VI.D

AIR DISCONNECT SWITCHES

AIR DISCONNECT SWITCH RATINGS

PENNSYLVANIA - NEW JERSEY - MARYLAND INTERCONNECTION
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This report presents principles and procedures to be used in establishing normal and emergency ratings for air disconnect switches. The resulting ratings can be used for selecting the most economical nameplate ratings for new disconnect switches. Disconnecting switches built under C37.30-1962, C37.30-1971 and prior standards and also C37.30-1992 are included. Ratings are intended for use on all nonenclosed indoor and outdoor air disconnecting switches affecting the PJM Interconnection. Although this rating method is intended to be all inclusive, it is recognized that exceptions may be necessary for special conditions. For rating information on enclosed disconnect switches refer to C37.30-1992.

BACKGROUND

The recognition that various designs of switches can carry different normal and emergency currents led to the establishment of ratings based on switch capabilities, operating procedures, physical environment, and special conditions.

The primary difference between this revision and the original issue results from application of values from current IEEE standards as follows:

Original Issue: n = 1.8	Limit on loadability = 180%
Current Issue: n = 2.0	Limit on loadability = 200%

(The 180% limit on loadability was based on the disconnect switch performance test which is run at 180% of rating. The lower value of n may have been taken from the breaker standards that use the value 1.8.)

Calculating loadability factors using the current values results in a 1%-5% lower summer value for calculations of normal, greater than 24 hrs., and 2 - 24 hr. ratings (see Appendix III) and in 4% - 10% lower winter values, than when calculated under the previous guide. The more significant impact is on ratings of less than 2 hours.

DISCUSSION OF RATING METHOD

The rating methods established by this report is based primarily on the following:

a) Ambient temperature

b) Maximum temperature determined to be acceptable for various switch parts under normal and emergency conditions.

c) Acceptable loss of foreseeable life for emergency conditions.

d) Temperature rise based on the square law.

DEFINITIONS

The following are definitions of terms used in this report for use in determining PJM switch ratings:

Rated Continuous Current (Nameplate Rating) (I_r)

Maximum current in amperes at rated frequency a switch can carry continuously without any part exceeding its limit of observable temperature rise.

Adjusted Rated Continuous Current (I)

Rated continuous current corrected to limit of observable temperature rise using specific temperature rise by test.

Normal Current Rating (I_n)

Current which can be carried continuously without any switch part exceeding the normal allowable maximum temperature.

Test Observable Temperature Rise (θ)

Actual steady-state temperature rise above ambient temperature of any part of a switch when tested at rated continuous current.

Limit of Observable Temperature Rise (θ_r)

Maximum value of observable temperature rise of any part of a switch as limited by ANSI C37.30-1992, Table 3. The values are listed in Table I of this report.

Allowable Maximum Temperature (θmax)

Maximum temperature which any switch part can withstand continuously.
Values from ANSI C37.30-1992 are listed in Table I of this report.

Emergency Allowable Maximum Temperature (θmax_e)

Maximum temperature which any part can withstand for emergency rating duration.

SWITCH EMERGENCY RATING DURATIONS

Disconnecting switches are installed in series circuits with other station equipment and lines. Durations for switch emergency ratings match durations for associated station equipment and line ratings and are tabulated below. The rating durations are adequate to meet the loading requirements for any switch, regardless of its location.

Switch Emergency Rating Durations

1-15 minutes
2 hours
10 hours
24 hours
1 week
1 month
6 months

AMBIENT TEMPERATURE

Since maximum switch temperature is a function of prevailing ambient temperature, the value of ambient temperature is important for determination of ratings. For short-time intervals the maximum expected ambient temperature is of prime importance. Temperature records surveyed by the PJM Companies resulted in agreement on use of the following temperatures which are consistent with those used for all PJM equipment ratings.

