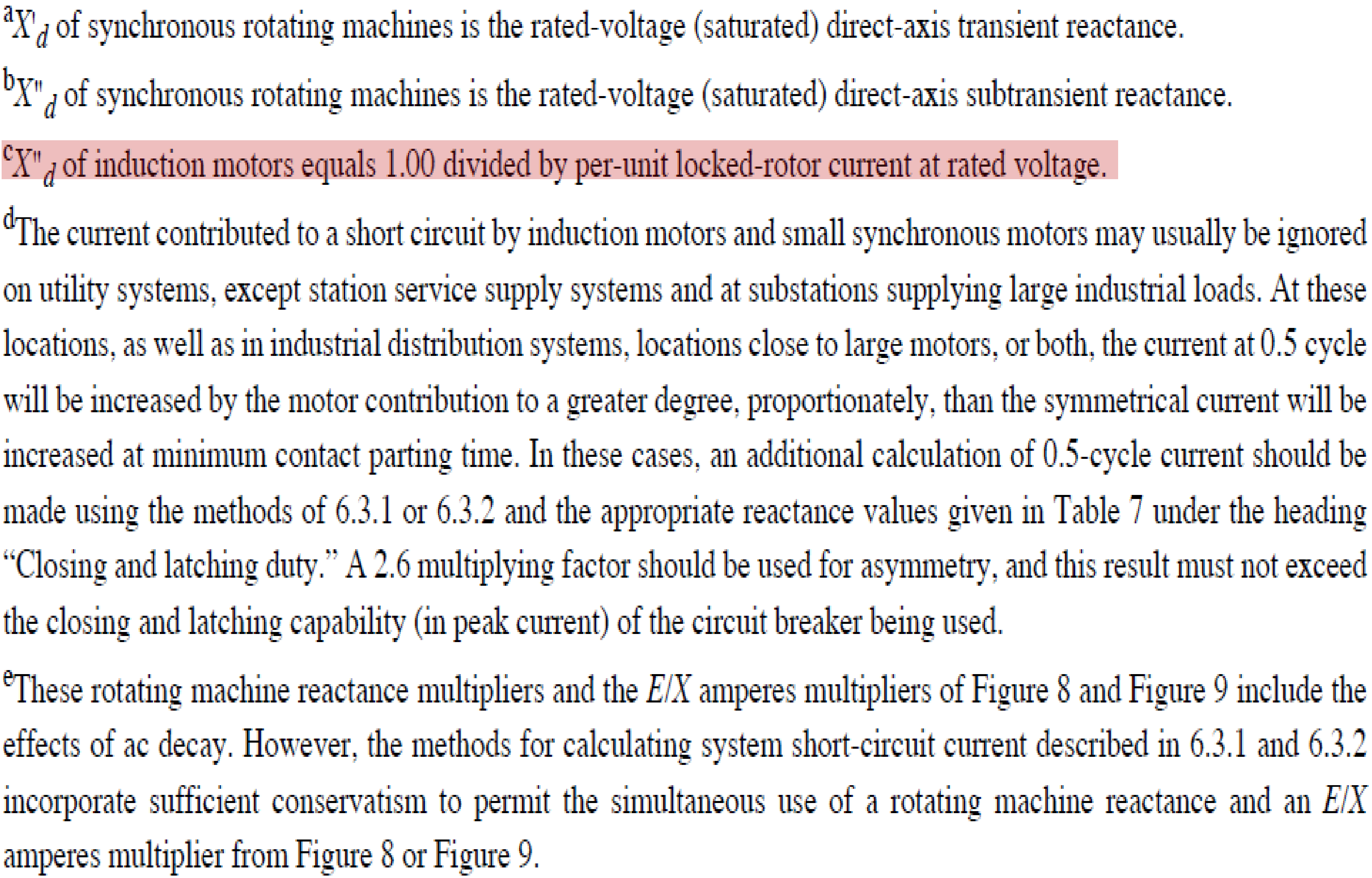
6.4.1 Rotating machine reactances

Basically, initial short-circuit current of rotating machines is determined by the machine subtransient reactances. For the simplified and more accurate methods of short-circuit current calculation, Table 7 shows the reactances that are used.

Table 7—Reactances

Type of rotating machine	Positive sequence reactances for calculating	
	Interrupting duty (per unit)	Closing and latching duty (per unit)
All turbo-generators, all hydro-generators with amortisseur windings, and all condensers[a]	$1.0\ X''_d$	$1.0\ X''_d$
Hydro-generators without amortisseur windings[a]	$0.75X'_d$	$0.75X'_d$
All synchronous motors[b,d,e]	$1.5\ X''_d$	$1.0\ X''_d$
Induction motors[c,d,e]		
Above 1000 hp at 1800 r/min or less Above 250 hp at 3,600 r/min	$1.5\ X''_d$	$1.0\ X''_d$
From 50 hp to 1000 hp at 1800 r/min or less From 50 hp to 250 hp at 3,600 r/min	$3.0\ X''_d$	$1.2\ X''_d$
Neglect all three-phase induction motors below 50 hp and all single-phase motors		

C37.010-1999 – Table 7



[a]X'_d of synchronous rotating machines is the rated-voltage (saturated) direct-axis transient reactance.

[b]X''_d of synchronous rotating machines is the rated-voltage (saturated) direct-axis subtransient reactance.

[c]X''_d of induction motors equals 1.00 divided by per-unit locked-rotor current at rated voltage.

[d]The current contributed to a short circuit by induction motors and small synchronous motors may usually be ignored on utility systems, except station service supply systems and at substations supplying large industrial loads. At these locations, as well as in industrial distribution systems, locations close to large motors, or both, the current at 0.5 cycle will be increased by the motor contribution to a greater degree, proportionately, than the symmetrical current will be increased at minimum contact parting time. In these cases, an additional calculation of 0.5-cycle current should be made using the methods of 6.3.1 or 6.3.2 and the appropriate reactance values given in Table 7 under the heading "Closing and latching duty." A 2.6 multiplying factor should be used for asymmetry, and this result must not exceed the closing and latching capability (in peak current) of the circuit breaker being used.

[e]These rotating machine reactance multipliers and the E/X amperes multipliers of Figure 8 and Figure 9 include the effects of ac decay. However, the methods for calculating system short-circuit current described in 6.3.1 and 6.3.2 incorporate sufficient conservatism to permit the simultaneous use of a rotating machine reactance and an E/X amperes multiplier from Figure 8 or Figure 9.

C37.010-1999 – Figure 19

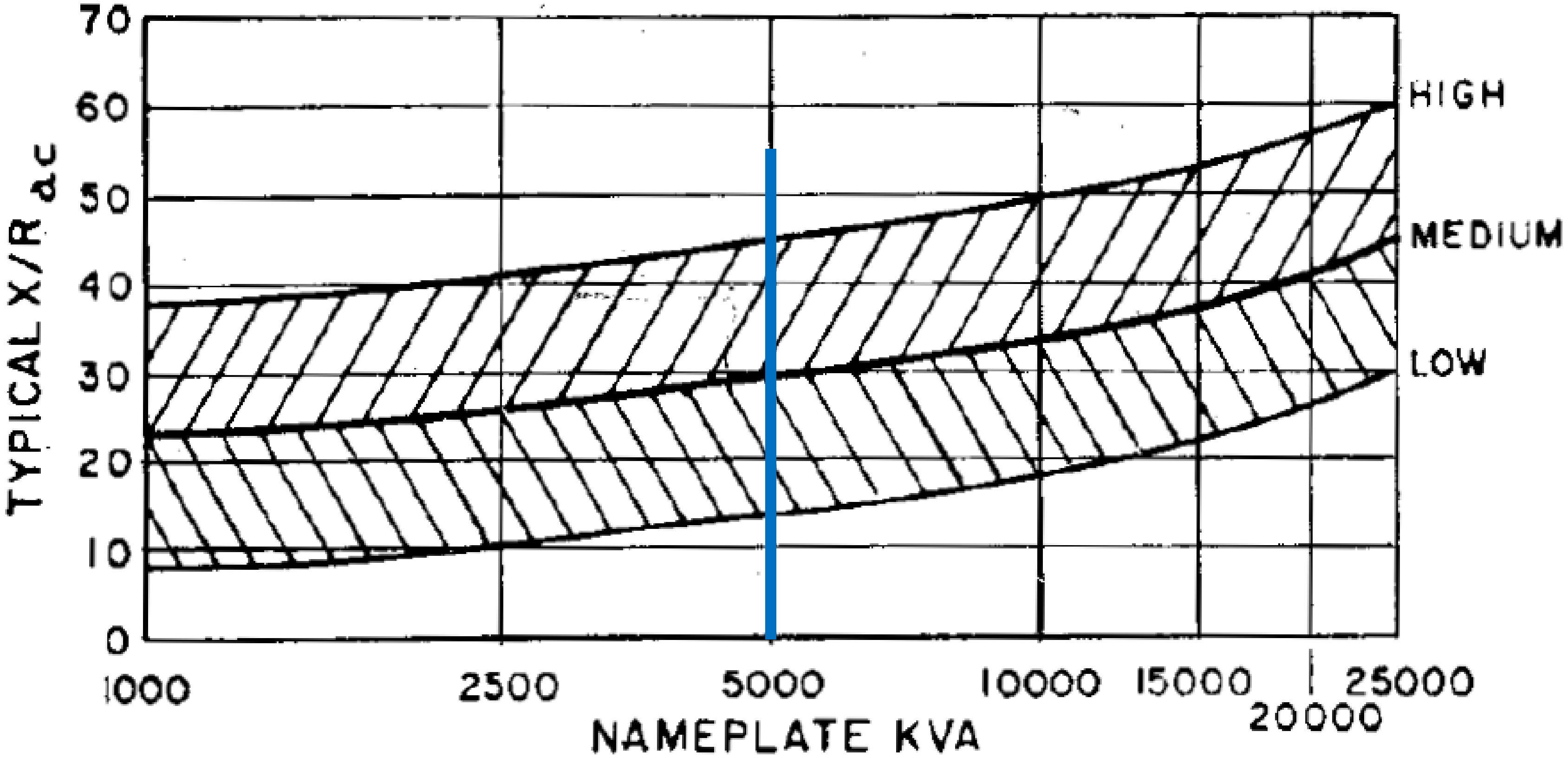


Figure 19—X/R range for small solid rotor and salient pole generators and synchronous motors at 60 Hz

Find Generator X_{pu} & R_{pu}

$$Z_{Generator,pu} = Z_G \frac{MVA_{BASE}}{MVA_{Generator}}$$

Given

$$X_{pu} = X''_d \frac{MVA_{BASE}}{MVA_{Generator}} = 0.1\frac{100}{5} = \underline{2.0}$$

$$R_{pu} = \frac{X_{pu}}{X/R} = \frac{2.0}{30} = \underline{0.067}$$

C37.010-1999 – Figure 17

Based on class of transformer, obtain the proper factor from the table below. Multiply the transformer MVA-ampere rating by this factor before using Figure 17 to obtain the typical *X/R* value.

Class	Rating in MVA	Factor
OA	All ratings	1.67
FA	Up to 14.9	1.33
FA	16 and up	1.25
FOA	All ratings	1.00

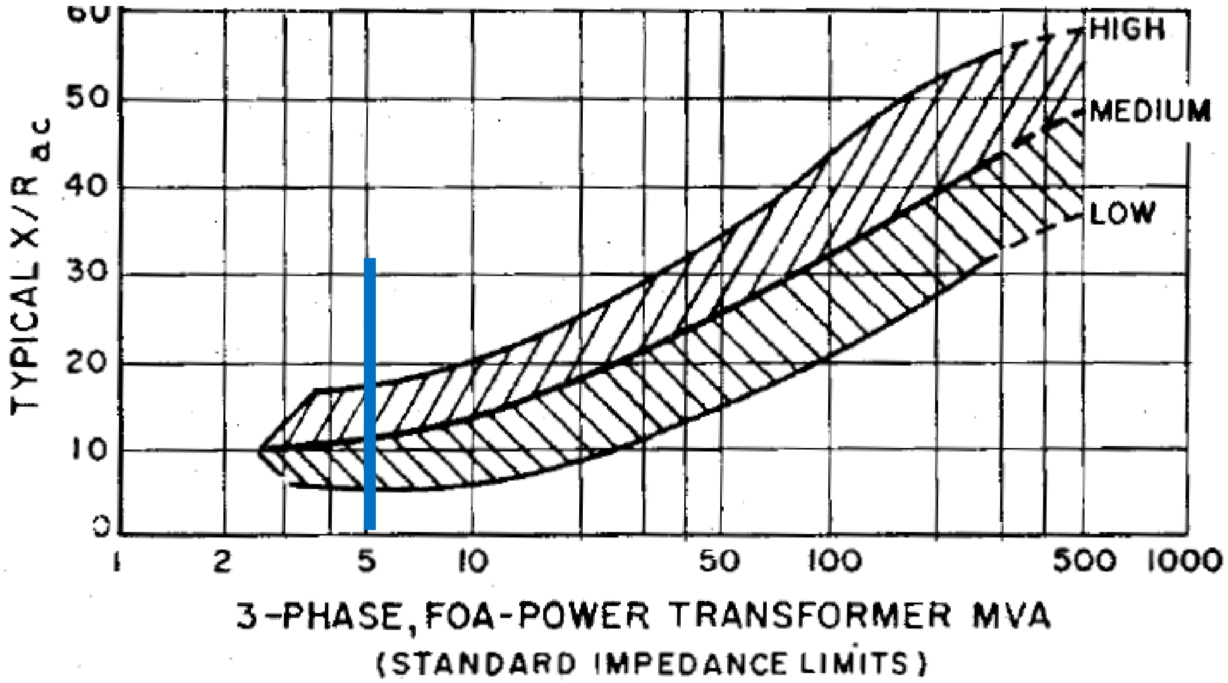


Figure 17—X/R range for power transformers at 60 Hz

Find Transformer T_1 and T_2, X_{pu} & R_{pu}

$$Z_{XFMR,pu} = Z_{XFMR}\frac{MVA_{BASE}}{MVA_{XFMR}}$$

Given

$$X_{1,pu} = X\frac{MVA_{BASE}}{MVA_{XFMR,1}} = 0.057373\frac{100}{5} = \underline{1.147}$$

$$R_{1,pu} = R\frac{MVA_{BASE}}{MVA_{XFMR,1}} = 0.003825\frac{100}{5} = \underline{0.077}$$

$$X_{2,pu} = X\frac{MVA_{BASE}}{MVA_{XFMR,2}} = 0.059184\frac{100}{1} = \underline{5.918}$$

$$R_{2,pu} = R\frac{MVA_{BASE}}{MVA_{XFMR,2}} = 0.009864\frac{100}{1} = \underline{.986}$$

Find Feeder F_1 and F_2, X_{pu} & R_{pu}

$$Z_{Feeder,pu} = Z_F \frac{MVA_{BASE}}{kV^2} \qquad \underline{X\Omega/1000' = 0.054} \qquad \underline{R\Omega/1000' = 0.16}$$

