Serial Number: RFP-FQ16146/NAC
Date of Issue: August 22, 2017
Original Proposal Due Date: Feb. 3, 2017
Revised Proposal Due Date: January 16, 2018

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
600 FIFTH STREET, N.W.
WASHINGTON, DC 20001

August 22, 2017
AMENDMENT NO. 5
REQUEST FOR PROPOSALS
FOR
POTOMAC YARD METRORAIL STATION
FQ16146/NAC

TO WHOM IT MAY CONCERN:

The Request For Proposals and Proposal Documents accompanying RFP FQ16146/NAC requesting Proposals for the above project are hereby changed in part as listed below.

I. GENERAL INFORMATION

This amendment changes the due date for Proposals to January 16, 2018, modifies other schedule milestones and requirements for revised technical and price proposals, and responds to Contractor Questions on the referenced project.

II. CHANGES TO DOCUMENTS

The Request For Proposals and Proposal Documents accompanying solicitation RFP/FQ16146/NAC are hereby changed in part as follows:

1. VOLUME 1 – DIVISIONS 0 AND 1

Delete the following pages and in lieu thereof substitute the accompanying pages:

DELETE	SUBSTITUTE	DESCRIPTION
00 10 00 -1	00 10 00 -1	Revised
00 10 00 -4	00 10 00 -4	Revised
00 20 00 -1	00 20 00 -1	Revised
00 20 00 -17	00 20 00 -17	Revised
00 20 00 -18	00 20 00 -18	Revised
00 43 40 -3	00 43 40 -3	Revised
00 43 40 -4	00 43 40 -4	Revised
00 80 00 -2	00 80 00 -2	Revised

2. VOLUME 3.1 – PROJECT DIRECTIVE DRAWINGS:

Add the following Drawing(s):

DRAWING NUMBER	DRAWING TITLE	DESCRIPTION
C11-CP-001	Signal and Trackwork Pre-Construction (Existing)	New
C11-CP-002	Signal and Trackwork Construction Complete Pre-Cutover	New

C11-CP-003	Signal and Trackwork Track 1 Cut-Over	New
C11-CP-004	Signal and Trackwork Track 2 Cut-Over	New

3. **VOLUME 4 – REPORTS**
   Add the following report:
   Potomac Yard Station Traction Power Study. Prepared by AECOM, July, 2017

4. **CONTRACTOR QUESTIONS**
   This amendment includes responses to contractor questions. Previous Authority responses provided in amendments 1, 2, or 3 still apply except as specifically noted herein.

5. **ACKNOWLEDGEMENT**

   Offerors are required to acknowledge receipt of this amendment on the Technical and Price Proposal Forms (Pages 00 41 20-1 and 00 41 30-1) in the space provided. Failure to acknowledge all amendments may cause the bid to be considered not responsive to the invitation, which would require rejection of the Proposal.

Norie A. Calvert
Contracting Officer

Enclosures

* * * * *

SECTION 00 10 00

PROPOSING REQUIREMENTS – DESIGN BUILD

00 10 10 REQUEST FOR PROPOSAL:

This Section includes Project information for Proposers.

NOTICE TO OFFERORS

Contract No. FQ16146/NAC includes RFP Documents for:

Project Name: POTOMAC YARD METRORAIL STATION

TECHNICAL PROPOSAL for the Work described herein shall be submitted to the Contract Administrator, Nichel Crooks, through WMATA's PMSS. Technical and Price Proposals shall be separate proposals and
submitted before 3:00 PM (local time) on January 16, 2018. All questions are to be directed to Contract # administrator.

DIRECTIONS TO SUBMITTING PROPOSER: Read and comply with the Solicitation Instructions. In addition to other submission requirements set forth in this Request for Proposal and all Amendments, the following must be properly executed, completed, and submitted separately as part of the offer:

A. TECHNICAL PROPOSAL:

1. Technical Proposal Form (properly executed)[1]
2. Technical Proposal

B. PRICE PROPOSAL:

1. Price Proposal Form (properly executed[1])
2. Price Schedule
3. Price Guarantee
4. Proposal Data Form with Supporting Data
5. Representations and Certifications
6. List of DBE Certified Firms[2]
7. DBE Data[3]

PROPOSAL(S) MUST SET FORTH FULL, ACCURATE, AND COMPLETE INFORMATION AS REQUIRED BY THIS REQUEST FOR PROPOSAL, INCLUDING ALL AMENDMENTS

[1] The separate sealed Technical and Price Proposal Forms must be marked with offer under Solicitation RFP No. FQ16146/NAC and with acknowledgement of all Amendments.
[[2] Proposed DBE firms must be certified WMATA DBE firms ***prior to submittal*** of Schedule of DBE Participation and Letters of Intent in order to be applied toward the DBE goal established for the Contract. Non-WMATA Certified DBE firms may be utilized by the Proposer but will not be applied toward the goal calculations.]
[3] DBE Data and List of WMATA DBE-Certified Firms must be updated and included in Best and Final Offer (BAFO) submission(s).

A. Potomac Yard Metro Station Final Environmental Impact Statement (FEIS),

B. Record of Decisions (RODs) from the Federal Transit Administration (FTA) and the National Park Service (NPS),

C. Section 106 Memorandum of Agreement (MOA),

D. Phase II Environmental Site Assessment

E. The City of Alexandria's Development Special Use Permit (DSUP2016-004, 2016-005, 2016-005) conditions

The above stated documents are provided in this Solicitation FQ16146/NAC. All cost associated with the required compliance shall be included in the Design Builders proposal. See SECTION 00 30 00 INFORMATION AVAILABLE TO PROPOSERS.

B. Basis of Design: As specified in Section 01 11 20, DESIGN AND PROGRAM REQUIREMENTS.

00 10 13 PROJECT SOLICITATION SCHEDULE:

A. The solicitation schedule for this Project is as follows:

1. Issue Revised Request for Proposal: July 11, 2017
2. One-on-One Meeting No. 1: Weeks of September 4 and September 11, 2017
3. Site Visits: by Appointment September-October 2017
4. One-on-One Meeting No. 2: October 23, 2017
5. One-on-One Meeting No. 3: December 4, 2017
6. Technical and Price Proposal: January 16, 2018
7. Projected Contract Award: May 15, 2018
8. Notice to Proceed: June 1, 2018

END OF SECTION

SECTION 00 20 00

INSTRUCTIONS TO PROPOSERS (RFP)

This Section includes procedures with which Proposers must comply and conditions affecting award of the Contract.

00 20 01 GENERAL INSTRUCTIONS

A. Definitions as used herein:

1. The term "Solicitation" used in this document means this Request for Proposals (RFP).

2. The term "Offer" and "Proposal" are synonymous and mean a response to this Solicitation.

3. The term “PMSS” used in this document refers to the Authority’s project management software system.

4. For further explanation of Contract terms, refer to Section 00 70 01, DEFINITIONS, of the General Conditions.

B. Method of Procurement:

1. This is a Best Value, single-phase, negotiated procurement.

a. Requires the Proposer(s) to prepare and submit separately Technical and Price Proposals based on the scope of Work set forth in the Solicitation. See Section 01 11 10, SUMMARY OF WORK. The Technical and Price Proposals will be evaluated separately based on the Technical Evaluation Factors stated under Section 00 20 03, TECHNICAL AND PRICE PROPOSAL FORMAT, PROCEDURES AND EVALUATION FACTORS, AND INSTRUCTIONS, and the Price Evaluation Factors stated in the same section.

b. DELETED

2. Oral presentation and Best and Final Offers may be required.

C. Basis for Award:

1. Award will be made to that Proposer:

a. whose offer is judged by an integrated assessment of the evaluation criteria to be the most advantageous to the Authority based on technical merit and price as identified in Section 00 20 03, TECHNICAL AND PRICE PROPOSAL FORMAT, PROCEDURES AND EVALUATION FACTORS, AND INSTRUCTIONS, and

b. that the Authority deems responsible in accordance with the WMATA Procurement Procedures Manual.

2. The Authority reserves the right to conduct discussions with the Proposers. If it is determined that discussions are necessary, the Authority will establish a competitive range of all of the most highly rated technical Proposals.

3. The Authority will make a single award to one Proposer as the result of this Solicitation. See Notes to Proposers in Section 00 43 40, PRICE PROPOSAL SCHEDULE, for further award information.

2. ATCs shall not increase the Project Limit of Disturbance (LOD), nor necessitate modifications to environmental approvals obtained by Owner;

3. ATCs shall not require Metrorail service interruptions greater than 72-hour weekend shutdowns for purposes of construction;

4. ATCs shall not modify zinc roof materials and natural stone finishes;

5. ATCs must maintain the north entrance pavilion and pedestrian bridge in the location specified in Section 32 05 10;

6. ATCs must retain the architectural character of the original RFP design and DSUP Drawings;

7. ATCs shall provide safe, convenient, ADA-compliant access to the station for pedestrians and cyclists approaching from Potomac Greens Drive and Carpenter Road.

D. One-on-One Meetings

E. Purpose of one-on-one meetings is to obtain WMATA and City of Alexandria feedback on potential ATCs

1. Three (3) One-on-One meetings will be scheduled for each proposer.

2. Agenda for the first One-on-One meeting:

a. Proposer to advise whether the city's target price of $170,000,000 is reasonably attainable. The target price is not a maximum and Bidders will not be deemed non-responsive if the price proposal exceeds the target price.

b. Proposer presentation of potential ATC concepts;

3. Agenda for the second and third One-on-One meetings:

a. Review draft revised DSUP submission;

b. Agree in principle on ATC concepts that would be acceptable to the Owner. However, ATCs are subject to final approval as part of proposal evaluation, and further modification during BAFO negotiations.

4. WMATA and the City will treat One-on-One discussions confidentially.

5. Comments made by WMATA and the City at One-on-One meetings are non-binding.

F. Ownership of ATCs

1. All ATCs submitted become the intellectual property of the Owner. Owner has the right to use ATCs from unsuccessful proposers.

G. Stipends

1. Proposers who submit qualifying Bids and ATCs, but who are not selected, will receive a stipend of $500,000. Selected contractor does not receive a stipend. Include all costs in Proposal. If the contract is not awarded, all proposers will receive the stipend.

H. Incorporation of ATCs in Contract

1. Approved ATCs will be incorporated in the Construction Contract.

00 25 00 PRE-PROPOSAL MEETINGS SCHEDULE

A. Unless otherwise notified, a pre-Proposal conference will be held as noted in the Project Solicitation Schedule, Section 00 10 13, PROJECT SOLICITATION SCHEDULE. The purpose of this conference will be to answer questions regarding, or requests for clarifications of, the Solicitation documents. It is requested that Proposers submit their questions and requests for clarifications of the terms, conditions, and requirements of this Request for Proposal to the Contracting Officer in writing either in advance of the meeting or during the meeting. Questions from the floor, however, are permissible.

B. Site visits will be limited to those Design Builders who submit a proposal and will be scheduled after the proposals are received.

C. Proposers are required to visit the Site of the Work and inform themselves of all local conditions that may affect the Work or the cost thereof.

D. The Site Visit will be scheduled by the Authority in advance and each appointment shall be limited to no more than 45 minutes. The Design Builders will be limited to one (1) appointment with a maximum number of six (6) members of the Design Build team in attendance. The Authority will not grant access to areas within the WMATA Right of Way including the tracks and Traction Power Substation (TPSS).

E. The Proposer acknowledges and agrees that it shall be bound by all the terms of the Contract regardless of its attendance at the pre-Proposal conference, or the thoroughness of its preliminary Site-condition investigation prior to submitting its Proposal.

00 26 00 PRE-AWARD MEETING

A. The Authority requires that a pre-award meeting with the successful Proposers be held prior to the actual award of the Contract. The purpose of the meeting will be to review the successful Proposer’s understanding of the Contract Documents, contractual requirements prior to award, and to confirm the successful Proposer's capabilities, financial standing, and past experience.

B. The pre-award meeting will be held in the Washington Metropolitan area and shall be chaired by the Authority and attended by representatives of the Authority, the successful Proposer, and its Key Staff nominated for assignment to the Contract, the Designer, the Design-Builder, including major subcontractors if so requested by the Authority. Concerned parties shall each be represented by persons thoroughly familiar with and authorized to conclude matters relating to the Work described in the RFP Documents.

C. Agenda discussion items for the meeting may include, but are not limited to, the following:

1. Requirements for acceptability of payment and performance bonds.

2. Requirements for DBE participation.

3. Verification of qualifications of Key Staff. The Design-Builder shall not substitute any Key Staff identified in its Technical Proposal As Finally Accepted without the written approval of the Authority. The Design-Builder shall provide the Authority with all information as may be reasonably requested regarding substitutions, and any proposed substitutes shall share similar or better qualities than the person substituted.

4. Requirements for quality assurance/quality control.

5. Percentage of construction work to be performed by Design-Builder’s forces.

6. Verification of successful Proposer’s experience with similar work, including previous Authority contracts, scheduling capabilities, and financial standing.

7. Understanding of work described in the RFP Documents and the physical constraints associated with the Work.

(6) Contractor shall provide a quotation for the demolition and restoration of the Potomac Greens Drive traffic circle, the demolition and restoration of Old Town Greens tot lots and tennis courts removed for construction access and temporary relocation of tot lot. Old Town Greens tot lot shall be relocated to a site within Old Town Greens HOA.

(7) Contractor shall provide a quotation for all station structure work at and above the platform level, including platforms, mezzanines, and vertical transportation.

(8) Contractor shall provide a quotation for station finishes, which include, but are not limited to:

- paver tiles
- kiosks
- light fixtures
- platform edge
- platform lighting
- bathrooms
- benches

(9) Contractor shall provide a quotation for all costs related to the construction of off-site AC room and access road as well as all electrical equipment, ductbanks, conduit, and connections. Equipment costs include, but are not limited to design, installation, testing, and commissioning.

(10) DELETED.

(11) Contractor shall provide a quotation for the north pedestrian bridge and Entry Pavilion, connecting to the future North Potomac Yard development.

(12) Traction Power, Automatic Train Control, and Communications: Contactor shall provide a quotation for
equipment costs which include, but are not limited to design, supply, installation, and testing. Contractor # shall include cost to implement recommendations to traction power system as described in the July, 2017 Potomac Yard Station Traction Power Study.

(13) Hazardous Waste: The contractor shall provide a quotation for the removal and disposal of hazardous waste from the site. For inclusion in this category, soil must fail the toxicity characteristic leaching procedure. Soil in this category shall be assumed to be contaminated with other constituents, including, but not limited to, arsenic, petroleum, and benzene, toluene, ethyl benzene, and xylenes (BTEX). Quote shall include the cost of characterization, removal, transportation, and disposal.

(14) PCB-Contaminated Soil: The contractor shall provide a quotation for the removal and disposal of PCB-contaminated soil from the site. For inclusion in this category, concentration of PCBs shall exceed 1 mg/kg. Soil in this category shall be assumed to be contaminated with other constituents, including, but not limited to, arsenic, petroleum, and BTEX. Quote shall include the cost of characterization, removal, transportation, and disposal.

(15) Petroleum Contaminated Soil 1: The contractor shall provide a quotation for the removal and disposal of petroleum-contaminated soil from the site. For inclusion in this category, soils shall have a concentration of petroleum hydrocarbons (TPH) equal to or greater than 500 mg/kg, and/or of BTEX equal to or greater than 10 mg/kg. Soils in this category shall be assumed to be contaminated with arsenic above background. Quote shall include the cost of characterization, removal, transportation, and disposal.

(16) Petroleum Contaminated Soil 2: The contractor shall provide a quotation for the removal and disposal of petroleum-contaminated soil from the site. For inclusion in this category, soils shall have a concentration of petroleum hydrocarbons (TPH) equal to or greater than 50 mg/kg, and less than 500 mg/kg, and total BTEX less than 10 mg/kg. Soils in this category shall be assumed to be contaminated with arsenic above background. Quote shall include the cost of characterization, removal, transportation, and disposal.

(17) NOT USED

(18) The City of Alexandria shall waive all fees associated with obtaining City of Alexandria Permits. Fee schedules for all other permits required for the Potomac Yard Station, including, but not limited to, National

Park Service, Virginia Department of Transportation, Corps of Engineers, and any other State or Federal permit required shall be the responsibility of the Design Builder.

Contractor shall provide a quotation for an allowance to cover costs associated with permit fees for any permit fees not expressly waived by the City of Alexandria.

(19) Contractor shall provide an invoice for an allowance applicable to the cost incurred by the Design Builder which is paid directly to the utility companies for fees. Allowance will cover Design Builder costs such as tap and connection fees, applications, and inspections fees. Other utility cost including, but not limited to, design and utility installation do not apply to this allowance and shall be included in the Site Work Bid Item in the Design Builder's proposal.

00 82 04 PROJECT SCHEDULE

Modify Section 00 72 04, PERIOD OF PERFORMANCE AND/OR PROJECT SCHEDULE, to delete Paragraphs A, B, and C, and substitute the following Paragraph and subparagraphs, and Paragraph D:

The Design-Builder shall perform, complete, and advance all Work under this Contract in accordance with the schedule set out:

Interim & Final Work Completion:

a. Milestone 1: Development Special Use Permit (DSUP) submittal to city of Alexandria. **NTP+30 cds**

b. Milestone 2: DSUP approval by city of Alexandria. **NTP+200 cds**

c. Milestone 3: **Construction Access and Trailers:** Complete required demolition of Old Town Greens Park and construction access preparation including construction fencing and gates, erection of Design Builder and WMATA Construction Trailers (Field Office) and parking lot, construction access pedestrian bridge, and all temporary utilities that will be required for the Construction Trailers and construction access throughout the duration of the contract. **NTP+450 cds**

d. Milestone 4: **Approvals and Permits:** Complete design and permitting required to obtain City of Alexandria Site Plan approvals and associated permits, including the issuance of Certificate of Appropriateness and Building Permits - Complete all jurisdictional approval processes including but not limited to the receipt of Final Site Plan Approval from the City of Alexandria, and Board of Architectural Review approvals, as well as all appropriate approvals and permits from the City of Alexandria, National Park Service, and the Corp of Engineers required to construct the Potomac Yard Metrorail Station. **NTP+ 575 cds**

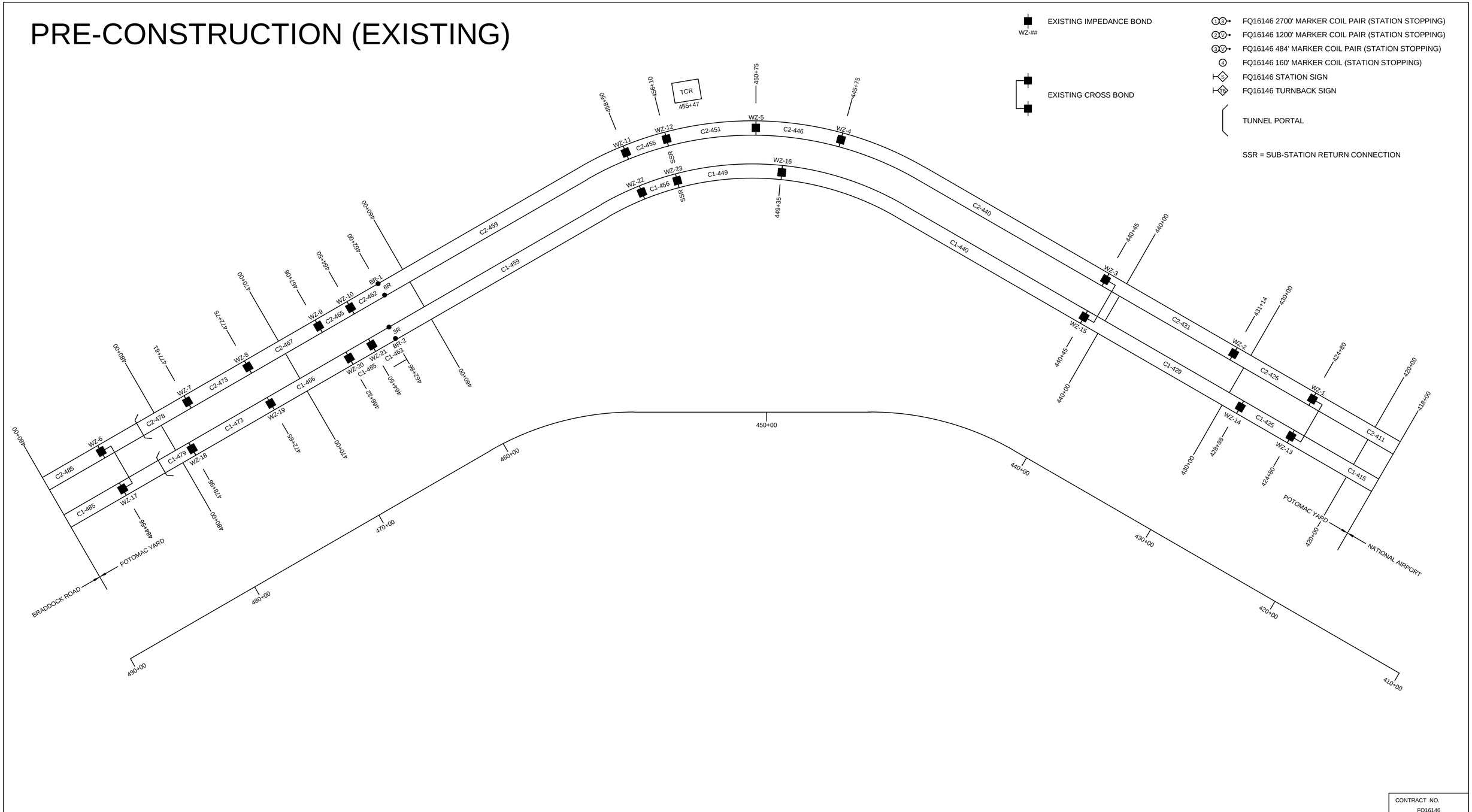
e. Milestone 5: **Complete IT Rooms and Systems Facilities:**– Complete construction of all required communications and IT rooms. The rooms shall be complete and securable, with HVAC, plywood backboard installation on walls, and static resistant flooring, fiber and copper backbone installation and testing and make ready for WMATA installation of IT equipment. All wiring, cables and/or fiber optic lines and appurtenances shall be installed, tested, and commissioned, **NTP+ 1150 cds**

f. Note: WMATA IT Complete Communications, and IT Room Equipment Installation **NTP Milestone 5 + 60 cds**

g. Milestone 6: **Complete Station Structure and Track Work**: Completion of the Station Structure, mezzanines, platforms, and roofs, track work, Automatic Train Control, and Traction Power required for abandonment of existing tracks. Complete initial Safety Certification items. Completion of the AC Room building and equipment, Tie Breaker, Train Control rooms and equipment. Commencement of train service through the Station for the remaining duration of contract. Decommission existing tracks and systems as required to commence construction of the Pedestrian bridges. **NTP+ 1270 cds**

h. Milestone 7: **Final Station Completion-** Complete Station, Pedestrian Bridges, Entry Pavilions, and all ancillary facilities and equipment, and Potomac Yard Park. Conduct final Inspection, complete remaining Safety Certification Items. Complete all building systems and equipment commissioning , testing (Pre-functional & Functional Tests) and systems integration, as well as LEED Commissioning. Complete all required O&M training including videotaping and documentation. Complete submission of all deliverables including final as-builts, warranty documents, lien releases, spare parts etc., Facility ready for WMATA Revenue Service. **NTP+ 1450 cds**.

PRE-CONSTRUCTION (EXISTING)



CONTRACT NO.
FQ16146

DESIGNED	ACC	04/28/2017 DATE
DRAWN	GAV	05/01/2017 DATE
CHECKED	ACC	05/03/2017 DATE
APPROVED	WP	05/10/2017 DATE

REFERENCE DRAWINGS

NUMBER	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION
05/10/17	MM	POTOMAC YARD STATION FQ16146

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

DEPARTMENT OF TRANSIT INFRASTRUCTURE AND ENGINEERING SERVICES
OFFICE OF THE CHIEF ENGINEER, INFRASTRUCTURE

SUBMITTED _____ DATE

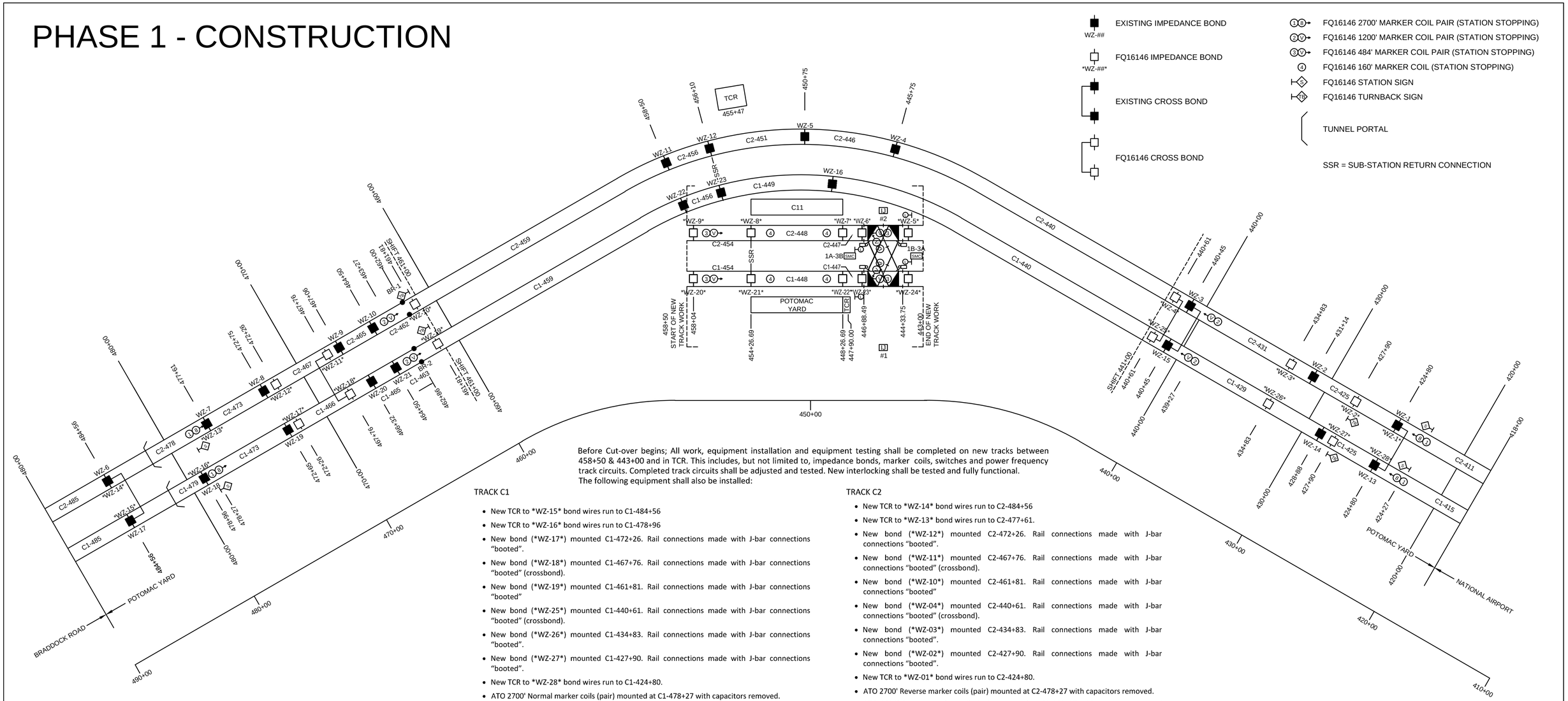
APPROVED _____ CHIEF ENGINEER DATE

SIGNAL AND TRACK WORK
PRE-CONSTRUCTION (EXISTING)

LOCATION: POTOMAC YARD STATION
AUTOMATIC TRAIN CONTROL

SCALE	DRAWING NO.	SHEET NO.
NONE	C11-CP-001	

PHASE 1 - CONSTRUCTION



Before Cut-over begins; All work, equipment installation and equipment testing shall be completed on new tracks between 458+50 & 443+00 and in TCR. This includes, but not limited to, impedance bonds, marker coils, switches and power frequency track circuits. Completed track circuits shall be adjusted and tested. New interlocking shall be tested and fully functional.
The following equipment shall also be installed:

TRACK C1

- New TCR to *WZ-15* bond wires run to C1-484+56
- New TCR to *WZ-16* bond wires run to C1-478+96
- New bond (*WZ-17*) mounted C1-472+26. Rail connections made with J-bar connections "booted".
- New bond (*WZ-18*) mounted C1-467+76. Rail connections made with J-bar connections "booted" (crossbond).
- New bond (*WZ-19*) mounted C1-461+81. Rail connections made with J-bar connections "booted"
- New bond (*WZ-25*) mounted C1-440+61. Rail connections made with J-bar connections "booted" (crossbond).
- New bond (*WZ-26*) mounted C1-434+83. Rail connections made with J-bar connections "booted".
- New bond (*WZ-27*) mounted C1-427+90. Rail connections made with J-bar connections "booted".
- New TCR to *WZ-28* bond wires run to C1-424+80.
- ATO 2700' Normal marker coils (pair) mounted at C1-478+27 with capacitors removed.
- ATO 1200' Normal marker coils (pair) mounted at C1-463+27 with capacitor removed and variable unit disconnected.
- ATO 1200' Reverse marker coils (pair) mounted at C1-439+27 with capacitor removed and variable unit disconnected.
- ATO 2700' Reverse marker coils (pair) mounted at C1-424+27 with capacitors removed.
- ATO 2700' Normal "S" sign mounting pole installed at C1-478+27.
- ATO 2700' Reverse "S" sign mounting pole installed at C1-424+27.
- Turnback 10 sign mounting pole installed at C1-461+81.
- Turnback 20 sign mounting pole installed at C1-427+90.

TRACK C2

- New TCR to *WZ-14* bond wires run to C2-484+56
- New TCR to *WZ-13* bond wires run to C2-477+61.
- New bond (*WZ-12*) mounted C2-472+26. Rail connections made with J-bar connections "booted".
- New bond (*WZ-11*) mounted C2-467+76. Rail connections made with J-bar connections "booted" (crossbond).
- New bond (*WZ-10*) mounted C2-461+81. Rail connections made with J-bar connections "booted"
- New bond (*WZ-04*) mounted C2-440+61. Rail connections made with J-bar connections "booted" (crossbond).
- New bond (*WZ-03*) mounted C2-434+83. Rail connections made with J-bar connections "booted".
- New bond (*WZ-02*) mounted C2-427+90. Rail connections made with J-bar connections "booted".
- New TCR to *WZ-01* bond wires run to C2-424+80.
- ATO 2700' Reverse marker coils (pair) mounted at C2-478+27 with capacitors removed.
- ATO 1200' Reverse marker coils (pair) mounted at C2-463+27 with capacitor removed and variable unit disconnected.
- ATO 1200' Normal marker coils (pair) mounted at C2-439+27 with capacitor removed and variable unit disconnected.
- ATO 2700' Normal marker coils (pair) mounted at C2-424+27 with capacitors removed.
- ATO 2700' Reverse "S" sign mounting pole installed at C2-478+27.
- ATO 2700' Normal "S" sign mounting pole installed at C2-424+27.
- Turnback 14 sign mounting pole installed at C2-461+81.
- Turnback 24 sign mounting pole installed at C2-427+90.

NOTE:

This cut-over plan is an example to be used for planning purposes. Actual cut-over plan shall be prepared by contractor based on contractor's final design.

CONTRACT NO. FQ16146

DESIGNED	ACC	04/28/2017 DATE
DRAWN	GAV	05/01/2017 DATE
CHECKED	ACC	05/03/2017 DATE
APPROVED	WP	05/10/2017 DATE

REFERENCE DRAWINGS

NUMBER	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION
05/10/17	MM	POTOMAC YARD STATION FQ16146

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

DEPARTMENT OF TRANSIT INFRASTRUCTURE AND ENGINEERING SERVICES
OFFICE OF THE CHIEF ENGINEER, INFRASTRUCTURE

SUBMITTED _____ DATE

APPROVED _____ CHIEF ENGINEER DATE

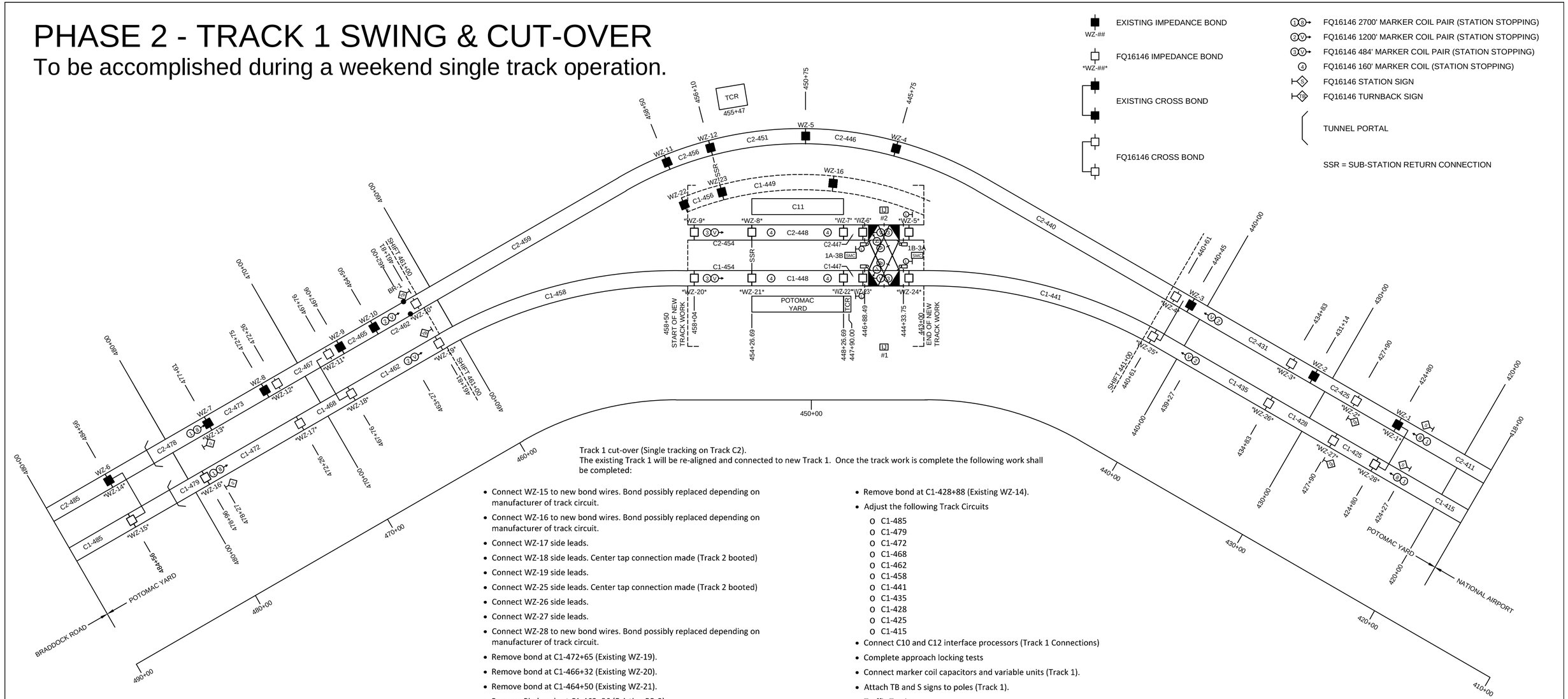
SIGNAL AND TRACK WORK
CONSTRUCTION COMPLETE PRE-CUTOVER

LOCATION: POTOMAC YARD STATION
AUTOMATIC TRAIN CONTROL

SCALE	DRAWING NO.	SHEET NO.
NONE	C11-CP-002	

PHASE 2 - TRACK 1 SWING & CUT-OVER

To be accomplished during a weekend single track operation.



Track 1 cut-over (Single tracking on Track C2).
The existing Track 1 will be re-aligned and connected to new Track 1. Once the track work is complete the following work shall be completed:

- Connect WZ-15 to new bond wires. Bond possibly replaced depending on manufacturer of track circuit.
- Connect WZ-16 to new bond wires. Bond possibly replaced depending on manufacturer of track circuit.
- Connect WZ-17 side leads.
- Connect WZ-18 side leads. Center tap connection made (Track 2 booted)
- Connect WZ-19 side leads.
- Connect WZ-25 side leads. Center tap connection made (Track 2 booted)
- Connect WZ-26 side leads.
- Connect WZ-27 side leads.
- Connect WZ-28 to new bond wires. Bond possibly replaced depending on manufacturer of track circuit.
- Remove bond at C1-472+65 (Existing WZ-19).
- Remove bond at C1-466+32 (Existing WZ-20).
- Remove bond at C1-464+50 (Existing WZ-21).
- Remove Pin bonds at C1-462+86 (Existing BR-2).
- Remove bond at C1-458+50 (Existing WZ-22).
- Remove bond at C1-440+45 (Existing WZ-15).
- Remove bond at C1-428+88 (Existing WZ-14).
- Remove bond at C1-428+88 (Existing WZ-14).
- Adjust the following Track Circuits
  - C1-485
  - C1-479
  - C1-472
  - C1-468
  - C1-462
  - C1-458
  - C1-441
  - C1-435
  - C1-428
  - C1-425
  - C1-415
- Connect C10 and C12 interface processors (Track 1 Connections)
- Complete approach locking tests
- Connect marker coil capacitors and variable units (Track 1).
- Attach TB and S signs to poles (Track 1).
- Traffic Testing
- Control line testing

Safe braking testing can continue throughout the week during non revenue hours or with single tracking on Track 2.

When cut-over is complete, revenue trains will run in manual mode on track C1 with an absolute block between C12-04 signal and C10-26 signal until safe braking tests are complete. Revenue trains will **NOT** service Potomac Yard passenger station.

NOTE:

This cut-over plan is an example to be used for planning purposes. Actual cut-over plan shall be prepared by contractor based on contractor's final design.

CONTRACT NO. FQ16146

DESIGNED	ACC	04/28/2017 DATE
DRAWN	GAV	05/01/2017 DATE
CHECKED	ACC	05/03/2017 DATE
APPROVED	WP	05/10/2017 DATE

REFERENCE DRAWINGS

NUMBER	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION
05/10/17	MM	POTOMAC YARD STATION FQ16146

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

DEPARTMENT OF TRANSIT INFRASTRUCTURE AND ENGINEERING SERVICES
OFFICE OF THE CHIEF ENGINEER, INFRASTRUCTURE

SUBMITTED _____ DATE

APPROVED _____ CHIEF ENGINEER DATE

SIGNAL AND TRACK WORK
TRACK 1 CUT-OVER

LOCATION: POTOMAC YARD STATION
AUTOMATIC TRAIN CONTROL

SCALE	DRAWING NO.	SHEET NO.
NONE	C11-CP-003	

PHASE 3 - TRACK 2 SWING & CUT-OVER

To be accomplished during a weekend single track operation.

EXISTING IMPEDANCE BOND (WZ-##)

FQ16146 IMPEDANCE BOND (*WZ-##*)

EXISTING CROSS BOND

FQ16146 CROSS BOND

FQ16146 2700' MARKER COIL PAIR (STATION STOPPING)

FQ16146 1200' MARKER COIL PAIR (STATION STOPPING)

FQ16146 484' MARKER COIL PAIR (STATION STOPPING)

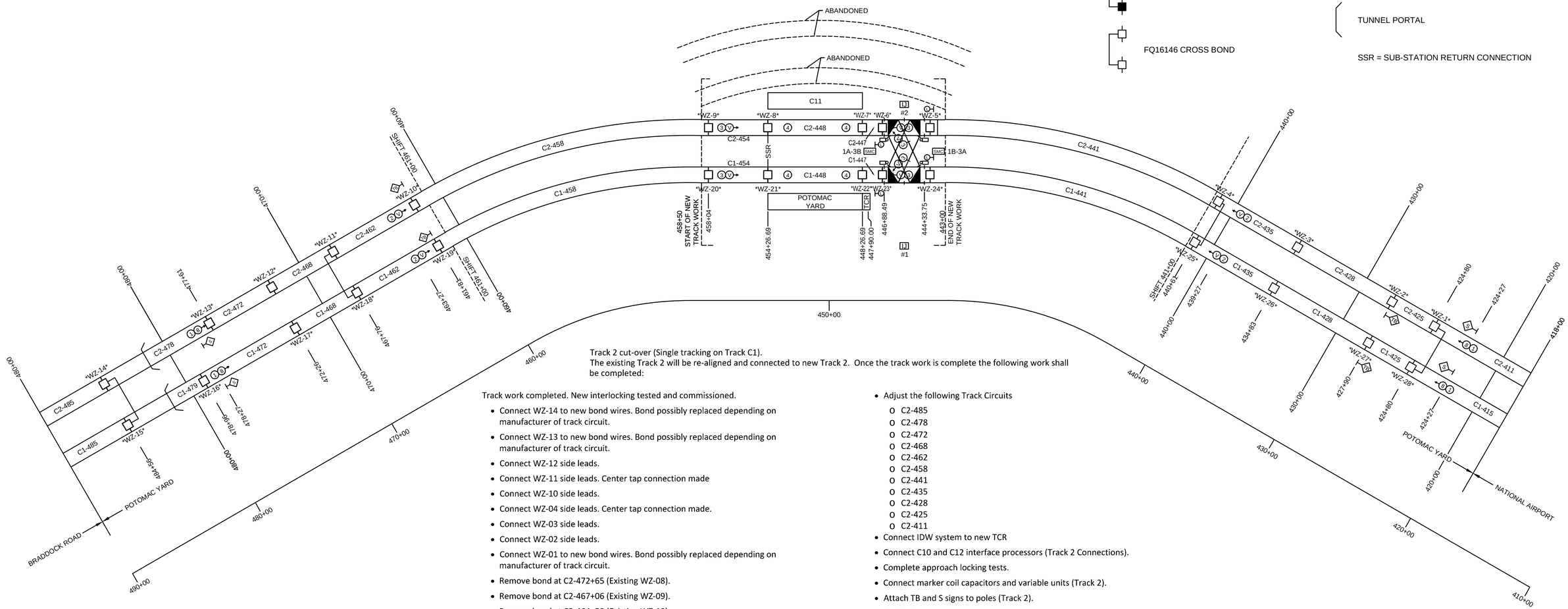
FQ16146 160' MARKER COIL (STATION STOPPING)

FQ16146 STATION SIGN

FQ16146 TURNBACK SIGN

TUNNEL PORTAL

SSR = SUB-STATION RETURN CONNECTION



Track 2 cut-over (Single tracking on Track C1).
The existing Track 2 will be re-aligned and connected to new Track 2. Once the track work is complete the following work shall be completed:

Track work completed. New interlocking tested and commissioned.

- Connect WZ-14 to new bond wires. Bond possibly replaced depending on manufacturer of track circuit.
- Connect WZ-13 to new bond wires. Bond possibly replaced depending on manufacturer of track circuit.
- Connect WZ-12 side leads.
- Connect WZ-11 side leads. Center tap connection made
- Connect WZ-10 side leads.
- Connect WZ-04 side leads. Center tap connection made.
- Connect WZ-03 side leads.
- Connect WZ-02 side leads.
- Connect WZ-01 to new bond wires. Bond possibly replaced depending on manufacturer of track circuit.
- Remove bond at C2-472+65 (Existing WZ-08).
- Remove bond at C2-467+06 (Existing WZ-09).
- Remove bond at C2-464+50 (Existing WZ-10).
- Remove Pin bonds at C2-462+00 (Existing BR-1).
- Remove bond at C2-458+50 (Existing WZ-11) If necessary.
- Remove bond at C2-440+45 (Existing WZ-03).
- Remove bond at C2-431+14 (Existing WZ-02).

- Adjust the following Track Circuits
  - o C2-485
  - o C2-478
  - o C2-472
  - o C2-468
  - o C2-462
  - o C2-458
  - o C2-441
  - o C2-435
  - o C2-428
  - o C2-425
  - o C2-411
- Connect IDW system to new TCR
- Connect C10 and C12 interface processors (Track 2 Connections).
- Complete approach locking tests.
- Connect marker coil capacitors and variable units (Track 2).
- Attach TB and S signs to poles (Track 2).
- Traffic Testing.
- Control line testing.
- Crossover testing would be completed once all straight though testing is done.

Safe braking testing can continue throughout the week during non revenue hours or with single tracking on Track 1.

When cut-over is complete, revenue trains will run in manual mode on both tracks C1 and C2 with an absolute block between C12 and C10 interlockings until safe braking tests are complete. Revenue trains can service Potomac Yard passenger station.

NOTE:

This cut-over plan is an example to be used for planning purposes. Actual cut-over plan shall be prepared by contractor based on contractor's final design.

CONTRACT NO. FQ16146

DESIGNED	ACC	04/28/2017 DATE
DRAWN	GAV	05/01/2017 DATE
CHECKED	ACC	05/03/2017 DATE
APPROVED	WP	05/10/2017 DATE

REFERENCE DRAWINGS

NUMBER	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION
05/10/17	MM	POTOMAC YARD STATION FQ16146

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

DEPARTMENT OF TRANSIT INFRASTRUCTURE AND ENGINEERING SERVICES
OFFICE OF THE CHIEF ENGINEER, INFRASTRUCTURE

SUBMITTED _____ DATE

APPROVED _____ CHIEF ENGINEER DATE

SIGNAL AND TRACK WORK
TRACK 2 CUT-OVER

LOCATION: POTOMAC YARD STATION
AUTOMATIC TRAIN CONTROL

SCALE	DRAWING NO.	SHEET NO.
NONE	C11-CP-004	

RFP FQ 16146 - Potomac Yard Rail Station

RFI No.	Question	Response
214	RFP Amendment 4 / Paragraph 8 /Page 8 indicates Amendment #5 containing the Traction Power Upgrades information would be provided by 7/31/17. Please provide this information.	Traction Power information is provided in Amendment 5.
215	Please provide the Revit Model and CAD files of all the RFP and amendments design and engineering drawings, survey and any other base maps available, they are urgently needed in order to progress ATC development.	Response will be provided in a future amendment.
216	In the Specification Section 28 40 06, Part 2.01 A, we kindly request to add the following. "Other manufacturers are acceptable to supply RTUs to WMATA on the condition the proposed equipment is better or equal to the requirements in this specification."	Response will be provided in a future amendment.
217	Volume 1 - 01 11 00 - 1.01 - B.2: States construction of the AC Room shall not commence prior to transition of revenue trains through the station. Please clarify this requirement and reasoning?	To allow adequate clearances from the live tracks during the construction of the AC Room.
218	General – Fire Rated Cables – with the delisting from Underwriters Laboratory (UL) of fire rated cables (i.e. UL 2196) when used with GRS conduit, the fire code (NFPA 72) requirement for meeting a 2 hour or 1 hour fire rating for the fire alarm and EVAC cable systems will not be achievable utilizing GRS conduit. What is WMATA's directive for meeting NFPA 72 Fire Code regarding Fire Alarm, and PA EVAC cable systems?	Contractor shall comply with NFPA 72.
219	General – ETS System - The existing ETS system for the Blue Line is based on the older relay based design. WMATA has recently introduced a newer ETS design on the Silver Line to include a relay based systems with a parallel communication based PLC / RTU monitoring system. What is WMATA's directive for implementing this new communication based monitoring ETS system for this project?	Response will be provided in a future amendment.
220	Our initial review of Amendment 4 and the contract documents indicates the following as missing. Please provide: a. ETS specifications. (SCADA info is provided in Amendment 4 which is part of the ETS specification but not all of it) b. Drawings: i. C11-CTVR-001 Signal and Trackwork Pre-Construction (Existing) ii. C11-CTVR-002 Signal and Trackwork Construction Complete Pre-Cutover iii. C11-CTVR-003 Signal and Trackwork Track 1 Cut-Over iv. C11-CTVR-004 Signal and Trackwork Track 2 Cut-Over v. DD-TW-CR- 013 ST-TW-CR-013 Composite Rail with Type A Protection Cover vi. DD-TW-CR-014 ST-TW-CR-014 Type A Protection Cover Assembly Details and Sections vii. DD-TW-CR-015 ST-TW-CR-015 Composite Rail with Type B Protection Board viii. DD-TW-CR-016 ST-TW-CR-016 Type B Protection Cover Assembly Details and Sections	Items b.i., b.ii., b.iii. And b.iv. are included in Amendment 5; however the drawing numbers have been changed to the numbers listed in the cover letter (the new numbering format is C11-CP-XXX). The other items will be included in a future amendment.
221	Previously submitted RFI's 208 & 209 attempted to confirm the basis for the conceptual structural design presented in the project directive drawings. The responses did not address this. Acknowledging the response to RFI 208 that dimensions for structural elements are minimum requirements, it is important to understand the basis for these minimums, especially in light of very significant changes in the latest WMATA design criteria, design loads due to wind being just one example. In so doing the level of effort needed for design going forward can be understood, and the potential variability in resulting member sizes can be accounted for. Kindly provide the design criteria and/or building code(s) used to determine sizes and dimensions for the structural members as provided in the project directive drawings.	Response will be provided in a future amendment.
222	We respectfully request that WMATA set up an additional one on one meeting for teams to discuss potential ATC concepts in a preliminary format to vet potential acceptability prior to investing the significant resources necessary to fully develop the ATC's content, as required under specification 00 24 10 part B, for formal consideration.	See revised schedule included in Amendment 5.

AECOM

Washington Metropolitan Area Transit Authority

Potomac Yard Station
Traction Power System Study

July, 2017

60248359

Potomac Yard Station

Traction Power System Study

Study to assess the impact in the Traction Power System of the construction of a new station located along the existing Blue and Yellow lines between the National Airport and Braddock Road Metrorail Stations.

Quality information

Document name	Ref	Prepared for	Prepared by	Date	Reviewed by
Potomac Yard Station Traction Power System Study	60248359-REP-RS-001-161018	AECOM USA	AECOM Madrid	2017/04/27	Jorge Garzón

Revision history

Revision	Revision date	Details	Name	Position
01	2017/04/27		Jorge Garzón	
02	2017/05/09		Daniel Campos	
03	2017/06/12		Ian Lazzara	
04	2017/07/14		Jorge Garzón	

This document has been prepared by AECOM Limited for the sole use of our client (the "Client") and in accordance with generally accepted consultancy principles, the budget for fees and the terms of reference agreed between AECOM Limited and the Client. Any information provided by third parties and referred to herein has not been checked or verified by AECOM Limited, unless otherwise expressly stated in the document. No third party may rely upon this document without the prior and express written agreement of AECOM Limited.

Executive Summary

The City of Alexandria in cooperation with the Washington Metropolitan Area Transit Authority (WMATA) proposes construction of a new Metrorail station located along the existing Blue and Yellow lines between the National Airport and Braddock Road Metrorail Stations. The purpose of the proposed Potomac Yard Metrorail Station is to improve accessibility to the regional Metrorail system in the Potomac Yard area and provide more transportation choices for current and future residents, employees, and businesses by establishing a new access point.

AECOM performed a load simulation to model the new Potomac Yard Metrorail Station impacts to the existing Traction Power System. In addition, the load study recommended upgrades to the existing system to meet WMATA requirements and modeled the system upgrades as well as impacts to the upgraded system with the addition of a new tie breaker station (TBS) at the proposed Potomac Yard Metrorail Station and modeling of that system with the removal of the existing C11 TBS.

Three operational scenarios were simulated to fully evaluate Traction Power System configurations against the WMATA Traction Power System requirements: Normal (all equipment in service); Abnormal (single rectifier/transformer outage); and Emergency (complete traction power substation (TPSS) out of service). In addition, three metrics were analyzed to evaluate each of the Traction Power System configurations: train voltages; train currents; train power availability; and rail-to-ground voltages. The simulation results, as shown in the **Table ES-1** (Voltages thresholds), **ES-2** (Power thresholds) and **ES-3** (Current thresholds), show that the existing Traction Power System is not properly sized to introduce the new Potomac Yard Metrorail Station under the normal, abnormal and emergency operational conditions.

Table ES-1. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Normal Operation	525	**505**[1]	75	85	58.1
Abnormal operation. National Airport	**514**	499	79	85	54
Abnormal operation. Potomac Yard	514	496	82	85	52
Abnormal operation. Braddock Rd	519	504	77	84	57.7
Emergency operation. National Airport	**440**[2]	**436**[3]	103	105	24.1
Emergency operation. Potomac Yard	**413**[4]	**433**[5]	104	104	26.1
Emergency operation. Braddock Rd	475	458	85	85	39.8

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 525V less than 14 seconds*
[2] *below 450V less than 8 seconds*
[3] *below 450V less than 15 seconds*
[4] *below 450V less than 3 seconds*
[5] *below 450V less than 3 seconds*

Table ES-2. TPSS power for normal, abnormal and emergency operation.

Subestations	TPS	TPS Rating	TPS config	Normal operation Baseline TPS Loading	Outage condition 1 Rect Outage Loading	Outage condition TPS Outage Loading
18TH & FERN	C09	4 MW	2+2	**113 %**	122 %	**190 %**
NATIONAL AIRPORT	C10	7 MW	2+2+3	98 %	**152 %**	135 %
POTOMAC YARD	C11	6 MW	3+3	**137 %**	**232 %**	**175 %**
BRADDOCK ROAD	C12	9 MW	3+3+3	84 %	114 %	119 %
DUKE STREET	C97	6 MW	2+2+2	101 %	105 %	141 %

Note: Baseline loading must be <100%
Contingency loading must be <146%

Therefore, system upgrades were recommended and simulated such as increasing specific TPSS power, increase of feeder quantities, replacement of steel contact rail to composite rail at specific track locations and resizing of specific feeder breakers**, Table 23**.

Simulations of the upgraded system have determined that all of the metrics analyzed under the three operational scenarios met WMATA requirements, except the train voltage metric when the Potomac Yard Substation was out of service, as shown in **Table ES-3**. The proposed system upgrades have been analyzed; however they have not been fully designed, coordinated or incorporated into the Potomac Yard Metrorail Station design.

Table ES-3. Upgraded system. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Normal Operation	541	**533**	70	91	73.7
Abnormal operation. National Airport	541	528	75	93	70.0
Abnormal operation. Potomac Yard	541	526	73	93	71.6
Abnormal operation. Braddock Rd	541	533	73	90	73.5
Emergency operation. National Airport	454	450	111	117	40.1
Emergency operation. Potomac Yard	**443**[1]	464	117	113	40.5
Emergency operation. Braddock Rd	480	465	99	97	43.3

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 450V less than 3 seconds*

Additionally, two track system configurations were simulated with the upgraded system:

- Installation of a new TBS close to Potomac Yard Station (location = 447+50 CLF).
- Installation of a new TBS close to Potomac Yard Station (location = 447+50 CLF) and the removal of C11 TBS (Potomac RR Yard North Tie Breaker Station).

The two track system configurations were only simulated under the normal operation and emergency operation (complete loss of a TPSS). Neither the abnormal operation conditions nor the loss of Braddock Road TPSS were simulated because the existing system met the thresholds for those operational scenarios.

The simulation results revealed that all the analysis metrics (train voltages, train currents, etc.) met the WMATA Traction Power System requirements except when the C11 TBS was removed. Adding the new TBS with the existing C11 TBS slightly improves the performance of the upgraded system, specifically the train voltages of the upgraded system under the emergency scenario. **Table ES-4** and **Table ES-5** summarize the upgraded system with the two track system configurations under the normal and two emergency operational scenarios (failed National Airport TPSS and failed Potomac Yard TPSS, respectively).

Table ES-4. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Normal Operation.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Upgraded system	541	533	70	91	73.7
Upgraded system with additional TBS	541	533	70	91	73.7
Upgraded system with additional TBS and without C11 TBS	541	528	70	91	72.0

Table ES-5. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Emergency Operation.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Upgraded system National Airport out of service	454	450	111	117	40.1
Upgraded system with additional TBS National Airport out of service	454	450	111	117	40.2

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Upgraded system with additional TBS and without C11 TBS National Airport out of service	451	**445**[1]	108	114	37.9
Upgraded system Potomac Yard out of service	**443**[2]	464	117	113	40.1
Upgraded system with additional TBS Potomac Yard out of service	454	464	122	113	41.6
Upgraded system with additional TBS and without C11 TBS Potomac Yard out of service	**444**[2]	463	120	115	38.3

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 450V less than 3 seconds*
[2] *below 450V less than 2 seconds*

Additional tables and graphs supporting the conclusions above are found in the body of this report. This report is organized as follows:

- **Section 1** provides an overview of the project, defines abbreviations and acronyms, and provides a list of reference documents and drawings relevant to this report.
- **Section 2** describes data inputs and assumptions used to model simulations.
- **Section 3** defines the simulated scenarios.
- **Section 4** describes and presents existing system simulations and results.
- **Section 5** describes and presents the recommended upgraded system simulations and results.
- **Section 6** details the simulation results of the upgraded system with the new Potomac Yard TBS and new Potomac Yard TBS and removal of the existing C11 TBS.

The following appendices are included in this report:

- **Appendix 1** tabulates the TPSS currents, feeder quantities and breaker ratings that require an upgrade.
- **Appendix 2** shows the RMS current graphs.
- **Appendix 3** shows the current vs voltage graphs of all trains in all scenarios. The performance limitation of the rolling stock is appreciated.

