Division 1-22

National Grid underwent a North American Electric Reliability Corporation (NERC) Standards Compliance Audit conducted by Northeast Power Coordinating Council (NPCC) in April of 2011. NPCC's audit included evaluation of the Narragansett Electric Company's compliance with NERC Standard FAC-008, "Facility Ratings Methodology."

The result of NPCC's compliance audit of FAC-008 was "No Finding." The public audit report, documenting Narragansett Electric's compliance with this standard, is attached under "Reference Documents" located at the end of the process narrative.

FAC-008-1: Facility Ratings Methodology

Purpose of Standard:

To ensure that Facility Ratings used in the reliable planning and operation of the Bulk Electric System (BES) are determined based on an established methodology or methodologies.

Requirement R1 and sub-requirements

The Transmission Owner and Generator Owner shall each document its current methodology used for developing Facility Ratings (Facility Ratings Methodology) of its solely and jointly owned Facilities. The methodology shall include all of the following:

- **R1.1.** A statement that a Facility Rating shall equal the most limiting applicable Equipment Rating of the individual equipment that comprises that Facility.
- **R1.2.** The method by which the Rating (of major BES equipment that comprises a Facility) is determined.
  - **R1.2.1**. The scope of equipment addressed shall include, but not be limited to, generators, transmission conductors, transformers, relay protective devices, terminal equipment, and series and shunt compensation devices.
  - **R1.2.2.** The scope of Ratings addressed shall include, as a minimum, both Normal and Emergency Ratings.
- **R1.3.** Consideration of the following:
  - **R1.3.1.** Ratings provided by equipment manufacturers.
  - **R1.3.2.** Design criteria (e.g., including applicable references to industry Rating practices such as manufacturer's warranty, IEEE, ANSI or other standards).
  - **R1.3.3.** Ambient conditions.
  - **R1.3.4.** Operating limitations.
  - **R1.3.5.** Other assumptions.

Compliance with R1 (incl. R1.1-R1.3):

Requirement R1:
The facility ratings for National Grid's New England facilities are maintained in a software program (PG65) that calculates the limiting ratings for each branch of the system. Reports can be generated to provide detailed or summary output. Each branch is represented by all elements in series that have thermal ratings between two electrical nodes. The PG65 program is based on guidance provided in ISO-NE Planning Procedure 7 (PP7). The following responds to each subpart of the requirement:

R1.1: The current methodology used for developing Facility Ratings is documented and maintained in the PG65 Program Manual. PG65 is a software program that calculates the current carrying capability (rating) of each element in a branch and then identifies the most limiting element for each branch of the system. The PG65 program is based on guidance provided in ISO-NE Planning Procedure (PP7) on how to calculate the rating for each type of equipment.

The Statement that a Facility Rating shall equal the most limiting applicable Equipment Rating of the individual equipment that comprises that facility is located in TGP26 National Grid Transmission Facility Ratings, 5/10/10, Issue 3, Paragraph 4.3, page 5.

R1.2: The PG65 Program Manual sets forth the method by which the ratings are determined in section PG65, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011.

R1.2.1: The method by which the ratings are determined includes:
- Generators [Not Applicable]
- Transmission line conductors (PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011, Paragraph 3.6.1, page 6)
- Transformers (PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011, Paragraph 3.6.8, page 11)
- Relay protective devices (PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011, Paragraph 3.6.12, page 13)
- Terminal Equipment (PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011, Paragraph 3.6, page 6)
- Series and shunt compensation devices: National Grid doesn't own any series compensation. National Grid provides equipment ratings for the NPCC Bulk Power System shunt devices based on manufacturer nameplate ratings.

R1.2.2: The scope of ratings addressed includes Normal Ratings and Emergency Ratings as noted in PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011, Section 1, Page 3.

R1.3 The PG65 Program considers the following:

R1.3.1 Ratings provided by equipment manufactures are considered by ISO-NE PP7, Procedures for Determining and Implementing Transmission Facility Ratings in New England, 2/14/2007, Page 4, Item 2

R.1.3.2 Design criteria are considered by ISO-NE PP7, Procedures for Determining and Implementing Transmission Facility Ratings in New England, 2/14/2007, various references throughout.

R1.3.3 Ambient Conditions are considered by PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011, Section 3, Page 4

R1.3.4 Operating Limitations are considered by ISO-NE PP7, Procedures for Determining and Implementing Transmission Facility Ratings in New England, 2/14/2007, various references throughout.

R1.3.5 Other assumptions included in the methodology are contained throughout PG65 Manual, Thermal Ratings Program for Transmission Line Circuits, Jan 11, 2011 & ISO-NE PP7, Procedures for Determining and Implementing Transmission Facility Ratings in New England, 2/14/2007

Note: All documents referenced above are attached under “Reference Documents”

Requirement R2

The Transmission Owner and Generator Owner shall each make its Facility Ratings Methodology available for inspection and technical review by those Reliability Coordinators, Transmission Operators, Transmission Planners, and Planning Authorities that have responsibility for the area in which the associated Facilities are located, within 15 business days of receipt of a request.

Compliance with R2:

If an entity requested (and is entitled) to receive facility rating methodology information, National Grid would respond to such a request for facility ratings methodologies within 15 business days, in accordance with this requirement. During the past 3 years (the most recent auditable period) we have not received any such requests from any other entities to inspect our facility ratings methodology.

Requirement R3
If a Reliability Coordinator, Transmission Operator, Transmission Planner, or Planning Authority provides written comments on its technical review of a Transmission Owner's or Generator Owner's Facility Ratings Methodology, the Transmission Owner or Generator Owner shall provide a written response to that commenting entity within 45 calendar days of receipt of those comments. The response shall indicate whether a change will be made to the Facility Ratings Methodology and, if no change will be made to that Facility Ratings Methodology, the reason why.

Compliance with R3:
If an entity cited above submitted written comments of their technical review of The Narragansett Electric Company's Facility Ratings Methodology, National Grid would provide a written response to that commenting entity within 45 calendar days of receipt of those comments. The documented response would indicate whether or not a change will be made to the Facility Ratings Methodology. If no change, the response will document the reason why.

Reference Documents:

NERC Standard **NPCC Audit Report** (Password is NPCC_NEP_041111)

FAC-008-1.pdf (17 KB)

pw_2011_public_NPCC_NECO.doc (...

R1

TGP26_Issue _May 2010.pdf (25.

R1

ISO-NE~1.PDF (612 KB)

R1

pg65-manual.doc (366 KB)

There are no documents referenced in the responses to R2 & R3.

ISO NEW ENGLAND PLANNING PROCEDURE NO. 7

PROCEDURES FOR DETERMINING AND IMPLEMENTING TRANSMISSION FACILITY RATINGS IN NEW ENGLAND

EFFECTIVE DATE: August 31, 2005

REFERENCES: ISO New England Operating Procedure No. 16, Transmission System Data

ISO New England Operating Procedure No. 19, Transmission Operations

NERC Standard FAC-008-1 – Facilities Rating Methodology

Transmission Operating Agreement (TOA)

TABLE OF CONTENTS

1.0 INTRODUCTION

These procedures describe:

1) The collaborative development of ratings for (a) transmission equipment connected at 69kV and above on the electric power system in New England and (b) all generator step up transformers attached to generators of 1 MW or greater that participate in the Energy Market; and

2) The provision for reviewing the ratings of individual transmission facilities prior to their permanent implementation by ISO New England (the ISO).

The Market Participants and the ISO are responsible for collaborating in both the development of rating procedures and establishment of ratings.

ISO New England Operating Procedure No. 16, Transmission System Data (OP 16), requires Market Participants to determine equipment ratings and provide them to the ISO. Ratings for new facilities and changes to ratings of existing facilities shall be determined in a manner consistent with the collaboratively developed ratings methodologies described in Section 2 and, as required, shall be collaboratively reviewed in accordance with Section 3.

The ISO is responsible for:

1) Maintaining documentation describing individual Market Participants' current rating methodologies,

2) Administering technical reviews of such methodologies and changes to them,

3) Initiating improvements in rating methodologies to gain consistency and system capacity, and

4) As required, coordinating technical reviews of new and revised ratings as they are submitted per OP 16.

The System Design Task Force of the Reliability Committee (SDTF), chaired by ISO staff, provides the structure for Market Participant/ISO collaboration in developing rating methodologies and establishing ratings. The task force is the primary source of technical advice on ratings methodologies and review of individual equipment ratings. The Reliability Committee will be informed of any such advisory recommendations provided to the ISO.

These procedures address only static ratings, which are determined based on a specific set of input assumptions that can be adjusted for ambient temperature conditions. Temporary ratings can be determined for use in particular situations; these are addressed in Section 2.6 below. Dynamic ratings are not employed in operating the New England power system or in administrating the electricity markets.

2.0 COLLABORATIVE DEVELOPMENT OF RATING PROCEDURES

APPROACH

1) Loadings in excess of a component's continuous capability will contribute to accelerated wear, reduced equipment life and potential failure and represent a risk to the equipment owner as well as those using the power system. While it is important that the methodologies reflect an acceptable level of equipment risk, it is also important that the methodologies be consistently applied throughout the transmission system since they ultimately determine the capacity of the system.

2) No single methodology is universally accepted for determining the thermal capability of each component of the transmission system. However, guidelines for rating transmission equipment were developed by NEPOOL in 1970 for use by individual equipment owners. There continues a general consistency in methods, although there are also some differences. This PP7 is established to reintroduce guidelines representative of "best ratings practices" and to initiate improvements in individual owners' rating methodologies, where appropriate, to gain consistency of application and to maximize transmission system capability while maintaining acceptable levels of risk to equipment and maintaining reliability.

3) Consistency of a Market Participant's rating practices with the collaboratively developed ratings methodologies is determined as described in Section 2.5, below.

TRANSMISSION EQUIPMENT TO BE RATED

Each Market Participant shall establish methodologies for rating the following components, as applicable:

Overhead Conductors
Underground Cables
Power Transformers
Series and Shunt Reactive Elements
Circuit Breakers
Disconnect Switches
Current Transformers
Line Traps
Substation Buses
Current Transformer Circuits
VAR Compensators
HVDC Systems

As described in Section 2.4 below, guidelines representative of "Best Rating Practices" for each of the above components are provided in the Appendices.

RATINGS AND LIMITS TO BE ASSIGNED

Transmission equipment shall be assigned ratings and limits for the conditions listed below:

- Winter Normal Rating (W NOR)
- Winter Long-Time Emergency Rating (W LTE)
- Winter Short-Time Emergency Rating (W STE)
- Winter Drastic Action Limit (W DAL)
- Summer Normal Rating (S NOR)
- Summer Long-Time Emergency Rating (W STE)
- Summer Short-Time Emergency Rating (S STE)
- Summer Drastic Action Limit (S DAL)

Where:

The Winter and Summer ratings are determined using the input assumptions of Appendix A, General Rating Parameters. The periods for which Winter and Summer ratings apply are defined in ISO Operating Procedure 16, Transmission System Data (OP16).

ISO Operating Procedure 19, Transmission Operations (OP19) describes the conditions in which the Normal Ratings and Emergency Ratings are applied, actions to be taken to maintain equipment loadings within ratings and limits and the associated allowable durations of time associated with operation at each rating. These conditions and times must be consistent with those used to determine the corresponding ratings. Thus,

The Normal Rating is the rating, adjusted for ambient conditions, which will allow maximum equipment loading without incurring loss of life above design criteria. The design criteria are described in Appendix A, General Rating Parameters.

Emergency Ratings, which exceed normal ratings, involve loss of life or loss of tensile strength in excess of design criteria. Consistent with OP19, the emergency ratings shall be calculated to using the following time durations.

Winter LTE (W LTE) - 4 hours
Summer LTE (S LTE) - 12 hours

Winter STE (W STE) - 15 minutes
Summer STE (S STE) - 15 minutes

Drastic Action Limits, unlike normal and emergency loading ratings, are limits that require immediate action to be taken to prevent damage to equipment. Their calculation is described below.

2.1.1 Calculation of Drastic Action Limits:

For purposes of calculation, the Drastic Action Limit is defined as the current flow, which would cause the circuit component to reach its 15-minute emergency thermal limit, if allowed to flow for five minutes, assuming the following conditions:

1) The summer and winter ambient conditions as described in paragraph 2.1 of Appendix A, General Rating Parameters; and

2) A pre-disturbance circuit loading of 75% of the normal terminal equipment rating or 75% of the conductor sag limitation, whichever is less, for the appropriate season.

The use of five minutes in computing the Drastic Action Limit does not indicate that five minutes, or any other time increment, exists for which current of the calculated magnitude may safely be allowed to flow. A prescribed "drastic action" is required to return the circuit loading to the long-time emergency rating for the appropriate season.

NEW ENGLAND "BEST RATING PRACTICES"

1) Rating methodologies for each equipment type specified in Section 2.2 shall be collaboratively developed and included as appendices to this PP7. Initially, reference will be made to applicable sections of the former rating guidelines (NEPOOL Capacity Rating Procedures) until the section is reviewed, updated and replaced.

2) Such methodologies shall be developed consistent with the requirements of Section 2.3 recognizing the previous NEPOOL rating guidelines, individual Market Participant practices, currently applicable equipment standards, equipment manufacturer recommendations and good utility practice.

3) The ISO shall initiate a SDTF review of each section of the appendix at least every 5 years or following a major revision of an applicable rating standard.

CONFORMANCE OF MARKET PARTICIPANT RATING METHODOLOGIES

1) Market Participants shall provide, to ISO New England, fully documented copies of the current methodologies used to rate each applicable equipment type specified in Section 2.2 within 15 business days of receipt of a request. Such documentation will include reference to standards employed and will allow determination of how ratings for each condition in Section 2.3 are computed. It will identify differences from the "Best Rating Practices" described above, including, as appropriate, the wind velocities, ambient temperatures, equipment temperatures and other pertinent assumptions used. Software deemed proprietary and not provided will be made available for on site inspection/testing. Whenever a Market Participant modifies their rating methodologies, this same information shall be provided to the ISO, as is

pertinent to the change, before any rating using such methodology is submitted in accordance with OP16.

2) Such documentation shall be submitted electronically to an ISO mailbox established for this purpose.

3) Any differences from the requirements of Section 2.3 are violations of OP16 and will be dealt with accordingly.

4) Any differences in a Market Participant's methodologies from those of the "Best Rating Practices" shall be accompanied with either a statement of intent and schedule for introducing modifications to adhere to the "Best Rating Practices" or written justification for that Market Participant's continuing the non-conforming practice.

5) Within 30 days of receiving a Market Participant's written justification for a non-conforming practice, the SDTF Chair will solicit advice from the SDTF and, as appropriate, other task forces or subcommittees of the Reliability Committee. The SDTF will coordinate consideration of any justification for the non-conforming practice and evaluate and judge its continued use and provide a recommendation to the ISO. The ISO will act on all such SDTF recommendations within 60-days.

6) The ISO may also initiate a technical review of the documentation submitted by a Market Participant and may solicit advice from the SDTF or other task forces or subcommittees of the Reliability Committee in evaluating its conformance with the "Best Rating Practices".

7) Written comments regarding the conformance of a Market Participant' practices will be provided to the Market Participant.

   - Those differences deemed justifiable will be formalized by letter and recorded in Attachment 1 to this PP7 as an "Accepted Alternative Rating Practice" specific to that Market Participant.

   - Those differences determined to be unjustified will be identified and accompanied with a request they be modified to conform.

8) Market Participants shall provide a written response to the ISO within 45 days, indicating:

   - Acknowledgement that an "Accepted Alternative Rating Practice" will be included in Attachment 1 of PP7, or

   - Acceptance of a request to modify the rating practice and a scope and schedule for introducing such modifications, or

- No change to that methodology will be forthcoming and why. This response may initiate a disagreement as described in Section 4, below.

9) The ISO shall maintain documentation of each Market Participant's current methodologies and comparisons with the requirements of Section 2.3 and the "Best Rating Practices" contained in the appendices to this PP7. Any differences and their disposition will be noted. Copies of all rating methodology documentation provided under this PP7 (including for methodologies later superseded), and documentation of all comparisons with the PP7 appendices, as well as any associated correspondence with Market Participants, shall be retained for 3 years.

10) SDTF discourse when evaluating exceptions to a "Best Rating Practice" should be considered when that methodology is next reviewed.

Temporary Ratings

1) The intent of these procedures is to provide uniform, well-documented methodologies for rating transmission line and terminal equipment. When a Market Participant deems it necessary to meet system events or unusual weather conditions, they may provide sets (Normal, LTE, STE) of temporary ratings for specific facilities as described in ISO New England Operating Procedure No. 19, Transmission Operations (OP19). Such ratings will typically recognize factors such as local ambient temperatures or and equipment preloading and would be available to be invoked by system operators.

2) If temporary ratings are employed, a description of the rating methodology shall be provided to the ISO, along with a description of any differences from the equipment owner's methodology provided in conformance of Section 2.5, above.

3.0 Collaborative Review of Transmission Facility Ratings

Approach

1) OP 16 requires that Market Participants supply ratings that are representative of all elements of the New England transmission network.

2) OP 16 also requires that, prior to implementation, ISO review all such data to verify that it is complete, reasonable and consistent with related data and reasons for the change.

3) In cases where ISO identifies a rating as questionable following discussion of such data with the equipment owner, the collaborative review procedure of Section 3.2

shall be employed. During the period of such a review, the new rating data will be granted provisional approval and its implementation will proceed.

COLLABORATIVE REVIEW OF TRANSMISSION FACILITY RATINGS

1) Upon determining that a rating remains questionable, ISO shall notify the Market Participant that a review of the rating has been initiated. The NX-9 Administrator shall then discuss the rating issue with the Chair of the SDTF.

2) Should it be decided that further review of the rating is not appropriate, the Market Participant shall be so notified and implementation of the rating data would continue.

3) Should it be decided that further review of the rating is appropriate, the Market Participant shall be notified that the rating has not been accepted pending outcome of a review by the SDTF. The rating would continue through the implementation process but with provisional approval.

4) The Chair of the SDTF shall then initiate a review of the rating by the task force, considering the rating submission and supporting information, the rating practices of the Market Participant, the "Best Rating Practices", and the applicable standards.

5) If the SDTF agrees that the rating as submitted is reasonable, and the ISO also agrees, ISO shall so notify the Market Participant and the rating shall be approved.

6) If the SDTF agrees the rating as submitted is unreasonable, and the Market Participant accepts the SDTF determination, the Market Participant shall initiate a revised data submittal.

7) If the SDTF agrees the rating as submitted is unreasonable, and the Market Participant does not accept the SDTF determination, the issue would be settled as described in Section 4, below.

8) If the SDTF agrees that the rating as submitted is reasonable, and the ISO disagrees, the issue would be settled as described in Section 4, below.

4.0 DISAGREEMENTS

Should there be disagreement between the ISO and any Market Participant regarding Sections 2.5 or 3.2, the language of Section 3.06 (a) (v) of the Transmission Operating Agreement shall govern the disagreement.

5.0 APPENDICES

The following is a list of the documents that describe the accepted practices for determining ratings of the indicated equipment types. The individual documents are updated from time to time as the SDTF modifies the "Best Rating Practices" per Section 2.4, above.

Appendix A - General Rating Parameters
Appendix B - Overhead Conductors
Appendix C - Underground Cables
Appendix D - Power Transformers
Appendix E - Series and Shunt Reactive Elements
Appendix F - Circuit Breakers
Appendix G - Disconnect Switches
Appendix H - Current Transformers
Appendix I - Line Traps
Appendix J - Substation Buses
Appendix K - Current Transformer Circuits
Appendix L - VAR Compensators
Appendix M - HVDC Systems

Document History

Rev. 0 App.: SDTF – 3/22/05; RC – 6/14/05; NPC – 8/5/05; ISO-NE – 8/31/05
Rev. 1 4/11/06 Editorial changes to maintain consistency with Appendices
Rev. 2 2/14/07 Sections 2.4 and 2.5 modified to conform with NERC Standard FAC-008-1

APPENDIX A
GENERAL RATING PARAMETERS

1.0 INTRODUCTION

This Appendix A describes the general parameters that should be used in calculating ratings for (a) transmission equipment connected at 69kV and above on the electric power system in New England (except underground cables) and (b) all generator step up transformers attached to generators of 1 MW or greater that participate in the Energy Market.

Such parameters for underground cables are described in Appendix C, Underground Cables.

2.0 AMBIENT TEMPERATURES AND WIND VELOCITIES

A complete discussion of ambient temperatures and wind velocities will be found in Reference 1, "Ambient Temperatures and Wind Velocity for Rating Calculations."

AMBIENT TEMPERATURES

The following table of ambient temperatures should be used for determining normal and emergency equipment ratings:

Table A 1
Ambient Temperature For Determining Equipment Ratings

	Overhead Conductors		Power and Current Transformers		All Other Equipment	
	Normal	**Emergency**	**Normal**	**Emergency**	**Normal**	**Emergency**
Winter	10 °C	10 °C	5 °C	10 °C	10 °C	10 °C
Summer	38 °C	38 °C	25 °C	32 °C	28 °C	28 °C

With the exception of the summer ambient temperature for overhead conductors (addressed in Section 2.1.1, below), the above ambient temperatures were developed from Hartford, Connecticut area temperature statistics for the years 1905 to 1970 and reaffirmed following analysis of similar data from eight locations throughout New England for the years 1975-2004. This data is summarized in Table A2 (Hartford Area) and Table A3 (New England).

Table A 2
Hartford, CT Area Temperature Data
1905-1970

	Average of the Daily Maximums[1]		Average of the Monthly Maximums[2]		Daily Mean[3]	
	°F	ºC	°F	ºC	°F	ºC
January	35.1	1.7	54.0	12.2	27.2	-2.7
February	36.1	2.3	53.0	11.7	27.7	-2.4
March	45.5	7.5	66.1	18.9	36.9	2.7
April	58.0	14.4	79.0	26.1	48.0	9.0
May	69.6	20.9	86.9	30.5	58.6	14.8
June	78.3	24.6	92.0	33.3	67.8	19.9
July	83.2	28.4	94.0	34.4	70.8	21.6
August	82.5	28.1	91.0	32.8	70.8	21.6
September	77.1	25.1	87.0	30.6	62.2	16.8
October	63.9	17.7	81.0	27.2	51.1	10.6
November	50.5	10.3	66.0	18.9	42.0	5.5
December	38.0	3.3	57.0	13.9	30.4	-0.9

Table A 3
New England Temperature Data (Eight Locations[4])
1975-2004

	Average of the Daily Maximums[1]		Average of the Monthly Maximums[2]		Daily Mean[3]	
	°F	ºC	°F	ºC	°F	ºC
January	32.29	0.18	52.04	11.13	25.01	-3.88
February	36.89	2.71	54.78	12.65	29.23	-1.54
March	44.08	6.70	65.84	18.81	36.10	2.26
April	55.45	13.03	78.49	25.80	46.65	8.16
May	66.28	19.03	85.24	29.59	57.08	13.93
June	75.38	24.11	90.06	32.25	66.55	19.19
July	79.86	26.59	91.21	32.89	71.18	21.76
August	79.39	26.30	90.69	32.60	70.94	21.63
September	72.15	22.30	85.19	29.54	63.58	17.53
October	59.65	15.36	76.65	24.81	51.00	10.56
November	48.90	9.40	66.79	19.33	41.63	5.35
December	39.26	4.04	58.93	14.96	32.20	0.11

1 This is the average of the daily maximum temperatures for each month.
2 This is the average of the monthly maximum temperature over 65 years.
3 This is the average of the daily maximum and minimum temperatures over the month.
4 Based on eight New England locations of Hartford/Windsor Locks and Bridgeport in CT, Boston and Worcester in MA, Burlington VT, Providence RI, Concord NH and Portland ME.