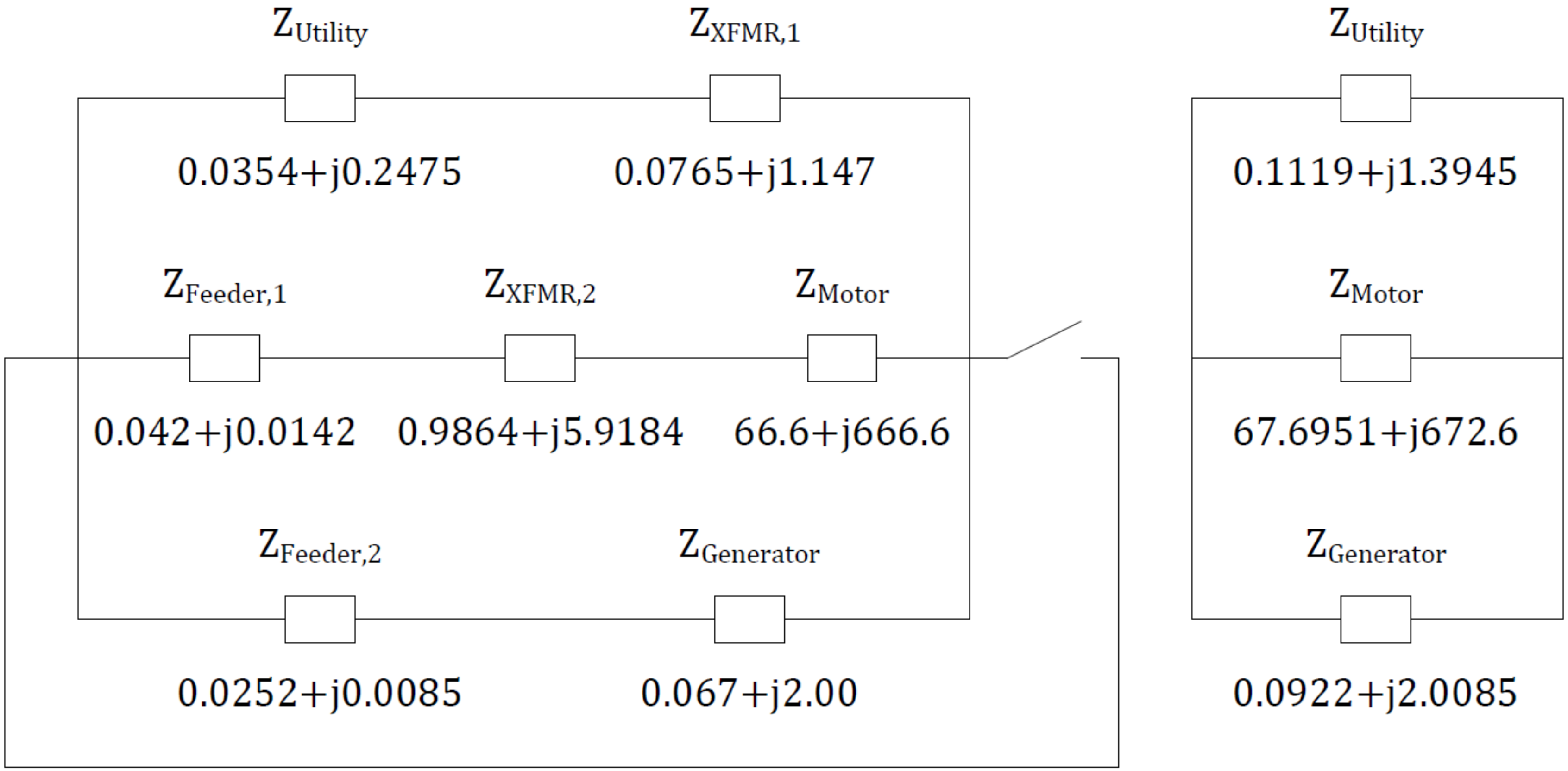
$$X_{1,pu} = X\Omega \frac{\#1}{1000'} \frac{MVA_{BASE}}{kV^2} = 0.054 \frac{500'}{1000'} \frac{100}{13.8^2} = \underline{0.014}$$

$$R_{1,pu} = R\Omega \frac{\#1}{1000'} \frac{MVA_{BASE}}{kV^2} = 0.16 \frac{500'}{1000'} \frac{100}{13.8^2} = \underline{0.042}$$

$$X_{2,pu} = X\Omega \frac{\#2}{1000'} \frac{MVA_{BASE}}{kV^2} = 0.054 \frac{300'}{1000'} \frac{100}{13.8^2} = \underline{0.009}$$

$$R_{2,pu} = R\Omega \frac{\#2}{1000'} \frac{MVA_{BASE}}{kV^2} = 0.16 \frac{300'}{1000'} \frac{100}{13.8^2} = \underline{0.025}$$

Solve for Fault at Bus 2



$$Z_U = 0.112 + j1.395 = 1.39\angle 85.41°$$

$$Z_M = 67.69 + j672.6 = 676\angle 84.25°$$

$$Z_G = 0.092 + j2.009 = 2.01\angle 87.37°$$

Calculate 3φ Fault Current

$$Z_{U\&M} = Z_U \,||\, Z_M = \frac{945.71\angle 169.67°}{677.39\angle 84.26°} = \underline{1.396\angle 85.41°} = \underline{0.112 + j1.392}$$

$$Z_{eq} = Z_{U\&M} \,||\, Z_G = \frac{2.807\angle 172.78}{3.406\angle 86.57°} = \underline{0.824\angle 86.21°} = \underline{0.054 + j0.822}$$

$$I_{BASE} = \frac{100}{13.8\sqrt{3}} = \underline{4.184kA}$$

$$I_{FAULT} = \frac{1}{Z_{eq}}\left(I_{BASE}\right) = \frac{1}{0.824}\left(4.184kA\right) = \underline{5.078kA}$$

$$\frac{X}{R} = \frac{0.822}{0.054} = \underline{15.11}$$

Calculate 3φ Fault Current

$$R_{With,Motor} = \frac{1}{1/.112 + 1/67.69 + 1/.092} = \underline{0.0505}$$

$$X_{With,Motor} = \frac{1}{1/1.395 + 1/672.59 + 1/2.009} = \underline{0.8221}$$

$$\frac{X}{R} = \frac{0.8221}{0.0505} = \underline{16.27}$$

$$Z_{With,Motor} = 0.0505 + j0.8221 = \underline{0.824\angle 86.48^{\circ}}$$

$$Z_{Ignoring,Motor} = 0.0506 + j0.8231 = \underline{0.825\angle 86.49^{\circ}}$$

Short Cuts

$$\text{Compare to Vector:}$$

$$I_{FAULT_{Angular}} = \frac{1}{0.824}\left(4.184kA\right) = \underline{5.08kA}$$

$$I_{FAULT_{Ignoring\,Resistance}} = \frac{1}{0.822}\left(4.184kA\right) = \underline{5.09kA}$$

$$I_{FAULT_{Ignoring\,Motor}} = \frac{1}{0.823}\left(4.184kA\right) = \underline{5.07kA}$$

C37.010-1999 – Table 10

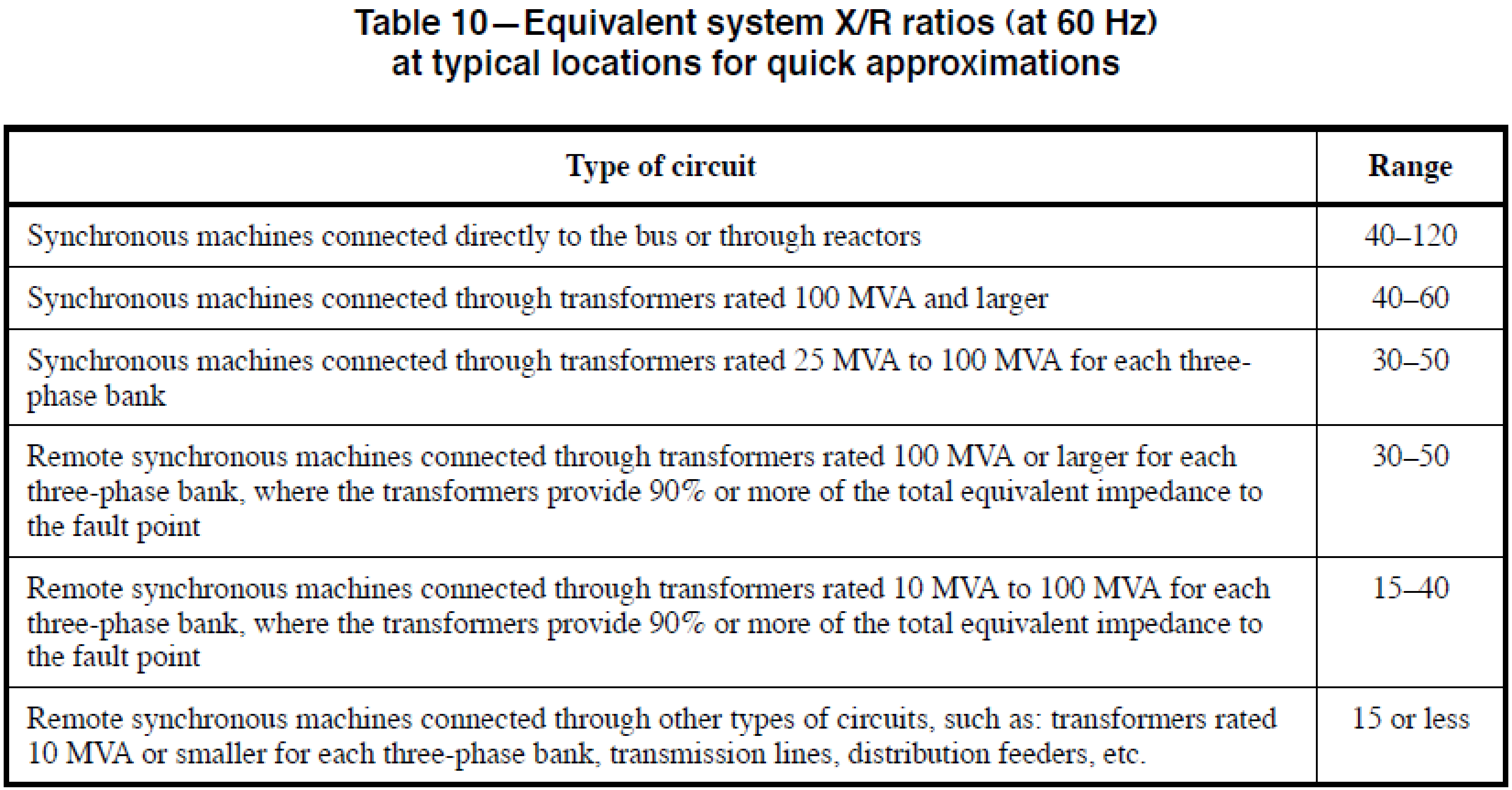


Table 10—Equivalent system X/R ratios (at 60 Hz) at typical locations for quick approximations

Type of circuit	Range
Synchronous machines connected directly to the bus or through reactors	40–120
Synchronous machines connected through transformers rated 100 MVA and larger	40–60
Synchronous machines connected through transformers rated 25 MVA to 100 MVA for each three-phase bank	30–50
Remote synchronous machines connected through transformers rated 100 MVA or larger for each three-phase bank, where the transformers provide 90% or more of the total equivalent impedance to the fault point	30–50
Remote synchronous machines connected through transformers rated 10 MVA to 100 MVA for each three-phase bank, where the transformers provide 90% or more of the total equivalent impedance to the fault point	15–40
Remote synchronous machines connected through other types of circuits, such as: transformers rated 10 MVA or smaller for each three-phase bank, transmission lines, distribution feeders, etc.	15 or less

Typical Circuit Breaker Timing

Opening time (cycles)	Rated interrupting time
1.0	2 cycle
1.5 (25ms)	3 cycle
2.5 (42ms)	5 cycle
3.5	8 cycle

Contact part = opening time + ½ cycle for minimum relay time

C37.010-1999 – Figure A.10

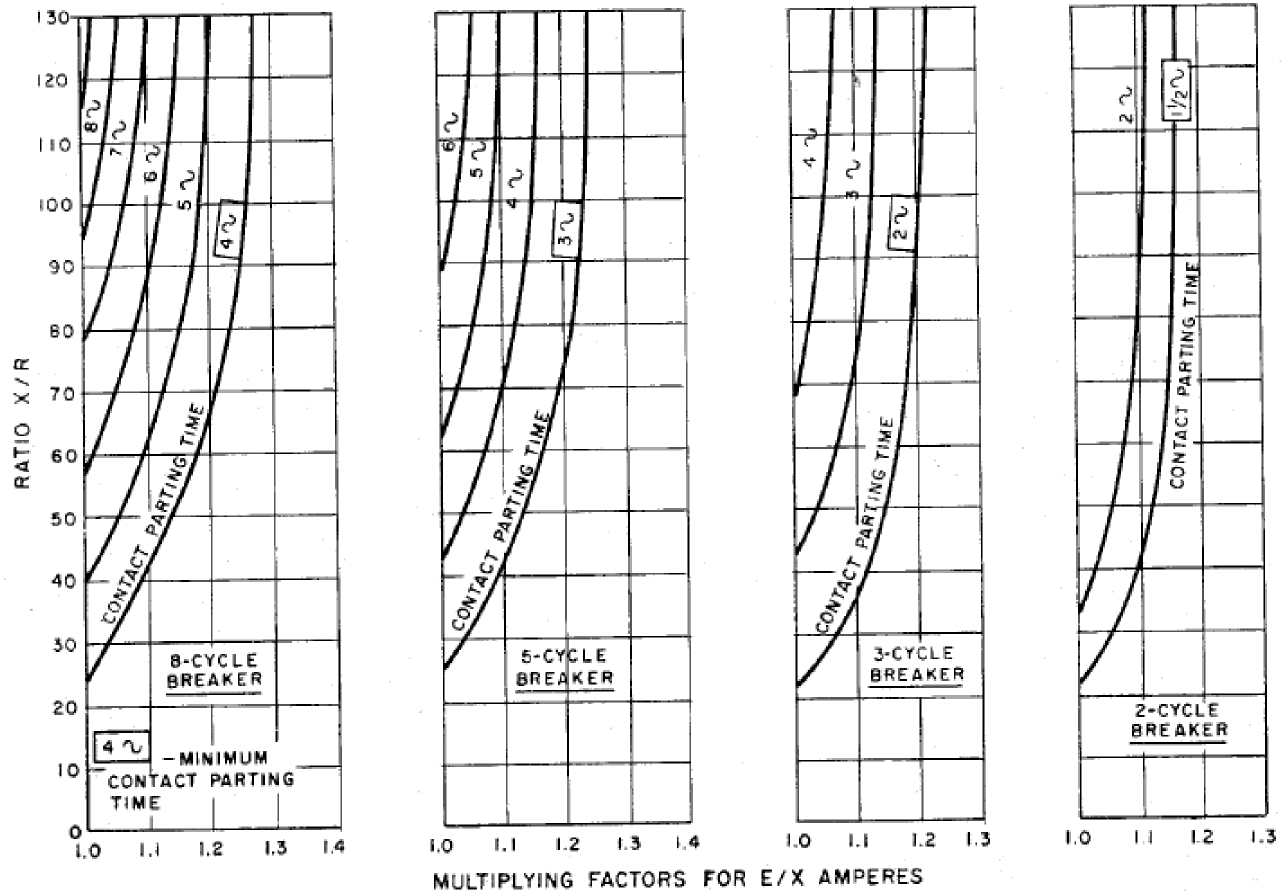


Figure A.10—Three-phase fault multiplying factors that include effects of ac and dc decrement (at 60 Hz)