Table of Contents

Executive Summary 4

Introduction 14

1.1. Abbreviations and Acronyms 15

1.2. Reference Documents and Drawings 16

Input Data and Assumptions 18

2.1. Constraints 18

2.2. Railway Line Alignment 18

2.3. Location and Characteristics of the TPSS and TBS and Feeders 18

2.4. Electrical Parameters of the Traction Power System 20

2.5. Rolling Stock 21

2.6. Headway 22

Simulated Scenarios 24

3.1. Normal Operation 24

3.2. Abnormal Operation 24

3.3. Emergency Operation 24

Results of the Simulations 26

4.1. Normal Operation 26

4.2. Abnormal Operation 28

4.3. Emergency Operation 36

4.4. Simulation Results Summary 43

System Upgrades and Simulations 47

5.1. TPSS and Feeders Upgrade 47

5.2. Contact Rail Upgrade 48

5.3. Feeder Breakers Upgrade 49

5.4. Upgrade System Simulations 50

5.5. Simulation Results Summary 66

System Upgrades and Simulations with an Additional TBS at Potomac Yard 71

6.1. Tie Breaker Stations 71

6.2. Simulations 71

6.3. Simulation Results Summary 84

Conclusions 88

7.1. Conclusions 88

Appendix 1. RMS Current Tables. 92

Appendix 2. RMS Current Graphs. 105

Current System 105

Upgraded System 123

Appendix 3. Currents vs Voltages Graphs. 142

Current System 142

Upgraded System 146

List of Tables

Table 1. Abbreviations and acronyms. 15
Table 2. Reference documents provided as input data. 16
Table 3.Existing TPSS, TBS and feeders. 18
Table 4. TPSS currents for normal and abnormal operation. 44
Table 5. TPSS currents for emergency operation. 44
Table 6 TPSS power for normal, abnormal and emergency operation. 44
Table 7. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. 45
Table 8 Positive and Negative feeder currents ratings. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%. 45
Table 9. TPSS and feeders upgrade. 47
Table 10. Feeder breakers upgrade. 49
Table 11. Upgraded System. TPSS currents for normal and abnormal operation. 68
Table 12. Upgraded system. TPSS currents for normal and emergency operation. 68
Table 13 TPSS power for normal, abnormal and emergency operation. 68
Table 14. Upgraded system. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. 69
Table 15 Positive and Negative feeder currents ratings. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%. 69
Table 16. TBS location. 71
Table 17. Upgraded system with new TBS. Train and rail-to-ground voltages for normal and emergency operation and power availability. 85
Table 18. Upgraded system with new TBS and without C11 TBS. Train and rail-to-ground voltages for normal and emergency operation and power availability. 86
Table 19. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Normal Operation. 86
Table 20. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Emergency Operation. National Airport Substation Out of Service. 86
Table 21. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Emergency Operation. Potomac Substation Out of Service. 86
Table 22 Rectifier Upgrades 89
Table 23 Positive and Negative feeder cable Upgrades 89
Table 24 Positive Feeder breaker Upgrades 89
Table 25. Current system. Positive and Negative feeder currents and breaker ratings. 92
Table 26 Current system. Positive and Negative feeder currents and breaker ratings. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%. 95
Table 27. Upgraded system. Positive and Negative feeder currents and new upgrades required. 98
Table 28 Upgraded system. Positive and Negative feeder currents and new upgrades required. 101

List of Figures

Figure 1. Metrorail System Map. Metrorail Pocket Guide 50.532 (REV. 4/14). 14
Figure 2. Location of the proposed Potomac Yard Metrorail Station, between National Airport and Braddock Road Metrorail Stations. 15
Figure 3. Railcar Electrical Performance Characteristics. 22
Figure 4. Train voltages in the track section under normal operation. 26
Figure 5. Train currents in the track section under normal operation. 27
Figure 6. Power availability in the track section under normal operation. 27
Figure 7. Rail-to-ground voltages in the track section under normal operation. 28
Figure 8.Train voltages in the track section for National Airport Substation under abnormal operation. 29
Figure 9.Train currents in the track section for National Airport Substation under abnormal operation. 29
Figure 10. Power availability in the track section for National Airport Substation under abnormal operation. 30
Figure 11.Rail-to-ground voltages in the track section for National Airport Substation under abnormal operation. 30
Figure 12.Train voltages in the track section for Potomac Yard Substation under abnormal operation. 31
Figure 13.Train currents in the track section for Potomac Yard Substation under abnormal operation. 31
Figure 14. Power availability in the track section for Potomac Yard Substation under abnormal operation. 32
Figure 15.Rail-to-ground voltages in the track section for Potomac Yard Substation under abnormal operation. 32
Figure 16.Train voltages in the track section for Braddock Road Substation under abnormal operation. 33
Figure 17.Train currents in the track section for Braddock Road Substation under abnormal operation. 34
Figure 18. Power availability in the track section for Braddock Road Substation under abnormal operation. 34
Figure 19.Rail-to-ground voltages in the track section for Braddock Road Substation under abnormal operation. 35
Figure 20.Train voltages in the track section for National Airport under emergency operation. 36

Figure 21.Train currents in the track section for National Airport under emergency operation. 36
Figure 22. Power availability in the track section for National Airport under emergency operation. 37
Figure 23.Rail-to-ground voltages in the track section for National Airport under emergency operation. 37
Figure 24.Train voltages in the track section for Potomac Yard under emergency operation. 38
Figure 25.Train currents in the track section for Potomac Yard under emergency operation. 39
Figure 26. Power availability in the track section for Potomac Yard under emergency operation. 39
Figure 27.Rail-to-ground voltages in the track section for Potomac Yard under emergency operation. 40
Figure 28.Train voltages in the track section for Braddock Road under emergency operation. 40
Figure 29.Train currents in the track section for Braddock Road under emergency operation. 41
Figure 30. Power availability in the track section for Braddock Road under emergency operation. 41
Figure 31.Rail-to-ground voltages in the track section for Braddock Road under emergency operation. 42
Figure 32. Upgraded system. Train voltages in the track section under normal operation. 50
Figure 33. Upgraded system. Train currents in the track section under normal operation. 51
Figure 34. Upgraded system. Power availability in the track section under normal operation. 51
Figure 35. Upgraded system. Rail-to-ground voltages in the track section under normal operation. 52
Figure 36. Upgraded system. Train voltages in the track section for National Airport Substation under abnormal operation. 53
Figure 37. Upgraded system. Train currents in the track section for National Airport Substation under abnormal operation. 53
Figure 38. Upgraded system. Power availability in the track section for National Airport Substation under abnormal operation. 54
Figure 39. Upgraded system. Rail-to-ground voltages in the track section for National Airport Substation under abnormal operation. 54
Figure 40. Upgraded system. Train voltages in the track section for Potomac Yard Substation under abnormal operation. 55
Figure 41. Upgraded system. Train currents in the track section for Potomac Yard Substation under abnormal operation.55
Figure 42. Upgraded system. Power availability in the track section for Potomac Yard Substation under abnormal operation. 56
Figure 43. Upgraded system. Rail-to-ground voltages in the track section for Potomac Yard Substation under abnormal operation. 56
Figure 44. Upgraded system. Train voltages in the track section for Braddock Road Substation under abnormal operation. 57
Figure 45. Upgraded system. Train currents in the track section for Braddock Road Substation under abnormal operation. 58
Figure 46. Upgraded system. Power availability in the track section for Braddock Road Substation under abnormal operation. 58
Figure 47. Upgraded system. Rail-to-ground voltages in the track section for Braddock Road Substation under abnormal operation. 59
Figure 48. Upgraded system. Train voltages in the track section for National Airport under emergency operation. 59
Figure 49. Upgraded system. Train currents in the track section for National Airport under emergency operation. 60
Figure 50. Upgraded system. Power availability in the track section for National Airport under emergency operation. 60
Figure 51. Upgraded system. Rail-to-ground voltages in the track section for National Airport under emergency operation. 61
Figure 52. Upgraded system. Train voltages in the track section for Potomac Yard under emergency operation. 62
Figure 53. Upgraded system. Train currents in the track section for Potomac Yard under emergency operation. 62
Figure 54. Upgraded system. Power availability in the track section for Potomac Yard under emergency operation. 63
Figure 55. Upgraded system. Rail-to-ground voltages in the track section for Potomac Yard under emergency operation.63
Figure 56. Upgraded system. Train voltages in the track section for Braddock Road under emergency operation. 64
Figure 57. Upgraded system. Train currents in the track section for Braddock Road under emergency operation. 64
Figure 58. Upgraded system. Power availability in the track section for Braddock Road under emergency operation. 65
Figure 59. Upgraded system. Rail-to-ground voltages in the track section for Braddock Road under emergency operation. 65
Figure 60. Upgraded system with the new TBS. Train voltages in the track section under normal operation. 72
Figure 61. Upgraded system with the new TBS. Train currents in the track section under normal operation. 72
Figure 62. Upgraded system with the new TBS. Power availability in the track section under normal operation. 73
Figure 63. Upgraded system with the new TBS. Rail-to-ground voltages in the track section under normal operation. 73
Figure 64. Upgraded system with the new TBS and without C11 TBS. Train voltages in the track section under normal operation. 74
Figure 65. Upgraded system with the new TBS and without C11 TBS. Train currents in the track section under normal operation. 74
Figure 66. Upgraded system with the new TBS and without C11 TBS. Power availability in the track section under normal operation. 75

Figure 67. Upgraded system with the new TBS and without C11 TBS. Rail-to-ground voltages in the track section under normal operation. 75
Figure 68. Upgraded system with the new TBS. Train voltages in the track section for National Airport under emergency operation. 76
Figure 69. Upgraded system with the new TBS. Train currents in the track section for National Airport under emergency operation. 76
Figure 70. Upgraded system with the new TBS. Power availability in the track section for National Airport under emergency operation. 77
Figure 71. Upgraded system with the additional TBS. Rail-to-ground voltages in the track section for National Airport under emergency operation. 77
Figure 72. Upgraded system with new TBS and without C11 TBS. Train voltages in the track section for National Airport under emergency operation. 78
Figure 73. Upgraded system with the new TBS and without C11 TBS. Train currents in the track section for National Airport under emergency operation. 78
Figure 74. Upgraded system with the new TBS and without C11 TBS. Power availability in the track section for National Airport under emergency operation. 79
Figure 75. Upgraded system with the new TBS and without C11 TBS. Rail-to-ground voltages in the track section for National Airport under emergency operation. 79
Figure 76. Upgraded system with the new TBS. Train voltages in the track section for Potomac Yard under emergency operation. 80
Figure 77. Upgraded system with the new TBS. Train currents in the track section for Potomac Yard under emergency operation. 80
Figure 78. Upgraded system with the new TBS. Power availability in the track section for Potomac Yard under emergency operation. 81
Figure 79. Upgraded system with the new TBS. Rail-to-ground voltages in the track section for Potomac Yard under emergency operation. 81
Figure 80. Upgraded system with the new TBS and without C11 TBS. Train voltages in the track section for Potomac Yard under emergency operation. 82
Figure 81. Upgraded system with the new TBS and without C11 TBS. Train currents in the track section for Potomac Yard under emergency operation. 82
Figure 82. Upgraded system with the new TBS and without C11 TBS. Power availability in the track section for Potomac Yard under emergency operation. 83
Figure 83. Upgraded system with the new TBS and without C11 TBS. Rail-to-ground voltages in the track section for Potomac Yard under emergency operation. 83
Figure 84.Instant and RMS currents for 18th and Fern Substation under normal operation. 105
Figure 85.Instant and RMS currents for National Airport Substation under normal operation 106
Figure 86.Instant and RMS currents for Potomac Yard Substation under normal operation. 106
Figure 87. Instant and RMS currents for Braddock Road Substation under normal operation. 107
Figure 88.Instant and RMS currents for Duke Street Substation under normal operation. 107
Figure 89.18th and Fern Substation Instant and RMS currents for National Airport Substation under abnormal operation. 108
Figure 90. National Airport Substation Instant and RMS currents for National Airport Substation under abnormal operation. 108
Figure 91. Potomac Yard Substation Instant and RMS currents for National Airport Substation under abnormal operation. 109
Figure 92. Braddock Road Substation Instant and RMS currents for National Airport Substation under abnormal operation. 109
Figure 93. Duke Street Substation Instant and RMS currents for National Airport Substation under abnormal operation. 110
Figure 94. 18th and Fern Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 111
Figure 95. National Airport Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 111
Figure 96. Potomac Yard Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation 112
Figure 97. Braddock Road Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 112
Figure 98. Duke Street Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. . 113
Figure 99. 18th and Fern Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 114
Figure 100. National Airport Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 114
Figure 101. Potomac Yard Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 115

Figure 102. Braddock Road Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 115
Figure 103. Duke Street Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 116
Figure 104. 18th and Fern Substation Instant and RMS currents for National Airport under emergency operation. 117
Figure 105. Potomac Yard Substation Instant and RMS currents for National Airport under emergency operation. 117
Figure 106. Braddock Road Substation Instant and RMS currents for National Airport under emergency operation. 118
Figure 107. Duke Street Substation Instant and RMS currents for National Airport under emergency operation. 118
Figure 108. 18th and Fern Substation Instant and RMS currents for Potomac Yard under emergency operation. 119
Figure 109. National Airport Substation Instant and RMS currents for Potomac Yard under emergency operation. 119
Figure 110. Braddock Road Substation Instant and RMS currents for Potomac Yard under emergency operation. 120
Figure 111. Duke Street Substation Instant and RMS currents for Potomac Yard under emergency operation. 120
Figure 112. 18th and Fern Substation Instant and RMS currents for Braddock Road under emergency operation. 121
Figure 113. National Airport Substation Instant and RMS currents for Braddock Road under emergency operation. 121
Figure 114. Potomac Yard Substation Instant and RMS currents for Braddock Road under emergency operation. 122
Figure 115. Duke Street Substation Instant and RMS currents for Braddock Road under emergency operation. 122
Figure 116. Upgraded system. Instant and RMS currents for 18th and Fern Substation under normal operation. 123
Figure 117. Upgraded system. Instant and RMS currents for National Airport Substation under normal operation. 124
Figure 118. Upgraded system. Instant and RMS currents for Potomac Yard Substation under normal operation. 124
Figure 119. Upgraded system. Instant and RMS currents for Braddock Road Substation under normal operation. 125
Figure 120. Upgraded system. Instant and RMS currents for Duke Street Substation under normal operation. 125
Figure 121. Upgraded system. 18th and Fern Substation Instant and RMS currents for National Airport Substation under abnormal operation. 126
Figure 122. Upgraded system. National Airport Substation Instant and RMS currents for National Airport Substation under abnormal operation. 126
Figure 123. Upgraded system. Potomac Yard Substation Instant and RMS currents for National Airport Substation under abnormal operation. 127
Figure 124. Upgraded system. Braddock Road Substation Instant and RMS currents for National Airport Substation under abnormal operation. 127
Figure 125. Upgraded system. Duke Street Substation Instant and RMS currents for National Airport Substation under abnormal operation. 128
Figure 126. Upgraded system. 18th and Fern Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 129
Figure 127. Upgraded system. National Airport Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 129
Figure 128. Upgraded system. Potomac Yard Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 130
Figure 129. Upgraded system. Braddock Road Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 130
Figure 130. Upgraded system. Duke Street Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation. 131
Figure 131. Upgraded system. 18th and Fern Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 132
Figure 132. Upgraded system. National Airport Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 132
Figure 133. Upgraded system. Potomac Yard Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 133
Figure 134. Upgraded system. Braddock Road Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 133
Figure 135. Upgraded system. Duke Street Substation Instant and RMS currents for Braddock Road Substation under abnormal operation. 134
Figure 136. Upgraded system. 18th and Fern Substation Instant and RMS currents for National Airport under emergency operation. 135
Figure 137. Upgraded system. Potomac Yard Substation Instant and RMS currents for National Airport under emergency operation. 135
Figure 138. Upgraded system. Braddock Road Substation Instant and RMS currents for National Airport under emergency operation. 136
Figure 139. Upgraded system. Duke Street Substation Instant and RMS currents for National Airport under emergency operation. 136
Figure 140. Upgraded system. 18th and Fern Substation Instant and RMS currents for Potomac Yard under emergency operation. 137
Figure 141. Upgraded system. National Airport Substation Instant and RMS currents for Potomac Yard under emergency operation. 137

Figure 142. Upgraded system. Braddock Road Substation Instant and RMS currents for Potomac Yard under emergency operation. 138
Figure 143. Upgraded system. Duke Street Substation Instant and RMS currents for Potomac Yard under emergency operation. 138
Figure 144. Upgraded System. 18th and Fern Substation Instant and RMS currents for Braddock Road under emergency operation. 139
Figure 145. Upgraded system. National Airport Substation Instant and RMS currents for Braddock Road under emergency operation. 139
Figure 146. Upgraded system. Potomac Yard Substation Instant and RMS currents for Braddock Road under emergency operation. 140
Figure 147. Upgraded system. Duke Street Substation Instant and RMS currents for Braddock Road under emergency operation. 140
Figure 148. Currents vs Voltages under normal operation. 142
Figure 149. Currents vs Voltages under National Airport substation abnormal operation. 142
Figure 150. Currents vs Voltages under Potomac Yard substation abnormal operation. 143
Figure 151. Currents vs Voltages under Braddock Road substation abnormal operation. 143
Figure 152. Currents vs Voltages under National Airport substation emergency operation. 144
Figure 153. Currents vs Voltages under Potomac Yard substation emergency operation. 144
Figure 154. Currents vs Voltages under Braddock Road substation emergency operation. 145
Figure 155. Currents vs Voltages under normal operation. 146
Figure 156. Currents vs Voltages under National Airport substation abnormal operation. 146
Figure 157. Currents vs Voltages under Potomac Yard substation abnormal operation. 147
Figure 158. Currents vs Voltages under Braddock Road substation abnormal operation. 147
Figure 159. Currents vs Voltages under National Airport substation emergency operation. 148
Figure 160. Currents vs Voltages under Potomac Yard substation emergency operation. 148
Figure 161. Currents vs Voltages under Braddock Road substation emergency operation. 149

Introduction

01

Introduction

The Washington Metropolitan Area Transit Authority (WMATA) Metrorail System consists of six Metrorail lines (Red, Orange, Silver, Blue, Yellow, and Green). Today, Metrorail serves 91 stations (47 subway, 38 surface, and six aerial stations) and has 118 miles of track. All stations and trains are accessible to people with disabilities.

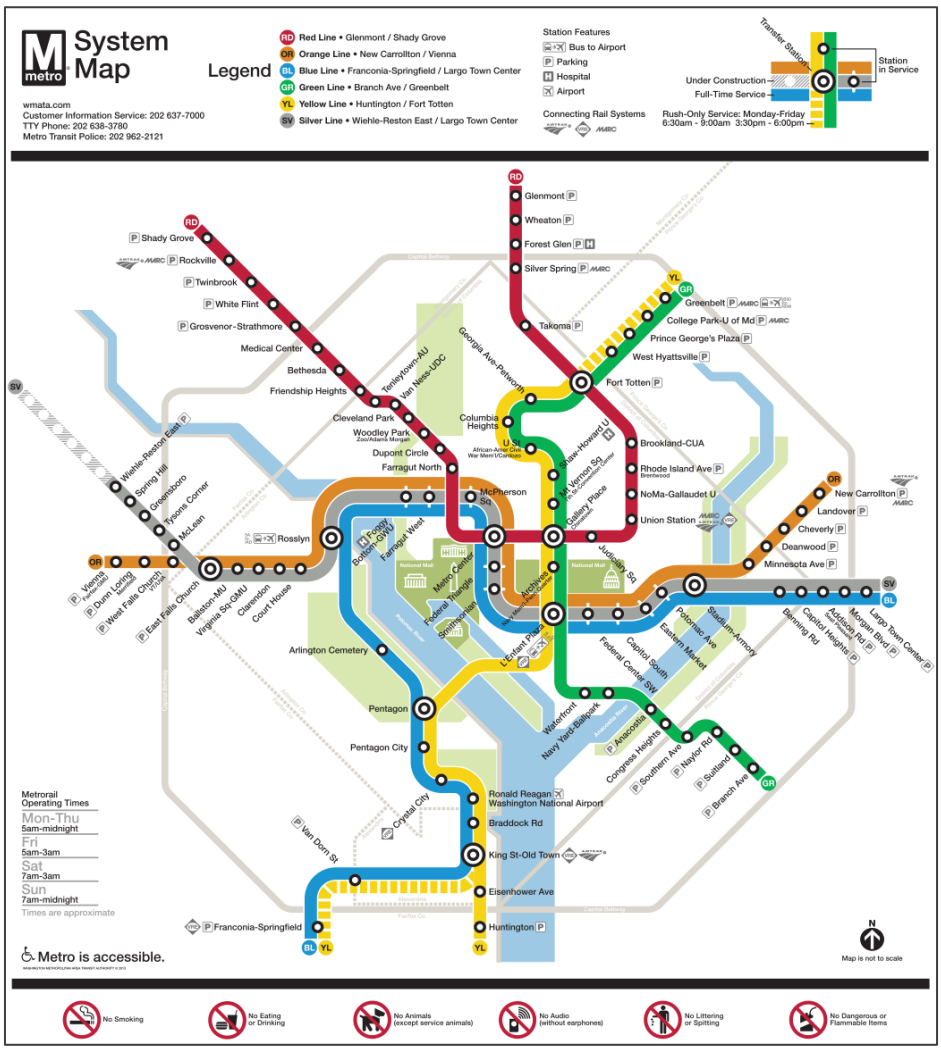


Figure 1. Metrorail System Map. Metrorail Pocket Guide 50.532 (REV. 4/14).

The City of Alexandria in cooperation with WMATA proposes the construction of a new Metrorail station located along the existing Blue and Yellow lines between the National Airport and Braddock Road Metrorail Stations. The new Metrorail station, Potomac Yard Metrorail Station, will improve accessibility to the Potomac Yard area and provide more transportation choices for current and future residents, employees, and businesses by establishing a new access point to the regional Metrorail system.

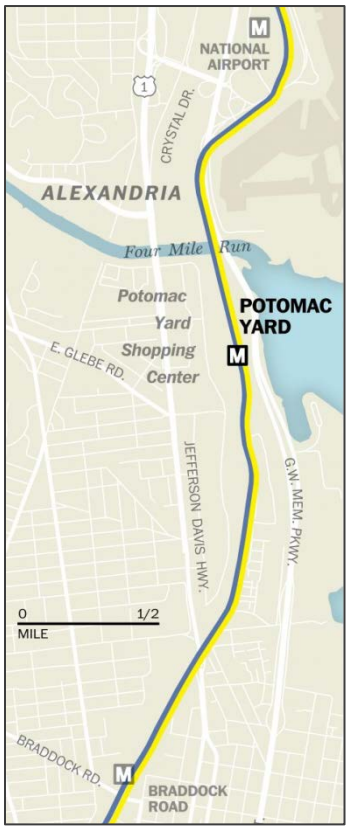


Figure 2. Location of the proposed Potomac Yard Metrorail Station, between National Airport and Braddock Road Metrorail Stations.

In order to determine whether modifications of the existing Traction Power System are required to accommodate the new Potomac Yard Metrorail Station, simulations were done with the addition of the new Potomac Yard Metrorail Station into the existing Traction Power System. Different scenarios were considered to check if the Traction Power System is properly sized; including but not limited to a degradation of traction power substation (TPSS) conditions.

The analysis of the simulations included a comparison of normal, abnormal, and emergency conditions of the train voltages, train currents, and train power availability, as a percentage between the demand and load power available.

1.1. Abbreviations and Acronyms

The list of abbreviations and acronyms used throughout the document is included in the following table:

Table 1. Abbreviations and acronyms.

Abbreviation	Meaning
A	Ampere
AW0	Added Weight-0 (empty car)
AW2	Added Weight-2 (load with some seated and some standing passengers)
CLF	Hundreds of Linear Feet
DC, dc	Direct Current
ft	Feet
klbf	Kip-force (kilopound-force)
lbs	Pounds
Mph	Miles per hour
mphps	Miles per hour per second
RMS	Root Mean Square
TRU	Transformer Rectifier Unit
TBS	Tie Breaker Station
TPSS	Traction Power Substation
V	Volt
W,KW,MW	Watt, Kilo Watt (10^3 Watts), Mega Watt (10^6 Watts)
WMATA	Washington Metropolitan Area Transit Authority

1.2. Reference Documents and Drawings

The following table includes the list of reference documents and drawings taken as a base for the study.

Table 2. Reference documents provided as input data.

Reference	Title	Edition
[RD-01]	POTOMAC YARD METRORAIL STATION TASK 1601.DESIGN REFINEMENT AND REQUISITE APPROVALS. SCOPE OF WORKS. “NTP 16-65-MCAP-20.pdf”	08/2015
[RD-02]	POTOMAC YARD METRORAIL STATION TRACKWORKS PLANS. “Potomac Yard 20160715.pdf”	07/2016
[RD-03]	WMATA Task Order 11-FQ10061-ENSS-01. Service Evaluation Study Final Load Flow Report. “6351 ENSS-01 Service Evaluation Vol 1 R0 3.pdf”	09/2012
[RD-04]	WMATA Task Order 11-FQ10061-ENSS-01. Service Evaluation Study Final Load Flow Report. Volume 2 - Appendices “6351 ENSS-01 Service Evaluation Vol 2 R0 3.pdf”	09/2012
[RD-05]	DULLES CORRIDOR METRORAIL PROJECT. Traction Power Load Flow Study Draft Report. “DRC 1143 Traction Power Load Flow Study Draft.docx”	01/2011
[RD-06]	7000 SERIES RAILCARS. TECHNICAL SPECIFICATIONS. “7K Spec_BAFO_A015_091217_Conformed.pdf”	12/2009
[RD-07]	Compilation of documents containing information regarding profile, alignment, WMATA Design Criteria, Contact Rail Schematic Diagrams, … “C11 Potomac RR - Service Evaluation - SOW - Data.pdf”	09/2016
[RD-08]	C-ROUTE CONTACT RAIL UPDATE “Steel & Composite Contact Rail.xlsx”	08/2015
[RD-09]	“Normalized ATS Performance Levels Form Station For Station TWC Transmitt.docx”	09/2016
[RD-10]	ATP SPEED COMMANDS CONTROL LINE DIAGRAM ROUTE C. “Control Lines for C-line.pdf”	11/2012
[RD-11]	“Sample Substation Outage Operation.pdf”	

Input Data and Assumptions

02

Input Data and Assumptions

This section details key parameters and assumptions for the Traction Power System simulations including simulation constraints, geometrical and electrical characteristics of the line, rolling stock characteristics, and operational scenarios.

2.1. Constraints

The scope of the simulations is limited to the track layout and stations (including the new proposed Potomac Yard Metrorail Station) and speed restrictions for the track section corresponding to both the Blue and Yellow lines located between King Street Station and Pentagon Station. The substations for the Traction Power System analysis span from C09TP (18th & Fern) to C97TP (Duke Street Substation) and include the two TPSS at the ends of the track section.

2.2. Railway Line Alignment

The track alignment, profile and chainage were obtained from the information contained in the *"C11 Potomac RR - Service Evaluation - SOW - Data.pdf"* file, referenced as document [RD-07].

2.3. Location and Characteristics of the TPSS and TBS and Feeders

The location and characteristics of the TPSS, TBS and their corresponding feeders were provided in *"C11 Potomac RR - Service Evaluation - SOW - Data.pdf",* referenced as [RD-07]. This information is reflected in the **Table 3**.

Table 3.Existing TPSS, TBS and feeders.

TPSS/TBS/STATION	Location [CLF]	Power [MW]	Feeders (P-positive, N-negative)	1000 kcmil Cables (Quantity)	Cable length (ft)
PENTAGON CITY STATION	293+70	-			
C09TP 18TH & FERN SUBSTATION	316+84	2+2 (4 MW)	P31	4	130
			P32	4	122
			P33	5	110
			P34	4	100
			N1	6	130
			N2	6	130
CRYSTAL CITY STATION	334+38	-			
C09TB CRYSTAL CITY TIE BREAKER STATION	338+17	-	P41	4	100
			P42	4	100
			P43	4	100
			P44	4	100
			P46	4	100
NATIONAL AIRPORT STATION	365+47	-			

TPSS/TBS/STATION	Location [CLF]	Power [MW]	Feeders (P-positive, N-negative)	1000 kcmil Cables (Quantity)	Cable length (ft)
C10TP NATIONAL AIRPORT SUBSTATION	369+24	2+2+3 (7 MW)	P31	5	220
			P32	5	190
			P33	4	225
			P34	4	150
			P36	3	120
			P37	4	300
			N1	6	280
			N2	6	260
C11TB POTOMAC RR YARD NORTH TIE BREAKER STATION	405+86	-	P41	4	150
			P42	4	150
			P43	4	150
			P44	4	150
POTOMAC YARD STATION	451+27 [2]	-			
C11TP POTOMAC RR YARD SUBSTATION	453+25	3+3 (6 MW)	P31	5	180
			P32	5	180
			P33	5	160
			P34	5	160
			N1	6	180
			N2	6	190
C12TB BRASHFORD LANE TIE BREAKER STATION	492+25	-	P41	4	150
			P42	4	150
			P43	4	150
			P44	4	150
C12TP BRADDOCK ROAD SUBSTATION	517+47	3+3+3 (9 MW)	P31	5	600
			P32	4	630
			P33	6	210
			P34	5	250
			P35	4	300
			N1	6	200
			N2	6	220
BRADDOCK ROAD STATION	524+79	-			
C13TB KING STREET TIE BREAKER STATION	553+10	-	P41	4	120
			P42	4	120
			P43	4	120
			P44	4	120
			P45	4	100
KING STREET STATION	558+65	-			
C97TP DUKE STREET SUBSTATION	569+90	2+2+2 (6 MW)	P31	4	250
			P32	4	250
			P33	4	250
			P34	4	250
			P35	4	250
			P36	4	250
			N1	6	200
			N2	6	200

Note: Items in blue identify station locations

2.4. Electrical Parameters of the Traction Power System

Rail line characteristics:

- Contact rail:
  - Steel 150-lb. Resistance: 0.00456 Ω/1000 ft (90ºC) [1.]
  - Composite. Resistance: 0.00256 Ω/1000 ft (90ºC) 1

The entire contact rail was modeled as steel[2] for the existing system to simulate a worst case scenario.

- Running rail: 115-lb RE. Resistance: 0.0124 Ω/1000 ft per rail (0.0062 Ω/1000 ft per track at 90ºC) [1]
- Feeder cable: soft-drawn copper 1000 kcmil [3]
  - Resistance: 0.0135 Ω/1000 ft (90ºC) [1]
  - Ampacity: 744 A (all equipment in service) [3]
  - Ampacity: 998 A (under outage conditions) [3]
- Cross bonding cable positions are located at maximum 2000 ft intervals along the track line [3]. The RFP allowed for continuously cross bonded between tracks so it is understood that cross bonding currents are out of the scope of this report.
- Terrain resistivity: 200 Ωm [2]
- Rail to earth resistance: 500 Ω per 1000 ft of single track[3]
- The two rails of each track are infinitely bonded.[3]

Electrical Performance Characteristics:

- Nominal full load voltage: 700 Vdc (6.0% regulation) [3]
- Nominal no-load voltage: 742 Vdc [4]
- Minimum vehicle operating voltage: 525 Vdc under normal conditions (all TPSS functioning normally) [5]
- Minimum vehicle operating voltage: 475 Vdc under abnormal conditions (single rectifier transformer unit outage) [4]
- Minimum vehicle operating voltage: 450 Vdc under emergency conditions (one TPSS outage) [4]
- Maximum rail-to-ground voltage:
  - Normal conditions (all substations are in normal service, reduced train performance is not allowed): 100 Vdc [3]
  - Abnormal condition (a single rectifier is out of service, reduced train performance is not allowed): 120 Vdc [3]
  - Maximum rail-to-ground voltage (emergency operation, a complete substation is out of service, reduced performance is allowed): 150 Vdc [3]
  - The transformer/rectifier unit can provide maximum load during three hours of 146% [3] of nominal power, which is equivalent to 161% [4] of nominal power during two hours, per NEMA RI9.
- According [RD-04], *Appendix A,* the summer load condition scenario is worse than the winter load condition. Therefore this study is conducted only as the worst case scenario.
- Two 8-car trains are modeled at Potomac Yard Station pocket tracks.[3] The trains are ready to operate with the full auxiliary equipment powered on.[2]

---

[1] [RD-03], page 53.
[2] Assumption
[3] [RD-01]
[4] [RD-07]
[5] [RD-03], page 53

2.5. Rolling Stock

- Train consist: 8-car trains WMATA 7K vehicles [3]
- Length: 75 ft. [6]
- Load: 84,500 lbs (empty AW0) [7] + 26,250 lbs (175 persons at 150 lbs) [8] = 110,750 (full load AW2)
- Rotatory masses coefficient: 10% of AW0 weight [8]
- Adhesive load: 100% [6] (4 motor per car)
- Max power: 798 KW [9]
- Max tractive effort: 15.1 klbf (26.5 mph) [9]
- Max acceleration service: 2.8 mphps [6]
- Max deceleration service: 2.2 mphps [6]
- Max speed: 75 mph [6]
- Traction vs speed and resistance vs speed graphs for one car IAW 7000 Series Rail Car Technical Specifications [6]
- Rolling resistance [9]:
  - R[lbf] = 196.09 + 2.1294V + 0.0664V^2 for 1 vehicle AW2. V [mph]
- Ride resistance factor in tunnel: 2.5 [2]
- Power efficiency: 84% [2]
- Auxiliary power: 90 kW per car [7]
- Regenerative braking: without regenerative braking in normal and outages scenarios operations [3]
- Nominal/full load voltage: 700 Vdc [3]
- Minimum supply voltage: 525 Vdc [8]
- Maximum line current per car: 1620 A (considered only for traction, plus auxiliary current) [9]
- Train performance [6]: "Equipment shall operate correctly over the entire voltage range and provide rated output with the exceptions as noted elsewhere in this specification. For voltages above 650V the propulsion system shall provide full performance. For voltages below 650V the propulsion system may operate at lower performance. The lower performance shall not be less than the ratio of the actual voltage to 650 V, except that the torque provided by the propulsion system shall reduce from around 80% at 520 V to around zero at 430V."

[6] [RD-06]
[7] Per Design Criteria 9, Rev.3
[8] [RD-03], page 52.
[9] [RD-07], figure 23.1

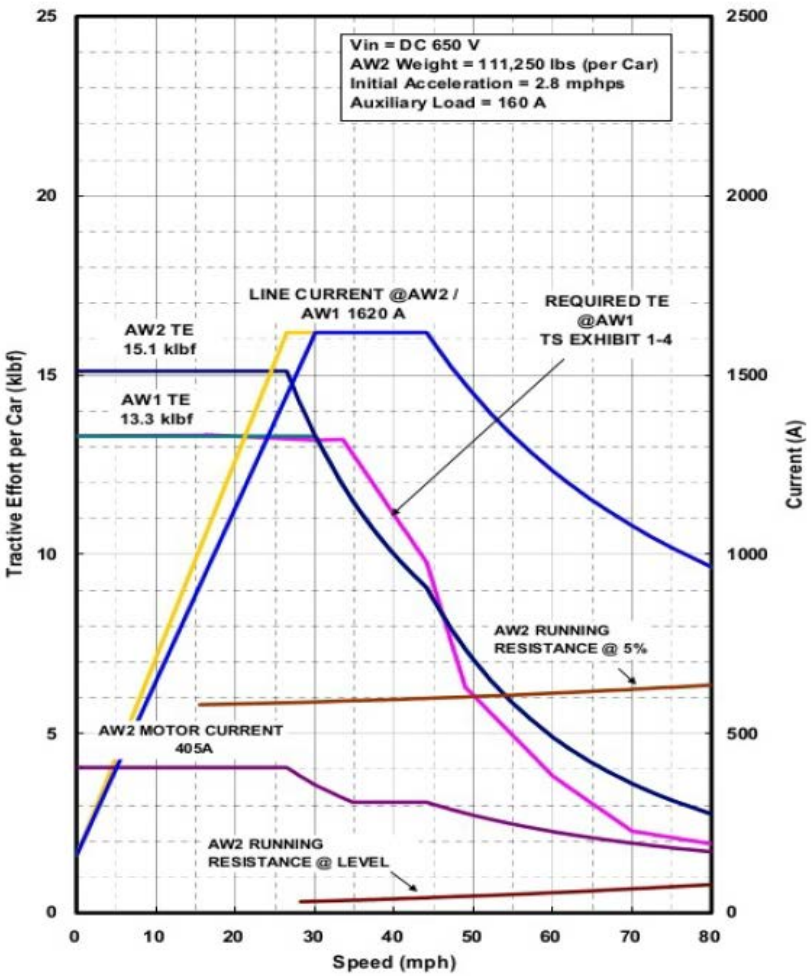


Figure 3. Railcar Electrical Performance Characteristics.

2.6. Headway

Simulations assumed 120 second headways between trains running in both directions between Pentagon and King Street Stations as required by the RFP.

Simulated Scenarios

03

Simulated Scenarios

The following three scenarios were simulated:

- Normal operation;
- Abnormal operation; and
- Emergency operation.

3.1. Normal Operation

A normal operation scenario occurs when the Traction Power System is working such that all the substations in the specified track section are fully operational, including the corresponding TBS and rail lines. In the normal operation scenario, degraded operational components are not permitted and rolling stock is running at the established headway, the maximum allowed speed, and with the maximum acceleration.

3.2. Abnormal Operation

An abnormal operation scenario occurs when a single rectifier or a transformer unit is out of service. In an abnormal operational scenario, the outage of the rectifier group that causes a worst case scenario is selected. Three abnormal operation scenarios were simulated:

a) Potomac TPSS rectifier group out of service

b) National Airport TPSS rectifier group out of service

c) Braddock Road TPSS rectifier group out of service

For any of these scenarios, it is assumed that all associated TBS are working properly. Degraded operational components are not permitted and the rolling stock is running at the established headway, the maximum allowed speed, and with the maximum acceleration.

3.3. Emergency Operation

An emergency operation scenario occurs when a complete TPSS is out of service. Three emergency operation scenarios were simulated:

a) Potomac TPSS out of service

b) National Airport TPSS out of service

c) Braddock Road TPSS out of service

For any of these scenarios it is considered that all the associated TBS are working properly and the TPSS DC bus and feeders remain in service. The trains can operate in degraded conditions according to the speed and acceleration defined in the “Normalized ATS Performance Level" tables [RD-09] for the PL mode reflected in “Sample Substation Outage Operation” tables [RD-11]. For consistency with the rest of the stations, the trains departing form the Potomac Yard Metrorail Station will run at 20 mph and half acceleration when operating in degraded conditions.

Results of the Simulations

04

Results of the Simulations

This section presents the simulation results for the three defined scenarios:

- Normal operation
- Abnormal operation
- Emergency operation

Results include graphs of the train voltages, train currents, train power availability, and rail-to-ground voltages. TPSS currents are tabulated in **Appendix 1** and RMS currents are graphically represented in **Appendix 2**.

4.1. Normal Operation

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 4** shows the train voltages of the simulated track section and also shows the minimum vehicle operating voltage threshold of 525 Vdc under normal operation.

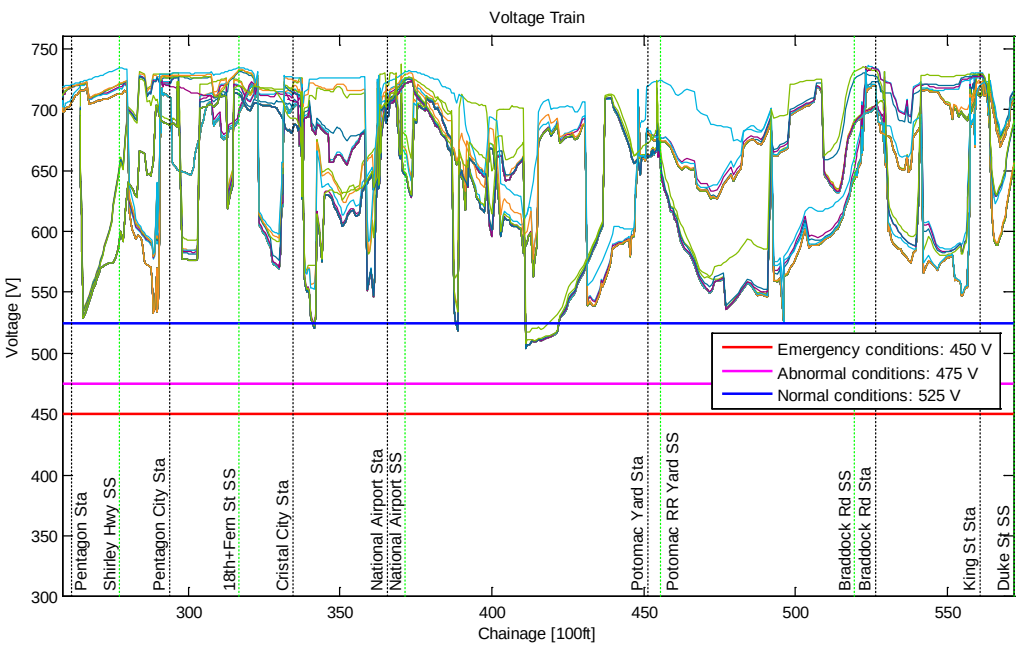


Figure 4. Train voltages in the track section under normal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified track section. **Figure 5** shows train currents of the simulated track section under normal operation.

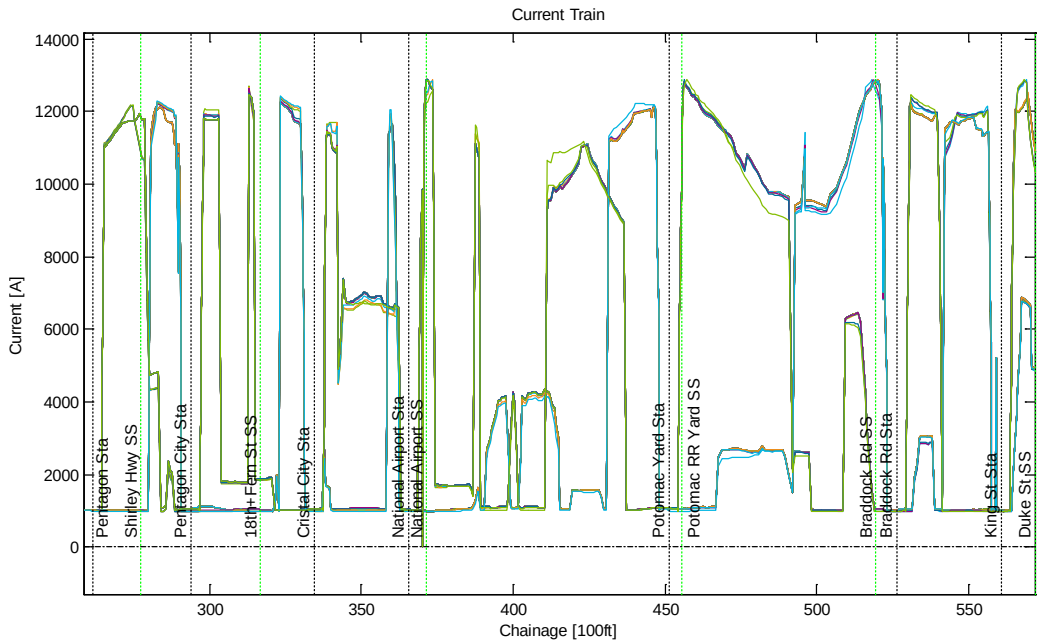


Figure 5. Train currents in the track section under normal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 6** shows the train power availabilities of the simulated track section under normal operation.

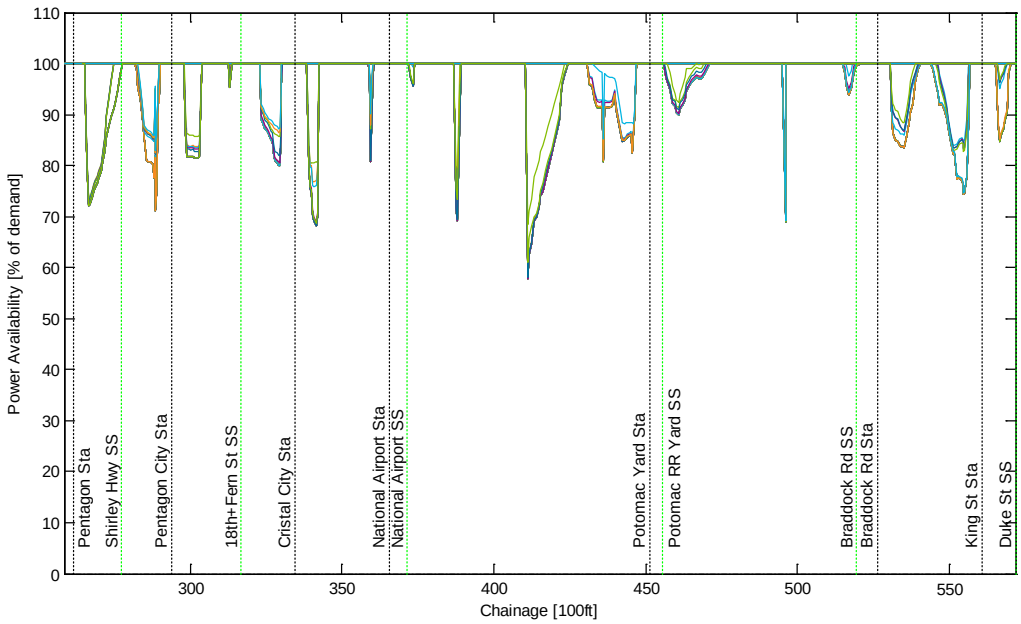


Figure 6. Power availability in the track section under normal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 7** shows rail-to-ground voltage limits of the simulated track section under normal operation. All of the rail-to-ground voltages in the tract section are under the 100 V limit.

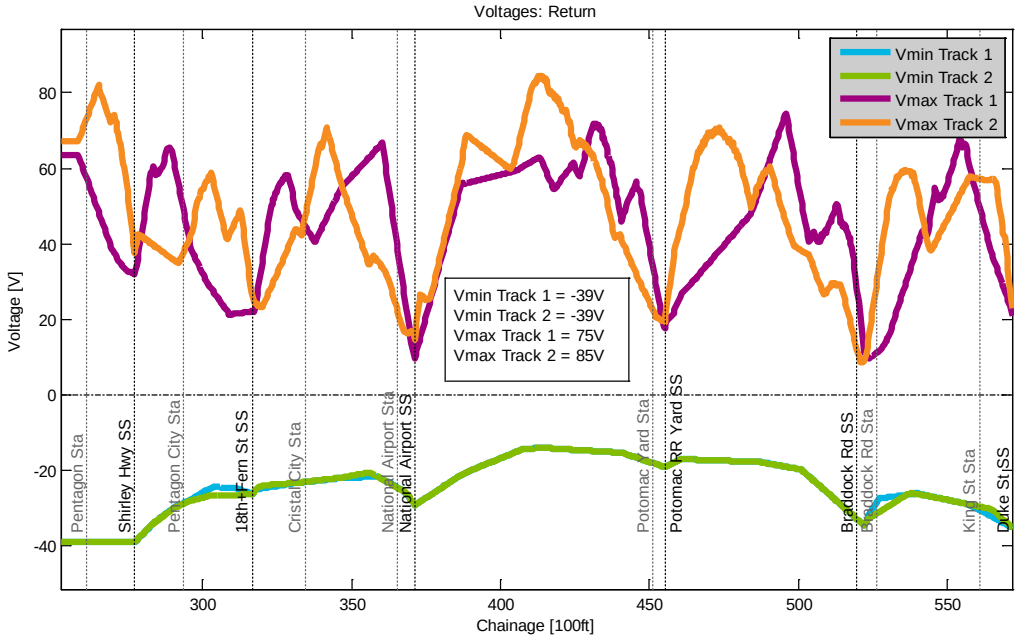


Figure 7. Rail-to-ground voltages in the track section under normal operation.

TPSS Currents

The traction power substation simulated RMS load current results under normal conditions are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

4.2. Abnormal Operation

National Airport Substation Rectifier Group Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 8** shows the train voltages of the simulated track section with the National Airport Substation out of service and also shows the minimum vehicle operating voltage threshold of 475Vdc under abnormal operation.

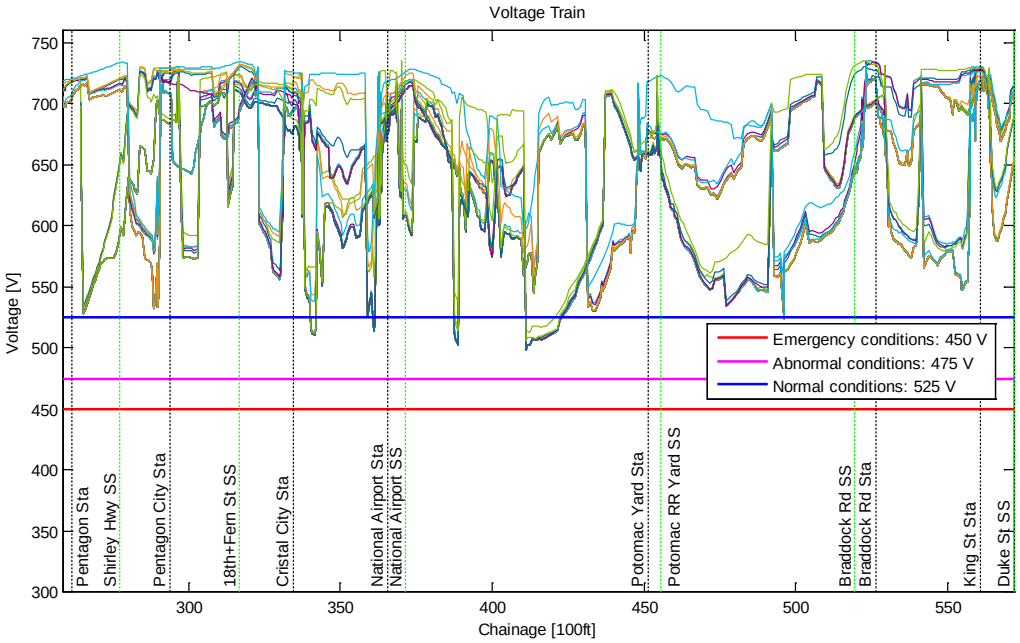


Figure 8.Train voltages in the track section for National Airport Substation under abnormal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 9** shows train currents of the simulated track section with the National Airport Substation under abnormal operation.

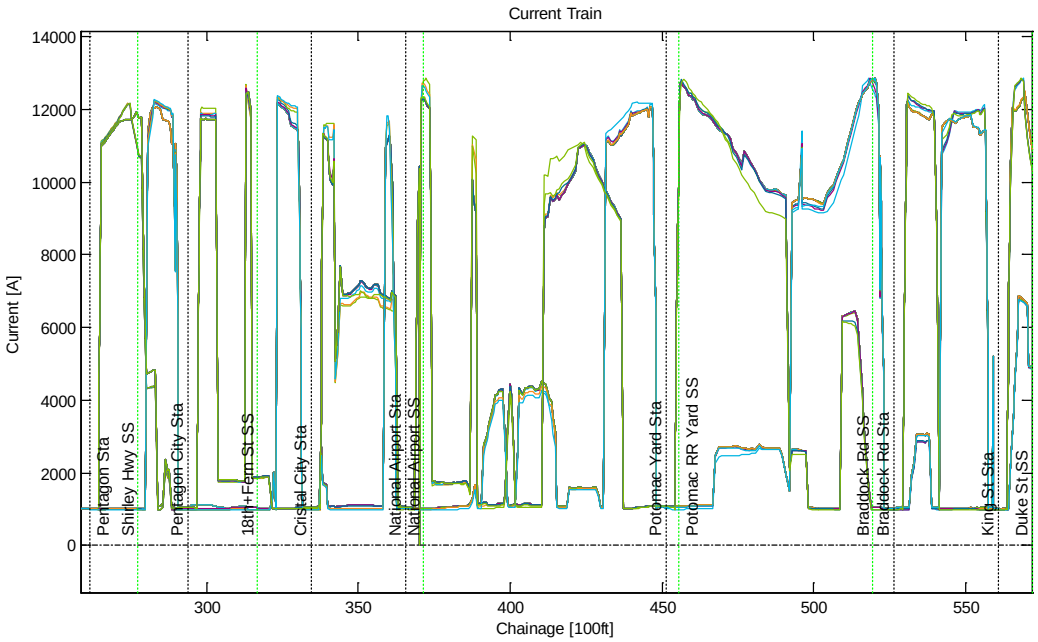


Figure 9.Train currents in the track section for National Airport Substation under abnormal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 10** shows the train power availabilities of the simulated track section with the National Airport Substation under abnormal operation.

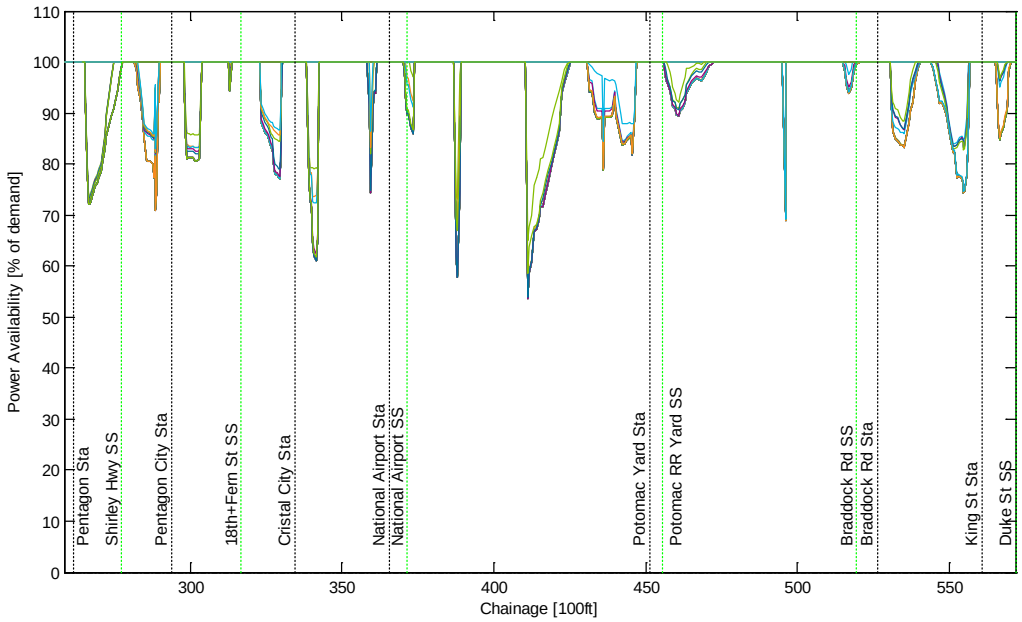


Figure 10. Power availability in the track section for National Airport Substation under abnormal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 11** shows rail-to-ground voltage limits of the simulated track section with the National Airport Substation under abnormal operation All of the rail-to-ground voltages in the tract section are under the 120 V limit.

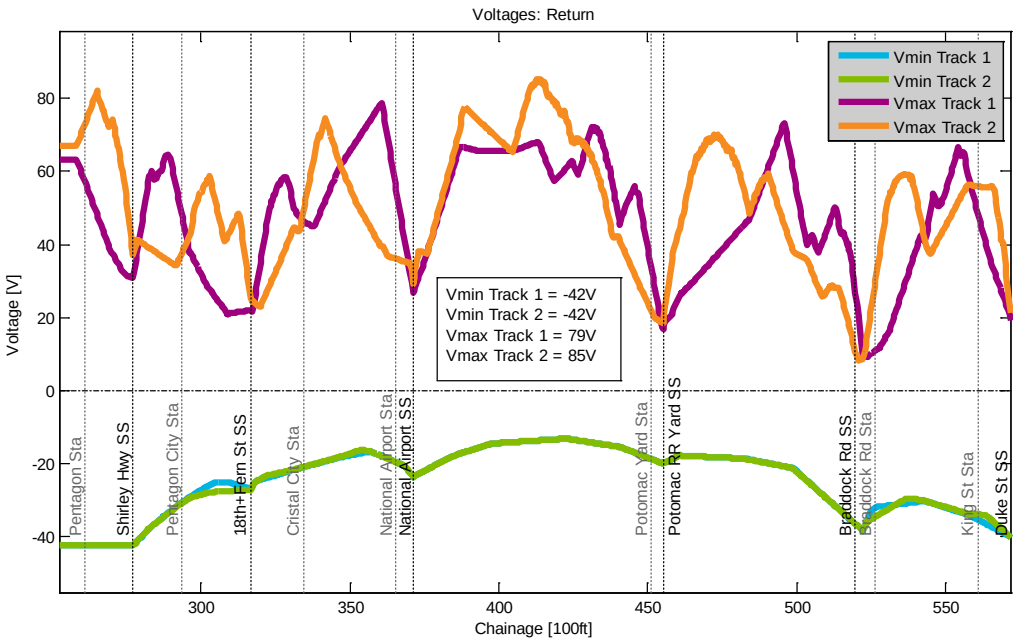


Figure 11.Rail-to-ground voltages in the track section for National Airport Substation under abnormal operation.

TPSS Currents

The traction power substation simulated RMS load current results under abnormal condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Potomac Yard Substation Rectifier Group Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 12** shows the train voltages of the simulated track section with the Potomac Yard Substation out of service and also shows the minimum vehicle operating voltage threshold of 475 Vdc under abnormal operation.

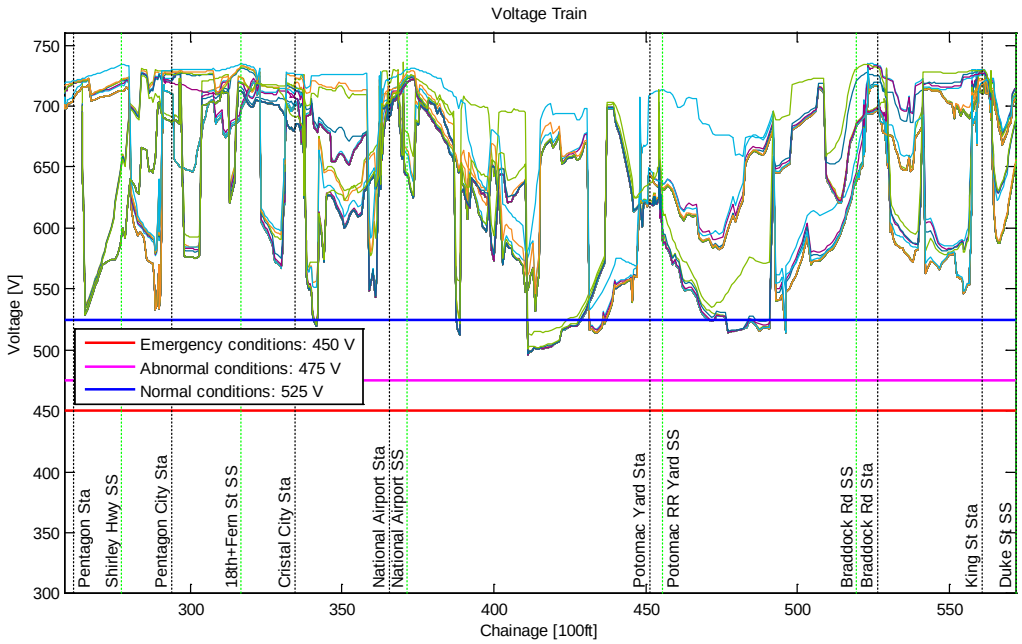


Figure 12.Train voltages in the track section for Potomac Yard Substation under abnormal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified track section. **Figure 13** shows train currents of the simulated track section with the Potomac Yard Substation under abnormal operation.

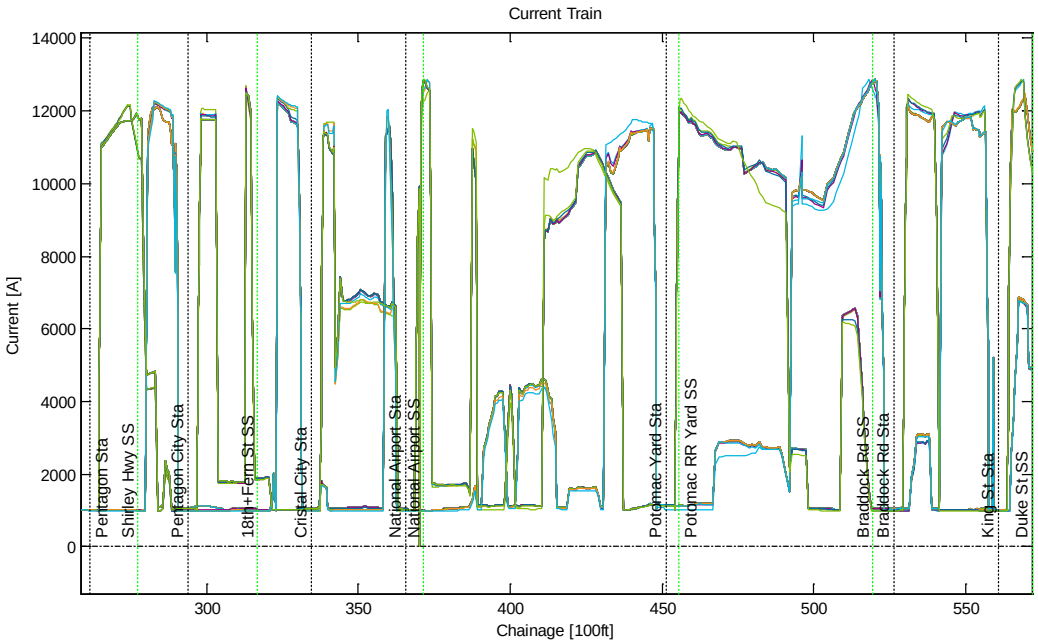


Figure 13.Train currents in the track section for Potomac Yard Substation under abnormal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 14** shows the train power availabilities of the simulated track section with the Potomac Yard Substation under abnormal operation.