The ambient temperature recommendations of Table A1 are based upon the following:

2.1.1 Overhead Conductors

The 38 ºC (100 °F) summer ambient temperature for overhead conductors conforms to the guidelines cited in Section 125.23 of Chapter 220 of the Code of Massachusetts Regulations, Installation and Maintenance of Transmission Lines (220 CMR 125.23) [Reference 2].

2.1.2 Power and Current Transformers

IEEE Standard C57.91-1995 (R2004), "Guide for Loading Mineral-Oil-Immersed Transformers" [Reference 3] recommends using "average daily temperatures" for the month involved in determining normal ratings and "average of maximum daily temperatures" for the month involved for emergency ratings. The Guide also recommends the use of a 5°C adder to be conservative. The ambient temperatures indicated in Table A1 are consistent with the recommendations for determining ambient temperatures set forth in the C57.91 including the recommended 5°C adder as based on the data of Table A2.

1) Normal ambient temperatures were derived from the Daily Mean temperatures of Table A2; Column 3 and emergency ambient temperatures were derived from the Average of the Daily Maximum temperatures of Table A2, Column 1.

2) However, weighted averages of temperatures appropriate to the summer and winter periods were used instead of monthly temperatures as suggested by the Guide. Winter temperatures were equally weighted over the 5-month period. Summer temperatures were determined by equal weighting of the temperatures for the months of June through September.

A recalculation of the ambient temperature values using the data of Table A3 compares favorably with the recommendations of Table A1. Only the Summer Emergency ambient temperature differed, being lower by less than 2ºC.

The criteria to be used for developing ambient temperature for current transformers will be the same as power transformers.

2.1.3 All Other Equipment

Conservative weighted averages of daily maximum ambient temperatures (Column 1 of Tables A2 and A3) should be used for determining ratings of all other line terminal equipment. Therefore, the average of August daily maximums should be used for summer ratings and the average of November daily maximums should be used for winter ratings.

Inspection of the August and November values in Column 1 of Tables A2 and A3 indicate that the New England temperatures are slightly lower than those of the Hartford area, being less than 2ºC lower in summer and less than 1ºC lower in winter.

After considering the data of Tables A2 and A3, the SDTF has determined that the longstanding ambient temperature recommendations of Table A1 should remain unchanged.

WIND VELOCITIES

A wind velocity of 3 fps should be assumed during both the winter and summer periods where applicable. These values were determined by the Conductor Rating Working Group of the System Design Task Force and accepted by NEPOOL and are documented in the report "An Analysis of Wind-Temperature Data and Their Effect on Current-Carrying Capacity of Overhead Conductors" [Reference 4].

3.0 EQUIPMENT TEMPERATURE

Equipment temperatures for normal loadings shall be in accordance with industry standards or loading guides where applicable. In cases where no industry approved guides exist for emergency loading, total equipment temperatures higher than design values may be allowed for emergency operation, at the discretion of the individual companies.

4.0 ASSUMED LOADING CONDITIONS

Where time-temperature relationships for annealing characteristics have been applied, the following estimated hours of operation at allowable equipment temperatures have been assumed, over a 30-year equipment life:

Normal Rating	13,200 hours
Long-Time Emergency (4 hour/12 hour) Rating	500 hours
Short-Time Emergency (15 minute) Rating	20 hours
Drastic Action Limit	Not Applicable

These estimates are based on the fact that annealing and loss of strength occur only when a device is operating at or near its rated temperature limit. For most locations on the transmission system, ambient temperature variations together with daily and seasonal cycling of load current will result in conditions where the equipment operates at temperatures considerably lower than rated values, most of the time.

The total duration of operation at emergency temperatures, with the exception of Drastic Action Limits, reflects a conservative estimate for contingency.

It should be recognized that, at locations where the load cycle is more severe, such as in proximity to a base load generator, the hours of operation at rated temperature would be expected to increase under normal operation. With more annealing taking place under normal loading, emergency ratings should be assigned with care. In fact, it is recommended that base loaded equipment, which is rated on the basis of loss of strength due to annealing, be assigned emergency ratings equal to normal ratings.

5.0 REFERENCES

1) ISO New England Report, "Ambient Temperatures and Wind Velocity for Rating Calculations", June 7, 2005. This document is included as Attachment 2 to PP7.

2) Code of Massachusetts Regulations, Installation and Maintenance of Transmission Lines (220 CMR 125)

3) IEEE C57.91-1995 (R2004), "IEEE Guide for Loading Mineral-Oil-Immersed Transformers"

4) System Design Task Force, "An Analysis of Wind-Temperature Data and Their Effect on Current-Carrying Capacity of Overhead Conductors" (SDTF-20), August 1983. This document is included as Attachment 3 to PP7.

Document History

Rev. 0 App.: SDTF – 3/22/05; RC – 6/14/05; NPC – 8/5/05; ISO-NE – 8/31/05

Rev. 1 4/11/06 Introduction corrected; editorial and format changes

APPENDIX B
OVERHEAD CONDUCTORS

1.0 INTRODUCTION

These procedures provide a "best ratings practice" to be used by equipment owners for determining normal and emergency load-current carrying capabilities of overhead conductors installed on the New England transmission system, 69kV and above.

2.0 STANDARDS

Overhead conductors are to be rated in accordance with IEEE Standard 738-1993, "IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors". This standard presents methods of relating current and temperature for bare overhead lines as a function of:

- conductor material
- conductor diameter
- conductor surface condition
- ambient weather conditions
- conductor electrical current

and indicates sources of the values to be used in the calculations. Included, but not part of the standard, are sample calculations and a computer program, RATEIEEE, that may be used for steady-state and transient calculations of temperature and thermal rating for bare overhead conductors.

3.0 APPLICATION GUIDE

Overhead conductor ratings shall be calculated as described below at a rated power frequency of 60 Hertz and nominal voltage, e.g. 69 kV, 115 kV, 230 kV or 345 kV.

MAXIMUM ALLOWABLE CONDUCTOR TEMPERATURE

Conductor ratings are dependent on choice of maximum allowable conductor temperature, which is normally selected to control two factors:

- loss of strength over time due to annealing, and
- adequate ground clearances due to conductor sag considering the effects of non-elastic elongation (creep).

3.1.1 Loss of Strength

Lines that are operated near their Normal rating continuously may be subjected to annealing. Ratings of such lines should be determined and reviewed on an individual basis so that any loss of strength remains within design limits as discussed in Section 4 of Appendix A.

An IEEE paper by J. R. Harvey, "Effect of Elevated Temperature on the Strength of Aluminum Conductors" [Reference 1] provides a verified method to determine conductor loss of strength.

3.1.2 Clearances

Clearance requirements are established by the National Electrical Safety Code [Reference 2] and applicable state codes. These codes also specify that ground clearances are to be calculated using the maximum conductor operating temperatures. Thus the reduced ground clearances due to sag and creep[1] must be considered in choosing a maximum allowable temperature.

3.1.3 Recommended Maximum Allowable Conductor Temperature

The determination of maximum allowable conductor temperatures is left to the discretion of each equipment owner, with due consideration for the conductor material; however, such temperatures must not be less than 100°C for any emergency rating.

Overhead Conductor Rating Methodology

IEEE Standard 738, first published in 1986, is based on the methods developed by House and Tuttle in their 1958 AIEE paper [Reference 3]. These same methods were used in the New England Electric System programs PG92 and PG108, which the System Design Task Force adopted for calculating conductor ratings in 1970, and from which some programs now in use evolved. Programs consistent with the methods of Standard 738-1993 are acceptable for use in rating overhead conductors in New England.

Standard 738-1993 and the included rating program, RATEIEEE, address both steady-state and transient ratings. Since the thermal time constant of a conductor is generally greater than 15 minutes, the steady-state calculation is to be applied in determining Normal and Long-Time Emergency ratings. The transient calculation is applied in determining Short-Time Emergency ratings and Drastic Action Limits. In all cases, adequate clearances must be maintained with conductor loadings at the rated values.

[1] Creep can cause permanent increased conductor sag and is defined as the non-elastic deformation or flow of material, which occurs with time under its installed tension and advanced by application of additional wind or ice load.

OVERHEAD CONDUCTOR RATING PARAMETERS

Overhead conductor rating calculations are based largely on the resistance and maximum allowable temperature of the conductor, and two environmental factors: ambient temperature and wind speed (the design values of which are discussed in Appendix A). However, other physical characteristics and environmental conditions also influence the calculation of conductor ratings. Some of these vary with the conductor or with location:

- Conductor Diameter
- Latitude
- Elevation
- Atmosphere (Clear/Industrial)
- Line Direction (North – South, East-West, etc.)
- and the appropriate parameters are left to the discretion of the facility owners.

Other parameters can be uniformly applied throughout New England:

- Wind direction: perpendicular to the conductor as discussed in the SDTF–20 report [Reference 4].
- Emissivity and Solar Absorptivity: While these parameters increase with conductor age and oxidation and are influenced by operating voltage and the condition of the atmospheric environment, a value of 0.75 is recommended for Emissivity. Absorptivity values of 0.5 to 0.7 are recommended as per IEEE Standard 738-1993.
- Azimuth: 90 degrees

CONNECTORS AND SPLICES

The loadability of connectors and splices must meet or exceed the loadability of the conductors for which they are sized. The individual owners are to confirm, with the manufacturers involved, that the connectors and splices, when installed in accordance with the methods actually used in each case, may be loaded safely to the proposed line ratings, without exceeding the maximum allowable temperature limits of the conductors.

4.0 REFERENCES

1) Harvey, J.R., "Effect of Elevated Temperature on the Strength of Aluminum Conductors", IEEE Transactions on Power Apparatus and Systems, T72-189-4.

2) ANSI C2-2002, National Electrical Safety Code

3) House, H. E. and Tuttle, P. D., "Current Carrying Capacity of ACSR", AIEE Transactions, Power Apparatus and Systems, pp. 1169-1178, Feb.1958

4) System Design Task Force, "An Analysis of Wind-Temperature Data and Their Effect on Current-Carrying Capacity of Overhead Conductors" (SDTF-20), August 1983.

Document History

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APPENDIX C
UNDERGROUND CABLES

1.0 INTRODUCTION

The following methodology applies to underground and submarine transmission lines, and covers the following type of cables and their accessories:

1) Impregnated paper or laminated paper - polypropylene insulated cables and accessories.
   - High Pressure Fluid Filled Pipe Type Cable (HPFF)
   - Low & Medium Pressure Self contained Liquid Filled Cable (LPOF)
   - High Pressure Gas Filled Cables (HPGF)

2) Extruded Solid dielectric cross linked polyethylene (XLPE) or Ethylene-Propylene-Rubber (EPR) insulated cables

2.0 UNDERGROUND CABLE STANDARDS

Underground cable facilities are generally designed per the following applicable industry standards. For impregnated paper or laminated paper polypropylene insulated cables and accessories, the industry standard and specifications include the following documents:

ASSOCIATION OF EDISON ILLUMINATING COMPANIES (AEIC)

1) AEIC CS 2-97, “Specification For Impregnated Paper And Laminated Paper Polypropylene Insulated Cable High Pressure Pipe Type” (6th Edition) dated March 1997 or latest revision thereof.

2) AEIC CS 31-95, “Specifications For Electrically Insulating Pipe Filling Liquids For High-Pressure Pipe-Type Cables” (2nd Edition) dated December, 1995 or latest revision thereof.

3) AEIC CS4-93, “Specifications For Impregnated-Paper-Insulated Low And Medium Pressure Self Contained Liquid Filled Cable” (8th Edition) dated January 1993 or latest revision thereof.

4) AEIC CG1-96, “Guide For Application Of Maximum Insulation Temperatures At The Conductor For Impregnated Paper Insulated Cables” (3rd Edition) dated April 1996 or latest revision thereof.

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

1) IEEE 404-2000, “IEEE Standard for Extruded and Laminated Dielectric Shielded Cable Joints Rated 2500 V to 500 000 V”.

2) IEEE 48-1996, "Standard Test Procedures And Requirements For Alternating Current Terminations 2.5 kV through 765 kV" dated 01 May 1996 or latest revision thereof.

INTERNATIONAL ELECTRO – TECHNICAL COMMISSION (IEC) SC 20.

Furthermore, for Oil Filled and Gas Pressure Transmission Cables, the industry standard and specifications include the following documents:

1) IEC 60141-1, "Tests On Oil - Filled And Gas Pressure Cables And Their Accessories – Part 1 Paper Or Polypropylene Paper"

Laminated Insulated, Metallic-Sheathed Cables And Accessories For Alternating Voltages Up To And Including 500 kV" (1993-09) and IEC 60141-1-am1 Amendment 1 (1995-02) and IEC 60141-1-am2 Amendment 2 (1998-08) or latest revisions thereof.

2) IEC 60141-4, "Tests On Oil - Filled And Gas Pressure Cables And Their Accessories – Part 4 Oil Impregnated Paper Insulated High Pressure Oil -Filled Pipe -Type Cables And Accessories For Alternating Voltages Up To And Including 400 kV" (1980-01) and IEC 60141-4-am1 Amendment 1 (1990-10) or latest revisions thereof.

ASSOCIATION OF EDISON ILLUMINATING COMPANIES (AEIC)

Furthermore, for extruded dielectric (cross linked polyethylene or ethylene propylene rubber insulated) cables and accessories, the industry standard and specifications include the following documents:

1) AEIC CS 7-93, "Specifications For Cross Linked Polyethylene Insulated Shielded Power Cables Rated 69 through 138 kV" (3rd Edition) dated June 1993 or latest revision thereof.

2) AEIC CG 6-95, "Guide For Establishing The Maximum Operating Temperatures Of Extruded Dielectric Insulated Shielded Power Cables" (1st edition) dated August 1995 or latest revision thereof.

3) AEIC CS 6-96, "Specifications For Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 69 kV And Above" (6th edition) dated April 1996

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

1) IEEE 48-1996, "Standard Test Procedures And Requirements For Alternating – Current Terminations 2.5 kV through 765 kV" dated 01 May 1996 or latest revision thereof.

2) IEEE 404-2000, “Standard For Cable Joints For Use With Extruded Dielectric Cables Rated 5000-138 000 V and Cable Joints For Use With Laminated Dielectric Cable Rated 2500-500 000V”.

INSULATED CABLE ENGINEERS ASSOCIATION (ICEA)

1) ICEA S-108-720, “Standard For Extruded Insulation Power Cables Rated Above 46 through 345 KV”, dated 7/15/04 or latest revision thereof.

INTERNATIONAL ELECTRO – TECHNICAL COMMISSION (IEC) SC 20.

1) IEC 60840, “Power Cables With Extruded Insulation And Their Accessories For Rated Voltages Above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) – Test Methods and Requirements” (2004-04) or latest revision thereof.

2) IEC 61443, “Short Circuit Temperature Limits Of Electric Cables With Rated Voltages Above 30 kV (36 kV) (1999-07)

3) IEC 62067, “Power Cables With Extruded Insulation And Their Accessories For Rated Voltages Above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) –Test Methods and Requirements” (2001-10) or latest revision thereof.

3.0 RATING ALGORITHMS

The AEIC cable standards listed in Section 2 specify the allowable temperatures for various types and voltages of cable insulations, which govern how much current may be transferred through the insulated conductor of the cable. The following are the two common algorithms used for calculating the predicted insulation temperature and thus the allowable operating ampacity for self cooled cable systems.

The preferred algorithm is that of the Neher-McGrath method outlined in "The Calculation Of Temperature Rise And Load Capability Of Cable Systems” [Reference 1]. An alternate method is that outlined in the International Electro-Technical Commission (IEC) Standard, "Calculation of the Continuous Current Ratings of Cables” (100% Load Factor) [Reference 2].

Calculation methods of the Continuous Current Ratings of Cables are outlined in the following Documents of the IEC.

1) IEC 60287-1-1, “Electric Cables – Calculation Of Continuous Current Ratings” Part 1-1: Current Rating Equations (100% Load Factor) And Calculation Of Losses – General” (2001-11) Ed. 1.2, IEC 60287-1-1-am1 AMENDMENT 1 (1995-08), and IEC 60287-1-1-am2 Amendment 2 (2001-08) or latest revisions thereof.

2) IEC 60287-1-2, "Electric Cables – Calculation Of Current Rating Part 1-1: Current Rating Equations (100% Load Factor) And Calculation Of Losses – Section 2 Sheath Eddy Current Loss Factors For Two Circuits In Flat Configuration" (1993-12) or latest revision thereof.

3) IEC 60287-1-3, "Electric Cables – Calculation Of Current Rating Part 1-3: Current Rating Equations (100% Load Factor) And Calculation Of Loses – Current Sharing Between Parallel Single-Core Cables And Calculation Of Circulating Current Losses" (2002-05) or latest revision thereof.

4) IEC 60287-2-1, "Electric Cables – Calculation Of Current Rating Part 2-1 Thermal Resistance – Section 1: Calculation Of Thermal Resistance" (2001-11) Ed. 1.1, and IEC 60287-2-1-am1 Amendment 1 (2001-08) or latest revisions thereof.

5) IEC 60287-2-1, "Electric Cables – Calculation Of Current Rating Part 2 Thermal Resistance – Section 2: Method For Calculating Reduction Factors For Groups Of Cables In Free Air, Protected From Solar Radiation" (1995-05) or latest revision thereof.

6) IEC 60287-3-1, "Electric Cables – Calculation Of Current Rating Part 3-1 Sections On Operating Conditions – Section 1: Reference Operating Conditions And Selection Of Cable Type" (1999-05) Ed. 1.1, and IEC 60287-3-1-am1 Amendment 1 (1999-02) or latest revisions thereof.

7) IEC 60287-3-2, "Electric Cables – Calculation Of Current Rating – Part 3 Sections On Operating Conditions – Section 2: Economic Optimization Of Power Cable Size" (1995-07), and IEC 60287-3-2-am1 (1996-10) Amendment 1 or latest revisions thereof.

8) IEC 60853-2, "Calculation Of The Cyclic And Emergency Current Rating Of Cables Part 2: Cyclic Rating Of Cables Greater Than 18/30 (36) kV And Emergency Ratings For Cables Of All Voltages" (1989-09) or latest revision thereof.

9) IEC 60853-3, "Calculation Of The Cyclic And Emergency Current Rating Of Cables Part 3: Cyclic Rating Factor For Cables Of All Voltages, With Partial Drying Of The Soil" (2002-02) or latest revision thereof.

10) IEC 60986, "Calculation Of Thermally Permissible Short-Circuit Currents, Taking Into Account Non-Adiabatic Heating Effects" (1988-11) or latest revision thereof.

The ratings of High Pressure Fluid Filled Pipe Type Cable systems can be further increased by the circulation of the dielectric fluid through the line pipe and cooling units (heat exchangers) via forced cooling. Forced Cooled ratings are calculated in accordance with the following International Institute of Electrical and Electronics Engineers (IEEE), International Council on Large Electric Systems (CIGRE) and Electric Power Research Institute (EPRI) Documents.

1) IEEE Transaction Paper 31 TP 65-124, "Application Of Oil Cooling In High-Pressure, Oil-Filled, Pipe-Type Circuits" by Mr. R. W. Burrell, IEEE Winter Power Meeting, New York, NY, January 31- February 5, 1965.

2) EPRI Report no. EL-3624, "Designer's Handbook For Forced-Cooled High-Pressure Oil –Filled Pipe-Type Cable Systems" dated July 1984 by Mr. D.W. Purnhagen

3) CIGRE Study Committee 21 Working Group 08, "The Calculation Of Continuous Ratings For Forced-Cooled High-Pressure Oil-Filled Pipe-Type Cables" Electra no. 113, July 1987, pp. 97-121.

The application of the above referenced algorithm is also explained Reference 3, EPRI *Underground Transmission Systems Reference Book* 1992 Edition, Chapter 5 pp. 197 - 273.

4.0 Acceptable Rating Calculation Methods

Rating methods for cables using the above algorithms are modeled by commonly used and acceptable computer programs in the following ways:

1) CYMCAP for Windows by CYME International Inc., a computer program, which utilizes the above algorithms.

2) USAMP+ for Windows by Underground Systems Incorporated (USI)

3) TRAMP by Underground Systems Incorporated (USI), Limited to Pipe Type Cable Systems

4) EPRI ACE program

5) Certain conditions of cable installation not adequately modeled by existing software may be rated using numerical methods and other calculation techniques following the above standards quoted in Sections 2 and 3 above.

6) Cable manufacturer proprietary software that performs the cable rating calculations using the above algorithms are acceptable, if proof of meeting all the standards quoted in Sections 2 and 3 above are available.

5.0 Input Assumptions

Inputs to the underground rating algorithms are as follows:

CABLE SYSTEM ENVIRONMENT

1) Earth Ambient Temperature: This is the temperature of the soil surrounding the cable. This temperature varies either cyclically through the year, with the maximum earth ambient temperature generally lagging one or two months behind the corresponding air temperature or remains constant depending upon the depth of the burial. However, high ambient earth temperatures and heavy system loading tend to coincide in the late summer. Earth ambient temperatures can often be obtained either from local soil conservation services or by the use of thermal probes. Representative Maximum Summer Ambient Earth Temperatures are shown in Reference 3, EPRI *Underground Transmission Systems Reference Book* (1992 Edition).

2) Soil, Concrete and Backfill Thermal Resistivity: The thermal resistivity of the backfill material(s) is a function of several variables, including the intrinsic value of the material itself (or mixture of materials), the moisture content, and the degree of compaction around the cables. A backfill having low thermal resistivity will generally have the following characteristics:

   - High Moisture Content
   - Highly compacted
   - Uniform sizing of components (well-graded)

Typical cable system backfill materials include thermal sand, stone screenings, weak concrete and/or fluidized thermal backfill. Representative thermal resistivity of these materials, with 5% - 0% moisture, range from 30 - 100 C°-cm/watt, as shown in Reference 3, Table 5-11 on Page 236. Typical design values are 60 for weak concrete or fluidized thermal backfill and 90 –100 for thermal sand and stone screenings.

The cable system environment typically consists of a combination of backfill material around the cable and native soils having higher thermal resistivities as described on pages 206 – 208 of Reference 3.

LOAD FACTOR

The load factor of each underground line should be determined. It generally should not be less than 75% for typical transmission lines and should be 100% for dedicated generator leads.

