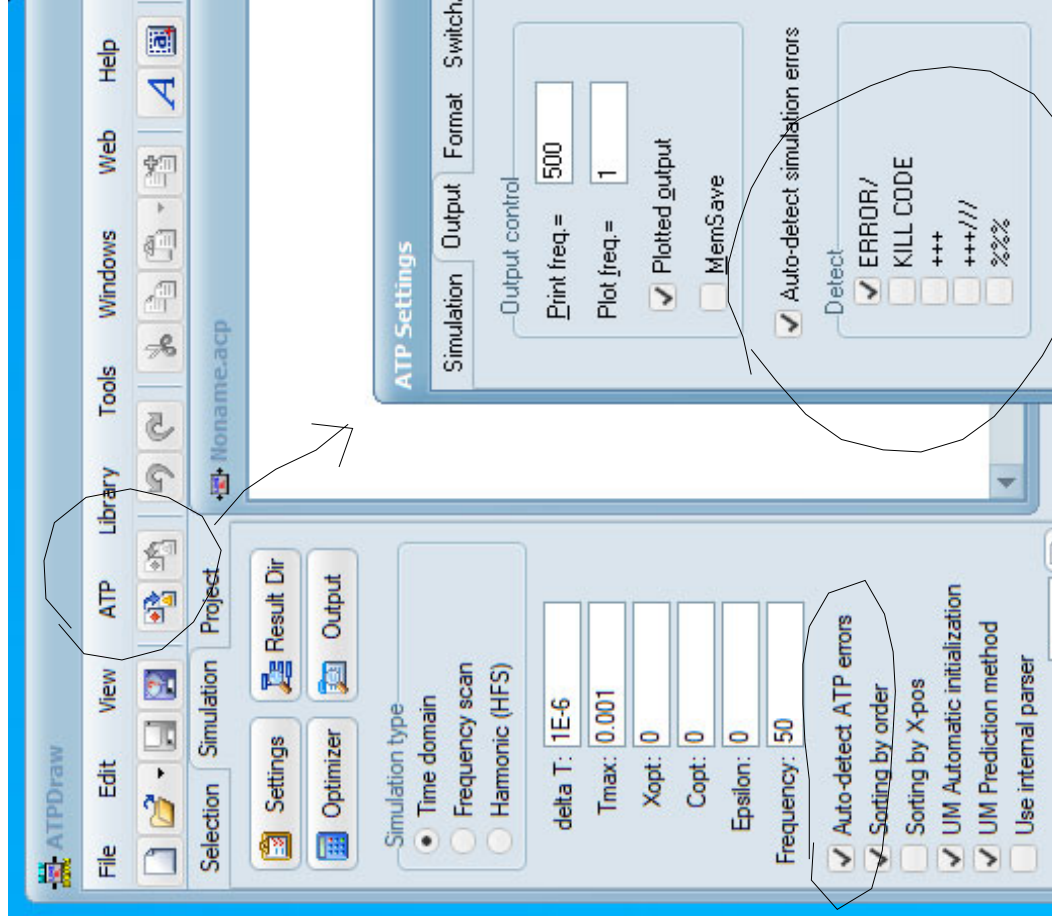


## Topics for Today:

- Startup
  - Web page: <https://pages.mtu.edu/~bamork/ee5220/>
  - Software - Matlab. ATP/EMTP [ License - [www.emtp.org](http://www.emtp.org) ]
  - ATP tutorials posted on our course web page
  - [EE5220-L@mtu.edu](mailto:EE5220-L@mtu.edu) (participation = half letter grade, 5%)
- HW#4 soon posted. Partnered exercise. Due 9am Tues Feb 15<sup>th</sup>.
- ATP Simulation pointers
- Cap Bank Switching (continued)
  - Circuit Breaker ratings - Capacitive Switching
  - Parameters
    - Cap Bank configurations
    - Current Limiting Reactors
- ATP - how it works internally
  - Conductance matrix formulation
  - Rs, Ls, Cs
  - Transmission lines

## ATP Simulation Pointer of the Day:

Select Auto-Detect Simulation Errors so that you are informed of anything unusual (not only errors or kill-codes) that may affect your simulation results. If you are aware of it, you can then fix it... Displaying run-time simulation Errors, Warnings, Caution messages is very prudent when building a new simulation.



**Note: If you select Auto-detect ATP Errors in left side bar, it will literally only look for ERRORS.**

**Better: Go to ATP > Settings and select auto-detect option. Then, select all possible errors, warnings, Kill-Codes.**

HMWK #1: Good!

HMWK #2: Good!

HMWK #3: ~ oops!



## Concerns

- ATP usage

- Concepts, HMWK 3



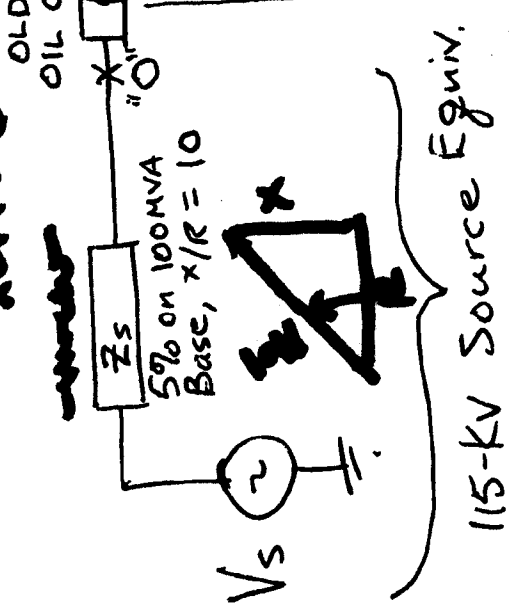
HMWK 3A

Due Fri: Feb 12th  
?