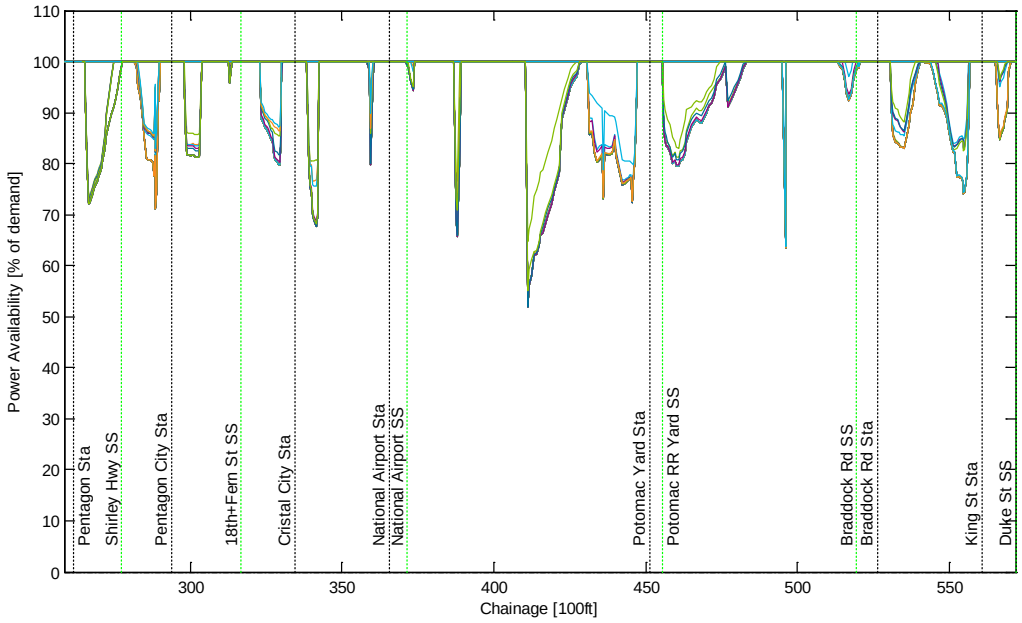


Figure 14. Power availability in the track section for Potomac Yard Substation under abnormal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 15** shows rail-to-ground voltage limits of the simulated track section with the Potomac Yard Substation under abnormal operation. All of the rail-to-ground voltages in the tract section are under the 120 V limit.

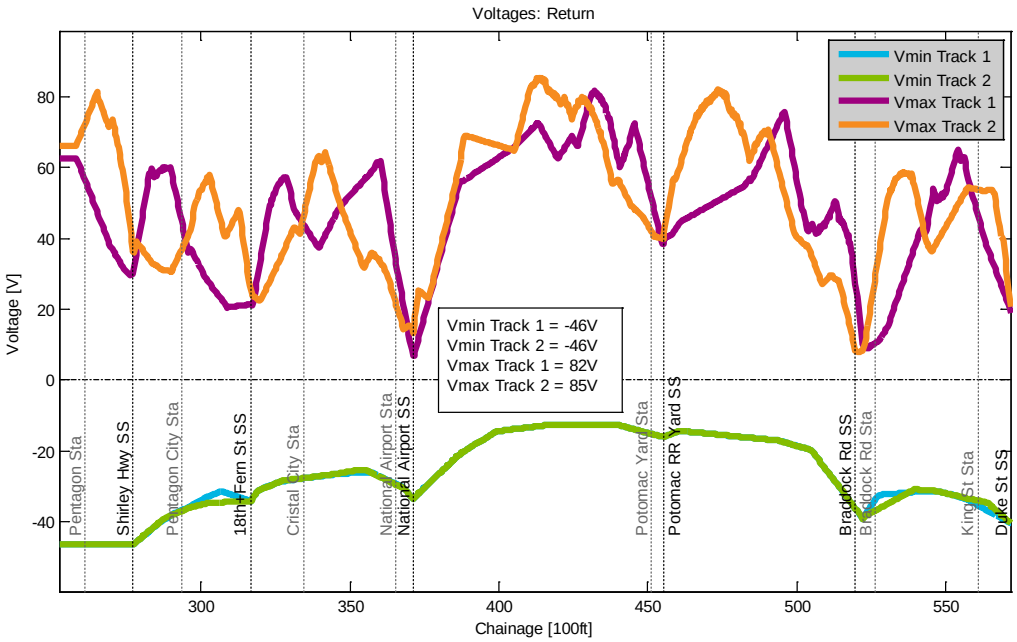


Figure 15.Rail-to-ground voltages in the track section for Potomac Yard Substation under abnormal operation.

TPSS Currents

The traction power substation simulated RMS load current results under abnormal conditions are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Braddock Road Substation Rectifier Group Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 16** shows the train voltages of the simulated track section with the Braddock Road Substation out of service and also shows the minimum vehicle operating voltage threshold of 475Vdc under abnormal operation.

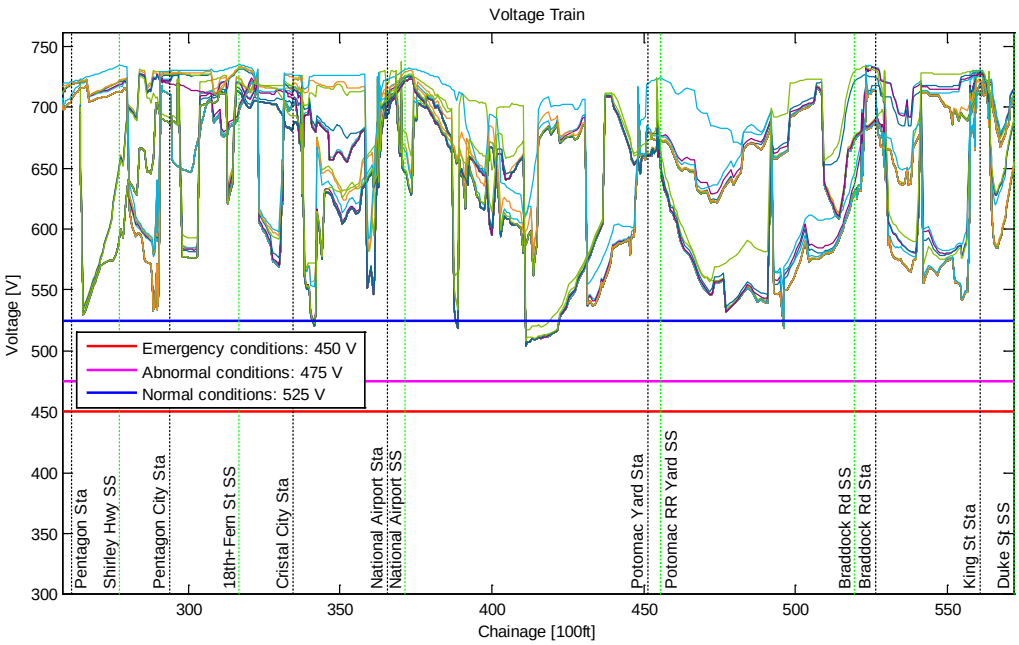


Figure 16.Train voltages in the track section for Braddock Road Substation under abnormal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 17** shows trains currents of the simulated track section with the Braddock Road Substation under abnormal operation.

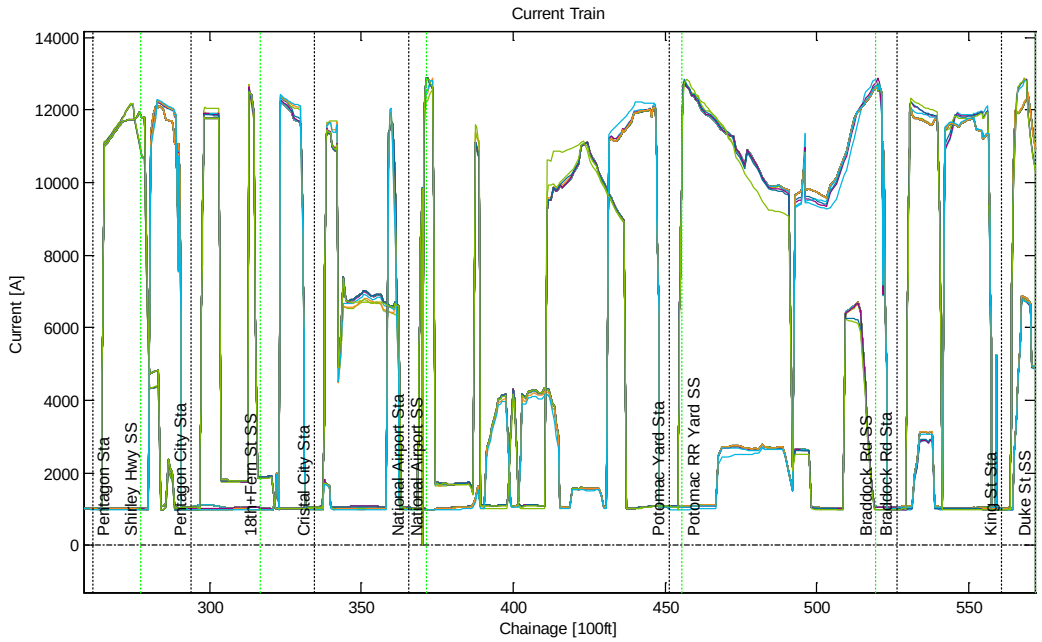


Figure 17.Train currents in the track section for Braddock Road Substation under abnormal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 18** shows the train power availabilities of the simulated track section with the Braddock Road Substation under abnormal operation.

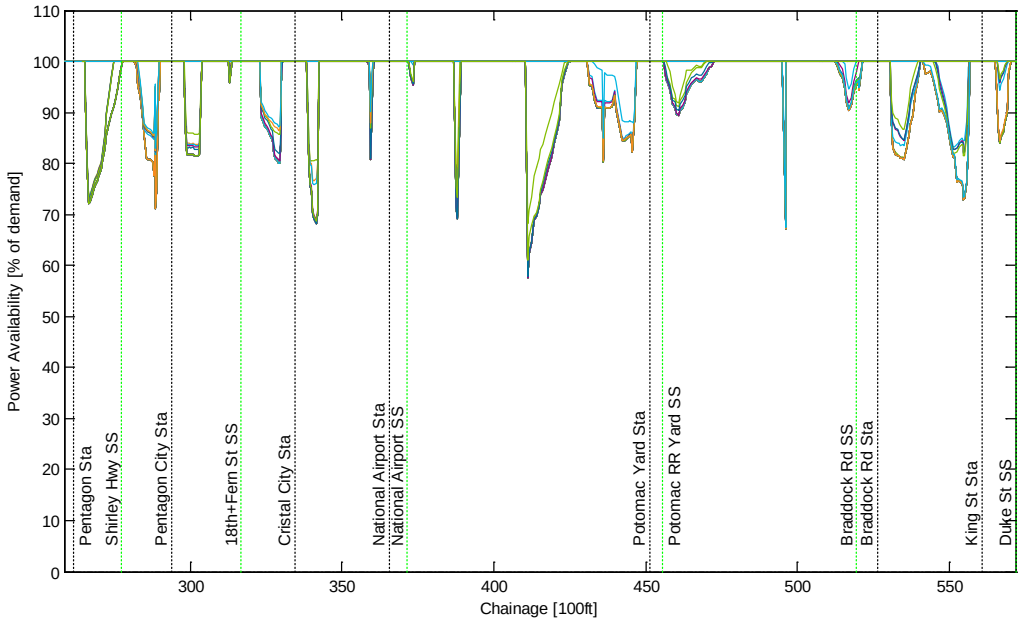


Figure 18. Power availability in the track section for Braddock Road Substation under abnormal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 19** shows rail-to-ground voltage limits of the simulated track section with the Braddock Road Substation under abnormal operation. All of the rail-to-ground voltages in the tract section are under the 120 V limit.

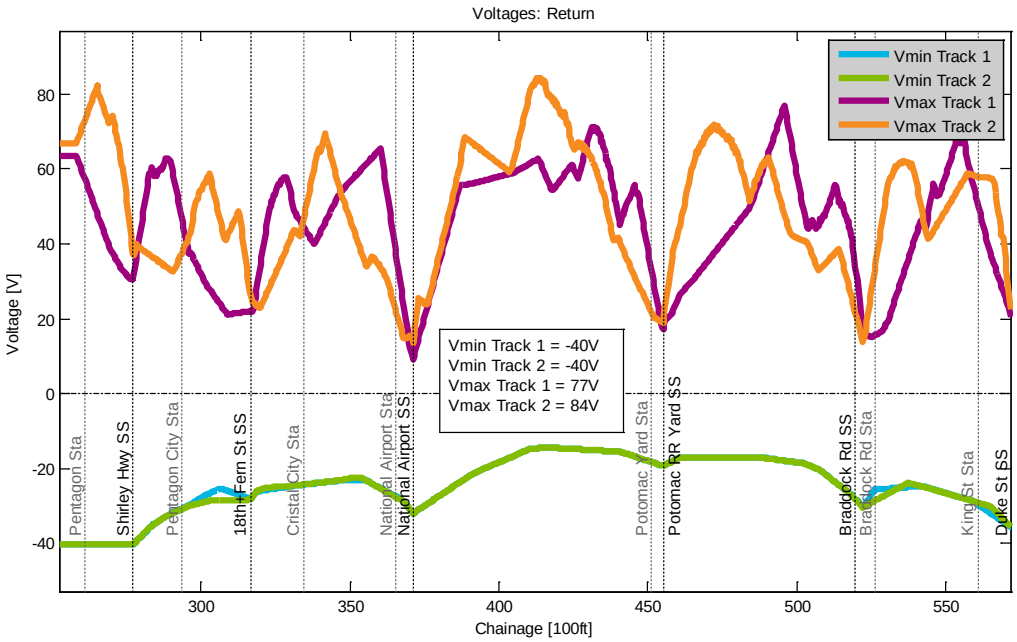


Figure 19.Rail-to-ground voltages in the track section for Braddock Road Substation under abnormal operation.

TPSS Currents

The traction power substation simulated RMS load current results under abnormal condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

4.3. Emergency Operation

National Airport Substation Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 20** shows the train voltages of the simulated track section with the National Airport out of service and also shows the minimum vehicle operating voltage threshold of 450 Vdc under emergency operation.

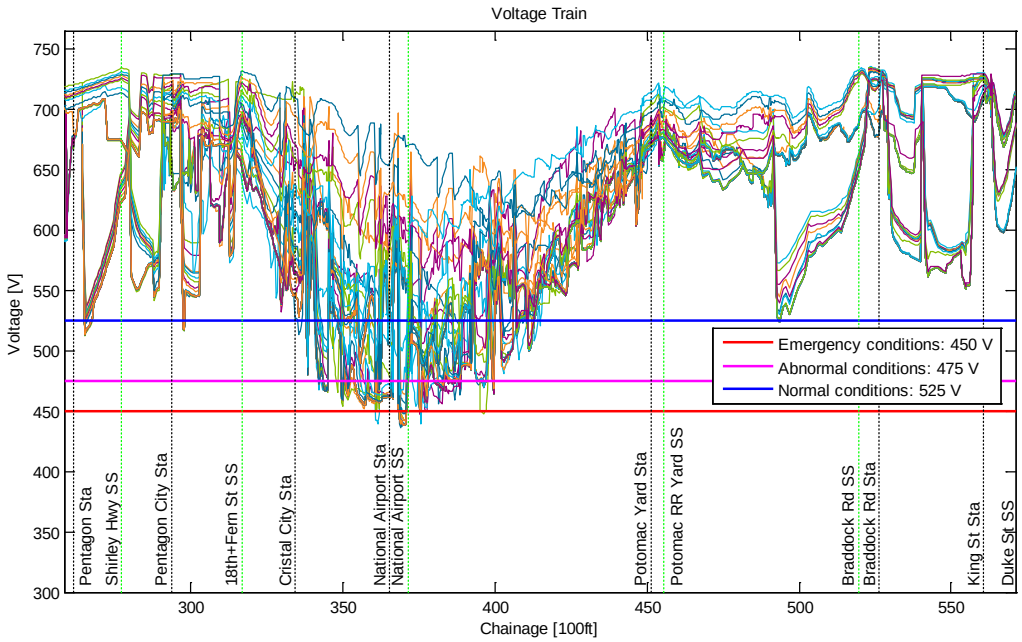


Figure 20.Train voltages in the track section for National Airport under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 21** shows the train currents of the simulated track section with the National Airport under emergency operation.

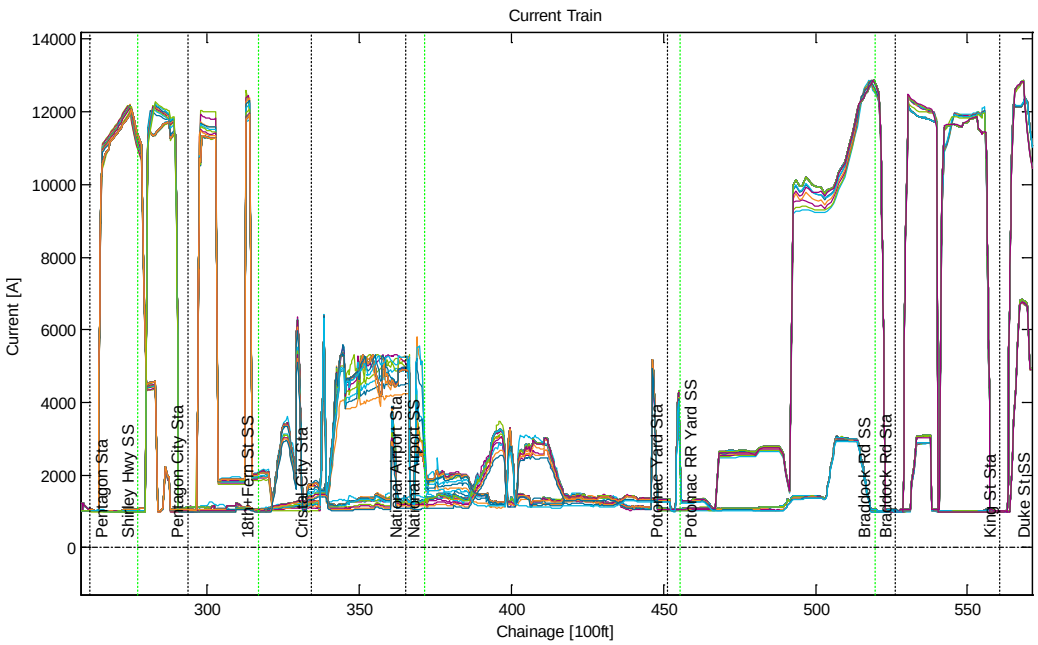


Figure 21.Train currents in the track section for National Airport under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 22** shows the train power availabilities of the simulated track section with the National Airport under emergency operation.

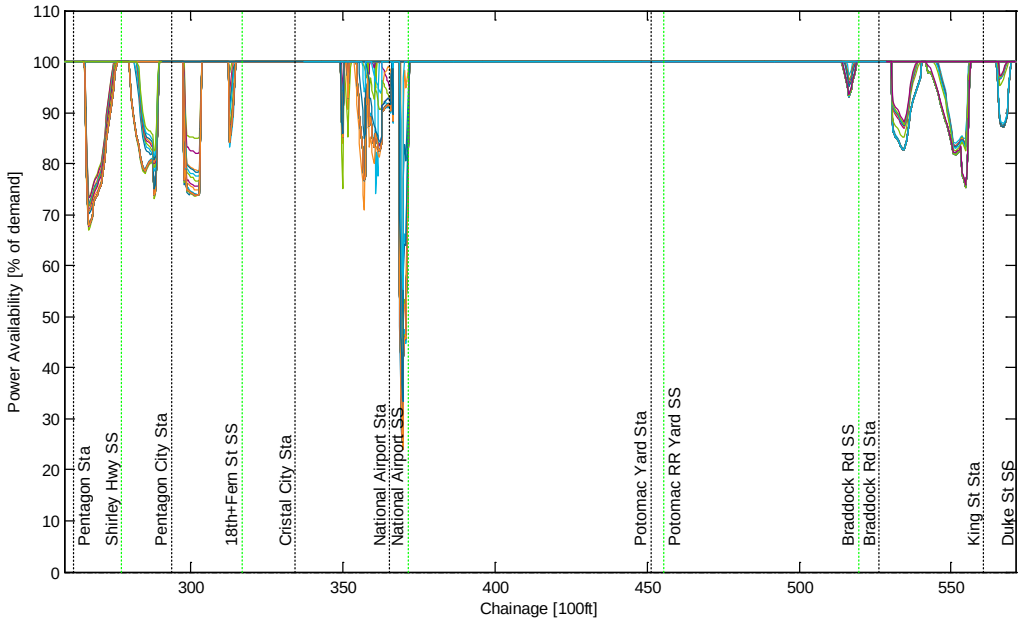


Figure 22. Power availability in the track section for National Airport under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 23** shows rail-to-ground voltage limits of the simulated track section with the National Airport under emergency operation. All of the rail-to-ground voltages in the tract section are under the 150 V limit.

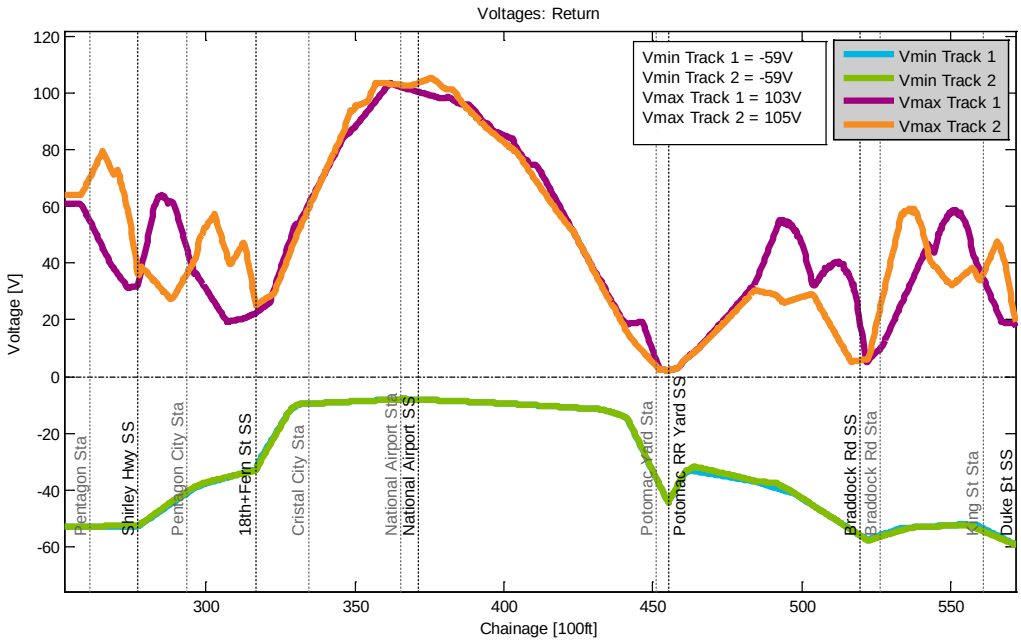


Figure 23.Rail-to-ground voltages in the track section for National Airport under emergency operation.

TPSS Currents

The traction power substation simulated RMS load current results under emergency condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Potomac Yard Substation Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 24** shows the train voltages of the simulated track section with the Potomac Yard out of service and also shows the minimum vehicle operating voltage threshold of 450 Vdc under emergency operation.

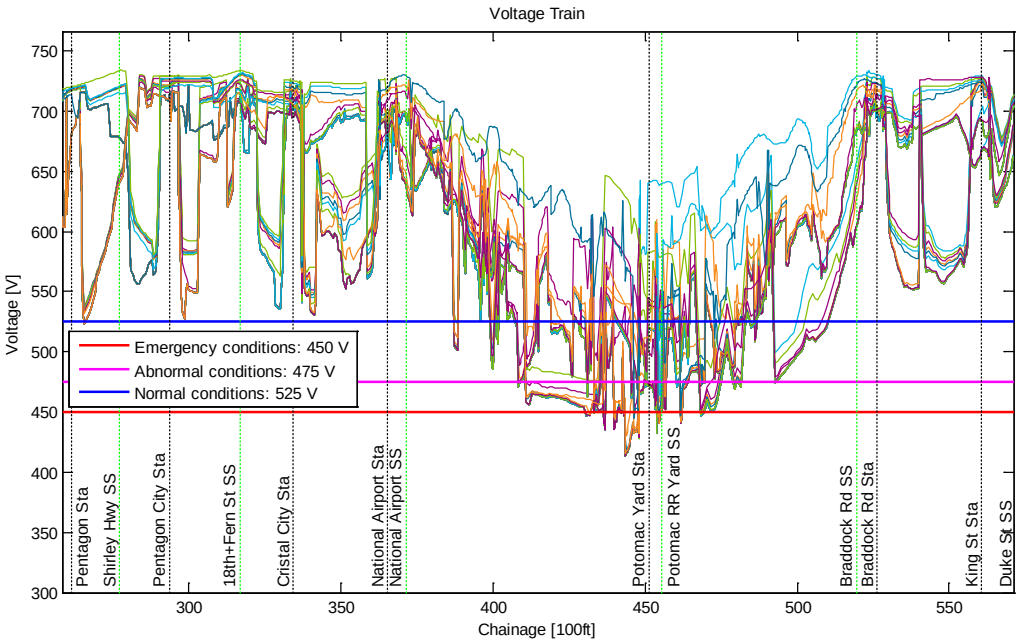


Figure 24.Train voltages in the track section for Potomac Yard under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 25** shows the train currents of the simulated track section with the Potomac Yard under emergency operation.

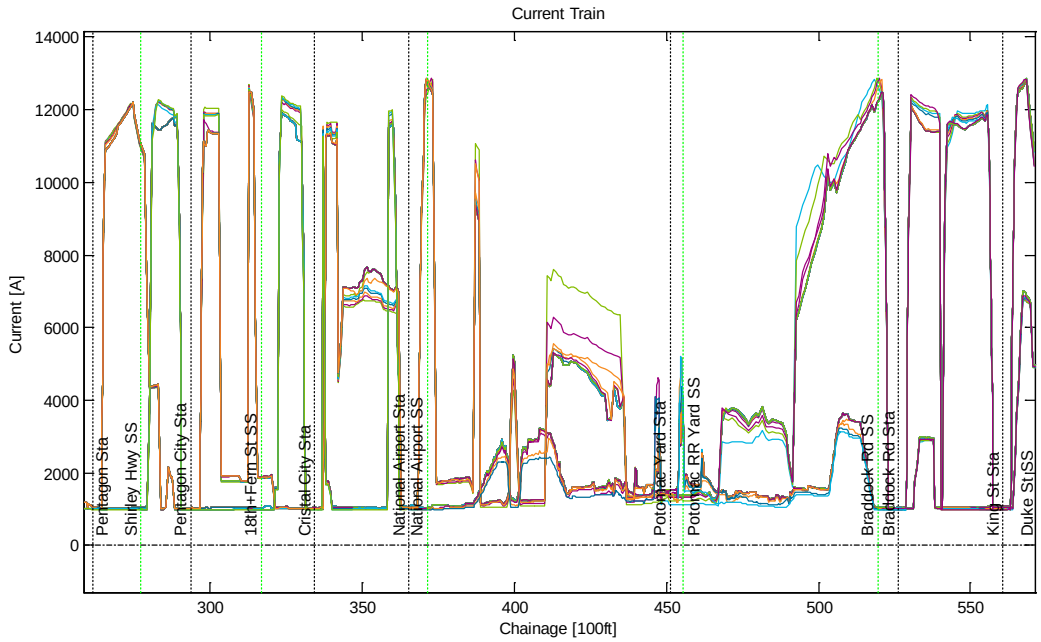


Figure 25.Train currents in the track section for Potomac Yard under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 26** shows the power availability of the simulated track section with the Potomac Yard under emergency operation.

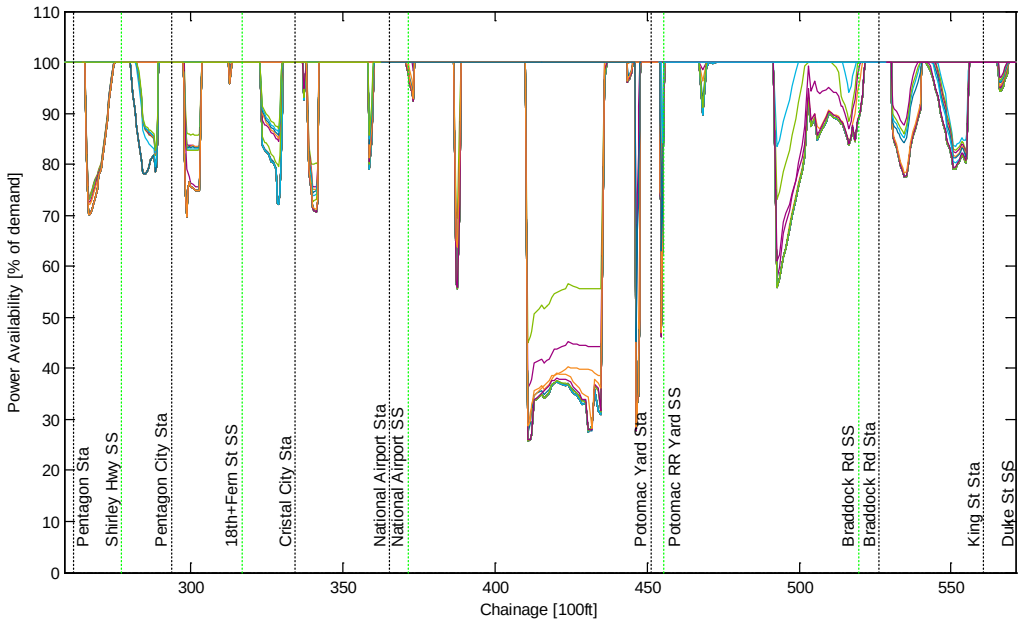


Figure 26. Power availability in the track section for Potomac Yard under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 27** shows rail-to-ground voltage limits of the simulated track section with the Potomac Yard under emergency operation. All of the rail-to-ground voltages in the tract section are under the 150 V limit.

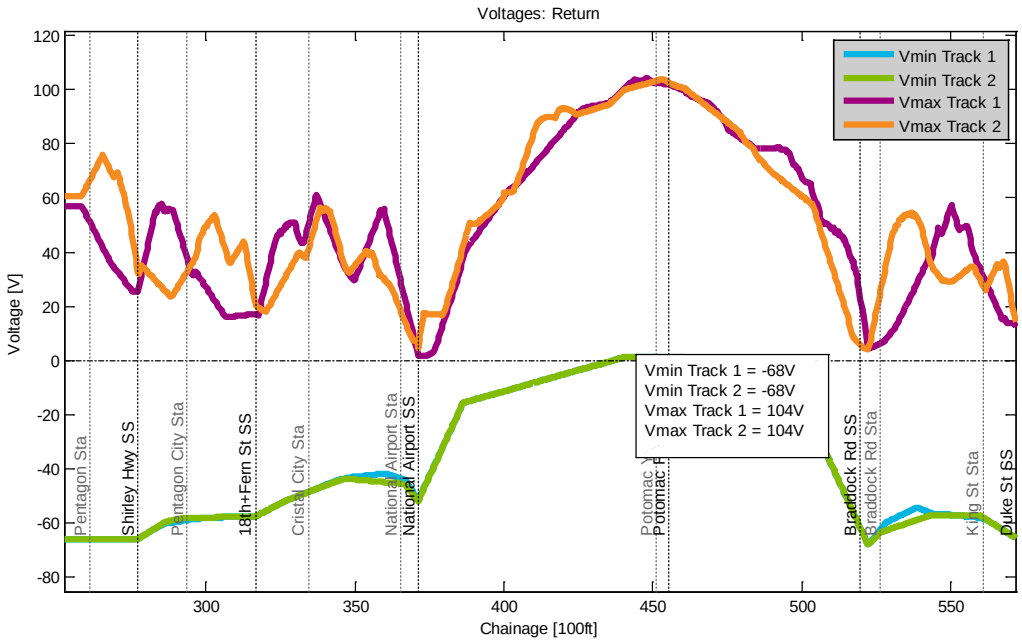


Figure 27.Rail-to-ground voltages in the track section for Potomac Yard under emergency operation.

TPSS Currents

The traction power substation simulated RMS load current results under emergency condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Braddock Road Substation Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 28** shows the train voltages of the simulated track section with the Braddock Road out of service and also shows the minimum vehicle operating voltage threshold of 450 Vdc under emergency operation.

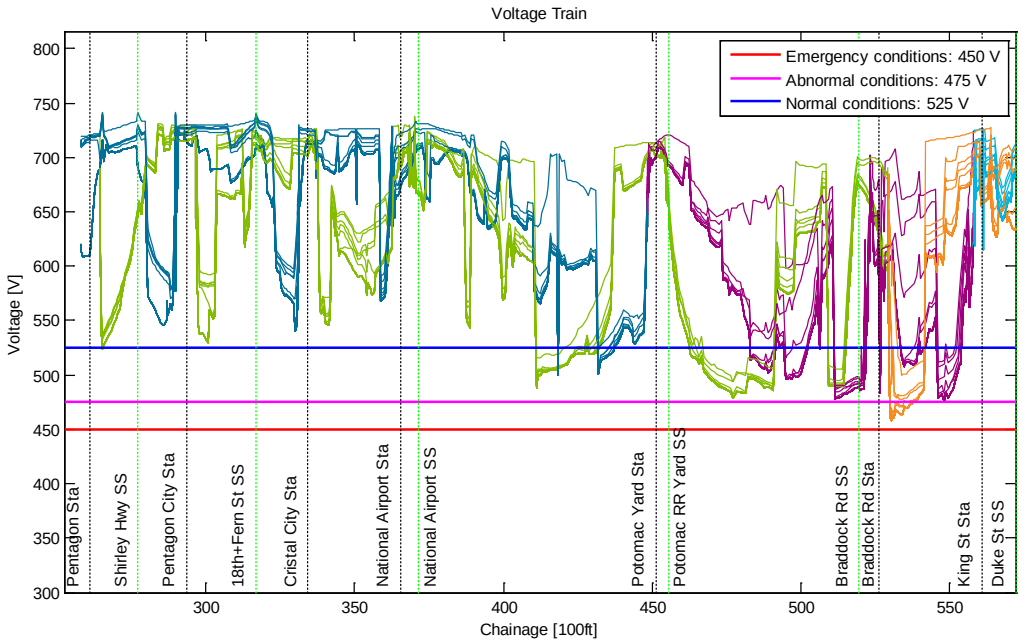


Figure 28.Train voltages in the track section for Braddock Road under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 29** shows the train currents of the simulated track section with the Braddock Road under emergency operation.

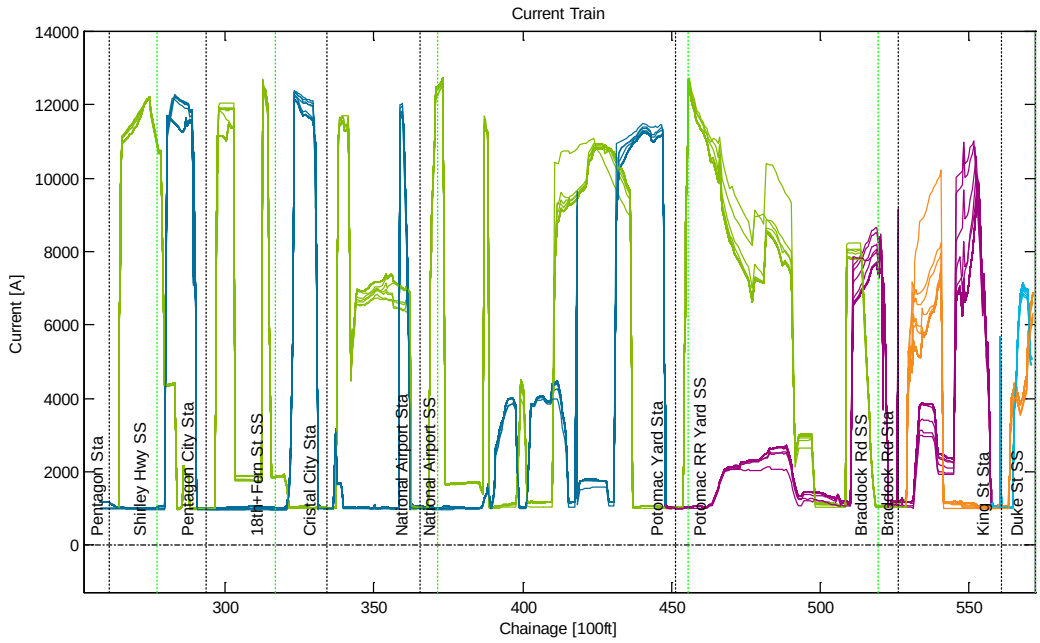


Figure 29.Train currents in the track section for Braddock Road under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 30** shows the train power availabilities of the simulated track section with the Braddock Road under emergency operation.

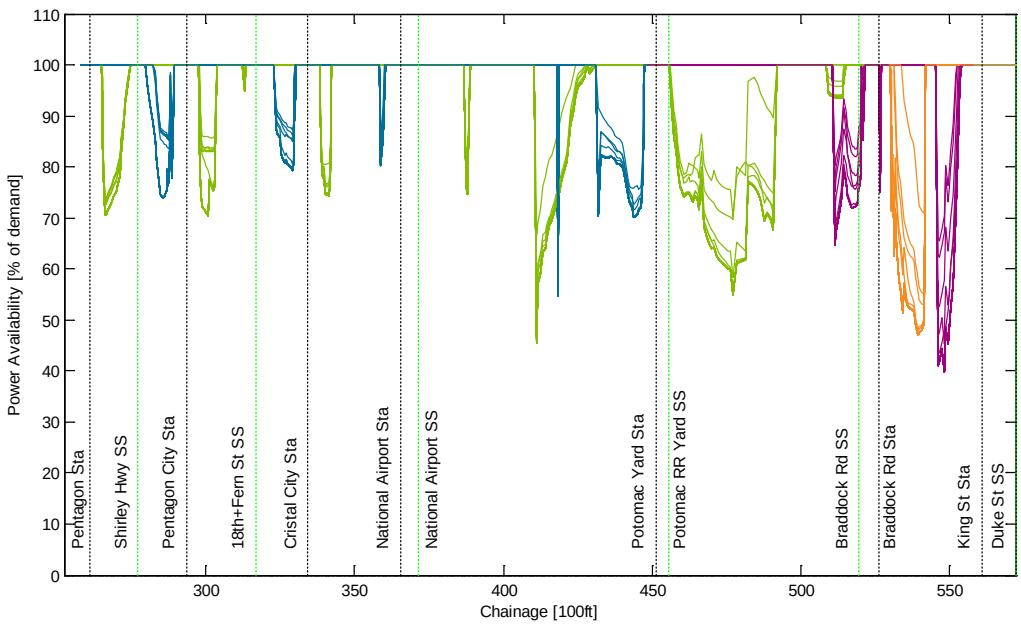


Figure 30. Power availability in the track section for Braddock Road under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 31** shows rail-to-ground voltage limits of the simulated track section with the Braddock Road under emergency operation. All of the rail-to-ground voltages in the tract section are under the 150 V limit.

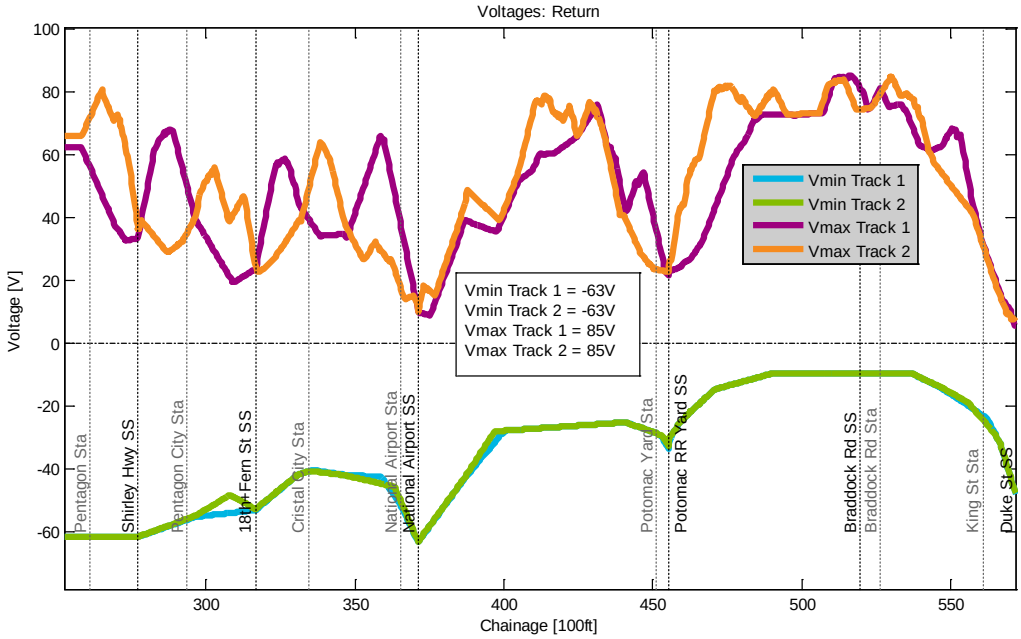


Figure 31.Rail-to-ground voltages in the track section for Braddock Road under emergency operation.

TPSS Currents

The traction power substation simulated RMS load current results under emergency condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

4.4. Simulation Results Summary

The following section is an analysis of the normal, abnormal and emergency operation of the existing Traction Power System by comparing the train voltages, train currents, train power availabilities and rail-to-ground voltages.

Normal Operation

The minimum vehicle operating train voltages fall below the threshold limit for normal operation (525V) several times for the track section between Crystal City and the proposed new Potomac Yard Metrorail Station. The lowest limit of 505V occurs approximately between National Airport and Potomac Yard Metrorail Stations, where the trains departing from National Airport increase the current demand because of the speed change from 45 to 65 mph.

The train power availability falls below the acceptable limit of 60 percent (58.1 percent) approximately between National Airport and Potomac Yard Metrorail Stations and is directly proportional to the increased train current demand from the increased speeds of the trains departing from National Airport.

The rail-to-ground voltages were well below the limit of 100V under normal operation. The maximum value identified in the simulation was 85V and corresponds to track 2 approximately between the Potomac Yard Station and National Airport Substations.

The TPSS RMS current exceeds the nominal value in the 18th & Fern, Potomac Yard and Duke Street Substations, but never exceeds the overload condition (146 percent of nominal) under normal operation.

Abnormal Operation

The Potomac TPSS rectifier group, National Airport TPSS rectifier group, and the Braddock Road TPSS rectifier group were each independently simulated as failures under the abnormal operation condition. The worst simulated scenario when analyzing train voltages occurred when the Potomac Yard Substation TPSS rectifier group failed. Under this worst case scenario the lowest value was 496V and occurred between the National Airport and Potomac Yard Metrorail Stations. Fortunately, the lower limit threshold of 475 V for abnormal operation was never exceeded.

As previously stated, the acceptable lower limit for power availability is 60 percent. The power availability falls down to 52 percent, 54 percent, and 57.7 percent for the Potomac Yard, National Airport, and Braddock Road, respectively, approximately between the National Airport and Potomac Yard Metrorail Stations.

The rail-to-ground values were well below the safety limit of 120V under abnormal operation. The worst instance with a value of 85V occurred approximately between the National Airport and Potomac Yard Metrorail Stations. Note that the value of 85V in the same location occurred under the normal operation.

The TPSS overload current limits were exceeded at both the National Airport and Potomac Yard Substations under abnormal operation with values of 8681 and 9959 A RMS respectively.

Emergency Operation

The Potomac TPSS, National Airport TPSS, and Braddock Road TPSS were each independently simulated as failures under the emergency operation condition. The train voltages must remain above 450 Vdc under emergency operation. The train voltages fell below the limit of 450V for emergency operation in multiple locations. The train voltages fell to 440 and 436 V for track 1 and track 2, respectively when the National Airport Substation was out of service. The train voltages fell to 413 and 433 V for track 1 and track 2, respectively when the Potomac Yard Substation was out of service.

The lowest acceptable limit for power availability is 60 percent, the power availability fell down to 24.1 percent, 26.1 percent and 39.8 percent at National Airport, Potomac Yard, and Braddock Road under emergency operation, respectively, and approximately between the National Airport and Potomac Yard Metrorail Stations.

The rail-to-ground values were well below the safety limit of 150 V. The worst instance with a value of 105 V occurred when the National Airport TPSS was out of service.

The TPSS overload current limits were exceeded when both the National Airport and Braddock Road Substations were out of service. In those instances, the adjacent substations must provide 10862 Arms (18th & Fern) and 14962 Arms (Potomac Yard) respectively.

Loads Summary for Normal, Abnormal and Emergency Operation

Table 4 lists the maximum current values for all of the TPSS in the simulated track under normal and abnormal operation. Tabulated values identified in red exceed the overload threshold for the specified operational mode.

Table 4. TPSS currents for normal and abnormal operation.

	TPSS LIMITS A (RMS)		SIMULATIONS RESULTS A (RMS)			
	NORMAL OPERATION	ABNORMAL OPERATION	NORMAL OPERATION	ABNORMAL OPERATION		
TPSS	NOMINAL	AVAILABLE LOAD		NATIONAL AIRPORT	POTOMAC YARD	BRADDOCK ROAD
18TH & FERN	5714 (2+2MW)	5714 (2+2MW)	6457	6945	6542	6475
NATIONAL AIRPORT	10000 (2+2+3MW)	5714 (2+2MW)	9791	**8681**	10471	9825
POTOMAC YARD	8571 (3+3MW)	4286 (3MW)	11728	12117	**9959**	12011
BRADDOCK ROAD	12857 (3+3+3MW)	8571 (3+3MW)	10843	10541	11357	9799
DUKE STREET	8571 (2+2+2MW)	8571 (2+2+2MW)	8638	8643	8714	8959

Table 5 lists the maximum current values for all of the TPSS in the simulated track under normal and emergency operation. Tabulated values identified in red exceed the overload threshold for the specified operational mode.

Table 5. TPSS currents for emergency operation.

	TPSS LIMITS A (RMS)	SIMULATIONS RESULTS A (RMS)		
	NORMAL OPERATION	EMERGENCY OPERATION		
TPSS	NOMINAL	NATIONAL AIRPORT	POTOMAC YARD	BRADDOCK ROAD
18TH & FERN	5714 (2+2MW)	**10862**	7443	6990
NATIONAL AIRPORT	10000 (2+2+3MW)	-	13453	9863
POTOMAC YARD	8571 (3+3MW)	12020	-	**14962**
BRADDOCK ROAD	12857 (3+3+3MW)	10662	15250	-
DUKE STREET	8571 (2+2+2MW)	8620	8698	12074

Table 6 lists the maximum overload values for all of the TPSS in the simulated track under normal, abnormal and emergency operation. Tabulated values identified in red exceed the overload threshold for the specified operational mode. For Baseline TPS loading must be <100% and for contingency loading must be <146%

Table 6 TPSS power for normal, abnormal and emergency operation.

Subestations	TPS	TPS Rating	TPS config	Normal operation Baseline TPS Loading	Outage condition 1 Rect Outage Loading	Outage condition TPS Outage Loading
18TH & FERN	C09	4 MW	2+2	**113 %**	122 %	**190 %**
NATIONAL AIRPORT	C10	7 MW	2+2+3	98 %	**152 %**	135 %
POTOMAC YARD	C11	6 MW	3+3	**137 %**	**232 %**	**175 %**
BRADDOCK ROAD	C12	9 MW	3+3+3	84 %	114 %	119 %
DUKE STREET	C97	6 MW	2+2+2	101 %	105 %	141 %

Note: Baseline loading must be <100%
Contingency loading must be <146%

Voltages Summary for Normal, Abnormal and Emergency Operation

Table 7 lists the maximum rail-to-ground voltages, train voltages and the minimum train power availability under normal, abnormal and emergency operation. Tabulated values identified in red are values that fall below the minimum operational

threshold. In this simulation, the voltage threshold for train voltages were exceeded, specifically Train Voltage Track 1 and Track 2 at the National Airport and Potomac Yard Metrorail Stations, during emergency operation.

Table 7. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Normal Operation	525	**505**[1]	75	85	58.1
Abnormal operation. National Airport	**514**	499	79	85	54
Abnormal operation. Potomac Yard	514	496	82	85	52
Abnormal operation. Braddock Rd	519	504	77	84	57.7
Emergency operation. National Airport	**440**[2]	**436**[3]	103	105	24.1
Emergency operation. Potomac Yard	**413**[4]	**433**[5]	104	104	26.1
Emergency operation. Braddock Rd	475	458	85	85	39.8

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 525V less than 14 seconds*
[2] *below 450V less than 8 seconds*
[3] *below 450V less than 15 seconds*
[4] *below 450V less than 3 seconds*
[5] *below 450V less than 3 seconds*

Positive and Negative Feeder Current Summary for Normal, Abnormal and Emergency Operation

Table 8 shows the currents ratings of positive and negative feeder under normal operation and contingency operation (abnormal and emergency). Tabulated values identified in red are values that overcome 100% in normal operation and overcome 134% in contingency operation.

Table 8 Positive and Negative feeder currents ratings. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%.

TPSS & TBS	Feeders (P-Positive N-Negative)	Existing No. of cables	Cable load / Rating Ratio Normal operation	Cable Load/ Rating Ratio Contingency Operation
C09TP-18th&Fern St	P34	4	**129%**	**173%**
C09TB1-Cristal City	P42	4	**105%**	**141%**
C09TB1-Cristal City	P44	4	**109%**	**146%**
C10TP-National Airport	P33	4	59%	**148%**
C10TP-National Airport	P34	4	**120%**	**158%**
C10TP-National Airport	N1	6	**100%**	**139%**
C10TP-National Airport	N2	6	**131%**	**170%**
C11TP-Potomac RR Yard	P34	5	**148%**	**165%**
C11TP-Potomac RR Yard	N1	6	**124%**	**162%**
C11TP-Potomac RR Yard	N2	6	**142%**	**174%**
C12TP-Braddock Rd	P31	5	**130%**	**178%**
C12TP-Braddock Rd	P32	4	87%	**154%**
C12TP-Braddock Rd	P34	5	**103%**	103%
C12TP-Braddock Rd	N1	6	**128%**	**181%**
C12TP-Braddock Rd	N2	6	**111%**	**163%**
C97TP-Duke St	P31	4	**111%**	**163%**
C97TP-Duke St	P32	4	**130%**	**136%**
C97TP-Duke St	P33	4	**101%**	109%
C97TP-Duke St	N1	6	91%	129%
C97TP-Duke St	N2	6	**107%**	**143%**

System Upgrades and Simulations

05

System Upgrades and Simulations

The previous section identified that the existing system under normal operation complies with WMATA traction power requirements. The existing system fell below the WMATA traction power requirements under abnormal and emergency operation. The upgrades—TPSS and feeders, contact rail, and feeder breakers—to the existing Traction Power System would allow the system to comply with WMATA requirements under normal, abnormal and emergency operations. In addition, this section presents the Traction Power System simulation results with the proposed upgrades.

5.1. TPSS and Feeders Upgrade

Table 9 shows the Traction Power Substations that need to be upgraded including the number of cables (1000 kcmil) required to support the feeds.

Table 9. TPSS and feeders upgrade.

TPSS/TBS/STATION	Current TPSS Units and rating [MW]	TPSS Units and rating after upgrade [MW]	Feeders (P-positive, N-negative)	Current 1000 kcmil Cables (Quantity)	1000 kcmil Cables after upgrade (Quantity)
PENTAGON CITY STATION					
C09TP 18TH & FERN SUBSTATION	2+2 (4MW)	**3+3 (6MW)**	P31	4	4
			P32	4	**5(*)**
			P33	5	5
			P34	4	**6**
			N1	6	6
			N2	6	6
CRYSTAL CITY STATION					
C09TB CRYSTAL CITY TIE BREAKER STATION	-	-	P41	4	4
			P42	4	**5**
			P43	4	4
			P44	4	**5**
			P46	4	4
NATIONAL AIRPORT STATION					
C10TP NATIONAL AIRPORT SUBSTATION	2+2+3 (7MW)	**3+3+3 (9MW)**	P31	5	5
			P32	5	5
			P33	4	**5**
			P34	4	**6(*)**
			P36	3	3
			P37	4	4
			N1	6	**8**
			N2	6	**8**
C11TB POTOMAC RR YARD NORTH TIE BREAKER STATION	-	-	P41	4	4
			P42	4	4
			P43	4	4
			P44	4	4
POTOMAC YARD STATION					

TPSS/TBS/STATION	Current TPSS Units and rating [MW]	TPSS Units and rating after upgrade [MW]	Feeders (P-positive, N-negative)	Current 1000 kcmil Cables (Quantity)	1000 kcmil Cables after upgrade (Quantity)
C11TP POTOMAC RR YARD SUBSTATION	3+3 (6MW)	**3+3+3 (9MW)**	P31	5	5
			P32	5	5
			P33	5	5
			P34	5	**8**
			N1	6	**9**
			N2	6	**9**
C12TB BRASHFORD LANE TIE BREAKER STATION	-	-	P41	4	4
			P42	4	4
			P43	4	4
			P44	4	4
C12TP BRADDOCK ROAD SUBSTATION	3+3+3 (9MW)	3+3+3 (9MW) UPGRADE NOT REQUIRED	P31	5	**7**
			P32	4	**5**
			P33	6	6
			P34	5	**6**
			P35	4	4
			N1	6	**9**
			N2	6	**9**
BRADDOCK ROAD STATION					
C13TB KING STREET TIE BREAKER STATION	-	-	P41	4	4
			P42	4	4
			P43	4	4
			P44	4	4
			P45	4	4
KING STREET STATION					
C97TP DUKE STREET SUBSTATION	2+2+2 (6MW)	2+2+2 (6MW) UPGRADE NOT REQUIRED	P31	4	**5**
			P32	4	**6**
			P33	4	**5**
			P34	4	4
			P35	4	4
			P36	4	4
			N1	6	**7**
			N2	6	**7**

(*) The quantity of the feeders after upgrade is defined by the number of 1000 kcmil cables required after the upgraded system simulations. The results of the upgraded system simulations provide new current distributions that cause the feeders to be resized. For detailed information on currents distribution see **Table 25** and **Table 27** in **Appendix 1**.

5.2. Contact Rail Upgrade

The proposed contact rail upgrade, to minimize the train voltage drop, replaces the steel contact rail with composite rail in sections with the higher voltage drops. This section corresponds to both track 1 and track 2 between the National Airport and Braddock Road Substations.

5.3. Feeder Breakers Upgrade

The following feeder breakers need to be upgraded to comply with the current requirements for the proposed upgraded system, as reflected in the **Table 10**.

Table 10. Feeder breakers upgrade.

TPSS & TBS	Feeders (P-Positive N-Negative)	Breaker ratings [A]	Breaker rating upgraded [A]	Increase in rating over existing
C09TP-18th&Fern St	P34	4000	6000	2000
C09TB1-Cristal City	P42	4000	6000	2000
C09TB1-Cristal City	P44	4000	6000	2000
C11TP-Potomac RR Yard	P34	6000	8000	2000
C12TP-Braddock Rd	P31	6000	8000	2000
C97TP-Duke St	P31	4000	6000	2000

5.4. Upgrade System Simulations

This section shows the results of the simulations for the three defined scenarios after the system upgrades:

- Normal operation.
- Abnormal operation.
- Emergency operation.

Graphs of the train voltages, train currents, train power availability and rail-to-ground voltages are shown in the following subsections. TPSS currents are tabulated in **Appendix 1** and RMS currents are graphically represented in **Appendix 2**.

Normal Operation

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 32** shows the train voltages of the simulated track section and also shows the minimum vehicle operating voltage threshold of 525 Vdc under normal operation for the upgraded system.

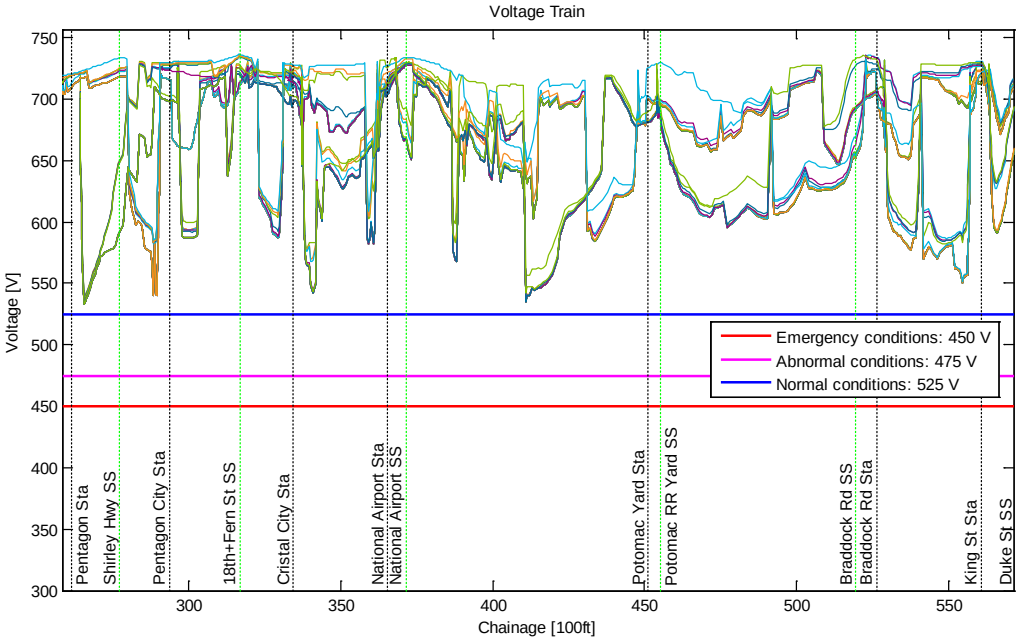


Figure 32. Upgraded system. Train voltages in the track section under normal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified track section. **Figure 33** shows train currents of the simulated track section under normal operation for the upgraded system.

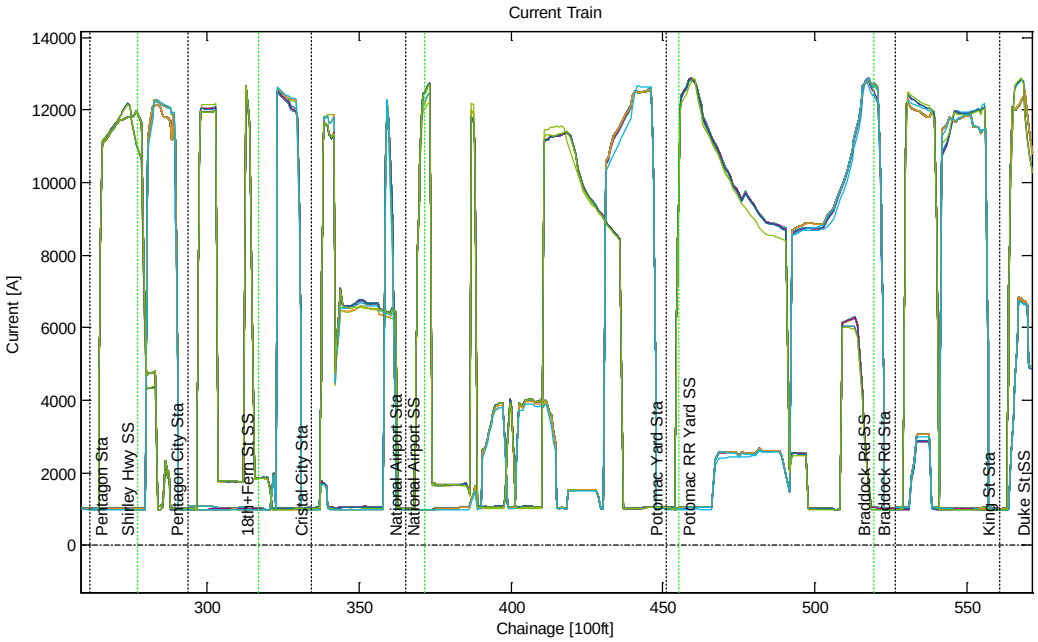


Figure 33. Upgraded system. Train currents in the track section under normal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 34** shows the train power availabilities of the simulated track section under normal operation for the upgraded system.