ADJACENT HEAT SOURCES

Adjacent heat sources (i.e.: adjacent heat pipes, distribution lines, or transmission lines) are to be taken into account as outlined in Reference 3, p. 206 and pp. 227-229. Hot Spots should be identified throughout the cable system.

BONDING SCHEMES

Bonding schemes such as multipoint/single point/cross bonding etc. are to be taken into account for the rating of the cable.

CABLE AND DUCT/PIPE CHARACTERISTICS

The cable's characteristics (conductor size, type and stranding, insulation type and thickness, metallic shield type and thickness and/or size and number of wires, etc., jacket type and thickness) are to be taken into account. If the installation is in conduit or pipe, include the dimensions and type of conduit or pipe (if used), pipe or conduit filling medium (typically air, or dielectric fluid as in the case of high pressure dielectric fluid filled pipe type cable) as outlined in Reference 3, pp. 203-204. Installation Characteristics

INSTALLATION CHARACTERISTICS

The cross Section of the Cable Environment, depth of burial, spacing and configuration (vertical and/or horizontal spaced, close triangular etc) of adjacent phases, number of circuits, spacing and configuration of adjacent circuits and/or external heat sources, type of installation (direct burial or in conduit of pipe), type and dimensions of backfill material, type of native soil etc. as outlined in the EPRI *Underground Transmission Systems Reference Book* pp. 205-206 (1992 Edition).

6.0 CABLE RATINGS

The ratings of underground cables are largely influenced by the ambient earth temperature and properties of the surrounding soil and the way the cable is installed and operated.

Network operators need to know the amount of energy they are allowed to transport at normal and at emergency operation without causing excessive loss of life of the cable system. Rating calculations are made for normal and emergency operations.

NORMAL RATING

The Normal rating is that in which a cable operates continuously with negligible loss of life. Typically this is based on pipe limits and conductor temperatures:

PIPE TEMPERATURE LIMITS: Prevent Soil Thermal runaway.
  55° C Thermal Sand
  60° C Concrete
  60° C Forced Cooling
PAPER CABLES: Conductor Temperature Limit: 85° C
XLPE CABLES: Conductor Temperature Limit: 90° C

This calculation is based on either Neher – McGrath [Reference 1] or IEC 287 [Reference 2] as applied to high voltage cables. This is the current that the cable system is expected to carry through its normal load cycle for an indefinite period of time without exceeding its normal operating temperature.

EMERGENCY RATINGS

6.1.1 Long Time Emergency Rating (LTE)

Long Time Emergency Ratings (LTE) are defined in OP19. Conductor temperatures for paper and XLPE Cables are not to exceed 105°C for 300 Hrs./5Years. These calculations are based on Neher – McGrath [Reference 1] and/or IEC 60853, cited in Section 3.0.

6.1.2 Short Time Emergency Rating (STE)

Short Time Emergency Ratings (STE) are defined in OP19. Consistent with OP19, the 15-minute conductor rating shall not reach temperature limits as specified in LTE above. These calculations are based on Neher – McGrath [Reference 1] and/or IEC 60853, cited in Section 3.0.

6.1.3 Drastic Action Limit (DAL)

Drastic Action Limits (DAL) are defined in OP19. Consistent with OP19, the 5-minute conductor rating shall not reach temperature limits as specified in LTE above. These calculations are based on Neher – McGrath [Reference 1] and/or IEC 60853, cited in Section 3.0.

7.0 REFERENCES

1) Neher and McGrath, "The Calculation Of Temperature Rise And Load Capability Of Cable Systems”, AIEE Transactions on Power Apparatus and Systems, vol. 76, October 1957.

2) International Electro-Technical Commission Publication 287, "Calculation of the Continuous Current Ratings of Cables” (100% Load Factor), 2nd Edition, 1982

3) Electric Power Research Institute, *Underground Transmission Systems Reference Book*, 1992

<u>Document History</u>

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Rev. 1 4/11/06 Add Section 7, References; editorial changes

APPENDIX D
POWER TRANSFORMERS

1.0 INTRODUCTION

The following methodology applies to power transformers with a least one winding connected at a voltage of 69 kV or higher. The methodology has four major sections, autotransformers, load serving transformers, phase-shifting transformers and generator step-up transformers.

2.0 STANDARDS

Ratings for power transformers shall be calculated consistent with IEEE Standard C57.91-1995 (R2004), "IEEE Guide for Loading Mineral-Oil-Immersed Transformers", and C57.91-1981, "IEEE Guide for Loading Mineral-Oil-Immersed Transformers".

3.0 APPLICATION GUIDE

AUTOTRANSFORMERS-SIXTY FIVE DEGREE RISE

Autotransformers shall be given four load-carrying ratings: normal, long time emergency (LTE), short time emergency (STE), and drastic-action limit (DAL). Autotransformer owners should use caution in assigning DAL limits higher than the STE limit because thermal models in transformer rating tools may not be designed to model very short time intervals.

The assumptions in Table D1 below shall be used to calculate these ratings for an oil-immersed, **sixty-five degree rise** autotransformer. The rating of the autotransformer shall be calculated at 60 Hertz, nominal voltage, at the fixed tap that will be utilized when the autotransformer is in service, and with any forced cooling (fans and/or pumps) in operation. If the autotransformer has a load tap changer the rating shall be calculated at the tap that gives the most conservative rating.

Table D 1
Assumptions for 65 Degree Rise Autotransformer Ratings

Assumptions	Summer Normal/LTE/STE/DAL	Winter Normal/LTE/STE/DAL	Notes
Ambient temperature (^oC)	25/32/32/32	5/10/10/10	1
Duration in hours	8760/12/0.25/0.083	8760/4/0.25/0.083	2
Top oil temperature (^oC)	105/110/110/110	105/110/110/110	3
Conductor hot spot temperature (^oC)	120/140/150/150	120/140/150/150	3,4,5
Maximum loss of insulation life (LOL)	Excessive LOL should be avoided	Excessive LOL should be avoided	6
Maximum transformer rating (% of nameplate)	150-200	150-200	7
Minimum Preload (% of nameplate rating)	75%	75%	8
Minimum Post load (% of nameplate rating)	75%	75%	8

Notes:
1. Temperature is from PP7 Appendix A Section 2.1.
2. Duration is from PP7 Section 2.31.
3. Temperatures are from IEEE C57.91-1995 (R2004) Tables 7 and 8.
4. The hot spot temperature for normal ratings is based on IEEE C57.91-1995 (R2004) section 9.3.1 that states that transformers may be operated above 110 ^oC hot spot temperature for short periods provided that they are operated for much longer periods below 110 ^oC.
5. Conductor hot spot temperature limited to 150 degrees to prevent formation of gas bubbles in the autotransformer's insulating fluid. Refer to IEEE C57.91-1995 (2004) Annex A for more information.
6. IEEE C57.91-1995 (R2004) states in its introduction that the relationship between transformer life and transformer insulation life is a question that remains to be solved. Therefore no loss of autotransformer insulation life limit (LOL) has been specified. If LOL is calculated in their transformer-rating tool, autotransformer owners should review the calculated LOL and review the prudence of a rating that results in calculated LOL being much higher than is typical.
7. IEEE C57.91-1995 (R2004) Table 7 lists the suggested maximum transformer loading as 200% of the nameplate rating. This maximum should be not be exceeded. A maximum rating as low as 150% may be used because of manufacturer's recommendations, or the condition of the autotransformer. Autotransformer owners should ensure that autotransformer components such as tap changers; bushings and current transformers can withstand the ratings that are given to the autotransformer.
8. Flat pre-load and post-load levels of at least 75% of the autotransformer's nameplate rating or actual load cycle data should be use to calculate the ratings of an autotransformer. When pre-load or post-load levels will exceed 75% of nameplate, a higher flat pre-load and post-load level or actual load cycle data should be used.

AUTOTRANSFORMERS -FIFTY-FIVE DEGREE RISE

Transformers with fifty-five degree rise were generally replaced as a standard offering by most manufacturers about 1966. These autotransformers shall be given four load carrying ratings; normal, long time emergency (LTE), short time emergency (STE) and drastic-action limits (DAL). Autotransformer owners should use caution in assigning DAL limits higher than the STE limit because thermal models in transformer rating tools may not be designed to model very short time intervals.

The assumptions in the following table shall be used to calculate these ratings for an oil-immersed, **fifty-five degree rise** autotransformer. The rating of the autotransformer shall be calculated at 60 Hertz, nominal voltage, at the fixed tap that will be utilized when the autotransformer is in service, and with any forced cooling (fans and/or pumps) in operation. If the autotransformer has a load tap changer the rating shall be calculated at the tap that gives the most conservative rating.

Table D 2
Assumptions for 55 Degree Rise Autotransformer Ratings

Assumptions	Summer Normal/LTE/STE/DAL	Winter Normal/LTE/STE/DAL	Notes
Ambient temperature (^oC)	25/32/32/32	5/10/10/10	1
Duration in hours	8760/12/0.25/0.083	8760/4/0.25/0.083	2
Top oil temperature (^oC)	95/100/100/100	95/100/100/100	3
Conductor hot spot temperature (^oC)	105/140/150/150	105/140/150/150	3,4,5
Maximum loss of insulation life (LOL)	Excessive LOL should be avoided	Excessive LOL should be avoided	6
Maximum transformer rating (% of nameplate)	150-200%	150-200%	7
Minimum Preload (% of nameplate rating)	75%	75%	8
Minimum Post load (% of nameplate rating)	75%%	75%	8

Notes:
1. Temperature is from PP7 Appendix A Section 2.1
2. Duration is from PP7 Section 2.31.
3. Temperatures are from IEEE C57.91-1981 and C57.91-1995 (R2004).
4. The hot spot temperature for normal ratings is based on IEEE C57.91-1981 section 4.1.3 that states that transformers may be operated above 95^{o}C for short periods provided that they are operated for much longer periods below 95^{o}C. The 105^{o}C limit is derived by comparing the values in Figure 3 and Figure 4.
5. Conductor hot spot temperature limited to 150 degrees to prevent formation of gas bubbles in the autotransformer's insulating fluid. Refer to IEEE C57.91-1995 (R2004) Annex A for more information.
6. IEEE C57.91-1995 (R2004) states in its introduction that the relationship between transformer life and transformer insulation life is a question that remains to be solved. Therefore no loss of autotransformer insulation life limit (LOL) has been specified. If LOL is calculated in their transformer-rating tool,

autotransformer owners should review the calculated LOL and review the prudence of a rating that results in calculated LOL being much higher than is typical.

7. IEEE C57.91-1995 (R2004) Table 7 lists the suggested maximum transformer loading as 200% of the nameplate rating. This maximum should be not be exceeded. A maximum rating as low as 150% may be used because of manufacturer's recommendations, or the condition of the autotransformer. Autotransformer owners should ensure that autotransformer components such as tap changers; bushings and current transformers can withstand the ratings that are given to the autotransformer.
8. Flat pre-load and post-load levels of at least 75% of the autotransformer's nameplate rating or actual load cycle data should be use to calculate the ratings of an autotransformer. When pre-load or post-load levels will exceed 75% of nameplate, a higher flat pre-load and post-load level or actual load cycle data should be used.

LOAD SERVING TRANSFORMERS

Load serving transformers shall be given four load carrying ratings; normal, long time emergency (LTE), short time emergency (STE) and drastic-action limits (DAL). Since operation of load-serving transformers does not impact the high voltage transmission system, the transformer owner may determine the criteria for rating a load-serving transformer. Also the duration associated with LTE, STE and DAL limits may vary from the durations in PP7 Section 2.3.

PHASE SHIFTING TRANSFORMERS

Phase-shifting transformers shall be given four load carrying ratings; normal, long time emergency (LTE), short time emergency (STE) and drastic-action limits (DAL). These ratings shall be based on information provided by the manufacturer.

GENERATOR STEP-UP TRANSFORMERS

Generator step-up transformers shall be given a normal load carrying rating. This rating shall be based on information provided by the manufacturer and on IEEE C57.91-1995 (R2004).

4.0 REFERENCES

None

Document History

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APPENDIX E
SERIES AND SHUNT REACTIVE ELEMENTS

1.0 INTRODUCTION

The following methodology applies to series capacitors, shunt capacitors, series reactors and shunt reactors connected at voltages 69 kV or above.

2.0 STANDARDS

Ratings for series capacitors shall be calculated consistent with IEEE Standard 824-2004, "IEEE Standard for Series Capacitors in Power Systems".

Ratings for shunt capacitors shall be calculated consistent with IEEE Standard 18-2002, "IEEE Standard for Shunt Power Capacitors".

Ratings for series reactors shall be calculated consistent with IEEE Standard C57.16-1996, "IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors".

Ratings for shunt reactors shall be calculated consistent with IEEE Standard C57.21-1990 (R2004), "IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA".

3.0 APPLICATION GUIDE

SERIES CAPACITORS

The impedance, normal rating, long time emergency rating, short time emergency rating, drastic action limit, and short circuit current withstand rating of a series capacitor bank shall be the values provided by the manufacturer or calculated by the owner at 60 Hertz and nominal system voltage e.g. 69 kV, 115 kV, 230 kV or 345 kV consistent with IEEE Standard 824.

SHUNT CAPACITORS

The kVA rating of a shunt capacitor bank shall be the rating provided by the manufacturer or calculated by the owner at 60 Hertz and nominal system voltage e.g. 69 kV, 115 kV, 230 kV or 345 kV consistent with IEEE Standard 18.

SERIES REACTORS

The impedance, losses, normal rating, long time emergency rating, short time emergency rating, drastic action limit, and short circuit current withstand rating of a series reactor bank shall be the values provided by the manufacturer or calculated by the owner at 60 Hertz and nominal system voltage e.g. 69 kV, 115 kV, 230 kV or 345 kV consistent with IEEE Standard C57.21.

SHUNT REACTORS

The kVA rating, losses and impedance of a shunt reactor shall be the values provided by the manufacturer or calculated by the owner at 60 Hertz and nominal system voltage e.g. 69 kV, 115 kV, 230 kV or 345 kV. The impedance of the shunt reactor shall be measured at full voltage as described in IEEE Standard C57.21.

4.0 REFERENCES

None.

Document History

Rev. 0 App.: SDTF – 9/9/05; RC – 10/4/05; NPC – 11/4/05; ISO-NE – 11/30/05
Rev. 1 4/11/06 Editorial changes

APPENDIX F
CIRCUIT BREAKERS

1.0 INTRODUCTION

These procedures provide a “best ratings practice” to be used by equipment owners for determining normal and emergency load-current carrying capabilities of circuit breakers installed on the New England transmission system, 69kV and above.

2.0 STANDARDS

Circuit breakers are to be rated in accordance with the latest edition of ANSI/IEEE Standard C37.010-1999, “Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis” and any supplements to the standard as issued. This Standard deals with general service and temperature conditions and provides calculations of continuous and emergency load current capability, based on the methods of ANSI/IEEE Standard C37.04-1999, “Rating Structure for AC High-Voltage Circuit Breakers”. ANSI/IEEE Standard C37.04-1999 also establishes the basis for all other assigned ratings, including short circuit current which establishes the highest currents that the circuit breaker shall be required to close and latch against, to carry, and to interrupt. Both ANSI/IEEE Standards C37.010 and C37.04 apply to circuit breakers manufactured and tested in accordance with ANSI Standard C37.06-2000, “AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis – Preferred Ratings and Related Required Capabilities”, and any supplements to the standard, as issued. Circuit breakers designed, manufactured, or installed to meet other standards should be applied and assigned ratings in accordance with the manufacturer’s recommendations.

The formulae of ANSI/IEEE Standard C37.010 are to be applied as described and illustrated in Section 3.0, Application Guide.

3.0 APPLICATION GUIDE

Circuit Breaker load current ratings shall be calculated as described below at a rated power frequency of 60 Hertz and nominal voltage, e.g. 69 kV, 115 kV, 230 kV or 345 kV. Required fault interrupting capability, rated closing, latching and short-circuit current capability, reclosing capability, interrupting performance and rated transient recovery voltage shall be as specified in Sections 5.8 and 5.9 of ANSI/IEEE Standard C37.04. Current transformers that are part of the circuit breaker installation are normally selected so they will not limit the circuit breaker continuous or emergency ratings. Refer to Appendix H for current transformer rating procedures.

CONTINUOUS LOAD CURRENT CAPABILITY

ANSI/IEEE Standard C37.04-1999 establishes rated continuous current at an ambient design temperature of 40 °C, based on maximum permissible total temperature limitations within the breaker. The continuous current that can be carried at a given ambient temperature while not exceeding the permissible total temperature limitations is given by:

$$I_s = I_r \left(\frac{\theta \max - \theta a}{\theta r} \right)^{\frac{1}{1.8}} \quad (1)$$

Where:

I_s is allowable continuous current at the actual ambient temperature θa

I_r is rated continuous current at 40 °C (Nameplate Rating)

$\theta \max$ is allowable hottest-spot total temperature ($\theta \max = \theta r + 40$ °C)

θa is actual ambient temperature expected (between –30 °C and 60 °C)

θr is allowable hottest-spot temperature rise at rated current

Values of $\theta \max$ are provided in ANSI/IEEE Standard 37.04-1999, Table 1, "Limits of temperature and temperature rise for various parts and materials of circuit breakers"

EMERGENCY LOAD CURRENT CAPABILITY

Operation at a current higher than rated continuous current is permissible for short periods following operation at a current less than that permitted by the existing ambient temperature. The higher current is calculated using an increased hot-spot total temperature, $\theta \max(1)$, and temperature rise, θr, of breaker components above that used in calculating continuous current ratings. Such emergency ratings are only to be applied to outdoor circuit breakers, which must be maintained in essentially new condition. Following the emergency period, the load current must be limited to 95% of the rated continuous current (adjusted for ambient temperature) for at least 2 hours.

3.1.1 Extended Period Emergencies

Equation (1), above, can be adjusted to calculate current loadings for the periods associated with Long Time Emergency (LTE) conditions:

$$I_s = I_r \left(\frac{\theta \max(1) - \theta a}{\theta r} \right)^{\frac{1}{1.8}} \quad (2)$$

Where:

$\theta \max(1)$ is maximum allowable hottest-spot total temperature under emergency conditions. $\theta \max(1) = (\theta r + k$ °C$) + 40$ °C; use k = 15 °C for 0 to 4 hours duration (Winter LTE) and 10 °C for 4 to12 hours duration (Summer LTE) Short Time Emergencies.

3.1.2 Short Time Emergencies

A circuit breaker can be subjected to currents higher than those calculated using Equation (2), above, for shorter periods, provided that no component exceeds the limits of total temperature specified in Table 1 of ANSI/IEEE Standard 37.04-1999 by more than 15 °C. The permissible time for carrying short-time current is given by Equation (3), which can be restated to determine the permissible short-time current in terms of time and temperature (Equation (4)).

$$t_s = \tau\left[-1n\left(1-\frac{\theta\max(1)-Y-\theta a}{Y\left[\left(\frac{I_s}{I_i}\right)^{1.8}-1\right]}\right)\right] \tag{3}$$

$$I_s = I_r\left[\frac{\theta\max(1)-Ye\frac{-t_s}{\tau}-\theta_a}{(\theta\max-40)\left(1-e\frac{-t_s}{\tau}\right)}\right]^{\frac{1}{1.8}} \tag{4}$$

$$\text{Where } Y = (\theta\max-40)(I_i/Ir)^{1.8} \tag{5}$$

And:

$$\theta\max(1) = (\theta r + k\ °C) + 40\ °C;\ \text{use } k = 15\ °C \text{ for short periods } (<4 \text{ hours})$$

t_s is permissible time for carrying current I_s at ambient θa after initial current I_i
τ is the thermal time constant of the circuit breaker
I_s is short-time load current
I_i is the maximum initial current carried in the 4 hour period prior to application of I_s
Values of τ for circuit breakers rated 123 kV and above are given in ANSI/IEEE Standard 37.04-1999, Table 4, "Typical thermal time constants", as 0.5 hours.

LOADABILITY MULTIPLIERS

The following Table F1 has been prepared using the methods of ANSI/IEEE Standard C37.010-1999 and the conditions described below. The resulting loadability multipliers are used to adjust nameplate ratings to conform to the New England rating definitions consistent with the stated ambient temperatures, equipment temperatures and operational conditions.

3.1.3 Conditions:

1) The typical breaker may be an oil or oilless type with silver-to-silver contacts, ANSI Standard bushings, and Class A insulated current transformers. It is designed and rated for operation in an ambient temperature of 40 °C. The thermal time constant (τ) is 0.5 hour. (Since the 65 °C rating of the bushings and CTs are limiting, copper-to-copper contacts can be used.)

2) Use 10 °C for winter ambient and 28 °C for summer ambient temperatures as specified in Appendix A.

3) During a designated emergency overloading period the breaker owner will allow a 10°C or 15°C increase above the normal θmax for the hottest spot temperature of the applicable breaker component.

4) All components of the breaker subject to these thermal limitations shall be well maintained and in essentially new condition.

5) The allowable emergency loadings follow a period of 4 hours or more, during which the loading does not exceed 75 percent of the normal rating at the designated winter or summer ambient temperature.

Table F 1
Loadability Multipliers

Ratings	Loadability Multipliers to be Applied to Nameplate Rating	
	Winter	Summer
Normal	1.23	1.10
Emergency – 15 Minutes (STE)	1.83	1.67
Emergency – 4 hours (LTE)	1.34	-
Emergency – 12 hours (LTE)	-	1.18
Drastic Action Limit (DAL)	2.00	2.00

Note: ANSI Standard C37.010-1999 limits the loadability multiplier to a maximum value of 2.00.