Rating Durations	Summer (April thru October)	Winter (November thru March)
Normal and Emergency		
Greater than 24 Hrs.	30°C	10°C
Emergency 24 Hrs. or Less	35°C	10°C

NORMAL RATINGS

The normal current rating of a switch is that current which can be carried continuously without any switch part exceeding the normal allowable maximum temperature. The prime considerations in establishing the normal current rating of a switch are ambient temperature and limit of observable temperature rise. The normal current rating is calculated by compensating the adjusted continuous rated current (rated continuous current if temperature rise from heat run test is not available) for specific ambient temperature.

EMERGENCY RATINGS

Emergency ratings for durations of two hours to six months are determined based on operation up to the emergency allowable maximum temperature for the limiting switch part. Emergency allowable maximum temperatures are based on the establishment of a reasonable reduction of yield strength resulting from operation at some elevated temperature for an acceptable estimated frequency of application of emergency ratings over the life of the switch. Reduction of yield strength resulting from such operation for hard-drawn copper and heat-treated aluminum alloy materials used in the majority of switch blades is shown in Appendix II. Emergency allowable maximum temperatures of 10°C and 20°C above the normal allowable maximum temperature for ratings greater than twenty-four hours, and for ratings of twenty-four hours and less duration, respectively, result in acceptable reductions of yield strength and are utilized in this report. The yield strength reductions will not materially affect satisfactory operation for momentary or three second short circuit currents, or for operation when coated with ice. Emergency ratings for durations of less than two hours are determined based on the switch thermal time constant which is a function of the heat storage capacity of the switch. Loading prior to applying less than two hour emergency ratings is assumed to be 100% of the normal rating for the prevailing ambient temperature. Although ratings can be increased by assuming pre-load current less than 100% of normal rating, this type of rating is difficult to supervise.

The emergency ratings established by this method are limited to 200% of the normal rating.

DETERMINATION OF RATINGS

Switch ratings can be determined as follows:

a) If no information is available on switch material, the minimum ratings listed in Table II**,** summarized below, can be applied.

Minimum Loadability Factor of Material Classes A – F
(Percent of Switch Adjusted Rated Continuous Current)

Rating Duration	Minimum Rating Winter	Minimum Rating Summer

Normal	134	115
Greater than 24 hrs.	141	127
2 to 24 hrs.	147	130
15 minutes	166	151
10 minutes	177	163
5 minutes	206	195

b) If switch material or the standard under which the switch was manufactured is known, refer to Table I and then determine ratings from Table II or Appendix I or Appendix II.

It is recognized that many switches manufactured under C37.30-1962 and prior, contain materials which may not permit up-rating to the temperature limitations of C37.30-1971 & 1992. In order to determine the rated continuous current for these switches at the new temperature limitations, and the exact material classes, the switch manufacturers should be consulted.

MAINTENANCE REQUIREMENTS

Satisfactory performance of switches carrying loads based on ratings established by this report are dependent upon adequate maintenance. Required frequency and extent of maintenance will be determined by atmospheric conditions at a given switch location, frequency of switch operation, application of short circuit current, and applicability of emergency ratings. The ability of a switch to carry normal, emergency, or short circuit currents may be seriously impaired if the switch is not properly maintained.

Where periodic maintenance cannot be made, it is suggested that the switch be opened and closed several times to clean the contacts and free the moving parts.

INTERRUPTER SWITCH RATINGS

Rating methods included in this report can be applied to switch live parts other than those enclosed in an interrupter. Manufacturers should be consulted for thermal ratings of interrupters.

