VI.D

AIR DISCONNECT SWITCHES

GUIDE FOR DETERMINATION OF

DISCONNECT SWITCH RATINGS

PJM INTERCONNECTION

Heritage MAAC Group

A task force of the Transmission and Substation Subcommittee

R. W. Munley	Baltimore Gas and Electric Company
D. J. Lemmerman	Exelon
V. C. Jhonsa	Pepco Holdings Incorporated
D. M. Egan	PJM Interconnection, L.L.C.
R. Vresko	PPL Electric Utilities
A. Mannarino	Public Service Electric and Gas Company

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REVISION HISTORY

August 1970:   Rev. 0 – Original Document

February 1999:   Rev. 1 – Format changes, general revisions.

October 2009:   Rev. 2 - General revision and document standardization and clarification of emergency and load dump ratings, and revision of associated equations.

SCOPE AND PURPOSE

This guide presents principles and procedures to be used in establishing normal, emergency 4 hour, and load dump current carrying capabilities for disconnect switches. The resulting thermal ratings can be used for selecting the most economical nameplate ratings for new disconnect switches. All disconnect switches built under prior standards; and the existing standards listed in the references of this report are included. 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 1997.

BACKGROUND

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

The primary purpose of revising this document is to clarify certain definitions and bring documents up to date to the latest revision to the industry standards.

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, C37.30-1992 and prior standards and also C37.30-1997 are included. Ratings are intended for use on all non enclosed 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 C37.30-1997.

HISTORICAL BACKGROUND

Scope change from 1970 version to 1999

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.)

Scope change from 1999 version to 2009

The primary difference from the 2009 and 1999 version is ratings provided in this guide are now limited to Normal, Emergency and Load Dump to align with PJM operating practice. The revision also included and document standardization, sample calculation corrections and clarification of emergency and load dump ratings, including revision of associated equations.

DISCUSSION OF RATING METHOD

The rating methods established by this report represent compromises in the various factors included in the latest thinking of the utility industry. The method developed is based primarily on the following:

1. Ambient temperature (θ_a).
2. Temperature rise as a function of the 2.0 power of the current.
3. Maximum temperature determined to be acceptable for various switch parts under normal and emergency conditions.
4. Acceptable loss of foreseeable life for emergency conditions.

It is assumed that power levels will be maintained and managed within the requirements of PJM Manual 3, Section 2, "Thermal Operating Guidelines." PJM operating philosophy strives to restore loads to below the Normal Rating in four hours or less. The intent of this guide is that equipment loading will not be above the Normal Rating for greater than four hours. It is understood that under a single event restoration, cumulative time of loading, in excess of the Normal Rating, beyond four hours may occur. Operating in excess of four hours above the Normal Rating for a single event restoration should be evaluated by the equipment owner.

DEFINITIONS

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

Adjusted Rated Continuous Current (I)
Continuous current capability of a line trap corrected to Limit of Observable Temperature Rise using specific Test Observable Temperature Rise data. Note: I = I_r when the specific temperature rise test data is not available.

Ambient Temperature (θ_a)
Expected air temperature surrounding the rated disconnect switch.

Emergency Allowable Maximum Temperature (θ_{max_e})
Maximum temperature which any portion of a switch part can withstand for various emergency rating durations, e.g., θ_{max_e} = 4 hour maximum temperature, etc.

Emergency Current Rating (I$_{ea}$)
Short time currents that can be carried for a specified period of time, at selected ambient temperature, without any part of switch exceeding its emergency allowable maximum temperature. In PJM, the Emergency Current Rating is for a four hour duration, e.g., I_{ea_4}= 0 to 4 hour emergency current.

Limit of Observable Temperature Rise (θ_r)
Maximum value of observable temperature rise of any part of a switch as limited by ANSI C37.30-1997, Table2. Values are listed in Table 1 of this report.

Load Dump Current Rating ($I_{s_{0.25}}$)
In PJM, a Load Dump Current Rating is a Short Time Emergency Current Capability for 15 minutes duration e.g., $I_{s_{0.25}}$ is the current which can be carried 15 minutes, or a ¼ of an hour.