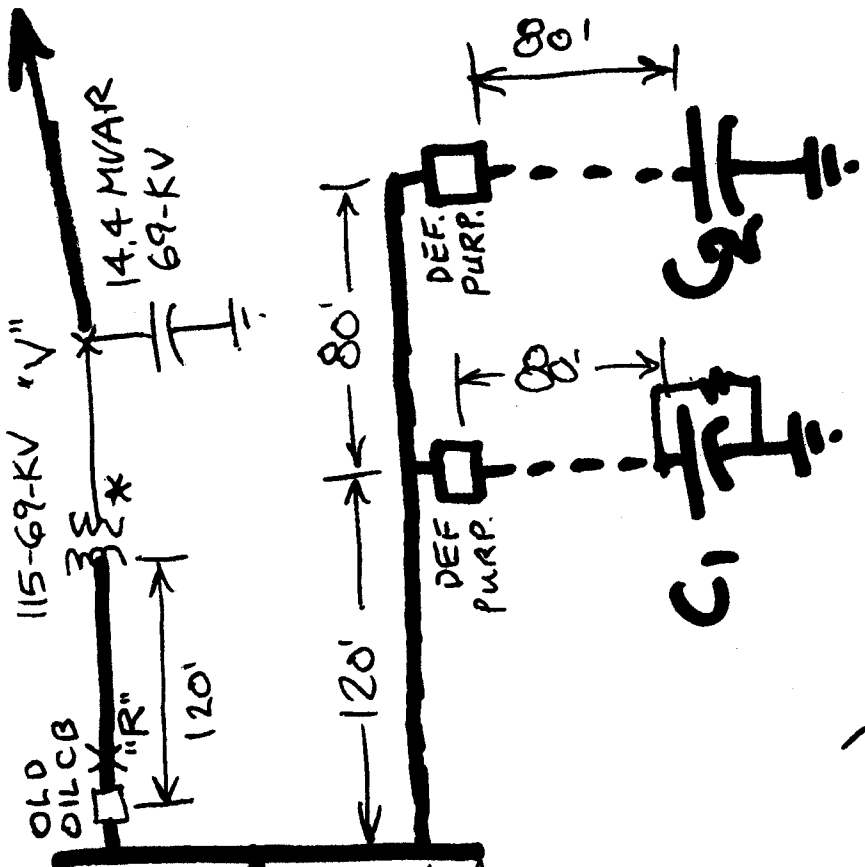
# Homework 4 - Cap Bank Switching

## The System:

(L-N Per-Phase Equir.)  
 $X/R = 6$



115-kV Source Equip.



$C_1 = C_2 = 40 \text{ MVAR}$   
 BANKS  
 $0.08 \text{ W/KVAR}$

\*Transformer:

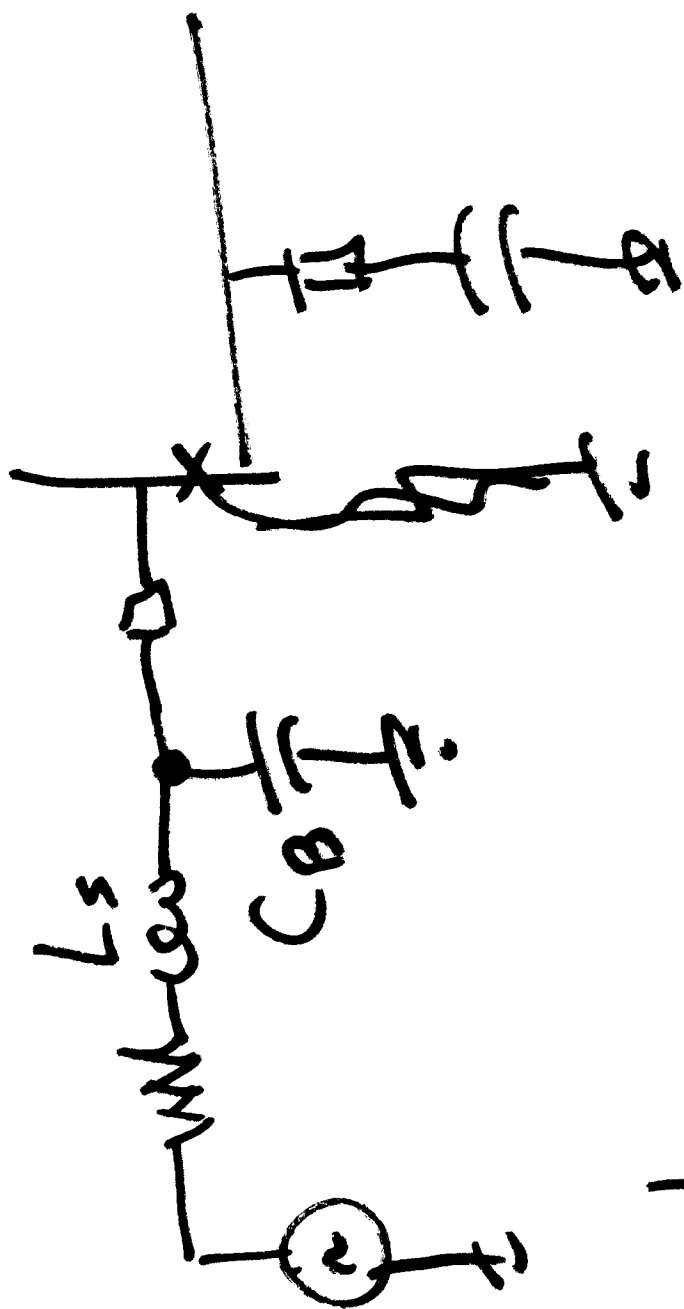
5% impedance,  $X/R = 30$   
 on 125 MVA Base