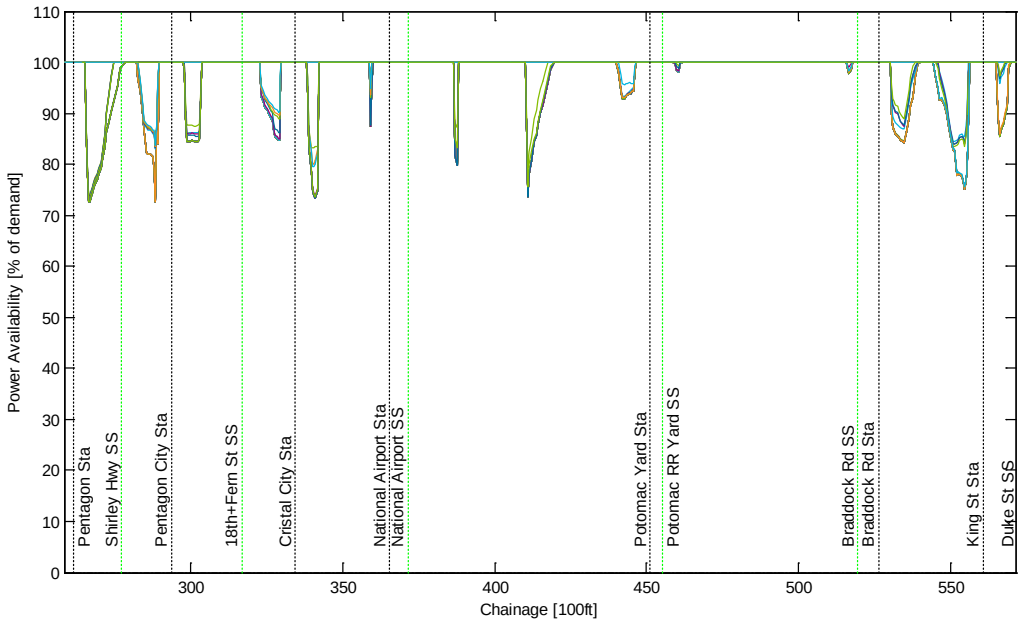


Figure 34. Upgraded system. Power availability in the track section under normal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 35** shows rail-to-ground voltage limits of the simulated track section under normal operation for the upgraded system. All of the rail-to-ground voltages in the tract section are under the 100 V limit.

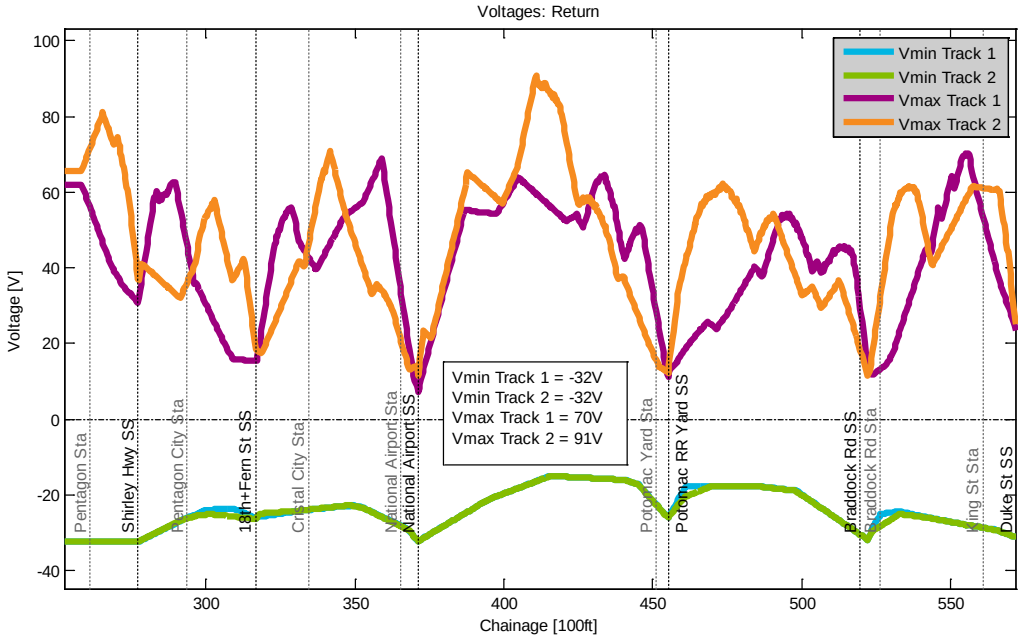


Figure 35. Upgraded system. Rail-to-ground voltages in the track section under normal operation.

TPSS Currents

The traction power substation simulated RMS load current results under normal conditions are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Abnormal Operation – National Airport Substation Rectifier Group Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 36** shows the train voltages of the simulated track section with the National Airport Substation out of service and also shows the minimum vehicle operating voltage threshold of 475Vdc under abnormal operation for the upgraded system.

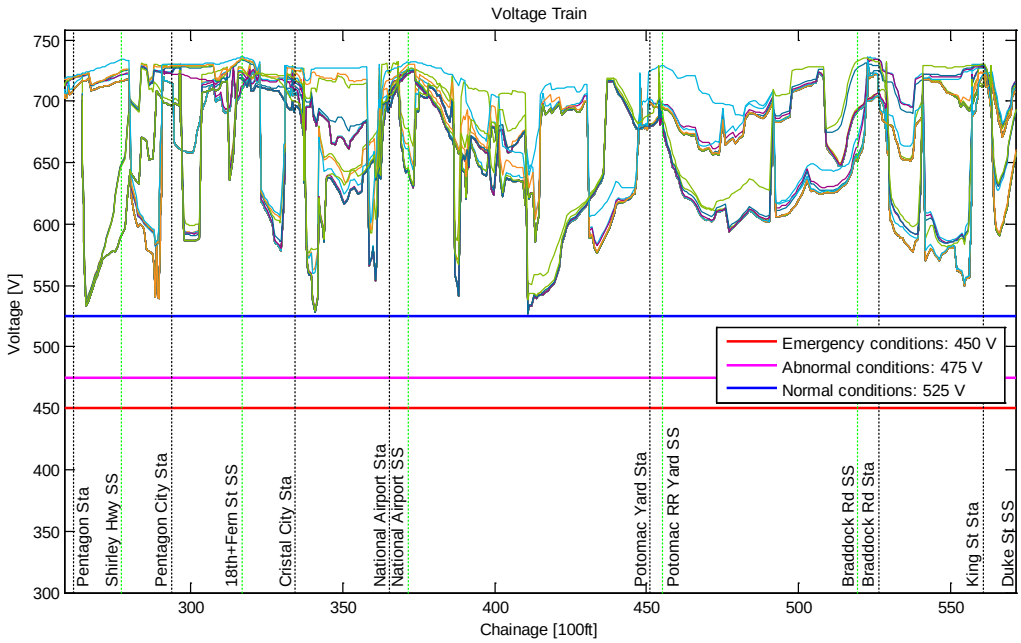


Figure 36. Upgraded system. Train voltages in the track section for National Airport Substation under abnormal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 37** shows train currents of the simulated track section with the National Airport Substation under abnormal operation for the upgraded system.

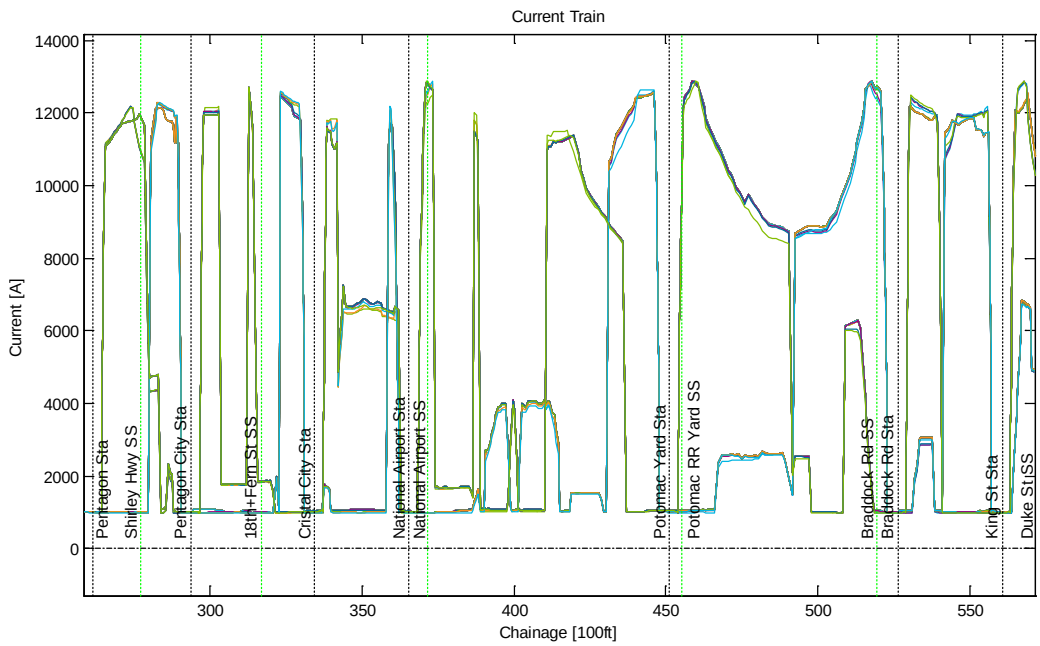


Figure 37. Upgraded system. Train currents in the track section for National Airport Substation under abnormal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 38** shows the train power availabilities of the simulated track section with the National Airport Substation under abnormal operation for the upgraded system.

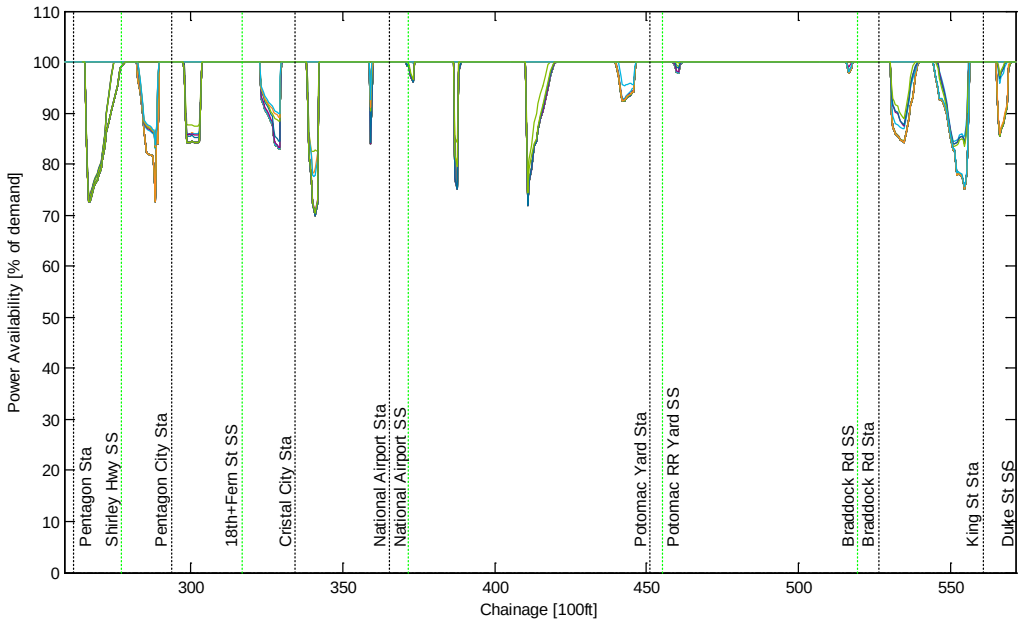


Figure 38. Upgraded system. Power availability in the track section for National Airport Substation under abnormal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 39** shows rail-to-ground voltage limits of the simulated track section with the National Airport Substation under abnormal operation for the upgraded system. All of the rail-to-ground voltages in the tract section are under the 120 V limit.

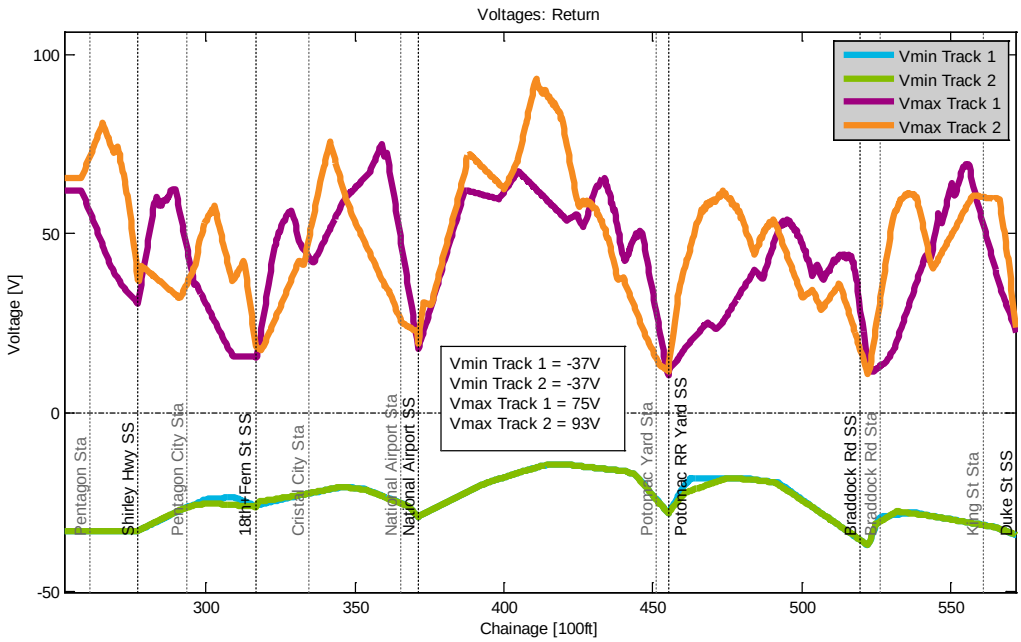


Figure 39. Upgraded system. Rail-to-ground voltages in the track section for National Airport Substation under abnormal operation.

TPSS Currents

The traction power substation simulated RMS load current results under abnormal condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Abnormal Operation – Potomac Yard Substation Rectifier Group Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 40** shows the train voltages of the simulated track section with the Potomac Yard Substation out of service and also shows the minimum vehicle operating voltage threshold of 475Vdc under abnormal operation for the upgraded system.

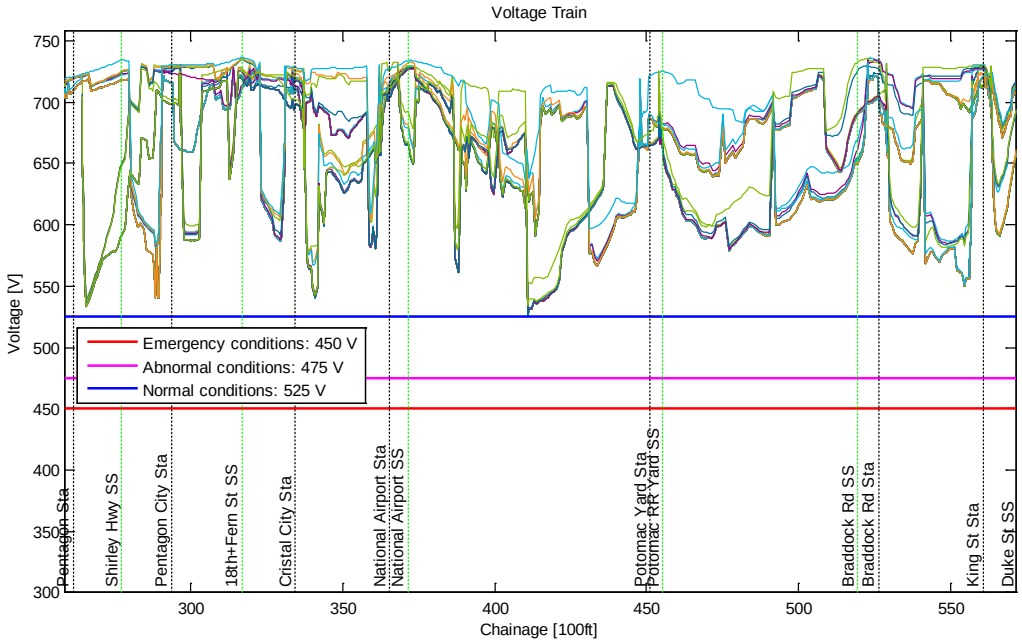


Figure 40. Upgraded system. Train voltages in the track section for Potomac Yard Substation under abnormal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 41** shows train currents of the simulated track section with the Potomac Yard Substation under abnormal operation for the upgraded system.

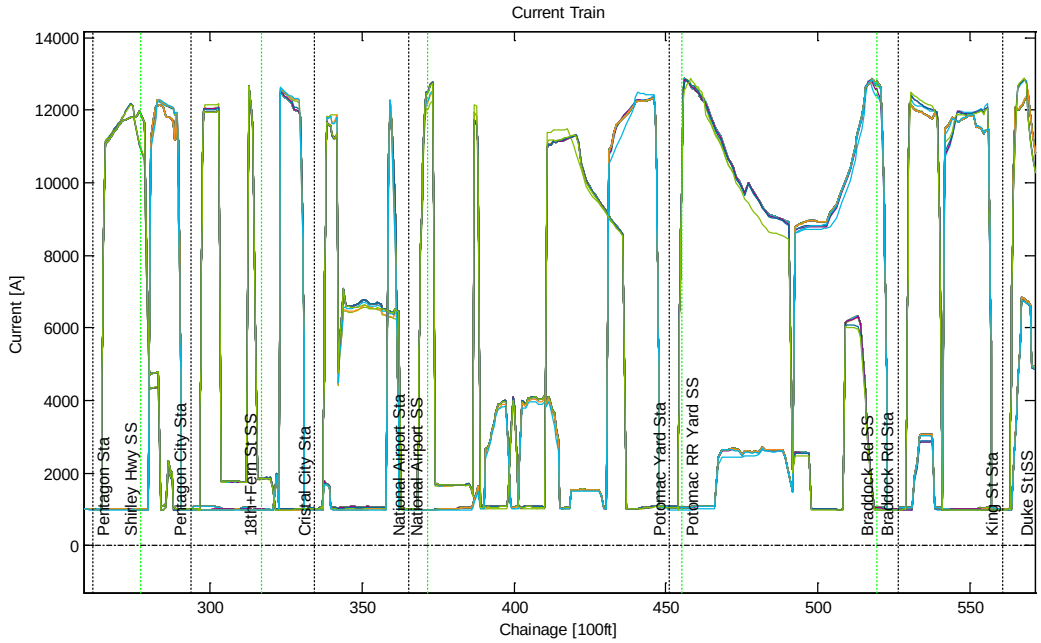


Figure 41. Upgraded system. Train currents in the track section for Potomac Yard Substation under abnormal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 42** shows the train power availabilities of the simulated track section with the Potomac Yard Substation under abnormal operation for the upgraded system.

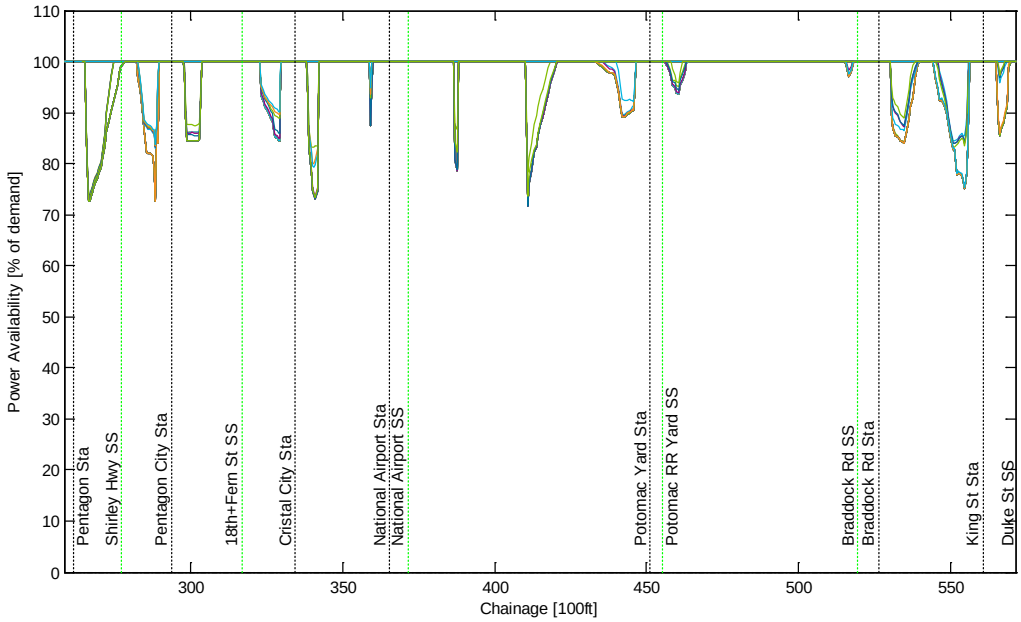


Figure 42. Upgraded system. Power availability in the track section for Potomac Yard Substation under abnormal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 43** shows rail-to-ground voltage limits of the simulated track section with the Potomac Yard Substation under abnormal operation for the upgraded system. All of the rail-to-ground voltages in the tract section are under the 120 V limit.

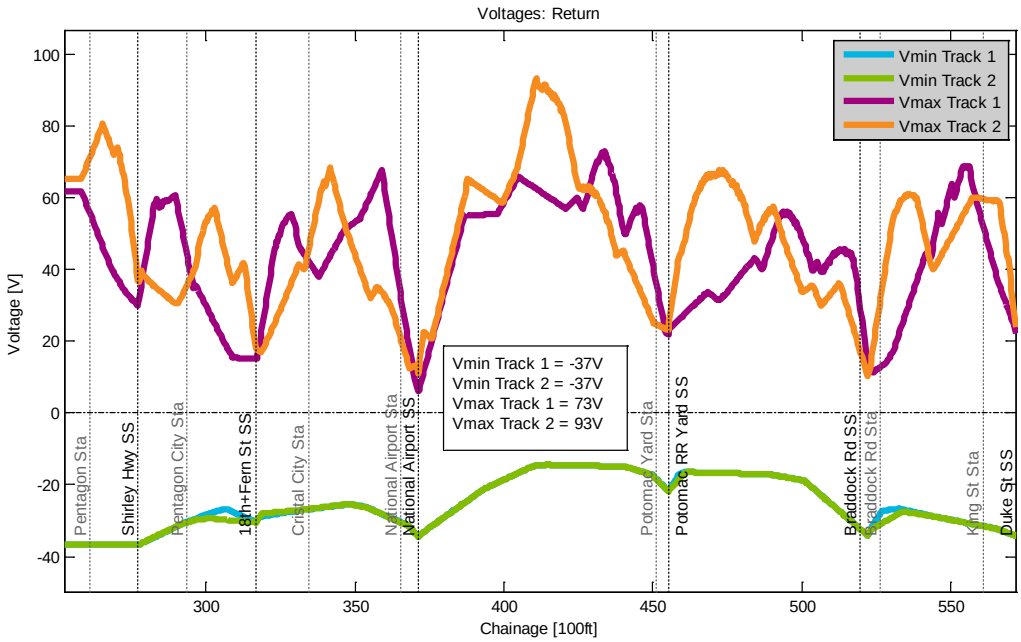


Figure 43. Upgraded system. Rail-to-ground voltages in the track section for Potomac Yard Substation under abnormal operation.

TPSS Currents

The traction power substation simulated RMS load current results under abnormal condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Abnormal Operation – Braddock Road Substation Rectifier Group Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 44** shows the train voltages of the simulated track section with the Braddock Road Substation out of service and also shows the minimum vehicle operating voltage threshold of 475Vdc under abnormal operation for the upgraded system.

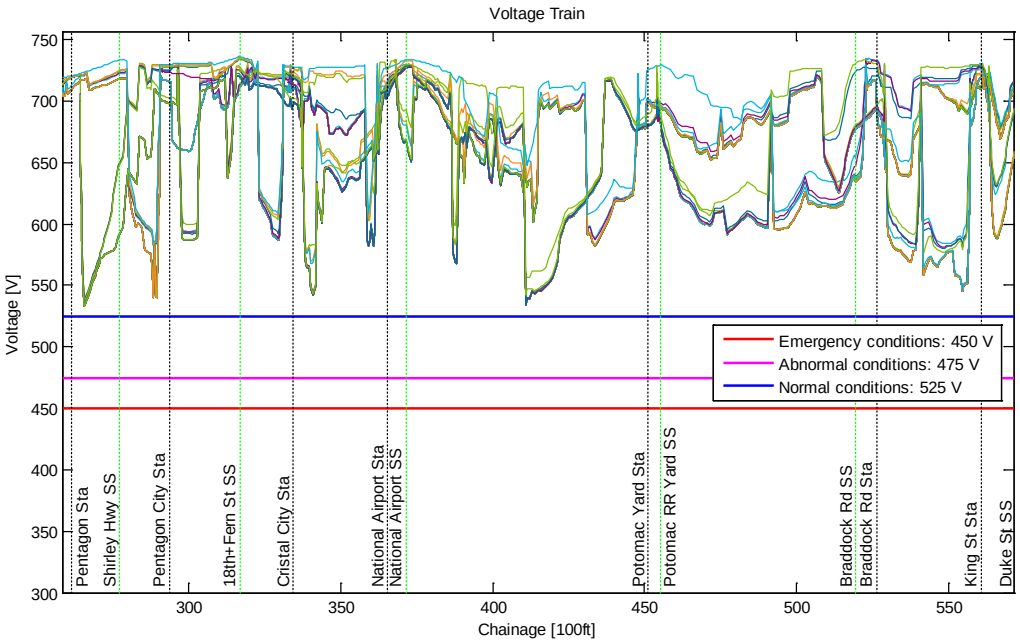


Figure 44. Upgraded system. Train voltages in the track section for Braddock Road Substation under abnormal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 45** shows train currents of the simulated track section with the Braddock Road Substation under abnormal operation for the upgraded system.

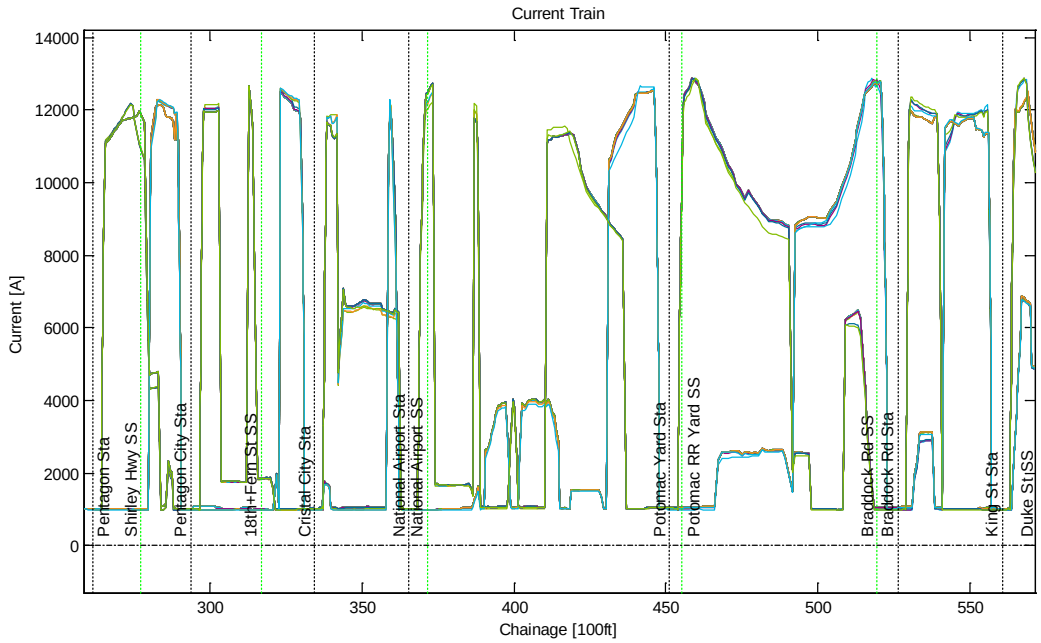


Figure 45. Upgraded system. Train currents in the track section for Braddock Road Substation under abnormal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 46** shows the train power availabilities of the simulated track section with the Braddock Road Substation under abnormal operation for the upgraded system.

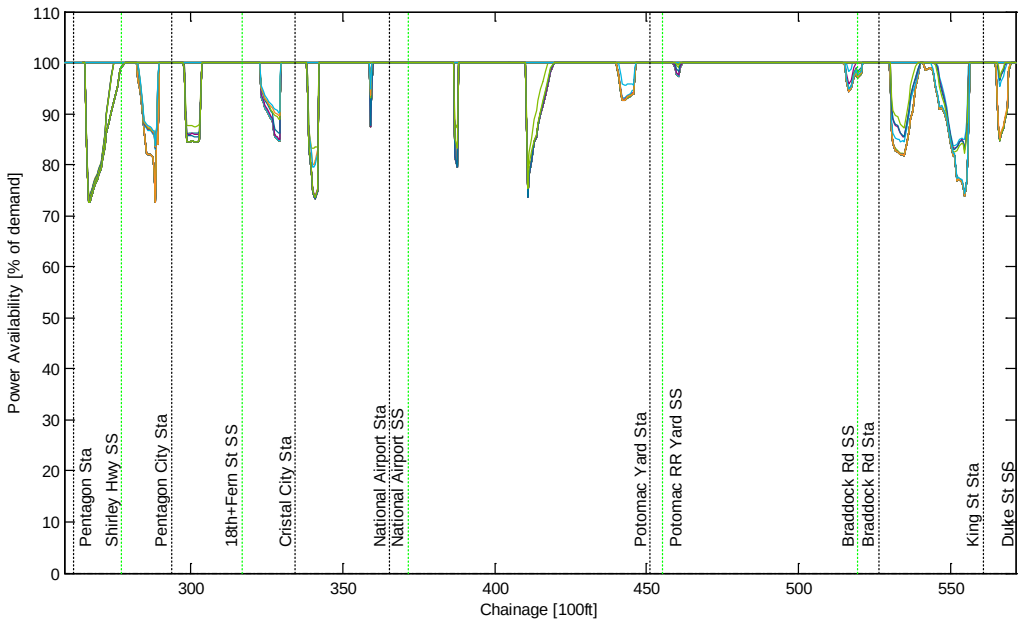


Figure 46. Upgraded system. Power availability in the track section for Braddock Road Substation under abnormal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 47** shows rail-to-ground voltage limits of the simulated track section with the Braddock Road Substation under abnormal operation for the upgraded system. All of the rail-to-ground voltages in the tract section are under the 120 V limit.

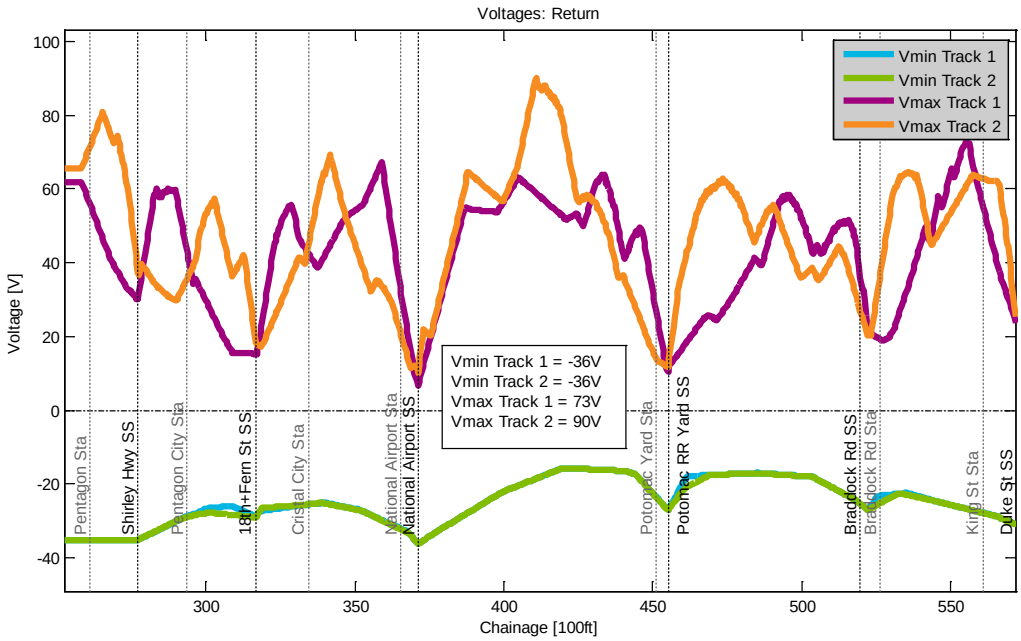


Figure 47. Upgraded system. Rail-to-ground voltages in the track section for Braddock Road Substation under abnormal operation.

TPSS Currents

The traction power substation simulated RMS load current results under abnormal condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Emergency Operation – National Airport Substation Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 48** shows the train voltages of the simulated track section with the National Airport out of service and also shows the minimum vehicle operating voltage threshold of 450 Vdc under emergency operation for the upgraded system.

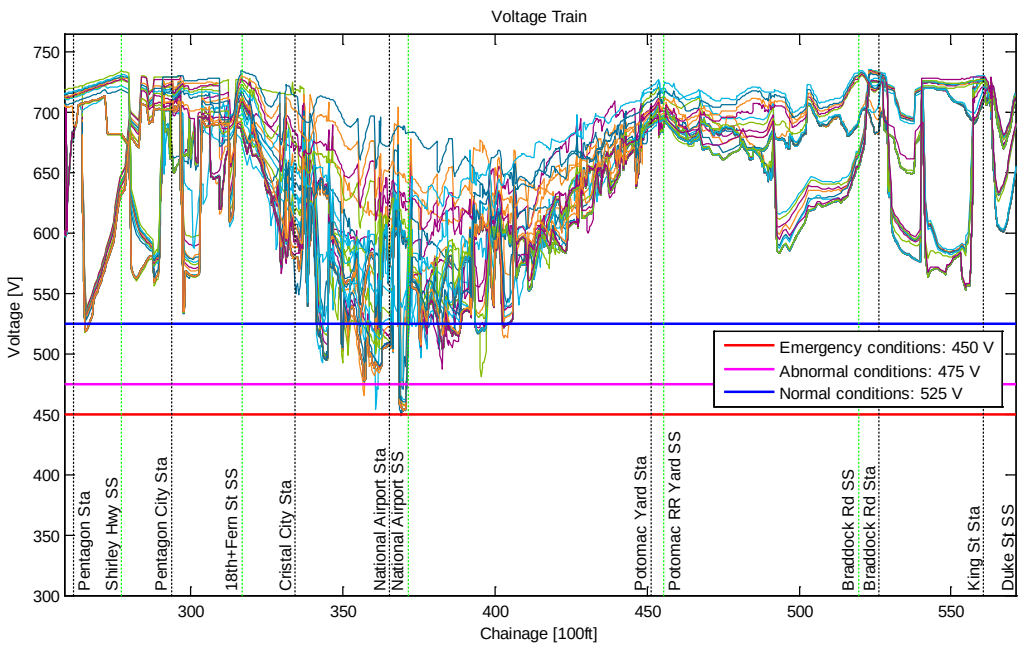


Figure 48. Upgraded system. Train voltages in the track section for National Airport under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 49** shows the train currents in the simulated track section with the National Airport under emergency operation for the upgraded system.

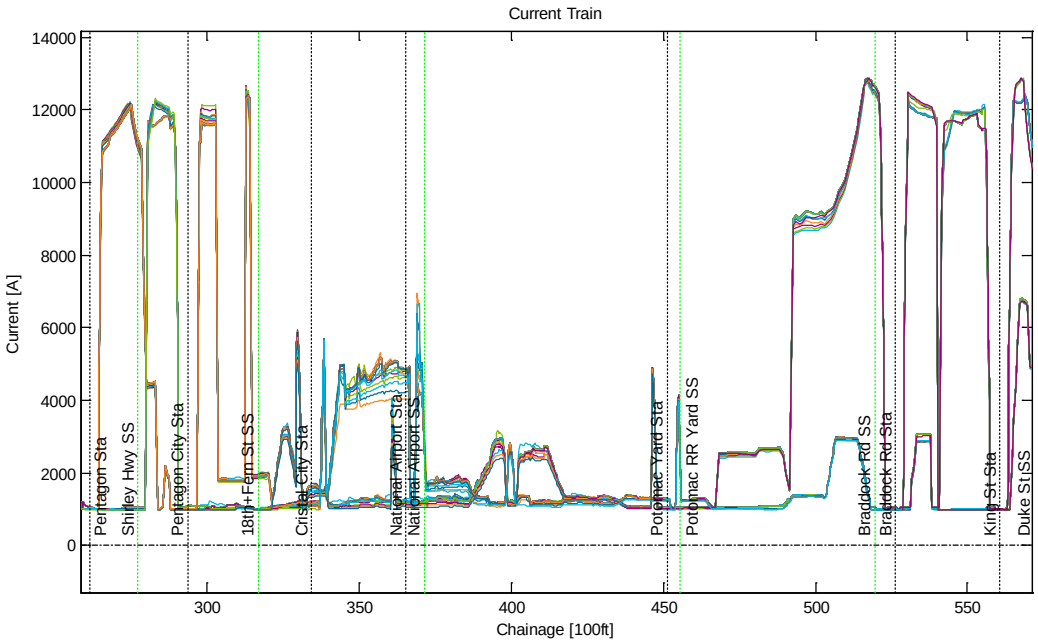


Figure 49. Upgraded system. Train currents in the track section for National Airport under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 50** shows the train power availabilities of the simulated track section with the National Airport under emergency operation for the upgraded system.

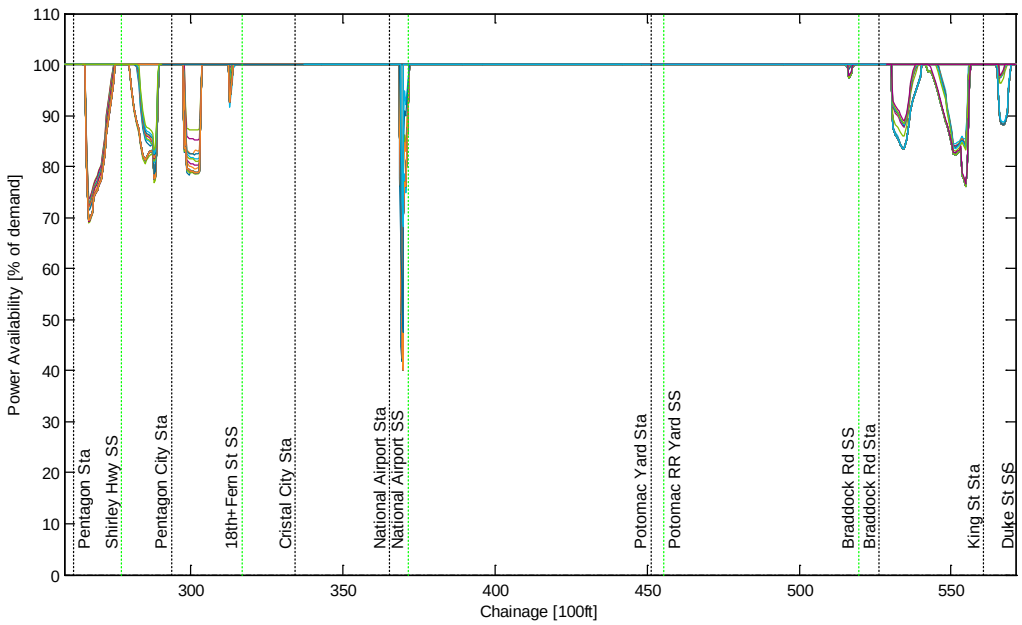


Figure 50. Upgraded system. Power availability in the track section for National Airport under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 51** shows the rail-to-ground voltage limits of the simulated track section with the National Airport under emergency operation for the upgraded system. All of the rail-to-ground voltages in the tract section are under the 150 V limit.

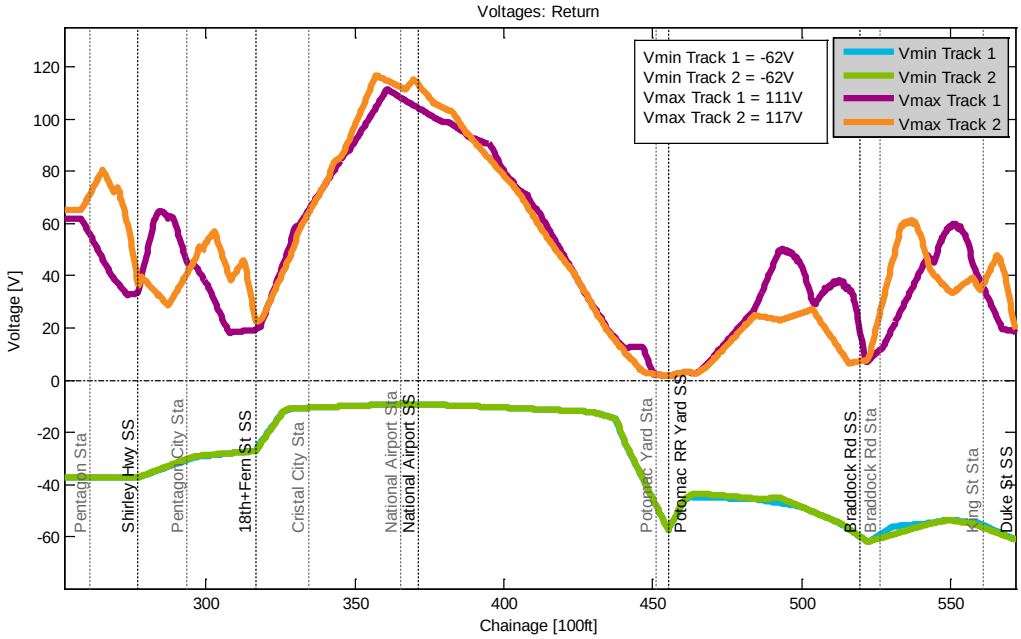


Figure 51. Upgraded system. Rail-to-ground voltages in the track section for National Airport under emergency operation.

TPSS Currents

The traction power substation simulated RMS load current results under emergency condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Emergency Operation – Potomac Yard Substation Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 52** shows the train voltages of the simulated track section with the Potomac Yard out of service and also shows the minimum vehicle operating voltage threshold of 450 Vdc under emergency operation for the upgraded system.

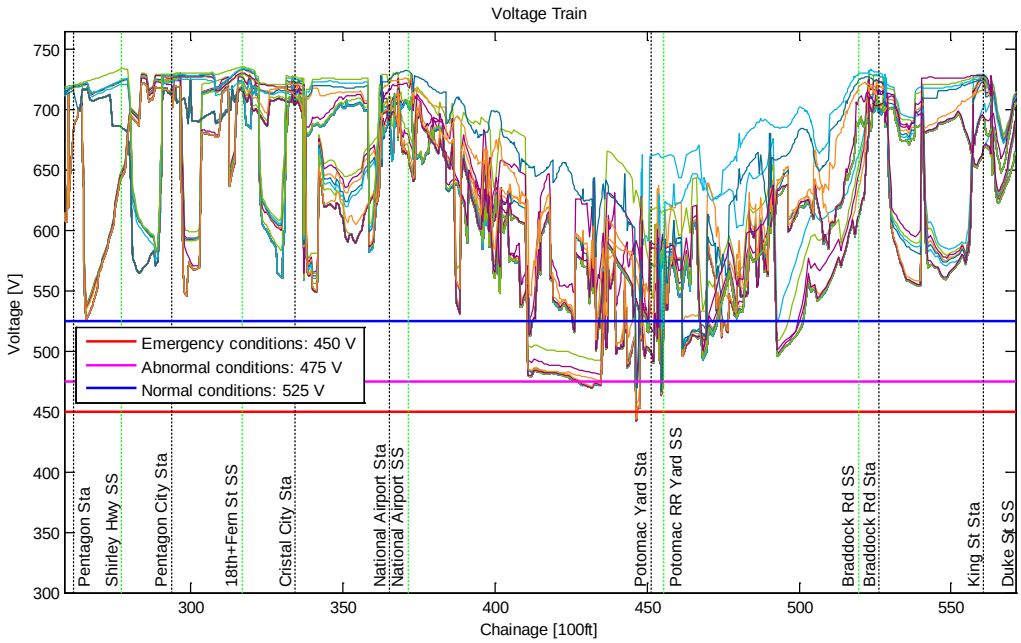


Figure 52. Upgraded system. Train voltages in the track section for Potomac Yard under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 53** shows the train currents in the simulated track section with the Potomac Yard under emergency operation or the upgraded system.

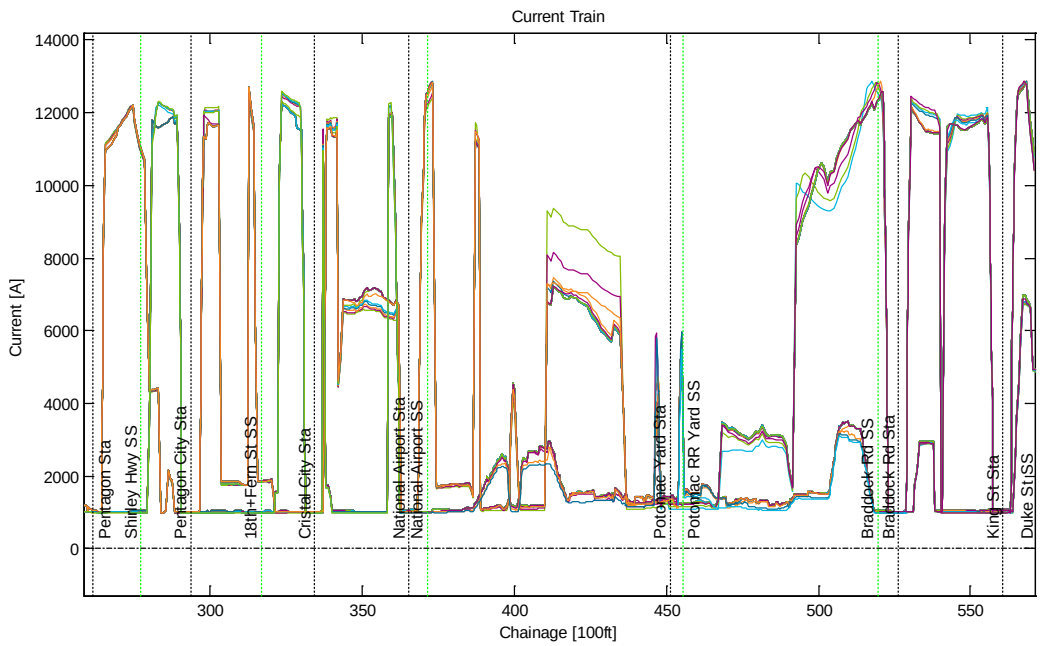


Figure 53. Upgraded system. Train currents in the track section for Potomac Yard under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 54** shows the power availability in the simulated track section with the Potomac Yard under emergency operation or the upgraded system.

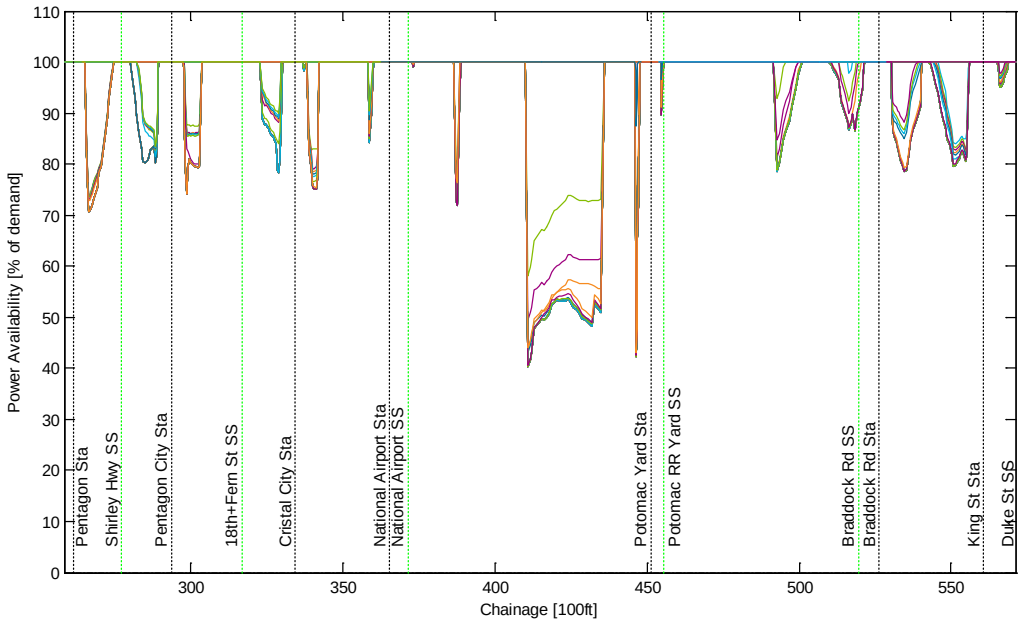


Figure 54. Upgraded system. Power availability in the track section for Potomac Yard under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 55** shows the rail-to-ground voltage limits of the simulated track section with the Potomac Yard under emergency operation or the upgraded system. All of the rail-to-ground voltages in the tract section are under the 150 V limit.

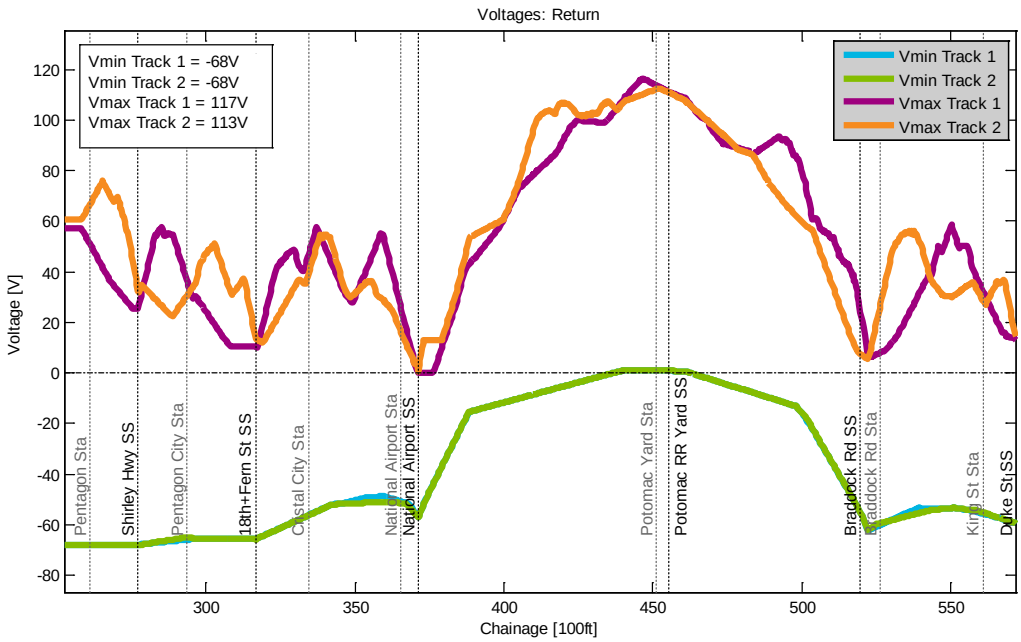


Figure 55. Upgraded system. Rail-to-ground voltages in the track section for Potomac Yard under emergency operation.

TPSS Currents

The traction power substation simulated RMS load current results under emergency condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

Emergency Operation – Braddock Road Substation Out of Service

Train Voltages

In a Traction Power System consisting of substation equipment, feeders, tie-breakers and rails, every train should have the minimum voltage to function properly. **Figure 56** shows the train voltages of the simulated track section with the Braddock Road out of service and also shows the minimum vehicle operating voltage threshold of 450 Vdc under emergency operation for the upgraded system.

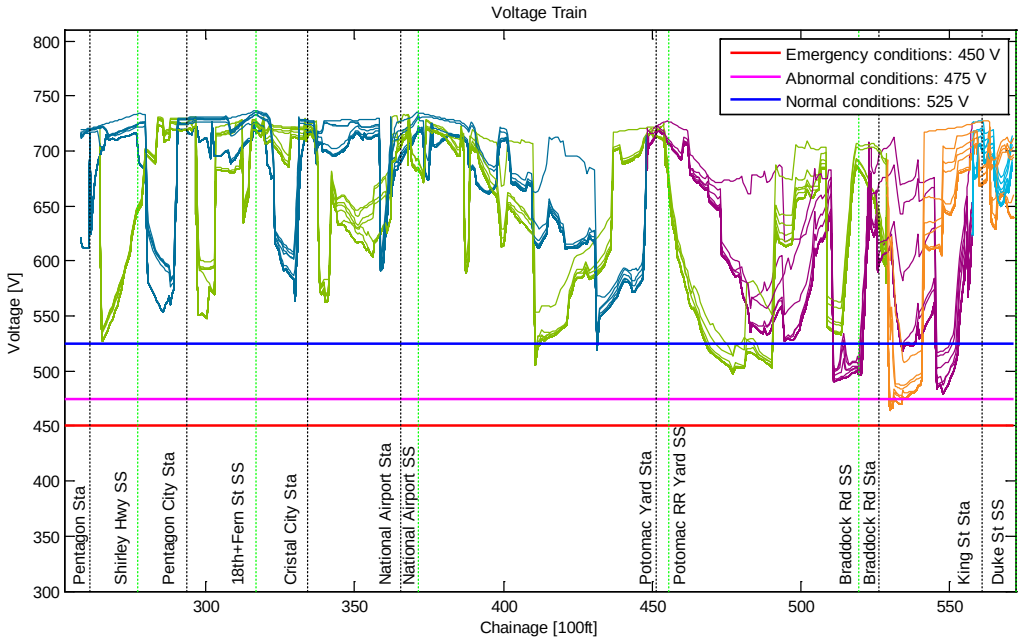


Figure 56. Upgraded system. Train voltages in the track section for Braddock Road under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 57** shows the train currents of the simulated track section with the Braddock Road under emergency operation for the upgraded system.

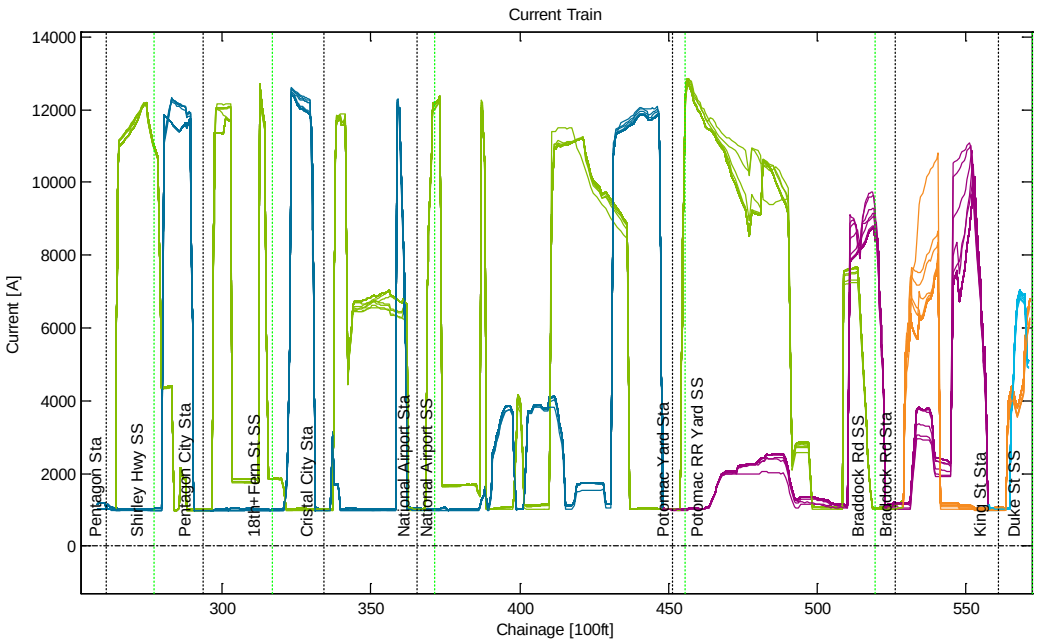


Figure 57. Upgraded system. Train currents in the track section for Braddock Road under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 58** shows the train power availabilities of the simulated track section with the Braddock Road under emergency operation for the upgraded system.

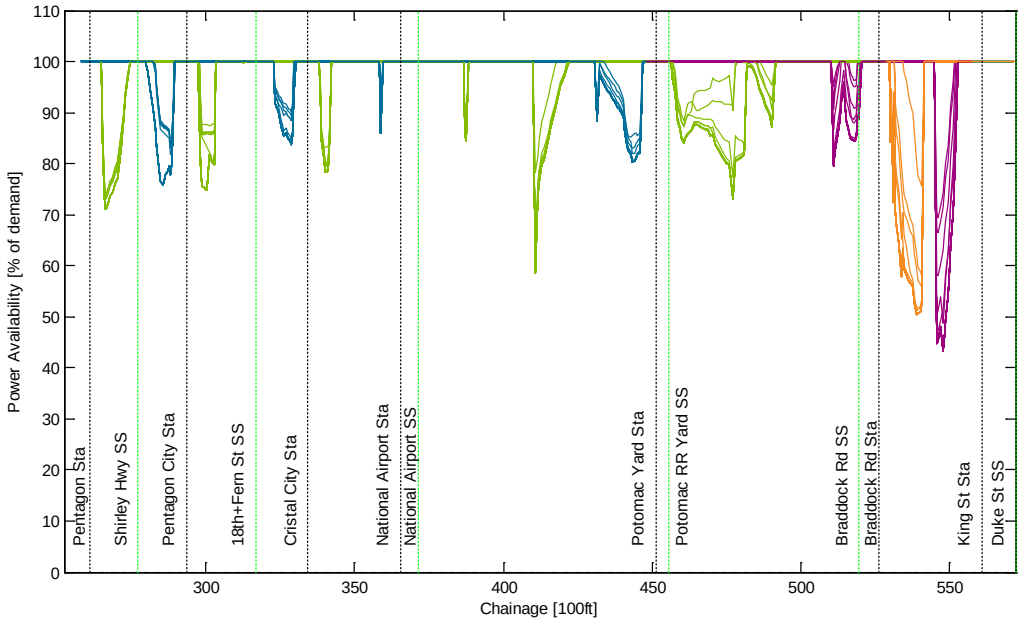


Figure 58. Upgraded system. Power availability in the track section for Braddock Road under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 59** shows the rail-to-ground voltage limits of the simulated track section with the Braddock Road under emergency operation for the upgraded system. All of the rail-to-ground voltages in the tract section are under the 150 V limit.

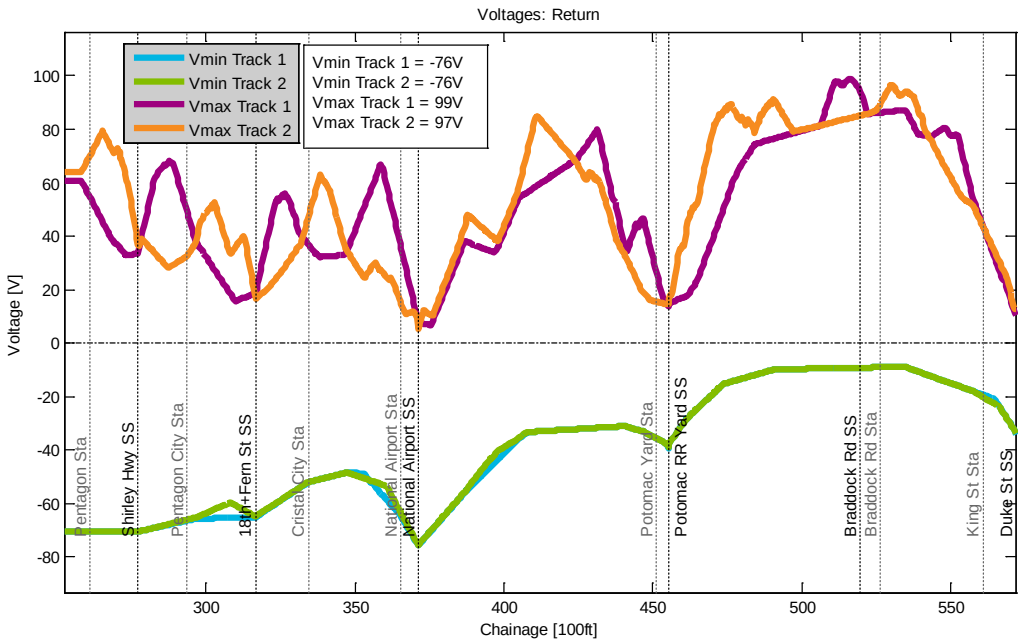


Figure 59. Upgraded system. Rail-to-ground voltages in the track section for Braddock Road under emergency operation.