C37.010-1999 – Figure A.11

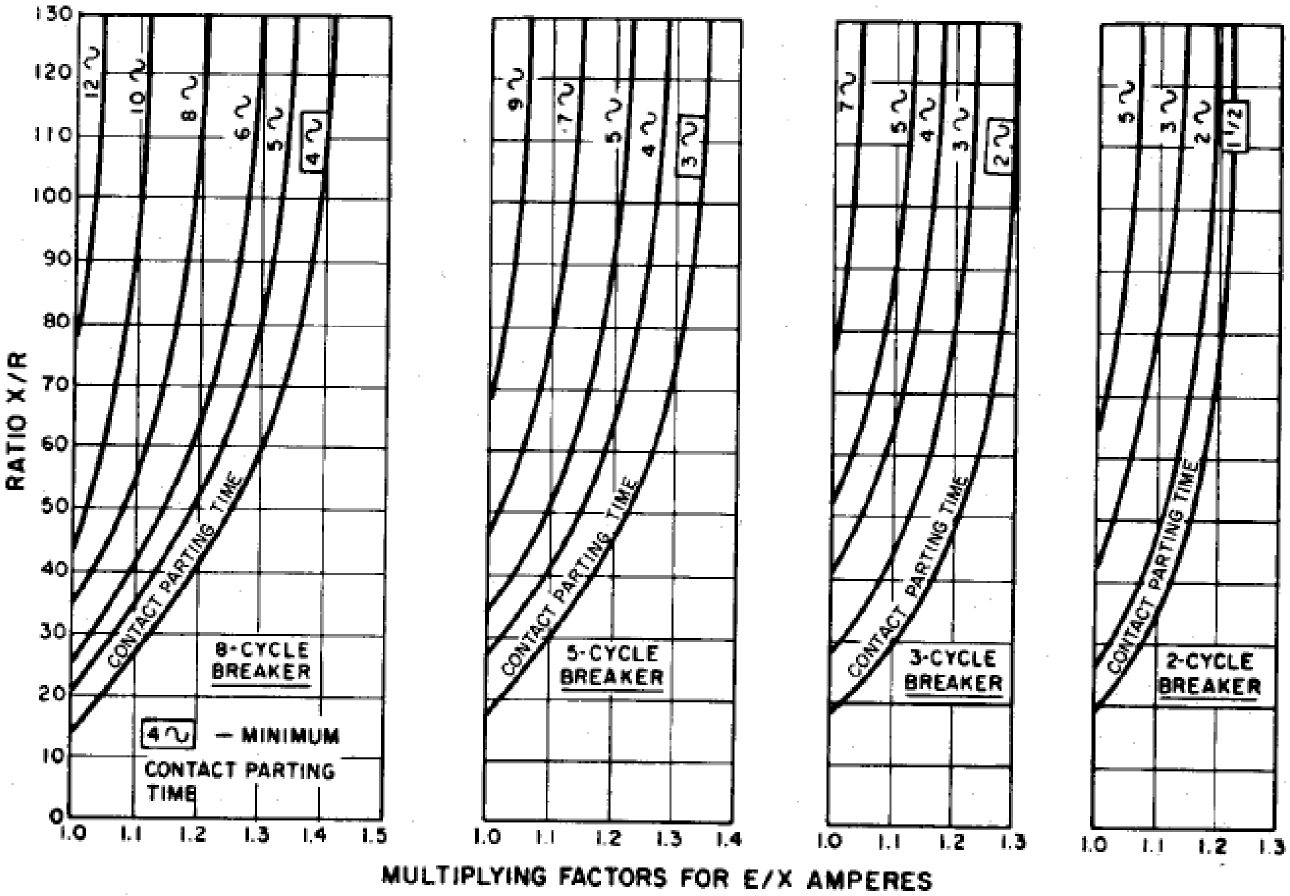


Figure A.11—Line-to-ground fault multiplying factors that include effects of ac and dc decrement

C37.010-1999 – Figure A.12

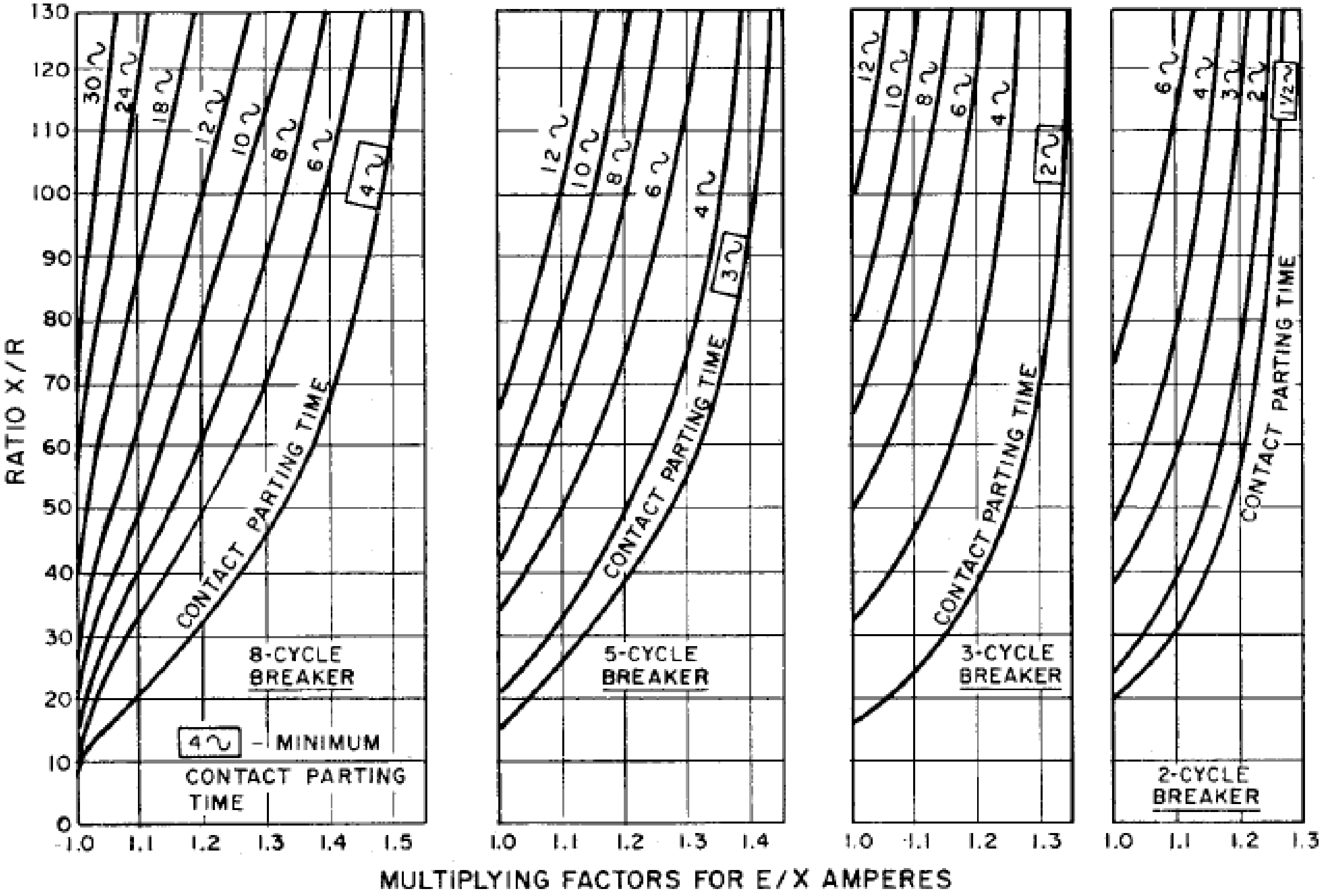


Figure A.12—Three-phase and line-to-ground fault multiplying factors that include effects of dc decrement only

Asymmetrical Capability

- Based on X/R of 17 @ 60 Hz and 14 @ 50 Hz
- Breaker ability fixed at contact part time
- Asymmetrical capability is constant for entire time up to max tripping delay of 2 seconds

- Old S factors and new %DC

$$I_{TOTAL} = I_{Symmetrical}\sqrt{1+2\ {\frac{\%dc}{100}}^{2}}$$

Choosing an MV CB Using *K* Factor

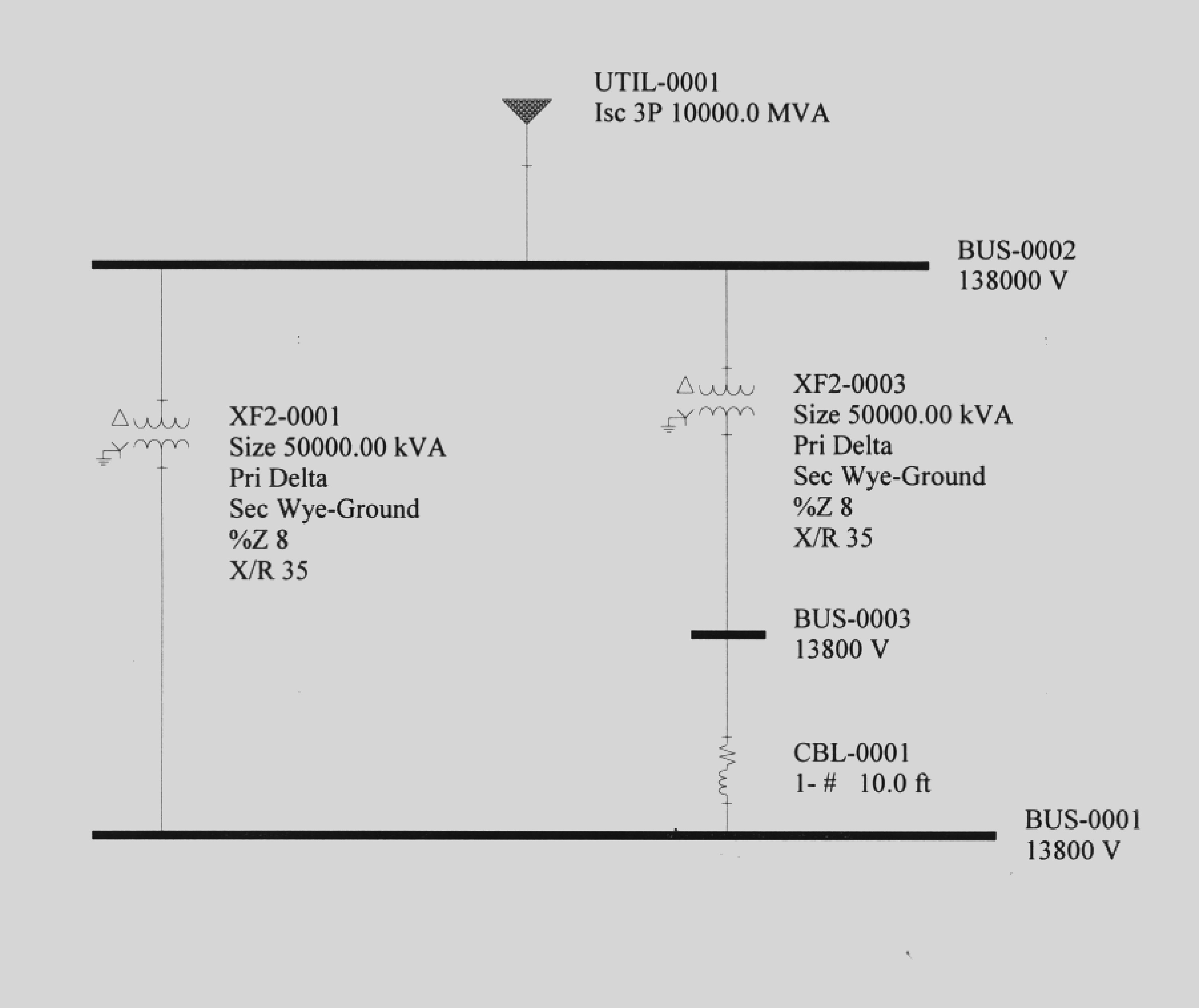
- *K* is rated voltage range factor, a ratio between rated maximum voltage (V) and voltage at maximum symmetrical interrupting capability, which = V/*K*
- At voltages between V and V/*K*, symmetrical interrupting capability is:

  I_{sc} = I*V/System Voltage
- At voltages of V/*K* and below, sym-metrical interrupting capability is *K*I

Choosing
Metal-Clad Switchgear

- The ratings of metal-clad switchgear in general follow the ratings of the circuit breaker used in the switchgear
- Main bus continuous current rating must be specified for the switchgear
  - Standard ratings are 1200 A, 2000 A, and 3000 A
  - Higher ratings may be available, but designers should attempt to use standards