EXAMPLE - LOADABILITY MULTIPLIER CALCULATIONS

Data Used:

θ max = 105 °C

θ max(1) = 105 °C + 15 °C = 120 °C (for DAL, STE and Winter LTE)

= 105 °C + 10 °C = 115 °C (for Summer LTE)

θr = 65 °C

θa = 10 °C Winter and 28 °C Summer

ts = 15 Minutes (for STE)

= 5 Minutes (for DAL)

τ = 0.5 hour = 30 minutes

e = 2.7183

1. Normal rating

$$I_s = I_r \left(\frac{\theta\max - \theta a}{\theta r}\right)^{\frac{1}{1.8}} \qquad \text{Equation (1)}$$

Winter

$$I_s = I_r \left(\frac{105-10}{65}\right)^{\frac{1}{1.8}} = 1.23\, I_r$$

Summer

$$I_s = I_r \left(\frac{105-28}{65}\right)^{\frac{1}{1.8}} = 1.10\, I_r$$

2. Long-Time Emergency rating

$$I_s = I_r \left(\frac{\theta\max(1) - \theta a}{\theta r}\right)^{\frac{1}{1.8}} \qquad \text{Equation (2)}$$

Winter (4 hours)

$$I_s = I_r \left(\frac{120-10}{65}\right)^{\frac{1}{1.8}} = 1.34\, I_r$$

Summer (12 hours)

$$I_s = I_r \left(\frac{115-28}{65}\right)^{\frac{1}{1.8}} = 1.18\, I_r$$

3. Short-Time Emergency rating

$$I_s = I_r \left[\frac{\theta \max(1) - Ye\frac{-t_s}{\tau} - \theta_a}{(\theta \max - 40)\left(1 - e\frac{-t_s}{\tau}\right)}\right]^{\frac{1}{1.8}} \qquad \text{Equation (4)}$$

And $Y = (\theta \max - 40)(I_i / Ir)\ 1.8$ Equation (5)

Winter (15 minutes)

Where $I_i = (0.75 \text{ x } 1.23\ I_r) = 0.9225\ I_r$

$$I_s = I_r \left(\frac{120 - (105-40)(\frac{0.9225 I_r}{I_r})^{1.8}(e)^{\frac{-15}{30}} - 10}{(105-40)(1-e^{\frac{-15}{30}})}\right)^{\frac{1}{1.8}}$$

$$I_s = I_r \left[\frac{120 - 34.09 - 10}{25.58}\right]^{\frac{1}{1.8}} = 1.83\, I_r$$

Summer (15 minutes)

Where $I_i = (0.75 \text{ x } 1.10_r) = 8.25\ I_r$

$$I_s = I_r \left(\frac{120 - (105-40)(\frac{0.825 I_r}{I_r})^{1.8}(e)^{-\frac{15}{30}} - 28}{25.58}\right)^{\frac{1}{1.8}}$$

$$I_s = I_r \left[\frac{120 - 27.88 - 28}{25.58}\right]^{\frac{1}{1.8}} = 1.67\, I_r$$

4. Drastic Action Limit

Use equations (4) and (5) as above

Winter (5 minutes)

Where $I_i = (0.75 \text{ x } 1.23 \ I_r) = 0.9225 \ I_r$

$$I_s = I_r \left[\frac{120 - (105-40)\left(\frac{0.9225 I_r}{I_r}\right)^{1.8} e^{-\frac{5}{30}} - 10}{(105-40)(1-e^{-\frac{5}{30}})} \right]^{\frac{1}{1.8}}$$

$$= I_r \left[\frac{120 - 47.58 - 10}{9.98} \right]^{\frac{1}{1.8}}$$

$= 2.77 \ I_r$, so use $2.0 \ I_r$

Summer (5 minutes)

Where $I_i = (0.75 \text{ x } 1.10 \ I_r) = 0.825 \ I_r$

$$I_s = I_r \left[\frac{120 - (105-40)\left(\frac{0.825 I_r}{I_r}\right)^{1.8} e^{\frac{-5}{30}}}{9.98} - 28 \right]^{\frac{1}{1.8}}$$

$$I_s = I_r \left[\frac{120 - 38.92 - 28}{9.98} \right]^{\frac{1}{1.8}}$$

$= 2.53 \ I_r$, so use $2.0 \ I_r$

Document History

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Rev. 1 4/11/06 Editorial changes

APPENDIX G
DISCONNECT SWITCHES

1.0 INTRODUCTION

These procedures provide a "best ratings practice" to be used by equipment owners for determining normal and emergency load-current carrying capabilities of disconnect switches installed on the New England transmission system, 69kV and above.

2.0 STANDARDS

Disconnect switches are to be rated in accordance with ANSI/IEEE Standard C37.30-1997, "IEEE Standard Requirements for High-Voltage Switches" and IEEE Standard C37.37-1996, "IEEE Loading Guide for AC High-Voltage Air Switches (in Excess of 1000 V). ANSI/IEEE Standard C37.30-1997 establishes limits of allowable temperature rise and provides calculations of continuous load current capability, while IEEE Standard C37.37-1996 provides continuous and emergency loadability factor curves and calculations of emergency load current capability. Many disconnect switches manufactured under ANSI Standard C37.30-1962 and prior standards contain materials that may not permit rating to temperature limitations of more recent standards; this equipment should be assigned ratings in accordance with manufacturers' recommendations.

The formulae of the above Standards are to be applied as described and illustrated in Section 3.0, Application Guide, which uses the temperature limitations for air switches established by Table 2 of ANSI/IEEE Standard C37.30-1997.

3.0 APPLICATION GUIDE

Disconnect switch load current ratings shall be calculated as described below at a rated power frequency of 60 Hertz and nominal voltage, e.g. 69 kV, 115 kV, 230 kV or 345 kV. Rated voltages and withstand and load-making current capabilities shall be as specified in Section 5 ANSI/IEEE Standard C37.30-1997.

CONTINUOUS LOAD CURRENT CAPABILITY

ANSI/IEEE Standard C37.30-1997 establishes rated continuous current at an ambient design temperature of 25 °C, based on permissible temperature limitations for the materials used in each switch part. The allowable continuous current that can be carried at a given ambient temperature while not exceeding the permissible total temperature limitations is given by:

$$I_s = I_r \left(\frac{\theta \max - \theta a}{\theta r} \right)^{0.5} \qquad \text{Equation (1)}$$

Where:

I_s is allowable continuous current at the actual ambient temperature θa

I_r is rated continuous current (Nameplate Rating)

$\theta \max$ is allowable maximum temperature of the limiting switch part

θa is actual ambient temperature expected (between –30 °C and 40 °C)

θr is the limit of observable temperature rise at rated current of the switch part

Values of $\theta \max$ and θr are provided in ANSI/IEEE Standard 37.30-1997, Table 2, "Temperature limitations for air switches". When switch test data is available and observable temperature rise is less than guaranteed (θr), all ratings may be adjusted as follows for each material class:

$$I = I_r \left(\frac{\theta r}{\theta} \right)^{0.5} \qquad \text{Equation (2)}$$

Where:

I is adjusted rated continuous current

I_r is rated continuous current at 25 °C (Nameplate Rating)

θ is test observable temperature rise at nameplate rated continuous current

θr is the limit of observable temperature rise at rated current of the switch part

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

EMERGENCY LOAD CURRENT CAPABILITY

Operation at a current higher than allowable continuous current is permissible for limited periods following at least a 2 hour period of operation at a current less than that permitted by the existing ambient temperature. The higher current is calculated using a maximum emergency temperature, $\theta \max(e)$, of the switch components that is 20 °C above the maximum temperature used in calculating continuous current ratings. Emergency ratings are to be limited to 200 percent of the rated continuous current (adjusted for specific temperature rise and ambient temperature) and are only to be applied to switches that are maintained in essentially new condition.

3.1.1 Extended Period Emergencies

Equation (1), above, can be adjusted to calculate current loadings for the periods associated with Long Time Emergency (LTE) conditions:

$$I_{e(lt)} = I_r \left(\frac{\theta \max(e) - \theta a}{\theta r} \right)^{0.5} \quad \text{Equation (3)}$$

Where:

$I_{e(lt)}$ is the permissible Long Time Emergency current, and $\theta \max(e)$ is the allowable maximum temperature under emergency conditions, being 20°C greater than the values of $\theta \max$ as provided in Table 2 of ANSI/IEEE Standard 37.30-1997.

3.2.2 Short Time Emergencies

Disconnect switches can be subjected to currents higher than those calculated using Equation (3), above, for periods not exceeding the thermal time constant of the switch, generally 30 minutes. The permissible Short-Time Emergency (STE) and Drastic Action Limit (DAL) currents can be calculated using the following Equation (4) and substituting 15 minutes or 5 minutes, respectively, for the time duration, *d*:

$$I_{e(st)} = I_r \left[\frac{1}{\theta r} \left(\frac{\theta \max_e - \theta \max}{1 - e^{-d/\tau}} + \theta \max - \theta a \right) \right]^{0.5} \quad \text{Equation (4)}$$

Where:

$I_{e(st)}$ is the permissible short time current, and
d is the appropriate time duration (15 minutes for STE and 5 minutes for DAL)
τ is the thermal time constant of the switch in minutes

Values of τ may be conservatively assumed to be 30 minutes for switches rated 1200 Amperes or greater. Contact the manufacturer for switches rated less than 1200 Amperes.

LOADABILITY MULTIPLIERS

The following Table G1 has been prepared using the methods of ANSI/IEEE Standards C37.37-1996 and C37.30-1997 for the switch and conditions described below. The resulting loadability multipliers are used to adjust nameplate ratings to conform to the New England rating definitions consistent with the stated ambient temperatures, equipment temperatures and operational conditions.

Conditions:

1) The subject disconnect switch has an Allowable Continuous Current Class (ACCC) of DO6 (consult C37.37-1996 for other switches with different material classes and ACCC designations). It has a nameplate rating of 1200 Amperes and a thermal time constant (τ) of 30 minutes.

2) Use 10 °C for winter ambient and 28 °C for summer ambient temperatures as specified in Appendix A.

3) During an emergency period, the owner will allow switch component temperatures to increase 20 °C above their normal allowable maximum temperatures.

4) All components of the switch subject to these thermal limitations shall be properly maintained to carry rated current without exceeding their limit of observable temperature rise.

5) The allowable emergency loadings follow a period of 2 hours or more, during which the loading does not exceed the normal rating at the designated winter or summer ambient temperature.

Table G 1
Loadability Multipliers

Ratings	Loadability Multipliers To be Applied to Nameplate Rating	
	Winter	Summer
Normal	1.34	1.20
Emergency – 12 hours (LTE)	-	1.38
Emergency – 4 hours (LTE)	1.47	-
Emergency – 15 Minutes (STE)	1.66	1.62
Drastic Action Limit (DAL)	2.00	2.00

NOTE: ANSI Standard C37.37-1996 limits the loadability multiplier to a maximum value of 2.00 times the rated continuous current at a given ambient temperature.

EXAMPLE - LOADABILITY MULTIPLIER CALCULATIONS

Table 2 of ANSI/IEEE Standard 37.30-1997 indicates that a switch with an ACCC designation of DO6 (as described above) has components with different temperature limitations as follows:

Switch-part Class Designation	Allowable Max Temperature °C θmax	Limit of Observable Temp Rise °C θr
DO4	90	43
FO6	105	53

Loadability multipliers are calculated for both component classes and applied as follows:

1) The switch part having the lowest θr determines loadability with ambient temperatures above 25 °C (i.e., Summer conditions); and

2) the switch part having the highest θr determines loadability with ambient temperatures below 25 °C (i.e., Winter conditions).

Data for the switch described above:

$\theta max(e) = \theta max + 20$ °C

θ_a = 10 °C Winter and 28 °C Summer

t_s = 15 Minutes (for STE)
= 5 Minutes (for DAL)

τ = 30 minutes

e = 2.7183

1) Normal rating

$$I_s = I_r \left(\frac{\theta \max - \theta a}{\theta r} \right)^{0.5} \qquad \text{Equation (1)}$$

Winter
For FO6 components:

$$I_s = I_r \left(\frac{105 - 10}{53} \right)^{0.5} = 1.34\, I_r$$

Summer
For DO4 components:

$$I_s = I_r \left(\frac{90 - 28}{43} \right)^{0.5} = 1.20\, I_r$$

2) Long-Time Emergency rating

$$I_{e(lt)} = I_r \left(\frac{\theta \max(e) - \theta a}{\theta r} \right)^{0.5} \qquad \text{Equation (3)}$$

Winter (4 hours)
For FO6 components:

$$I_{e(lt)} = I_r \left(\frac{105 + 20 - 10}{53} \right)^{0.5} = 1.47\, I_r$$

Summer (12 hours)
For DO4 components:

$$I_{e(lt)} = I_r \left(\frac{90+20-28}{43}\right)^{0.5} = 1.38\ I_r$$

3) Short-Time Emergency Rating (15 minutes)

$$I_{e(st)} = I_r \left[\frac{1}{\theta r}\left(\frac{\theta \max_e - \theta \max}{1-e^{-d/\tau}} + \theta \max - \theta a\right)\right]^{0.5} \qquad \text{Equation (4)}$$

Winter
For FO6 components:

$$I_{e(st)} = I_r \left[\frac{1}{53}\left(\frac{105+20-105}{1-e^{-15/30}} + 105 - 10\right)\right]^{0.5} = 1.66\ I_r$$

Summer
For DO4 components:

$$I_{e(st)} = I_r \left[\frac{1}{43}\left(\frac{90+20-90}{1-e^{-15/30}} + 90 - 28\right)\right]^{0.5} = 1.62\ I_r$$

4) Drastic Action Limit (5 minutes)

Use equation (4) as above. But since, from Appendix A, Drastic Action Limits are calculated based on a pre-disturbance circuit loading of 75% of the normal terminal equipment rating, the initial current (at 75% of allowable current) and its corresponding initial maximum temperature are first determined:

Winter
Initial current at 75% of Normal rating = $I_i = 0.75\ (1.34\ I_r) = 1.0\ I_r$

Corresponding initial maximum temperature $\theta \max_i$:

$$I_i = I_r \left(\frac{\theta \max_i - \theta a}{\theta r}\right)^{0.5} \qquad \text{Form of Equation (1)}$$

$$I_i/I_r = 1.0 = \left(\frac{\theta \max_i - 10}{53}\right)^{0.5} ;\ \theta \max_i = 63\ °C$$

For FO6 components:

$$I_{e(dal)} = I_r \left[\frac{1}{53}\left(\frac{105+20-63}{1-e^{-5/30}} + 63 - 10\right)\right]^{0.5} = 2.93\ I_r$$

However, emergency ratings cannot exceed 200% of rated continuous current (nameplate) rating. Thus, $I_{e(dal)}$ is limited to 2.00 I_r.

Summer

Initial current at 75% of Normal rating = I_i = 0.75 (1.20 I_r) = 0.90 I_r

Corresponding initial maximum temperature θmax_i :

$$I_i = I_r \left(\frac{\theta \max_i - \theta a}{\theta r} \right)^{0.5}$$ Form of Equation (1)

$$I_i/I_r = 0.90 = \left(\frac{\theta \max_i - 28}{43} \right)^{0.5}; \quad \theta max_i = 63\ °C$$

For DO4 components:

$$I_{e(dal)} = I_r \left[\frac{1}{43} \left(\frac{90 + 20 - 63}{1 - e^{-5/30}} + 63 - 28 \right) \right]^{0.5} = 2.81\ I_r$$

However, emergency ratings cannot exceed 200% of rated continuous current (nameplate) rating. Thus, $I_{e(dal)}$ is limited to 2.00 I_r.

4.0 REFERENCES

None

Document History

Rev. 0 App.: SDTF – 2/22/06; RC – 3/14/06; NPC –4/ 7/06; ISO-NE – 4/10/06

APPENDIX H
CURRENT TRANSFORMERS

1.0 INTRODUCTION

These procedures provide a "best ratings practice" to be used by equipment owners for determining normal and emergency load-current carrying capabilities of current transformers installed on the New England transmission system, 69kV and above.

2.0 STANDARDS

Current transformers are to be rated in accordance with ANSI/IEEE Standard C57.13-1993 (R2003), "IEEE Standard Requirements for Instrument Transformers". As this standard does not provide methods to determine emergency ratings, such rating practices were developed by the System Design Task Force and are described in the following application guide.

3.0 APPLICATION GUIDE

Current transformer ratings shall be calculated as described below at a rated power frequency of 60 Hertz and nominal voltage, e.g. 69 kV, 115 kV, 230 kV or 345 kV.

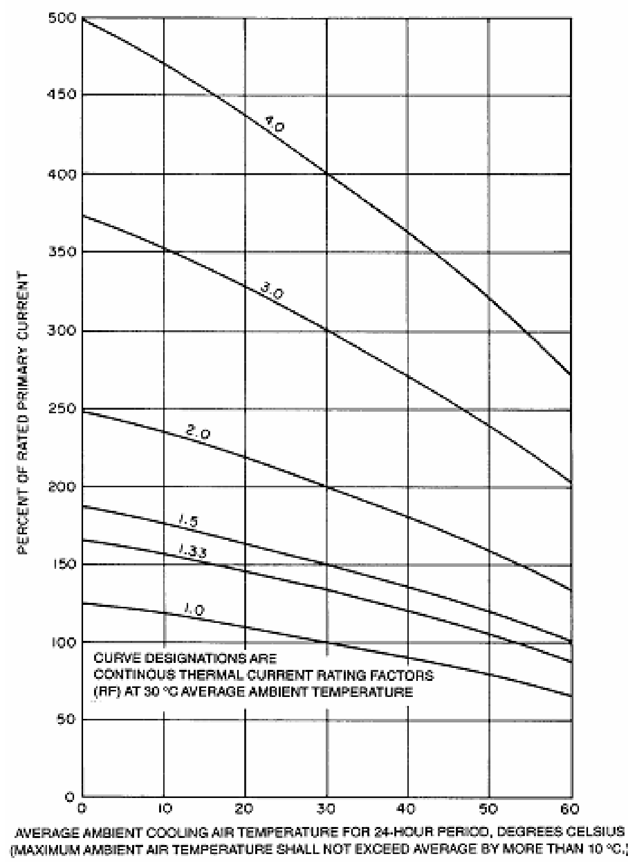
INDEPENDENT (FREE-STANDING) CURRENT TRANSFORMERS

These are current transformers that are purchased and installed separately from other equipment.

3.1.1 Normal Rating

The Normal Rating of an independent current transformer is its rated continuous current capability, which is determined by its continuous thermal current rating factor (RF; this is standard nameplate information) and the average cooling air temperature. ANSI/IEEE Standard C57.13-1993 (R2003) establishes rated continuous current for current transformers according to thermal current rating factor at a design temperature rise of 55 °C above an ambient temperature of 30 °C. Figure 1 is reproduced from the ANSI/IEEE Standard and provides the percent of rated primary current that can be carried continuously by devices of that design without causing established temperature limits to be exceeded. For example, Normal summer and winter ratings for independent current transformers with an RF of 1.5 are found to be 160% and 180% of nameplate, respectively, using the ambient temperatures specified in Appendix A of Planning Procedure No. 7.

Figure 1
55°C Rise Current Transformer Basic Loading Characteristics (In Air)[1]



3.1.2 Emergency Ratings

If emergency conditions require temporary loading beyond normal continuous current capability, the multiplying factors in Table H1 can be applied, recognizing that such loadings may produce moderate loss of life. Before this is done, revised continuous rating values should be determined using Figure 1 and the emergency ambient temperatures specified in Appendix A. The appropriate factors in Table H1 then are applied to the revised continuous rating values to determine the emergency ratings.

Table 1 was originally prepared for the NEPOOL Capacity Rating Procedures using a major manufacturer's curve of allowable overload following rated load to produce not more than a 1 percent loss of life for an oil-filled current transformer. Values for butyl-molded and compound

[1] These curves are based on the assumption that average winding temperature rise are proportional to current squared.

filled transformers were extrapolated on the basis of correspondingly shorter thermal time constants than for oil-filled units.

Table H 1
Emergency Rating Multiplying Factors

Duration of Emergency	Transformer Type		
	Oil-Filled	Butyl-Molded	Compound
0-1 ½ Hr.	1.7	1.6	1.4
4-24 Hr.	1.4	1.3	1.2

3.1.2 Loadability Multipliers

Table H2 has been prepared using the above methods and the conditions described below. The resulting loadability multipliers are used to adjust nameplate ratings to conform to the New England rating definitions consistent with the stated ambient temperatures and stated conditions.

Conditions:

(1) The current transformer is an independent, oil filled, current transformer, with thermal rating factor of 1.5.
(2) Use 5 ºC for winter and 25 ºC for summer ambient temperature to determine Normal ratings and 10 ºC for winter and 32 ºC for summer ambient temperature to determine Emergency ratings, all as specified in Appendix A of Planning Procedure No. 7.
(3) Accuracy and thermal capability of the secondary circuit and the secondary devices is satisfactory at the ratings in Table H2.
(4) The loss of life associated with the emergency ratings in Table H2 is acceptable.

Table H 2
Loadability Multipliers To Be Applied To Nameplate Rating of an Independent, Oil-Filled Current Transformer with a 1.5 Rating Factor

Ratings	Winter	Summer
Normal	1.8	1.6
Emergency – 15 Minutes (STE)	3.0	2.5
Emergency – 4 Hours (LTE)	2.5	----
Emergency – 12 Hours (LTE)	----	2.1
Drastic Action Limit (DAL)[2]	3.2	2.6

[2] A higher DAL multiplier is permitted since the current transformer thermal time constant is typically several times longer than the 5 minutes used in determining the DAL.

INTERNAL BUSHING CURRENT TRANSFORMERS

These are current transformers that use the current-carrying parts of major equipment as their primary windings and are usually purchased as integral parts of such equipment. On a multi-ratio transformer, the secondary winding is tapped.

3.1.3 Normal Continuous Capability

Most manufacturers state that internal bushing current transformers furnished with a piece of equipment have thermal capabilities that equal the capability of the equipment.

1) For a single-ratio or multi-ratio internal bushing current transformer operating at a nominal primary current rating equal to the nameplate rating of the equipment with which it is used, the current transformer shall be rated as having the same thermal capability as the equipment.

2) For a single-ratio internal bushing current transformer with a rating less than that of the equipment in which it is installed, the calculated equipment capability should be reduced by the factor:

$$\sqrt{I_{ct}/I_e}$$

Where I_{ct} is the current transformer nameplate primary current rating and I_e is the equipment nameplate current rating.

3) For a multi-ratio internal bushing current transformer with a maximum rating equal to the nameplate rating of the equipment in which it is installed, but which is operating on a reduced tap, the calculated equipment capability should be reduced by the factor:

$$\sqrt{I_t/I_n}$$

Where I_t is the reduced tap current rating, and In is the maximum current rating of the current transformer.

If information is not readily available on the continuous thermal rating factor of a bushing current transformer, the manufacturer should be consulted.

3.1.4 Emergency Loading

The emergency capability of the equipment in which the bushing current transformer is installed is first calculated. With this value as a base, apply the applicable principle outlined in Section 3.2.1, above, to determine how the emergency capability of that equipment should be modified, because of the current transformer.

EXTERNAL BUSHING CURRENT TRANSFORMERS

These are current transformers that use the current-carrying parts of major equipment as their primary windings, and are not usually purchased as integral parts of such equipment. Such current transformers are to be assigned ratings in accordance with the manufacturer's recommendations.

DEVICES CONNECTED TO CURRENT TRANSFORMER SECONDARY CIRCUITS

In all cases where current transformer secondaries may be loaded in excess of 5 amperes, a careful check should be made of the effect this will have on the devices connected in the secondary circuits, with respect to both accuracy and thermal capability. Refer to Appendix K, Current Transformer Circuit Components for accepted practices for determining ratings of such equipment.

4.0 REFERENCES

None.

Document History

Rev. 0 App.: SDTF – 10/18/05; RC – 11/1/05; NPC – 12/2/05; ISO-NE – 12/30/05

APPENDIX I
LINE TRAPS

1.0 INTRODUCTION

These procedures provide a "best ratings practice" to be used by equipment owners for determining normal and emergency load-current carrying capabilities of Line Traps installed on the New England transmission system, at 69kV and above.