KEY FOR Buswork: (Lecture 7, p. 3)  
 (Table is for 115kV)

— 5" AL Sched 40 Tube

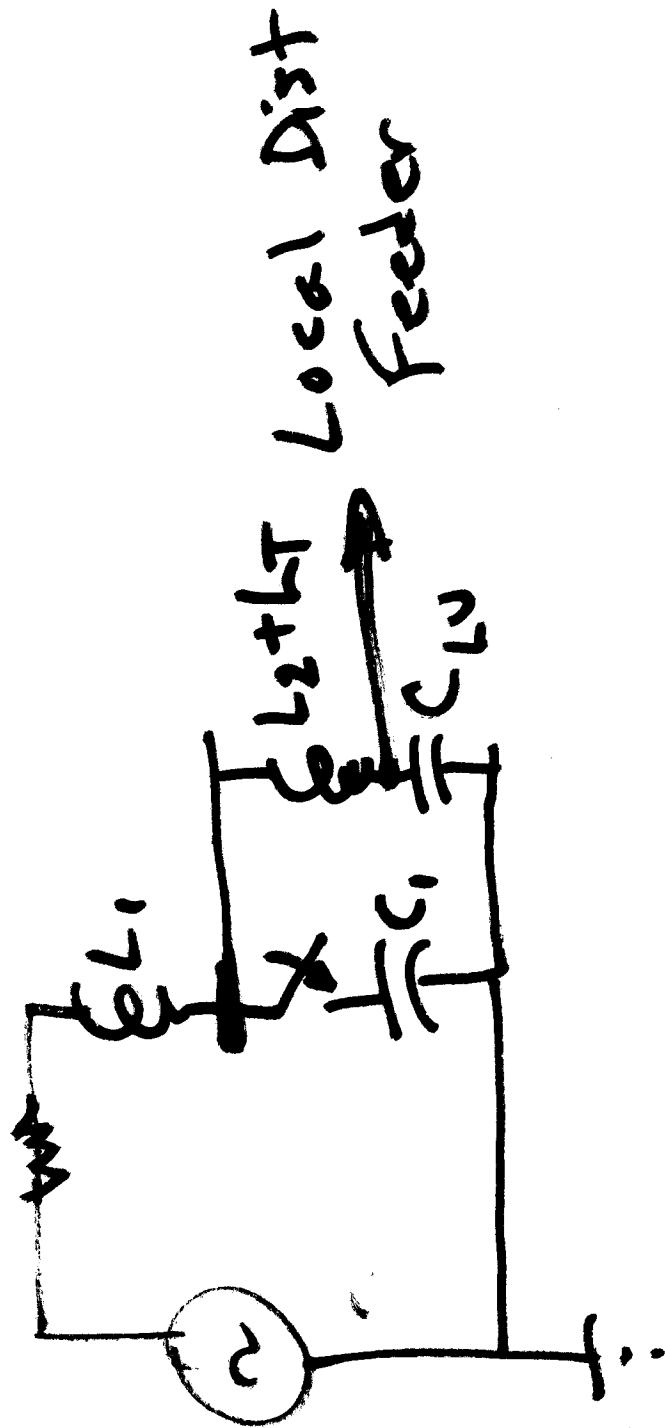
- - - 1590 MCM

— Not important (negligible since part of zone of high-freq oscillations).



—

# Voltage Mag



NOTES FOR TABLES 1A, 2A, AND 3A

(Numbers in parentheses in the tables refer to the following correspondingly numbered notes)

(1) No ratings for back-to-back shunt capacitor bank or cable switching applications are established for general-purpose circuit breakers. The shunt capacitor bank or cable shall be electrically isolated as defined in 5.13.2 of ANSI/IEEE C37.04-1979.

For general-purpose circuit breakers exposed to transient inrush currents from nearby capacitor banks during fault conditions, the capacitance transient inrush peak current on closing shall not exceed the lower of either  $\sqrt{2}$  times K times rated short-circuit current ( $\sqrt{2} \cdot K \cdot I$ ), or 50,000 peak amperes. The product of transient inrush current peak and transient inrush current frequency shall not exceed  $2 \times 10^7$ . The service capability and circuit breaker condition for this duty shall be as specified in ANSI/IEEE C37.04-1979, 5.10.3.3. For reference, see ANSI/IEEE C37.012-1979, 4.10.2.