SKM Model

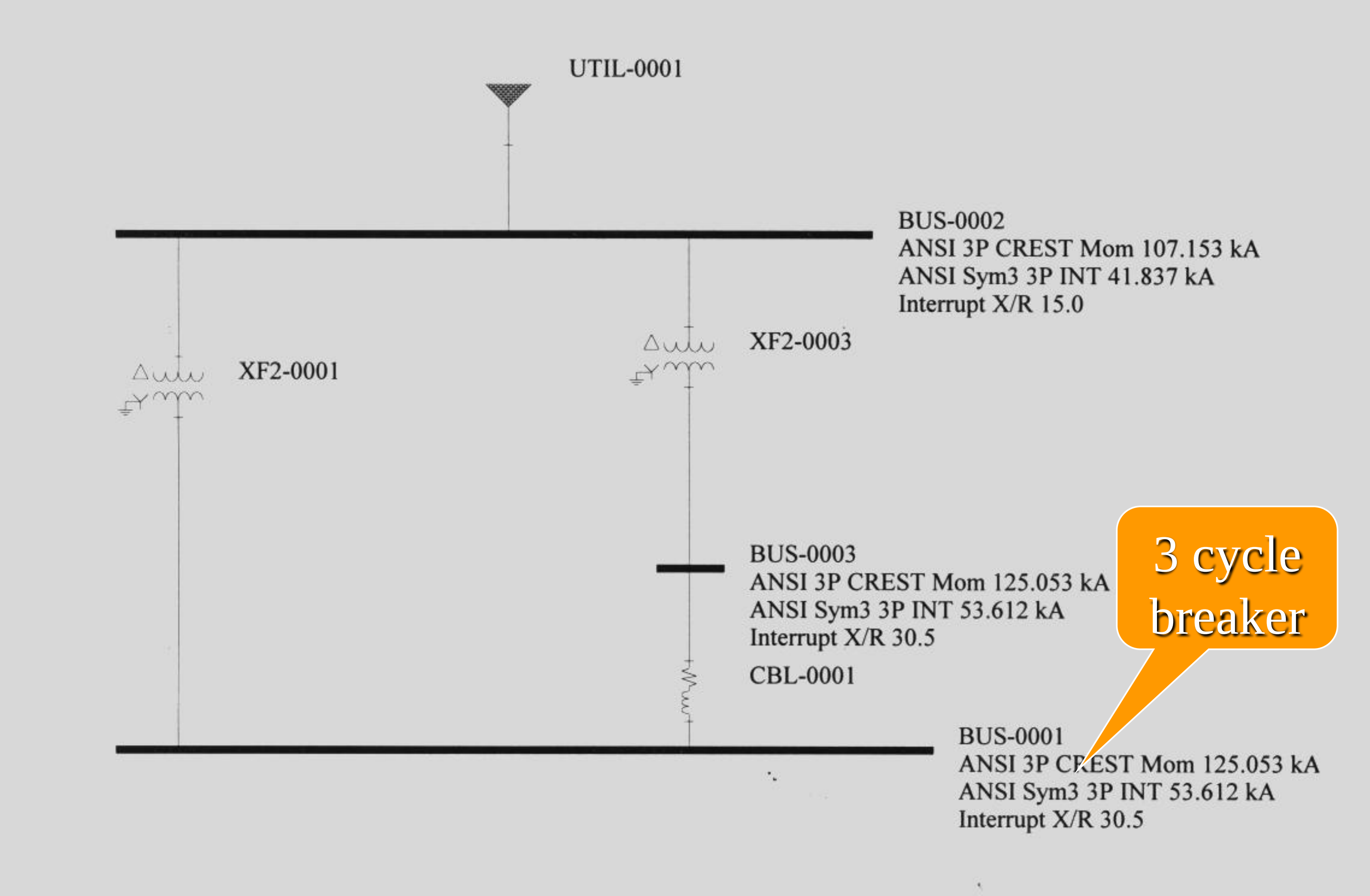

UTIL-0001
Isc 3P 10000.0 MVA
BUS-0002
138000 V
XF2-0001
Size 50000.00 kVA
Pri Delta
Sec Wye-Ground
%Z 8
X/R 35
XF2-0003
Size 50000.00 kVA
Pri Delta
Sec Wye-Ground
%Z 8
X/R 35
BUS-0003
13800 V
CBL-0001
1- # 10.0 ft
BUS-0001
13800 V

Choosing an MV CB

X/R Considerations

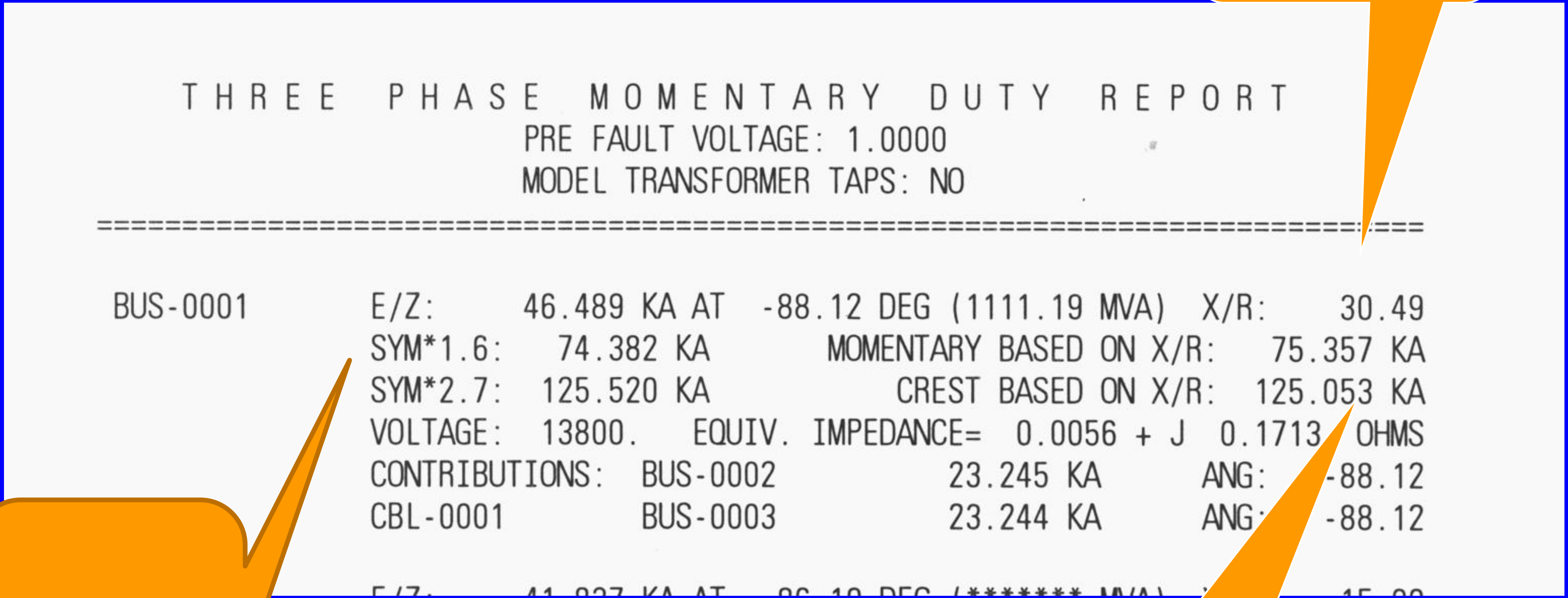
- Simplified E/X method of calculating short-circuit current may be used up to 100% of breaker rating if X/R does not exceed 15
- Simplified E/X method may be used up to 80% of breaker rating for any X/R
- For currents over 80% and X/R over 15, more exact short circuit calculations are required

SKM Model



3 cycle breaker

SKM Momentary



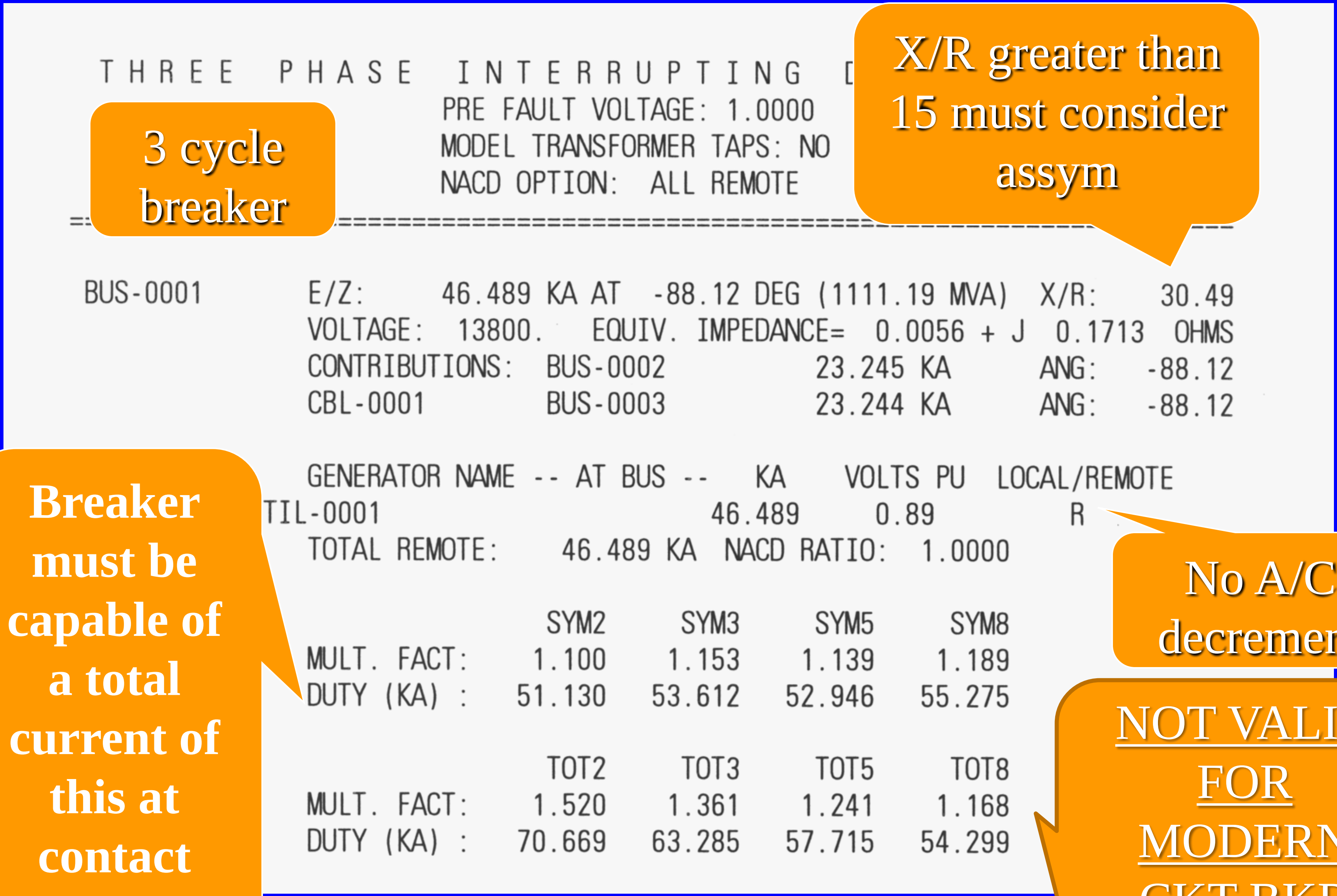
```
THREE PHASE MOMENTARY DUTY REPORT
            PRE FAULT VOLTAGE: 1.0000
            MODEL TRANSFORMER TAPS: NO
==============================================================================

BUS-0001        E/Z:     46.489 KA AT  -88.12 DEG (1111.19 MVA)  X/R:    30.49
                SYM*1.6:   74.382 KA      MOMENTARY BASED ON X/R:   75.357 KA
                SYM*2.7:  125.520 KA          CREST BASED ON X/R:  125.053 KA
                VOLTAGE:  13800.   EQUIV. IMPEDANCE=  0.0056 + J  0.1713  OHMS
                CONTRIBUTIONS:  BUS-0002          23.245 KA      ANG:   -88.12
                CBL-0001        BUS-0003          23.244 KA      ANG:   -88.12
```

x/r greater than 15

Mom not RMS anymore

Crest value

Short Circuit Interrupting



```
   THREE  PHASE  INTERRUPTING  D
                  PRE FAULT VOLTAGE: 1.0000
                  MODEL TRANSFORMER TAPS: NO
                  NACD OPTION:  ALL REMOTE
==============================================================================

 BUS-0001        E/Z:     46.489 KA AT  -88.12 DEG (1111.19 MVA)  X/R:    30.49
                 VOLTAGE:  13800.   EQUIV. IMPEDANCE=  0.0056 + J  0.1713  OHMS
                 CONTRIBUTIONS:  BUS-0002          23.245 KA       ANG:   -88.12
                 CBL-0001        BUS-0003          23.244 KA       ANG:   -88.12

                 GENERATOR NAME -- AT BUS --    KA    VOLTS PU  LOCAL/REMOTE
TIL-0001                                    46.489     0.89          R
                 TOTAL REMOTE:     46.489 KA  NACD RATIO:  1.0000

                               SYM2      SYM3      SYM5      SYM8
                 MULT. FACT:   1.100     1.153     1.139     1.189
                 DUTY (KA) :  51.130    53.612    52.946    55.275

                               TOT2      TOT3      TOT5      TOT8
                 MULT. FACT:   1.520     1.361     1.241     1.168
                 DUTY (KA) :  70.669    63.285    57.715    54.299
```

3 cycle breaker

X/R greater than 15 must consider assym

Breaker must be capable of a total current of this at contact part

No A/C decrement

NOT VALID FOR MODERN CKT BKR

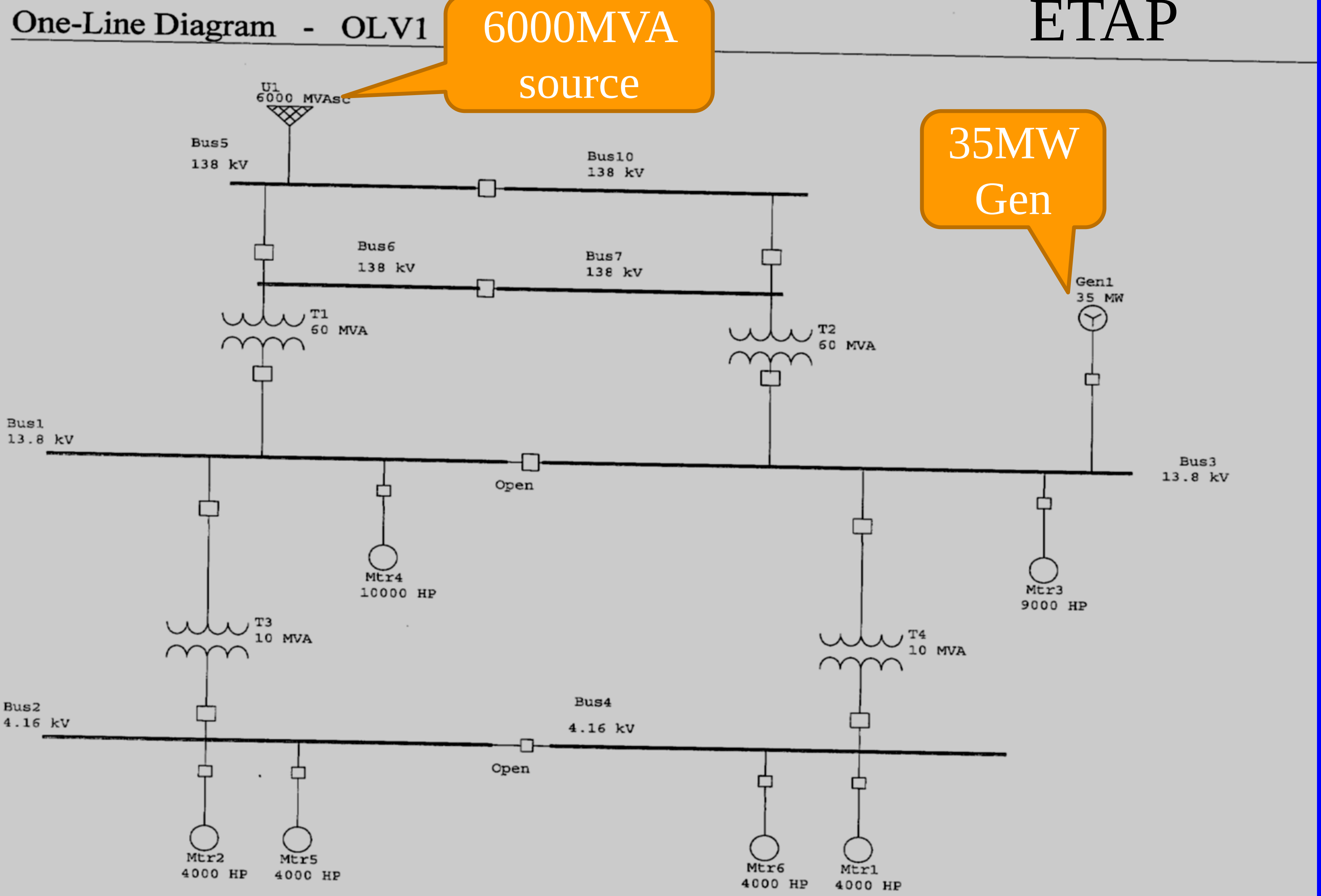
Circuit Breaker Ratings

PowlVac Breaker Type	Max Voltage (kV)	Interrupting Symmetrical (kA rms) Note (1)	Obsolete MVA Class	Continuous Current (A)	Cubicle width (In.)	Power Frequency Withstand (kV)	BIL crest (kV)	Close and Latch (10cycle) Momentary (kA, crest)	%DC Interrupting Current (%)	Rated Interrupting Time (3) (cycle/msec)	Short Time Current (3 sec.)	Back to Back Cap Switching (Amps) (4)
05PV36SND	4.76	36	250	1200, 2000	26	19	60	97	50	3 / 50	36	
05PV36STD	↓	36	250	1200, 2000, 3000, 4000(2)	36	↓	↓	97	↓	↓	36	
05PV50SND	↓	50	350	1200, 2000	26	↓	↓	135	↓	↓	50	
05PV50STD	↓	50	350	1200, 2000, 3000, 4000(2)	36	↓	↓	135	↓	↓	50	
05PV63STD	↓	63	500	1200, 2000, 3000, 4000(2)	36	↓	↓	170	↓	↓	63	1640
15PV25STD	15	25	500	1200, 2000, 3000, 4000(2)	36	36	95	67	50	3 / 50	25	1640
15PV36STD	↓	36	750	1200, 2000, 3000, 4000(2)	↓	↓	↓	97	↓	↓	36	1640
15PV50STD	↓	50	1200	1200, 2000, 3000, 4000(2)	↓	↓	↓	135	↓	↓	50	1640
15PV63STD	↓	63	1500	1200, 2000, 3000, 4000(2)	↓	↓	↓	170	↓	↓	63	1640