TABLE I
TEMPERATURE LIMITATIONS FOR INDOOR AND OUTDOOR AIR SWITCHES

Switch Part	Switch Part Material Class	Allowable Maximum Temperature $\varnothing max$ (^oC)	Limit of Observable Temperature Rise at Rated Continuous Current Non-Enclosed Switches $\varnothing_r$ (^oC)	Emergency Allowable Maximum Temperature $\varnothing max_e$ (^oC)	
				For rating durations Greater than 24 Hrs. $\varnothing max_{e24}$	For Ratings of 24 Hr. Duration or Less $\varnothing max_{e2}$
All Parts-Switches Manufactured to 30^{o}C Rise (IEEE C37.30-1962)	A01	70	30	80	90
Contacts in Air[1]					
a. Copper or Copper Alloy	B02	75	33	85	95
b. Copper or Copper Alloy to Silver or Equiv.	D04	90	43	100	110
c. Silver, Silver Alloy or Equiv.	F06	105	53	115	125
Conducting Material Joints					
a. Copper or Alum.	D04	90	43	100	110
b. Silver, Silver Alloy or Equiv.	F06	105	53	115	125
Switch Terminals with Bolted Connections	D04	90	43	100	110
Other Current Carrying Parts					
a. Copper or Copper Alloy Castings	F06	105	53	115	125
b. Hard Drawn Copper Parts	C03	80	37	90	100
c. Heat Treated Alum. Alloy Parts	F06	105	53	115	125
Woven Wire Flexible Connectors	B02	75	33	85	95

1. Contacts as used here include (a) stationary and moving contacts that engage and disengage, and (b) contacts that have relative movement, but remain engaged.

TABLE II
TABLE OF SWITCH LOADABILITY FACTORS
(% OF SWITCH ADJUSTED RATED CONTINUOUS CURRENT)

Switch Material Class[3]	A	B	C	D	F	
Allowable Max. Temp.	70°C	75°C	80°C	90°C	105°C	Min. Rating of A, B, C, D & F

Rating Duration	W[1]	S[2]	W	S	W	S	W	S	W	S	W	S
Normal	141	115	140	117	138	116	136	118	134	119	134	115
> 24 Hrs.	153	129	151	129	147	127	145	128	141	127	141	127
2 - 24 Hrs.	163	135	160	135	156	133	152	132	147	130	147	130
15 Min.[4,5]	192	169	187	166	181	161	174	157	166	151	166	151
10 Min.[4,5]	209	188	203	183	195	177	187	171	177	163	177	163
5 Min.[4,5]	252	230	244	227	233	218	221	208	206	195	206	195

1. Winter ambient temperature 10°C for all Rating Durations.

2. Summer ambient temperature 30°C for Normal and Greater than 24-hour Ratings;
35°C for Rating Durations 24 hours or less.

3. Refer to Table I for Switch Material Class.

4. These emergency rating factors are based on switch half-hour thermal time constants. This time is conservative for the majority of switches rated 1200 amperes and above. For other time constants special calculations can be made.

5. Underlined rating factors have been limited to 200% of normal rating.

APPENDIX I - FORMULAE AND SAMPLE CALCULATIONS

1.0 Correction of Rated Continuous Current - When switch temperature rise is less than guaranteed, ratings may be adjusted as follows for each material class.

$$I = I_r \left(\frac{\varnothing_r}{\varnothing} \right)^{1/n} \quad (1)$$

I_r = Rated continuous current (nameplate rating)

I = Adjusted rated continuos current

θ = Test observable temperature rise at rated continuos current

θ_r = Limit of observable temperature rise at rated continuous current

n = 2

Note: For subsequent calculations the adjusted rated continuous current (I) should be used when test data is available. When test data is not available, use rated continuous current (I_r).

2.0 Calculation of Normal (Continuous) Current Ratings -

Winter and summer ratings will not be equal to rated continuous current, but can be determined as follows:

$$I_n = I \left(\frac{\varnothing \max - \varnothing_a}{\varnothing_r} \right)^{1/n} \quad (2)$$

I_n = Normal current rating

θ_a = Ambient temperature

θmax = Allowable maximum temperature

3.0 Calculation of Emergency Ratings Greater Than 24-Hour Duration -

Winter and summer emergency ratings of duration's greater than 24 hours can be determined as follows:

$$I_{e24} = I \left(\frac{\varnothing \max_{e24} - \varnothing_a}{\varnothing_r} \right)^{1/n} \quad (3)$$

I_{e24} = Emergency rating of greater than 24 hours duration

θmax_{e24} = Emergency (greater than 24 hours) allowable maximum temp., (∅max +10°C)