2.0 STANDARDS

Line traps are to be rated according to the current version of: ANSI Standard C93.3-1995, "Requirements for Power Line Carrier Line Traps."

3.0 APPLICATION GUIDE

Line trap ratings shall be calculated using one of the methods described below at a rated power frequency of 60 Hertz and nominal voltage, e.g. 69 kV, 115 kV, 230 kV or 345 kV. Line Traps have limited overload capacity; therefore the continuous current rating should be selected to be above the winter four-hour emergency rating of the circuit in which it is installed. Furthermore, Line Traps must have a higher short-circuit capability and a continuous current rating greater than other any of the other components in the circuit (i.e. circuit breakers, disconnect switches, etc).

RATING ALGORITHMS

The rating methods used by various manufacturers are based on the following common elements:

- Ambient temperature (θ_a);
- Temperature rise, which is a function of the I^2R losses;
- A pre-determined maximum temperature acceptable for various line traps under normal and emergency conditions;
- Acceptable limits of loss of life of line trap due to the above.

NORMAL RATINGS

The primary considerations in defining the normal current rating of a line trap are ambient temperature and maximum allowable temperature rise. In the absence of a heat run tests, the manufacturer can calculate the normal current rating by a compensation method for a specific ambient temperature.

Based on the premise that hottest spot temperature rise is proportional to I^2R losses, the following equation can be used to determine a normal capability at any ambient temperature without exceeding the hottest spot design limit:

$$I_A = I_D \sqrt{\frac{T_H - T_A}{T_H - T_D}}$$

Where,

I_A = capability at ambient T_A (amperes)
I_D = nominal rating of line trap, rated continuous current (amperes)
T_H = maximum hottest spot design temperature[1] (°C)
T_A = ambient temperature[2] (°C)
T_D = design ambient temperature[3] (°C)

EMERGENCY RATINGS

When defining the emergency current rating of a line trap, for ratings of twenty-four hours and less in duration, the emergency allowable maximum temperature limits of 30°C above the normal allowable maximum temperature shall be utilized.

Operation at the specified emergency allowable maximum temperatures shall not affect the accuracy of the tuning pack in the line trap. NEMA Standard SG-11 [Reference 1] specifies that the resonant frequency shall not vary more than two percent for ambient temperatures within the range of minus 40°C to plus 40°C.

Emergency ratings for durations of less than two hours are determined based on the line trap's Thermal Time Constant, which is a function of the heat storage capacity of the line trap. Loading prior to applying less than two-hour emergency rating is assumed to be 100-percent of the normal rating for the prevailing ambient temperature.

If manufacturer data for heat run tests are not available then the Line Trap ratings can be calculated using the assumptions in Section 3.3.1 and Table I1. If the Line Trap manufacturer is known, Line Trap ratings can be calculated using the assumptions in Section 3.3.2, referring to Table I3 to determine the Line Trap identification number and then Table I4 to determine the ratings.

[1] Hottest spot temperature rise from ANSI Standard C93.3-1995 Table 6, plus 40°C design ambient, if manufactured to ANSI standards.
[2] As defined in Appendix A, section 2.1.
[3] If manufactured to ANSI standards, 40°C

3.1.1 Ratings Using Multiplying Factors

The methodology identified in this section is based on information provided by leading manufacturers of Line Traps and is documented in the Report of the Ad Hoc Line Trap Rating Procedure Working Group of the System Design Task Force [Reference 1].

Table I 1
Loadability Multipliers to be Applied to Nameplate Rating

Ratings	Winter	Summer
Normal	1.13	1.05
Emergency – 12 Hours	-	1.21
Emergency – 4 Hours	1.30	-
Emergency – 15 Minutes	1.69	1.58
D.A.L.	1.86	1.73

Where,

- The Line Traps meet the design requirements of ANSI Standard C93.3-1995.
- The maximum winter ambient is 10°C, and the maximum summer ambient is 28°C.
- The Line Trap is designed for a hottest spot temperature rise of 110°C over a 40°C ambient.[4] (Insulation Temperature Index of 130)
- Normal ratings are determined by using the methods introduced in Section 3.2 above
- Emergency ratings are found by applying the multiplying factors of Table I2 below to the Normal ratings

Table I 2
Multipliers to be Applied to Normal rating to Determine Emergency Ratings

Duration of Emergency	Multiplying Factor
4-48 Hours	1.15
15 Minutes	1.50
D.A.L.	1.65

3.1.2 Ratings Using Identification Numbers

Line Trap ratings shall be calculated by referring to Table I3 to determine the Line Trap identification number and then Table I4 to determine the ratings.

[4] Taken from ANSI Standard C93.3-1995, Table 6

Table I 3
Line Trap Identification

Line Trap Identification	Line Trap Identifying Number & Nomograph Number	Limit of Observable Temperature Rise at Rated Current θ_r	Normal Allowable Maximum Temperature $\theta \max_n$	Emergency Allowable Maximum Temperature $(\theta \max_e 2)$ Rating Durations: Greater than 24 Hours $(\theta \max_e 2)$	Emergency Allowable Maximum Temperature $(\theta \max_e 2)$ Rating Durations: 24 Hours or Less $(\theta \max_e 2)$
		ºC	ºC	ºC	ºC
General Electric Type CF (1954-1965)	1	90	130	145	160
Westinghouse Type M	2	110	150	165	180
Trench Type L	3	110	150	170	190
General Electric Type CF (after 1965)	4	115	155	170	190

Table I 4
Percent Of Adjusted Rated Continuous Current[5]

Line Trap Identifying Number[6]	1		2		3		4	
Rating Duration	**W**[7]	**S**[8]	**W**[7]	**S**[8]	**W**[7]	**S**[8]	**W**[7]	**S**[8]
Normal	115	105	112	104	112	104	112	104
Emergency greater than 24 Hrs	123	113	119	110	120	110	118	110
Emergency 2 to 24 Hrs	130	118	125	116	129	119	126	117
Emergency 15 Minutes	149	141	142	135	150	144	144	138

ADDITIONAL FORMULAS

ANSI C93.3-1995 Table A1 indicates short time overload capabilities for line traps. The 15-minute capabilities according to Table I1 of this procedure are more generous than those arrived by the calculation methods described in Section 3.3.2 of this procedure. In contrast, the 4-hour and 12-hour capabilities in Table I1 are more conservative than those arrived by the calculation methods described in section 3.3.2 of this procedure.

[5] Percent of rated continuous current if heat run test data is available
[6] Refer to Table I3 for line trap identifying number
[7] Winter ambient temperature is 10°C for all rating durations
[8] Summer ambient temperatures are 30°C for rating durations greater than 24 hours and 35°C for rating durations 24 hours and less

3.1.3 Correction of Rated Continuous Current

When a line trap test temperature rise is not provided by the manufacturer, the ratings may be adjusted as follows:

$$I = Ir(\theta_r / \theta)^{1/n}$$

Where,

I = Adjusted rated continuous current corrected to the maximum temperature rise allowed for a normal rating in the event the temperature rise tested at the factory is less than the maximum allowed temperature rise.

Ir = Rated continuous current (nameplate rating) that a line trap can carry continuously without exceeding its limits of observable temperature rise. This value is given by the manufacturer.

θ = The Steady-state temperature-rise above ambient temperature when tested at rated continuous current (nameplate rating) in the factory.

θ_r = Limit of observable temperature rise at rated continuous current corresponding to I.

n = 1.8 (A factor or constant)

For subsequent calculations, the adjusted rated continuous current should be used when test data are available.

3.1.4 Calculation of Current Ratings for Durations Greater Than 2 Hours

Winter and summer ratings for durations greater than 2 hours can be determined as follows:

$$I_a = I(\theta \max_{\max h} - \theta_a / \theta_r)^{1/n}$$

Where,

I = Adjusted rated current (amperes)
I_a = Current rating to be calculated for a specific duration (amperes)
θ_a = Ambient temperature (°C)
$\theta \max h$ = Allowable maximum hottest spot temperature[9] (°C)
θr = Allowable temperature rise at rated current (°C)

[9] 40°C plus applicable maximum temperature rise, which varies based on expected duration

3.1.5 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:

$$\mathrm{I}_{e2} = I\left[I/\theta_r\left[\theta\max_{e2} - \theta\max_n/(I - e - t/\tau) + \theta\max_n - \theta_0\right]\right]^{1/n}$$

Where,

I_{e2} = Emergency rating of less than 2 hours (amperes)
t = Rating duration (minutes)
θ_0 = Winter minimum temperature (°C)
$\theta\max_n$ = Summer maximum Temperature (°C)
τ = Thermal time constant of a line trap[10] (minutes)

4.0 REFERENCES

1) NEMA Standard SG-11 (1955) "Coupling Capacitor Potential Devices and Line Traps"

2) Report of the Ad Hoc Line Trap Rating Procedure Working Group of the System Design Task Force, June 1990

Document History

Rev. 0 App.: SDTF – 10/18/05; RC – 11/1/05; NPC – 12/2/05; ISO-NE – 12/30/05
Rev. 1 4/11/06 Editorial and format changes

[10] The thermal time constant of a line trap preferably should be obtained from the manufacturer's test data or it can be conservatively used as 30-minutes. The length of time required for the temperature to change from the initial value to the ultimate value if the initial rate of change was continued until the ultimate temperature was reached.

APPENDIX J
SUBSTATION BUSES

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1.0 INTRODUCTION

These procedures provide a "best rating practice" to be used by equipment owners for determining normal and emergency load-current capabilities of buses on the New England transmission system, 69 kV and above.

2.0 STANDARDS

2.1 SUBSTATION BUSES

Bare, outdoor, non-enclosed buses and cables of circular cross section will be rated in accordance with the following:

1. IEEE Standard 605-1998, "Guide for Design of Substation Rigid Bus Structures" is a primary reference for ampacity ratings for tubular bus and bare circular wire cables /conductors used in substations.
2. IEEE Standard 738-1993, "Guide for Calculating the Current-Temperature relationship of Bare Overhead Conductors".
3. Methods outlined in Sections 6-2 through 6-9 of the "*Alcoa Conductor Engineering Handbook*, 1957."

Buses and cables which do not have a circular cross section, or which are forced cooled, enclosed, indoors, or insulation covered are to be assigned ratings by their owners, in accordance with manufacturer recommendations.

3.0 APPLICATION GUIDE

3.1 RIGID SUBSTATION BUSES

The ampacity rating calculations of rigid, Aluminum or Copper, outdoor, exposed non-enclosed buses and conductors involves parameters such as ambient temperature, maximum conductor temperature limitations, wind speed, wind direction, solar gain, emissivity, and absorptivity. The maximum temperature at which the bus can operate is limited by loss of strength (loss of life) due to temperature cycles and mechanical movement due to expansion. Rigid substation bus ratings shall be assigned in accordance with IEEE Standard 605-1998.

3.1.1 Ambient Temperature

Ratings should be based on the ambient conditions as defined in Appendix A to this procedure.

3.1.2 Maximum Allowable Temperature

The maximum temperature limit at which the rigid bus is permitted to operate should be determined with consideration of the following:

- Loss of life over a period of rigid bus life
- Maximum allowable movement due to expansion and contraction.
- Unbalanced loading effects due to paralleling of buses

The maximum temperature at which the bus can operate varies with the rigid bus material (e.g. copper, aluminum and its alloys) and is best determined by consulting manufacturer recommendations.

3.1.3 Wind Speed and Wind Direction

The wind direction and wind speed are integral components of the calculation of Rigid Substation Bus thermal ratings. Wind direction perpendicular to the conductor (a 90-degree cross wind) shall be utilized. With regard to wind speed, IEEE Standard 605-1998 includes the mathematical models to be used to calculate Substation Rigid Bus thermal ratings, where a wind speed of 2 fps is used. However, for New England, a wind speed up to 3 fps shall be allowed.

3.2 FLEXIBLE SUBSTATION BUSES

Flexible substation bus ratings shall be assigned in accordance with IEEE Standard 738-1993. IEEE Standard 738-1993, and the included rating program RATEIEEE, address both steady-state and transient ratings. Since the thermal time constant of a flexible bus conductor is generally greater than 15 minutes, the steady-state calculation is to be applied in determining Normal and Long-Time Emergency ratings. The transient calculation is applied in determining Short-Time Emergency ratings and Drastic Action Limits. In all cases, adequate clearances must be maintained with flexible bus conductor loadings at the rated values.

3.2.1 Ambient Temperature

Ratings should be based on the ambient conditions as defined in Appendix A to this procedure.

3.2.2 Maximum Allowable Temperature

The maximum temperature limit at which the flexible bus is permitted to operate should be determined with consideration of the following:

- The maximum loss of strength due to annealing
- Loss of life over a period of flexible bus life
- Unbalanced loading effects due to paralleling of buses

The maximum temperature at which the bus can operate varies with the flexible bus material (e.g. copper, aluminum and its alloys) and is best determined by consulting manufacturer recommendations.

3.2.3 Wind Speed and Wind Direction

The wind direction and wind speed are integral components of the calculation of flexible substation bus thermal ratings. Wind direction perpendicular to the conductor (a 90-degree cross wind) shall be used and a wind speed up to 3 fps shall be allowed.

3.3 CONNECTORS

The loadability of connectors and splices must meet or exceed the loadability of the conductors for which they are sized. The individual owners are to confirm, with the manufacturers involved, that the connectors and splices, when installed in accordance with the methods actually used in each case, may be loaded safely to the proposed line terminal ratings, without exceeding the maximum allowable temperature limits of the conductors.

4.0 REFERENCES

1) Anderson Electric Corporation, *Technical Data: A Reference for the Electrical Power Industry*. Leeds, Ala.: Anderson Electric Corporation, 1964.

2) The Aluminum Association, *Aluminum Electrical Conductor Handbook.* New York: The Aluminum Association, 1971.

3) NEMA Standard Publication No. CC-1-2005, "Electric Power Connection for Substations". This publication provides "standard test methods and performance requirements for the electrical and mechanical characteristics of connectors under normal operating conditions."

4) ANSI Standard C119.4-2003, "Electric Connectors – Connectors for Use Between Aluminum and Aluminum or Aluminum to Copper Bare Overhead Connectors". "This standard establishes the current-carrying and mechanical performance requirements for connectors used for continuous service on conductors under normal operating conditions."

Document History

Rev. 0 App.: SDTF – 4/3/06; RC – 4/4/06; ISO-NE – 5/8/06

APPENDIX K
CURRENT TRANSFORMER CIRCUIT COMPONENTS

1.0 INTRODUCTION

These procedures provide a "best ratings practice" to be used by equipment owners for determining normal and emergency load-current carrying capabilities of current transformer circuit components, including relay protective devices, installed on the New England transmission system, at 69kV and above.

2.0 STANDARDS

None

3.0 APPLICATION GUIDE

Current Transformer (CT) circuit component ratings shall be determined as described below at a rated power frequency of 60 Hertz.

While the thermal capabilities of relays vary by manufacturer and application, the relays and associated equipment conform to the applicable ANSI/IEEE and IEC Standards noted in References 1, 2, 3 and 4. Therefore, ratings shall be based on information provided by the manufacturer. Furthermore, the individual owners are to confirm, with the manufacturers involved, that the associated current transformer circuit components (i.e. meters, transducers, relays, etc…) are not the limiting component of the transmission circuit.

Guidance on the thermal capabilities of older relays and other connected equipment used in CT secondary circuits is provided in Attachment 4 of this document [Reference 5]. However, these lists do not include all possible or more recently available current transformer circuit components.

4.0 REFERENCES

1) ANSI/IEEE Standard C57.13-1993 (R2003), "IEEE Standard Requirements for Instrument Transformers"

2) ANSI/IEEE C37.90-1989, "Standard for Relays and Relay Systems Associated with Electric Power Apparatus"

3) International Electrotechnical Commission (IEC) 60255, Protective Relay Standards

4) ANSI C2-2002, *National Electrical Safety Code*

5) Relay Working Group of the System Design Task Force Report, "Thermal Capabilities of Components in the Current Circuit Starting at the CT Terminals", Revised July 1980, Corrected October 2004 and included as Attachment 4 of this document.

Document History

Rev. 0 App.: SDTF – 4/3/06; RC – 4/4/06; ISO-NE – 5/8/06

APPENDIX L
VAR COMPENSATORS

1.0 INTRODUCTION

The following methodology applies to VAR compensators such as Static Synchronous Compensator (Statcoms), Static Var Compensators (SVCs), Dynamic Volt-Ampere Reactive (D-VAR), and synchronous condensers connected at voltages 69 kV or above.

2.0 STANDARDS

None.

3.0 APPLICATION GUIDE

The kVA rating of a VAR compensator shall be the rating provided by the manufacturer as calculated at 60 Hertz and nominal system voltage e.g. 69 kV, 115 kV, 230 kV or 345 kV.

4.0 REFERENCES

None.

<u>Document History</u>

Rev. 0 App.: SDTF – 10/18/05; RC – 11/1/05; NPC – 12/2/05; ISO-NE – 12/30/05

APPENDIX M
HVDC SYSTEMS

1.0 INTRODUCTION

The following methodology applies to HVDC converters and associated transmission systems connected to the New England transmission system at 69 kV or above.

2.0 STANDARDS

None.

3.0 APPLICATION GUIDE

The rating of an HVDC system (which includes converters, converter transformers, conductors and associated equipment such as filters, switches and busses) is one aspect of its performance protocol, being determined by the facility's specifications, design and operation. Accordingly, ratings shall be based on information provided by the manufacturer.

The rating to be assigned is the Maximum Continuous Capacity, which is the maximum capacity (MW), excluding the added capacity available through means of redundant equipment, for which continuous operation under normal conditions is possible [Reference 1]. Since power flows through an HVDC system are continuously controlled, the LTE, STE and DAL ratings are the same as the Maximum Continuous Capacity.

4.0 REFERENCES

1) CIGRE Working Group 14-04 Report, Protocol for Reporting the Operational Performance of HVDC Transmission Systems, included as Annex B (Informative) of IEEE Standard 1240-2000, IEEE Guide for the Evaluation of the Reliability of HVDC Converter Stations

Document History

Rev. 0 App.: SDTF – 3/21/06; RC – 4/4/06; ISO-NE – 5/8/06

ATTACHMENT 1

ACCEPTABLE ALTERNATIVE RATING PRACTICES

These documents can be found at
http://www.iso-ne.com/rules_proceds/isone_plan/

ATTACHMENT 2

AMBIENT TEMPERATURES AND WIND VELOCITY FOR RATING CALCULATIONS

This document can be found at
http://www.iso-ne.com/rules_proceds/isone_plan/

ATTACHMENT 3

ANALYSIS OF WIND-TEMPERATURE DATA AND EFFECT ON CURRENT-CARRYING CAPACITY OF OVERHEAD CONDUCTORS

This document can be found at
http://www.iso-ne.com/rules_proceds/isone_plan/

ATTACHMENT 4

CAPACITY RATING PROCEDURES

This document can be found at
http://www.iso-ne.com/rules_proceds/isone_plan/

ATTACHMENT 5

REPORT OF THE LINE TRAP RATING PROCEDURE WORKING GROUP OF THE SYSTEM DESIGN TASK FORCE

This document can be found at
http://www.iso-ne.com/rules_proceds/isone_plan/

nationalgrid

United States Operations

Transmission Group Procedure

TGP26

National Grid Transmission Facility Ratings

Authorized by

Paul R. Renaud Date: 5/27/10

Paul Renaud, Vice President,
Transmission Asset Management,
National Grid USA Service Company, Inc.

National Grid USA Service Company, Inc.
40 Sylvan Road
Waltham, MA 02451-1120

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Table of Contents

1.0 Change Control

Version	Date	Modification	Author(s)	Reviews and Approvals by
Issue 1	May 30, 2007	Initial Document	Will Houston John W. Martin	David Wright, Vice President, Transmission Asset Management
Issue 2	September 14, 2007	Address NERC FAC-008, -009 requirements	Joseph J. Hipius	David Wright, Vice President, Transmission Asset Management
Issue 3	May 10, 2010	Added 'Communication and Scheduling of Rating Change Notifications' in Section 3 with a reference to the new section in the scope. Revised paragraph 3.2 to provide more detail. Revised 3.5 (previously 3.4) to refer to ISO & control centers & separate out notice to joint owners. Added new address.	Dana Walters	Paul Renaud, Vice President, Transmission Asset Management

This document should be reviewed at least every two years.

2.0 Scope

National Grid Transmission Planning is responsible for developing the facility ratings that are used to operate the National Grid Transmission System.

The New England and New York Control Centers incorporate facility ratings into the Energy Management System (EMS) for real-time monitoring and operation of the Transmission System. In addition, facility ratings are used in power flow and contingency analysis applications.

Two procedures applying to transmission facility ratings are described in this TGP:

The *Notification Procedure* defines the process for notifying the New England and New York Control Centers and the appropriate Independent System Operators (ISO) of facility rating changes developed by National Grid Transmission Planning. This applies to new facility ratings and changes to current facility ratings. Included in the Notification Procedure is a description of how the need for rating changes are communicated and scheduled.

The *Request and Review Procedure* describes the process for responding when requests for ratings methodology are received, and for when comments on the ratings methodology are received.

The procedures described in this TGP are designed to fulfill the needs of our system operators and the requirements of NERC standards FAC-008 and FAC-009.

3.0 Notification Procedure

3.1. Facility rating changes will be posted to the appropriate Thermal Ratings Database by Transmission Planning.

3.2. Transmission Planning will notify the appropriate ISO (ISO-NE or NYISO) of new/revised facility ratings with an identification of the most limiting elements (NE to use NX-9 forms database located on the Transmission Planning shared drive, following procedures in OP-16; NY to follow Technical Bulletin 160).

3.3. All owners of jointly-owned transmission facilities should be notified of any rating changes no later than the time that the applicable ISO is notified.

3.4. Transmission Planning will notify the New England and New York Control Centers of new/revised facility ratings by email notification to the “Facility Ratings” email distribution, attaching a file containing copies of the revision (NX-9 forms for NE).

3.5. By providing notice to the ISO’s and Control Centers, Transmission Planning will be effectively providing facility ratings to the applicable Reliability Coordinators, Planning Coordinators, Transmission Planners, and Transmission Operators[1] consistent with NERC requirements.

New England Control Center

3.6. The Control Center Supervisor will submit the facility ratings changes to EMS support using the Display/Comments/Rating Change Request form (Appendix A) and update the Ratings Binder in the Control Room.

3.7. EMS support staff will make the required changes to the EMS and notify the New England Control Center Supervisor upon completion.

3.8. The New England Control Center Supervisor will verify the changes have been incorporated into the EMS.

New York Control Center

3.9. Transmission Planning shall notify the NY Control Center of new or revised ratings via e-mail.

[1] These entities refer to organizations registered with NERC in these roles.

3.10. Prior to using the revised rating, a review will be performed against the old rating to check that the revision is within reason. If clarification or changes are required, Transmission Planning should be notified.

3.11. The New York Control Center will post the changes to the Thermal Ratings “Red” Books, change EMS and the Security Model as necessary.