Normal Allowable Maximum Temperature (θ_{max})
The maximum allowable temperature that any part of switch can withstand continuously. In this report it is defined as $\theta_{max} = \theta_r + 40\,°C$.

Normal Current Rating (I_n)
Current that can be carried continuously without any part of switch exceeding its normal allowable maximum temperature.

Rated Continuous Current (Nameplate Rating) (I_r)
Maximum current in amperes at rated frequency any switch part can carry continuously without exceeding its Limit of Observable Temperature Rise.

Short Time Emergency Current Capability (I_s)
Short time emergency currents which can be carried for less than 4 hours, e.g., $I_{s_{0.25}}$ is the current which can be carried for a ¼ of an hour.

Short Time Rating Duration (t)
Duration of the short term rating (< 4 hours) in minutes.

Test Observable Temperature Rise (θ)
Measured steady-state temperature rise above ambient temperature of any part of switch when tested at rated continuous current.

Thermal Time Constant (τ)
The length of time required, in minutes, for the initial temperature to reach 63.2% of final value after a change in current in the switch. In practice, it is generally agreed that after 4 time constants that the ultimate temperature is reached (actually 98.2% of its final value). Assumed to be 30 minutes (1/2 hour) minimum for all switches in this report.

AMBIENT TEMPERATURE

Since maximum switch temperature is a function of prevailing ambient temperature, θ_a, 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 (Normal, Emergency and Load Dump).

Description	Summer	Winter
PJM Planning Basis Temperatures	35 °C	10 °C

PJM Operations utilizes ambient adjusted ratings in 5 °C increments. The method described in this document allows the calculation of these capabilities.

NORMAL RATINGS

The normal current rating of a disconnect switch is that current which can be carried continuously without any switch part exceeding its normal allowable maximum temperature. The prime considerations in defining 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 rated continuous current (rated continuous current, if temperature rise from heat run test is not available) for specific ambient temperature.

EMERGENCY & LOAD DUMP CURRENT RATINGS

Emergency ratings for durations of less than four hours, for example load dump current ratings, are determined based on the any switch part thermal time constant which is a function of the heat storage capacity of the any part of switch. Loading prior to applying emergency ratings, including load dump current ratings, shall be 100% or less of the normal rating for the ambient temperature. Ratings can be increased by assuming the pre-load current is less than 100% of the normal rating; however, safely operating to this type of rating is difficult and is not recommended.

Emergency ratings 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 (≈10%). 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. The emergency allowable maximum temperatures are 20°C above the normal allowable maximum temperature. The yield strength reductions will not materially affect satisfactory operation for short circuit currents or for operation when coated with ice. Emergency ratings 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 emergency ratings

is assumed to be 100% of the normal rating for the prevailing ambient temperature. Ratings can be increased by assuming pre-load current less than 100% of normal rating. For a time constant of 30 minutes, a three hour cool down period is recommended.   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.

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

Rating Duration	Minimum Rating Winter (%)	Minimum Rating Summer (%)
Normal	131	108
4 hrs.	142	128
15 minutes	157	145

    b)   If switch material classes are 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 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.

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 NON-ENCLOSED INDOOR AND OUTDOOR AIR SWITCHES

| Switch Part | Allowable maximum temperature, θ_{max} (°C) | Non-enclosed indoor and outdoor switches | |
| | | Limit of observable temperature rise at rated current, θ_r (°C)[*] | Switch-part class designation |
	Column 1	Column 2	Column 3
All Parts-Switches Manufactured to 30°C Rise (IEEE C37.30-1962)	70	30	A01
(a) Contacts in air[†]			
(1) Copper or copper alloy	75	33	B02
(2) Copper or copper alloy to silver or silver alloy, or equivalent	90	43	D04
(3) Silver, silver alloy, or equivalent	105	53	F06
(b) Conducting mechanical joints			
(1) Copper or aluminum	90	43	D04
(2) Silver, silver alloy, or equivalent	125	67	F06
(c) Switch terminals with bolted connections	90	43	D04
(d) Welded or brazed joints or equivalent	105	53	F06
(e) Other current-carrying parts			
(1) Copper or copper alloy castings	105	53	F06
(2) Hard-drawn copper parts[**]	80	37	C03
(3) Heat-treated aluminum allow parts	105	53	F06
(4) Woven-wire flexible connectors	75	33	B02