(2) The capacitance switching current ratings are the highest values that the circuit breaker shall be required to switch at any voltage up to rated maximum voltage.  
(3) When applied on shunt capacitor banks, the current rating shall be selected to include the effects of a positive tolerance in capacitance, system and capacitor bank grounding, and additional current magnitude and heating due to harmonics.

(4) The rated transient inrush current peak is the highest magnitude that the circuit breaker shall be required to close at any voltage up to the rated maximum voltage, and shall be as determined by the system and unmodified by the circuit breaker. The rated transient inrush current frequency is the natural frequency that the circuit breaker shall be required to close at 100 percent of its rated back-to-back shunt capacitor bank or cable switching current.

For application at less than 100% of rating, the product of the inrush current peak and natural frequency shall not exceed the product of the rated transient current peak and the rated transient inrush current frequency. (This product defines a maximum rate of change of inrush current and a minimum inductance between the banks or cables.)

(5) Tables 2A and 3A only. The transient inrush current in circuit breakers applied in GIS substations has a very high equivalent frequency (up to the MHz range, depending on the bus length) with an initial peak current of several thousand amperes (depending on the surge impedance of the bus). For reference, see ANSI/IEEE C37.012-1979, 4.8.4.1.2. Contact the manufacturer to determine the ability of the circuit breaker to withstand these inrush current stresses.

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Table 1 (See Page 10)  
Preferred Ratings for Indoor Oilless Circuit Breakers\*

Rated Maximum Voltage (1) kV, rms	Rated Voltage Range Factor K (2)	Rated Continuous Current at 60 Hz (3) Amperes, rms	Rated Short-Circuit Current† (at Rated Maximum kV) (4) (5) (6) (16) kA, rms	Transient Recovery Voltages (9)				Rated Interrupting Time (7) cycles	Rated Maximum Voltage Divided by K (4) (5) (8) kV, rms	Maximum Symmetrical Interrupting Capability and Rated Short-Time Current (4) (5) (8) kA, rms	Closing and Latching Capability 2.7K times Rated Short-Circuit Current (4), kA, Crest
				Rated Point P Time to T <sub>2</sub> ‡ μ sec	Rated Rate R kV/μ sec	Rated Delay Time T <sub>1</sub> μ sec	Rated Maximum Voltage Divided by K (4) (5) (8) kV, rms				
4.76	1.36	1200	8.8	-	-	-	5	3.5	12	32	
4.76	1.24	1200, 2000	29	-	-	-	5	3.85	36	97	
4.76	1.19	1200, 2000, 3000	41	-	-	-	5	4.0	49	132	
8.25	1.25	1200, 2000	33	-	-	-	5	6.6	41	111	
15.0	1.30	1200, 2000	18	-	-	-	5	11.5	23	62	
15.0	1.30	1200, 2000	28	-	-	-	5	11.5	36	97	
15.0	1.30	1200, 2000, 3000	37	-	-	-	5	11.5	48	130	
38.0	1.65	1200, 2000, 3000	21	-	-	-	5	23.0	35	95	
38.0	1.0	1200, 3000	40	-	-	-	5	38.0	40	108	

\*For rated dielectric test values, see Table 4.

†For the related required capabilities associated with the rated short-circuit current of the circuit breaker, see Note 4.

‡These rated values are not yet standardized. Work is in progress.



11A

Table 1A (See Page 11)  
Preferred Capacitance Current Switching Ratings for  
Indoor Oilless Circuit Breakers

Rated Maximum Voltage kV, rms	Rated Short-Circuit Current kA, rms	Rated Continuous Current (3) Amperes, rms	General-Purpose Circuit Breakers			Definite-Purpose Circuit Breakers			Shunt Capacitor Bank or Cable			Back-to-Back		
			Rated Capacitance Switching Current (1) (2)			Rated Capacitance Switching Current (2)			Shunt Capacitor Bank or Cable			Back-to-Back		
			Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Overhead Line Current Amperes, rms	Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Current (3) Amperes, rms	Inrush Current (4) Peak Current kA	Current (3) Amperes, rms	Inrush Current (4) Peak Current kA	Frequency Hz
4.76	8.8	1200	1	400	1	630	630	630	15	630	15	2000		
4.76	29	1200	1	400	1	630	630	630	15	630	15	2000		
4.76	29	2000	1	400	1	1000	1000	1000	15	1000	15	1270		
4.76	41	1200, 2000	1	400	1	630	630	630	15	630	15	2000		
4.76	41	3000	1	400	1	1000	1000	1000	15	1000	15	1270		
8.25	33	1200	1	250	1	630	630	630	15	630	15	2000		
8.25	33	2000	1	250	1	1000	1000	1000	15	1000	15	1270		
15.0	18	1200	2	250	2	630	630	630	15	630	15	2000		
15.0	18	2000	2	250	2	1000	1000	1000	15	1000	15	1270		
15.0	28	1200	2	250	2	630	630	630	15	630	15	2000		
15.0	28	2000	2	250	2	1000	1000	1000	15	1000	15	1270		
15.0	37	1200	2	250	2	630	630	630	15	630	15	2000		
15.0	37	2000	2	250	2	1000	1000	1000	18	1000	18	2400		
15.0	37	3000	2	250	2	1600	1600	1600	25	1600	25	1330		
38.0	21	1200, 2000, 3000	5	50	5	250	250	250	18	250	18	6000		
38.0	40	1200, 3000	5	50	5	250	250	250	25	250	25	8480		