3.12. The changes will be tracked on the attached log (Appendix B). The logs will be filed at the New York Control Center once the change is complete.

Communication and Scheduling of Rating Change Notifications

3.13. Transmission Planning will use the Strategy and Sanction paper process to initially communicate when there is a need for updating facility ratings with any new strategies.

3.14. Transmission Planning and Program Management will work together to track project progress and to make timely submissions to the ISOs.

3.15. The schedule for when information is required to be submitted to the ISOs varies with the ISO and the type of change. This information is detailed in the supporting document “Process for Identification and Scheduling of Rating Changes”.

4.0 Request and Review Procedure

4.1. When requests for National Grid’s facility ratings methodology are received from Reliability Coordinators, Transmission Operators, Transmission Planners, and Planning Coordinators that have responsibility for the areas in which the facilities are located are received, Transmission Planning shall provide the ratings methodology to the requesting entity within 15 business days of the receipt of the request.

4.2. When a Reliability Coordinator, Transmission Operator, Transmission Planner, or Planning Coordinator provides written comments on its technical review of National Grid’s facilities ratings methodology, Transmission Planning shall provide a written response to the commenting entity within 45 calendar days of receipt of those comments.

4.2.1. Transmission Planning shall obtain the input and assistance of any engineering groups necessary and coordinate the development of the response.

4.2.2. The response shall indicate whether a change will be made to National Grid’s facilities rating methodology, and, if no change will be made to the methodology, the reason why.

4.3. When a Reliability Coordinator, Transmission Operator, Transmission Planner, or Planning Coordinator requests identification of the most limiting equipment on a facility, and how the ratings for that facility would change if that most limiting equipment were not considered, Transmission Planning shall provide the requested information within 30 calendar days.

4.4. Transmission Planning shall maintain records of all requests and comments received under paragraphs 4.1, 4.2 and 4.3, including the dates received, the dates of the responses, and the responses provided.

5.0 Retention Requirements

5.1. Transmission Planning shall maintain records of all ratings changes and notifications made under section 3.0 of this procedure and retain this information for, which ever is greater, a minimum of three years from the date of notification or a minimum of one year after a project is completed.

5.2. Transmission Planning shall maintain records of all requests and comments received under paragraphs 4.1, 4.2 and 4.3, including the dates received, the dates of the responses, and the responses provided, and shall retain this information for, which ever is greater, a minimum of three years from the date of each response or a minimum of one year after a project is completed.

6.0 Renewal Frequency

This procedure will be reviewed on a two-year frequency or whenever relevant NERC FAC standards are revised, whichever occurs first.

Appendix A

Display/Comment/Rating Change Request

Routine: _____ **Priority:** ______

District: Central _____ Western_____ North Shore_____ Merrimack_____ Granite_____

Coastal ________ Capital ________ South Shore _______ Southeast _______

LCC: NSTAR _______ CONVEX ________ NH _________ VELCO ________

Display Name:

____

Type of Change:

____

Are Comments Page Changed needed? **Yes** _____________ **No**______________

Change Initiated By:

____

Routing:		**Initials**	**Date**
	Coordinator	__________	___________
	Supervisor	__________	___________
	DB/Display	__________	___________
	Designer – Smallworld/Print Comments	__________	___________
	Installation	__________	___________
	Verification	__________	___________
	Copy to Dist. Eng.	__________	___________

Log#: ___________

Comments:

____

____

____

Appendix B

THERMAL RATINGS CHANGE LOG

Line____

Date______________________________________

Description of Change____

Ratings have been reviewed and accepted by the Transmission Control Center.

Reviewed by: ___________________________________Date_________________

Red Book Changed.

Performed by: ___________________________________Date_________________

Security Model Changed.

Performed by: ___________________________________Date_________________

EMS Thermal Ratings Changed.

Performed by: ___________________________________Date_________________

Confidential Information (including Privileged and Critical Energy Infrastructure Information)
Has Been Removed

NPCC, Inc.
NORTHEAST POWER COORDINATING COUNCIL, INC.
1040 AVE OF THE AMERICAS, NEW YORK, NY 10018 TELEPHONE (212) 840-1070 FAX (212) 302-2782

Compliance Audit Report
Public Version

The Narragansett Electric Company
NERC ID# NCR07218

Confidential Information (including Privileged and Critical Energy Infrastructure Information) Has Been Removed

Date of Audit: April 11 to May 12, 2011

Confidential Information (including Privileged and Critical Energy Infrastructure Information)
Has Been Removed

TABLE OF CONTENTS

Executive Summary

A compliance audit of The Narragansett Electric Company (NECO), NERC ID # - NCR07218 was conducted from April 11, 2011 to May 12, 2011. At the time of the audit, NECO was registered for the TO, DP, LSE and PSE functions.

The audit team evaluated NECO for compliance with 27 requirements in the 2011 NERC Compliance Monitoring and Enforcement Program (CMEP). The audit team assessed compliance with the NERC Reliability Standards and applicable Regional Reliability Standards for the period of June 18, 2007 to April 11, 2011. NECO submitted information and documentation for the audit team's evaluation of compliance with requirements. The audit team reviewed and evaluated all information provided by NECO to assess compliance with standards applicable to NECO at this time.

Based on the information and documentation provided by NECO, the audit team found NECO to have no findings of non-compliance with 20 applicable requirements. The audit team determined that 7 requirements were not applicable to NECO. The audit team identified no Possible Violation(s). There were no ongoing or recently completed mitigation plans and therefore none were reviewed by the audit team.

Any Possible Violations were processed through the NERC and NPCC CMEP. The following is a link to the general NOP page located on the NERC public website: http://www.nerc.com/filez/enforcement/index.html

The NPCC audit team lead certifies that the audit team adhered to all applicable requirements of the NERC Rules of Procedure (ROP) and Compliance Monitoring and Enforcement Program (CMEP).[1]

Audit Process

The compliance audit process steps are detailed in the NPCC CMEP. The NPCC CMEP generally conforms to the United States Government Accountability Office Government Auditing Standards and other generally accepted audit practices.

[1] This statement replaces the Regional Entity Self-Certification process.

Objectives

All Registered Entities are subject to an audit for compliance with all reliability standards applicable to the functions for which the Registered Entity is registered.[2] The audit objectives are to:

- Review compliance with the requirements of reliability standards that are applicable to NECO, based on the functions that NECO is registered to perform;
- Validate compliance with applicable reliability standards from the NERC 2011 Implementation Plan list of actively monitored standards and additional NERC Reliability Standards selected by NPCC;
- Validate compliance with applicable regional standards from the NPCC 2011 Implementation Plan list of actively monitored standards;
- Validate evidence of self-reported violations and previous self-certifications;
- Observe and document NECO's compliance program and culture;
- Review the status of mitigation plans.

Scope

The scope of the compliance audit included the NERC Reliability Standards from the NPCC 2011 Implementation Plan. In addition, this audit included a review of mitigation plans or remedial action directives which have been completed or pending in the year of the compliance audit.

At the time of the audit, NECO was registered for the functions of TO, DP, LSE and PSE. The audit team evaluated NECO for compliance during the period of June 18, 2007 to April 11, 2011.

Confidentiality and Conflict of Interest

Confidentiality and conflict of interest of the audit team are governed under the NPCC Delegation Agreement with NERC and Section 1500 of the NERC Rules of Procedure. NECO was informed of NPCC's obligations and responsibilities under the agreement and procedures. The work history for each audit team member was provided to NECO. NECO was given an opportunity to object to an audit team member's participation on the basis of a possible conflict of interest or the existence of other circumstances that could interfere with an audit team member's impartial performance of duties. NECO had not submitted any objections by the stated fifteen day objection due date and accepted the audit team member participants without objection. There have been no denials of or access limitations placed upon this audit team by NECO.

[2] North American Electric Reliability Corporation CMEP, paragraph 3.1, Compliance Audits

Methodology

The audit team reviewed the information, data, and evidence submitted by NECO and assessed compliance with requirements of the applicable reliability standards. Submittal of information and data were sent to NPCC 30 days before the scheduled date of the entity review. Additional information relevant to the audit could be submitted until the conclusion of the exit briefing. After that date, only data or information which was relevant to the content of the report or its finding can be submitted upon agreement by the audit team lead.

The audit team requested and received additional information and sought clarification from subject matter experts during the audit.

The audit team reviewed documentation provided by NECO. Data, information and evidence submitted in the form of policies, procedures, e-mails, logs, studies, data sheets, etc. which were validated, substantiated and cross-checked for accuracy as appropriate. Requirements which required a sampling to be conducted were developed based upon the significance of the sampling to the reliability of the bulk electric system (BES).

Findings were based on the audit team's knowledge of the BES, the NERC Reliability Standards and their professional judgment. All findings were developed based upon the consensus of the audit team.

Company Profile

The Narragansett Electric Company is a wholly owned subsidiary of National Grid USA. NECO serves 465,000 customers in 38 communities in Rhode Island. NECO's peak load was 1,825 MW in 2010. NECO has 47 Miles of 345 kV transmission lines, 259 miles of 115 kV transmission lines as well as 14 miles of 69 kV transmission lines. The New England Control Center/ REMVEC is a central dispatch office and satellite dispatching center providing security services in support of ISO-NE and on behalf of National Grid affiliates, with operations in Vermont, New Hampshire, Massachusetts and Rhode Island, twenty-nine municipals and Fitchburg Gas & Electric (FG&E). The New England Control Center/REMVEC's staff and facilities are provided, operated, and managed by National Grid USA Service Company. In addition to the services it provides in support of the ISO, the Control Center/REMVEC performs services on behalf of Narragansett Electric Company ("NEC"), under an agreement called the "REMVEC II agreement". Some of the services the New England Control Center/REMVEC performs on behalf of NEC are services that sustain NEC's compliance with NERC Reliability Standards.

Audit Participants

The following is a listing of all personnel from the Audit Team and NECO who were present during the meetings or interviews.

Confidential Information (including Privileged and Critical Energy Infrastructure Information) Has Been Removed

Audit Team Participants

Title	Entity
Lead Auditor	NPCC
Auditor	NPCC
Auditor	NPCC
Audit Manager	NPCC

NECO Audit Participants

Title	Entity
Director – Reliability Compliance	NGRID
Lead Auditor	NGRID
Manager, PTO	NGRID
Counsel	NGRID
Manager, Protection Standards	NGRID
Sr. Coordinator	NGRID

Audit Results

The audit team evaluated NECO for compliance with 27 requirements in the 2011 NERC Compliance Monitoring and Enforcement Program (CMEP). The audit reviewed NERC Reliability Standards for the period of June 18, 2007 to April 11, 2011. NECO submitted information and documentation for the audit team's evaluation of compliance with requirements. The audit team reviewed and evaluated all information provided by NECO to assess compliance with standards applicable to NECO at this time.

Based on the information and documentation provided by NECO, the audit team found NECO to have no findings of non-compliance with 20 applicable requirements. The audit team determined that 7 requirements were not applicable to NECO. The audit team identified no Possible Violation(s).

Findings

The following table details the findings for compliance for the scope identified for this audit.

Reliability Standard	Requirement	Finding
CIP-001-1	R1.	No Finding
CIP-001-1	R2.	No Finding
CIP-001-1	R3.	No Finding
CIP-001-1	R4.	No Finding
COM-001-1.1	R6	Not Applicable
IRO-004-1	R4.	No Finding

Confidential Information (including Privileged and Critical Energy Infrastructure Information)
Has Been Removed

IRO-005-2	R13.	No Finding
FAC-003-1	R1	No Finding
FAC-003-1	R2	No Finding
FAC-008-1	R1	No Finding
FAC-008-1	R2	No Finding
FAC-009-1	R1	No Finding
FAC-009-1	R2	No Finding
MOD-004-1	R3	Not Applicable
MOD-004-1	R10	Not Applicable
PRC-004-1	R2.	No Finding
PRC-005-1	R1.	No Finding
PRC-005-1	R2.	No Finding
PRC-008-0	R1	No Finding
PRC-008-0	R2	No Finding
PRC-011-0	R1	Not Applicable
PRC-017-0	R1	Not Applicable
PRC-017-0	R2	Not Applicable
PRC-023-1	R1	No Finding
PRC-023-1	R2	Not Applicable
TOP-002-2a	R3.	No Finding
TOP-002-2a	R18.	No Finding

Compliance Culture

NECO's compliance culture was reviewed by the audit team. National Grid has a comprehensive FERC compliance program. This program addresses compliance for all its regulated subsidiaries including New England Power, Narragansett Electric, Massachusetts Electric, and Granite State Electric and includes compliance with NERC Reliability Standards.

National Grid plc ("NGPLC") and National Grid USA ("NGUSA") (collectively, "National Grid" or "the Company") operates its compliance program through a variety of centralized, enterprise-wide processes and procedures in coordination with employees within various parts of the global business.

During all contact, NGRID and NECO staff was professional in their approach to compliance and understood the importance of the compliance and its role in maintaining reliability and security. For those that participated in the audit, it was clear that all were committed to both compliance and the improved reliability and security that a strong compliance program leads to.

Additional information pertaining to the compliance culture of NECO can be found in the Internal Compliance Survey.

A. Introduction

1. **Title:** **Facility Ratings Methodology**
2. **Number:** FAC-008-1
3. **Purpose:** To ensure that Facility Ratings used in the reliable planning and operation of the Bulk Electric System (BES) are determined based on an established methodology or methodologies.
4. **Applicability**
   - **4.1.** Transmission Owner
   - **4.2.** Generator Owner
5. **Effective Date:** August 7, 2006

B. Requirements

R1. The Transmission Owner and Generator Owner shall each document its current methodology used for developing Facility Ratings (Facility Ratings Methodology) of its solely and jointly owned Facilities. The methodology shall include all of the following:

- **R1.1.** A statement that a Facility Rating shall equal the most limiting applicable Equipment Rating of the individual equipment that comprises that Facility.
- **R1.2.** The method by which the Rating (of major BES equipment that comprises a Facility) is determined.
  - **R1.2.1.** The scope of equipment addressed shall include, but not be limited to, generators, transmission conductors, transformers, relay protective devices, terminal equipment, and series and shunt compensation devices.
  - **R1.2.2.** The scope of Ratings addressed shall include, as a minimum, both Normal and Emergency Ratings.
- **R1.3.** Consideration of the following:
  - **R1.3.1.** Ratings provided by equipment manufacturers.
  - **R1.3.2.** Design criteria (e.g., including applicable references to industry Rating practices such as manufacturer's warranty, IEEE, ANSI or other standards).
  - **R1.3.3.** Ambient conditions.
  - **R1.3.4.** Operating limitations.
  - **R1.3.5.** Other assumptions.

R2. The Transmission Owner and Generator Owner shall each make its Facility Ratings Methodology available for inspection and technical review by those Reliability Coordinators, Transmission Operators, Transmission Planners, and Planning Authorities that have responsibility for the area in which the associated Facilities are located, within 15 business days of receipt of a request.

R3. If a Reliability Coordinator, Transmission Operator, Transmission Planner, or Planning Authority provides written comments on its technical review of a Transmission Owner's or Generator Owner's Facility Ratings Methodology, the Transmission Owner or Generator Owner shall provide a written response to that commenting entity within 45 calendar days of receipt of those comments. The response shall indicate whether a change will be made to the

Facility Ratings Methodology and, if no change will be made to that Facility Ratings Methodology, the reason why.

C. Measures

M1. The Transmission Owner and Generator Owner shall each have a documented Facility Ratings Methodology that includes all of the items identified in FAC-008 Requirement 1.1 through FAC-008 Requirement 1.3.5.

M2. The Transmission Owner and Generator Owner shall each have evidence it made its Facility Ratings Methodology available for inspection within 15 business days of a request as follows:

M2.1 The Reliability Coordinator shall have access to the Facility Ratings Methodologies used for Rating Facilities in its Reliability Coordinator Area.

M2.2 The Transmission Operator shall have access to the Facility Ratings Methodologies used for Rating Facilities in its portion of the Reliability Coordinator Area.

M2.3 The Transmission Planner shall have access to the Facility Ratings Methodologies used for Rating Facilities in its Transmission Planning Area.

M2.4 The Planning Authority shall have access to the Facility Ratings Methodologies used for Rating Facilities in its Planning Authority Area.

M3. If the Reliability Coordinator, Transmission Operator, Transmission Planner, or Planning Authority provides documented comments on its technical review of a Transmission Owner's or Generator Owner's Facility Ratings Methodology, the Transmission Owner or Generator Owner shall have evidence that it provided a written response to that commenting entity within 45 calendar days of receipt of those comments. The response shall indicate whether a change will be made to the Facility Ratings Methodology and, if no change will be made to that Facility Ratings Methodology, the reason why.

D. Compliance

1. Compliance Monitoring Process

1.1. Compliance Monitoring Responsibility

Regional Reliability Organization

1.2. Compliance Monitoring Period and Reset Time Frame

Each Transmission Owner and Generator Owner shall self-certify its compliance to the Compliance Monitor at least once every three years. New Transmission Owners and Generator Owners shall each demonstrate compliance through an on-site audit conducted by the Compliance Monitor within the first year that it commences operation. The Compliance Monitor shall also conduct an on-site audit once every nine years and an investigation upon complaint to assess performance.

The Performance-Reset Period shall be 12 months from the last finding of non-compliance.

1.3. Data Retention

The Transmission Owner and Generator Owner shall each keep all superseded portions of its Facility Ratings Methodology for 12 months beyond the date of the change in that methodology and shall keep all documented comments on the Facility Ratings Methodology and associated responses for three years. In addition, entities found non-compliant shall keep information related to the non-compliance until found compliant.

The Compliance Monitor shall keep the last audit and all subsequent compliance records.

1.4. Additional Compliance Information

The Transmission Owner and Generator Owner shall each make the following available for inspection during an on-site audit by the Compliance Monitor or within 15 business days of a request as part of an investigation upon complaint:

1.4.1 Facility Ratings Methodology

1.4.2 Superseded portions of its Facility Ratings Methodology that had been replaced, changed or revised within the past 12 months

1.4.3 Documented comments provided by a Reliability Coordinator, Transmission Operator, Transmission Planner or Planning Authority on its technical review of a Transmission Owner's or Generator Owner's Facility Ratings methodology, and the associated responses

2. Levels of Non-Compliance

2.1. Level 1: There shall be a level one non-compliance if any of the following conditions exists:

2.1.1 The Facility Ratings Methodology does not contain a statement that a Facility Rating shall equal the most limiting applicable Equipment Rating of the individual equipment that comprises that Facility.

2.1.2 The Facility Ratings Methodology does not address one of the required equipment types identified in FAC-008 R1.2.1.

2.1.3 No evidence of responses to a Reliability Coordinator's, Transmission Operator, Transmission Planner, or Planning Authority's comments on the Facility Ratings Methodology.

2.2. Level 2: The Facility Ratings Methodology is missing the assumptions used to determine Facility Ratings or does not address two of the required equipment types identified in FAC-008 R1.2.1.

2.3. Level 3: The Facility Ratings Methodology does not address three of the required equipment types identified in FAC-008-1 R1.2.1.

2.4. Level 4: The Facility Ratings Methodology does not address both Normal and Emergency Ratings or the Facility Ratings Methodology was not made available for inspection within 15 business days of receipt of a request.

E. Regional Differences

None Identified.

Version History

Version	Date	Action	Change Tracking
1	01/01/05	1. Lower cased the word "draft" and "drafting team" where appropriate. 2. Changed incorrect use of certain hyphens (-) to "en dash" (–) and "em dash (—)." 3. Changed "Timeframe" to "Time	01/20/05

		Frame" and "twelve" to "12" in item D, 1.2.	

PROGRAM 65

Thermal Ratings Program for Transmission Line Circuits

March, 2004

National Grid USA

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Appendix H: Standard Input Parameters for copper tubing

1.0 INTRODUCTION

Program 65 (PG65) calculates thermal capabilities for transmission line circuits. The program, written in FORTRAN, calculates thermal ratings for the following circuit elements:

1. Overhead lines or drops
2. Bus conductors with circular cross-sections
3. Airbreak and Disconnect Switches
4. Circuit breakers
5. Internal bushing current transformers (BCTs)*
6. Independent current transformers
7. Air disconnect switches
8. Wave Traps

* Not rated exclusively. BCT's only affect the ratings of breakers and transformers they are in.

The program handles but does not calculate thermal ratings for the following elements:

1. Power transformers (also, phase shifters and regulators)
2. Underground cables
3. Bus conductors without circular cross-sections

Ratings of the above elements must first be determined outside the program and then supplied to the input file.

PG65 rates elements for the following conditions (for both summer and winter):

1. Normal conditions

2. Long time emergency (LTE): summer (12 hours), winter (4 hours)

3. Short time emergency (STE): 15 minutes

4. Drastic action limit (DAL): 5 minutes

2.0 RUNNING THE PROGRAM

The program is run by executing the latest version of "pg65.exe", using the input text file (e.g. "pg65.dat") as the input to the program. From a PC DOS prompt, the following syntax should be used to run the program:

```
C:\ pg65.exe<pg65.dat>pg65.out
```

The above syntax tells the PC to run "pg65.exe", using the "pg65.dat" as the input text file, and send the program output to "pg65.out". Note that the above syntax assumes both the executable file (pg65.exe), and the input text file, are located in the local directory.

3.0 PROGRAM INPUT

Information supplied to PG65 must be placed in a fixed formatted input text file (e.g. "pg65.dat"). Data given in this input file are to be placed in data card images. A card image is a string of information that takes up one line in the input file. Several cards are required for one circuit and the collection of these cards is called a deck. There are 6 types of data cards: A, AA, B, C1, C2, D, and E. The first column of each row in the input file must start with one of these 6 codes. All 6 data card types are required for each circuit* and the cards must be in order: the A card must come first, followed by the B card and so on until the E card is reached. Information handled by each card type is described below.

A card:	Ambient conditions*
AA card:	Ambient conditions (variable)**
B card:	Name and/or description of circuit or circuit section
C1 card:	Description of first terminal of circuit or circuit section
C2 card:	Description of second terminal of circuit or circuit section
D card:	Circuit element parameters and user comments
E card:	Information directing next action of PG65

*An A card does not have to be included in a deck if the E card of the previous deck directs PG65 to use the same A card.
** An AA card directs program to calculate ratings for a variety of ambient conditions.

All circuit element parameters are supplied in D cards. Each element requires one D card. The element code must immediately follow the letter D of each D card. Element codes used in PG65 are given below.

Element	Element Code
Overhead Line	O/H
Overhead Drop	DRP
Bus conductor	BUS
Air disconnect switch	ADS
Airbreak switch	ABS
Circuit Breaker	BKR
Bushing current transformer	BCT
Independent current transformer	ICT
Wave trap	WTP
Power transformer	XFM
Underground Cable	UCB

In addition to circuit element information, user comment information is supplied in D cards. Codes required for comment information are shown below. As with circuit elements, codes for comments must immediately follow the letter D of each D card.