[*] The limit of observable temperature rise listed in this column is suitable for use in rating switches for application in enclosures of IEEE Std C37.20.2-1993 and IEEE Std C37.20.3-1987, if the corresponding allowable maximum temperature listed in Column 1 is not exceeded when in the enclosure. The temperature rises are chosen to give a loadability of 1.22 at 25 °C.

[†] 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		F'		Min. Rating of A, B, C, D, F & F'	
Allowable Max. Temp.	70°C		75°C		80°C		90°C		105°C		125°C			
Rating Duration	W[1]	S[2]	W	S	W	S	W	S	W	S	W	S	W	S
Normal	141	108	140	110	138	110	136	113	134	115	131	116	131	108
4 Hours.	163	135	160	135	156	133	152	132	147	130	142	128	142	128
15 Min.[4]	192	169	187	166	181	161	174	157	166	151	157	145	157	145

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

[2]   Summer ambient temperature **35°C** for **all Rating Durations.**

[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.

ANNEX I - Informative

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.

$$I = I_r \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{n}} \qquad (1)$$

I_r = Rated continuous current (nameplate rating)

I = Adjusted rated continuous current

θ = Test observable temperature rise at rated continuous current

θ_r = Limit of observable temperature rise at rated continuous current

n = 2

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

$$I_n = I \left(\frac{\theta_{max} - \theta_a}{\theta_r}\right)^{\frac{1}{n}} \qquad (2)$$

I_n = Normal current rating

θ_a = Ambient temperature

θ_{max} = Allowable maximum temperature

3.0   Calculation of Emergency Rating of Four Hour Duration

       Winter and summer emergency ratings of four hour duration can be determined in the
       formula:

$$I_{ea_4} = I \left(\frac{\theta_{max_{e_4}} - \theta_a}{\theta_r} \right)^{\frac{1}{n}} \qquad (3)$$

I_{ea_4} = Emergency rating of 4 hour duration

$\theta_{max_{e_4}}$ = Emergency (4 Hour) allowable maximum temperature, $(\theta_{max} + 20\ °C)$

4.0   Calculation of Emergency Ratings of Less Than Four Hours Duration -

Winter and summer emergency ratings of less than 4-hours duration can be determined as follows:

$$I_{eat} = I \left[\left(\frac{\theta_{max_{e_4}} - \theta_a - \theta_r \left(\frac{I_a}{I} \right)^n e^{-\frac{t}{\tau}}}{\theta_r \left(1 - e^{-\frac{t}{\tau}} \right)} \right) \right]^{\frac{1}{n}} \qquad (4)$$

For determination of the PJM Load Dump rating, I_a is set equal I_n as determined in (2), I_r is adjusted to I as determined in (1), and by definition I_{eat} becomes $I_{s_{0.25}}$. With these preconditions, (4) simplifies to the following:

$$I_{s_{0.25}} = I \left[\frac{1}{\theta_r} \left(\frac{\theta_{max_{e_4}} - \theta_{max}}{1 - e^{\frac{-t}{\tau}}} + \theta_{max} - \theta_a \right) \right]^{\frac{1}{n}} \qquad (5)$$

I_{eat} = Emergency rating of less than 4 hours

t = Rating duration (minutes)

τ = Thermal time constant of the switch (minutes).   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 = Euler's constant

Note: Rating is limited to 200% of the normal rating.

5.0   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.