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Table 2 (See Page 10)  
 Preferred Ratings for Outdoor Circuit Breakers 72.5 kV and Below,  
 Including Circuit Breakers Applied in Gas Insulated Substations\*

Rated Maximum Voltage (1) kV, rms	Rated Voltage Range Factor K (2)	Rated Continuous Current at 60 Hz (3) Amperes, rms	Rated Short-Circuit Current† (at Rated Maximum kV) (4) (5) (6) (16) kA, rms	Transient Recovery Voltages (10) (11) (12)			Rated Interrupting Time (7) Cycles	Rated Maximum Voltage Divided by K kV, rms	Maximum Symmetrical Interrupting Capability and Rated Short-Time Current (4) (5) (8) kA, rms	Closing and Latching Capability 2.7K times Rated Short-Circuit Current (4)
				Rated Time to Point P I <sub>2</sub> μ sec	Rated Rate R kV/μ sec	Rated Delay Time T <sub>1</sub> μ sec				
15.5	1.0	600, 1200	12.5	36	-	5	15.5	12.5	34	
15.5	1.0	1200, 2000	20.0	36	-	5	15.5	20.0	54	
15.5	1.0	1200, 2000	25.0	36	-	5	15.5	25.0	68	
15.5	1.0	1200, 2000, 3000	40.0	36	-	5	15.5	40.0	108	
25.8	1.0	1200, 2000	12.5	52	-	5	25.8	12.5	34	
25.8	1.0	1200, 2000	25.0	52	-	5	25.8	25.0	68	
38.0	1.0	1200, 2000	16.0	63	-	5	38.0	16.0	43	
38.0	1.0	1200, 2000	20.0	63	-	5	38.0	20.0	54	
38.0	1.0	1200, 2000	25.0	63	-	5	38.0	25.0	68	
38.0	1.0	1200, 2000	31.5	63	-	5	38.0	31.5	85	
38.0	1.0	1200, 2000, 3000	40.0	63	-	5	38.0	40.0	108	
48.3	1.0	1200, 2000	20.0	80	-	5	48.3	20.0	54	
48.3	1.0	1200, 2000	31.5	80	-	5	48.3	31.5	85	
48.3	1.0	1200, 2000, 3000	40.0	80	-	5	48.3	40.0	108	
72.5	1.0	1200, 2000	20.0	106	-	5	72.5	20.0	54	
72.5	1.0	1200, 2000	31.5	106	-	5	72.5	31.5	85	
72.5	1.0	1200, 2000, 3000	40.0	106	-	5	72.5	40.0	108	

\*For rated dielectric test values, see Tables 4 and 5.

†For the related required capabilities associated with the rated short-circuit current of the circuit breaker, see Note 4.

12A ~~B~~

**Table 2A (See Page 11)**  
**Preferred Capacitance Current Switching Ratings for**  
**Outdoor Circuit Breakers 72.5 kV and Below, Including Circuit Breakers Applied**  
**in Gas Insulated Substations**

Rated Maximum Voltage kV, rms	Rated Short-Circuit Current kA, rms	Rated Continuous Current (3) Amperes, rms	General-Purpose Circuit Breakers Rated Capacitance Switching Current (1) (2)			Definite-Purpose Circuit Breakers Rated Capacitance Switching Current (2)				
			Overhead Line Current Amperes, rms	Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Current (3) Amperes, rms		
15.5	12.5	600, 1200	2	2	250	100	400	400	20	4240
15.5	20.0	1200, 2000	2	2	250	100	400	400	20	4240
15.5	25.0	1200, 2000	2	2	250	100	400	400	20	4240
15.5	40.0	1200, 2000, 3000	2	2	250	100	400	400	20	4240
25.8	12.5	1200, 2000	5	5	160	100	400	400	20	4240
25.8	25.0	1200, 2000	5	5	160	100	400	400	20	4240
38.0	16.0	1200, 2000	5	5	100	100	250	250	20	4240
38.0	20.0	1200, 2000	5	5	100	100	250	250	20	4240
38.0	25.0	1200, 2000	5	5	100	100	250	250	20	4240
38.0	31.5	1200, 2000	5	5	100	100	250	250	20	4240
38.0	40.0	1200, 2000, 3000	5	5	100	100	250	250	20	4240
48.3	20.0	1200, 2000	10	10	10	100	250	250	20	6800
48.3	31.5	1200, 2000	10	10	10	100	250	250	20	6800
48.3	40.0	1200, 2000, 3000	10	10	10	100	250	250	20	6800
72.5	20.0	1200, 2000	20	20	20	100	630	630	25	3360
72.5	31.5	1200, 2000	20	20	20	100	630	630	25	3360
72.5	40.0	1200, 2000, 3000	20	20	20	100	630	630	25	3360

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Table 3 (See Page 10)  
 Preferred Ratings for Outdoor Circuit Breakers 121 kV and Above,  
 Including Circuit Breakers Applied in Gas Insulated Substations\*