TPSS Currents

The traction power substation simulated RMS load current results under emergency condition are summarized in **Section 4.4**. The summary of TPSS currents, feeder quantities and breaker ratings are tabulated in **Appendix 1**. Instant and RMS currents are graphically represented in **Appendix 2**.

5.5. Simulation Results Summary

The following section is an analysis of the normal, abnormal and emergency operation of the existing system with the recommended system upgrades.

Normal Operation

Applying the system upgrades and running the simulations, the train voltages, train currents, train power availability, rail-to-ground voltages and TPSS currents stay within the nominal values. Specifically, the train voltages were above the threshold limit for normal operation (525V). The lowest value in the simulations was 533V.

The train power availability fell below 75 percent (73.7 percent) compared to 60 percent without the upgrades.

The rail-to-ground voltages were well below the 100V limit under normal operation. The maximum value identified in the simulation was 91V and corresponds to track 2, approximately between the Potomac Yard Station and National Airport Substations. Note that there were slightly more rail-to-ground voltages when the upgrades were added.

The TPSS RMS current never exceed the nominal value for any of the TPSS, as shown in **Table 11**.

Abnormal Operation

Similar to the simulations without the upgrades, the Potomac TPSS rectifier group, National Airport rectifier group, and the Braddock Road TPSS rectifier group were each independently simulated as failures under the abnormal condition. The worst simulated scenario when analyzing train voltages under the abnormal operation was when a rectifier group in the Potomac Yard Substation was out of service. Under this worst case scenario the lowest value was 526V which was well above the 475V lower limit and occurred approximately between the National Airport and Potomac Yard Metrorail Stations.

The acceptable lowest limit for power availability is 60 percent so the train power availabilities with the system upgrades were improved. The lowest power availability values with the system upgrades of the existing system fell to 70.0 percent, 71.6 percent, and 73.5 percent for National Airport, Potomac Yard, and Braddock Road, respectively.

The rail-to-ground values were well below the safety limit of 120V under abnormal operation. The worst instance with a value of 93V occurred approximately between the National Airport and Potomac Yard Metrorail Stations.

The TPSS overload current limits were never exceeded for any of the TPSS, as shown in **Table 11**.

Emergency Operation

The Potomac TPSS, National Airport TPSS and Braddock Road TPSS were each independently simulated as failures to evaluate the train voltages, train currents, train power availability, and rail-to-ground voltages under the emergency condition with the recommended system upgrades on the existing system.

National Airport TPSS Out of Service

Train voltages were within the 450 V limit allowed under emergency operation and occurred close to National Airport Station. The train departures from the Potomac Yard Station (between 368+70 and 370+70) where the trains demand a power boost to achieve the limit of 20 mph, in half acceleration caused the lowest train power availability to fall down below 40.1 percent.

The rail-to-ground values were well below the safety limit of 150V. The worst instance with a value of 117V occurred on track 2 in the vicinity of the National Airport Station.

The TPSS overload current limits were never exceeded for the National Airport Substation under emergency operation, as shown in **Table 12**.

Potomac Yard TPSS Out of Service

Train voltages fell below the 450V limit allowed under emergency operation and occurred near the Potomac Yard Substation with a value of 443 V on track 1. The low train voltage condition occurs when the trains are departing from the Potomac Yard Metrorail Station toward the National Airport. It should be noted that the low train voltage situation lasts a very short amount of time and is very close to the 450V limit.

The power availability fell down to 40.5 percent for the trains running between chain markers 410+70 and 435+00 between the National Airport and Potomac Yard Metrorail Station. The low power availability occurs because the trains departing from National Airport are not operating in a degraded operational condition running at full speed and full acceleration in that track section. It should be noted that there is a second point of low train power availability for a very short distance (100ft) and occurs on the departures from the Potomac Yard Station to National Airport, where the train performance is limited to 20mph and half acceleration.

The rail-to-ground values were well below the safety limit of 150V. The worst instance occurred near the Potomac Yard Substation under emergency operation with a value of 117V on track 1.

The TPSS overload current limits were never exceeded for the Potomac Yard Substation under emergency operation, as shown in **Table 12**.

Braddock Road TPSS Out of Service

The train voltages were above the 450V limit under emergency operation at all times in the simulation. The lowest limit of 465V on track 2 occurred for trains departing from the Braddock Road Metrorail Station toward King Street Metrorail Station.

The train power availability fell below 60 percent for the trains departing from both Braddock Road Metrorail Station and King Street Metrorail Station where the trains were affected by degraded operation mode (PL8) moving to get 49 mph with half acceleration.

A second critical point where the train power availability fell to a value below 60 percent occurs between the National Airport and Potomac Yard station where the trains are running with an increase speed form 45mph to 60mph.

The rail-to-ground values are all well below the safety limit of 150V. The worst instance occurred near the Braddock Road Substation under emergency operation with a value of 99V on the track 1.

The TPSS overload current limits were never exceeded for the Braddock Road Substation under emergency operation, as shown in **Table 12**.

Loads Summary for Normal, Abnormal, and Emergency Operation

Table 11 lists the maximum current values for the upgraded system of the TPSS under normal and abnormal operation. Note that the tabulated values do not exceed the overload thresholds.

Table 11. Upgraded System. TPSS currents for normal and abnormal operation.

	TPSS LIMITS A (RMS)		SIMULATIONS RESULTS A (RMS)			
	NORMAL OPERATION	ABNORMAL OPERATION	NORMAL OPERATION	ABNORMAL OPERATION		
TPSS	NOMINAL	AVAILABLE LOAD		NATIONAL AIRPORT	POTOMAC YARD	BRADDOCK ROAD
18TH & FERN	8571	4286	6891	7195	6924	6894
NATIONAL AIRPORT	12857	8571	9626	9049	9985	9663
POTOMAC YARD	12857	8571	11933	12225	11239	12282
BRADDOCK ROAD	12857	8571	10021	10057	10442	9322
DUKE STREET	8571	5714	8648	8651	8684	8953

Table 12 lists the maximum current values for the upgraded system of the TPSS for under normal and emergency operation.

Table 12. Upgraded system. TPSS currents for normal and emergency operation.

	TPSS LIMITS A (RMS)	SIMULATIONS RESULTS A (RMS)		
	NORMAL OPERATION	EMERGENCY OPERATION		
TPSS	NOMINAL	NATIONAL AIRPORT	POTOMAC YARD	BRADDOCK ROAD
18TH & FERN	8571	11091	7967	7491
NATIONAL AIRPORT	12857	-	13515	9729
POTOMAC YARD	12857	12251	-	16390
BRADDOCK ROAD	12857	10141	15108	-
DUKE STREET	8571	8579	8683	11886

Table 13 lists the maximum overload values for all of the TPSS in the simulated track under normal, abnormal and emergency operation. For Baseline TPS loading must be <100% and for contingency loading must be <146%. It can be considered that there is no substation in overload condition.

Table 13 TPSS power for normal, abnormal and emergency operation.

Subestations	TPS	TPS Rating	TPS config	Normal operation Baseline TPS Loading	Outage condition 1 Rect Outage Loading	Outage condition TPS Outage Loading
18TH & FERN	C09	6 MW	3+3	80 %	84 %	129 %
NATIONAL AIRPORT	C10	9 MW	3+3+3	75 %	106 %	105 %
POTOMAC YARD	C11	9 MW	3+3+3	93 %	131 %	127 %
BRADDOCK ROAD	C12	9 MW	3+3+3	78 %	109 %	118 %
DUKE STREET	C97	6 MW	2+2+2	101 %	104 %	139 %

Note: Baseline loading must be <100%
Contingency loading must be <146%

Voltages Summary for Normal, Abnormal, and Emergency Operation

Table 14 lists the maximum rail-to-ground voltages, rain voltages and the minimum train power availability for the upgraded system under normal, abnormal and emergency operation. All the values improved with the system upgrades,

except the train voltage under emergency operation when the Potomac Yard Station TPSS failed. Note that the threshold train voltages are 525V for normal operation, 475V for abnormal operation and 450V for emergency operation.

Table 14. Upgraded system. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Normal Operation	541	533	70	91	73.7
Abnormal operation. National Airport	541	528	75	93	70.0
Abnormal operation. Potomac Yard	541	526	73	93	71.6
Abnormal operation. Braddock Rd	541	533	73	90	73.5
Emergency operation. National Airport	454	450	111	117	40.1
Emergency operation. Potomac Yard	**443**[1]	464	117	113	40.5
Emergency operation. Braddock Rd	480	465	99	97	43.3

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 450V less than 3 seconds*

Positive and Negative Feeder Current Summary for Normal, Abnormal and Emergency Operation

Table 15 shows a check-up of the currents ratings of positive and negative feeder under normal operation and contingency operation (abnormal and emergency). Tabulated values identified in red are values that overcome 100% in normal operation and overcome 134% in contingency operation.

Table 15 Positive and Negative feeder currents ratings. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%.

TPSS & TBS	Feeders (P-Positive N-Negative)	Existing No. of cables	Cable load / Rating Ratio Normal operation	Cable Load/ Rating Ratio Contingency Operation
C09TP-18th&Fern St	P32	4	**102%**	103%
C10TP-National Airport	P34	4	96%	**136%**

System Upgrades and Simulations with an Additional TBS

06

System Upgrades and Simulations with an Additional TBS at Potomac Yard

Simulations identical to those performed in the prior sections were done with the additional changes to the existing track:

- The installation of a new TBS close to Potomac Yard Station (location = 447+50 CLF).
- The installation of a new TBS close to Potomac Yard Station (location = 447+50 CLF) and the removal of C11 TBS (Potomac RR Yard North Tie Breaker Station).

Only the normal and emergency (complete loss of a TPSS) conditions were simulated to the track with the new tie breaker station and removal of existing tie breaker station combinations.

6.1. Tie Breaker Stations

The specific location of the tie breaker stations are listed in **Table 16**.

Table 16. TBS location.

TBS	Location [CLF]
C11TB POTOMAC RR YARD NORTH TIE BREAKER STATION	405+86
Additional TBS	447+50

6.2. Simulations

The following sections show the results of the simulations for the tie breaker station combinations with the system upgrades identified in **Section 5**.

As in prior sections, graphs for the train voltages, train currents, train power availability and rail-to-ground voltages are shown in the following subsections. The TPSS currents are tabulated in **Appendix 1** and RMS currents are graphically represented in **Appendix 2**.

Normal Operation with New TBS

Train Voltages

As previously discussed, trains should have the minimum train voltages for the track system to function properly. The minimum train voltage under normal operation is 525V. **Figure 60** shows the train voltages of the simulated track section under normal operation with the upgraded system and a new TBS.

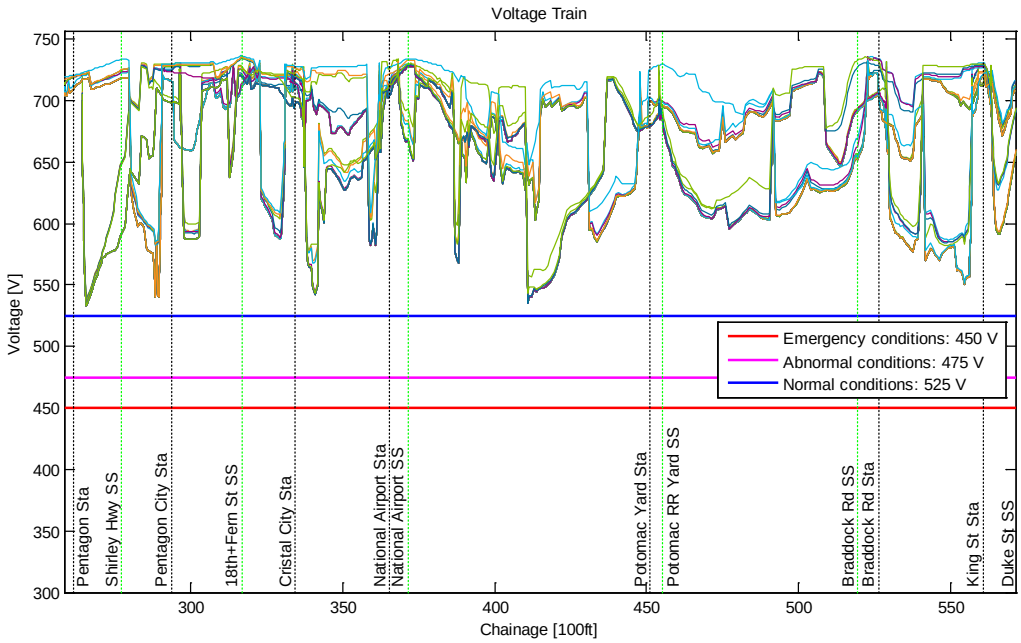


Figure 60. Upgraded system with the new TBS. Train voltages in the track section under normal operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified track section. **Figure 61** shows the train currents for the simulated track sections under normal operation with the upgraded system and new TBS.

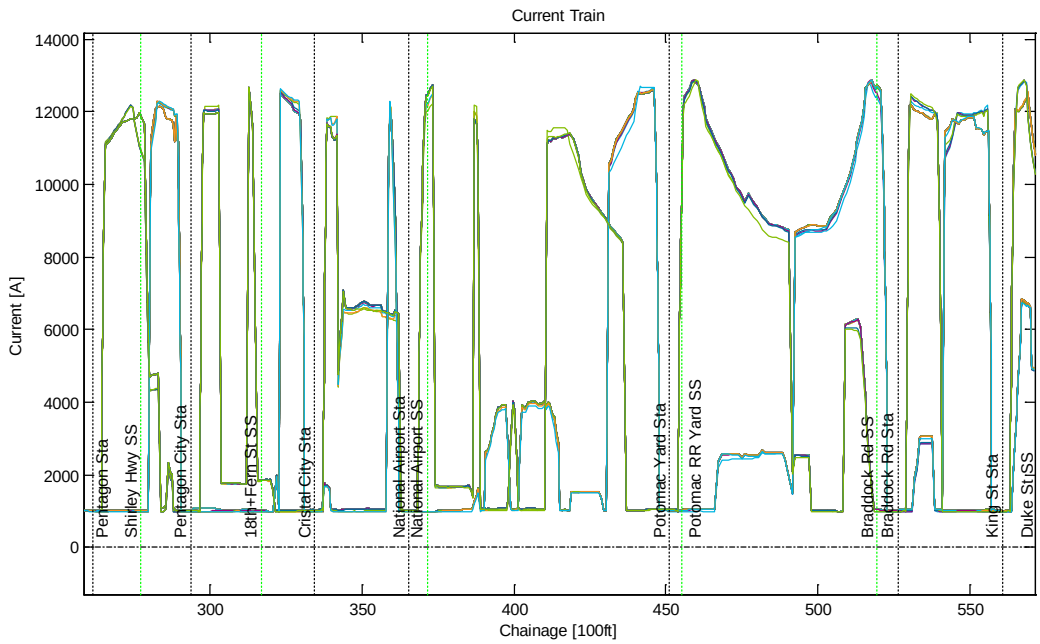


Figure 61. Upgraded system with the new TBS. Train currents in the track section under normal operation

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 62** shows the train power availabilities of the simulated track section under normal operation with the upgraded system and new TBS. The graph below shows that train power availability across the track is well within the acceptable range.

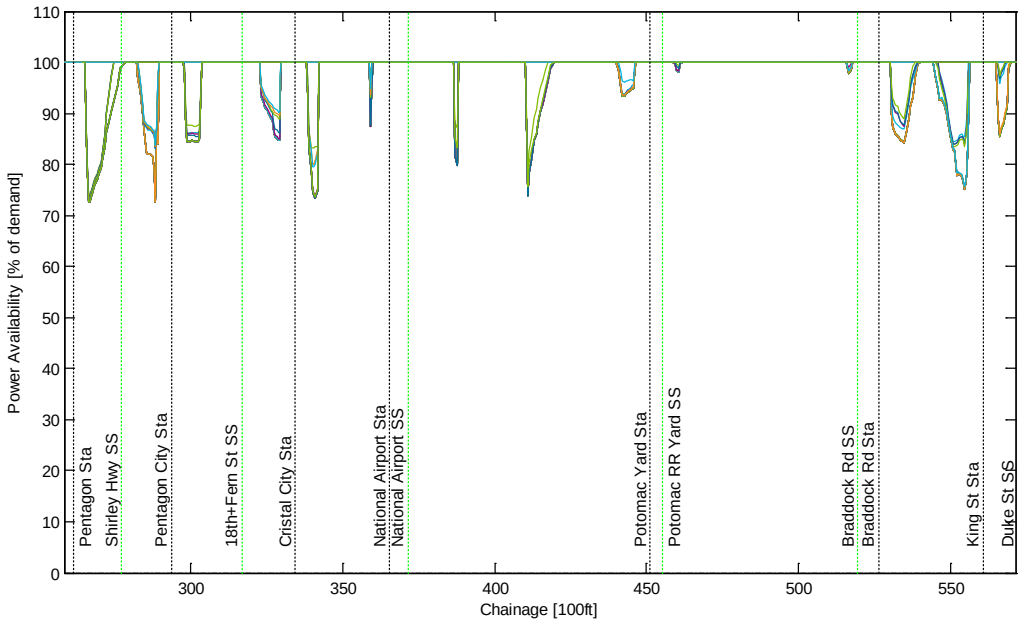


Figure 62. Upgraded system with the new TBS. Power availability in the track section under normal operation.

Rail-to-ground Voltages

The WMATA rail systems uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltages with respect to ground along the particular track section when trains are in operation. **Figure 63** shows rail-to-ground voltage limits of the simulated track section under normal operation with the upgraded system and new TBS. All of the rail-to-ground voltages in the track section are under the 100V limit.

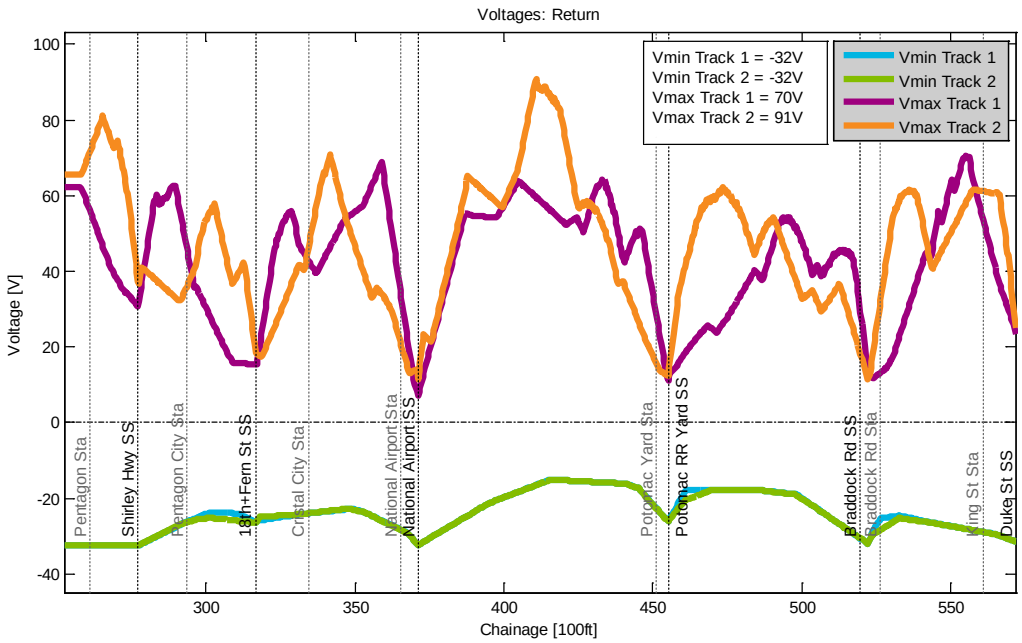


Figure 63. Upgraded system with the new TBS. Rail-to-ground voltages in the track section under normal operation.

Normal Operation with New TBS and without C11 TBS

Train Voltages

Trains should have the minimum train voltages for the track system to function properly. The minimum train voltage under normal operation is 525 V. **Figure 64** shows the train voltages of the simulated track section under normal operation with the upgraded system, new TBS and removal of C11 TBS.

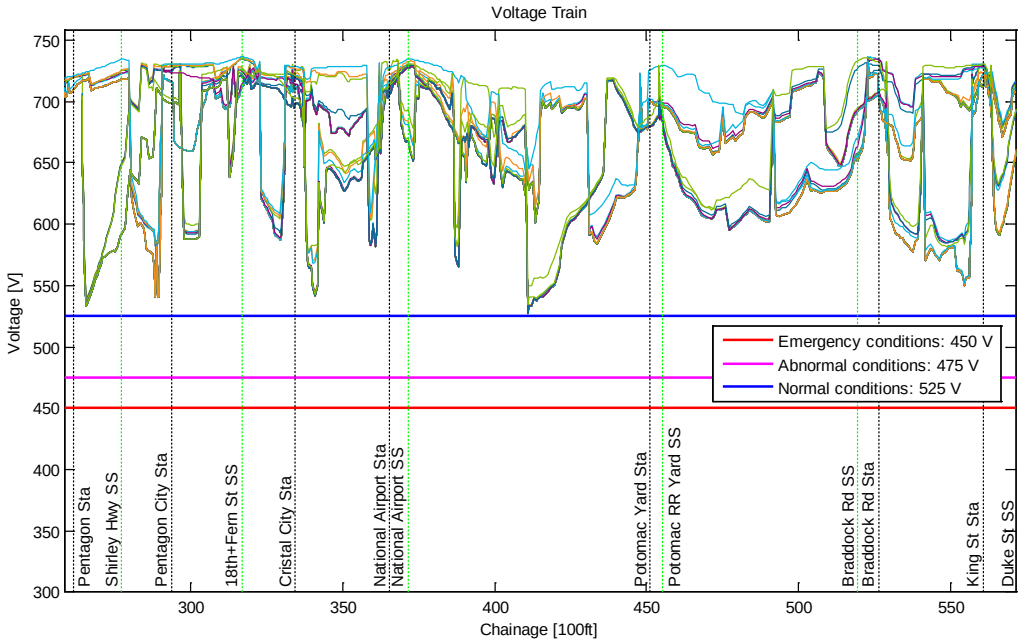


Figure 64. Upgraded system with the new TBS and without C11 TBS. Train voltages in the track section under normal operation.

Train Currents

The train currents results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified track section. **Figure 65** shows the train currents of the simulated track section under normal operation with the upgraded system, new TBS and removal of C11 TBS.

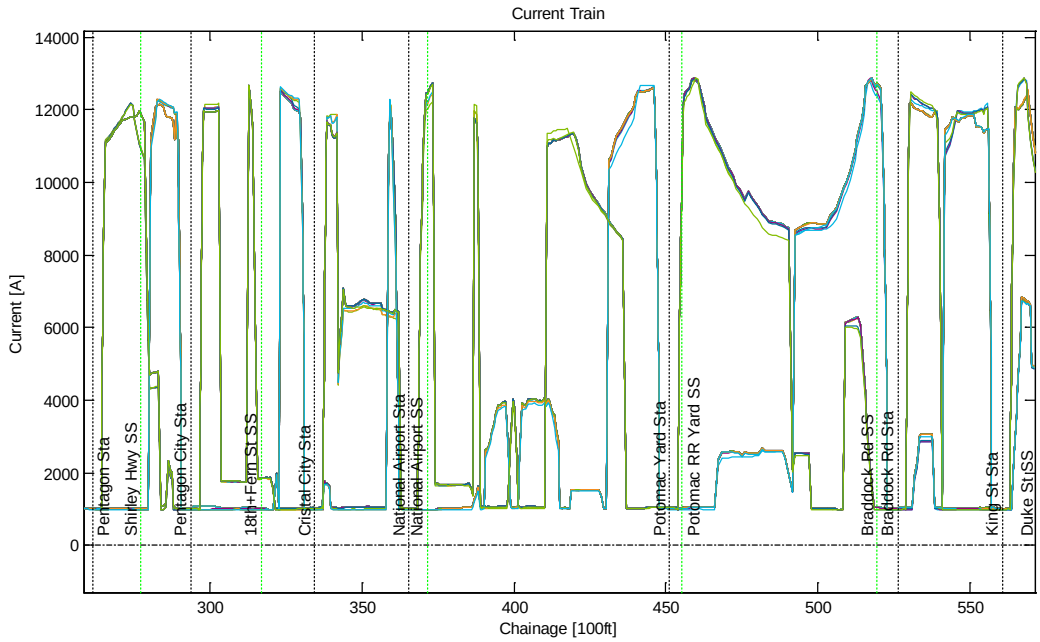


Figure 65. Upgraded system with the new TBS and without C11 TBS. Train currents in the track section under normal operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 66** shows the train power availabilities of the simulated track section under normal operation with the upgraded system, new TBS and removal of C11 TBS.

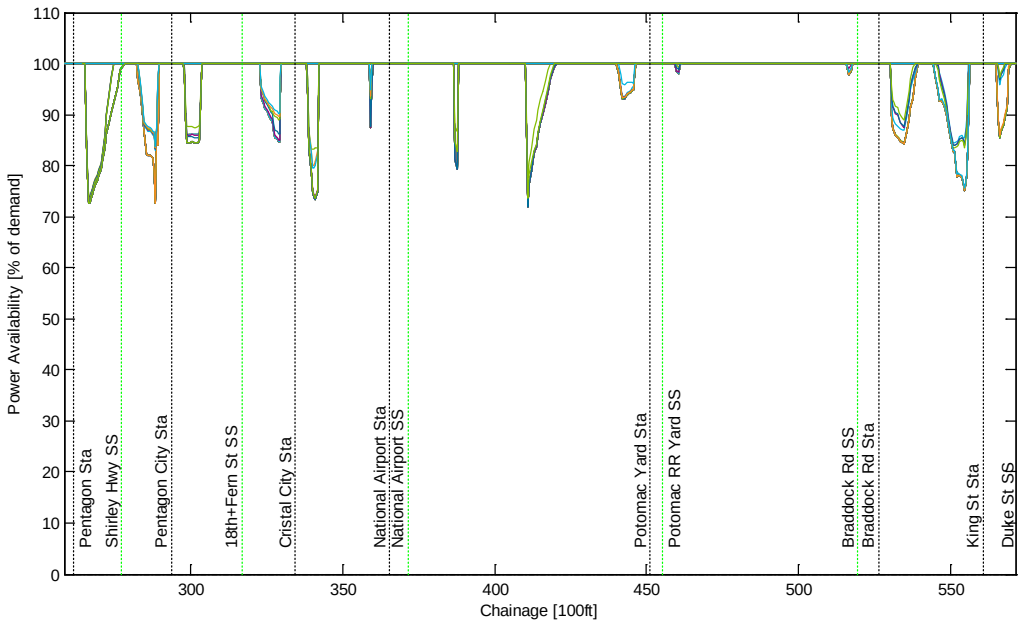


Figure 66. Upgraded system with the new TBS and without C11 TBS. Power availability in the track section under normal operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 67** shows rail-to-ground voltage limits of the simulated track section under normal operation with the upgraded system, new TBS and removal of C11 TBS.

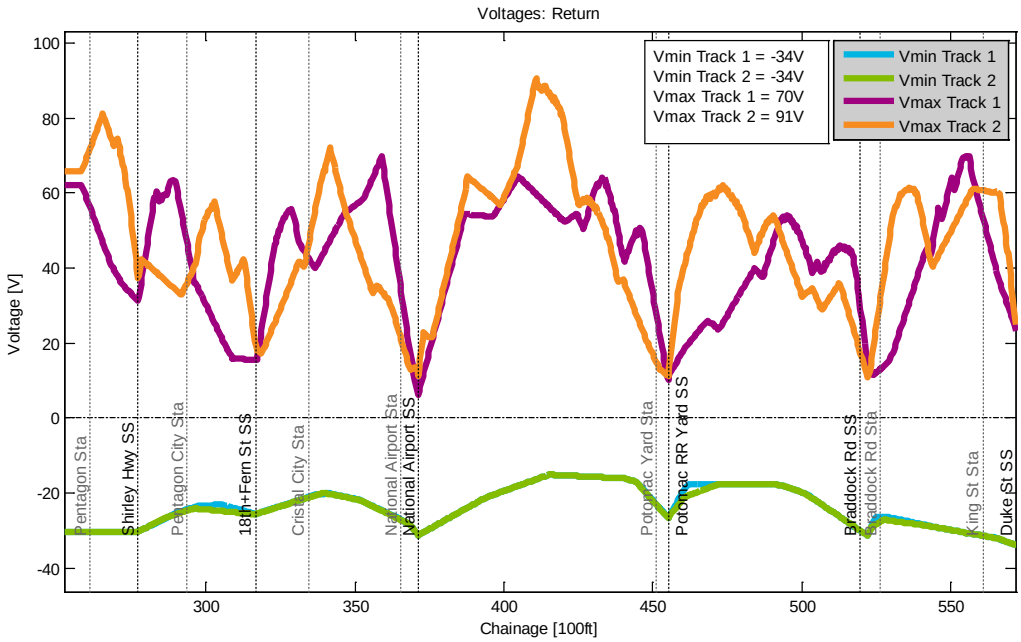


Figure 67. Upgraded system with the new TBS and without C11 TBS. Rail-to-ground voltages in the track section under normal operation.

Emergency Operation with New TBS and National Airport Substation Out of Service

Train Voltages

In a Traction Power System, trains should have the minimum voltages to function properly. The minimum train voltage under emergency operation is 450 V. **Figure 68** shows the train voltages of the simulated track section under National Airport emergency operation with the upgraded system and new TBS.

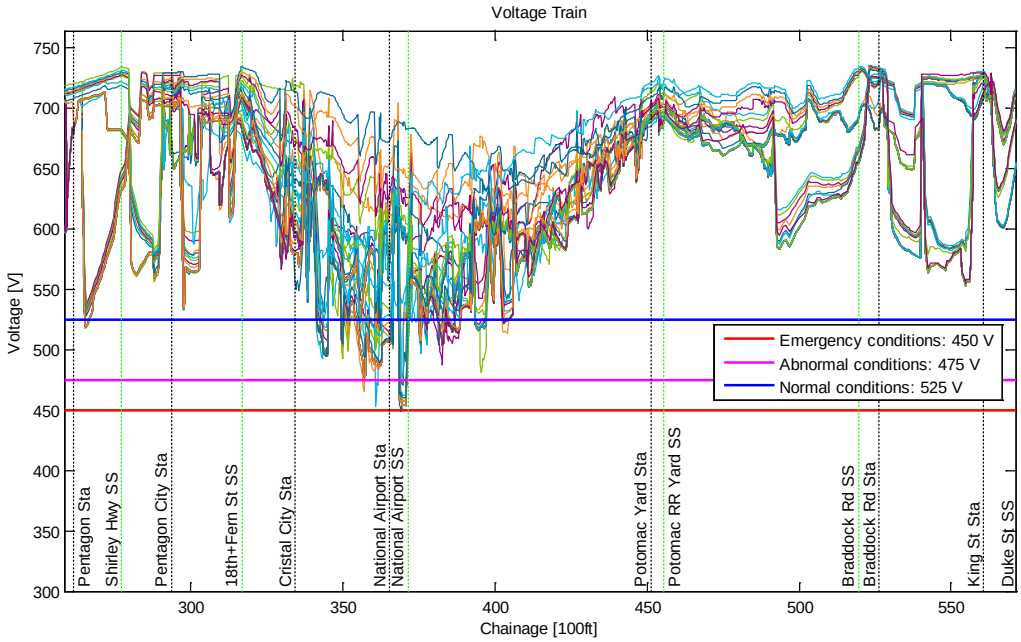


Figure 68. Upgraded system with the new TBS. Train voltages in the track section for National Airport under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 69** shows the train currents of the simulated track section with the National Airport under emergency operation, upgraded system and new TBS.

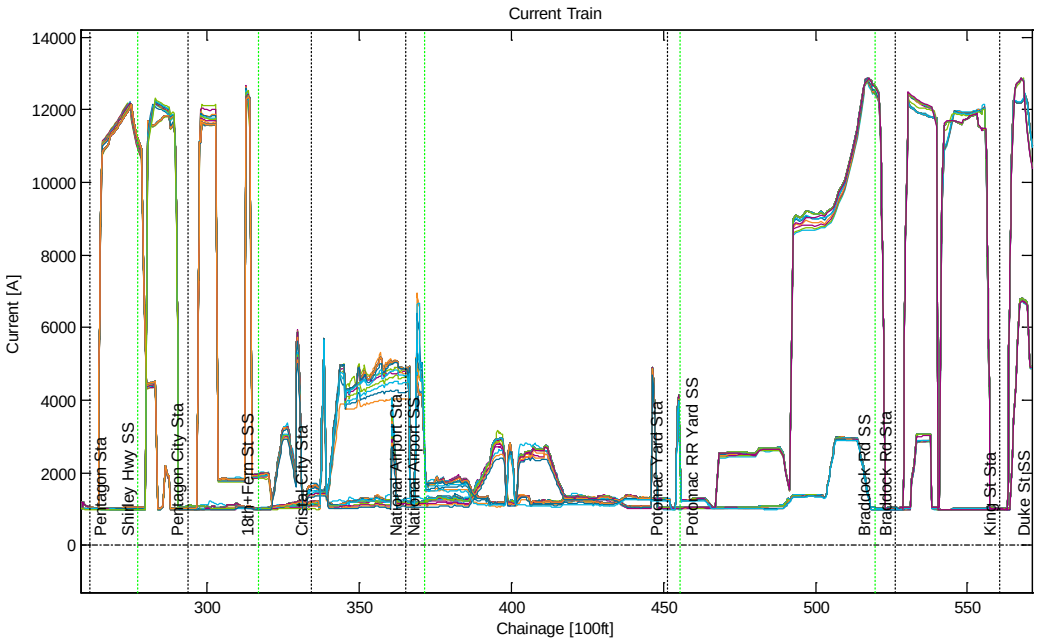


Figure 69. Upgraded system with the new TBS. Train currents in the track section for National Airport under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 70** shows the train power availabilities of the simulated track section with the National Airport under emergency operation, upgraded system and new TBS.

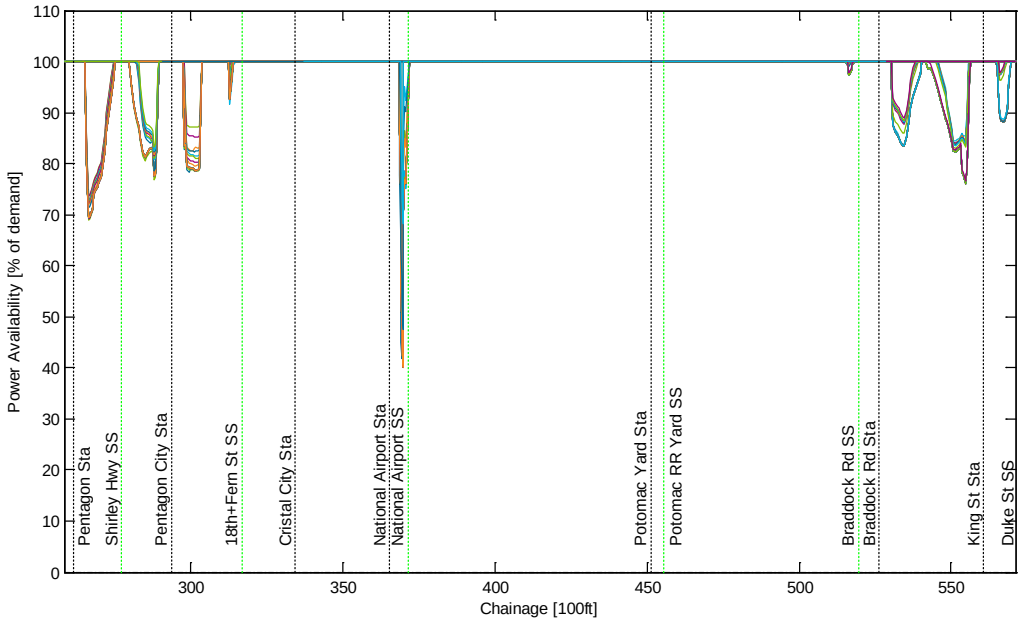


Figure 70. Upgraded system with the new TBS. Power availability in the track section for National Airport under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 71** shows the rail-to-ground voltage limits of the simulated track section with the National Airport under emergency operation, upgraded system and new TBS.

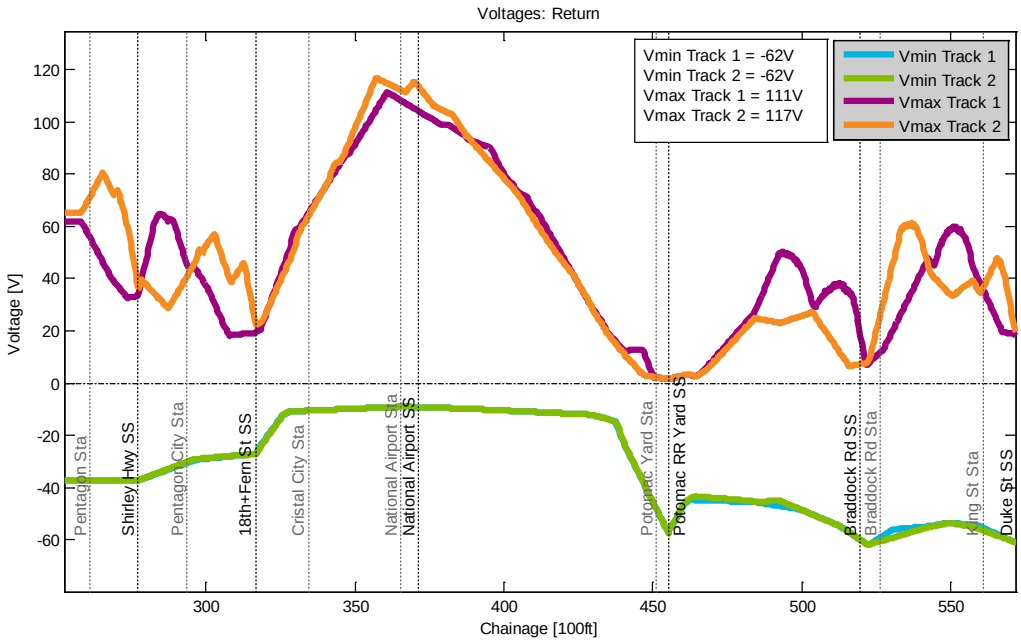


Figure 71. Upgraded system with the additional TBS. Rail-to-ground voltages in the track section for National Airport under emergency operation.

Emergency Operation with New TBS and removal of C11 TBS and National Airport Substation Out of Service

Train Voltages

In a Traction Power System, trains should have the minimum voltages to function properly. The minimum train voltage under emergency operation is 450 V. **Figure 72** shows the train voltages of the simulated track section with the National Airport under emergency operation, upgraded system and new TBS.

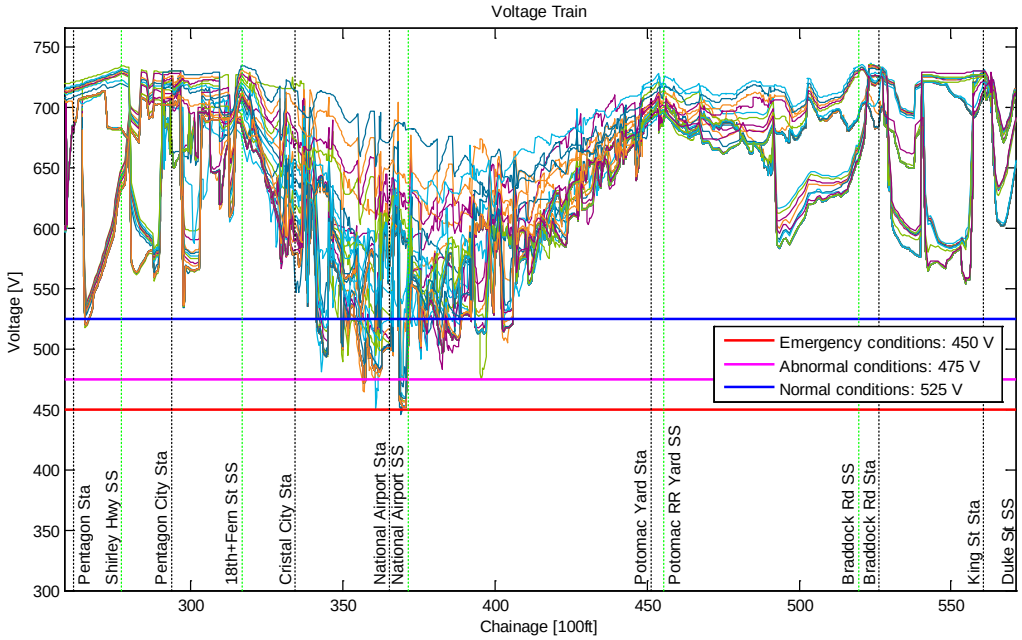


Figure 72. Upgraded system with new TBS and without C11 TBS. Train voltages in the track section for National Airport under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 73** shows the train currents of the simulated track section with the National Airport under emergency operation, upgraded system, new TBS and removal of C11 TBS.

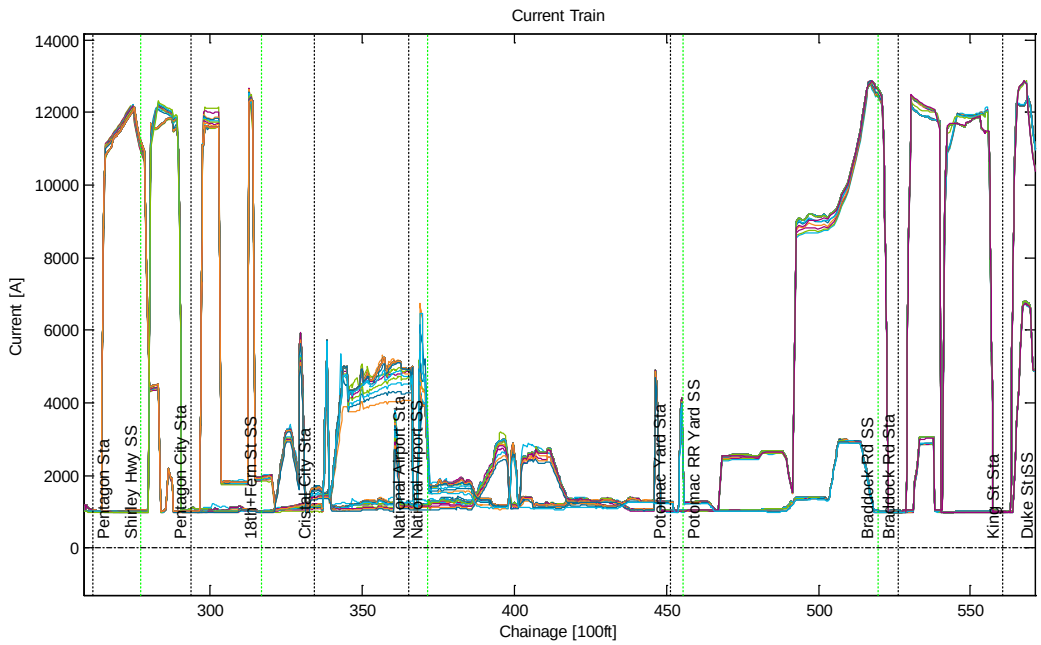


Figure 73. Upgraded system with the new TBS and without C11 TBS. Train currents in the track section for National Airport under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 74** shows the train power availabilities of the simulated track section with the National Airport under emergency operation, upgraded system, new TBS and removal of C11 TBS.

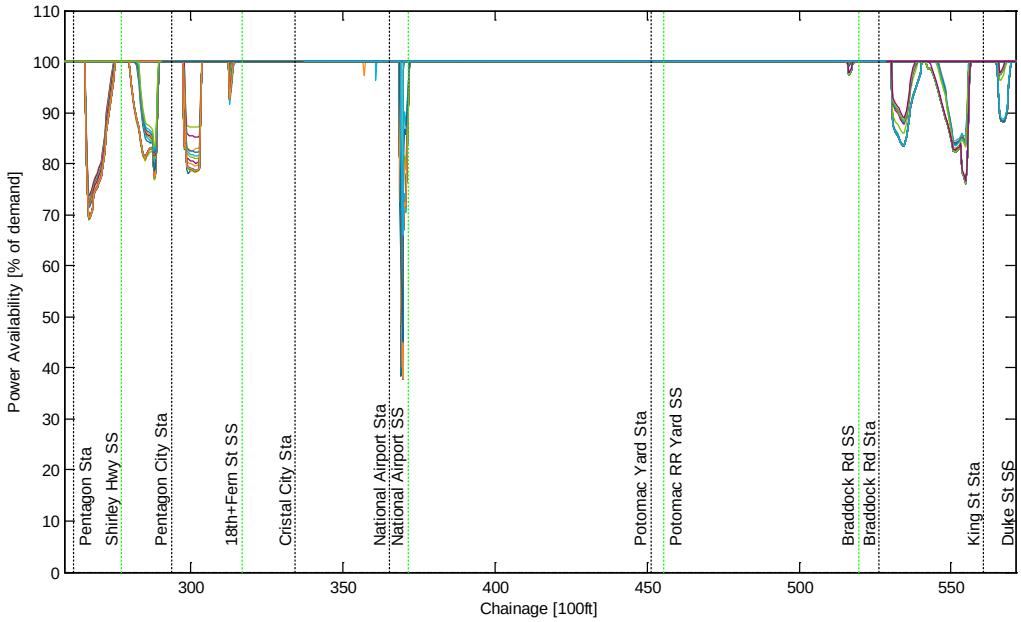


Figure 74. Upgraded system with the new TBS and without C11 TBS. Power availability in the track section for National Airport under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 75** shows rail-to-ground voltage limits of the simulated track section with the National Airport emergency under operation, upgraded system, new TBS and removal of C11 TBS.

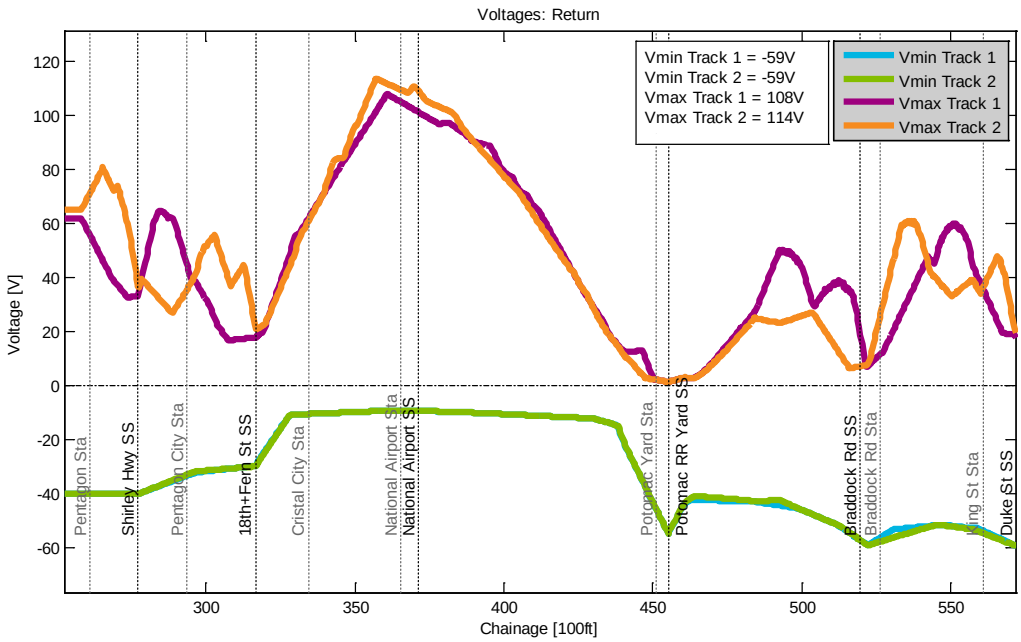


Figure 75. Upgraded system with the new TBS and without C11 TBS. Rail-to-ground voltages in the track section for National Airport under emergency operation.

Emergency Operation with New TBS and Potomac Yard Substation Out of Service

Train Voltages

In a Traction Power System, trains should have the minimum voltages to function properly. The minimum train voltage under emergency operation is 450V. **Figure 76** shows the train voltages of the simulated track section with the Potomac Yard under emergency operation, upgraded system and new TBS.

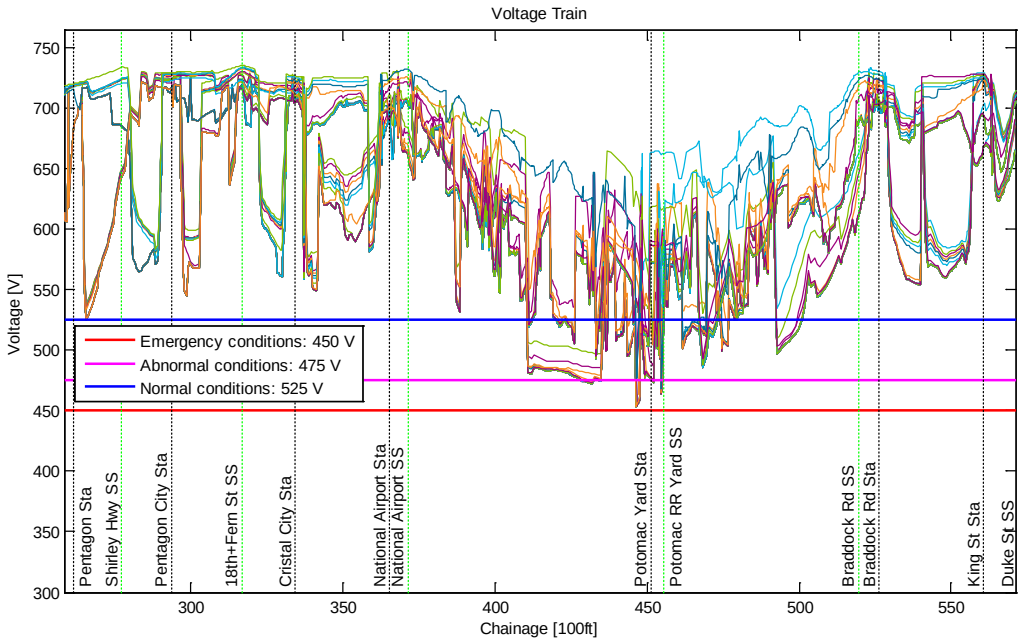


Figure 76. Upgraded system with the new TBS. Train voltages in the track section for Potomac Yard under emergency operation.

Train Currents

The train current results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified traction section. **Figure 77** shows the train currents of the simulated track section with the Potomac Yard under emergency operation, upgraded system and new additional TBS.

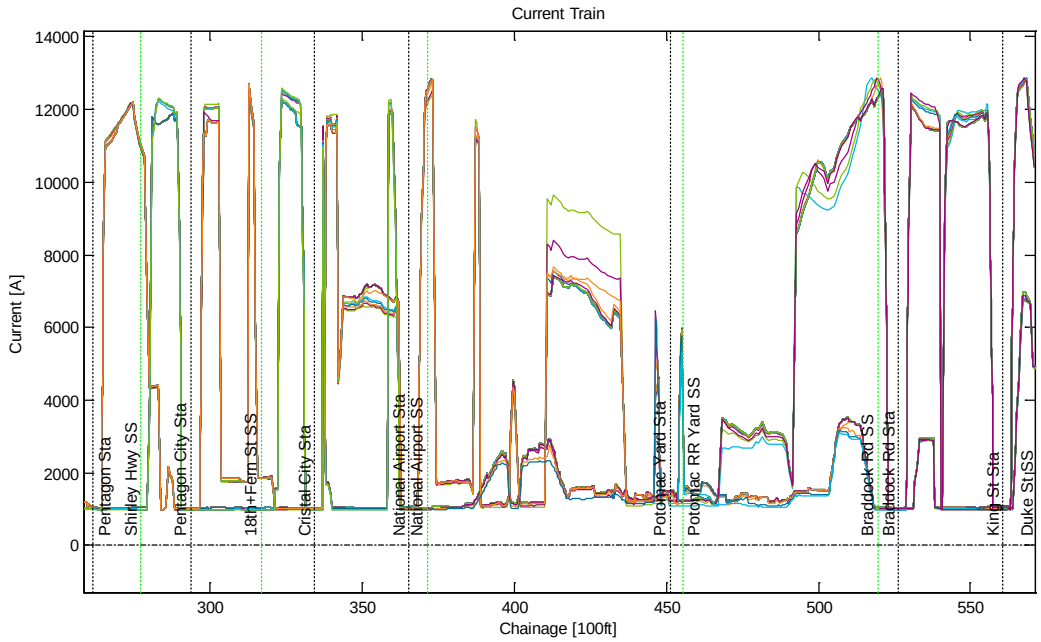


Figure 77. Upgraded system with the new TBS. Train currents in the track section for Potomac Yard under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 78** shows the power availability of the simulated track section with the Potomac Yard under emergency operation, upgraded system and new TBS.

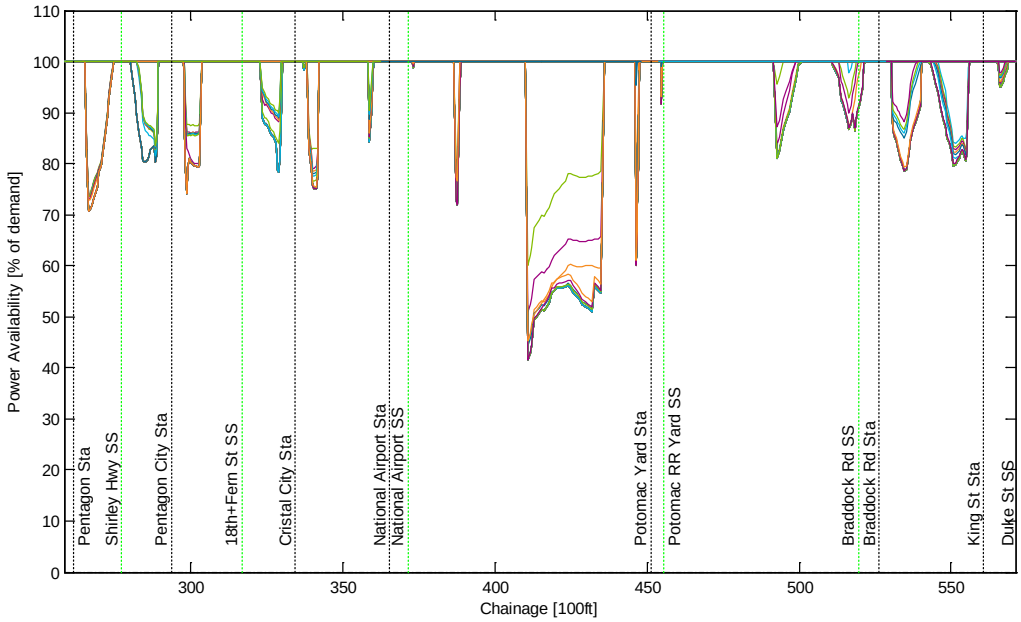


Figure 78. Upgraded system with the new TBS. Power availability in the track section for Potomac Yard under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 79** shows rail-to-ground voltage limits of the simulated track section with the Potomac Yard under emergency operation, upgraded system and new TBS.

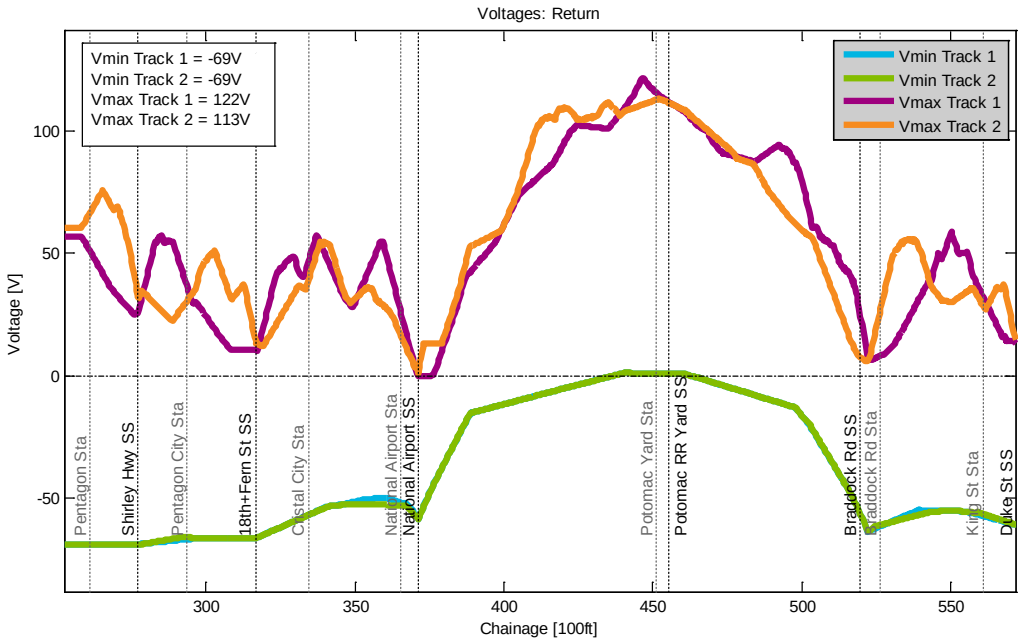


Figure 79. Upgraded system with the new TBS. Rail-to-ground voltages in the track section for Potomac Yard under emergency operation.

Emergency Operation with New TBS and removal of C11 TBS and Potomac Yard Substation Out of Service

Train Voltages

Trains should have the minimum train voltages for the track system to function properly. The minimum train voltage under emergency operation is 450V. **Figure 80** shows the train voltages of the simulated track section with the Potomac Yard under emergency operation, upgraded system, new TBS and removal of C11 TBS.

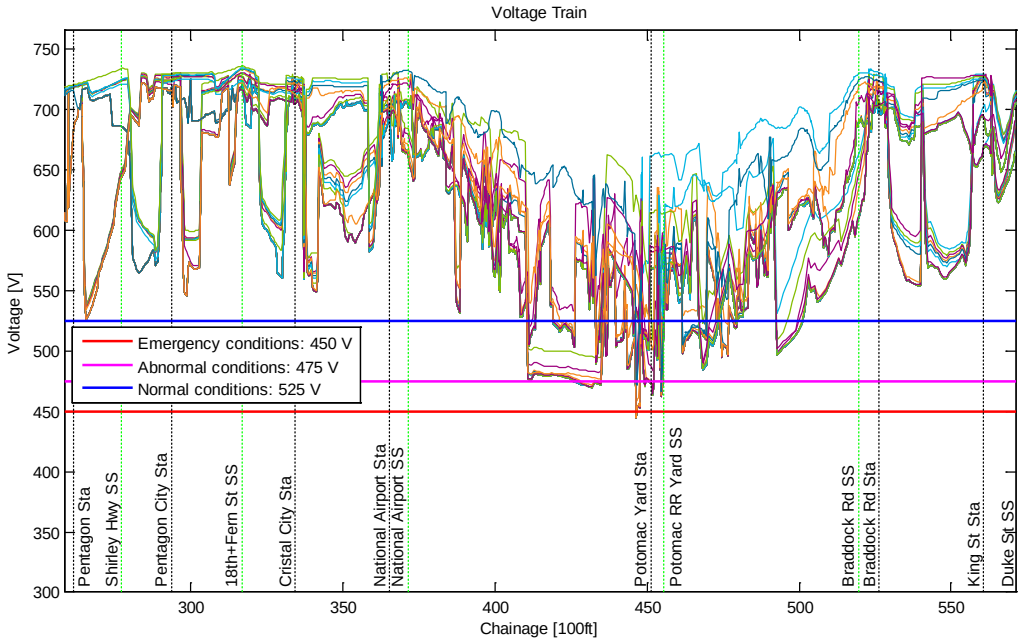


Figure 80. Upgraded system with the new TBS and without C11 TBS. Train voltages in the track section for Potomac Yard under emergency operation.