4.0 Calculation of Emergency Ratings of 2-to-24 Hour Duration -

Winter and summer emergency ratings of 2-to-24 hour duration can be determined as for greater than 24 hours by replacing θmax_{e24} by θmax_{e2} in the formula.

$$I_{e2} = I\left(\frac{\varnothing \max_{e2} - \varnothing_a}{\varnothing_r}\right)^{1/n} \qquad (4)$$

I_{e2} = Emergency rating of 2 to 24 hours duration

θmax_{e2} = Emergency (2 to 24 Hour) allowable maximum temperature, ($\varnothing$max +20^{o}C)

5.0 Calculation of Emergency Ratings of Less Than 2-Hours Duration -

Winter and summer emergency ratings of less than 2-hours duration can be determined as follows:

$$I_{et} = I\left[\frac{1}{\varnothing_r}\left(\frac{\varnothing \max_{e2} - \varnothing \max}{1 - e^{-t/\tau}} + \varnothing \max - \varnothing_a\right)\right]^{1/n} \qquad (5)$$

(*Rating is limited to 200% of normal rating.)

I_{et} = Emergency rating of less than 2 hours

t = Rating duration (minutes)

τ = Thermal time constant of the switch (minutes)

τ the thermal time constant of a switch preferably should be obtained by test, or can conservatively use 30 minutes for switches rated 1200 amperes and above.

e = 2.718

6.0 Determination of Switch Ratings -

For switches containing more than one material class, it will be necessary to determine ratings for each material class and select the limiting rating for the appropriate conditions.

7.0 Sample Calculations -

Assume an 800 ampere nameplate switch having silver to silver inlay contacts and a hard drawn copper blade exhibits temperatures from heat run test data as follows:

	Silver-to-Silver Contacts (F06)	Hard-drawn Copper Blade (C03)
Test Temperature (^{o}C)	30.8	23.7

Adjusted Continuous Rated Current

From (1): $$I = I_r\left(\frac{\varnothing_r}{\varnothing}\right)^{1/n}$$

Contacts $I = 800\left(\frac{53}{30.8}\right)^{.5} = 1049 amps$

Blade $I = 800\left(\frac{53}{30.8}\right)^{.5} = 1000 amps$

At least two adjusted nameplate values will be required for switches with more than one material class. Perhaps the simplest method for rating a switch is to calculate all ratings for each material and to apply the limiting rating for each condition.

Normal Ratings

From (2): $$I_n = I\left(\frac{\varnothing \max - \varnothing_a}{\varnothing_r}\right)^{1/n}$$

Contacts Summer $$1080\left(\frac{105-30}{53}\right)^{.5} = 1285 amps$$

Winter $$1080\left(\frac{105-10}{53}\right)^{.5} = 1446 amps$$

Blade Summer $$1030\left(\frac{80-30}{37}\right)^{.5} = 1197 amps$$

Winter $$1030\left(\frac{80-10}{37}\right)^{.5} = 1417 amps$$

Blade is limiting for both summer and winter ratings.

Emergency Ratings of Greater than 24 Hours Duration

From (3): $$I_{e24} = I\left(\frac{\varnothing \max_{e24} - \varnothing_a}{\varnothing_r}\right)^{1/n}$$

Contacts Summer $$1080\left(\frac{115-30}{53}\right)^{.5} = 1368 amps$$

Winter $$1080\left(\frac{115-10}{53}\right)^{.5} = 1520 amps$$

Blade Summer $$1030\left(\frac{90-30}{37}\right)^{.5} = 1312 amps$$

Winter $$1030\left(\frac{90-10}{37}\right)^{.5} = 1515 amps$$

Blade is limiting for summer rating .

Emergency Rating of 2 to 24 Hours Duration -

From (4): $$I_{e2} = I\left(\frac{\varnothing \max_{e2} - \varnothing_a}{\varnothing_r}\right)^{1/n}$$

Contacts Summer $$1080\left(\frac{125-35}{53}\right)^{.5} = 1407 amps$$

Winter $$1080\left(\frac{125-10}{53}\right)^{.5} = 1590 amps$$

Blade Summer $$1030\left(\frac{100-35}{37}\right)^{.5} = 1365 amps$$

Winter $$1030\left(\frac{100-10}{37}\right)^{.5} = 1606 amps$$

Blade is limiting in summer and contact slightly limiting in winter.