Rated Maximum Voltage (1) (13) kV, rms	Rated Voltage Range Factor K (2)	Rated Continuous Current at 60 Hz (3) Amperes, rms	Short-Circuit Current† (at Rated Maximum kV) (4) (5) (6) (17) kA, rms	Transient Recovery Voltage (14) (15)			Rated Interrupting Time (7) Cycles	Rated Maximum Voltage Divided by K (8) (9) kV, rms	Maximum Symmetrical Interrupting Capability and Rated Short-Circuit Current (4) (5) (8) kA, rms	Closing and Latching Capability 2.7K times Rated Short-Circuit Current (4), kA, Crest
				Rated Rate R kV/μ sec	Rated Time to Point P T <sub>2</sub> μ sec	Rated Delay Time T <sub>1</sub> μ sec				
121	1.0	1200	20	1.7	275	2.9	3	121	20	54
121	1.0	1600, 2000, 3000	40	1.8	260	2.9	3	121	40	108
121	1.0	2000, 3000	63	1.8	260	2.9	3	121	63	170
145	1.0	1200	20	1.7	330	3.2	3	145	20	54
145	1.0	1600, 2000, 3000	40	1.8	310	3.2	3	145	40	108
145	1.0	2000, 3000	63	1.8	310	3.2	3	145	63	170
145	1.0	2000, 3000	80	1.8	310	3.2	3	145	80	216
169	1.0	1200	16	1.7	395	3.4	3	169	16	43
169	1.0	1600	31.5	1.8	360	3.4	3	169	31.5	85
169	1.0	2000	40	1.8	360	3.4	3	169	40	108
169	1.0	2000	50	1.8	360	3.4	3	169	50	135
169	1.0	2000	63	1.8	360	3.4	3	169	63	170
242	1.0	1600, 2000, 3000	31.5	1.8	520	4.1	3	242	31.5	85
242	1.0	2000, 3000	40	1.8	520	4.1	3	242	40	108
242	1.0	2000	50	1.8	520	4.1	3	242	50	135
242	1.0	2000, 3000	63	1.8	520	4.1	3	242	63	170
362	1.0	2000, 3000	40	1.8	775	4.9	2	362	40	108
362	1.0	2000	63	1.8	775	4.9	2	362	63	170
550	1.0	2000, 3000	40	1.6	1325	5.4	2	550	40	108
550	1.0	3000	63	1.6	1325	5.4	2	550	63	170
800	1.0	2000, 3000	40	1.9	1530	7.9	2	800	40	108
800	1.0	3000	63	1.9	1530	7.9	2	800	63	170

\*For rated dielectric test values, see Tables 4 and 5.  
 †For the related required capabilities associated with the rated short-circuit current of the circuit breaker, see Note 4.

13A

Table 3A (See Page 11)  
 Preferred Capacitance Current Switching Ratings for  
 Outdoor Circuit Breakers 121 kV and Above, Including Circuit Breakers Applied  
 in Gas Insulated Substations

Rated Maximum Voltage kV, rms	Rated Short-Circuit Current kA, rms	Rated Continuous Current (3) Amperes, rms	General-Purpose Circuit Breakers Rated Capacitance Switching Current (1) (2)			Definite-Purpose Circuit Breakers Rated Capacitance Switching Current (2)			Shunt Capacitor Bank or Cable		
			Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Overhead Line Current Amperes, rms	Isolated Current (3) Amperes, rms	Current (3) Amperes, rms	Peak Current kA	Inrush Current (4) (5) Frequency Hz
121	20	1200	50	50	160	315	315	16	4250		
121	40	1600, 2000, 3000	50	50	160	315	315	16	4250		
121	63	2000, 3000	50	50	160	315	315	16	4250		
145	20	1200, 2000	63	63	160	315	315	16	4250		
145	40	1600, 2000, 3000	80	80	160	315	315	16	4250		
145	63	2000, 3000	80	80	160	315	315	16	4250		
145	80	2000, 3000	80	80	160	315	315	16	4250		
169	16	1200	100	100	160	400	400	20	4250		
169	31.5	1600	100	100	160	400	400	20	4250		
169	40	2000	100	100	160	400	400	20	4250		
169	50	2000	100	100	160	400	400	20	4250		
169	63	2000	100	100	160	400	400	20	4250		
242	31.5	1600, 2000, 3000	160	160	200	400	400	20	4250		
242	40	2000, 3000	160	160	200	400	400	20	4250		
242	50	2000	160	160	200	400	400	20	4250		
242	63	2000, 3000	160	160	200	400	400	20	4250		
362	40	2000, 3000	250	250	315	500	500	25	4250		
362	63	2000	250	250	315	500	500	25	4250		
550	40	2000, 3000	400	400	500	500	500	-	-		
550	63	3000	400	400	500	500	500	-	-		
800	40	2000, 3000	500	500	500	500	500	-	-		
800	63	3000	500	500	500	500	500	-	-		

**Table 2** Standard Values of BIL and BSL per ANSI C92, IEEE 1313.1

30	300	825	1925
45	350	900	2050
60	400	975	2175
75	450	1050	2300
95	500	1175	2425
110	550	1300	2550
125	600	1425	2675
150	650	1550	2800
200	700	1675	2925
250	750	1800	3050

*Source: Ref. 7.*

**Table 3** Standard Values of BIL and BSL per IEC 71.1

20	325	1300	2550
40	450	1425	2700
60	550	1550	2900
75	650	1675	
95	750	1800	
125	850	1950	
145	950	2100	
170	1050	2250	
250	1175	2400	