Train Currents

The train currents results identify the magnitude of the power the train is demanding as well as the location of the power demand in a specified track section. **Figure 81** shows the train currents of the simulated track section with the Potomac Yard under emergency operation, upgraded system, new TBS and removal of C11 TBS.

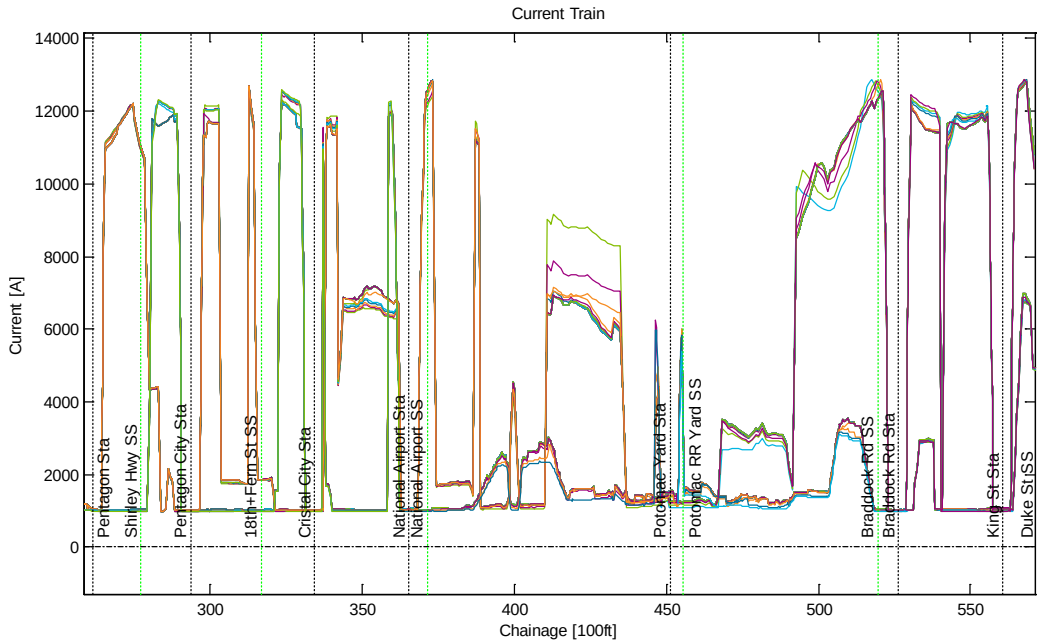


Figure 81. Upgraded system with the new TBS and without C11 TBS. Train currents in the track section for Potomac Yard under emergency operation.

Train Power Availabilities

Train power availability is the ratio of the power that the trains need to carry the desired movement against the power readily available due to the voltage limitations at each time step. Train power availability percentages between the sixty to one hundred percent range are acceptable. **Figure 82** shows the power availability of the simulated track section with the Potomac Yard under emergency operation, upgraded system, new TBS and removal of C11 TBS.

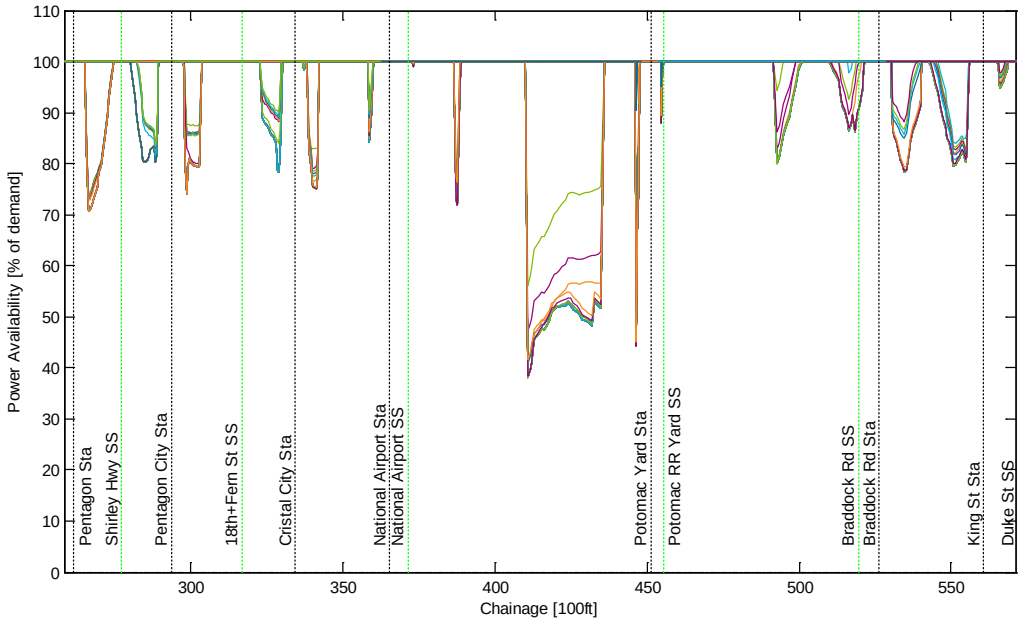


Figure 82. Upgraded system with the new TBS and without C11 TBS. Power availability in the track section for Potomac Yard under emergency operation.

Rail-to-ground Voltages

The WMATA rail system uses negative rails as the return circuit for the DC traction current. This configuration develops varying voltage with respect to ground along the particular track section when trains are in operation. **Figure 83** shows the rail-to-ground voltage limits of the simulated track section with the Potomac Yard under emergency operation, upgraded system, new TBS and removal of C11 TBS.

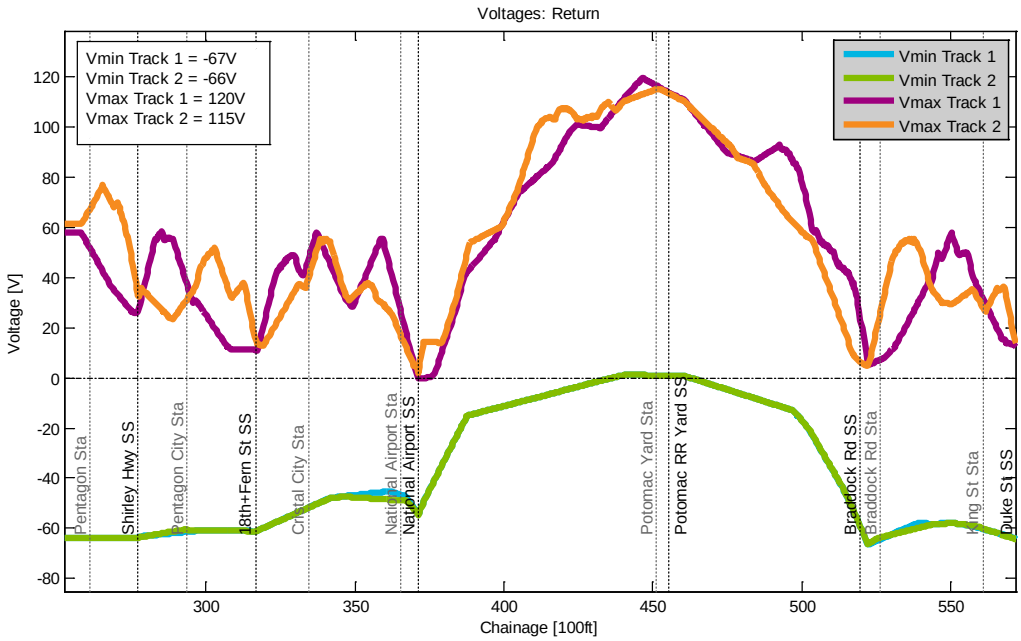


Figure 83. Upgraded system with the new TBS and without C11 TBS. Rail-to-ground voltages in the track section for Potomac Yard under emergency operation.

6.3. Simulation Results Summary

The following section is an analysis of the normal and emergency operation of the existing system with system upgrades and addition of a new TBS at the new Potomac Yard station and removal of the existing TBS at C11.

Normal Operation with the New TBS

Applying the system upgrades and running the simulations, the train voltages, train currents, train power availability, rail-to-ground voltages and TPSS currents stayed within the nominal values. Specifically, the Train voltages were well above the threshold limit for normal operation (525V). The lowest value in the simulations was 533V.

The train power availability fell below 75 percent (73.7 percent) compared to 60 percent without the upgrades.

The rail-to-ground voltages were well below the 100V limit under normal operation. The maximum value identified in the simulation was 91V and corresponds to track 2, approximately between the Potomac Yard Station and National Airport Substations. Note that there were slightly more rail-to-ground voltages when the upgrades were added.
Note that the train voltages, train currents, train power availability, rail-to-ground voltages results indicate that adding the new TBS did not show a difference from simply just upgrading the existing system as recommended in **Section 5**.

Normal Operation with the New TBS and without C11 TBS

The Train voltages never fell below the threshold limit under normal operation (525V). The lowest value of 528V occurred approximately between the National Airport and Potomac Yard Stations, where the trains departing form the National Airport Station changes speed from 45 mph to 65 mph, increasing the current demand.

The train power availability fell below the 75 percent (72 percent) approximately between the National Airport and Potomac Yard Metrorail Stations because of the increase in current demand.

The rail-to-ground voltages were well below the limit of 100V under normal operation. The maximum value of 91V occurred on track 2, approximately between the Potomac Yard Station and National Airport Substations.

Note that a slight reduction of train voltages, specifically between the National Airport and Potomac Yard Metrorail Stations was the only reduction by adding the new TBS and removal of the existing C11 TBS.

Emergency Operation with the New TBS

National Airport TPSS Out of Service

Train voltages were well above the limit of 450V under emergency operation close to the National Airport Metrorail Station. The train power availability fell down to 40.2 percent and occurs near the Potomac Yard Station (between 368+70 to 370+70) where the trains demand a power boost to achieve the limit of 20mph, in half acceleration.

The rail-to-ground values were well below the safety limit of 150V. The worst instance occurs near the National Airport Metrorail Station with a value of 117V on track 2 when the system is under the National Airport emergency operation. Note that the train voltages, train currents, train power availability, rail-to-ground voltages results indicate that adding the new TBS did not show a difference from simply just upgrading the existing system as recommended in **Section 5**.

Potomac Yard TPSS Out of Service

Train voltages were within the limit of 450V under emergency operation but were slightly better than simply just having the recommended system upgrades.

The power availability fell down to 41.6 percent and occurs when the simulated trains are running between the Chain Markers 410+70 and 435+00, between the National Airport and Potomac Yard Station, because the trains departing from National airport are not in degraded operational conditions and can run at full speed and full acceleration. Note that there is an instant of low train power availability for a very short distance (100ft) and corresponds with the train departures from the Potomac Yard Station to National Airport, where the train performance is limited to 20mph and half acceleration.

The rail-to-ground values were well below the safety limit of 150V. The worst instance occurs near the Potomac Yard Substation with a value of 122V on track 1 when the system is under the Potomac Yard emergency.

Emergency Operation with the New TBS and without C11 TBS

National Airport TPSS Out of Service

The Train voltages fell slightly below the limit of 450V under emergency operation near the National Airport Metrorail Station with a value of 445V on track 2. The train power availability fell down to 37.9% and occurs near the Potomac Yard Metrorail Station (between 368+70 to 370+70) where the trains demand a power boost to achieve the limit of 20 mph, in half acceleration.

The rail-to-ground values were well below the safety limit of 150V. The worst instance occurs near the National Airport Metrorail Station with a value of 114V on track 2 when the system is under the National Airport emergency operation.

Potomac Yard TPSS Out of Service

Train voltages fell slightly below the limit of 450V under emergency operation near the Potomac Yard Metrorail Station with a value of 444V on track 1 and occur when the trains are departing from the Potomac Yard Metrorail Station to the National Airport. It should be noted that threshold limit was exceeded for a very short amount of time and that the value is very close to the limit.

The power availability fell down to 38.3 percent and occurs when the simulated trains are running between the Chain Markers 410+70 and 435+00, between the National Airport and Potomac Yard Metrorail Station because the trains departing from National airport are not in degraded operational conditions and can run at full speed and full acceleration. Note that there is an instant of low train power availability for a very short distance (100ft) and corresponds with the train departures from the Potomac Yard Station to National Airport, where the train performance is limited to 20mph and half acceleration.

The rail-to-ground values were well below the safety limit of 150V. The worst instance occurs near the Potomac Yard Station with a value of 120V on track 1 when the system is under the Potomac Yard emergency.

Voltages Summary for Normal and Emergency Operation

Table 17 and **Table 18** list the maximum rail-to-ground values, train voltages and the minimum train power availability for the upgraded system with the new TBS and without existing C11 TBS under normal and emergency operation. Note that the threshold train voltages are 525V for normal operation, 475V for abnormal operation, and 450V for emergency operation. All the values slightly improved with the addition of the new TBS and slightly degraded under emergency operation.

Table 17. Upgraded system with new TBS. Train and rail-to-ground voltages for normal and emergency operation and power availability.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Normal Operation	541	533	70	91	73.7
Emergency operation. National Airport	454	450	111	117	40.2
Emergency operation. Potomac Yard	454	464	122	113	41.6

Table 18. Upgraded system with new TBS and without C11 TBS. Train and rail-to-ground voltages for normal and emergency operation and power availability.

Cases	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Normal Operation	541	528	70	91	72
Emergency operation. National Airport	451	**445**[1]	108	114	37.9
Emergency operation. Potomac Yard	**444**[2]	463	120	115	38.3

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 450V less than 3 seconds*
[2] *below 450V less than 2 seconds*

The following tables compare the results of the simulations with the upgraded system and with and without the existing TBS at C11 under both the normal and the emergency operations.

Table 19. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Normal Operation.

Cases. Normal operation	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Upgraded system	541	533	70	91	73.7
Upgraded system with additional TBS	541	533	70	91	73.7
Upgraded system with additional TBS and without C11 TBS	541	528	70	91	72.0

Table 20. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Emergency Operation. National Airport Substation Out of Service.

Cases. Emergency operation National Airport	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Upgraded system	454	450	111	117	40.1
Upgraded system with additional TBS	454	450	111	117	40.2
Upgraded system with additional TBS and without C11 TBS	451	**445**[1]	108	114	37.9

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 450V less than 3 seconds*

Table 21. Train and rail-to-ground voltages for normal, abnormal and emergency operation and power availability. Emergency Operation. Potomac Substation Out of Service.

Cases. Emergency operation Potomac Yard	Min. Train Voltage Track 1 [V]	Min. Train Voltage Track 2 [V]	Max. Rail Voltage Track 1 [V]	Max. Rail Voltage Track 2 [V]	Power Availability (% of demand)
Upgraded system	**443**[1]	464	117	113	40.1
Upgraded system with additional TBS	454	464	122	113	41.6
Upgraded system with additional TBS and without C11 TBS	**444**[2]	**463**	120	115	38.3

Note: Tabulated values identified in red are values that fall below the minimum operational threshold.

[1] *below 450V less than 3 seconds*
[2] *below 450V less than 2 seconds*

Conclusions

07

Conclusions

7.1. Conclusions

Results of the Traction Power System load simulation and model identified that inclusion of the proposed Potomac Yard Metrorail Station into the existing Traction Power System (without upgrades), which includes 8-car trains operating at 120 second headways, will not comply with WMATA requirements:

- Minimum train voltages fell below the threshold limit in both normal and emergency operation scenarios when the National Airport and Potomac Yard Substations were each independently out of service.
- TPSS load capacity was exceeded for National Airport and Potomac Yard Substations under the abnormal operation scenario.
- TPSS load capacity was exceeded at the Potomac Yard Metrorail Station when the Braddock Road Substation was out of service and at 18th & Fern when the National Airport Substation was out of service.
- Several TPSS and TBS breakers and feeders need to be upgraded to support the required loads to support the proposed Potomac Yard Metrorail Station.

The following upgrades were proposed and introduced into the simulation model to ensure the existing Traction Power System complies with WMATA requirements:

- Increase the power of 18th & Fern to 6MW and the National Airport and Potomac Yard Substations to 9MW. **Table 22**.
- Increase the feeder quantities to withstand the required currents as shown on **Table 9** in **Section 5.1**. Summarized on **Table 23**.
- Replace the steel contact rail with a composite contact rail in the track section between the National Airport and Braddock Road Substations.
- Resize the feeder breakers to the appropriate current ratings as shown on **Table 10**. Summarized on **Table 24**.

New simulations were done after the upgrades were applied to the existing Traction Power System and had the following results:

- Minimum train voltages were over the threshold limit for normal, abnormal, and emergency operation scenarios, except for when the Potomac Yard Substation was out of service. It should be noted that train voltage was under the threshold for a very short time and was very close to the limit.
- The TPSS overload rates were not exceeded under all the operation scenarios.
- The rail-to-ground voltages were well below the established thresholds under all the operation scenarios.
- The number of feeders proposed in **Table 9** were sufficient to supply the system current distribution.

Except for the case described above when Potomac Yard Substation was out of service, the upgraded system complies with WMATA requirements.

Additionally, new simulations were done to the upgraded system but with a new TBS located close to the Potomac Yard Metrorail Station and also with the removal of the existing C11 TBS and had the following results:

- Minimum train voltages were well over the threshold limit for normal and emergency operation scenarios, except when C11 TBS was removed. It should be noted that train voltages were close to the threshold and are short lived.
- The rail-to-ground voltages were well below the established thresholds under all the operation scenarios.

According to these results, the new TBS at the Potomac Yard Metrorail Station slightly improves the performance of the upgraded system. Specifically, the new TBS improves the train voltage (Track 1) when the upgraded system is under the emergency operation.

Therefore it can be concluded that adding the new TBS to the existing Traction Power System in addition to the upgrades will satisfy all of the WMATA requirements. A room to accommodate the TBS is included within the Potomac Yard Metrorail Station design.

There are several instances when the power availability is highly reduced, new solutions to improve the train power availability should be discussed in future Traction Power Studies.

Table 22 Rectifier Upgrades

TPSS	Existing rectifier	Existing Total MW	Upgrade Rectifiers	Upgrade Total MW	Increase in MW
C09TP-18th&Fern St	2+2 MW	4	3+3 MW	6	2
C10TP-National Airpot	2+2+3 MW	7	3+3+3 MW	9	2
C11TP-Potomac RR Yard	3+3 MW	6	3+3+3 MW	9	3
C12TP-Braddock Rd	3+3+3 MW	9	3+3+3 MW	9	0
C97TP-Duke St	2+2+2 MW	6	2+2+2 MW	6	0

Table 23 Positive and Negative feeder cable Upgrades

TPSS & TBS	Feeders (P-Positive N-Negative)	Existing No. of cables	Total Extra Cables at Upgrade	Total No. of Cables After Upgrade
C09TP-18th&Fern St	P32	4	1	5
C09TP-18th&Fern St	P34	4	2	6
C09TB1-Cristal City	P42	4	1	5
C09TB1-Cristal City	P44	4	1	5
C10TP-National Airport	P33	4	1	5
C10TP-National Airport	P34	4	2	6
C10TP-National Airport	N1	6	2	8
C10TP-National Airport	N2	6	2	8
C11TP-Potomac RR Yard	P34	5	3	8
C11TP-Potomac RR Yard	N1	6	3	9
C11TP-Potomac RR Yard	N2	6	3	9
C12TP-Braddock Rd	P31	5	2	7
C12TP-Braddock Rd	P32	4	1	5
C12TP-Braddock Rd	P34	5	1	6
C12TP-Braddock Rd	N1	6	3	9
C12TP-Braddock Rd	N2	6	3	9
C97TP-Duke St	P31	4	1	5
C97TP-Duke St	P32	4	2	6
C97TP-Duke St	P33	4	1	5
C97TP-Duke St	N1	6	1	7
C97TP-Duke St	N2	6	1	7

Table 24 Positive Feeder breaker Upgrades

TPSS & TBS	Feeders (P-Positive N-Negative)	Breaker ratings [A]	Breaker rating upgraded [A]	Increase in rating over existing
C09TP-18th&Fern St	P34	4000	6000	2000
C09TB1-Cristal City	P42	4000	6000	2000
C09TB1-Cristal City	P44	4000	6000	2000
C11TP-Potomac RR Yard	P34	6000	8000	2000
C12TP-Braddock Rd	P31	6000	8000	2000
C97TP-Duke St	P31	4000	6000	2000

7.2. Recommendations

As shown in this report, a number of upgrades have been simulated to allow the operation of the line according to the specifications in the RFP. These upgrades have been proven as valid and verified by the simulation results.

Some of the enhancements, especially the use of composite third rail, may be difficult to implement and will require developing temporary situations or even closing the line or reduce the service to just one track for a period of time.

In this report, the first simulation or baseline case was performed considering steel third rail and, as can be seen in the results, the third rail to rails voltage was below the admissible values for a number of simulations. The upgraded system did consider the composite third rail among other enhancement such as increasing the number of feeders and increasing the power rating of power transformers and rectifiers. These last enhancements (feeders and transformers) do increase the live rail to rail voltage in a very limited way when compared to the impedance reduction due to the composite third rail.

In order to solve this issue a series of recommendations to try to make the use of the composite third rail less critical:

1. Reduce the power performance of the trains. If travel time is less critical than 120 s headway, traction power demand and maximum speed limits along the section of interest can be reduced. The implementation of these solutions could lead to benefits regarding live rail to rail voltage drops. The extent of the benefits of this recommendation could need to be tested prior to its implementation
2. Increase the headway between trains at rush hour. If trains are not likely to run with such demanding headway, a larger one can be considered (i.e. 150 secs). This will have a positive impact in increasing the voltage level.
3. A combination of the above mentioned recommendations if any of them by its own is not enough.
4. Increase the nominal voltage of the line above 700 V. As extracted from the rolling stock characteristics, the trains can work up to 860 V with peaks up to 930 V. The increase of the voltage will have to be studied but it can be a viable solution to take into account.
5. The use of Thyristor rectifiers at the traction power substations. The use of a controlled power source will maintain the voltage at the substation closer to the rated voltage value of 700 V for a larger period but will need to add control equipment to trigger the thyristors.
6. A combination of the two prior recommendations.
7. The use of reinforcement feeders along the line in the section of interest. This is not the preferred option, but in case that the above mentioned recommendations are not enough, a reduction in the rail impedance can be obtained by adding parallel feeders along the line. This is deemed as the last possibility if the use of third rail composite is to be avoided.

The detailed extent of these actions needs further analysis and verification once a course of action is chosen. They are listed from less disruptive and more cost effective to more disruptive and costly.

Appendix 1.

RMS Current Tables.

A1

Appendix 1. RMS Current Tables.

Table 25 and **Table 26** show a summary of the Positive and Negative feeder currents, feeder quantities and breaker ratings.

New feeder quantities and breaker upgrades required for the current system are highlighted in yellow. Positive and Negative feeder current ratings exceeded are marked in red. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%.

Table 25. Current system. Positive and Negative feeder currents and breaker ratings.

	Input data							Simulation results							
TPSS / TBS	Breaker ratings	Breaker ratings Upgraded	Feeders (P-Positive, N-Negative)	1000 kcmil Cables (Quantity)	1000 kcmil Cables (Quantity) Upgraded	Nominal Ampacity normal operation [A]	Ampacity Abnormal operation [A]	Irms normal operation [A]	Irms National Airport abnormal operation [A]	Irms Potomac Yard abnormal operation [A]	Irms Braddock Road abnormal operation [A]	Irms National Airport emergency operation [A]	Irms Braddock Road emergency operation [A]	Irms Potomac Yard emergency operation [A]	Max rms [A] Outage
C09TP-18th&Fern St	4000		P31	4	4	2976	3992	1768	1751	1763	1768	1599	1507	1520	1768
C09TP-18th&Fern St	4000		P32	4	4	2976	3992	2862	2830	2903	2908	2522	2877	2812	2908
C09TP-18th&Fern St	6000		P33	5	5	3720	4990	3657	3855	3678	3657	4101	3584	3737	4101
C09TP-18th&Fern St	4000	6000	P34	4	6	2976	3992	2418	2659	2453	2419	5160	2380	2482	5160
C09TP-18th&Fern St			N1	6	6	4464	5988	3409	3636	3441	3410	5365	3509	3776	5365
C09TP-18th&Fern St			N2	6	6	4464	5988	3448	3682	3514	3481	5642	3731	3909	5642
C09TB1-Cristal City	4000		P41	4	4	2976	3992	1204	1217	1200	1201	2286	1285	1362	2286
C09TB1-Cristal City	4000	6000	P42	4	5	2976	3992	2188	2325	2209	2188	4204	2066	2016	4204
C09TB1-Cristal City	4000		P43	4	4	2976	3992	1204	1217	1200	1201	2286	1285	1362	2286
C09TB1-Cristal City	4000	6000	P44	4	5	2976	3992	2324	2497	2348	2325	4341	2210	2124	4341
C09TB1-Cristal City	4000		P46	4	4	2976	3992	1985	1987	1986	1985	929	1991	1477	1991
C10TP-National Airport	6000		P31	5	5	3720	4990	2671	2433	2639	2668	727	2671	2637	2671

TPSS / TBS	Input data							Simulation results							
	Breaker ratings	Breaker ratings Upgraded	Feeders (P-Positive, N-Negative)	1000 kcmil Cables (Quantity)	1000 kcmil Cables (Quantity) Upgraded	Nominal Ampacity normal operation [A]	Ampacity Abnormal operation [A]	Irms normal operation [A]	Irms National Airport abnormal operation [A]	Irms Potomac Yard abnormal operation [A]	Irms Braddock Road abnormal operation [A]	Irms National Airport emergency operation [A]	Irms Braddock Road emergency operation [A]	Irms Potomac Yard emergency operation [A]	Max rms [A] Outage
C10TP-National Airport	6000		P32	5	5	3720	4990	3503	3339	3479	3502	765	3652	3674	3674
C10TP-National Airport	6000		P33	4	5	2976	3992	1760	1580	2178	1779	727	1853	4401	4401
C10TP-National Airport	6000		P34	4	5	2976	3992	3568	3269	3798	3579	799	3638	4700	4700
C10TP-National Airport	6000		P36	3	3	2232	2994	1971	1954	1976	1971	370	1914	1978	1978
C10TP-National Airport	6000		P37	4	4	2976	3992								0
C10TP-National Airport			N1	6	8	4464	5988	4453	3929	4783	4469	0	4541	6224	6224
C10TP-National Airport			N2	6	8	4464	5988	5831	5299	6154	5848	0	5825	7579	7579
C11TB1-Potomac RR Yard North	4000		P41	4	4	2976	3992	1198	1103	1458	1211	1747	1445	2769	2769
C11TB1-Potomac RR Yard North	4000		P42	4	4	2976	3992	2040	1925	2175	2043	2233	2038	2844	2844
C11TB1-Potomac RR Yard North	4000		P43	4	4	2976	3992	1198	1103	1458	1211	1747	1445	2769	2769
C11TB1-Potomac RR Yard North	4000		P44	4	4	2976	3992	2040	1925	2175	2043	2233	2038	2844	2844
C11TP-Potomac RR Yard	6000		P31	5	5	3720	4990	3320	3404	3027	3336	2952	3302	724	3404
C11TP-Potomac RR Yard	6000		P32	5	5	3720	4990	3158	3257	2981	3168	3570	3217	742	3570
C11TP-Potomac RR Yard	6000		P33	5	5	3720	4990	3045	3115	2599	3163	2777	3804	724	3804
C11TP-Potomac RR Yard	6000	8000	P34	5	8	3720	4990	5491	5524	4928	5580	3015	6150	742	6150
C11TP-Potomac RR Yard			N1	6	9	4464	5988	5556	5741	4684	5698	5897	7225	0	7225
C11TP-Potomac RR Yard			N2	6	9	4464	5988	6318	6516	5445	6455	6138	7783	0	7783
C12TB1-Bashford Ln	4000		P41	4	4	2976	3992	1423	1432	1614	1452	1451	1984	2999	2999
C12TB1-Bashford Ln	4000		P42	4	4	2976	3992	2036	2054	2397	1988	679	1448	2922	2922
C12TB1-Bashford Ln	4000		P43	4	4	2976	3992	1423	1432	1614	1452	1451	1984	2999	2999
C12TB1-Bashford Ln	4000		P44	4	4	2976	3992	2036	2054	2397	1988	679	1448	2922	2922

TPSS / TBS	Input data							Simulation results							
	Breaker ratings	Breaker ratings Upgraded	Feeders (P-Positive, N-Negative)	1000 kcmil Cables (Quantity)	1000 kcmil Cables (Quantity) Upgraded	Nominal Ampacity normal operation [A]	Ampacity Abnormal operation [A]	Irms normal operation [A]	Irms National Airport abnormal operation [A]	Irms Potomac Yard abnormal operation [A]	Irms Braddock Road abnormal operation [A]	Irms National Airport emergency operation [A]	Irms Braddock Road emergency operation [A]	Irms Potomac Yard emergency operation [A]	Max rms [A] Outage
C12TP-Braddock Rd	6000	8000	P31	5	7	3720	4990	4830	4856	5171	4746	4826	1601	6619	6619
C12TP-Braddock Rd	6000		P32	4	5	2976	3992	2592	2612	3005	2525	2215	1386	4593	4593
C12TP-Braddock Rd	6000		P33	6	6	4464	5988	2948	2946	2915	2814	2964	1712	2798	2964
C12TP-Braddock Rd	6000		P34	5	6	3720	4990	3839	3836	3804	3677	3834	1386	3483	3836
C12TP-Braddock Rd	6000		P35	4	4	2976	3992	2833	2833	2844	2859	2970	2042	2992	2992
C12TP-Braddock Rd			N1	6	9	4464	5988	5717	5745	6144	5380	5821	0	8072	8072
C12TP-Braddock Rd			N2	6	9	4464	5988	4943	4972	5375	4604	5060	0	7270	7270
C13TB1-King St	4000		P41	4	4	2976	3992	2623	2624	2634	2668	2614	3659	2680	3659
C13TB1-King St	4000		P42	4	4	2976	3992	1359	1360	1373	1417	1334	2997	1712	2997
C13TB1-King St	4000		P43	4	4	2976	3992	2515	2516	2522	2538	2532	3495	2552	3495
C13TB1-King St	4000		P44	4	4	2976	3992	1359	1360	1373	1417	1334	2997	1712	2997
C13TB1-King St	4000		P45	4	4	2976	3992	1816	1816	1814	1803	1502	1176	1529	1816
C97TP-Duke St	4000	6000	P31	4	5	2976	3992	3317	3320	3348	3441	3352	4864	3596	4864
C97TP-Duke St	6000		P32	4	6	2976	3992	3860	3862	3885	3990	3835	4043	4061	4061
C97TP-Duke St	4000		P33	4	5	2976	3992	3000	2999	2996	2983	3107	2638	3246	3246
C97TP-Duke St	4000		P34	4	4	2976	3992	2816	2816	2814	2805	2763	2910	2993	2993
C97TP-Duke St	4000		P35	4	4	2976	3992								0
C97TP-Duke St	4000		P36	4	4	2976	3992								0
C97TP-Duke St			N1	6	7	4464	5988	4047	4050	4087	4209	4078	5753	4213	5753
C97TP-Duke St			N2	6	7	4464	5988	4757	4759	4793	4911	4711	6394	4572	6394

Table 26 Current system. Positive and Negative feeder currents and breaker ratings. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%.

TPSS / TBS	Feeders (P-Positive N-Negative)	Load currents [A RMS]		Breaker Rating [A]		No. de Cables		Breaker Load/ Rating Ratios		Cable Load / Rating Ratio Normal Operation		Cable Load/ Rating Ratio Contingency Operation	
		Normal operation	Max contingency operation	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading
C09TP-18th&Fern St	P31	1768	1768	4000	4000	4	4	44%	44%	59%	59%	59%	59%
C09TP-18th&Fern St	P32	2862	2908	4000	4000	4	4	73%	73%	96%	96%	98%	98%
C09TP-18th&Fern St	P33	3657	4101	6000	6000	5	5	68%	68%	98%	98%	110%	110%
C09TP-18th&Fern St	P34	2418	5160	4000	6000	4	6	129%	86%	81%	54%	173%	116%
C09TP-18th&Fern St	N1	3409	5365			6	6			76%	76%	120%	120%
C09TP-18th&Fern St	N2	3448	5642			6	6			77%	77%	126%	126%
C09TB1-Cristal City	P41	1204	2286	4000	4000	4	4	57%	57%	40%	40%	77%	77%
C09TB1-Cristal City	P42	2188	4204	4000	6000	4	5	105%	70%	74%	59%	141%	113%
C09TB1-Cristal City	P43	1204	2286	4000	4000	4	4	57%	57%	40%	40%	77%	77%
C09TB1-Cristal City	P44	2324	4341	4000	6000	4	5	109%	72%	78%	62%	146%	117%
C09TB1-Cristal City	P46	1985	1991	4000	4000	4	4	50%	50%	67%	67%	67%	67%
C10TP-National Airport	P31	2671	2671	6000	6000	5	5	45%	45%	72%	72%	72%	72%
C10TP-National Airport	P32	3503	3674	6000	6000	5	5	61%	61%	94%	94%	99%	99%
C10TP-National Airport	P33	1760	4401	6000	6000	4	5	73%	73%	59%	47%	148%	118%
C10TP-National Airport	P34	3568	4700	6000	6000	4	5	78%	78%	120%	96%	158%	126%
C10TP-National Airport	P36	1971	1978	6000	6000	3	3	33%	33%	88%	88%	89%	89%
C10TP-National Airport	P37	0	0	6000	6000	4	4	0%	0%	0%	0%	0%	0%
C10TP-National Airport	N1	4453	6224			6	8			100%	75%	139%	105%
C10TP-National Airport	N2	5831	7579			6	8			131%	98%	170%	127%
C11TB1-Potomac RR Yard North	P41	1198	2769	4000	4000	4	4	69%	69%	40%	40%	93%	93%
C11TB1-Potomac RR Yard North	P42	2040	2844	4000	4000	4	4	71%	71%	69%	69%	96%	96%
C11TB1-Potomac RR Yard North	P43	1198	2769	4000	4000	4	4	69%	69%	40%	40%	93%	93%

TPSS / TBS	Feeders (P-Positive N-Negative)	Load currents [A RMS]		Breaker Rating [A]		No. de Cables		Breaker Load/ Rating Ratios		Cable Load / Rating Ratio Normal Operation		Cable Load/ Rating Ratio Contingency Operation	
		Normal operation	Max contingency operation	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading
C11TB1-Potomac RR Yard North	P44	2040	2844	4000	4000	4	4	71%	71%	69%	69%	96%	96%
C11TP-Potomac RR Yard	P31	3320	3404	6000	6000	5	5	57%	57%	89%	89%	92%	92%
C11TP-Potomac RR Yard	P32	3158	3570	6000	6000	5	5	60%	60%	85%	85%	96%	96%
C11TP-Potomac RR Yard	P33	3045	3804	6000	6000	5	5	63%	63%	82%	82%	102%	102%
C11TP-Potomac RR Yard	P34	5491	6150	6000	8000	5	8	103%	77%	148%	92%	165%	103%
C11TP-Potomac RR Yard	N1	5556	7225			6	9			124%	83%	162%	108%
C11TP-Potomac RR Yard	N2	6318	7783			6	9			142%	94%	174%	116%
C12TB1-Bashford Ln	P41	1423	2999	4000	4000	4	4	75%	75%	48%	48%	101%	101%
C12TB1-Bashford Ln	P42	2036	2922	4000	4000	4	4	73%	73%	68%	68%	98%	98%
C12TB1-Bashford Ln	P43	1423	2999	4000	4000	4	4	75%	75%	48%	48%	101%	101%
C12TB1-Bashford Ln	P44	2036	2922	4000	4000	4	4	73%	73%	68%	68%	98%	98%
C12TP-Braddock Rd	P31	4830	6619	6000	8000	5	7	110%	83%	130%	93%	178%	127%
C12TP-Braddock Rd	P32	2592	4593	6000	6000	4	5	77%	77%	87%	70%	154%	123%
C12TP-Braddock Rd	P33	2948	2964	6000	6000	6	6	49%	49%	66%	66%	66%	66%
C12TP-Braddock Rd	P34	3839	3836	6000	6000	5	6	64%	64%	103%	86%	103%	86%
C12TP-Braddock Rd	P35	2833	2992	6000	6000	4	4	50%	50%	95%	95%	101%	101%
C12TP-Braddock Rd	N1	5717	8072			6	9			128%	85%	181%	121%
C12TP-Braddock Rd	N2	4943	7270			6	9			111%	74%	163%	109%
C13TB1-King St	P41	2623	3659	4000	4000	4	4	91%	91%	88%	88%	123%	123%
C13TB1-King St	P42	1359	2997	4000	4000	4	4	75%	75%	46%	46%	101%	101%
C13TB1-King St	P43	2515	3495	4000	4000	4	4	87%	87%	85%	85%	117%	117%
C13TB1-King St	P44	1359	2997	4000	4000	4	4	75%	75%	46%	46%	101%	101%
C13TB1-King St	P45	1816	1816	4000	4000	4	4	45%	45%	61%	61%	61%	61%

TPSS / TBS	Feeders (P-Positive N-Negative)	Load currents [A RMS]		Breaker Rating [A]		No. de Cables		Breaker Load/ Rating Ratios		Cable Load / Rating Ratio Normal Operation		Cable Load/ Rating Ratio Contingency Operation	
		Normal operation	Max contingency operation	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading	Existing	Upgrading
C97TP-Duke St	P31	3317	4864	4000	6000	4	5	122%	81%	111%	89%	163%	131%
C97TP-Duke St	P32	3860	4061	6000	6000	4	6	68%	68%	130%	86%	136%	91%
C97TP-Duke St	P33	3000	3246	4000	4000	4	5	81%	81%	101%	81%	109%	87%
C97TP-Duke St	P34	2816	2993	4000	4000	4	4	75%	75%	95%	95%	101%	101%
C97TP-Duke St	P35	0	0	4000	4000	4	4	0%	0%	0%	0%	0%	0%
C97TP-Duke St	P36	0	0	4000	4000	4	4	0%	0%	0%	0%	0%	0%
C97TP-Duke St	N1	4047	5753			6	7			91%	78%	129%	110%
C97TP-Duke St	N2	4757	6394			6	7			107%	91%	143%	123%

Table 27 and **Table 28** shows a check-up summary of the Positive and Negative feeder currents and breaking ratings after upgrades required for the system. New feeder quantities and breaker upgrades required for the upgraded system are highlighted in yellow. Feeder and breaker current ratings exceeded are marked in red. For Baseline feeder cable loading must be <100% and for contingency loading must be <134%.

Table 27. Upgraded system. Positive and Negative feeder currents and new upgrades required.

	Input data				Simulation results							
TPSS y TBS	Feeders (P-Positive, N-Negative)	1000 kcmil Cables (Quantity)	Nominal Ampacity normal operation [A]	Ampacity Abnormal operation [A]	Irms normal operation [A]	Irms National Airport abnormal operation [A]	Irms Potomac Yard abnormal operation [A]	Irms Braddock Road abnormal operation [A]	Irms National Airport emergency operation [A]	Irms Braddock Road emergency operation [A]	Irms Potomac Yard emergency operation [A]	Max rms [A] Outage
C09TP-18th&Fern St	P31	4	2976	3992	1855	1845	1853	1854	1788	1635	1647	1854
C09TP-18th&Fern St	P32	4	2976	3992	3044	3031	3042	3044	2812	3074	3003	3074
C09TP-18th&Fern St	P33	5	3720	4990	3672	3793	3683	3673	3797	3646	3786	3797
C09TP-18th&Fern St	P34	6	4464	5988	2314	2462	2329	2315	4746	2263	2419	4746
C09TP-18th&Fern St	N1	6	4464	5988	3616	3759	3632	3618	5452	3762	4035	5452
C09TP-18th&Fern St	N2	6	4464	5988	3669	3815	3686	3671	5787	3967	4159	5787
C09TB1-Cristal City	P41	4	2976	3992	1169	1169	1168	1169	2066	1194	1293	2066
C09TB1-Cristal City	P42	5	3720	4990	2061	2149	2070	2062	3875	1943	1984	3875
C09TB1-Cristal City	P43	4	2976	3992	1169	1169	1168	1169	2066	1194	1293	2066
C09TB1-Cristal City	P44	5	3720	4990	2143	2243	2152	2143	3985	2023	2084	3985
C09TB1-Cristal City	P46	4	2976	3992	1515	1505	1514	1515	835	1522	1508	1522
C10TP-National Airport	P31	5	3720	4990	2671	2571	2662	2670	645	2689	2659	2689
C10TP-National Airport	P32	5	3720	4990	3558	3465	3547	3557	1140	3664	3594	3664
C10TP-National Airport	P33	5	3720	4990	1671	1551	1874	1692	645	1810	4308	4308
C10TP-National Airport	P34	5	3720	4990	3573	3476	3718	3585	1191	3664	5047	5047
C10TP-National Airport	P36	3	2232	2994	1911	1977	1916	1912	554	1870	1921	1977
C10TP-National Airport	P37	4	2976	3992								0

	Input data				Simulation results							
TPSS y TBS	Feeders (P-Positive, N-Negative)	1000 kcmil Cables (Quantity)	Nominal Ampacity normal operation [A]	Ampacity Abnormal operation [A]	Irms normal operation [A]	Irms National Airport abnormal operation [A]	Irms Potomac Yard abnormal operation [A]	Irms Braddock Road abnormal operation [A]	Irms National Airport emergency operation [A]	Irms Braddock Road emergency operation [A]	Irms Potomac Yard emergency operation [A]	Max rms [A] Outage
C10TP-National Airport	N1	8	5952	7984	4321	4049	4488	4337	0	4447	6277	6277
C10TP-National Airport	N2	8	5952	7984	5819	5569	5994	5837	0	5811	7597	7597
C11TB1-Potomac RR Yard North	P41	4	2976	3992	1144	1075	1265	1157	1669	1422	2785	2785
C11TB1-Potomac RR Yard North	P42	4	2976	3992	2117	2072	2213	2123	2530	2198	3309	3309
C11TB1-Potomac RR Yard North	P43	4	2976	3992	1144	1075	1265	1157	1669	1422	2785	2785
C11TB1-Potomac RR Yard North	P44	4	2976	3992	2117	2072	2213	2123	2530	2198	3309	3309
C11TP-Potomac RR Yard	P31	5	3720	4990	3715	3798	3605	3734	3170	3726	801	3798
C11TP-Potomac RR Yard	P32	5	3720	4990	3327	3418	3250	3335	4007	3414	893	4007
C11TP-Potomac RR Yard	P33	5	3720	4990	2796	2841	2614	2945	2726	3982	801	3982
C11TP-Potomac RR Yard	P34	8	5952	7984	5471	5497	5349	5600	2650	7103	893	7103
C11TP-Potomac RR Yard	N1	9	6696	8982	5682	5821	5328	5855	6007	7906	0	7906
C11TP-Potomac RR Yard	N2	9	6696	8982	6417	6566	6089	6590	6261	8527	0	8527
C12TB1-Bashford Ln	P41	4	2976	3992	1292	1293	1335	1341	1330	2546	2810	2810
C12TB1-Bashford Ln	P42	4	2976	3992	1765	1777	1932	1724	505	1655	2904	2904
C12TB1-Bashford Ln	P43	4	2976	3992	1292	1293	1335	1341	1330	2546	2810	2810
C12TB1-Bashford Ln	P44	4	2976	3992	1765	1777	1932	1724	505	1655	2904	2904
C12TP-Braddock Rd	P31	7	5208	6986	4501	4518	4661	4426	4517	1749	6799	6799
C12TP-Braddock Rd	P32	5	3720	4990	2283	2295	2475	2201	1975	1324	4484	4484
C12TP-Braddock Rd	P33	6	4464	5988	3025	3023	3011	2904	2981	1618	2810	3023
C12TP-Braddock Rd	P34	6	4464	5988	3889	3888	3872	3734	3875	1324	3521	3888
C12TP-Braddock Rd	P35	4	2976	3992	2967	2967	2976	3013	2944	2018	3001	3013
C12TP-Braddock Rd	N1	9	6696	8982	5606	5624	5813	5275	5641	0	8092	8092

	Input data				Simulation results							
TPSS y TBS	Feeders (P-Positive, N-Negative)	1000 kcmil Cables (Quantity)	Nominal Ampacity normal operation [A]	Ampacity Abnormal operation [A]	Irms normal operation [A]	Irms National Airport abnormal operation [A]	Irms Potomac Yard abnormal operation [A]	Irms Braddock Road abnormal operation [A]	Irms National Airport emergency operation [A]	Irms Braddock Road emergency operation [A]	Irms Potomac Yard emergency operation [A]	Max rms [A] Outage
C12TP-Braddock Rd	N2	9	6696	8982	4659	4676	4865	4308	4791	0	7135	7135
C13TB1-King St	P41	4	2976	3992	2582	2582	2586	2617	2623	3418	2673	3418
C13TB1-King St	P42	4	2976	3992	1329	1329	1336	1380	1315	2847	1687	2847
C13TB1-King St	P43	4	2976	3992	2513	2514	2517	2537	2543	3255	2542	3255
C13TB1-King St	P44	4	2976	3992	1329	1329	1336	1380	1315	2847	1687	2847
C13TB1-King St	P45	4	2976	3992	1493	1493	1492	1484	1507	1220	1532	1532
C97TP-Duke St	P31	5	3720	4990	3292	3294	3306	3407	3343	4597	3607	4597
C97TP-Duke St	P32	6	4464	5988	3846	3847	3858	3965	3819	3870	4059	4059
C97TP-Duke St	P33	5	3720	4990	3116	3116	3114	3100	3130	2747	3272	3272
C97TP-Duke St	P34	4	2976	3992	2818	2818	2817	2807	2765	2927	2994	2994
C97TP-Duke St	P35	4	2976	3992								0
C97TP-Duke St	P36	4	2976	3992								0
C97TP-Duke St	N1	7	5208	6986	4058	4059	4076	4211	4050	5651	4201	5651
C97TP-Duke St	N2	7	5208	6986	4782	4783	4798	4928	4718	6319	4579	6319

Table 28 Upgraded system. Positive and Negative feeder currents and new upgrades required.

TPSS / TBS	Feeders (P-Positive N-Negative)	Load currents [A RMS]		Breaker Rating [A]		No. de Cables		Breaker Load/ Rating Ratios		Cable Load / Rating Ratio Normal Operation		Cable Load/ Rating Ratio Contingency Operation	
		Normal operation	Max contingency operation	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check
C09TP-18th&Fern St	P31	1855	1854	4000	4000	4	4	46%	46%	62%	62%	62%	62%
C09TP-18th&Fern St	P32	3044	3074	4000	4000	4	5	77%	77%	102%	82%	103%	83%
C09TP-18th&Fern St	P33	3672	3797	6000	6000	5	5	63%	63%	99%	99%	102%	102%
C09TP-18th&Fern St	P34	2314	4746	6000	6000	6	6	79%	79%	52%	52%	106%	106%
C09TP-18th&Fern St	N1	3616	5452			6	6			81%	81%	122%	122%
C09TP-18th&Fern St	N2	3669	5787			6	6			82%	82%	130%	130%
C09TB1-Cristal City	P41	1169	2066	4000	4000	4	4	52%	52%	39%	39%	69%	69%
C09TB1-Cristal City	P42	2061	3875	6000	6000	5	5	65%	65%	55%	55%	104%	104%
C09TB1-Cristal City	P43	1169	2066	4000	4000	4	4	52%	52%	39%	39%	69%	69%
C09TB1-Cristal City	P44	2143	3985	6000	6000	5	5	66%	66%	58%	58%	107%	107%
C09TB1-Cristal City	P46	1515	1522	4000	4000	4	4	38%	38%	51%	51%	51%	51%
C10TP-National Airport	P31	2671	2689	6000	6000	5	5	45%	45%	72%	72%	72%	72%
C10TP-National Airport	P32	3558	3664	6000	6000	5	5	61%	61%	96%	96%	98%	98%
C10TP-National Airport	P33	1671	4308	6000	6000	5	5	72%	72%	45%	45%	116%	116%
C10TP-National Airport	P34	3573	5047	6000	6000	5	6	84%	84%	96%	80%	136%	113%
C10TP-National Airport	P36	1911	1977	6000	6000	3	3	33%	33%	86%	86%	89%	89%
C10TP-National Airport	P37	0	0	6000	6000	4	4	0%	0%	0%	0%	0%	0%
C10TP-National Airport	N1	4321	6277			8	8			73%	73%	105%	105%
C10TP-National Airport	N2	5819	7597			8	8			98%	98%	128%	128%
C11TB1-Potomac RR Yard North	P41	1144	2785	4000	4000	4	4	70%	70%	38%	38%	94%	94%
C11TB1-Potomac RR Yard North	P42	2117	3309	4000	4000	4	4	83%	83%	71%	71%	111%	111%
C11TB1-Potomac RR Yard North	P43	1144	2785	4000	4000	4	4	70%	70%	38%	38%	94%	94%

TPSS / TBS	Feeders (P-Positive N-Negative)	Load currents [A RMS]		Breaker Rating [A]		No. de Cables		Breaker Load/ Rating Ratios		Cable Load / Rating Ratio Normal Operation		Cable Load/ Rating Ratio Contingency Operation	
		Normal operation	Max contingency operation	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check
C11TB1-Potomac RR Yard North	P44	2117	3309	4000	4000	4	4	83%	83%	71%	71%	111%	111%
C11TP-Potomac RR Yard	P31	3715	3798	6000	6000	5	5	63%	63%	100%	100%	102%	102%
C11TP-Potomac RR Yard	P32	3327	4007	6000	6000	5	5	67%	67%	89%	89%	108%	108%
C11TP-Potomac RR Yard	P33	2796	3982	6000	6000	5	5	66%	66%	75%	75%	107%	107%
C11TP-Potomac RR Yard	P34	5471	7103	8000	8000	8	8	89%	89%	92%	92%	119%	119%
C11TP-Potomac RR Yard	N1	5682	7906			9	9			85%	85%	118%	118%
C11TP-Potomac RR Yard	N2	6417	8527			9	9			96%	96%	127%	127%
C12TB1-Bashford Ln	P41	1292	2810	4000	4000	4	4	70%	70%	43%	43%	94%	94%
C12TB1-Bashford Ln	P42	1765	2904	4000	4000	4	4	73%	73%	59%	59%	98%	98%
C12TB1-Bashford Ln	P43	1292	2810	4000	4000	4	4	70%	70%	43%	43%	94%	94%
C12TB1-Bashford Ln	P44	1765	2904	4000	4000	4	4	73%	73%	59%	59%	98%	98%
C12TP-Braddock Rd	P31	4501	6799	8000	8000	7	7	85%	85%	86%	86%	131%	131%
C12TP-Braddock Rd	P32	2283	4484	6000	6000	5	5	75%	75%	61%	61%	121%	121%
C12TP-Braddock Rd	P33	3025	3023	6000	6000	6	6	50%	50%	68%	68%	68%	68%
C12TP-Braddock Rd	P34	3889	3888	6000	6000	6	6	65%	65%	87%	87%	87%	87%
C12TP-Braddock Rd	P35	2967	3013	6000	6000	4	4	50%	50%	100%	100%	101%	101%
C12TP-Braddock Rd	N1	5606	8092			9	9			84%	84%	121%	121%
C12TP-Braddock Rd	N2	4659	7135			9	9			70%	70%	107%	107%
C13TB1-King St	P41	2582	3418	4000	4000	4	4	85%	85%	87%	87%	115%	115%
C13TB1-King St	P42	1329	2847	4000	4000	4	4	71%	71%	45%	45%	96%	96%
C13TB1-King St	P43	2513	3255	4000	4000	4	4	81%	81%	84%	84%	109%	109%
C13TB1-King St	P44	1329	2847	4000	4000	4	4	71%	71%	45%	45%	96%	96%
C13TB1-King St	P45	1493	1532	4000	4000	4	4	38%	38%	50%	50%	51%	51%

TPSS / TBS	Feeders (P-Positive N-Negative)	Load currents [A RMS]		Breaker Rating [A]		No. de Cables		Breaker Load/ Rating Ratios		Cable Load / Rating Ratio Normal Operation		Cable Load/ Rating Ratio Contingency Operation	
		Normal operation	Max contingency operation	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check	Upgrading	Upgrading Check
C97TP-Duke St	P31	3292	4597	6000	6000	5	5	77%	77%	88%	88%	124%	124%
C97TP-Duke St	P32	3846	4059	6000	6000	6	6	68%	68%	86%	86%	91%	91%
C97TP-Duke St	P33	3116	3272	4000	4000	5	5	82%	82%	84%	84%	88%	88%
C97TP-Duke St	P34	2818	2994	4000	4000	4	4	75%	75%	95%	95%	101%	101%
C97TP-Duke St	P35	0	0	4000	4000	4	4	0%	0%	0%	0%	0%	0%
C97TP-Duke St	P36	0	0	4000	4000	4	4	0%	0%	0%	0%	0%	0%
C97TP-Duke St	N1	4058	5651			7	7			78%	78%	109%	109%
C97TP-Duke St	N2	4782	6319			7	7			92%	92%	121%	121%

Appendix 2.

RMS Currents Graphs.

A2

Appendix 2. RMS Current Graphs.

Current System

TPSS Currents for Normal Operation

Both instant current and RMS are represented from **Figure 84** to **Figure 88** for all the TPSS under study for normal operation.

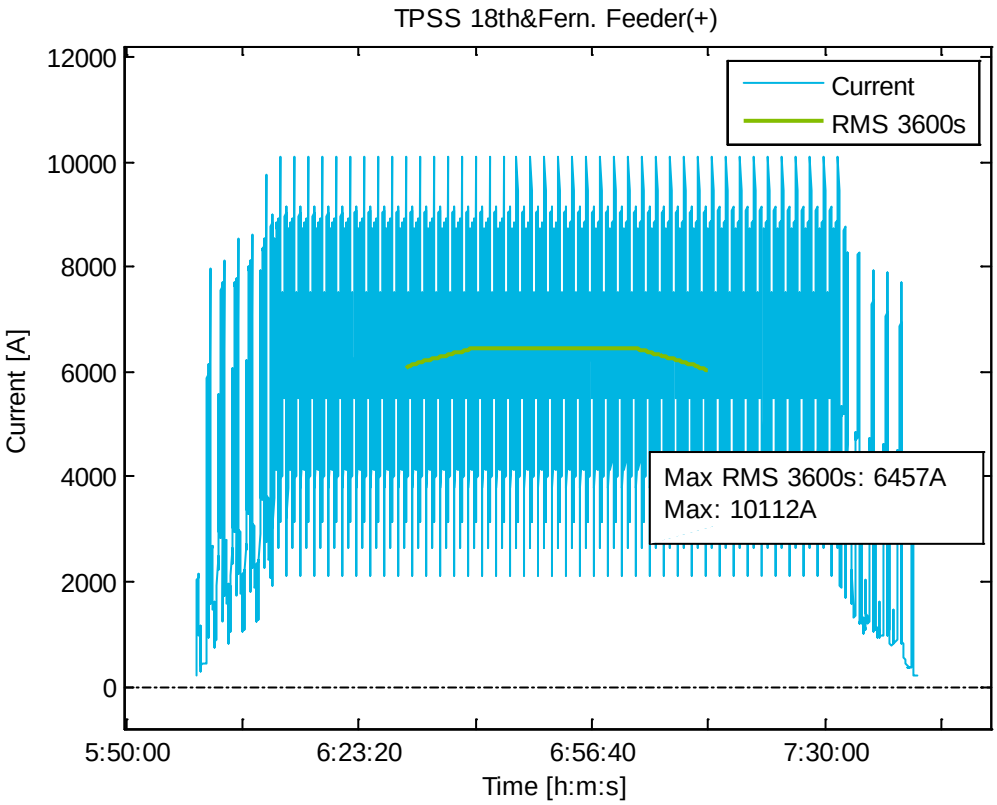


Figure 84.Instant and RMS currents for 18th and Fern Substation under normal operation.

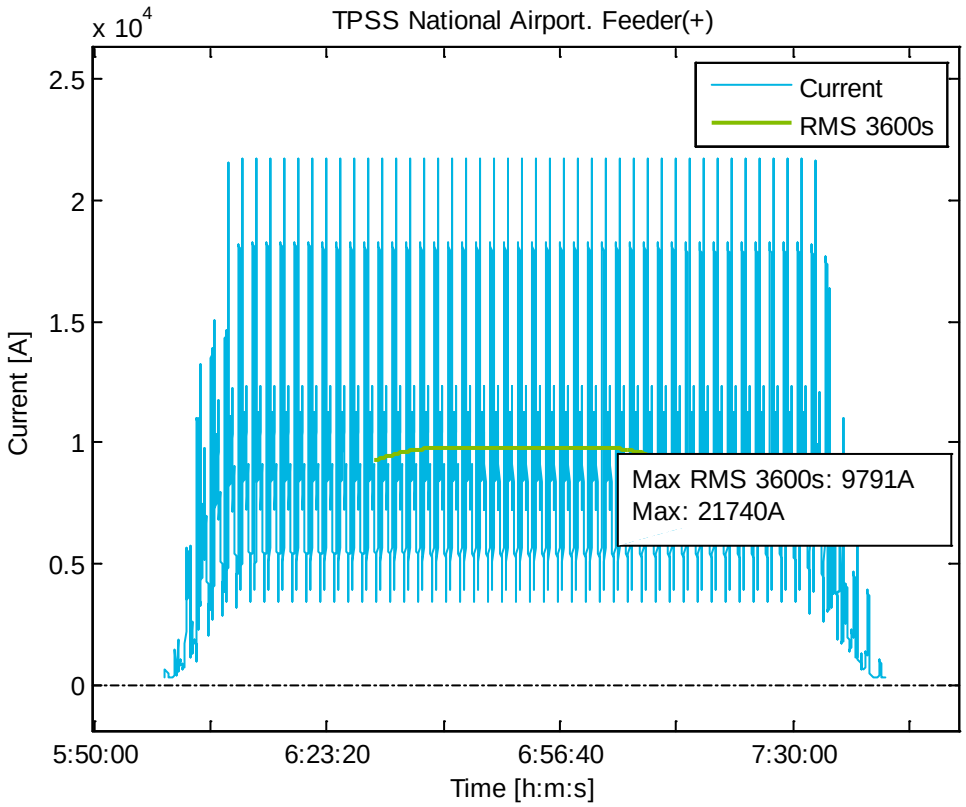


Figure 85.Instant and RMS currents for National Airport Substation under normal operation

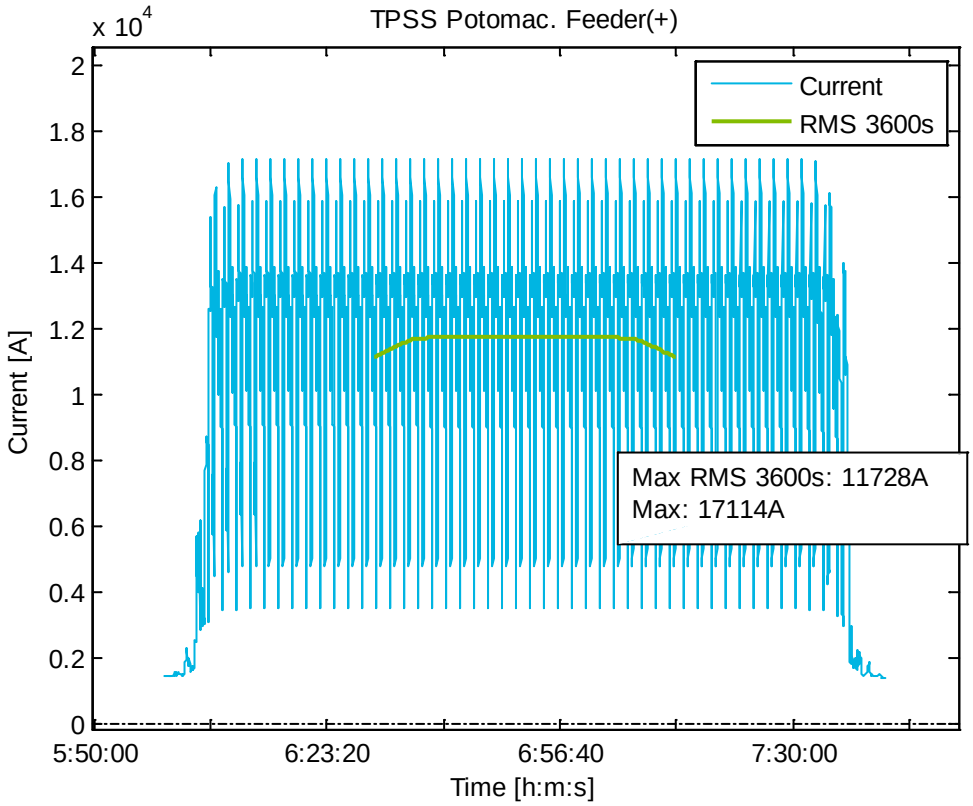


Figure 86.Instant and RMS currents for Potomac Yard Substation under normal operation.