Comment	Code
Other company's rating	COM
Relay Settings	REL
Remarks	REM

Field Format Types - Within each card, information supplied must be placed in specific fields. These fields are categorized by type and length. The FORTRAN code of PG65 defines the type and length of each field by the FORTRAN format. There are 4 different formats used in PG65: I, F, A, and free. An I format specifies that the field will only except integer values. An F format specifies that the field value can be a real number. An A format enables the field to accept character values (alphanumeric code). A few examples follow:

Format	Description
5A5	This field accepts an alphanumeric string that is up to 25 characters long. (5A5 is really 5 character fields, each of length 5, totaling a space of 25 characters)
F5.1	This field accepts a real number that contains up to one decimal place and is 5 characters long or less (including the decimal point).
I5	This field only accepts an integer that is 5 digits long or less.
Free	This field is "free" formatted. Data only needs to be separated by spaces or commas, not placed in specific columns.

Fields for each data card are defined in the next section.

3.1 **Data Card A** (ambient conditions)

The A data card has a free format input structure (only spaces are required between items).

Column	Format	Input Description
free	A1	A
free	---	Blanks
free	F5.1	O/H conductor summer ambient, °C
free	F5.1	O/H conductor winter ambient, °C
free	F5.1	Independent CT normal summer ambient, °C
free	F5.1	Independent CT normal winter ambient, °C
free	F5.1	Independent CT emergency summer ambient, °C
free	F5.1	Independent CT emergency winter ambient, °C
free	F5.1	Terminal equipment* summer ambient, °C
free	F5.1	Terminal equipment* winter ambient, °C
free	F5.2	Solar effect summer constant, Watts/ft./inch
free	F5.2	Solar effect winter constant, Watts/ft./inch
free	F5.1	O/H conductor summer wind velocity, ft./sec.
free	F5.1	O/H conductor winter wind velocity, ft./sec.
free	I5	Elevation above sea level, ft.

Sample A card:

```
A 37.8 10.0  25.0  5.0 32.0 10.0 28.0 10.0 5.59 2.41  3.0  3.0  500
```

Notes:

The values supplied in the sample A card above are the ones typically supplied to PG65. These values are based on information given in the "Capacity Rating Procedures" published in 1980 by the NEPOOL System Design Task Force (SDTF). These values produce seasonal ratings, for both summer and winter.

* Terminal equipment includes circular busses, wavetraps, switches, breakers and BCTs.

3.2 Data Card AA (directs program to calculate ambient based ratings)

An AA card is used in place of the A card to direct the program to calculate ambient based ratings. Note that an A card and AA card can't be used in the same input file. The input file must contain one or the other, but not both. Like the A card, the AA card is free format.

The following information is required in the AA card:

Column	Format	Input Descriptions
free	A2	'AA'
free	F5.1	First ambient temperature,°F
free	F5.1	Last ambient temperature,°F
free	F5.1	Step size, °F
free	F5.2	Solar constant
free	F5.1	Wind speed (ft/sec)
free	I5	Elevation above sea level, ft.

Example AA card:

```
AA    50.0 100.0 5.0  5.59  3.0  500
```

The above AA card directs PG65 to calculate circuit ratings for ambient temperatures ranging from 50°F to 100°F in increments of 5°F. Also it directs PG65 to use a solar constant of 5.59, a wind speed of 3.0 ft/s and an elevation of 500 ft. for each ambient temperature rating.

AA Card "Clamping Feature"- When using an AA card, PG65 source code limits the ambient temperatures applied to terminal equipment (circular busses, wavetraps, breakers, etc) and independent current transformers (ICTs) to those assumed when calculating summer seasonal ratings. These values are as follows:

Summer Seasonal Rating
Ambient Temperature Assumptions

Element	Ambient Temperature (°C)
Terminal equipment	28.0
ICT (normal rating)	25.0
ICT (Emergency ratings)	32.0
Overhead conductor	37.8

For example, if the AA card specifies the ambient temperature to be indexed from 10°C to 40°C, PG65 will not allow the terminal equipment ambient to be indexed above 28.0°C, the ICT normal ambient above 25.0°C, or the ICT emergency ambient above 32.0°C. In other words, ambient temperatures for these equipment would be "clamped" at their respective summer maximum values before reaching 40°C. Only overhead conductor ambient temperatures would be allowed to be indexed up to 40°C.

The purpose of limiting terminal equipment and ICT ambient temperatures is to prevent summer seasonal ratings from being higher than ambient ratings for ambient temperatures between 25°C to 37.8°C.

Consider calculating a 35°C ambient rating for a circuit which is thermally limited by a wavetrap. If a 35°C ambient is used for the wave trap, the 35°C ambient rating for the circuit would be lower than the summer seasonal circuit rating since the summer rating uses a 28.0°C ambient temperature for the wavetrap. System operators consider the summer seasonal rating to be a 37.8°C (100°F) ambient rating since, in the summer rating, the overhead conductor ambient is assumed to be 100°F . If system operators receive a 35°C circuit rating that is less than the "37.8°C" summer circuit rating, confusion will arise. To prevent this confusion, ambient temperatures for terminal equipment and ICTs are limited to those used for summer seasonal ratings.

Note that PG65 only limits ambient temperatures for terminal equipment and ICTs when an AA card is used (any ambient temp can be specified when using an A card).

3.3 Data Card B (name and/or description of circuit)

Column	Format	Input Description
1	A1	B
2-36	A35	Circuit name and description
37-41	F5.1	Nominal line-to-line voltage, kV
49-68	A40	Last revision date and initials of person making revision

Sample B card:

B D-204 (Section 3 of 3) 230.0 12/30/94 DML

3.4 Data Card C1 (description of terminal 1)

Column	Format	Input Description
1-2	A2	C1
3-32	A30	Terminal 1 description

Sample C1 card:

C1 Junction of lines 301 & 302

3.5 Data Card C2 (description of terminal 2)

Column	Format	Input Description
1-2	A2	C2
3-32	A30	Terminal 2 description

Sample C2 card:

C2 Carpenter Hill 115 kV bus #1

3.6 Data Cards D (circuit elements and user comments)

3.6.1 Overhead Lines or Line Drops

Column	Format	Input Description
1	A1	D
2-4	A3	O/H or DRP
25-29	5A5	Element description (conductor size, type, etc.)
30	I1	Material code(1 = copper, 2 = Aluminum or ACSR)
31-35	I5	Maximum conductor temperature, normal conditions, °C
36-40	I5	Maximum conductor temp, emergency conditions,°C
41-45	I5	# conductors per phase
46-50	I5	Conductor weight , lbs./ 1000 ft.*
51-55	I5	Steel Weight, lbs./1000 ft. **
56-60	I5	Conductor emissivity factor (optional)
61-65	I5	Blank
66-70	F5.0	Conductor diameter, inches
71-75	F5.0	Conductor AC resistance at 25 °C, Ohms/Mile

* For ACSR lines, aluminum weight is entered in this field
** Only relevant for ACSR lines (otherwise: leave blank)

Sample D card - O/H line:

DO/H 2-1113 ACSR “FINCH” 2 100 140 2 1055 376 1.293.0842

Notes:

The standard data source for ACSR and all aluminum conductor parameters is EPRI’s Transmission Line Reference Book (1982) (see Appendix E). The standard data source for copper conductor parameters is Westinghouse’s Electrical Transmission and Distribution Reference Book (1964) (see Appendix F).

The conductor emissivity factor can be specified in columns 56-60 if desired. However, if this field is left blank, a default value of 0.75 will be used. SDTF recommends use of 0.75 regardless of conductor type.

Drops from overhead lines to substation equipment are typically rated as overhead lines not as busses (see Appendix J for more information).

3.6.2 Bus Conductors with Circular Cross-Section

Column	Format	Input Description
1	A1	D
2-4	A3	BUS
5-29	5A5	Element description (conductor size, type, etc.)
30	I1	Material code (1 = copper, 2 = aluminum or ACSR)
31-35	I5	Maximum conductor temperature, normal conditions, °C
36-40	I5	Maximum conductor temperature, emergency conditions, °C
41-45	I5	# conductors per phase
46-50	I5	Conductor weight , lbs./ 1000 ft.*
51-55	I5	Steel Weight, lbs./1000 ft. **
56-60	I5	Conductor emissivity factor (optional)
61-65	I5	Blank
66-70	F5.0	Conductor diameter, inches
71-75	F5.0	Conductor resistance at 25 °C, Ohms/Mile

* For ASCR lines, aluminum weight is entered in this field
** Only relevant for ACSR lines (If line is not ACSR: leave blank)

Sample D card - bus conductor:

DBUS 2-1113 AL “MARIGOLD”   2   80 100   2 1045   1.216.0874

Notes:

For bus conductors, the maximum temperature under normal operating conditions is usually chosen to be 80 °C . This value is partially based on the set of guidelines published in the “Capacity Ratings Procedures” (April 1980). Section 8 of that document states that the maximum allowable bus temperature should be 10°C less than the maximum allowable temperature of any connected equipment. Since most disconnects and breakers have maximum normal temperatures of 90°C, the maximum normal temperature of bus conductors is typically limited to 80°C. For more information on bus conductor maximum temperatures, see page 3 of Appendix B.

The standard data source for aluminum pipe is the ALCOA Handbook (see Appendix G) while the standard source for copper tubing is the Anderson’s Electrical Technical Data Book (see Appendix H). The standard data sources for bus conductors are the same as those given for overhead lines (see Appendices E & F).

The conductor emissivitty factor can be specified in columns 56-60 if desired. However, if this field is left blank, a default value of 0.75 will be used. SDTF recommends use of 0.75 regardless of conductor type.

Drops from overhead lines to substation equipment are typically rated as overhead lines not as busses (see Appendix J for more information).

3.6.3 Air Disconnect Switches and Airbreak Switches

Column	Format	Input Description
1	A1	D
2-4	A3	(ADS if disconnect, ABS if Airbreak)
5-29	5A5	Element description (nameplate rating, ID#, etc.)
30	I1	Blank
31-35	I5	Nameplate current rating at 40°C, amperes
36-40	I5	Maximum allowable temperature of switch part at or above an ambient temp. of 25°C, °C
41-45	I5	Maximum allowable temperature of switch part below an ambient temp. of 25°C, °C
46-50	I5	Incremental emergency maximum temperature of switch part, °C
51-55	I5	Maximum temperature rise of switch part at or above ambient temperature of 25°C, °C
56-60	I5	Maximum temperature rise of switch part below an ambient temperature of 25°C, °C
61-65	I5	Switch thermal time constant, minutes

Sample D card - air disconnect switch:

DADS 2000 A (Post-1962), 1412-1 2000 90 105 20 43 53 30

Notes:

For switches **manufactured during 1962 or earlier**, the following parameters are typically used:

Max. allowable temp.			Max temp. rise	
≥ 25°C	< 25°C	Incr. emerg. temp.	≥ 25°C	< 25°C
70°C	70°C	30°C	30°C	30°C

For switches **manufactured after 1962**, the following parameters are typically used:

Max. allowable temp.			Max temp. rise	
≥ 25°C	< 25°C	Incr. emerg. temp	≥ 25°C	< 25°C
90°C	105°C	20°C	43°C	53°C

The thermal constant is assumed to be 30 minutes unless the nameplate rating is less than 1200 Amps in which case 15 minutes is used. This constant affects the STE and DAL ratings only.

For more information on disconnects and airbreaks, see page 2 of Appendix B.

3.6.4 Circuit Breakers

Column	Format	Input Description
1	A1	D
2-4	A3	BKR
5-29	5A5	Element description (nameplate rating, ID#, etc.)
30	I1	Blank
31-35	I5	Nameplate current rating at 40°C, amperes
36-40	I5	Pre-emergency operating current, amperes
41-45	I5	Maximum hottest spot temperature rise, °C
46-50	I5	Maximum hottest spot total temp, normal conditions, °C
51-55	I5	Maximum hottest spot total temp, emergency conditions, °C
56-60	I5	Circuit breaker thermal time constant, minutes

Sample D card - circuit breaker:

DBKR 2000 A (GAS), 1412-1 2000 1500 65 105 115 30

Notes:

Different breaker types possess different temperature limitations.

For **gas** and **air** type circuit breakers, the following temperature limits typically apply:

Max. temp. rise	Max. total temp. (normal)	Max. total temp. (emergency)
65°C	105°C	115°C

For **oil** type circuit breakers, the following temperature limits typically apply:

Max. temp. rise	Max. total temp. (normal)	Max. total temp. (emergency)
50°C	90°C	90°C

Like disconnect switches and airbreaks, the thermal constant is assumed to be 30 minutes unless the nameplate rating is less than 1200 Amps in which case 15 minutes is used. This constant affects the STE and DAL ratings only.

According to section 2.2 of the “Capacity Rating Procedures”, the pre-emergency operating current should not exceed 75% of the nameplate current rating.

For additional information on circuit breakers, see page 1 of Appendix B.

3.6.5 Internal Bushing Current Transformers

Column	Format	Input Description
1	A1	D
2-4	A3	BCT
5-29	5A5	Element description
30	I1	Ratio Code (1 = single ratio, 2 = multi-ratio)
31-35	I5	Rating of highest primary tap setting, amperes
36-40	I5	Rating of present primary tap setting, amperes

Sample D card - BCT:

```
DBCT 2000/1600A MR        2   2000  1600
```

Notes:

PG65 handles BCTs that are contained in circuit breakers and power transformers.

If a BCT is contained in a breaker or transformer, it must immediately precede the BKR or XFM card in the input file. A BCT card can also follow a BKR or XFM card. However, if a BCT card follows a BKR or XFM card but no BCT card precedes, PG65 will not execute correctly.

More information on BCTs is given in Appendix C.

3.6.6 Independent Current Transformers

Column	Format	Input Description
1	A1	D
2-4	A3	ICT
5-29	5A5	Element description (nameplate rating, type, etc.)
30	I1	Transformer type (1 = oil, 2 = butyl, 3 =compound)
31-35	I5	Nameplate current rating at 30°C, amperes
66-70	F5.0	Thermal rating factor

Sample D card - ICT:

```
DICT 3000/2000A  MR     1  3000                 1.0
```

Notes:

There is no field that allows the user to specify whether the ICT is single ratio or multi-ratio. For a multi-ratio ICT, the thermal rating factor varies with the tap setting. If the tap in use is no lower than half the nameplate rating (full-tap rating) or if the CT is single-ratio, then enter the nameplate rating with the nameplate thermal rating factor. If the tap is lower than half the nameplate rating, enter the rating of the tap in use and twice the nameplate thermal rating factor. A more detailed discussion is given on this topic in Appendix C.

3.6.7 Wave Traps

Column	Format	Input Description
1	A1	D
2-4	A3	WTP
5-29	5A5	Element description (nameplate rating, etc.)
30	I1	Blank
31-35	I5	Design current at design temperature, amperes
36-40	I5	Design temperature*, amperes
41-45	I5	Maximum hottest spot design temperature**, °C

Sample D card - wave trap:

```
DWTP 800A         800  40  150
```

Notes:

* Typically 40°C, if manufactured to ANSI standards.

**Typically 110°C above the design temperature, if manufactured to ANSI standards, which results in a maximum hottest spot temperature of 150°C.

3.6.8 Power Transformers (also phase shifters and regulators)

Column	Format	Input Description
1	A1	D
2-4	A3	XFM
5-29	5A5	Element Description (nameplate MVA rating, etc.)
30	I1	Blank
31-35	I5	Normal summer rating, MVA
36-40	I5	Normal winter rating, MVA
41-45	I5	Short-time emergency summer rating, MVA
46-50	I5	Short-time emergency winter rating, MVA
51-55	I5	Long-time emergency summer rating, MVA
56-60	I5	Long-time emergency winter rating, MVA
61-65	I5	Drastic action summer limit, MVA
66-70	F5.0	Drastic action winter limit, MVA
71-75	F5.0	Nameplate rating at highest cooling mode, MVA

Sample D card - power transformer:

```
DXFM         390  444  468  515  468  515  600  600 300
```

Notes:

PG65 **does not calculate** thermal capabilities of power transformers. Capabilities must first be determined outside the program and then supplied to the PG65 input file.

3.6.9 Underground Cables

Column	Format	Input Description
1	A1	D
2-4	A3	UCB
5-29	5A5	Element description (conductor size, type)
30	I1	Blank
31-35	I5	Normal summer rating, amperes
36-40	I5	Normal winter rating, amperes
41-45	I5	Short-time emergency summer rating, amps
46-50	I5	Short-time emergency winter rating, amps
51-55	I5	Long-time emergency summer rating, amps
56-60	I5	Long-time emergency winter rating, amps
61-65	I5	Drastic action summer limit, amperes
66-70	F5.0	Drastic action winter limit, amperes

Sample D card - underground cable:

```
DUCB  500 CU CABLE     296  296  763  763  336  336  823  823
```

Notes:

PG65 **does not calculate** thermal capabilities of underground cables. Capabilities of underground cables must first be determined outside the program and then supplied to the PG65 input file.

3.6.10 Busses With Noncircular Cross-Section

Column	Format	Input Description
1	A1	D
2-4	A3	BUS
5-60	-	Same as for underground cables

Notes:

PG65 **does not calculate** thermal capabilities of buses without circular cross-sections. Capabilities of non-circular busses must first be determined outside the program and then supplied to the PG65 input file (see Appendix I for noncircular bus predetermined ratings).

3.6.11 Other Company's Ratings of Circuit

Column	Format	Input Description
1	A1	D
2-4	A3	COM
5-60	-	Same as for underground cables

Notes:

If another company owns a section of a circuit, ratings of that section are supplied in this card. Other company's ratings are placed in the remarks section of the capabilities report.

3.6.12 Protective Relay Settings

Column	Format	Input Description
1	A1	D
2-4	A3	REL
5-29	5A5	Element description
30	I1	Blank
31-35	I5	Relay trip setting, amperes
36-40	I5	Relay terminal location (1 or 2)
41-45	I5	Relay direction (1 or 2 if directional relay) (0 if nondirectional relay)

Sample D card - relay settings:

DREL trip limit for 0.85 PF 910 1 2

Notes:

It is important to specify the correct relay direction in this card since directional relays only effect the capability of a circuit in one direction. For more information on protective relays, see Appendix D.

3.6.13 Remarks

Column	Format	Input Description
1	A1	D
2-4	A3	REM
5-156	A152	Remarks

Sample D card - remarks:

DREM REV 3/5/99 involved upgrade of breaker 101 from 1600A to 2000A.

Notes:

The user can supply comments pertaining to the circuit in this card. Up to 5 DREM cards can be used for each circuit. Comments given in this card are placed in the remarks section of the capabilities report.

3.7 Data Card E

Column	Format	Input Description
1	A1	E
31-35	A5	(1 = Another circuit follows, 2 = last deck, terminate)
36-40	A5	(1 = use same A card as previous deck, 2 = read new A card)

Sample E card:

E 2

Notes:

Each deck (set of cards for one circuit) must end with an E card. The information given in the E card directs the next action taken by PG65.

Adjusting Input for Transformer Circuits - When a circuit contains a power transformer, two voltage levels are present. PG65 however, only allows one voltage level to be specified per circuit. To obtain accurate results, all elements must be referred to one side of the transformer before entering data into the input file. For example, if a circuit contains a 345/115 kV transformer and the user selects 345 kV as the circuit voltage in the PG65 input file, the user must refer all elements on the 115 kV side of the transformer to the 345 kV side. Parameters to be changed are described below.

Conductor resistance:

Resistances of overhead lines and bus conductors are referred to one side by multiplying the resistance by the square of the transformer voltage ratio. In this particular example, conductor resistances for lines and busses on the 115 kV side should be referred to the 345 kV side as follows:

$$R_{345} = R_{115} \times \left(\frac{345kV}{115kV} \right)^2$$

Current ratings:

Current ratings should be adjusted for disconnects, airbreaks, breakers, BCTs, ICTs, and wave traps. In addition, input current ratings should be adjusted for pre-rated elements such as underground cables, non-circular busses, and other company's ratings if those ratings are rated for a voltage that is different from the voltage specified in the B card. Current ratings should be divided by the transformer voltage ratio. In this case, current ratings for all elements on the 115 kV side of the transformer should be referred to the 345 kV side as follows:

$$I_{345} = I_{115} \div \left(\frac{345kV}{115kV} \right)$$

4.0 PROGRAM OUTPUT

Three files are created when PG65 is executed; 2 are temporary files. The first temporary file, "fort.9", is a formatted echo of the input file. The second temporary file, fort.10, is a scratch file used by PG65 to determine STE and DAL ratings. The third file, name chosen by the user upon execution of PG65, is the circuit capabilities report.

Notes on the circuit capabilities report:

- If the limiting capabilities for a circuit are the same in both directions, only one set of limiting capabilities is displayed in the report. If the limiting capabilities in both directions are not equal, the report displays limiting capabilities for both directions.

- If a breaker or transformer is derated by a BCT, (BCT) is printed next to BREAKER or XFORMER in the "element" column of the report.

- The direction of a protective relay as specified in the input file is printed next to RELAY in the "element" column of the report.

- The maximum operating temperature of an overhead line as specified in the input file is printed next to O/H LINE in the “element” column of the report.

- The maximum conductor temperature of a circular bus for both normal and emergency conditions as specified in the input file is printed next to BUS in the “element” column of the report.

- Ambient condition information supplied to the A card is printed out in the top right hand corner of the capabilities report.