Notes:

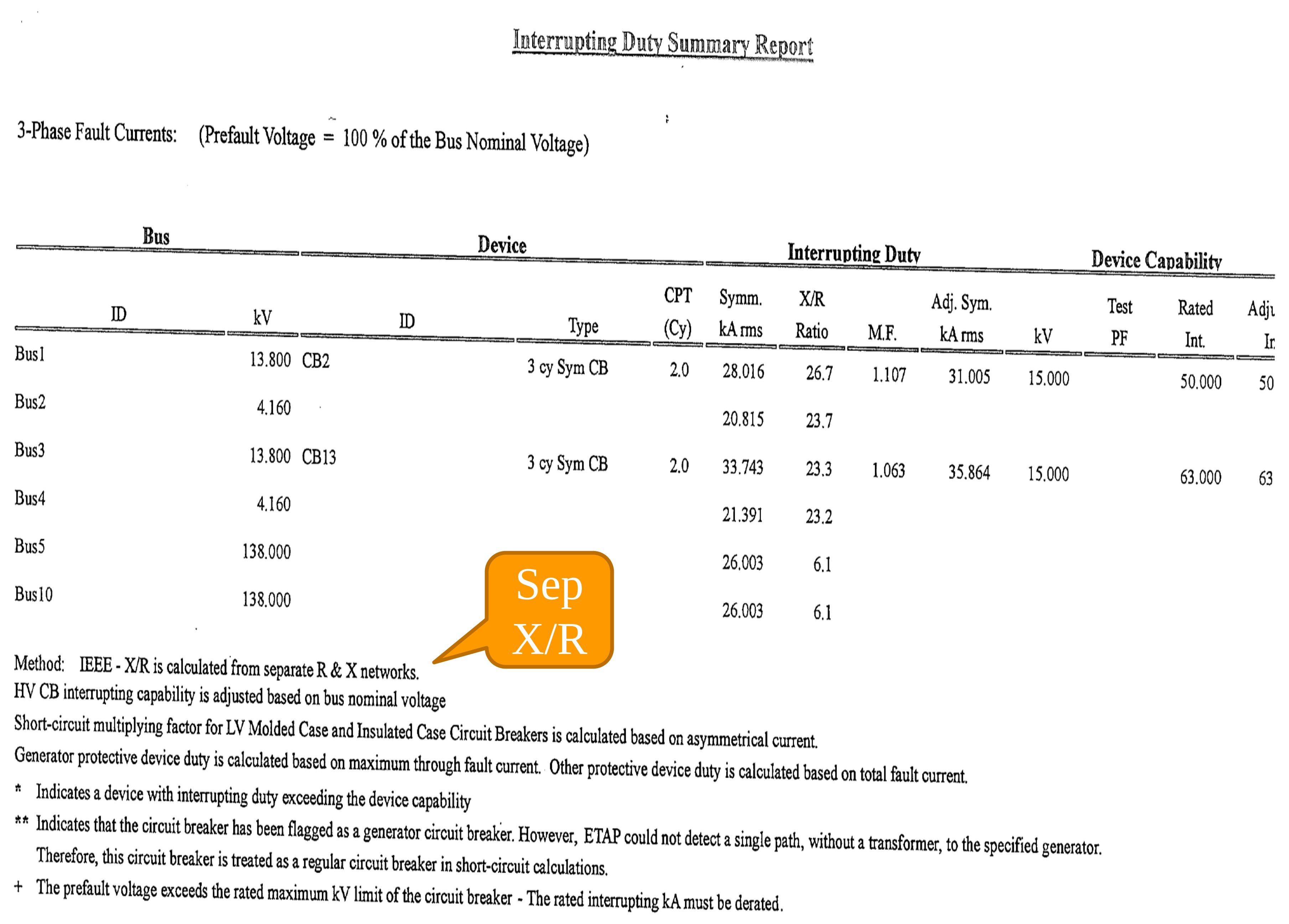
(1) Interrupting current constant for all voltages less than the maximum voltage. Rated voltage range factor k=1.
(2) Forced Air Cooling fans required for current in excess of 3000 amps.
(3) 5 cycle breakers available at the same %dc ratings
(4) Back to back capacitor switching rating is good for 1200, 2000, 3000, and 4000 continuous current ratings.
(5) Maximum tripping delay is 2 seconds for all circuit breaker as per the ANSI standards.

ETAP



6000MVA source

35MW Gen



Interrupting Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device			Interrupting Duty				Device Capability			
ID	kV	ID	Type	CPT (Cy)	Symm. kA rms	X/R Ratio	M.F.	Adj. Sym. kA rms	kV	Test PF	Rated Int.	Adju In
Bus1	13.800	CB2	3 cy Sym CB	2.0	28.016	26.7	1.107	31.005	15.000		50.000	50
Bus2	4.160				20.815	23.7						
Bus3	13.800	CB13	3 cy Sym CB	2.0	33.743	23.3	1.063	35.864	15.000		63.000	63
Bus4	4.160				21.391	23.2						
Bus5	138.000				26.003	6.1						
Bus10	138.000				26.003	6.1						

Sep X/R

Method: IEEE - X/R is calculated from separate R & X networks.

HV CB interrupting capability is adjusted based on bus nominal voltage

Short-circuit multiplying factor for LV Molded Case and Insulated Case Circuit Breakers is calculated based on asymmetrical current.

Generator protective device duty is calculated based on maximum through fault current. Other protective device duty is calculated based on total fault current.

* Indicates a device with interrupting duty exceeding the device capability

** Indicates that the circuit breaker has been flagged as a generator circuit breaker. However, ETAP could not detect a single path, without a transformer, to the specified generator. Therefore, this circuit breaker is treated as a regular circuit breaker in short-circuit calculations.

\+ The prefault voltage exceeds the rated maximum kV limit of the circuit breaker - The rated interrupting kA must be derated.

Momentary Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Momentary Duty					Device Capa	
ID	kV	ID	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm kA rms
Bus1	13.800	Bus1	Switchgear	29.290	28.3	1.613	47.249	78.497		77.00
	13.800	CB2	3 cy Sym CB	29.290	28.3	1.613	47.249	78.497		80.00
Bus2	4.160	Bus2	MCC	23.122	26.2	1.604	37.094	61.705		
Bus3	13.800	Bus3	Switchgear	34.938	24.6	1.596	55.775	92.886		77.00
	13.800	CB13	3 cy Sym CB	34.938	24.6	1.596	55.775	92.886		100.00
Bus4	4.160	Bus4	MCC	23.665	25.7	1.602	37.905	63.077		78.00
Bus5	138.000	Bus5	Bus	26.169	6.4	1.323	34.627	59.685		
Bus10	138.000	Bus10	Bus	26.169	6.4	1.323	34.627	59.685		

Method: IEEE - X/R is calculated from separate R & X networks.

Protective device duty is calculated based on total fault current.

The multiplication factors for high voltage circuit-breaker and high voltage bus momentary duty (asymmetrical and crest values) are calculated based on system X/R.

* Indicates a device with momentary duty exceeding the device capability

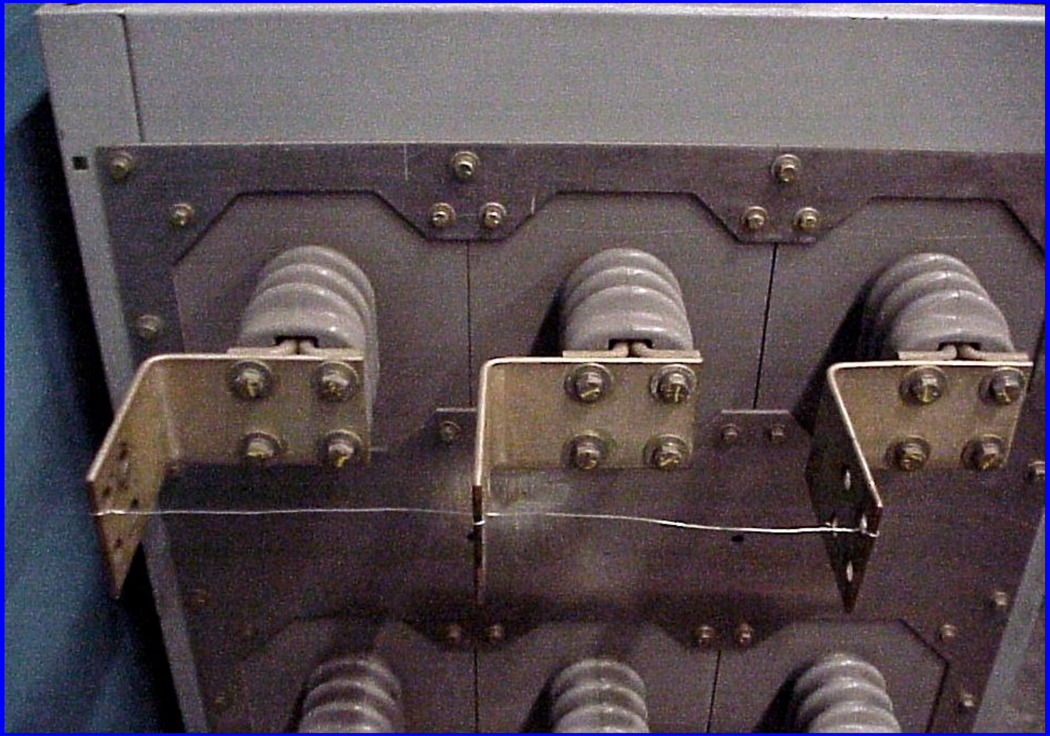
38kV 40kA circuit breaker cell

Arc Resistant Switchgear

- Arc flash hazards: *pressure wave, heat, and shrapnel*
- Accessibility: *Type 1, Type 2 and Type 2b*
- *C37.20.7 a combined test for ½ sec*

Bolted Fault vs. Arcing Fault in Medium-Voltage Switchgear

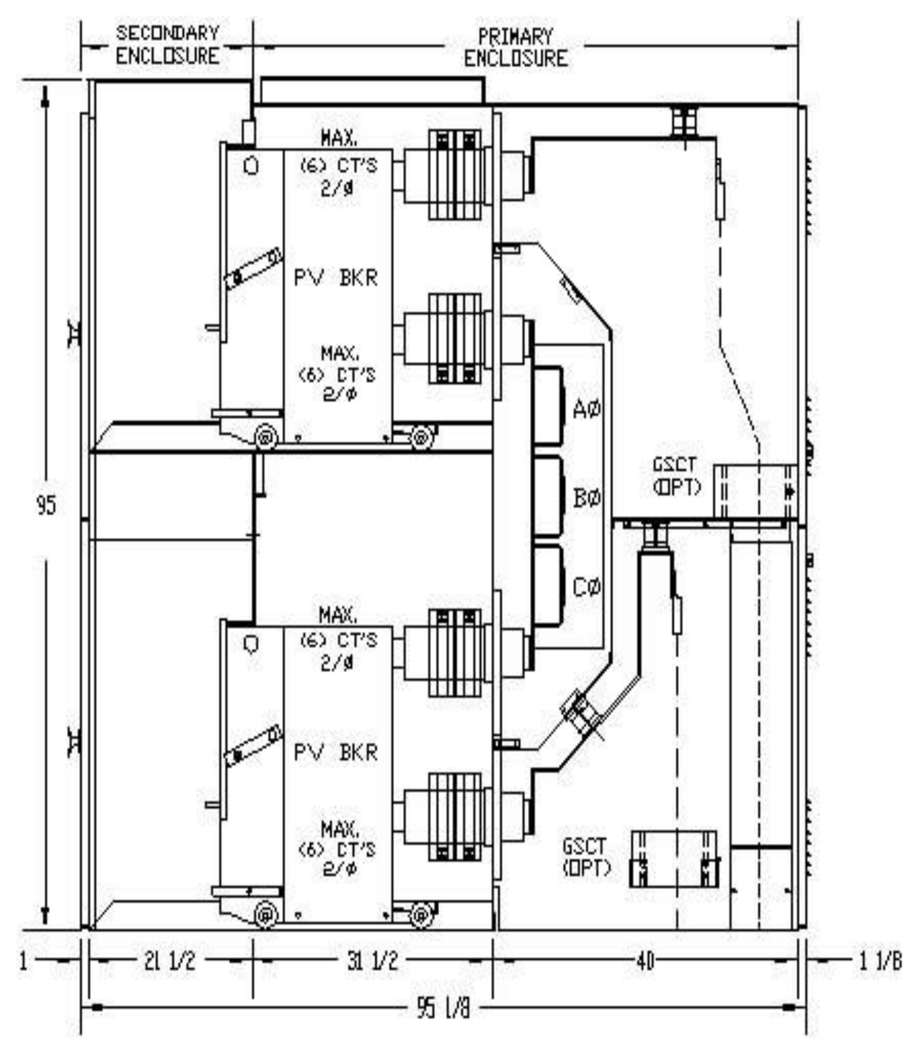
- Arc Faults
  - **Mechanical forces and Current I^2t**
  - **Heating and burning of conductors and enclosure**
  - **Radiation**
  - **Rapid overpressure of equipment and surroundings**