6.0   Sample Calculations

Assume a 1200 ampere nameplate switch having silver to silver inlay contacts and a hard-drawn copper blade that exhibits temperatures from heat run test data as follows:

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

Adjusted Continuous Rated Current

From (1): $I = I_r \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{n}}$

Contacts: $I = 1200 \left(\frac{53}{30.8}\right)^{\frac{1}{2}} = 1574 \; amps$

Blade: $I = 1200 \left(\frac{37}{23.7}\right)^{\frac{1}{2}} = 1499 \; amps$

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): $I_n = I \left(\frac{\theta_{max} - \theta_a}{\theta_r}\right)^{\frac{1}{n}}$

Contacts: Summer $1574 \left(\frac{105 - 35}{53}\right)^{.5} = 1809 \; amps$

             Winter $1574 \left(\frac{105 - 10}{53}\right)^{.5} = 2108 \; amps$

Blade: Summer $1499 \left(\frac{80 - 35}{37}\right)^{.5} = 1653 \; amps$

             Winter $1499 \left(\frac{80 - 10}{37}\right)^{.5} = 2062 \; amps$

The blade is limiting for both summer and winter Normal Ratings.

Emergency Rating (up to 4 Hours Duration)

From (3): $\quad I_{ea_4} = I\left(\dfrac{\theta_{max_{e_4}} - \theta_a}{\theta_r}\right)^{\frac{1}{n}}$

Contacts: Summer $\quad 1574\left(\dfrac{125-35}{53}\right)^{.5} = 2051\ amps$

Winter $\quad 1574\left(\dfrac{125-10}{53}\right)^{.5} = 2319\ amps$

Blade: Summer $\quad 1499\left(\dfrac{100-35}{37}\right)^{.5} = 1987\ amps$

Winter $\quad 1030\left(\dfrac{100-10}{37}\right)^{.5} = 2338\ amps$

The blade is limiting in summer and contact is limiting in winter for the Emergency Rating.

Load Dump Rating (up to 15 Minutes Duration)
(Assumes 30 minute switch time constant)

From (4): $\quad I_{s_{0.25}} = I\left[\dfrac{1}{\theta_r}\left(\dfrac{\theta_{max_{e_4}} - \theta_{max}}{1 - e^{\frac{-t}{\tau}}} + \theta_{max} - \theta_a\right)\right]^{\frac{1}{n}}$

Contacts: Summer $\quad 1574\left[\dfrac{1}{53}\left(\dfrac{125-105}{1-e^{\frac{-15}{30}}} + 105 - 35\right)\right]^{\frac{1}{2}} = 2377\ amps$

Winter $\quad 1574\left[\dfrac{1}{53}\left(\dfrac{125-105}{1-e^{\frac{-15}{30}}} + 105 - 10\right)\right]^{\frac{1}{2}} = 2611\ amps$

Note: The calculated winter rating is greater than 200% and would be limited to twice nameplate or 2400 amps.

Blade Summer $\quad 1499\left[\dfrac{1}{37}\left(\dfrac{100-80}{1-e^{\frac{-15}{30}}} + 80 - 35\right)\right]^{\frac{1}{2}} = 2413\ amps$

Winter $\quad 1499\left[\dfrac{1}{37}\left(\dfrac{100-80}{1-e^{\frac{-15}{30}}} + 80 - 10\right)\right]^{\frac{1}{2}} = 2710\ amps$

Note: The calculated ratings are greater than 200% and would be limited to twice nameplate or 2400 amps.

Contacts are limiting in summer and winter for the Load Dump Rating.

ANNEX II - Informative

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		

ANNEX III – Informative

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
Emergency	154	134
Load Dump	176	158

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%)
Emergency	147 (-7%)	130 (-4%)
Load Dump	166 (-10%)	151 (-7%)

( ) = Change from values in original issue dated August 1970

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	**108 (-7%)**
Emergency	147	130
Load Dump	166	151

( ) = **Change from Revision 1 dated February 1999.**

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

TABLE
1970 30C AMBIENT TABLE OF SWITCH LOADABILITY FACTORS
(% OF SWITCH ADJUSTED RATED CONTINUOUS CURRENT)

Switch Material Class	A		B		C		D		F		
Allowable Max. Temp. (∅max)	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
1999 30C AMBIENT 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

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