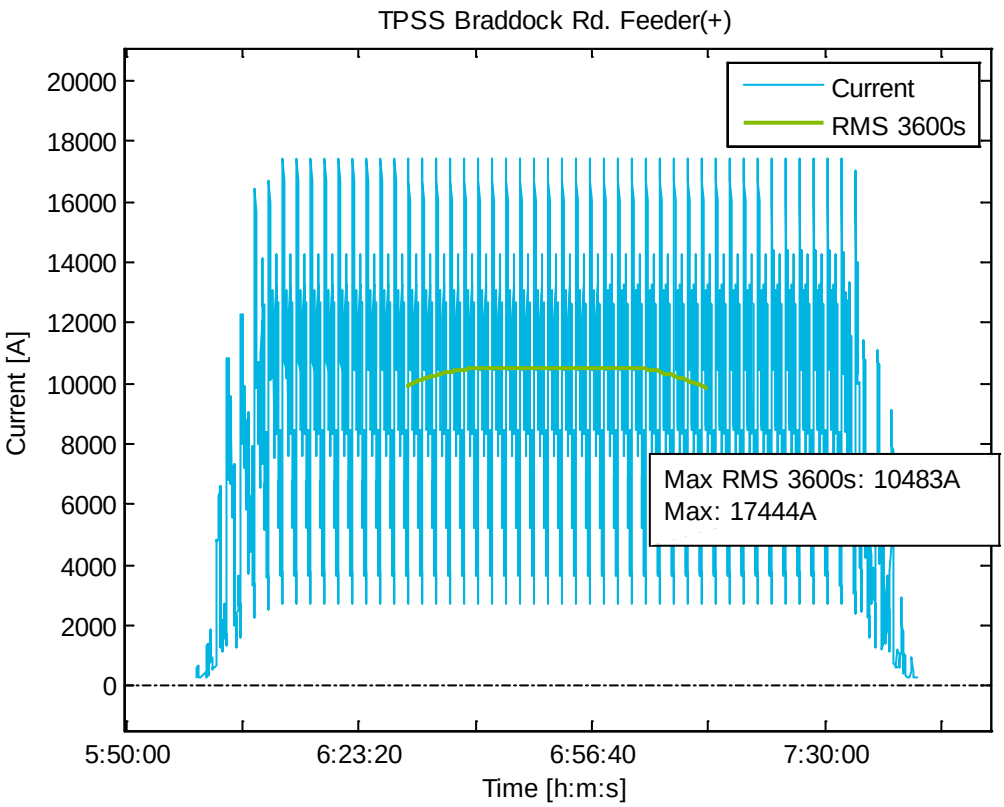


Figure 87. Instant and RMS currents for Braddock Road Substation under normal operation.

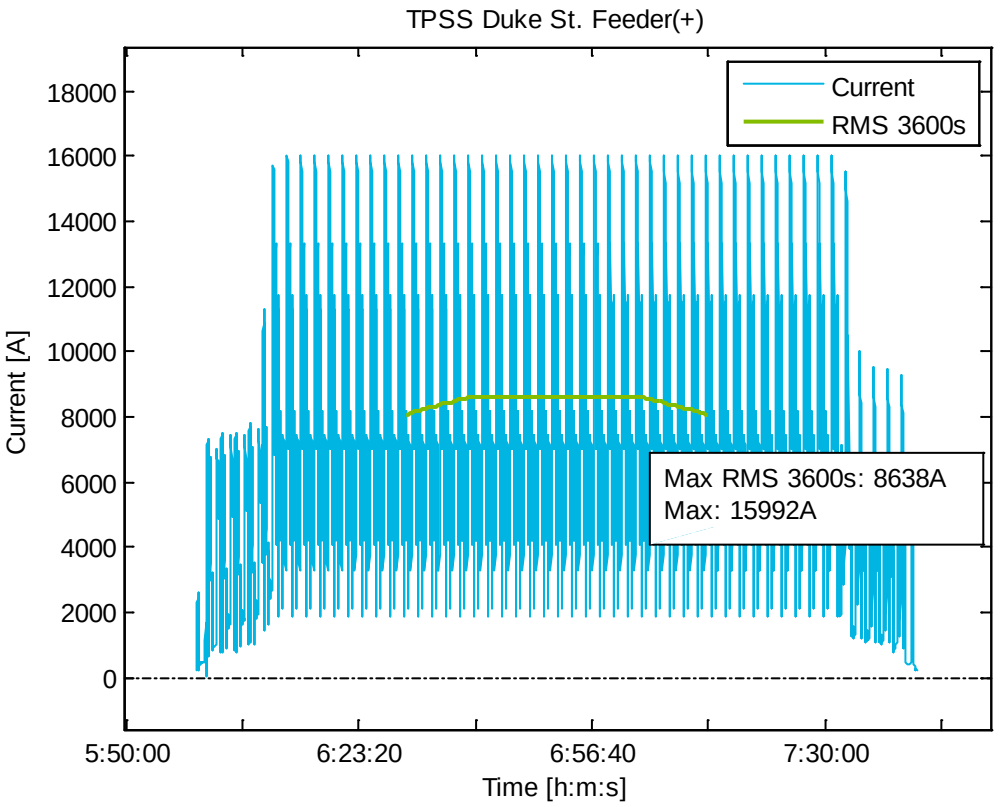


Figure 88.Instant and RMS currents for Duke Street Substation under normal operation.

TPSS Currents for National Airport Substation Abnormal Operation

Both instant current and RMS are represented from **Figure 89** to **Figure 93** for all the TPSS under study for National Airport Substation abnormal operation

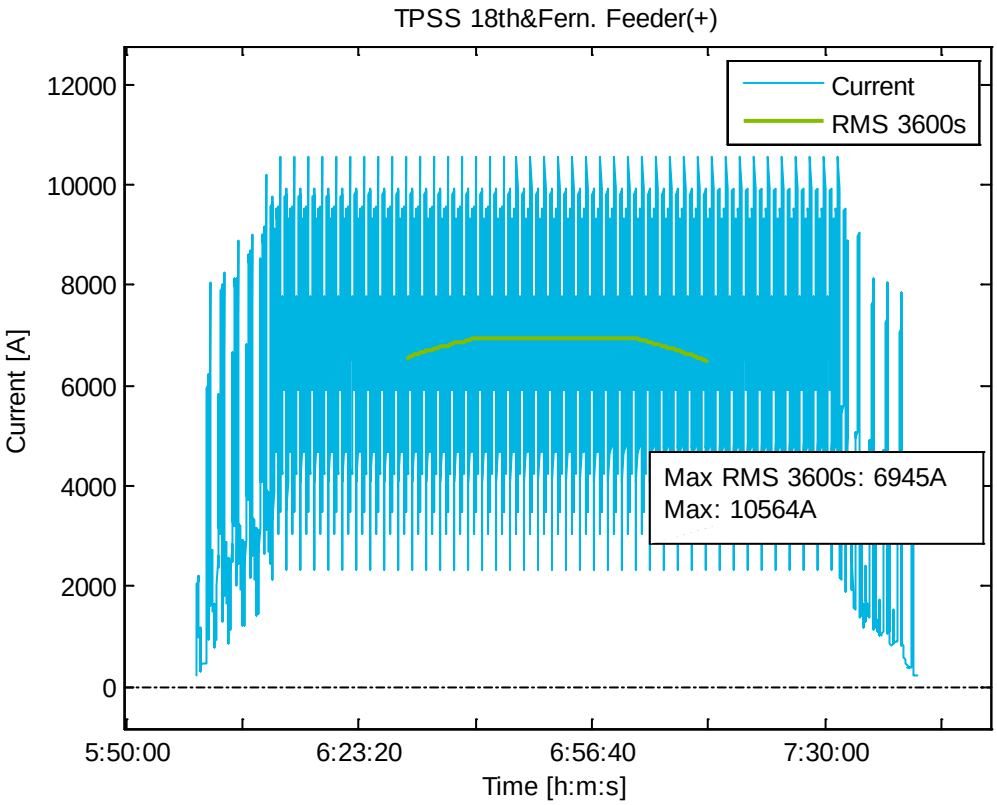


Figure 89.18th and Fern Substation Instant and RMS currents for National Airport Substation under abnormal operation.

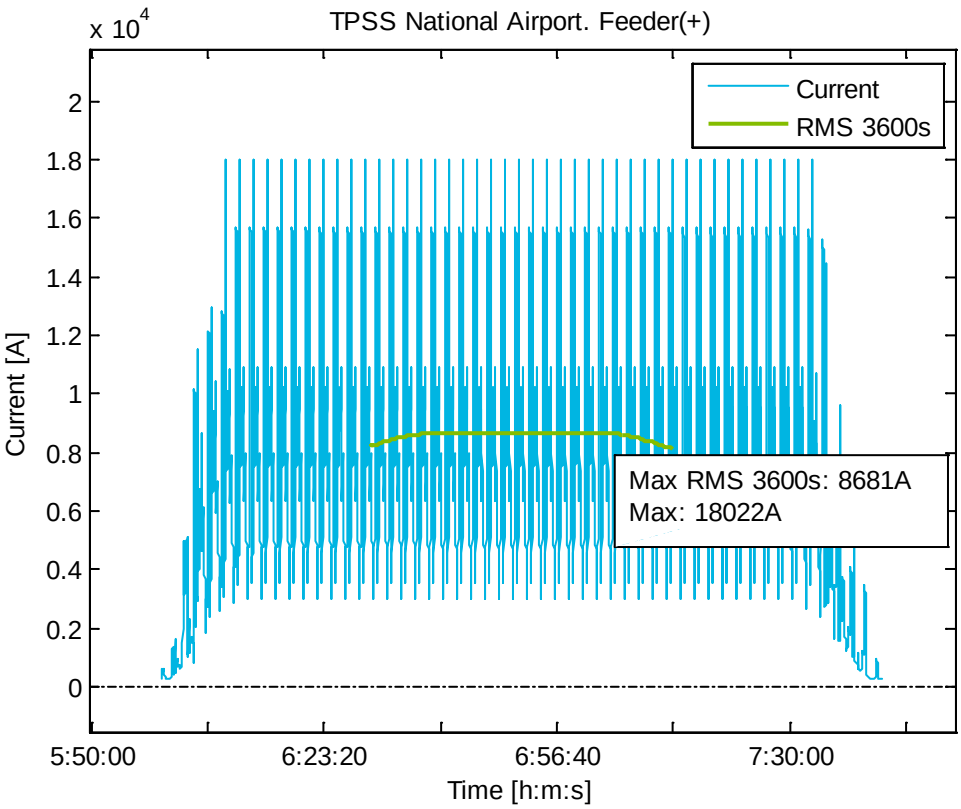


Figure 90. National Airport Substation Instant and RMS currents for National Airport Substation under abnormal operation.

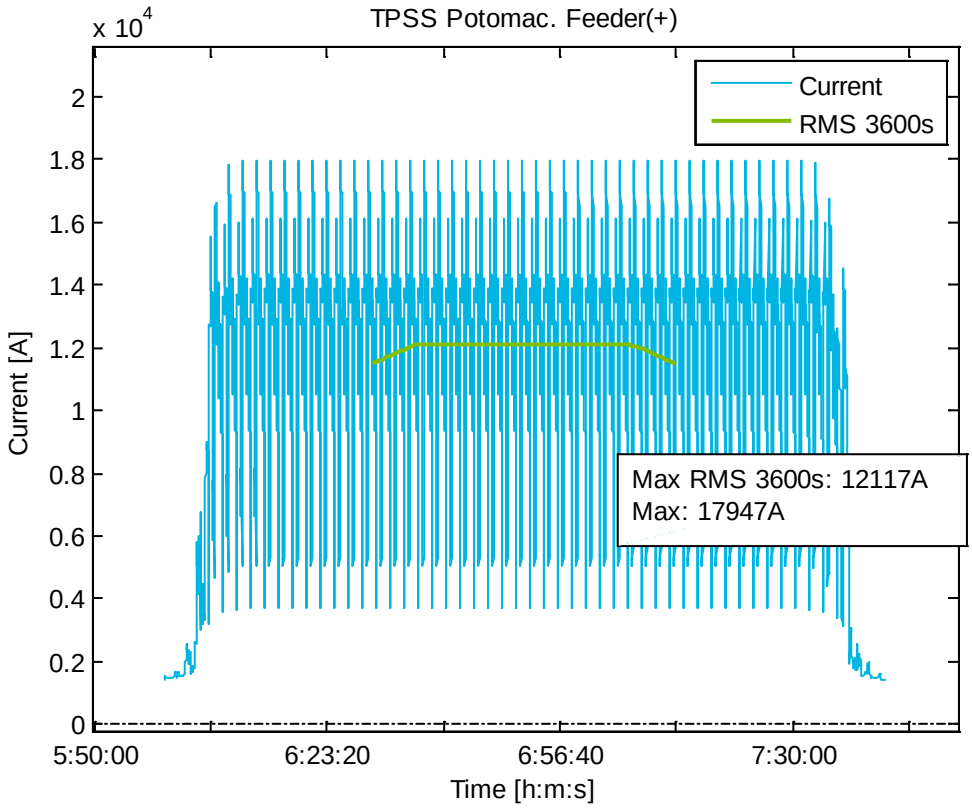


Figure 91. Potomac Yard Substation Instant and RMS currents for National Airport Substation under abnormal operation.

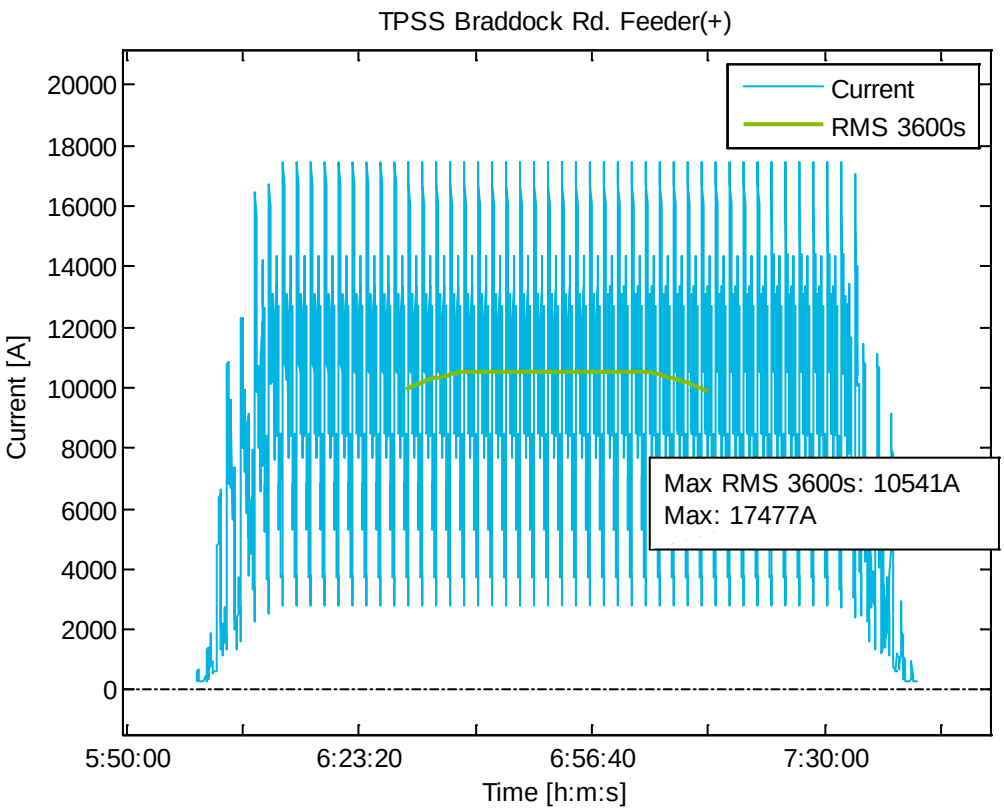


Figure 92. Braddock Road Substation Instant and RMS currents for National Airport Substation under abnormal operation.

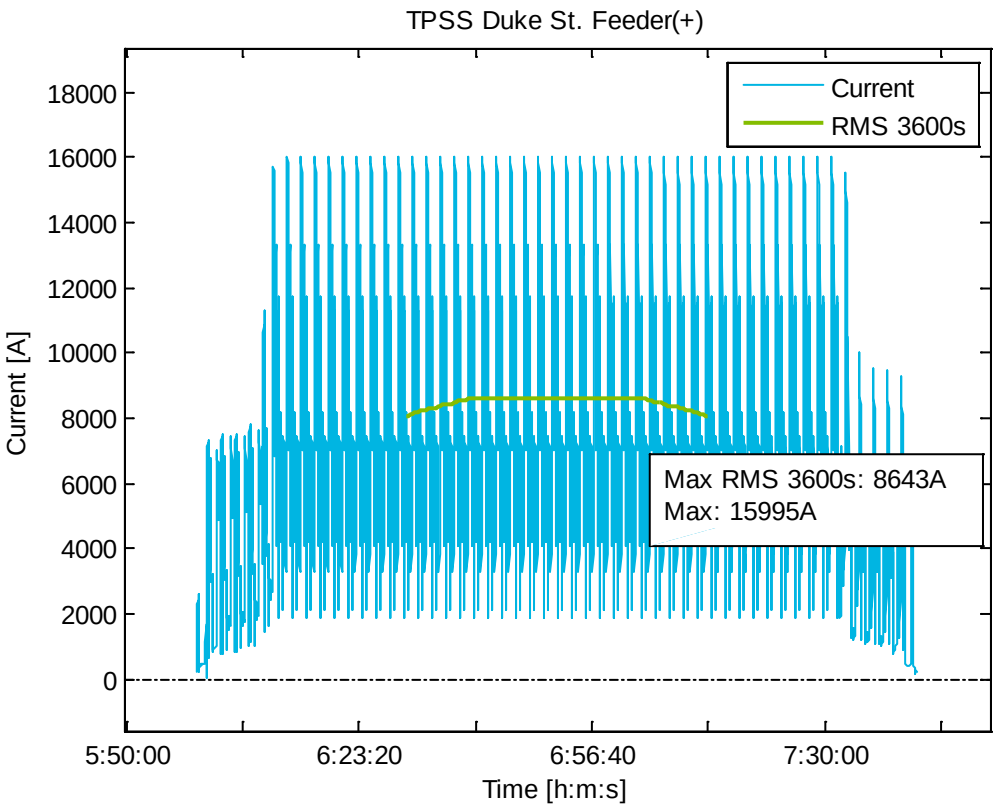


Figure 93. Duke Street Substation Instant and RMS currents for National Airport Substation under abnormal operation.

TPSS Currents for Potomac Yard Substation Abnormal Operation

Both instant current and RMS are represented from **Figure 94** to **Figure 98** for all the TPSS under study for Potomac Yard Substation abnormal operation.

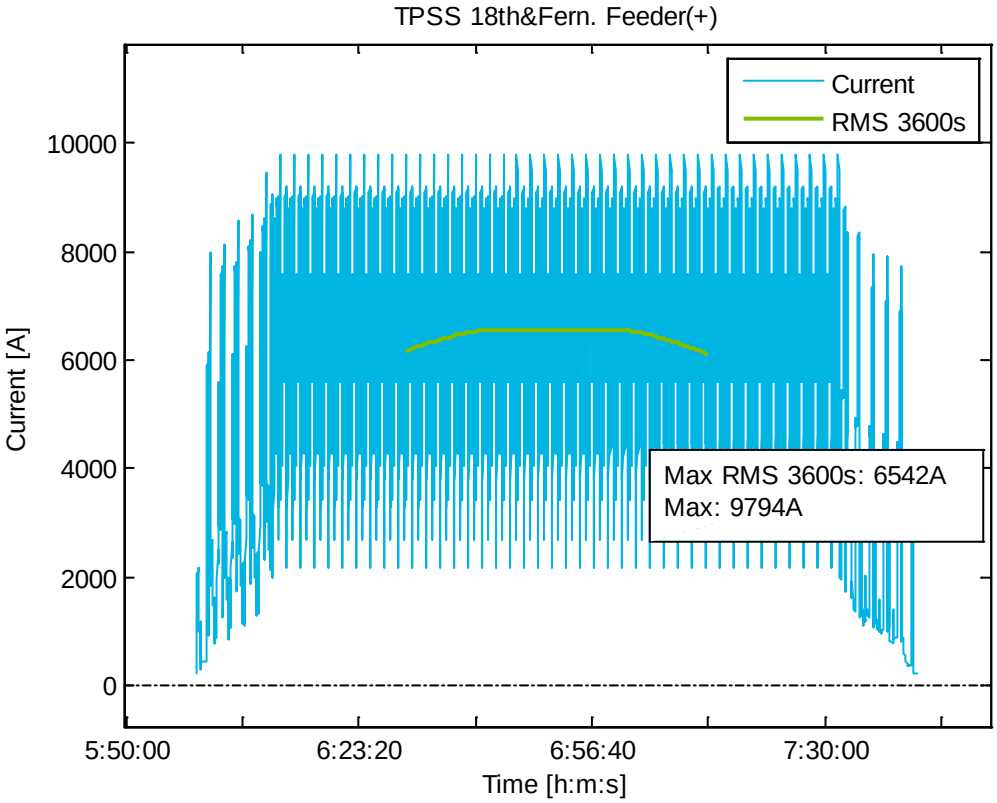


Figure 94. 18th and Fern Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

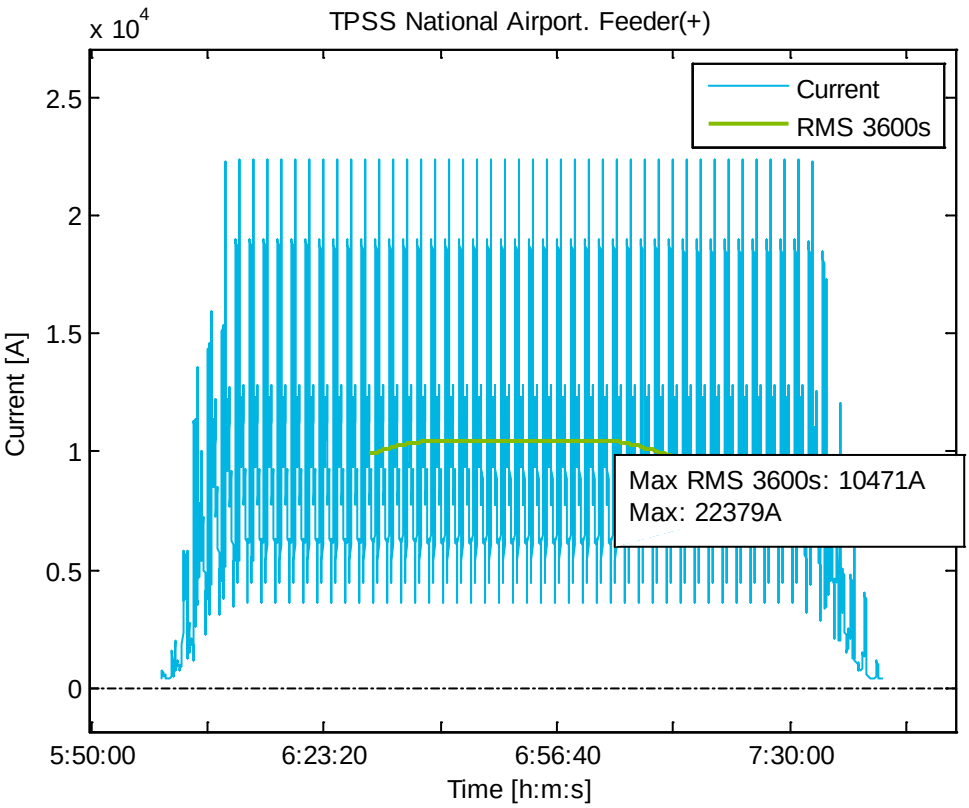


Figure 95. National Airport Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

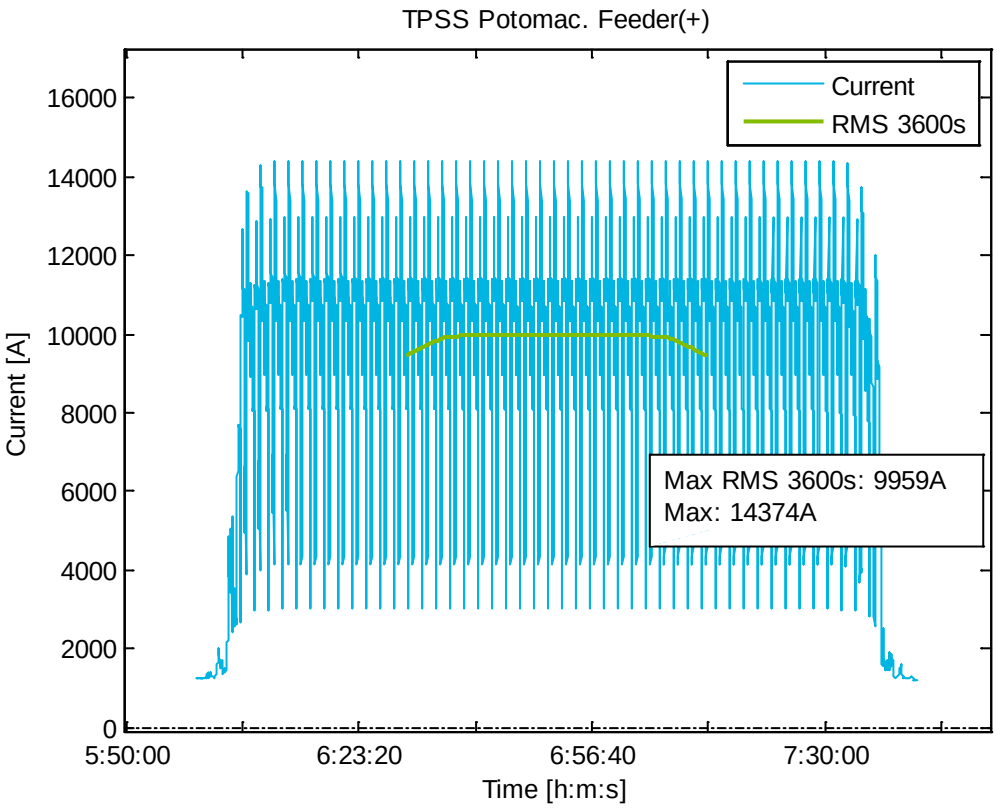


Figure 96. Potomac Yard Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation

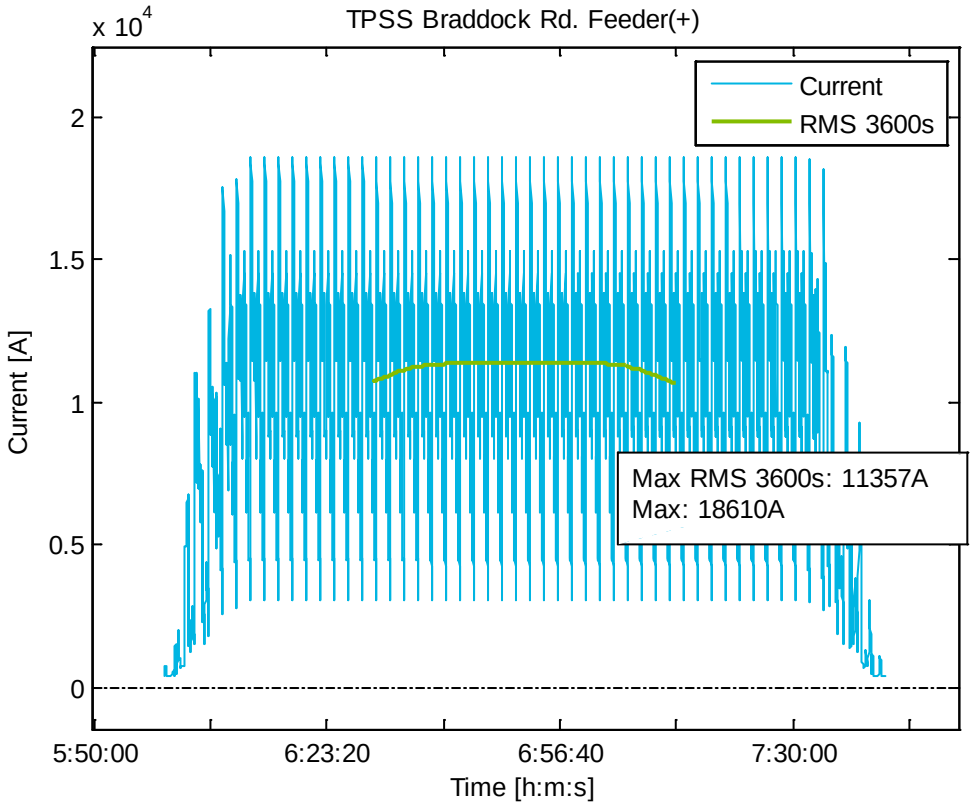


Figure 97. Braddock Road Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

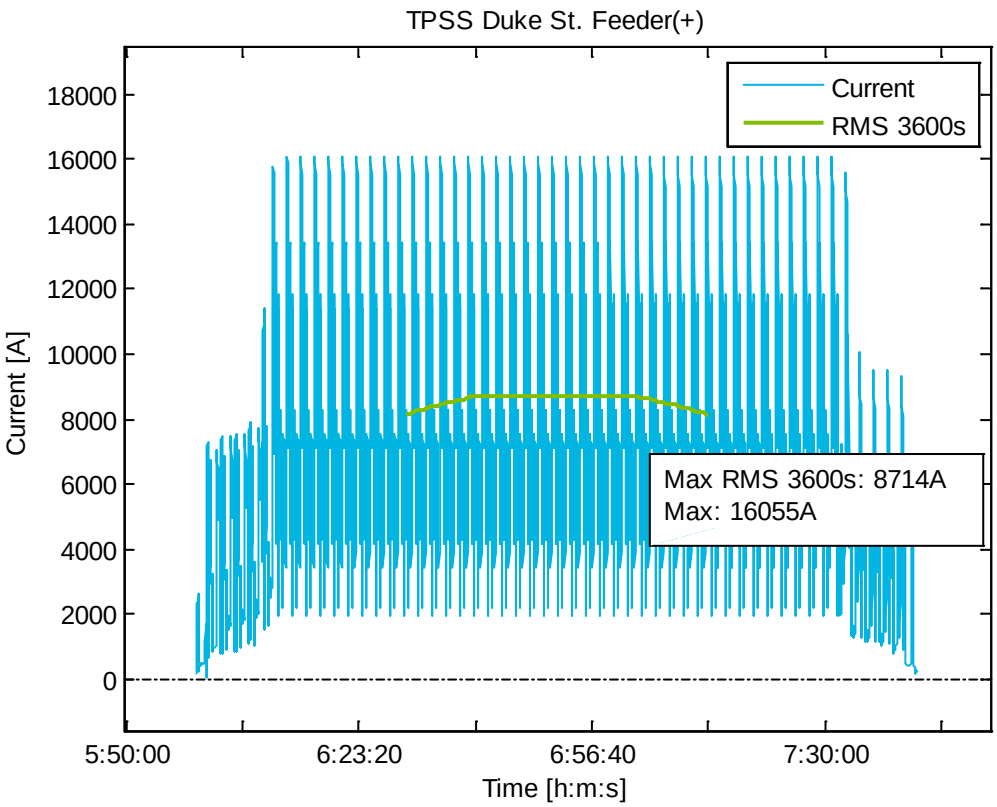


Figure 98. Duke Street Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

TPSS Currents for Braddock Road Substation Abnormal Operation

Both instant current and RMS are represented from **Figure 99** to **Figure 103** for all the TPSS under study for Braddock Road Substation abnormal operation.

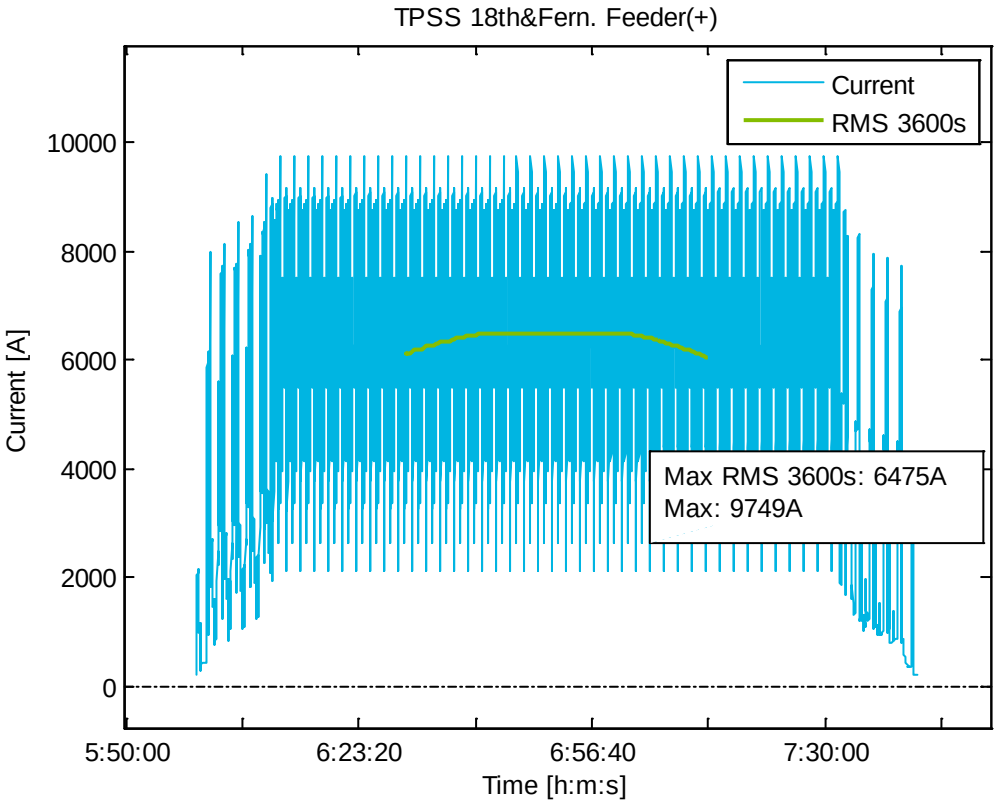


Figure 99. 18th and Fern Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

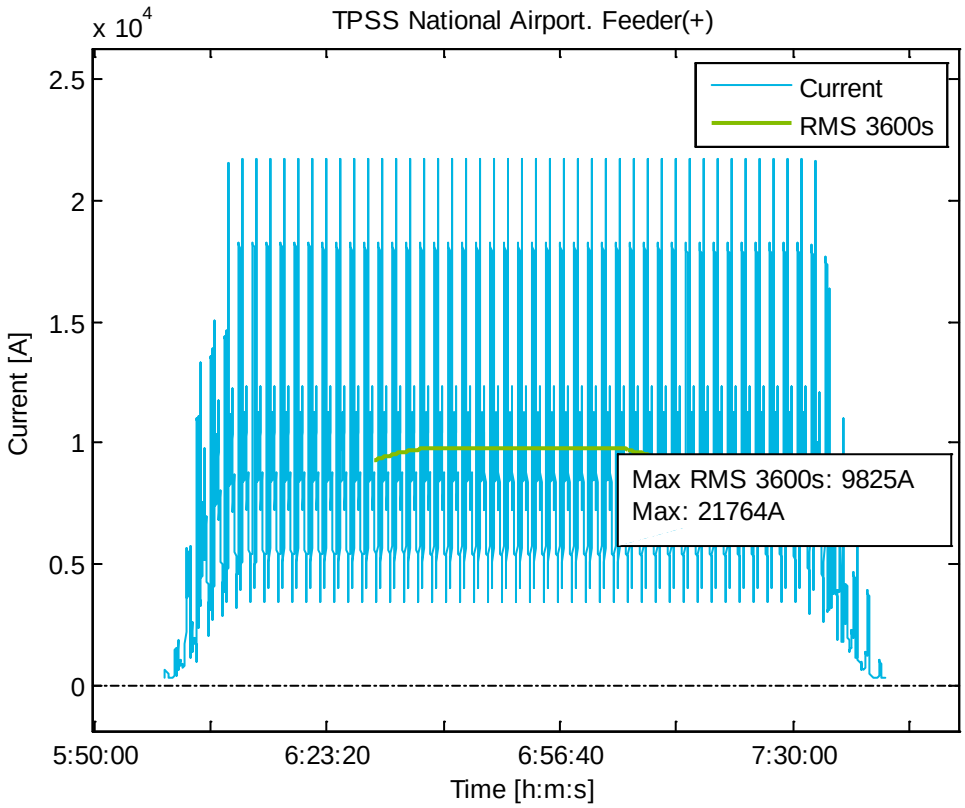


Figure 100. National Airport Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

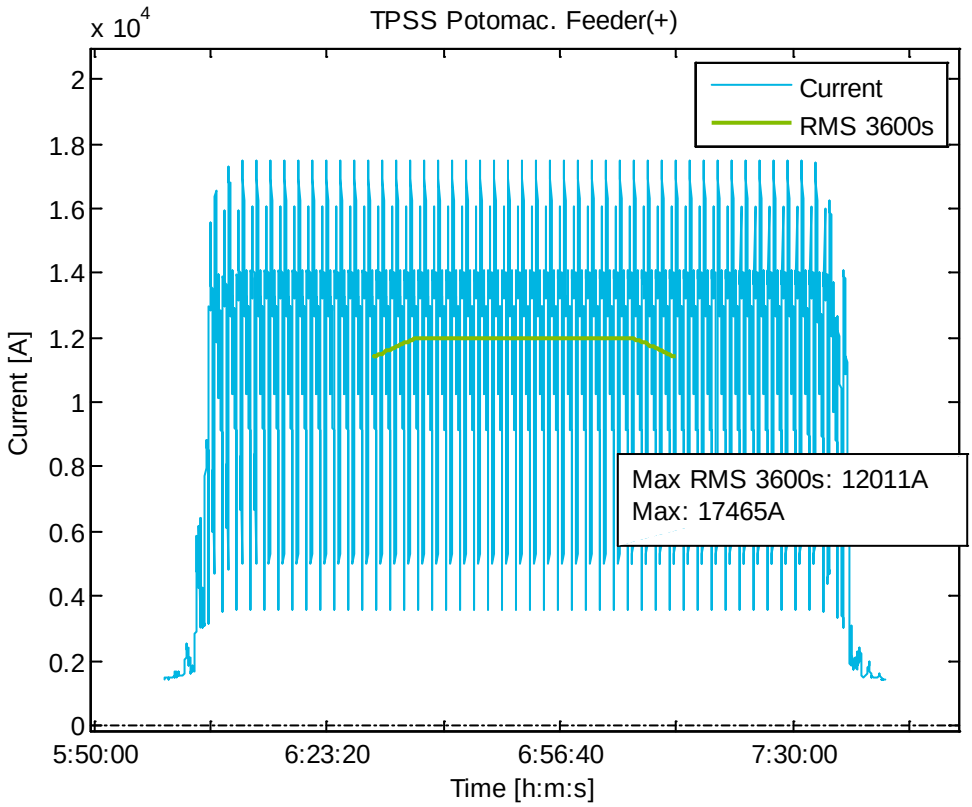


Figure 101. Potomac Yard Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

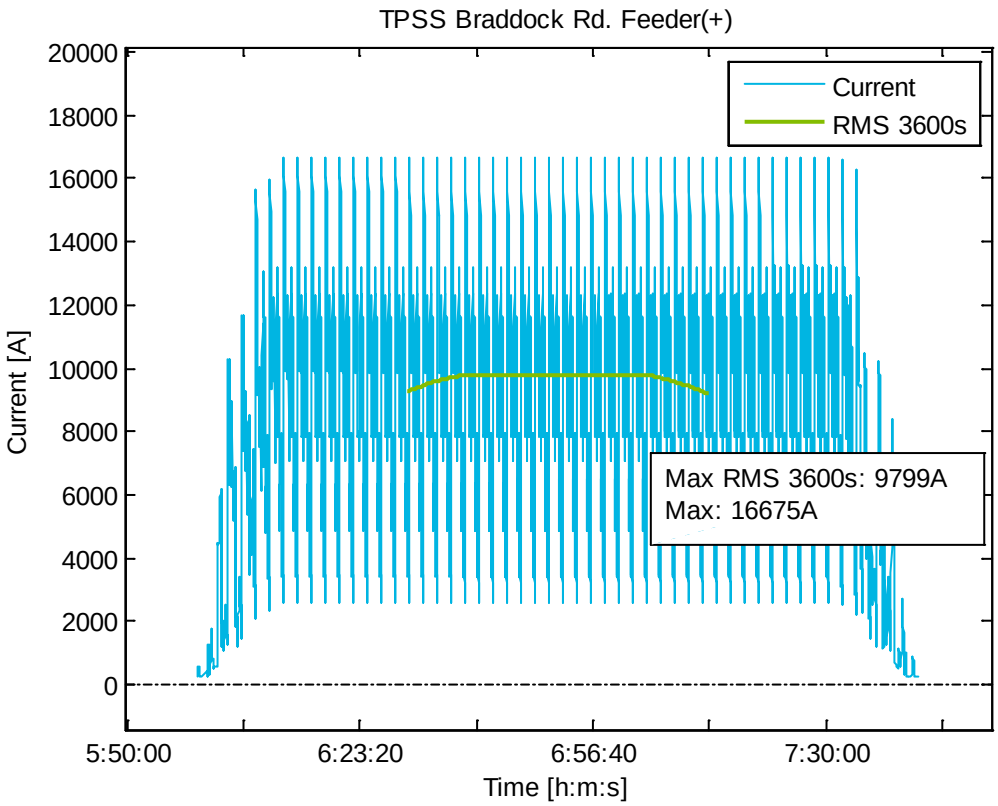


Figure 102. Braddock Road Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

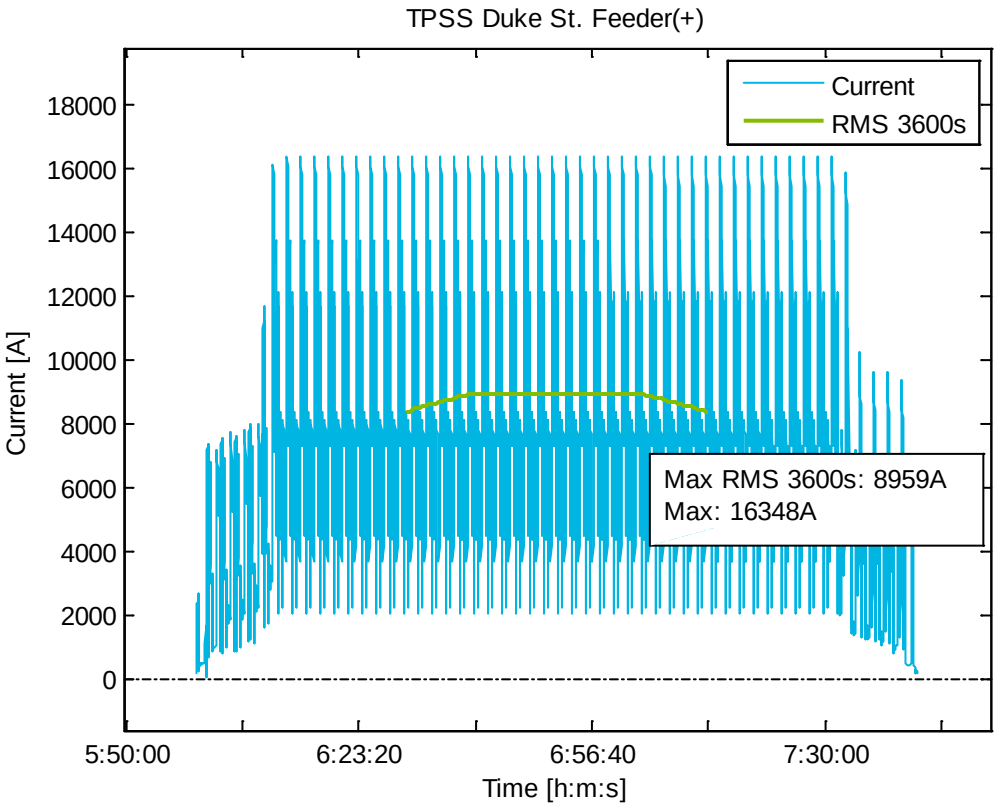


Figure 103. Duke Street Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

TPSS Currents for National Airport Emergency Operation

Both instant current and RMS are represented from **Figure 104** to **Figure 107** for all the TPSS under study for National Airport emergency operation.

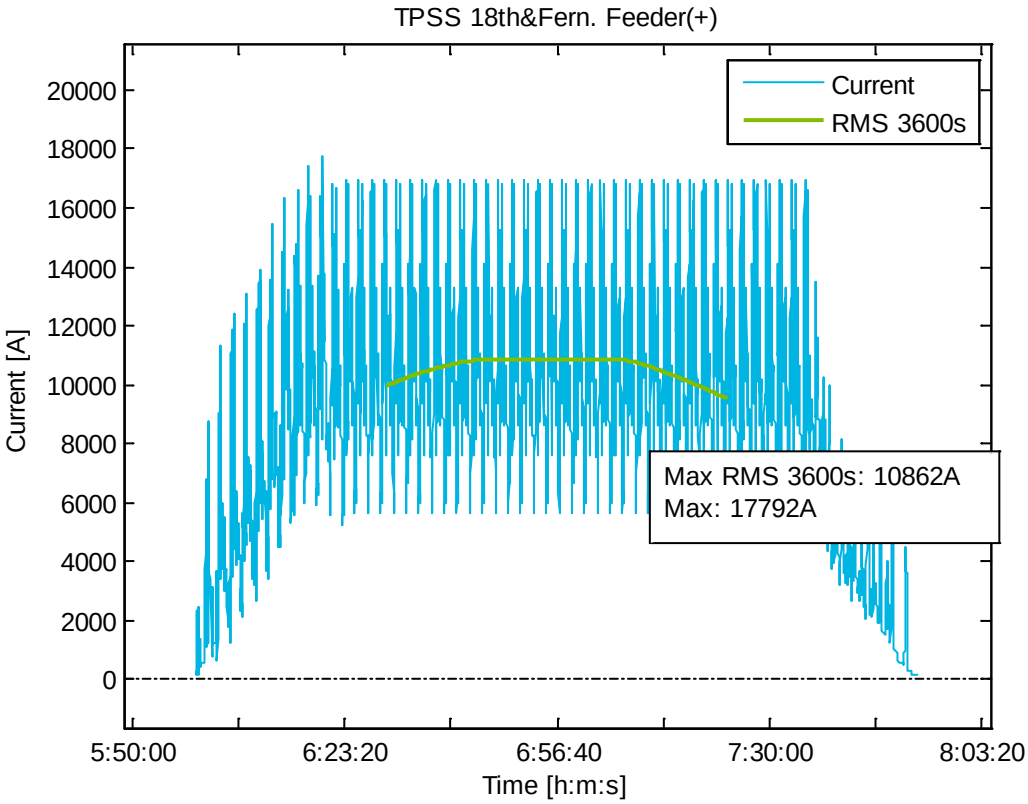


Figure 104. 18th and Fern Substation Instant and RMS currents for National Airport under emergency operation.

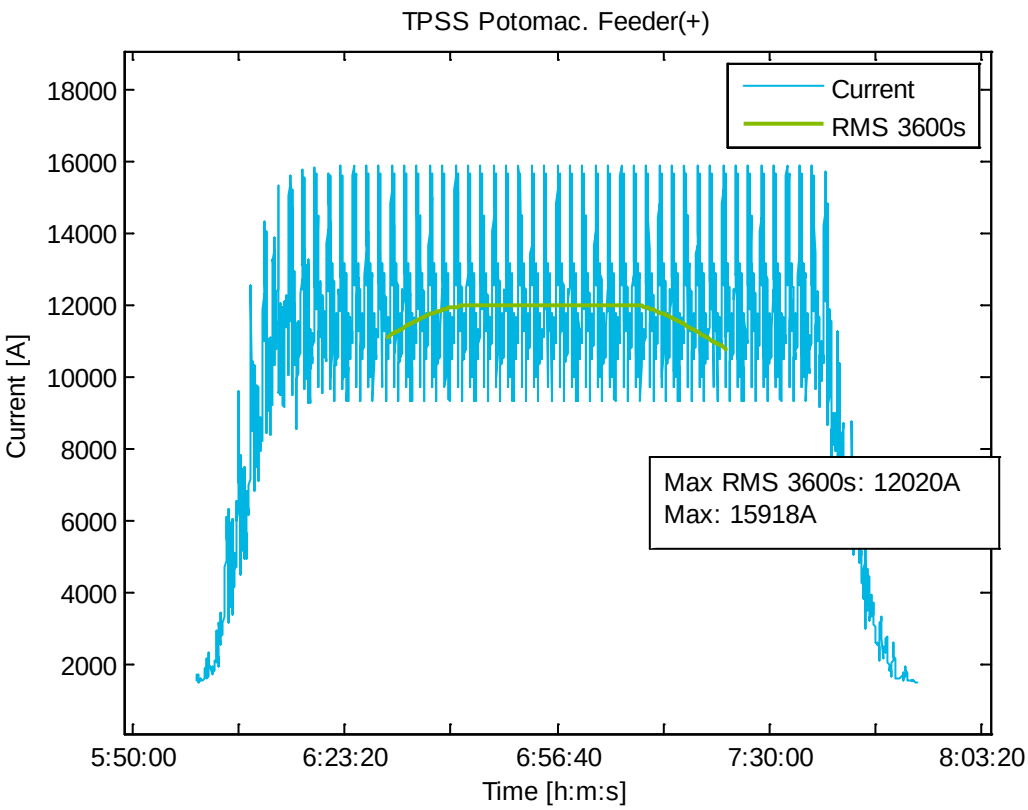


Figure 105. Potomac Yard Substation Instant and RMS currents for National Airport under emergency operation.

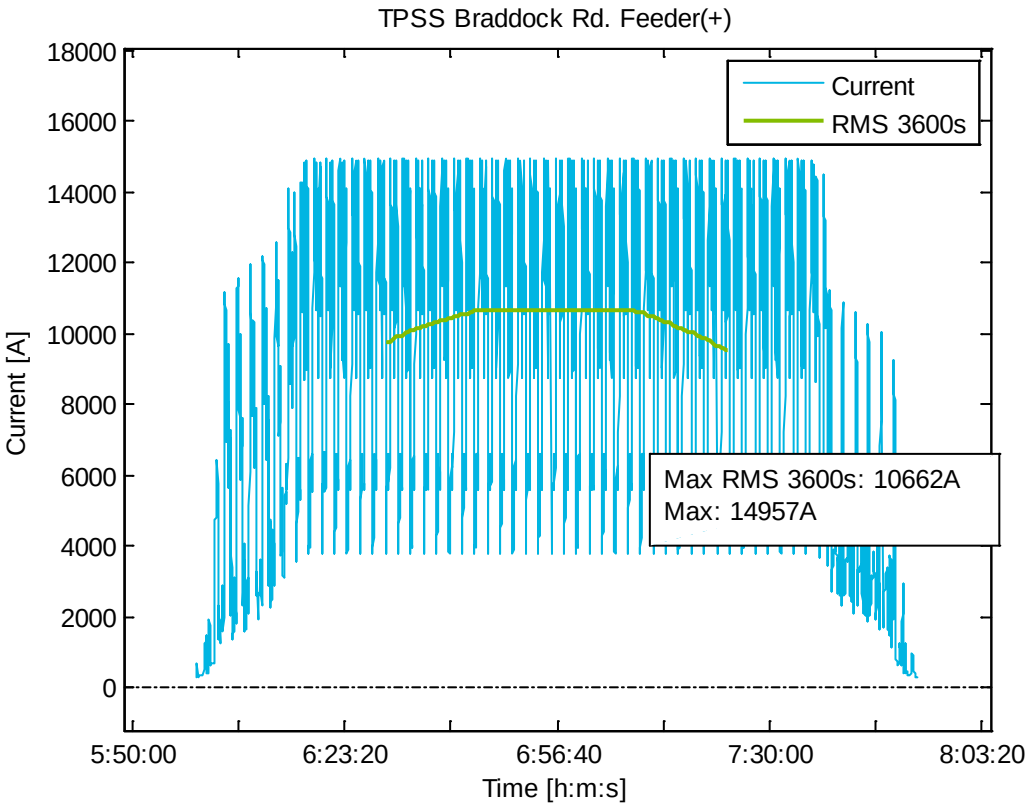


Figure 106. Braddock Road Substation Instant and RMS currents for National Airport under emergency operation.

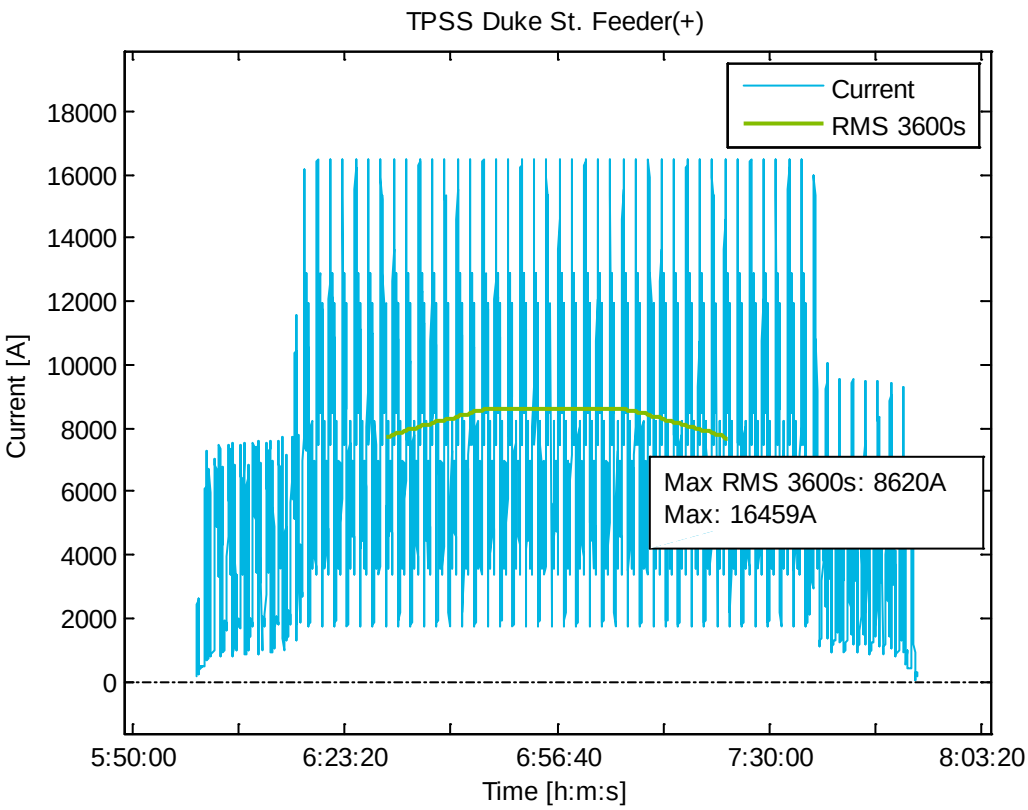


Figure 107. Duke Street Substation Instant and RMS currents for National Airport under emergency operation.

TPSS Currents for Potomac Yard Emergency Operation

Both instant current and RMS are represented from **Figure 108** to **Figure 111** for all the TPSS under study for Potomac Yard emergency operation.

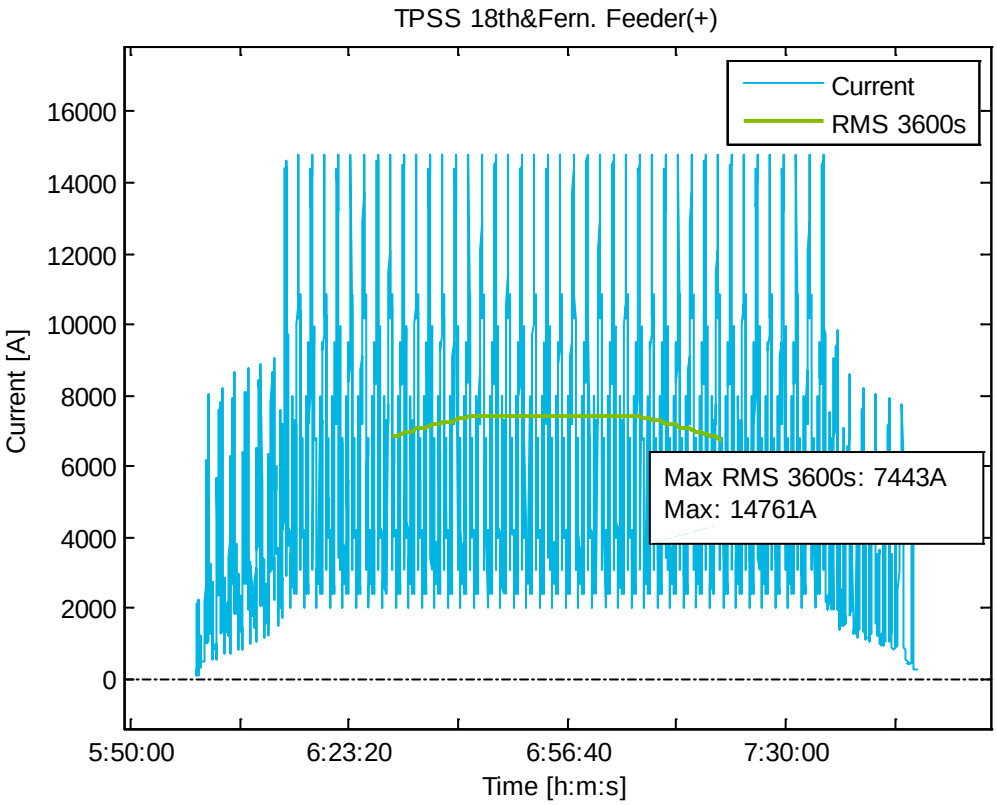


Figure 108. 18th and Fern Substation Instant and RMS currents for Potomac Yard under emergency operation.