*Source: Ref. 5.*

**Table 4** Transformer and Bushings BILs and BSLs

System nominal/ max system voltage, kV	Transformers BIL, kV	Transformers BSL, kV	Transformer bushings BIL, kV	Transformer bushings BSL, kV
1.2/-	30, 45		45	
2.5/-	45, 60		60	
5.0/-	60, 75		75	
8.7/-	75, 95		95	
15.0/-	95, 110		110	
25.0/-	150		150	
34.5/-	200		200	
46/48.3	200, 250		250	
69/72.5	250, 350		350	
115/121	350	280	450	
	*450	375	50	
	550	460		
138/145	450	375	450	
	*550	460	550	
	650	540	650	
161/169	550	460	550	
	*650	540	650	
	750	620	750	
230/242	650	540	650	
	*750	620	750	
	825	685	825	
345/362	900	745	900, 1050	
	*1050	870	1050	700
	1175	975	1175, 1300	825
500/550	1300	1080	1300	1050
	*1425	1180	1425	1110
	1550	1290	1550	1175
	1675	1390	1675	1175
765/800	1800	1500	1800	1360
	1925	1600	1925	—
	2050	1700	2050	—

\* Commonly used.

Source: Ref. 7, 8.

**Table 5** Insulation Levels for Outdoor Substations and Equipment

Rated max voltage, kV	NEMA Std, 6, outdoor substations		Circuit breakers		Disconnect switches	
	BIL, kV	10s power frequency voltage, kV	BIL, kV	BSL, kV	BIL, kV	BSL, kV estimate
8.25	95	30	95		95	
15.5	110	45	110		110	
25.8	150	60	150		125	
					150	
38.0	200	80	200		150	
					200	
48.3	250	100	250		250	
72.5	350	145	350		350	
121	550	230	550		550	
145	650	275	650		650	
169	750	315	750		750	
242	900	385	900		900	
	1050	455			1050	
362	1050	455	1300	825	1050	820
	1300	525		900	1300	960
550	1550	620	1800	1175	1550	1090
	1800	710		1300	1800	1210
800	2050	830	2050	1425	2050	1320
				1500		

Source: Ref. 5, 9.

**Table 6** BILs/BSLs of Gas Insulated Stations

Max system voltage, kV		IEC [10]		ANSI [11]	
IEC	ANSI	BIL, kV	BSL, kV	BIL, kV	BSL, kV
72.5	72.5	325	—	300, 350	—
100		450	—		
123	121	550	—	450, 550	—
145	145	650	—	550, 650	—
170	169	750	—	650, 750	—
245	242	950	—	750, 900	—, 720
300		1050	850		
362	362	1175	950	900, 1050	720, 825
420		1300	1050		
525	550	1425	1175	1300, 1550	1050, 1175
765	800	1800	1425	1800	1425



**Table 7** BILs of Cables (No BSLs provided),  
AEIC C54-79

Rated voltage, kV	BIL, kV
115, 120, & 130	550
138	650
161	750
230	1050
345	1300
500	1800

Source: Ref. 12.

**Table 8** IEC 71.1: BILs are Tied to Max. System Voltages for Max.  
System Voltage from 1 to 245 kV

Max system voltage, kV	BILs, kV	Max system voltage, kV	BILs, kV
3.6	20 or 40	52	250
7.2	40 or 60	72.5	325
12	60, 75 or 95	123	450 or 550
17.7	75 or 95	145	450, 550, or 650
24	95, 125 or 145	170	550, 650, or 750
36	145 or 170	245	650, 750, 850, 950, or 1050

Source: Ref. 3.

**Table 9** IEC BIL/BSLs, from IEC Publication 71.1

Max. system voltage, kV	Phase-ground BSL, BSL <sub>g</sub> , kV	Ratio BSL <sub>p</sub> /BSL <sub>g</sub>	BIL, kV
300	750	1.50	850 or 950
	850	1.50	950 or 1050
362	850	1.50	950 or 1050
	950	1.50	1050 or 1175
420	850	1.60	1050 or 1175
	950	1.50	1175 or 1300
	1050	1.50	1300 or 1425
550	950	1.70	1175 or 1300
	1050	1.60	1300 or 1425
	1175	1.50	1425 or 1550
800	1300	1.70	1675 or 1800
	1425	1.70	1800 or 1950
	1550	1.60	1950 or 2100

Source: Ref. 3.

Onwards are pages from standards assembled together for circuit breakers, transformers and bushings.

## 5.5 Voltage ratings and taps

### 5.5.1 General

Standard nominal system voltages and maximum system voltages are included in ANSI C84.1 and listed in Table 4.