Emergency Rating of 15 Minutes Duration -
(Assumes 30 minute switch time constant)

From (5): $$I_{et} = I\left[\frac{1}{\varnothing_r}\left(\frac{\varnothing \max_{e2} - \varnothing \max}{1 - e^{-t/\tau}} + \varnothing \max - \varnothing_a\right)\right]^{1/n}$$

Contacts - Summer $$1080\left[\frac{1}{53}\left(\frac{20}{.393} + 105 - 35\right)\right]^{.5} = 1631 amps$$

Winter $$1080\left[\frac{1}{53}\left(\frac{20}{.393} + 105 - 10\right)\right]^{.5} = 1791 amps$$

Blade Summer $$1030\left[\frac{1}{37}\left(\frac{20}{.393} + 80 - 35\right)\right]^{.5} = 1658 amps$$

Winter $$1030\left[\frac{1}{37}\left(\frac{20}{.393} + 80 - 10\right)\right]^{.5} = 1862 amps$$

Contacts and blade are limiting during summer for 15 minute rating.

APPENDIX II
LOSS OF TENSILE STRENGTH BASIS FOR EMERGENCY RATINGS

Allowable emergency loading hours for the life of the switch and reference to annealing characteristics of hard-drawn copper and heat-treated aluminum alloys will result in expected yield strength reductions listed below.

Alloy	Exposure Hrs.	Yield Strength at Norm. Allow. Max. Temp. Before Heating (PSI)	Yield Strength at Emergency Allow. Max. Temp. (PSI)	Reduction in Yield Strength (%)
Copper CD 110	220 Hrs. @ 100°C 2900 Hrs. @ 90°C	47,860	43,600	8.9
Alum. 6063-T6	220 Hrs. @ 125°C 2900 Hrs. @ 115°C	25,900	23,100	10.8

Although loading hours at emergency allowable maximum temperature can be accumulated by any combination of rating durations, an example is tabulated below.

Emergency Rating Duration	Estimated Frequency of application of emergency Ratings	Total Emergency Loading Hours For 30-Year Life	Emergency Allowable Maximum Temperature Copper **(°C)**	Emergency Allowable Maximum Temperature Aluminum **(°C)**
1-15 Minutes	Negligible Effect on Annealing	Negligible	100	125
2 Hours	Once per 3 years	20	100	125
10 Hours	Once per 3 years	100	100	125
24 Hours (10 Hour Loading)	Once per 3 years Total Hours 1 Minute to 24 Hour Ratings	100 220	100	125
1 Week (50 Hour Loading)	Once per 3 years	500	90	115
1 Month (220 Hour Loading)	Once per 5 years	1320	90	115
6 Months (1200 Hour Loading)	Once in Switch Life	1200	90	115
	Total Hours 1 Week to 6 Months Rating	3020		

APPENDIX III - Loadability Factor Differences from Original Issue

Minimum Loadability Factor of Switch Material Classes A - F
(Percent of Switch Adjusted Rated Continuous Current)

Rating Duration	Minimum Rating Winter	Minimum Rating Summer
Normal	138	117
Greater than 24 hrs.	146	130

2 to 24 hrs.	154	134
15 minutes	176	158
10 minutes	185	173
5 minutes	226	211

The following table is calculated using n = 2 and a loading limit of 200%

Minimum Loadability Factor of Material Classes A - F
(Percent of Switch Adjusted Rated Continuous Current)

Rating Duration	Minimum Rating Winter	Minimum Rating Summer
Normal	134 (-4%)	115 (-2%)
Greater than 24 hrs.	141 (-5%)	127 (-3%)
2 to 24 hrs.	147 (-7%)	130 (-4%)
15 minutes	166 (-10%)	151 (-7%)
10 minutes	177 (-8%)	163 (-10%)
5 minutes	206 (-20%)	195 (-6%)

( ) = Change from values in original issue

TABLE II from original issue calculated using n = 1.8 and 180% loadability limit.