Arc Fault Energy Directed Away from the Technician

MV Swgr

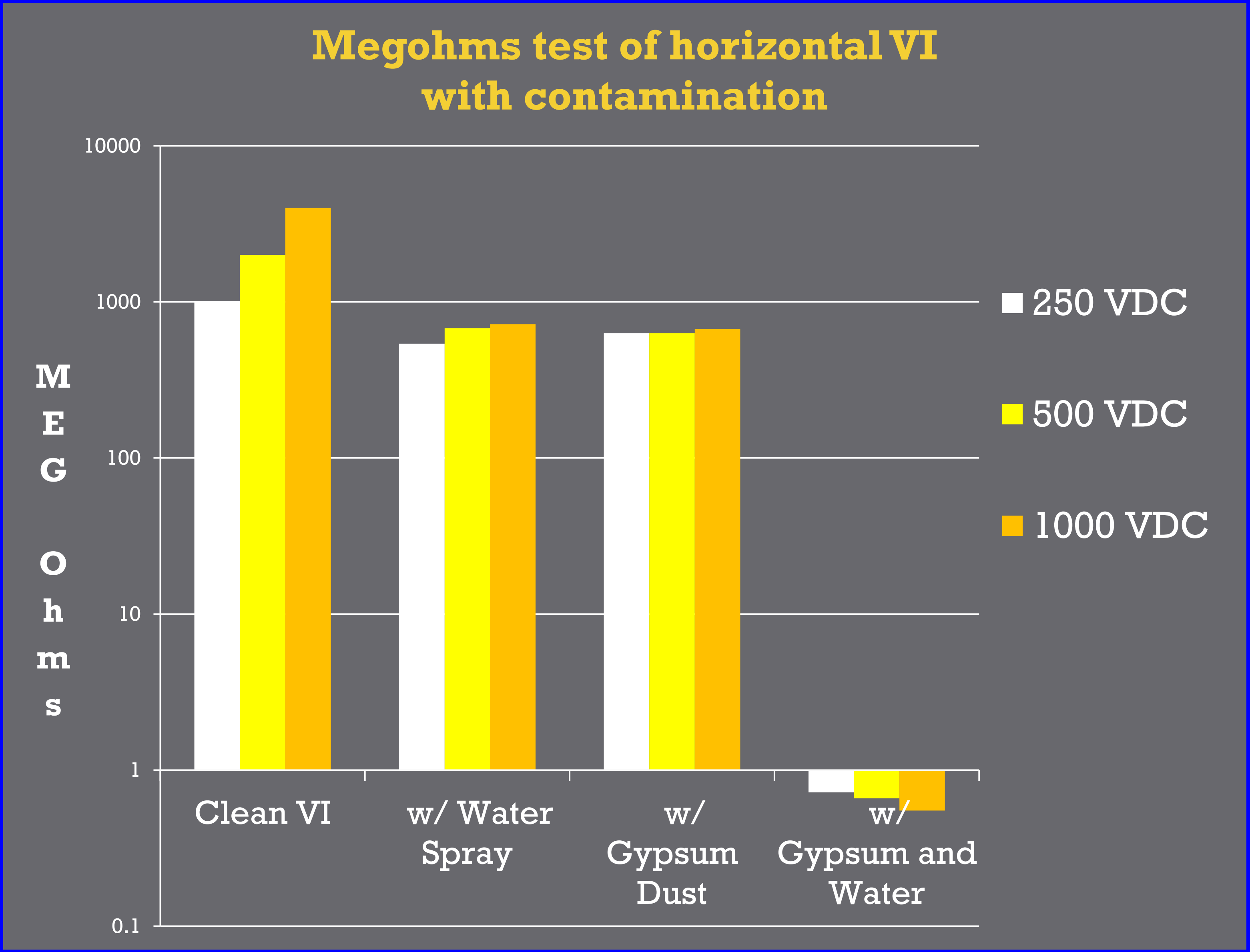
- Long creep paths to help eliminate tracking faults
- Minimal phase to phase supports
- Minimize hot spots
  - Conductor size
  - Surface area
  - Air flow rate
- Racking method
  - Assure alignment
  - Maintainable



Contamination and Aging

- Reliability center maintenance
- Climate controlled Substation
- Anti-condensation heaters
- Long creep paths
- Thermal limits
- Mechanism aging
  - Too many operation – mechanical wear
  - Too few operation – mechanical freezing

Visible corona across a contaminated VI


Megohms test of horizontal VI
with contamination
10000
1000
100
10
1
0.1
M
E
G
O
h
m
s
Clean VI
w/ Water Spray
w/ Gypsum Dust
w/ Gypsum and Water
250 VDC
500 VDC
1000 VDC

Additive Effective – Surface Flashover

- Non-uniform Electrical stresses
  - Localized partial discharges
- Elevated temp and ozone
  - Reactions with the polymeric insulation
- Low impedance high stress areas
  - Free electrons
  - Less stable molecules
- Electron Avalanche

Additive Effects - Flashover in Air

- Per design low level voltage stress limits

1" = 20kV

  - Few free electrons
  - No current flow
- As field strength increase or chemical bonding
  - More free electrons and more collisions
- Process continues resulting in conductive path
- Resulting in electron Avalanche

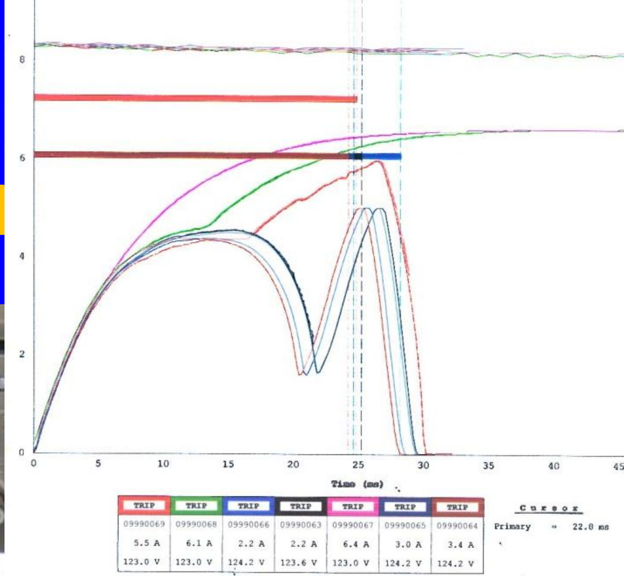
Failure Mechanism – Dielectric System

- Contamination
- Condensation

Failure Mechanis

- Dielectric System
  - Temperature
  - Altitude
  - Contamination
  - Partial Discharge

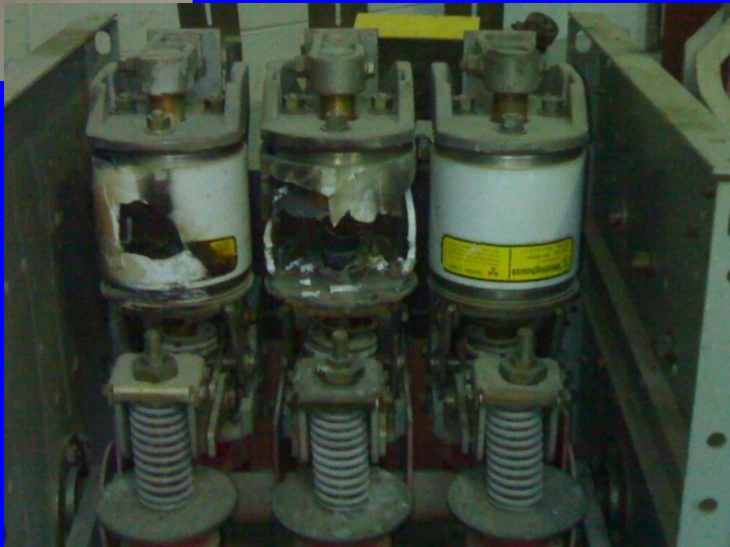
- Mechanical System
  - Temperature
  - Contamination



TRIP	TRIP	TRIP	TRIP	TRIP	TRIP	TRIP
09990069	09990068	09990066	09990063	09990067	09990065	09990064
5.5 A	6.1 A	2.2 A	2.2 A	6.4 A	3.0 A	3.4 A
123.0 V	123.0 V	124.2 V	123.6 V	123.0 V	124.2 V	124.2 V

Cursor

Primary = 22.8 ms



Choosing an MV CB

Service Conditions - Other

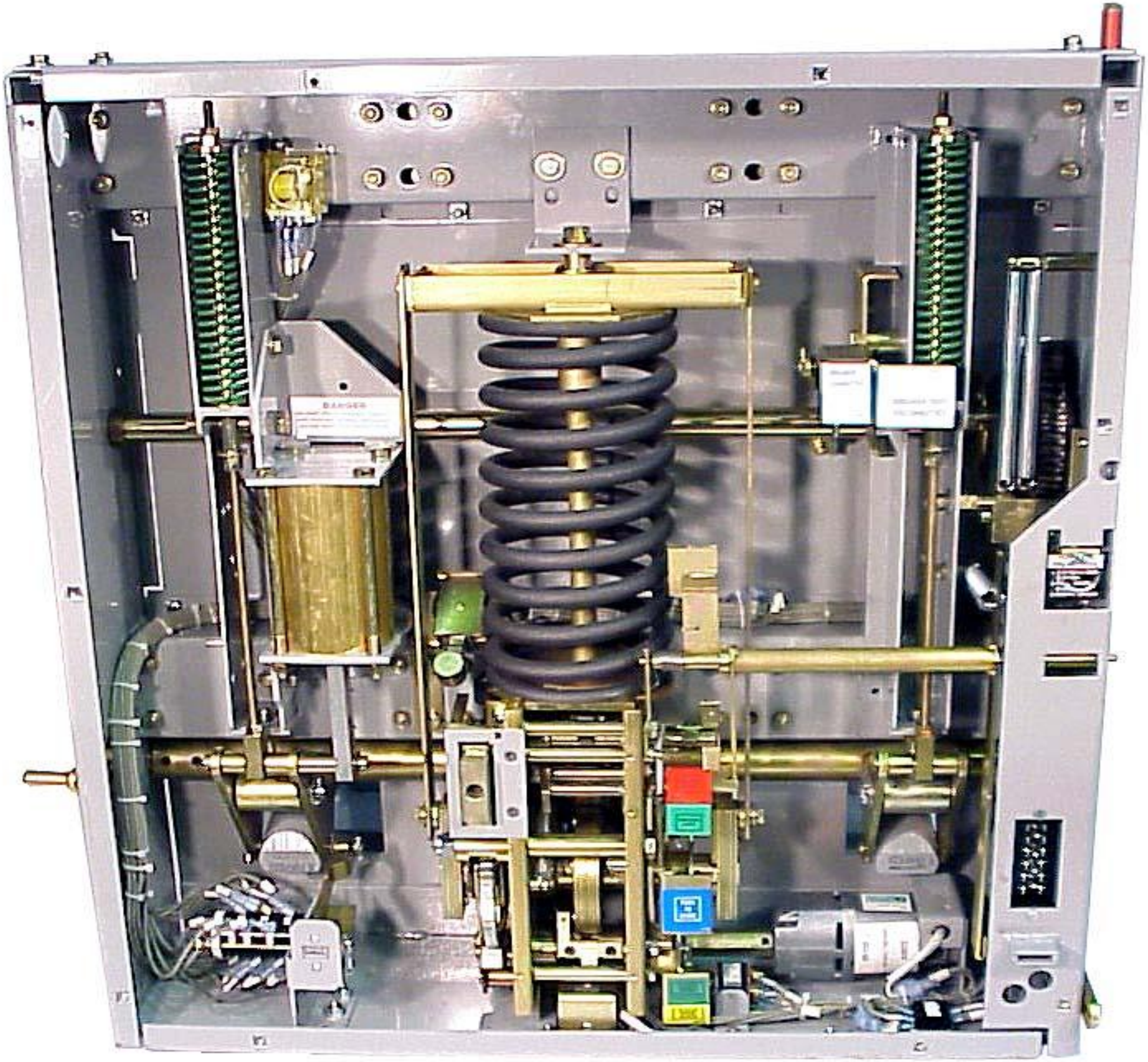
- Environmental conditions may require special construction or rating
- Seismic requirements
- Altitude adjustments
- Ambient
- User and vendor need to agree on requirements

Substation

- Climate control of substations
- Chemical filtration where required by coupons tests
- Windowed door to allow radio communication and door safety

ANSI Mechanical Endurance

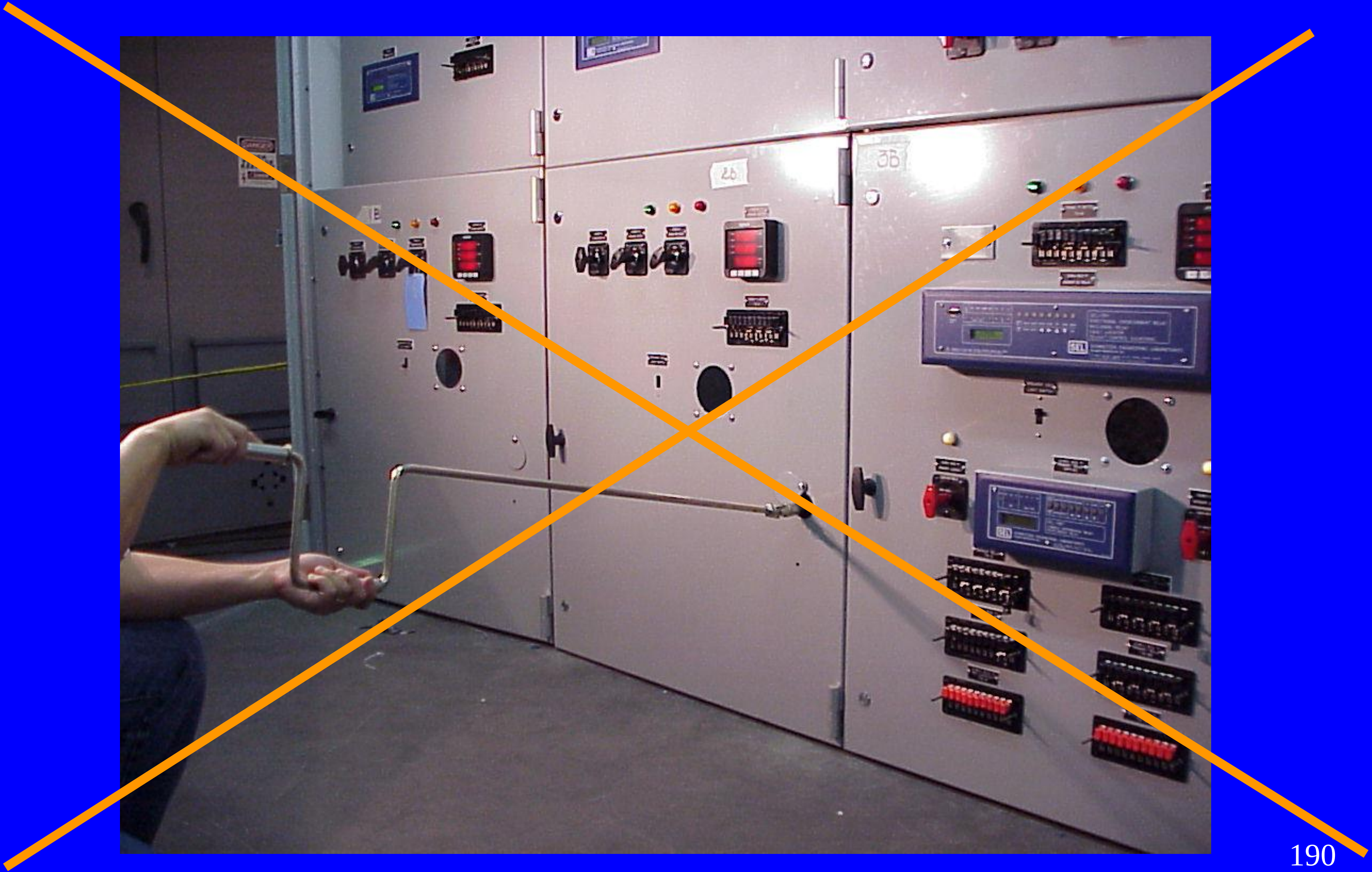
Line No.	Circuit Breaker Ratings			Number of Operations			
	Fixed Maximum Voltage MV, rms	Rated Continuous Current Amperes, rms	Rated Short-Circuit Current kA, rms	Between Servicing (2)	No-Load Mechanical (6)	Rated Continuous Current	Inrush Amps
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
	Indoor Circuit Breakers						
1	4.76, 15	1200, 2000	20, 25, 31.5	2000	10000	1000	750
2	4.76, 8.25,15	1200, 2000, 3000	40, 50	1000	5000	500	400
3	15	1200, 2000, 3000	63	500	5000	500	400
4	27	1200, 2000	16, 25	500	2500	200	100
5	38	1200, 2000, 3000	16, 25, 31.5, 40	250	1500	100	100
	Outdoor Circuit Breakers						
6	15.5 and above	All	All	500	2000	100	100