**Table 4—Relationship of nominal system voltage to maximum system voltage and basic lightning impulse insulation level (BIL) for systems 765 kV and below**

Application	Nominal system voltage, rms (kV)	Maximum system voltage, rms (from ANSI C84.1) (kV)	Basic lightning impulse insulation levels (BIL) in common use (kV crest)			
Distribution	1.2	—	30	—	—	—
	2.5	—	45	—	—	—
	5.0	—	60	—	—	—
	8.7	—	75	—	—	—
	15.0	—	95	—	—	—
	25.0	—	150	125	—	—
	34.5	—	200	150	<b>125</b>	—
	46.0	<b>48.3</b>	250	<b>200</b>	—	—
	69.0	<b>72.5</b>	350	<b>250</b>	—	—
Power	1.2	—	45	30	—	—
	2.5	—	60	45	—	—
	5.0	—	75	60	—	—
	8.7	—	95	75	—	—
	15.0	—	110	95	—	—
	25.0	—	150	—	—	—
	34.5	—	200	—	—	—
	46.0	<b>48.3</b>	250	<b>200</b>	—	—
	69.0	<b>72.5</b>	350	<b>250</b>	—	—
	115.0	<b>121.0</b>	<b>550</b>	450	<b>350</b>	—
	138.0	<b>145.0</b>	<b>650</b>	550	<b>450</b>	—
	161.0	<b>169.0</b>	<b>750</b>	650	<b>550</b>	—
	230.0	<b>242.0</b>	<b>900</b>	<b>825</b>	750	<b>650</b>
	345.0	<b>362.0</b>	<b>1175</b>	<b>1050</b>	<b>900</b>	—
	500.0	<b>550.0</b>	<b>1675</b>	<b>1550</b>	<b>1425</b>	<b>1300</b>
765.0	<b>800.0</b>	<b>2050</b>	<b>1925</b>	—	—	

**Table 16—Preferred dielectric withstand ratings for circuit breakers applied in gas-insulated substations<sup>a</sup>**

Line No.	Rated maximum voltage $U_r$ , rms kV, rms	Rating table No.	Dielectric withstand test voltages					
			Power frequency 1 min dry kV, rms	Impulse test (2)		Switching impulse (2)		
				Col 3	Col 4	Col 5	Col 6	
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6		
1	15	1	36	95	(3)	(3)		
2	15	1	50	110	(3)	(3)		
3	38	1, 5	60	150	(3)	(3)		
4	38	1, 5	80	200	(3)	(3)		
5	72.5	1, 5	140	300	(3)	(3)		
6	72.5	1, 5	160	350	(3)	(3)		
7	123	9	215	450	(3)	(3)		
8	123	9	260	550	(3)	(3)		
9	145	9	260	550	(3)	(3)		
10	145	9	310	650	(3)	(3)		
11	170	9	310	650	(3)	(3)		
12	170	9	365	750	(3)	(3)		
13	245	9	365	750	(3)	(3)		
14	245	9	425	900	(3)	(3)		
15	245	9	460	1050	(3)	(3)		
16	362	9	425	900	720	800		
17	362	9	500	1050	825	900		
18	362	9	555	1300	825	900		
19	550	9	615	1300	1050	1180		
20	550	9	740	1550	1175	1300		
21	550	9	860	1800	1175	1300		
22	800	9	860	1800	1425	1550		
23	800	9	960	2050	1425	1550		

<sup>a</sup>Numbers in parenthesis refer to the items in 8.1.

# Annex A

(informative)

## Electrical insulation characteristics

Table A.1 includes the electrical insulation characteristics for ratings that were a part of IEEE Std C57.19.01-1991, but which were not included in Table 1 of this standard. This information is provided for replacement purposes only.

**Table A.1—Electrical insulation characteristics for outdoor apparatus bushings (nominal system voltage 15–800 kV) (for replacement purposes only)**

Basic lightning impulse insulation level (BIL)	System voltage	Rated maximum line-to-ground voltage	Creepage distance minimum		Withstand tests					
					60 Hz		Lightning impulse			Wet switching impulse
					1 min dry rms	10 s wet rms	Full wave	Chopped wave crest minimum time to flashover		
								2 μs withstand	3 μs withstand	
(kV)	(kV)	(kV)	(mm) <sup>a</sup>	(in)	(kV)	(kV)	(kV)	(kV)	(kV)	(kV)
Col. 1	Col. 2	Col. 3	Col. 4		Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10
110	15	10	280	11	50	45	110	142	126	—
150	25	16	430	17	60	50	150	194	175	—
250	46	29	890	35	105	95	250	322	290	—
450	92TR <sup>b</sup>	73	1 680	66	185	155	450	—	520	—
550	115	88	2 010	79	260	230	550	710	632	—
650	138	102	2 340	92	310	275	650	838	750	—
750	161	102	2 900	114	365	315	750	968	865	—
750	161TR <sup>b</sup>	146	3 560	140	365	315	750	—	865	—
900	196	146	3 560	140	425	350	900	1 160	1 040	—
900	362	220	5 590	220	395	—	900	—	1 035	700
1 050	362	220	5 590	220	460	—	1 050	—	1 210	825
1 300	550	318	8 080	318	575	—	1 300	—	1 500	1 050
1 425	550	318	8 080	318	630	—	1 425	—	1 640	1 110
1 550	550	318	8 080	318	690	—	1 550	—	1 780	1 175
1 800	800	485	12 320	485	800	—	1 800	—	2 070	1 360

**NOTES**

1—Dry negative switching impulse withstand voltage of the bushing must be at least equal to the dry switching impulse withstand voltage for the corresponding BIL specified in IEEE Std C57.12.00-1993.

2—The above ratings are not a part of the main standard and are included in this annex for replacement purposes only.

<sup>a</sup>Primary units for dimensions are in millimeters.

<sup>b</sup>For reduced BIL transformers only.

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