TABLE II
TABLE OF SWITCH LOADABILITY FACTORS
(% OF SWITCH ADJUSTED RATED CONTINUOUS CURRENT)

Switch Material Class	A	B	C	D	F	
Allowable Max. Temp. **(Ømax)**	70°C	75°C	80°C	90°C	105°C	Min. Rating of A, B, C, D & F

Rating Duration	W[1]	S[2]	W	S	W	S	W	S	W	S	W	S
Normal	147	117	146	118	143	118	141	120	138	121	138	117
> 24 Hrs.	160	133	158	133	154	131	151	131	146	130	146	130
2 - 24 Hrs.	173	140	169	139	164	137	160	136	154	134	154	134
15 Min.	208	179	202	176	194	170	186	165	176	158	176	158
10 Min.	227	203	224	198	212	190	203	186	185	173	185	173
5 Min.	265	211	263	212	257	212	245	216	226	214	226	211

Table II calculated using n = 2 and using 200% as the rating limit.

TABLE II
TABLE OF SWITCH LOADABILITY FACTORS
(% OF SWITCH ADJUSTED RATED CONTINUOUS CURRENT)

Switch Material Class	A	B	C	D	F	
Allowable Max. Temp.	70°C	75°C	80°C	90°C	105°C	Min. Rating of A, B, C, D & F

Rating Duration	W[1]	S[2]	W	S	W	S	W	S	W	S	W	S
Normal	141	115	140	117	138	116	136	118	134	119	134	115
	-6	-2	-6	-1	-5	-2	-5	-2	-4	-2	-4	-2
> 24 Hrs.	153	129	151	129	147	127	145	128	141	127	141	127
	-7	-4	-7	-4	-7	-4	-6	-3	-5	-3	-5	-3
2 - 24 Hrs.	163	135	160	135	156	133	152	132	147	130	147	130
	-10	-5	-9	-4	-8	-4	-8	-4	-7	-4	-7	-4
15 Min.	192	169	187	166	181	161	174	157	166	151	166	151
	-16	-10	-15	-10	-13	-9	-12	-8	-10	-7	-10	-7
10 Min.	209	188	203	183	195	177	187	171	177	163	177	163
	-18	-15	-21	-15	-17	-13	-16	-15	-8	-10	-8	-10
5 Min.	252	230	244	227	233	218	221	208	206	195	206	195
	-13	+19	-19	+15	-24	+6	-24	-8	-20	-19	-20	-6

BIBLIOGRAPHY

1. "Alcoa Aluminum Bus Conductor Handbook", Aluminum Company of America, 1957.

2. IEEE Standard C37.30-1962, 1971& 1992 IEEE Standard Requirements for High-Voltage Air Switches

3. Standard C37.32-1990 American National Standard for Switchgear - High-Voltage Air Switches, Bus Supports, and Switch Accessories - Schedules of Preferred Ratings, manufacturing Specifications, and Application Guide.

4. IEEE Standard C37.34-1965, 1971 & 1994 IEEE Standard Test Code for High-Voltage Air Switches

5. "Current-Carrying Capacity of ACSR", H. E. House, P. D. Tuttle, IEEE Transactions, Vol. 78, 1959, pp. 1169-1173.

6. "Heating and Current Carrying Capacity of Bare Conductors for Outdoor Service", O.R. Schurig, C. W. Frick, General Electric Review, Schnectady, New York, Vol. 33, March 1930.

7. "New IEEE Temperature Limitations for Disconnecting Switches" IEEE Transactions, Vol. 88, 1969, pg. 1412-1423.

8. "The Aluminum Data Book", Reynolds Metal Company, Richmond Virginia, 1961.

9. IEEE Standard C37.37a-1992 IEEE Loading Guide for AC High-Voltage Air Switches Under Emergency Conditions. (Supplement to IEEE Std. C37.37-1979)