DANGER

Mechanical Endurance Tests

Element	Test Point	Evaluation
Primary contacts & Control contacts	500 cycles	Check alignment, penetration, and wear
Position interlocks	Every 50th cycle	Check function in withdrawn position
MOC & TOC	Every 50th cycle	Check contact continuity in all positions
Shutters	Every 50th cycle	Check function in the withdrawn and connected positions

Through door racking of standard equipment



- Cannon Plugs added to the front of the switchgear
- One control station used to open and close breakers

Remote C

Closed Door Racking

How to Remote Rack a Circuit


Racking 50-DHP-VR

Choosing an MV CB
Service Conditions - Other

- Environmental conditions may require special construction or rating
- Seismic requirements
- Altitude adjustments
- Ambient temp

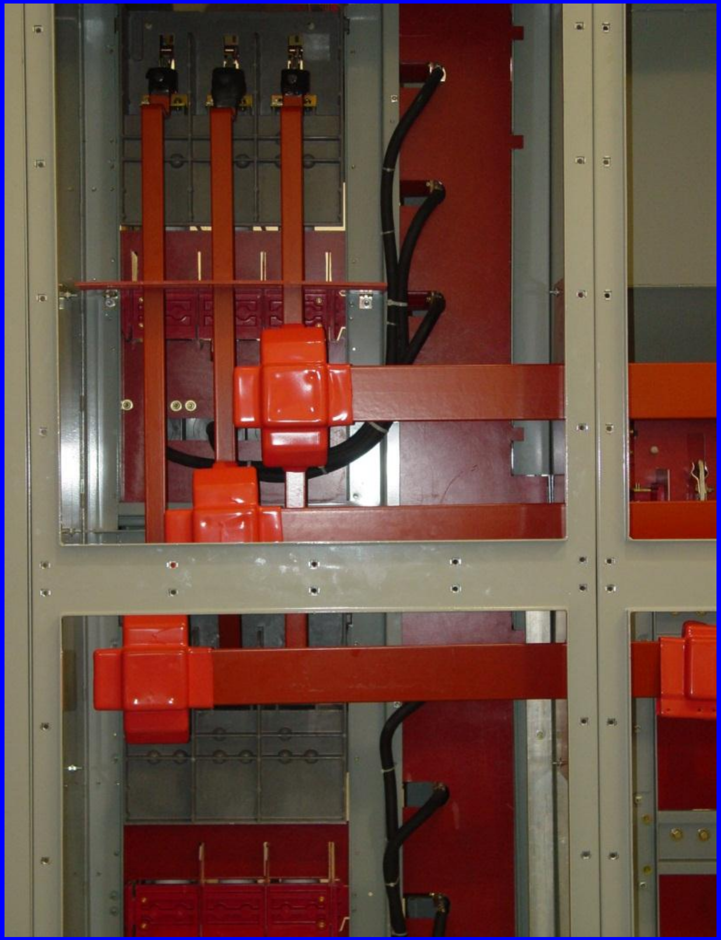
THE END MV SWGR

The End

MVMCC AR

MVMCC Arc Resistant

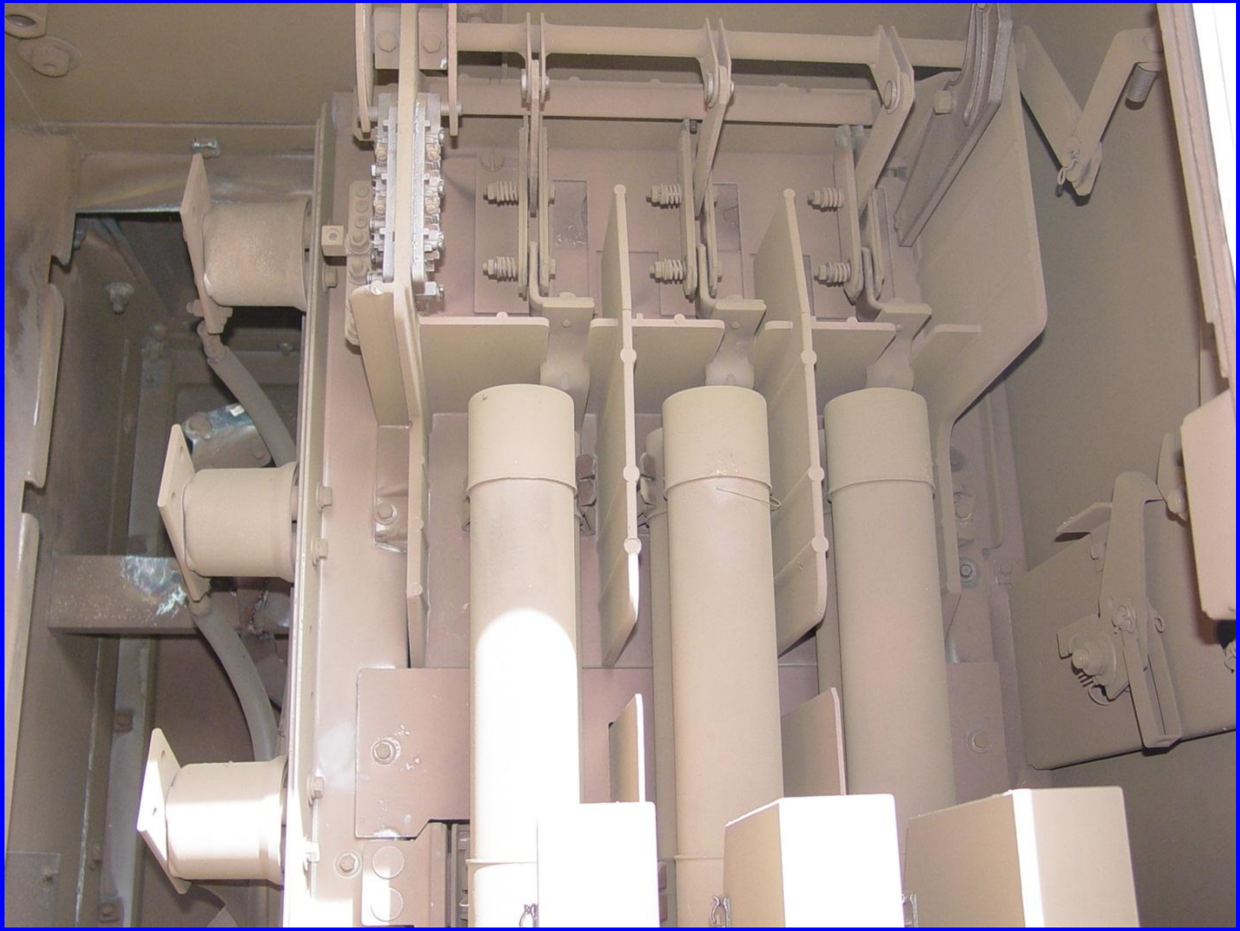
Main Bus Configuration



Fault location

- Line side of fuses

Equipment Damage



Adjacent Cell

Note while the section with the fault is a mess very little damage in the next cubicle

Arc Fault Test 50kA 5kV MCC

4160Voltage Measurement Fault

- Results of using a 1000 V meter on 4160 V

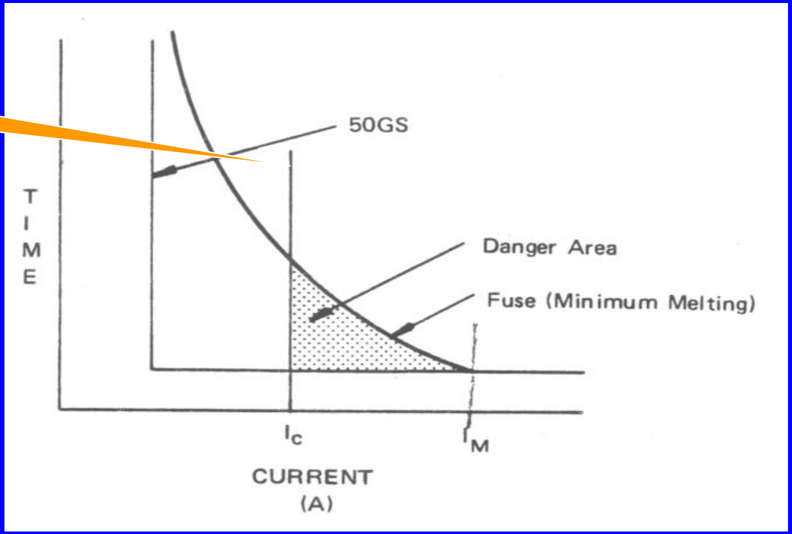
4160 Voltage measurement fault

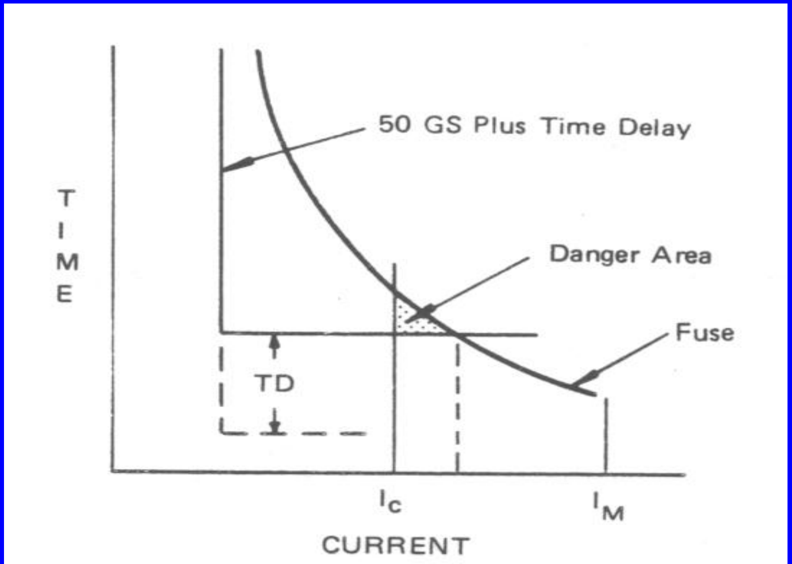
- PPE of the tech doing the measurement

Interrupting rating of Contactor

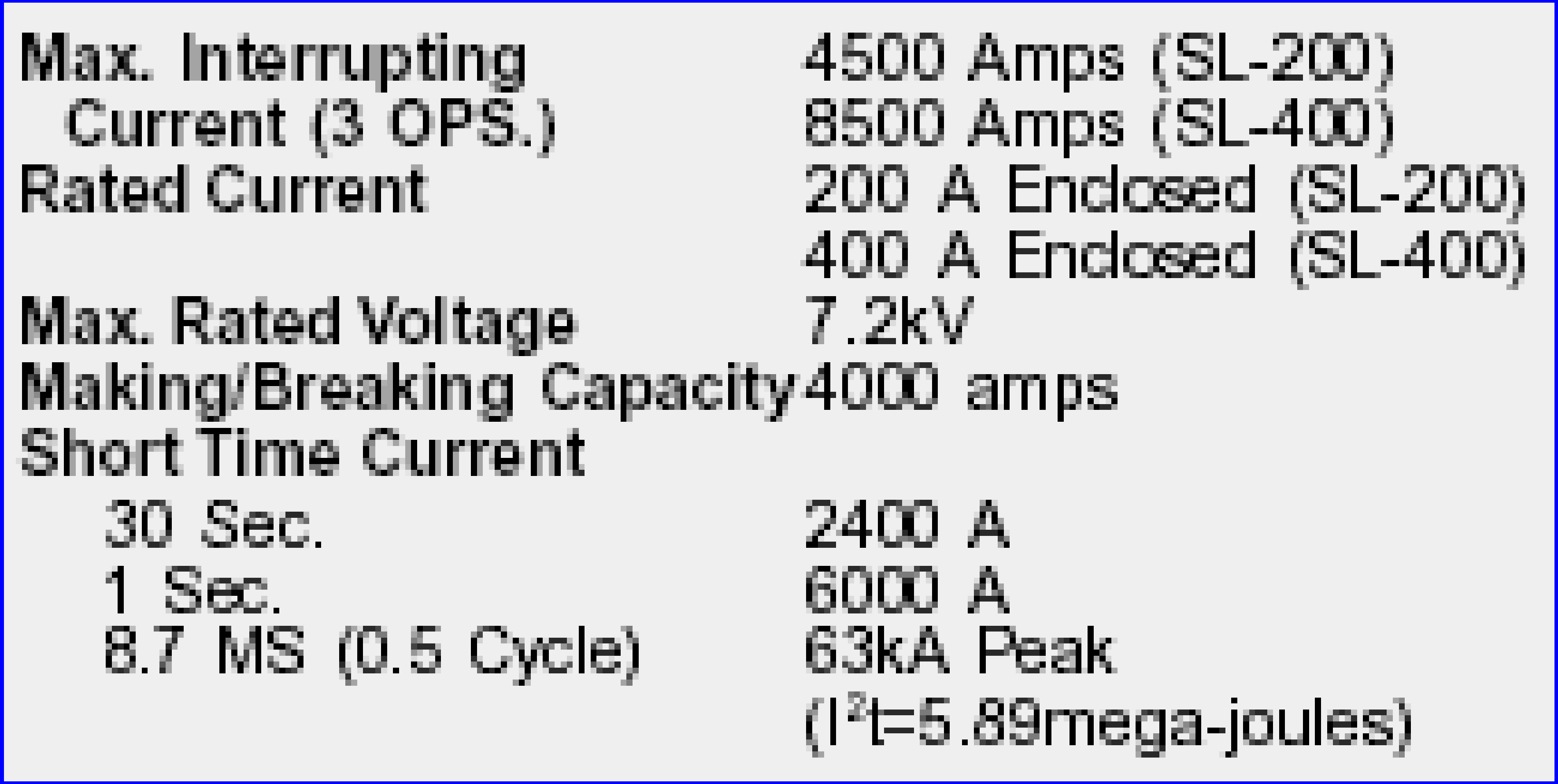
Contactor interrupting rating

- Set Time dial to
  - Allow 0.3 to 0.4 sec of max ground fault current
  - If coordinating with E2 Contactor make sure time delay required for contactor rating included