5.0 PROGRAMMER’S GUIDE

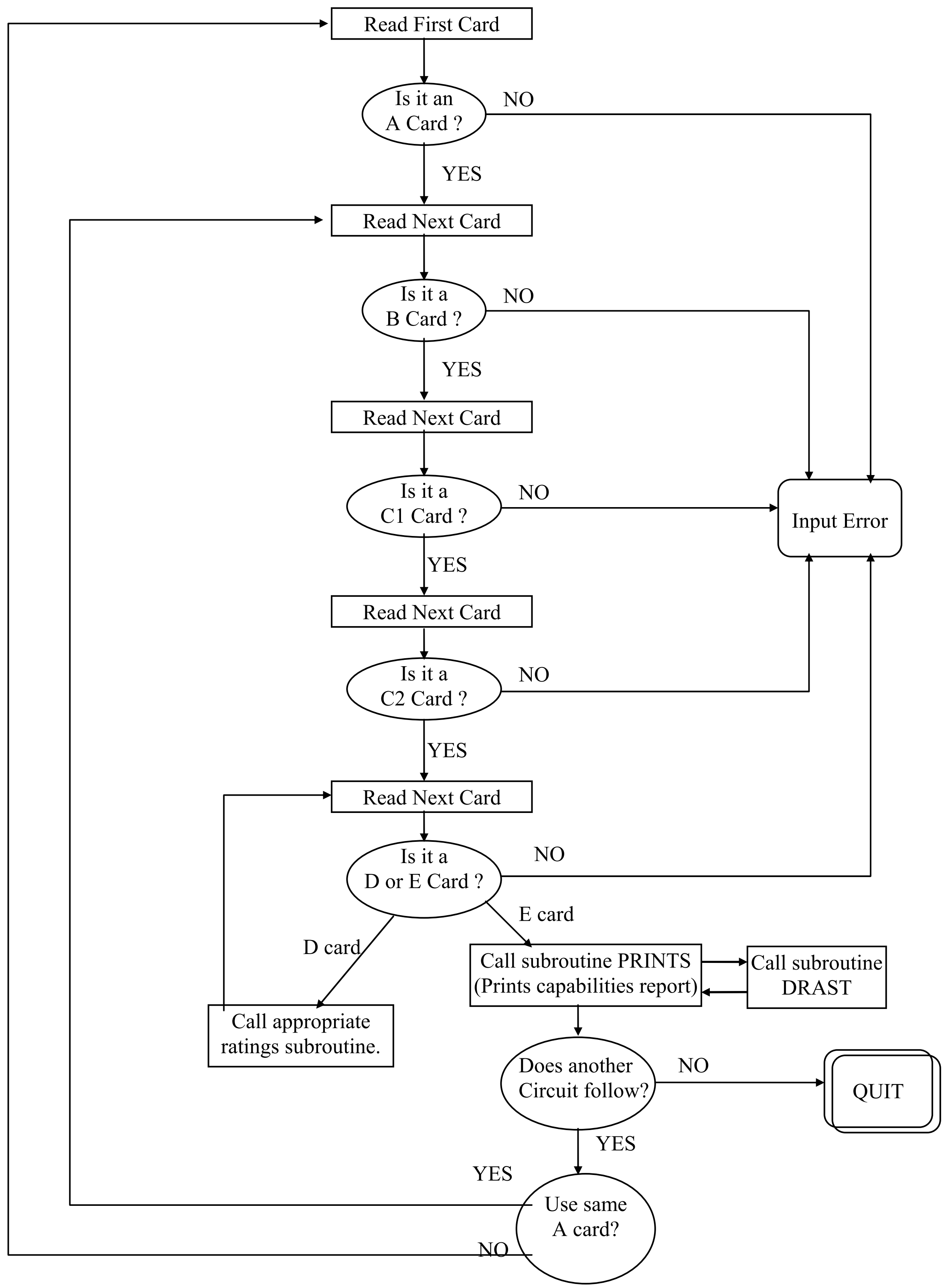
5.1 Introduction

PG65, written in FORTRAN, contains a main program, 17 subroutines and three programmer defined functions. A description of the main program is given below.

5.2 Main Program

The main program of PG65 reads the input data file and calls subroutines to perform rating calculations. Also, the main program generates the output file containing the input data echo. A flow chart of the main program is shown on the following page.

5.3 Program Flow-Chart



5.3 Subroutine Descriptions

PG65 contains 17 different subroutines. They are listed below.

Subroutine	Description
AIRSW	Calculates ratings for disconnects and airbreaks
BREAK	Calculates ratings for circuit breakers (does not calculate DAL ratings).
BUSHCT	Resolves whether BCT limits the capability of the breaker its in. If it does, the breaker is derated.
BUS1	Formats non-circular bus ratings for output
BUS2	Calculates ratings for circular bus conductors (does not calculate DAL ratings)
COMP	Formats other company's ratings for output
COUNT	Counts lines in fort.9 output file, skips to new page when required
INDCT	Calculates ratings for ICTs
LIMIT	Pertains to an output file that has been disabled
OVERHD	Calculates ratings for overhead lines & Drops (does not calculate DAL ratings)
PRINTS	Creates circuit capabilities report
RELAY	Formats relay information for output
TERM	Pertains to an output file that has been disabled
UCABLE	Formats cable ratings for output
WAVETP	Calculates ratings for wavetraps
XFORM	Formats transformer ratings for output
DRAST	Calculates STE and DAL ratings for overhead lines and circular bus conductors. Also, calculates DAL ratings for circuit breakers.

Notes on Selected Subroutines:

5.3.1 OVERHD

Subroutine OVERHD calculates normal and LTE ratings for overhead lines. STE and DAL ratings for overhead lines are calculated in the subroutine DRAST. Subroutine OVERHD writes overhead line information to a temporary storage file called fort.10. Information written to fort.10 is subsequently read by DRAST.

5.3.2 BUS2

Subroutine BUS2 calculates normal and LTE ratings for circular bus conductors. STE and DAL ratings for circular bus conductors are calculated in the subroutine DRAST. Subroutine BUS2 writes circular bus information to a temporary storage file called fort.10. Information written to fort.10 is subsequently read by DRAST.

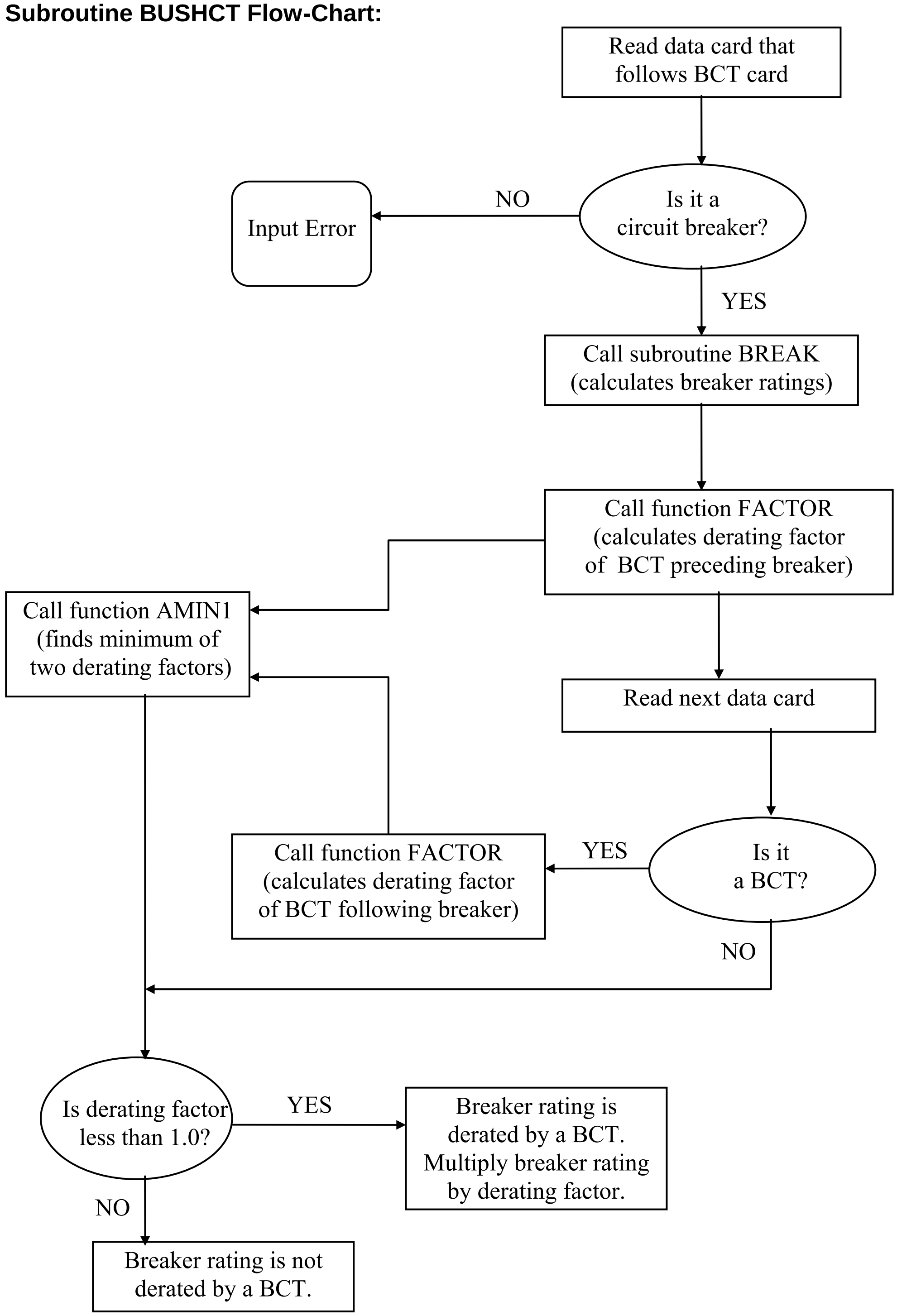
5.3.3 BREAK

Subroutine BREAK calculates normal, LTE and STE ratings for circuit breaker. DAL ratings for breakers are calculated in subroutine DRAST. Subroutine BREAK writes breaker information to a temporary storage file called fort.10. Information written to fort.10 is subsequently read by DRAST.

5.3.4 BUSHCT

Subroutine BUSHCT determines if a circuit breaker is derated by its BCTs. The flow chart on the following page illustrates the execution of BUSHCT.

Subroutine BUSHCT Flow-Chart:



5.3.5 PRINTS

Besides printing out the circuit capabilities report, subroutine PRINTS determines the minimum capabilities for each circuit. The minimum circuit capabilities are simply the minimum capabilities of all elements in the circuit. Before printing out the capabilities report, PRINTS calls subroutine DRAST.

5.3.3 DRAST

Subroutine DRAST calculates STE and DAL ratings overhead lines and circular bus conductors. In addition, DRAST calculates DAL ratings for circuit breakers. DRAST uses the minimum *normal* capabilities of the circuit determined in subroutine PRINTS as its pre-emergency load. Also, DRAST reads information from the temporary storage file; fort.10.

5.4 Function Descriptions

PG65 contains three programmer-defined functions. They are listed below.

Function	Description
FACTOR	Calculates derating factor for breakers with BCTs
MIN0	Returns minimum of two integers
AMIN1	Returns minimum of two real numbers

5.5 Variable Descriptions

Important variables contained in the program code are defined as follows.

Variable	Description
BKRDESCRIP	Flag for breaker: Flag = (BCT) if breaker is limited by a BCT, Flag = blank if not
BUSTEMPS	Maximum bus conductor temperatures (normal and emergency) as specified in DBUS card
CKTDESCRIP	Circuit description given in B card
CTESUM	ICT emergency summer ambient temp. specified in A card
CTEWIN	ICT emergency winter ambient temp. specified in A card
CTNSUM	ICT normal summer ambient temp. specified in A card
CTNWIN	ICT normal winter ambient temp. specified in A card
DATEA	Date of run
ELEMENT	Name of circuit element
ICAP	Ampere ratings of circuit element
ICODE	Circuit element code supplied in D card
IELEV	Elevation above sea level as specified in A card
INPUTS	Integers placed in columns 31-65 of D card
ISEQ	Data card letter
ITERM(1,1-6)	Terminal description for terminal 1 given in C1 card
ITERM(2,1-6)	Terminal description for terminal 2 given in C2 card
JCODE	Element description supplied in D card
MINCAP	Limiting ampere ratings of circuit
MINMVA	Limiting MVA ratings of circuit
MVACAP	MVA ratings of circuit element

MVAREM	MVA ratings of other company's portion of circuit
N1	Integer placed in column 30 of D card
OESUM	Other equipment summer ambient temp. specified in A card
OEWIN	Other equipment winter ambient temp. specified in A card
OHSUM	O/H conductor summer ambient temperature specified in A card
OHWIN	O/H conductor winter ambient temperature specified in A card
Q1	Real number placed in columns 66-70 of D card
Q2	Real number placed in columns 71-75 of D card
REMRK	Stores remarks given in DREM card
REMLINE	Indexes REMRK array
REVISED	Revision date and/or comments supplied in B card
SOLSUM	Solar effect summer constant specified in A card
SOLWIN	Solar effect winter constant specified in A card
VOLTKV	Circuit voltage supplied in B card
WINSUM	O/H conductor summer wind velocity specified in A card
WINWIN	O/H conductor winter wind velocity specified in A card

5.6 Equations used for Element Ratings

All calculations made in PG65 are based on the set of guidelines published in the Capacity Rating Procedures (1980). Refer to this document for additional information.

*Note: Unless otherwise specified, all temperature, time and current variables contained in the following equations have units of °C, minutes and amps, respectively.

5.6.1 Circuit Breakers

<u>Definition of Terms</u>

I_{np}	=	Nameplate current rating of circuit breaker at 40°C
I_{init}*	=	Operating current preceding emergency conditions
$\theta_{max,norm}$	=	Maximum allowable hottest spot total temperature under normal conditions.
$\theta_{max,emerg}$	=	Maximum allowable hottest spot total temperature under emergency conditions.
θ_{rise}	=	Rated allowable hottest spot temperature rise
τ	=	Circuit breaker thermal time constant
θ_a	=	Ambient temperature
t_s	=	Overload duration (5 min. for DAL, 15 min. for STE)

*For STE, I_{init} is value supplied to input data file by user.
*For DAL, I_{init} = (0.75)(minimum normal rating of all elements in circuit)

Normal Conditions

$$I_{norm} = I_{np}\left(\frac{\theta_{\max,norm} - \theta_a}{\theta_{rise}}\right)^{\frac{1}{1.8}}$$

Long Time Emergency Conditions

$$I_{LTE} = I_{np}\left(\frac{\theta_{\max,emerg} - \theta_a}{\theta_{rise}}\right)^{\frac{1}{1.8}}$$

Short Time Emergency and Drastic Action Conditions

$$I_{STE,DAL} = I_{np}\left[\frac{\theta_{\max,emerg} - \theta_{rise}\left(\frac{I_{init}}{I_{np}}\right)^{\frac{1}{1.8}} e^{-\frac{t_s}{\tau}} - \theta_a}{\theta_{rise}\left(1 - e^{-\frac{t_s}{\tau}}\right)}\right]^{\frac{1}{1.8}}$$

5.6.2 Disconnect Switches and Airbreaks

Definition of Terms

I_{np}	=	Nameplate current rating of switch or airbreak
θ_{max}	=	Maximum allowable temperature of switch part
θ_a	=	Ambient temperature
θ_{incr}	=	Incremental emergency maximum temperature of switch part
θ_{rise}	=	Maximum temperature rise of switch part
t_s	=	Overload duration (5 min for DAL, 15 min for STE)
τ	=	Switch thermal time constant

Normal Conditions

$$I_{norm} = I_{np}\sqrt{\frac{\theta_{\max} - \theta_a}{\theta_{rise}}}$$

Long Time Emergency Conditions

$$I_{LTE} = I_{np}\sqrt{\frac{\theta_{\max} - \theta_a + \theta_{incr}}{\theta_{rise}}}$$

STE and DAL Conditions

$$I_{STE,DAL} = I_{np}\sqrt{\frac{\frac{\theta_{incr}}{1 - e^{t_s/\tau}} + \theta_{\max} - \theta_a}{\theta_{rise}}}$$

NOTE: Breaker ratings can never exceed twice nameplate

5.6.3 Wave Traps

Definition of Terms

I_D = Design current rating at design temperature
θ_H = Maximum hottest spot design temperature
θ_A = Ambient temperature
θ_D = Design temperature

Normal Conditions

$$I_{norm} = I_D\sqrt{\frac{\theta_H - \theta_A}{\theta_H - \theta_D}}$$

Long Time Emergency Conditions

$$I_{LTE} = 1.15 \times I_{norm}$$

Short Time Emergency Conditions

$$I_{STE} = 1.5 \times I_{norm}$$

Drastic Action Limit

$$I_{DAL} = 1.65 \times I_{norm}$$

5.6.4 Independent Current Transformers

Definition of Terms

τ = Thermal time constant of ICT
θ_{norm} = ICT normal ambient temperature
θ_{emerg} = ICT emergency ambient temperature
MF = Multiplication factor governed by ICT type*

Normal Conditions

$$I_{norm} = \left[\frac{(125)(\tau) - (0.8)(\tau + 0.2)(\theta_{norm})}{100} \right]$$

LTE, STE, & DAL

$$I_{LTE,STE,DAL} = MF\left[\frac{(125)(\tau) - (0.8)(\tau + 0.2)(\theta_{emerg})}{100} \right]$$

*The following values are used for MF:

	Oil filled	Butyl-Molded	Compound
MF_{LTE}	1.4	1.3	1.2
MF_{STE}	1.7	1.6	1.4
MF_{DAL}	1.81	1.7	1.45

5.6.5 Internal Bushing Current Transformers

PG65 does not calculate the rating of a BCT. It only determines if a BCT derates the breaker that it is in by calculating the derating factor of the BCT.

Definition of Terms

DF	=	Derating factor
$I_{CT\ np}$	=	Nameplate primary current rating of BCT
$I_{CT\ set}$	=	Reduced tap current rating for multi-ratio BCTs
$I_{breaker}$	=	Nameplate current rating of circuit breaker

Single-Ratio BCTs

$$DF = \sqrt{\frac{I_{CT\ np}}{I_{breaker}}}$$

Multi-Ratio BCTs

$$DF = \sqrt{\frac{I_{CT\ set}}{I_{breaker}}}$$

If the derating factor is calculated to be less than one, the normal, LTE, STE and DAL ratings of the breaker are derated by the derating factor. If the derating factor is calculated to be more than one, breaker ratings are left unchanged.

5.6.6 Overhead Lines, Drops, & Bus conductors

Definition of Terms

ε	=	Emmisivity factor
θ_a	=	Ambient temperature, °C
θ_{ave}	=	Average of ambient and conductor temperatures, °C
θ_c	=	Conductor temperature, °C
$\theta_{c,init}$	=	Conductor temperature immediately preceding emergency loading
θ_{rise}	=	Conductor temperature rise over θ_a , °C
D	=	Conductor diameter, inches
ELEV	=	Elevation above sea level, ft
I	=	Conductor current, amps
k_f	=	Thermal conductivity of air, watts/(ft.)(°C)
K_s	=	Solar effect constant
m_f	=	Absolute viscosity of air, lbs/(hr.)(ft.)
P	=	Conductor thermal capacity, J/ft °C

p_f	=	Density of air, lbs/ft^3
q_c	=	Heat dissipated by convection
q_r	=	Heat dissipated by radiation
q_s	=	Solar heat absorbed by conductor
R_{25}	=	Conductor resistance at 25°C
R_o	=	Conductor resistance at operating temperature
t	=	Time, minutes
T_a	=	Ambient temperature, °K
T_c	=	Conductor temperature in °K (Degree Kelvin)
t_s	=	Overload duration (15 min for STE, 5 min for DAL)
V	=	Velocity of air stream, ft/hr.

<u>Normal and LTE Conditions</u>

$$I_{norm,LTE} = \sqrt{\frac{q_c + q_r - q_s}{R_o}}$$

Where:

$$R_o = \frac{(\theta_c + 234.5)}{259.5} R_{25} \quad \text{for copper}$$

$$R_o = \frac{(\theta_c + 228)}{253} R_{25} \quad \text{for aluminum and ACSR}$$

$$q_r = 13.81 \times 10^{-10} \times D \times \varepsilon \times (\theta_c{}^4 - \theta_a{}^4)$$

$$q_s = K_s \times D$$

When V < 0.65 ft/sec (natural convection), the following equation is used for q_c:

$$q_c = 0.283 p_f{}^{0.5} \times D^{0.75} \times (\theta_c - \theta_a)^{1.25}$$

When V = 0.65 ft/sec or greater (forced convection), PG65 makes two calculations for q_c and uses the greatest:

$$1. \quad q_c = \left(\left(1.01 + 0.371 \left(\frac{D \times p_f \times V}{m_f} \right)^{0.52} \right) k_f \left(\theta_c - \theta_a\right) \right.$$

$$2. \quad q_c = 0.1695 \left(\frac{D \times p_f \times V}{m_f} \right)^{0.6} k_f \left(\theta_c - \theta_a\right)$$

Where:

$$p_f = \frac{0.080695 - 0.2901(10^{-5})(ELEV) + 0.37(10^{-10})(ELEV^2)}{1 + 0.0036 / (\theta_{ave})}$$

$$m_f = 0.0415 + 1.2034(10^{-4})\theta_{ave} - 1.1442(10^{-7})\theta_{ave}{}^2 + 1.9416(10^{-10})\theta_{ave}{}^3$$

$$k_f = 0.00738 + 2.27889(10^{-5})\theta_{ave} - 1.34328(10^{-9})\theta_{ave}{}^2$$

STE and Drastic Action Conditions

In determining short-time emergency and drastic action limits, the program calculates the amount of load current that, when applied for a specified time interval (15 min. for STE, 5 min. for DAL), will cause the conductor temperature to rise to its maximum allowable.

When more heat is generated within the conductor than can be dissipated, the conductor temperature rises. This is quantified by the following power balance equation:

$$I^2 R + q_s = q_c + q_r + P \frac{d\theta_c}{dt}$$

where:

$P \frac{d\theta_c}{dt} =$ Amount of watts accumulated in conductor

The power balance equation can be rewritten as follows:

$$\theta_c = \int_o^{t_s} \left[\frac{I^2 R + q_s - q_c - q_r}{P} \right] dt + \theta_{c,init}$$

The goal is to determine the value of I which makes θ_c equal to the maximum allowable emergency temperature. Before this can be accomplished, the conductor temperature immediately preceding emergency loading ($\theta_{c,init}$) must be determined. $\theta_{c,init}$ can be calculated by assuming the conductor is in thermal equilibrium immediately before emergency loading. In other words, P $d\theta_c/dt$ is set to zero in the power balance equation:

$$I^2R + q_s = q_c + q_r$$

$\theta_{c,init}$ can be obtained by first solving for θ_{rise}:

$$A_4\theta_{rise} + A_3\theta_{rise} + A_2\theta_{rise} + A_1 = 0$$

These "A" factors are related to conductor characteristics and ambient conditions. In PG65, the Newton-Raphson method is used to find the realistic solution of θ_{rise} for this polynomial. The initial conductor temperature is then:

$$\theta_{c,init} = \theta_{rise} + \theta_a$$

Once $\theta_{c,init}$ is known, θ_c can be solved for by integrating the power balance equation containing the P $d\theta_c/dt$ term. Since direct integration of this expression is prevented by the temperature dependence of R_o, q_c and q_r, and because of the possibility that current will vary with time, a piece-wise linear integration using a relatively small time step is performed by PG65:

$$\theta_c = \sum_{a=1}^{n}\left[\frac{I^2R + q_s - q_c - q_r}{P}\right](a)(\Delta t) + \theta_{c,init}$$

where: $n = t_s / \Delta t$

PG-65 compares the calculated conductor temperature with the maximum allowable conductor temperature after each integration. If they do not match, the applied current is adjusted and the integration is repeated until convergence is reached.

Note:

The θ_c and θ_a parameters given in the above equations are specified by the user in the input data file.

In the case of overhead conductors, θ_c is set to the maximum conductor temperature specified in the DO/H card. This value is used for normal, LTE, STE and DAL calculations.

In the case of circular busses, two conductor temperatures are specified in the DBUS card: the maximum normal temperature and the maximum emergency temperature. For normal calculations, θ_c is set to the maximum normal temperature while for LTE, STE and DAL calculations, θ_c is set to the maximum emergency temperature.

The θ_a parameters for both circular busses and O/H lines are supplied by the user in the A card. Note that the θ_a parameters specified for O/H lines are typically different than those specified for circular busses (terminal equipment).

APPENDICES