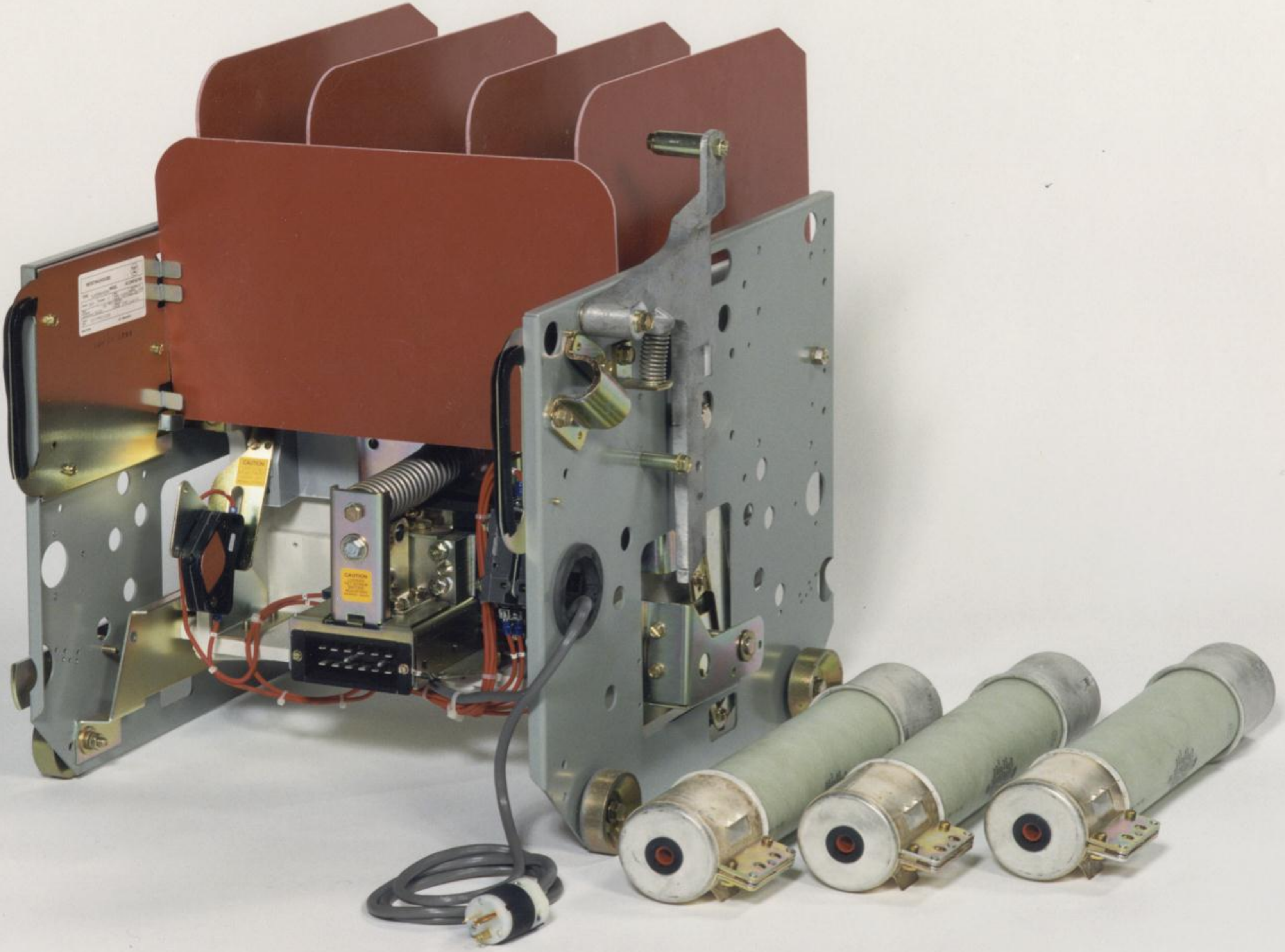




Interrupting Capacity



Max. Interrupting Current (3 OPS.)	4500 Amps (SL-200) 8500 Amps (SL-400)
Rated Current	200 A Enclosed (SL-200) 400 A Enclosed (SL-400)
Max. Rated Voltage	7.2kV
Making/Breaking Capacity	4000 amps
Short Time Current	
30 Sec.	2400 A
1 Sec.	6000 A
8.7 MS (0.5 Cycle)	63kA Peak (I^2t=5.89mega-joules)


CAUTION
CAUTION

Medium Voltage Motor Control Center

- Grounded metal overall enclosure
- Bare bus
- Switching device is electrically operated contactor, stationary or drawout
- Line disconnect with door interlock
- Fuses provide short circuit protection. Separate overload & ground fault

Medium Voltage Motor Control Center Ratings

- Max Voltage: *2500 V, 5000 V, 7200 V*
- BIL: *45 kV, 60 kV, 60 kV*
- Rated Continuous Current: *200 A, 400 A 700 A, 800A*
- Rated Short Circuit Current: = *Fuse Rating*
- Rated Short Time Current: *15 x for 1 sec.*

•Applications

- System configuration
- Motors
- Transformer Feeders
- Transfer Bus
- Capacitor Switching
- Generator Breakers

System Configuration

- Voltage levels / Load flow
- System grounding
- Reliability requirements
- Short Circuit
- Acceleration & re-acceleration requirements
- BIL Co-ordination

Motors

- Contactor or Circuit Breaker
- Over load protection shall not exceed the Continuous Current by more than 15%
- Surge protection use on critical motors due to low BIL
- Problems with interruption of an inductive circuit (motor during Locked Rotor)

Choosing Medium Voltage Motor Controllers and MCC's

- Most of the information required is the same as is required for choosing metal-clad switchgear
- The basic ratings are the same as in metal-clad switchgear: Voltage, current, frequency and service conditions
- Information about motors is required:
  - Full load and locked rotor currents
  - Acceleration time

Choosing Medium Voltage Motor Control Centers

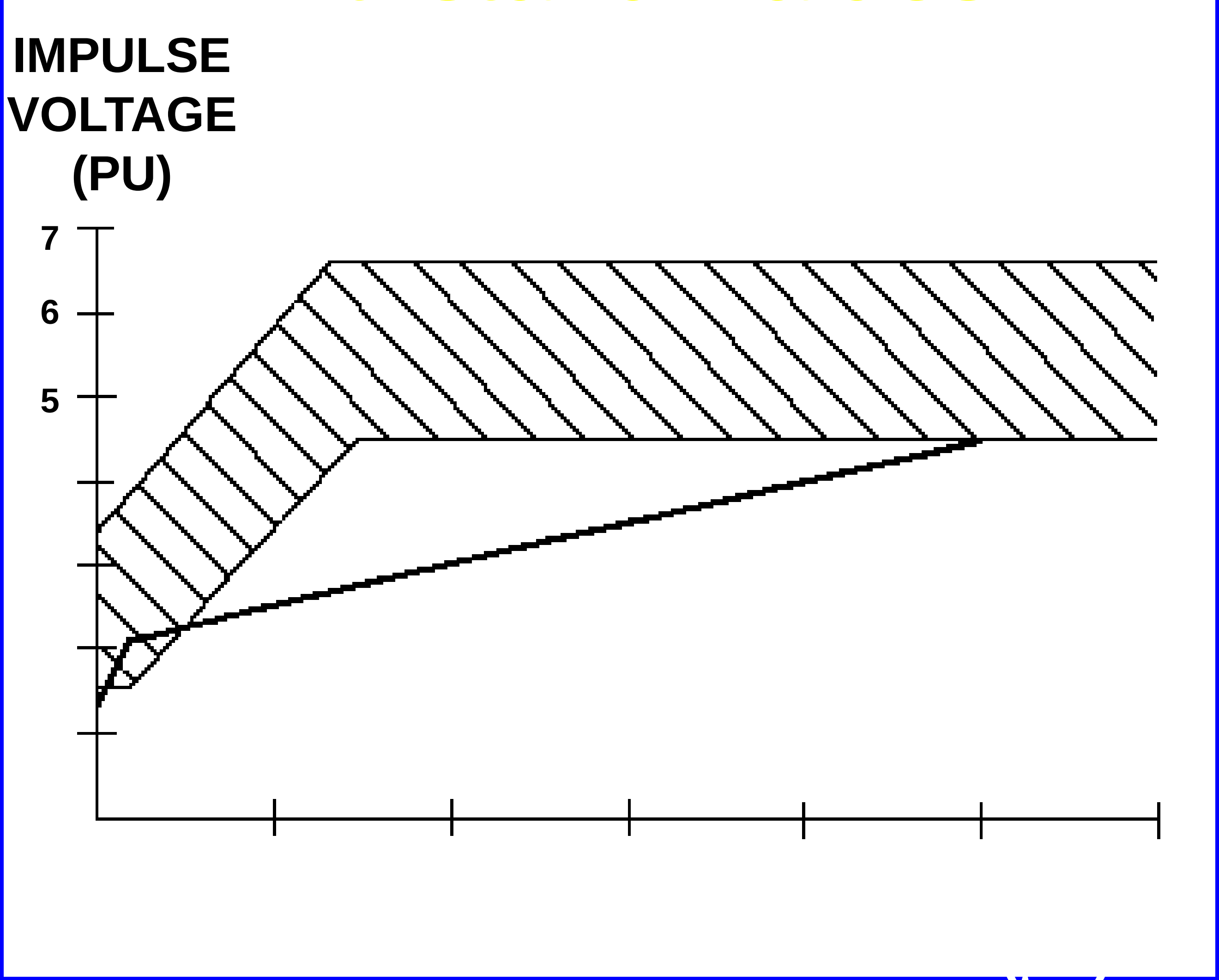
- The ratings of medium voltage motor control centers = the ratings of the controller
- Main bus continuous current rating must be specified for the MVMCC
  - No ratings given in applicable standards
  - Typical ratings offered by manufacturers are 800 A, 1200 A, 2000 A, and 2500 A, 3000A

Choosing MV Motor Controllers

Voltage Ratings

- Rated insulation voltage must equal or exceed system voltage
  - Standard ratings are 2500 V, 5000 V, and 7200 V.
  - Other ratings may be available
- B.I.L. rating must coordinate with rest of system
  - Standard includes List A and List B, based on exposure. List B is higher and is preferred
  - B.I.L. ratings are 45 kV for 2001-3600 V and 60 kV for 3601-7200 V. Note variation from switchgear

Recommended Motor Voltage Withstand Values



Motor Surge Voltages

Operation	V (pu)	Vacuum Breaker Probability	SF6 Breaker Probability
Closing	3	High	High
Opening a running motor	2	Very low	Very low
Opening a stalled motor	4-5	Medium / High	Low

Choosing MV Motor Controllers

Continuous Current Ratings

- Full load current of motor should not exceed continuous current rating of controller.
  - Standard enclosed ratings are 180 A, 360 A, 630 A, and 720 A
  - Previous standard listed open ratings of 200 A, 400 A, 700 A, and 800 A.
  - Standard includes motor horsepower table for reference only

Choosing MV Motor Controllers

Service-Limit Current Ratings

- Service-limit current rating is 115% of continuous current rating of controller
- Ultimate-trip current rating of overload relays should not exceed service-limit current rating of controller
- Controller may have temperature rise exceeding test limits when operating at service-limit current

Choosing MV Motor Controllers

Interrupting Current Ratings

- E1 controllers depend on interrupting ability of contactor, which is very low ~ 12kA max
- E2 controllers use current limiting fuses for interrupting faults
  - Standard ratings are 40 kA and 50 kA rms
- E2 controllers usually use a fuse which has only short-circuit protective ability
- Fuse must be coordinated with over-load relay and contactor

MVMCC

Choosing MV Motor Controllers

Service and Storage Conditions

- Standard service and storage conditions are covered in standard ICS 1, Clause 6
- Considerations are very much like those for switchgear
- Minimum ambient temperature is 0 C
- Altitude limit is 1 km (3,300 ft) for equipment with power semiconductors
- Special conditions must be called to manufacturer's attention

Choosing MV Motor Controllers
Reduced-Voltage Starters

- Reduced-voltage starting methods control effect on the power system of starting a large motor
- Load flow and voltage drop studies determine need
- May use any one of several starting methods:
  - Autotransformer is most common
  - Reactor is second choice; resistor is rare

Choosing MV Motor Controllers

Reduced-Voltage Starters

- Reduced-voltage starters include two or three contactors as well as the required autotransformer or reactor.
- All of these items taken together make up one controller
- Only one set of fuses is required for a complete reduced-voltage starter
- Interlocking, both mechanical and electrical, prevents false operation

Choosing MV Motor Controllers

Synchronous Motor Starters

- Basic features same as for an induction motor starter
- May be full-voltage or reduced-voltage
- A given size starter will usually handle a unity power factor synchronous motor larger than its induction motor or 0.8 pf synchronous motor size limit
- Otherwise, main difference is addition of field supply, excitation control and protection

Choosing MV Motor Controllers

Loads Other Than Motors (1)

- Contactors can be used to switch transformers or other feeder loads
- Usually, fully-rated current limiting fuses are used rather than motor starting fuses
- Overload protection may be omitted
- May use latched contactor , which may be mechanically and/or electrically opened and/or closed

Choosing MV Motor Controllers

Loads Other Than Motors (2)

- Contactors, especially vacuum contactors, can be used to switch capacitors
- Transformer and capacitor switching ratings are not standardized. Contact manufacturer for information
- **CAUTION! A latched contactor does not operate like a circuit breaker. It has no anti-pump feature and can fail if given close and trip signals together**

The End

Clearance for switchgear NEC table 110.26A and 110.34A

Nominal volts to Ground	**Clearance Condition 2**	**Clearance Condition 3**
0-150V	.914m – 3’	.914 - 3’
151-600V	1.07m – 3.5’	1.2m – 4’
601-2500V	1.2m – 4’	1.5m – 5’
2501-9000V	1.5m – 5’	1.8m – 6’
9001-25000V	1.8m – 6’	2.8m – 9’
25,001-75kV	2.5m – 8’	3.0m – 10’

Except. Working space not requires in back of switchgear or control assemblies where no renewable parts such as fuses or switches. (door swing or 30”)