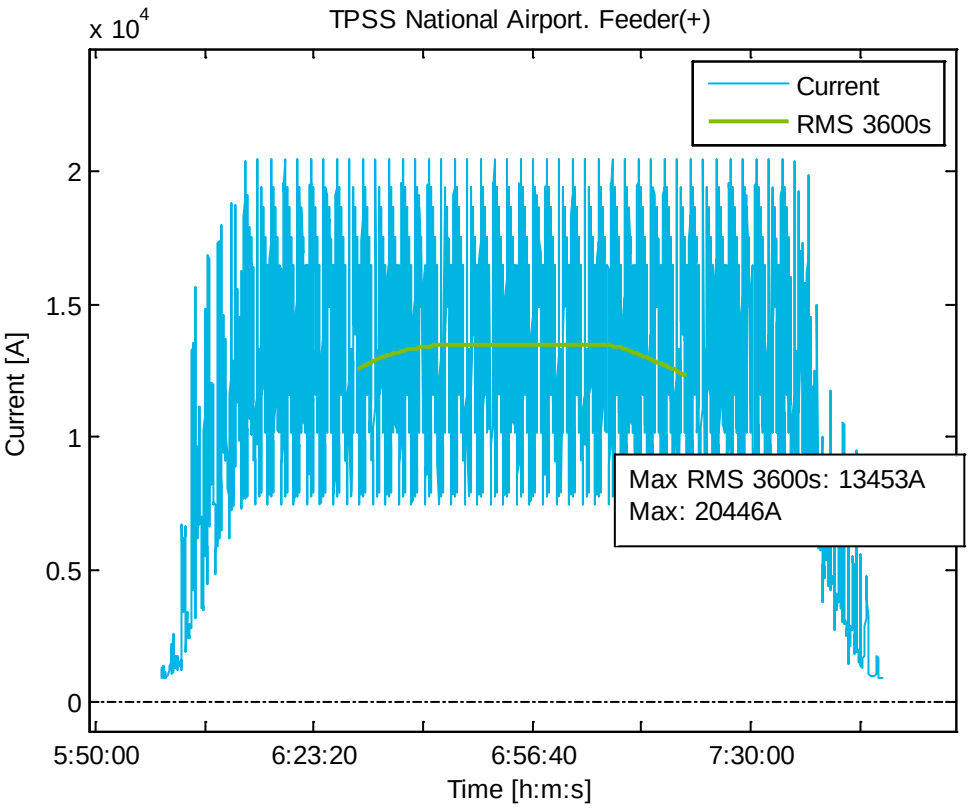


Figure 109. National Airport Substation Instant and RMS currents for Potomac Yard under emergency operation.

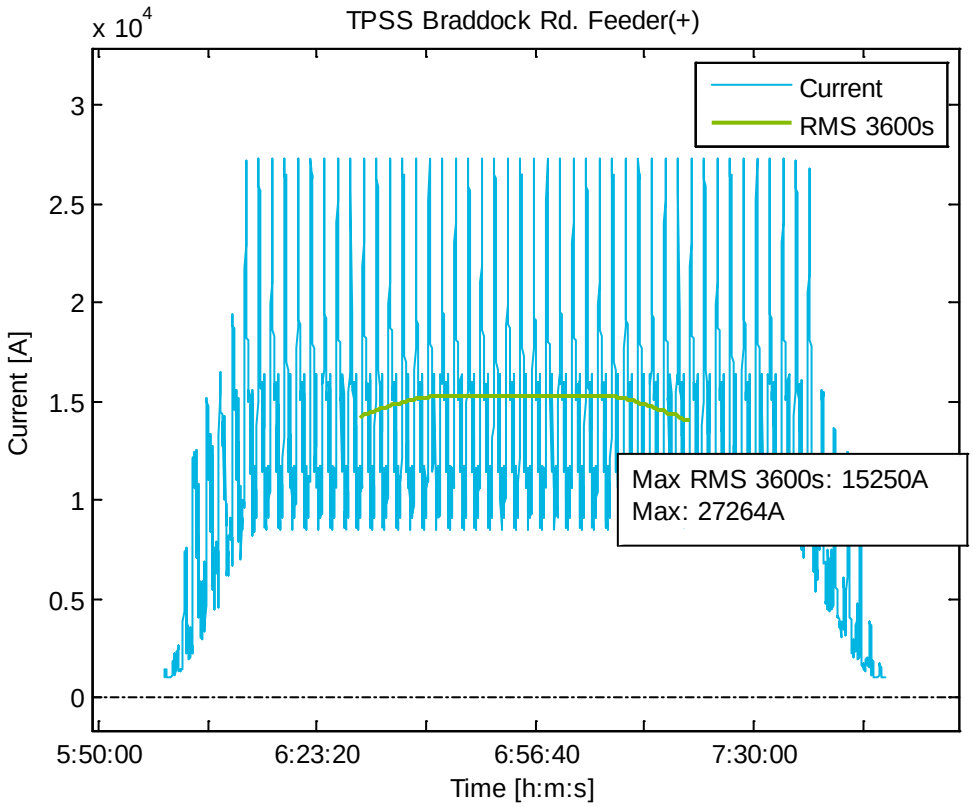


Figure 110. Braddock Road Substation Instant and RMS currents for Potomac Yard under emergency operation.

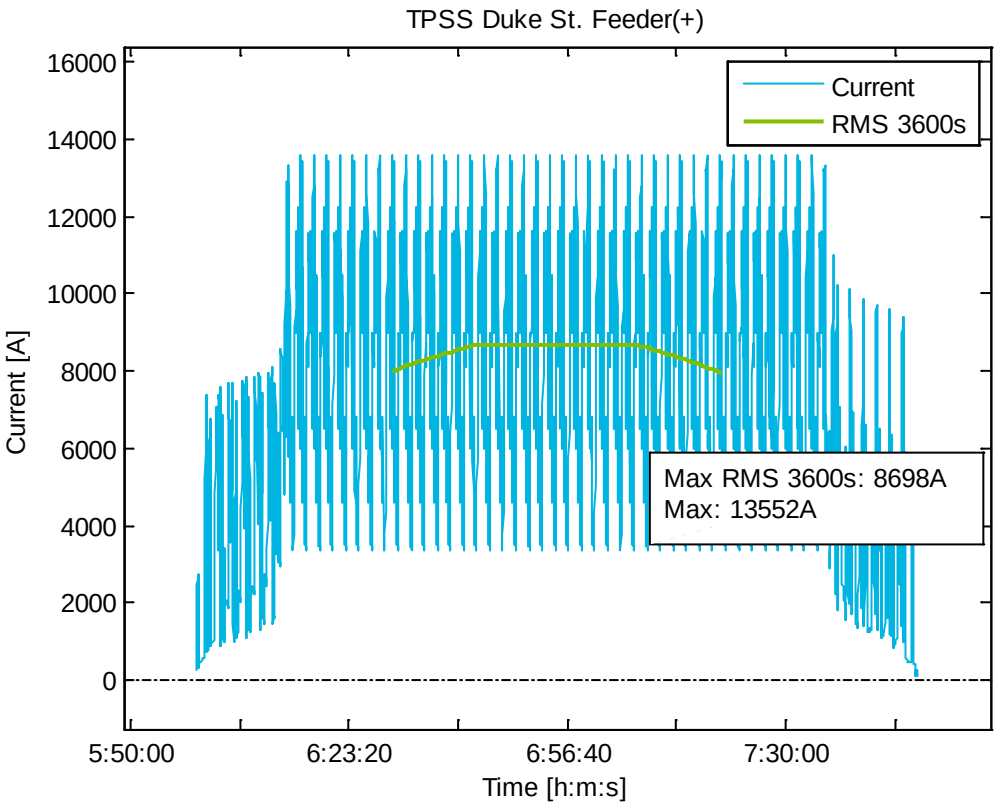


Figure 111. Duke Street Substation Instant and RMS currents for Potomac Yard under emergency operation.

TPSS Currents for Braddock Road Emergency Operation

Both instant current and RMS are represented from **Figure 112** to **Figure 115** for all the TPSS under study for Braddock Road emergency operation.

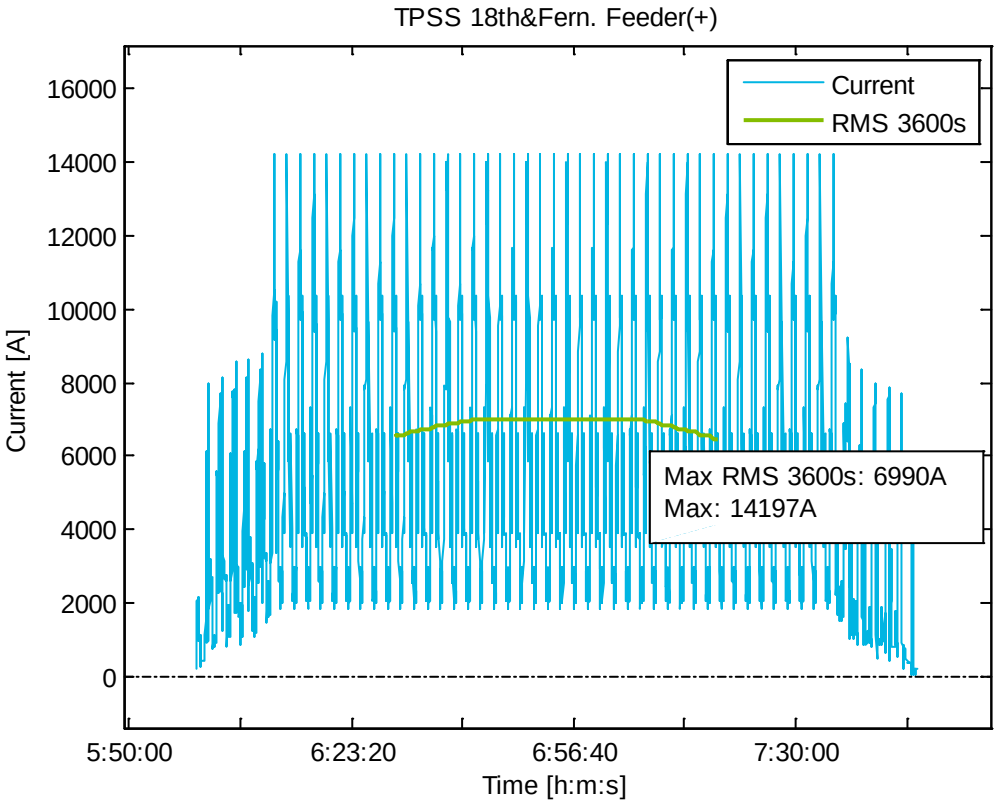


Figure 112. 18th and Fern Substation Instant and RMS currents for Braddock Road under emergency operation.

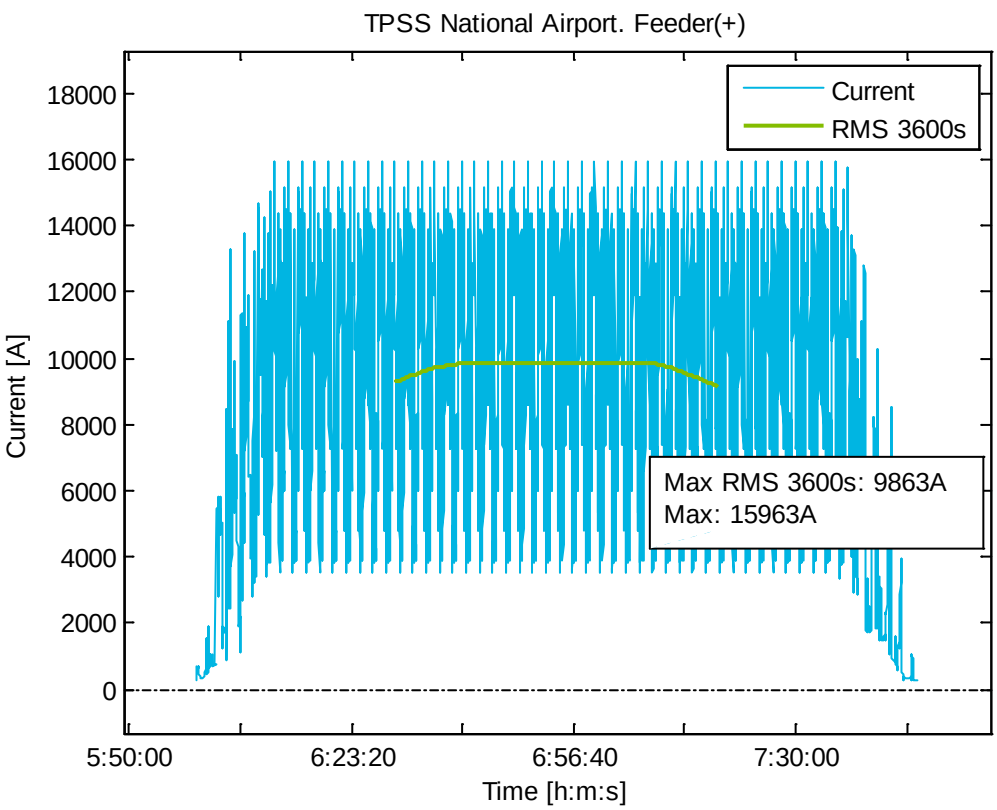


Figure 113. National Airport Substation Instant and RMS currents for Braddock Road under emergency operation.

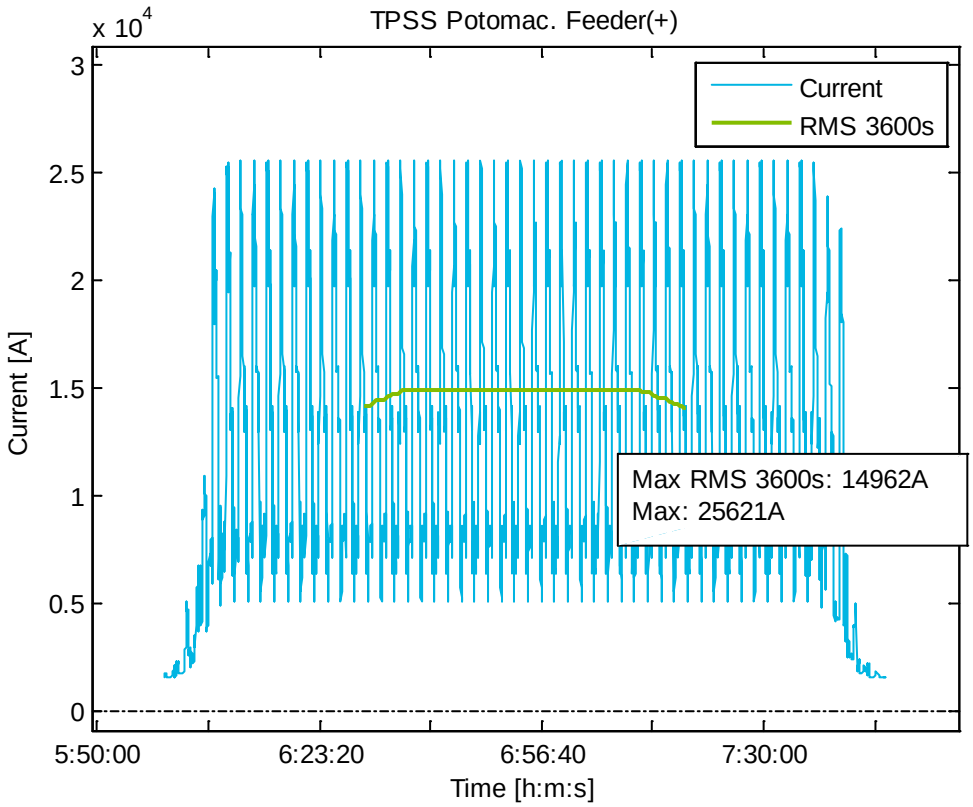


Figure 114. Potomac Yard Substation Instant and RMS currents for Braddock Road under emergency operation.

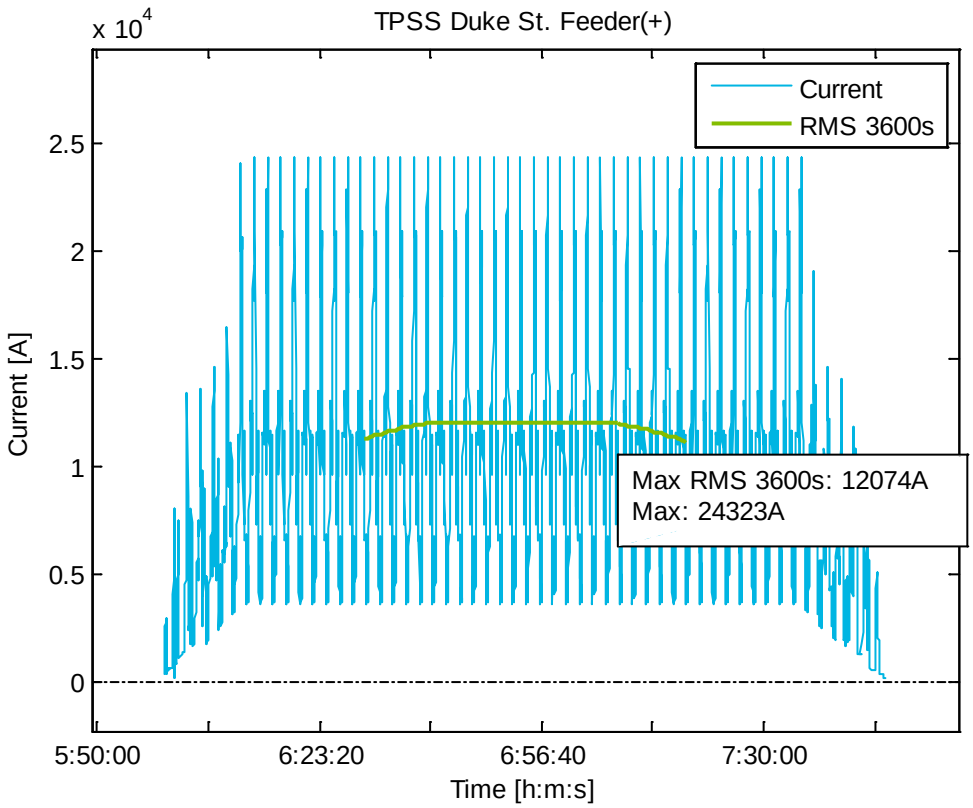


Figure 115. Duke Street Substation Instant and RMS currents for Braddock Road under emergency operation.

Upgraded System

TPSS Currents for Normal Operation

Both instant current and RMS are represented from **Figure 116** to **Figure 120** for all the TPSS under study for normal operation for the upgraded system.

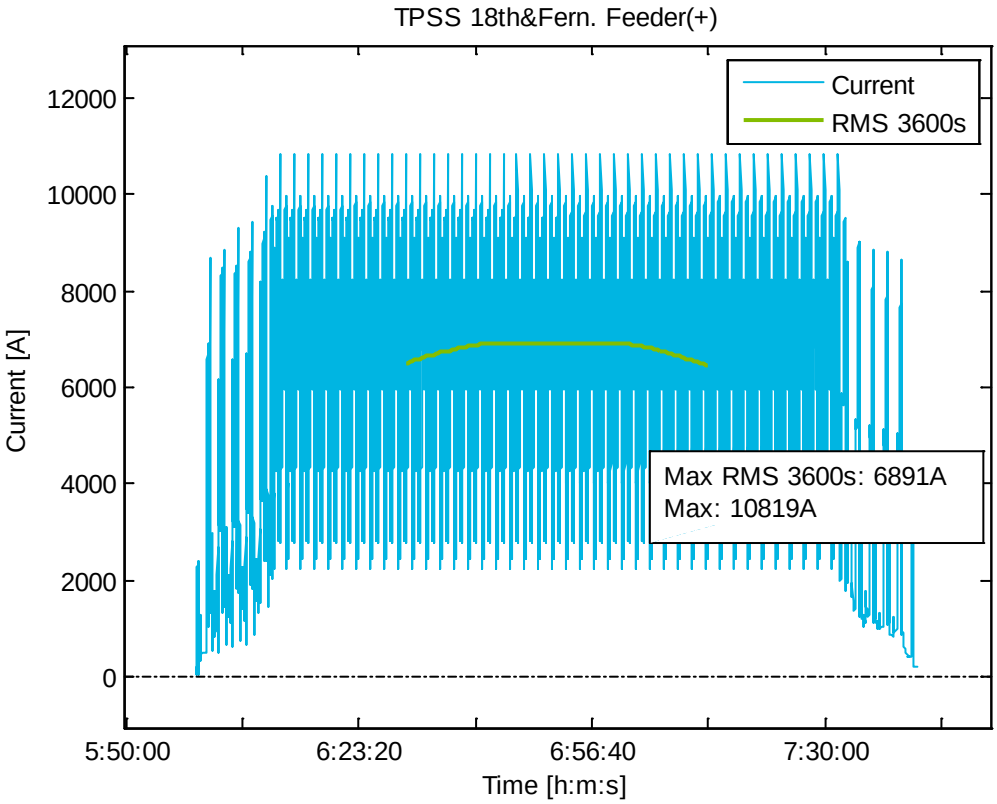


Figure 116. Upgraded system. Instant and RMS currents for 18th and Fern Substation under normal operation.

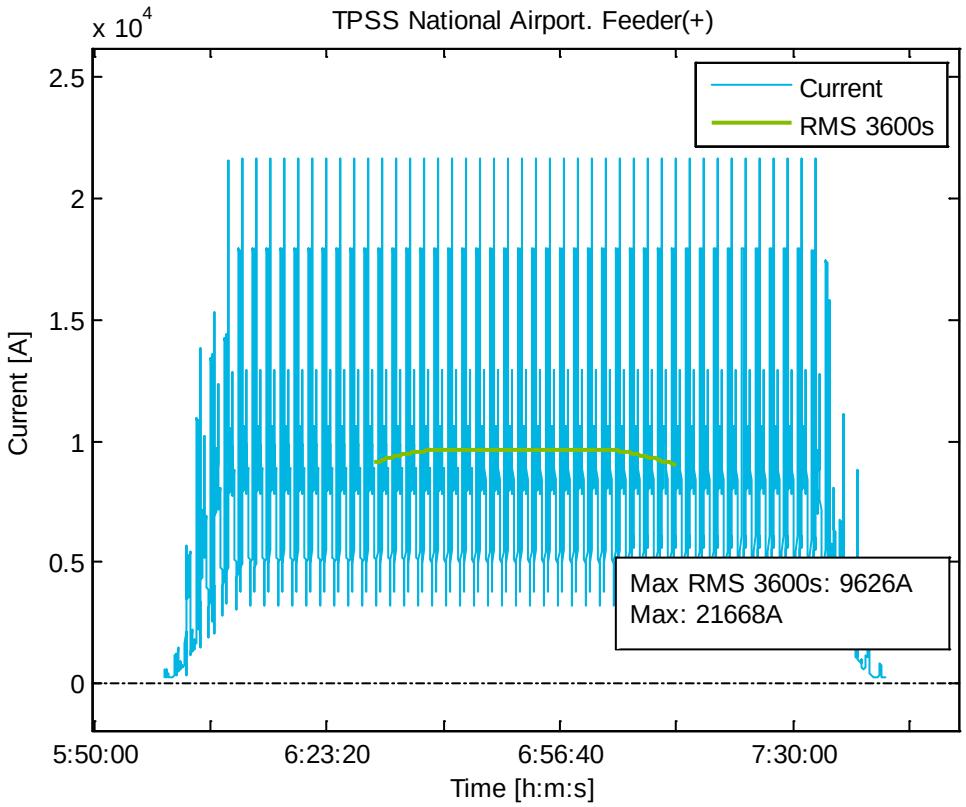


Figure 117. Upgraded system. Instant and RMS currents for National Airport Substation under normal operation.

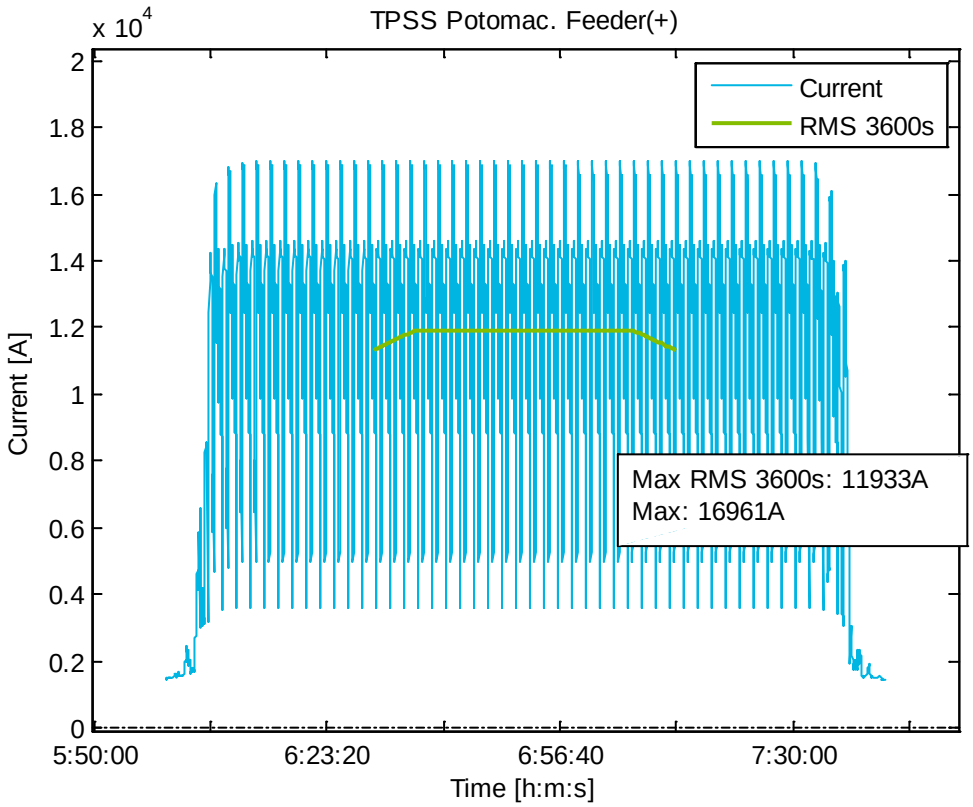


Figure 118. Upgraded system. Instant and RMS currents for Potomac Yard Substation under normal operation.

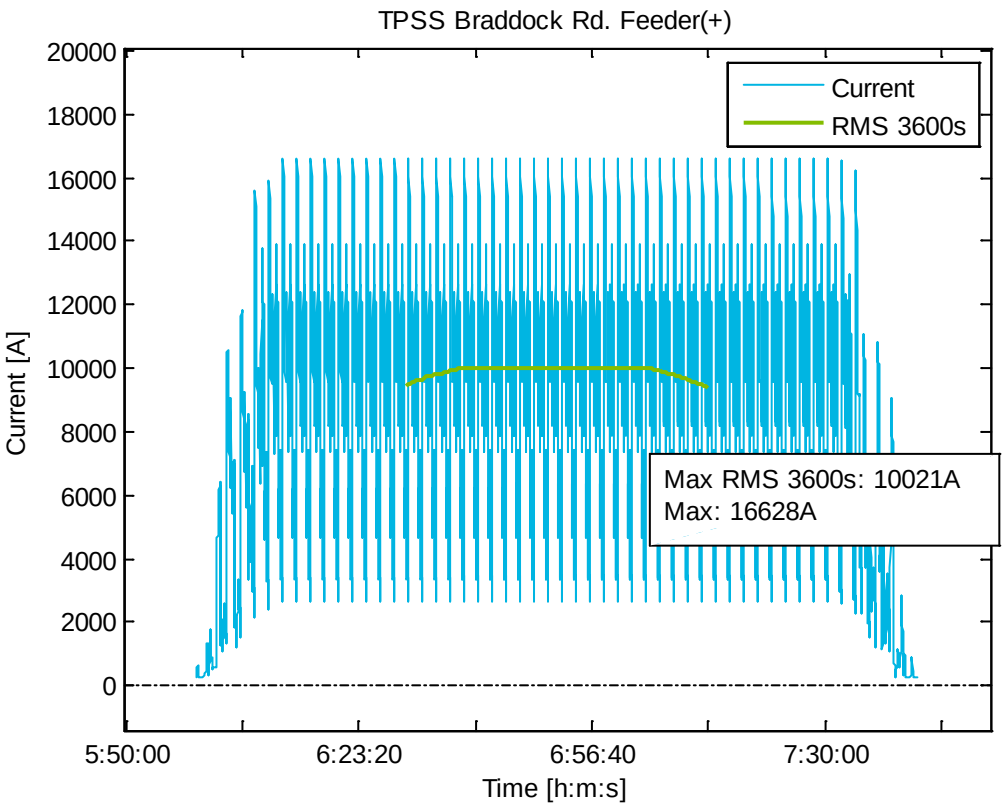


Figure 119. Upgraded system. Instant and RMS currents for Braddock Road Substation under normal operation.

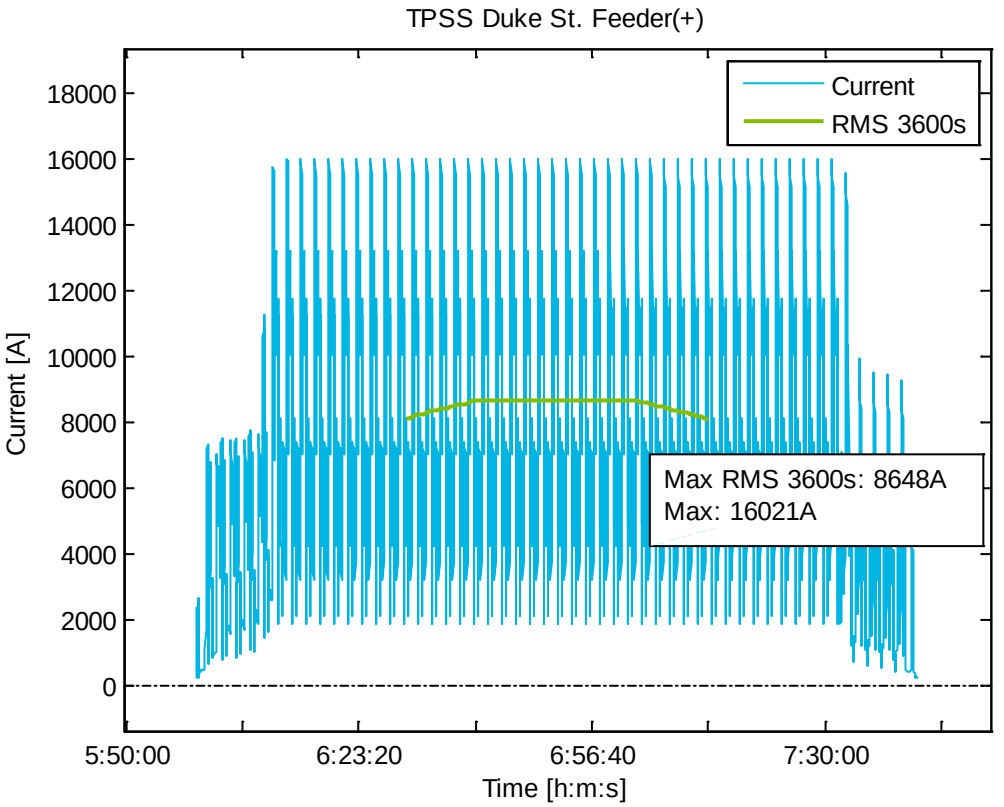


Figure 120. Upgraded system. Instant and RMS currents for Duke Street Substation under normal operation.

TPSS Currents for National Airport Substation Abnormal Operation

Both instant current and RMS are represented from **Figure 121** to **Figure 125** for all the TPSS under study for National Airport Substation abnormal operation for the upgraded system.

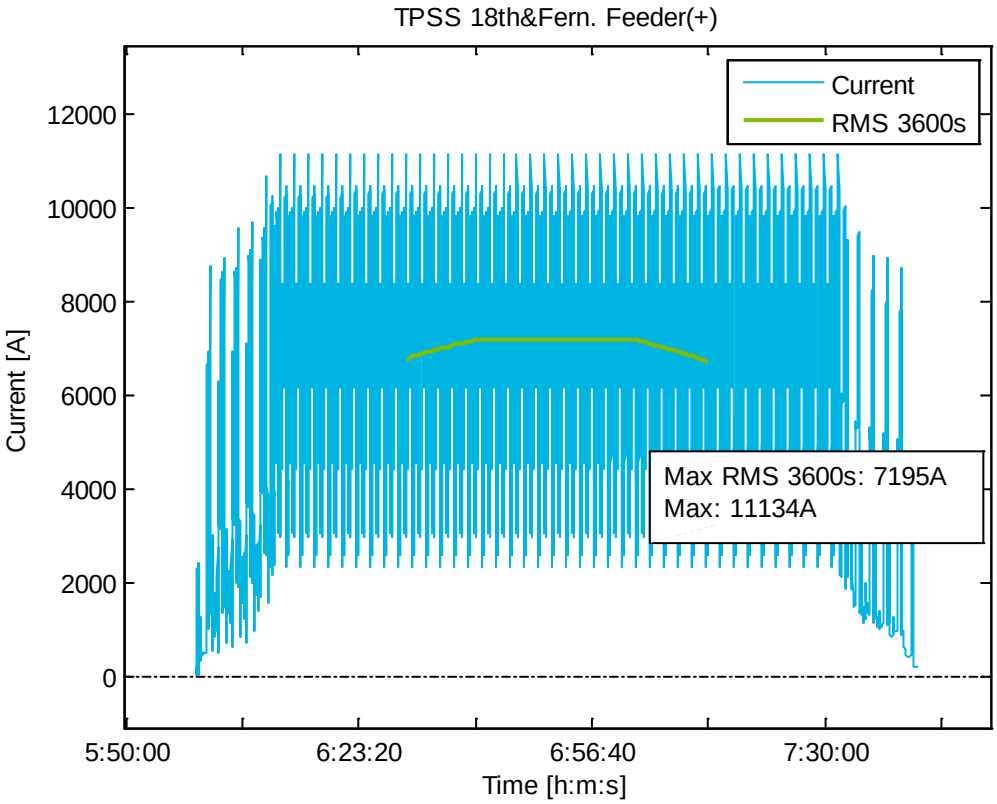


Figure 121. Upgraded system. 18th and Fern Substation Instant and RMS currents for National Airport Substation under abnormal operation.

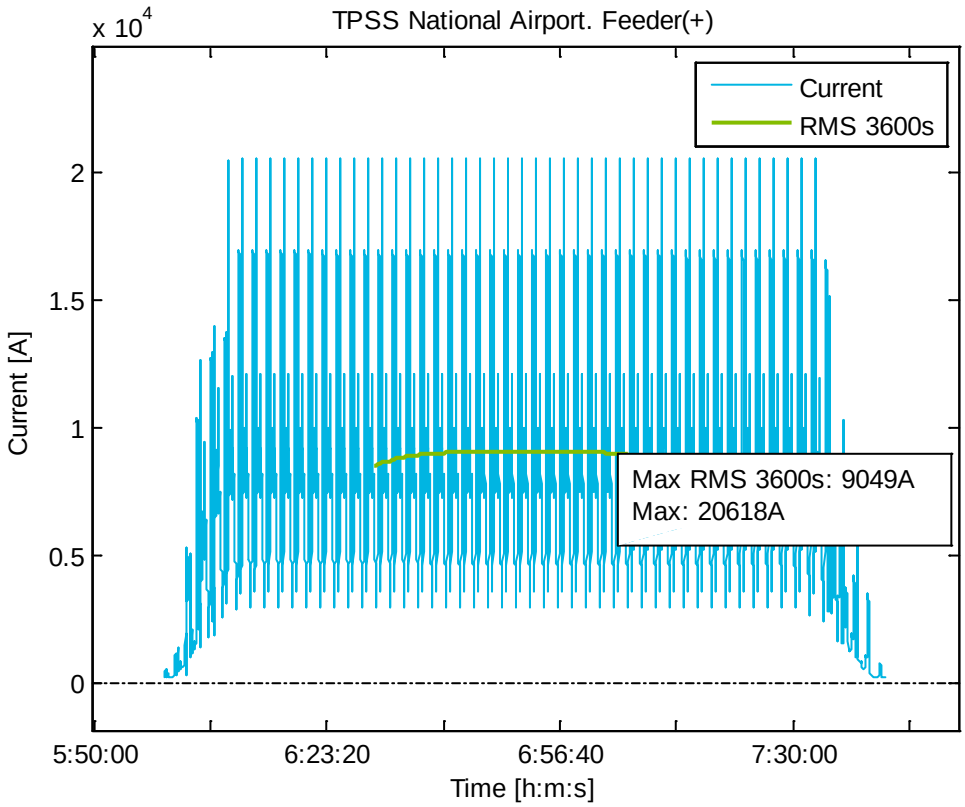


Figure 122. Upgraded system. National Airport Substation Instant and RMS currents for National Airport Substation under abnormal operation.

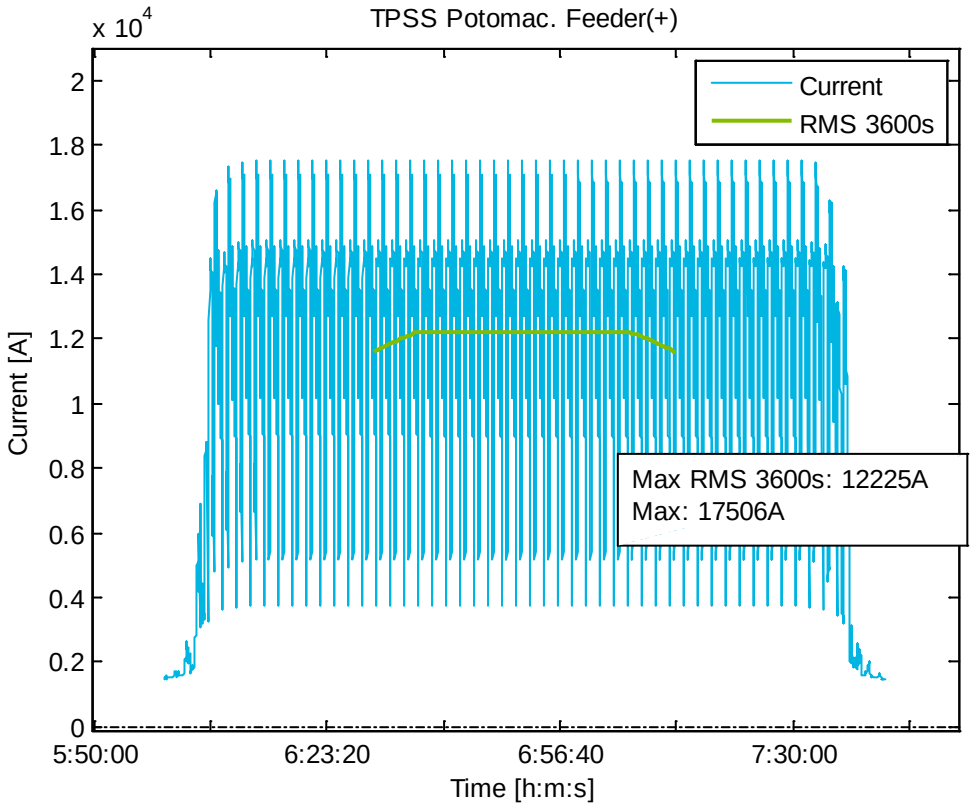


Figure 123. Upgraded system. Potomac Yard Substation Instant and RMS currents for National Airport Substation under abnormal operation.

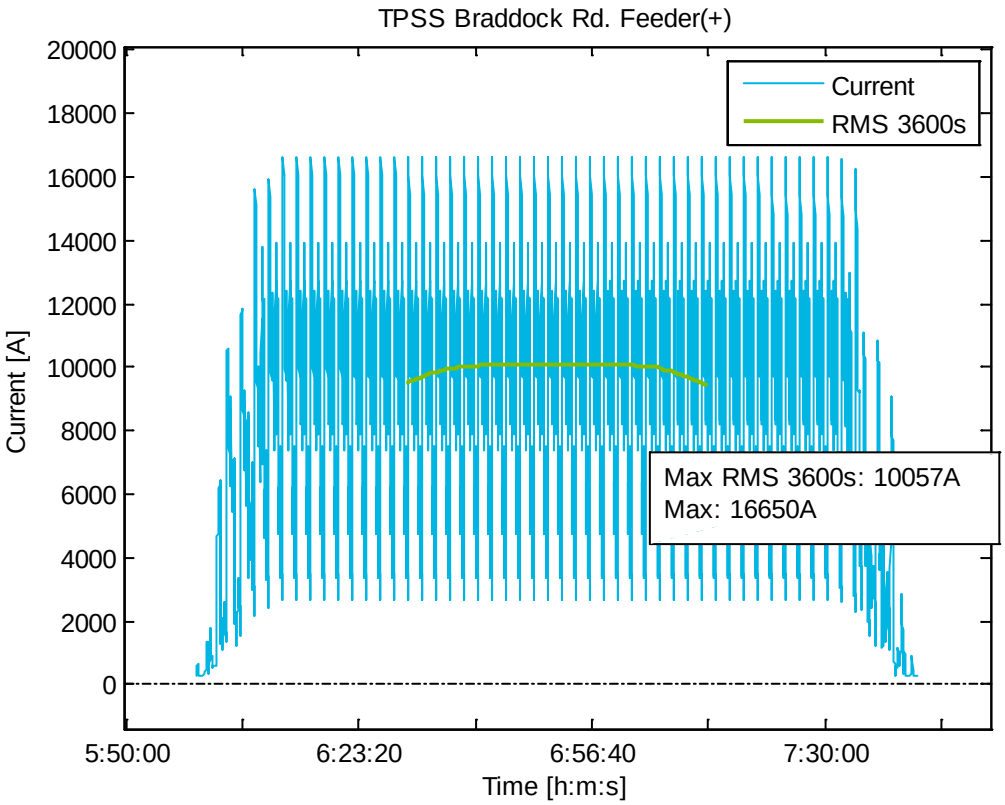


Figure 124. Upgraded system. Braddock Road Substation Instant and RMS currents for National Airport Substation under abnormal operation.

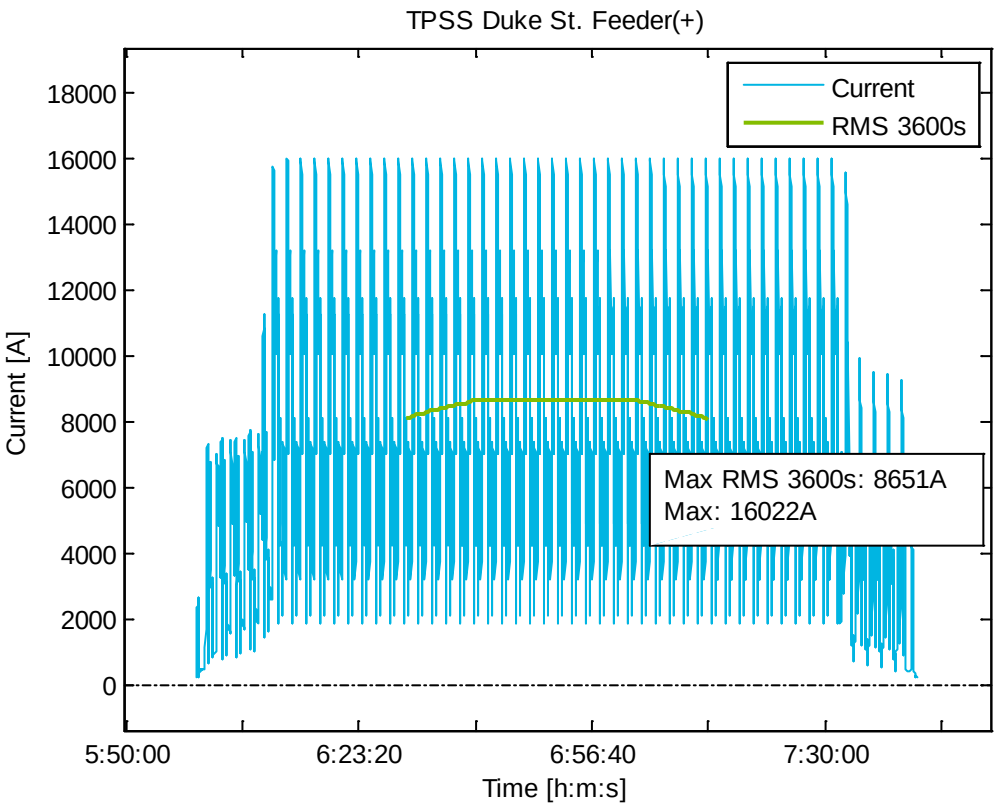


Figure 125. Upgraded system. Duke Street Substation Instant and RMS currents for National Airport Substation under abnormal operation.

TPSS Currents for Potomac Yard Substation Abnormal Operation

Both instant current and RMS are represented from **Figure 126** to **Figure 130** for all the TPSS under study for Potomac Yard Substation abnormal operation for the upgraded system

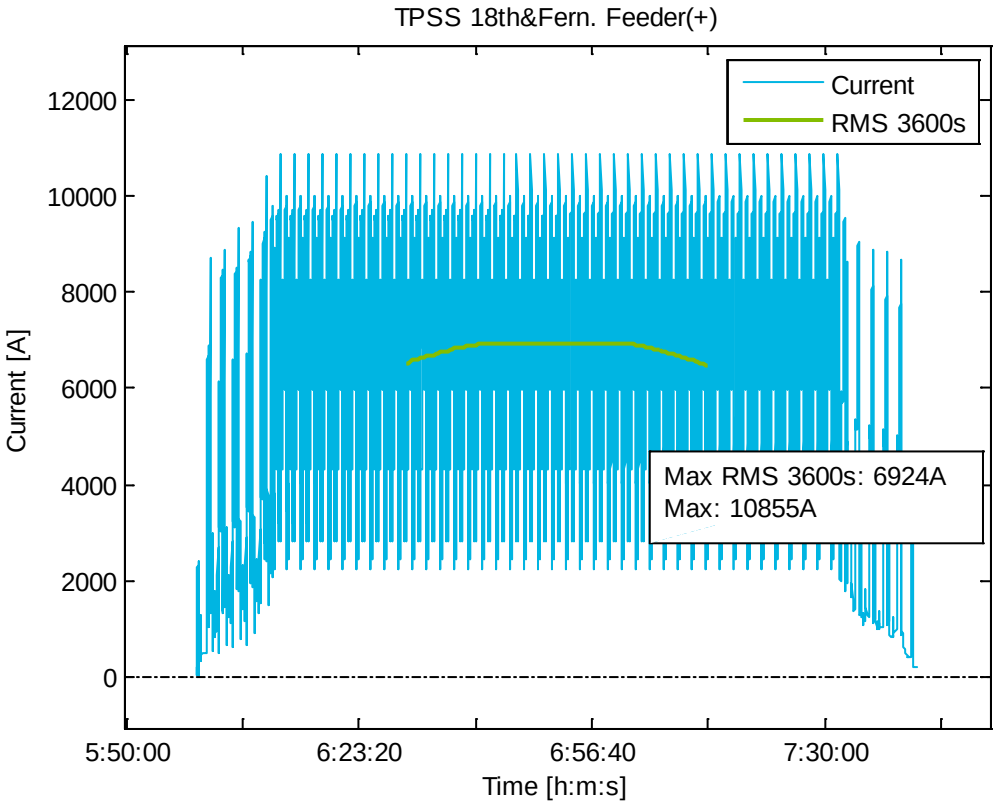


Figure 126. Upgraded system. 18th and Fern Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

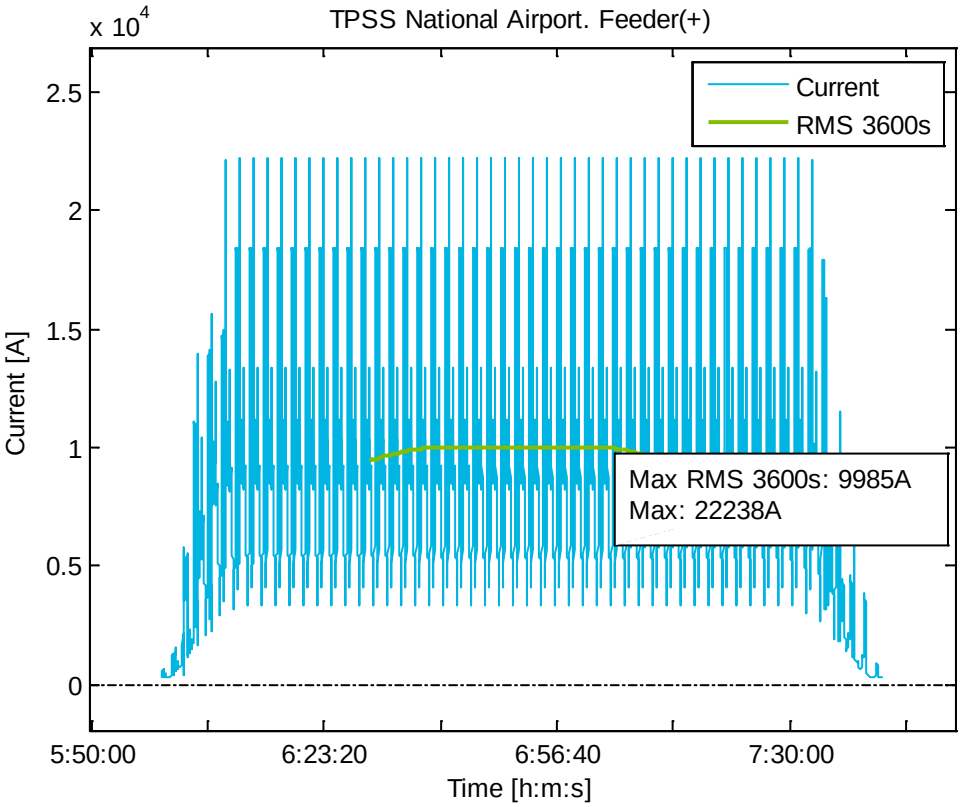


Figure 127. Upgraded system. National Airport Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

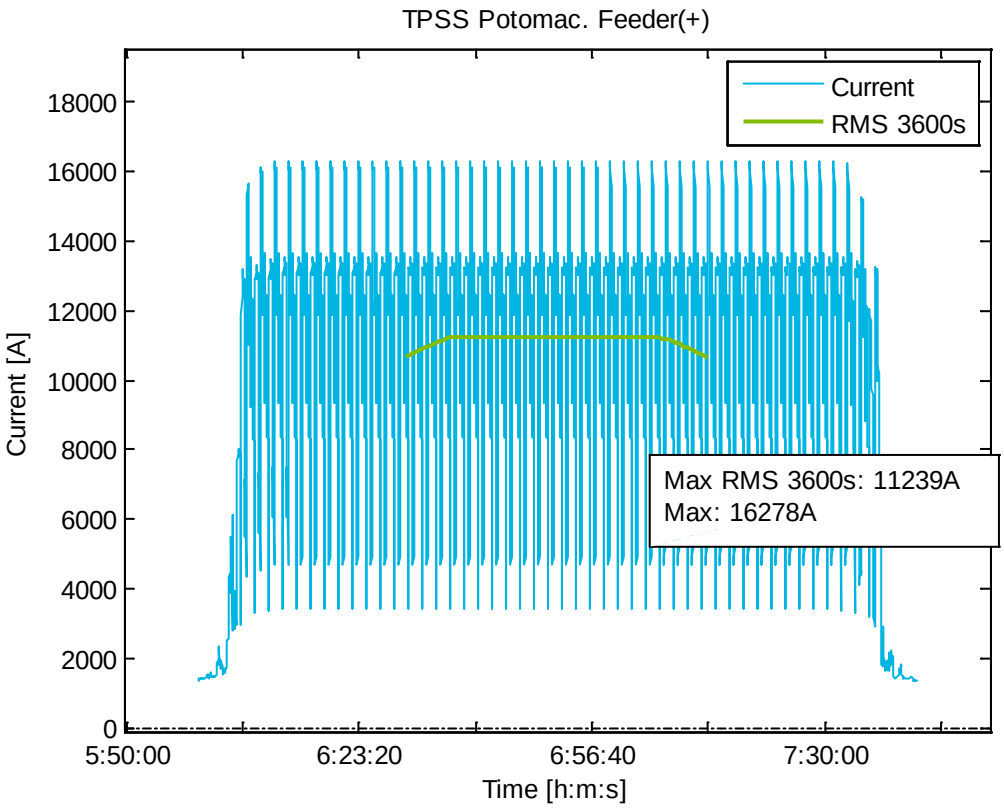


Figure 128. Upgraded system. Potomac Yard Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

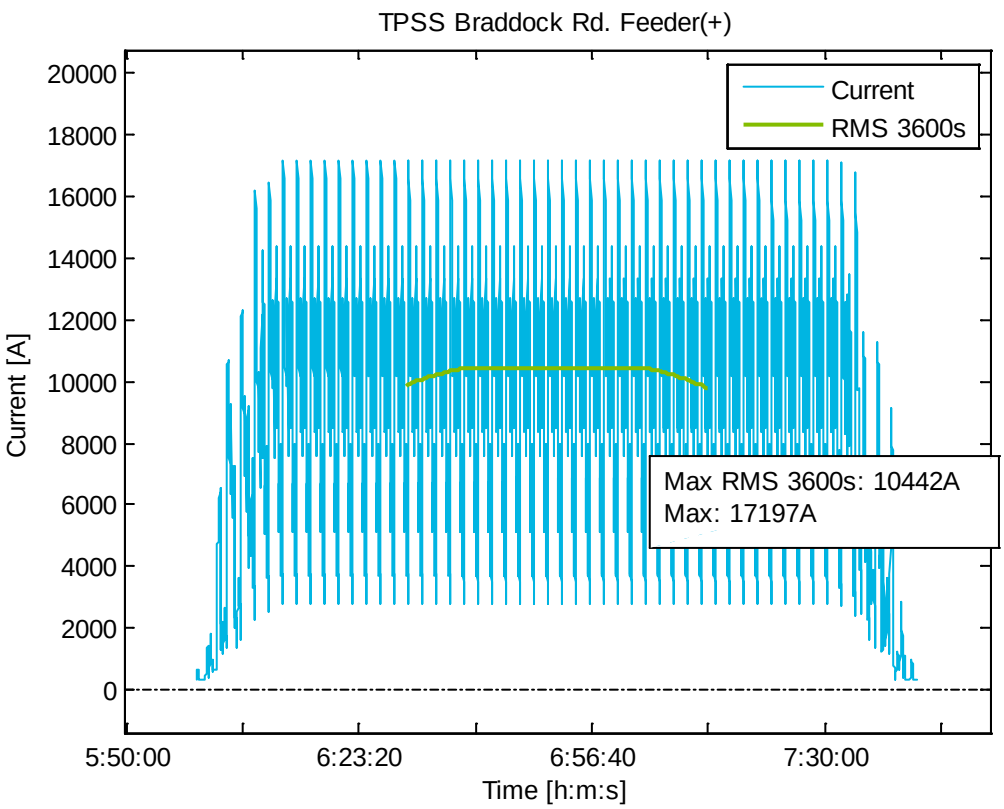


Figure 129. Upgraded system. Braddock Road Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

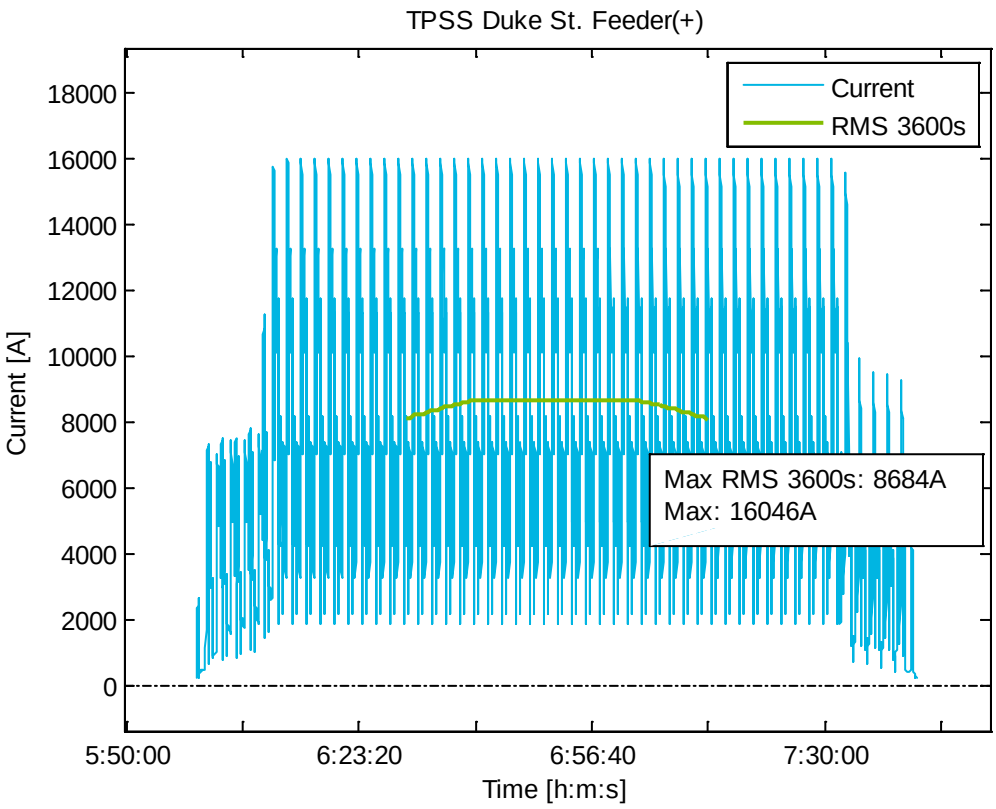


Figure 130. Upgraded system. Duke Street Substation Instant and RMS currents for Potomac Yard Substation under abnormal operation.

TPSS Currents for Braddock Road Substation Abnormal Operation

Both instant current and RMS are represented from **Figure 131** to **Figure 135** for all the TPSS under study for Braddock Road Substation abnormal operation for the upgraded system.

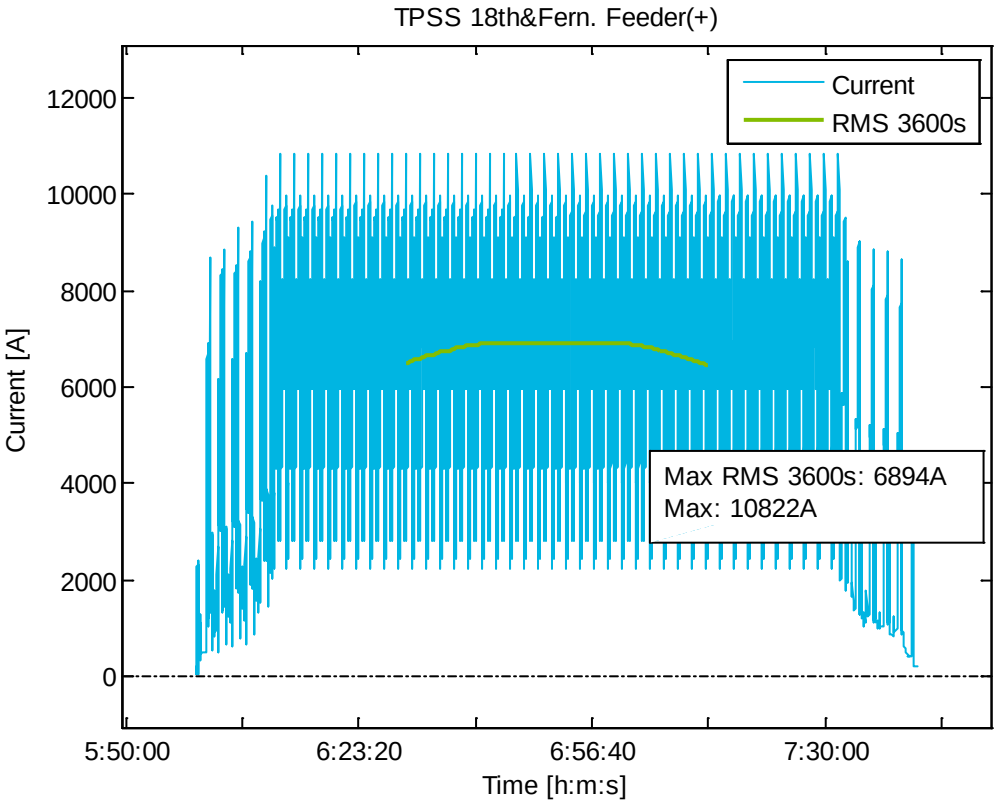


Figure 131. Upgraded system. 18th and Fern Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

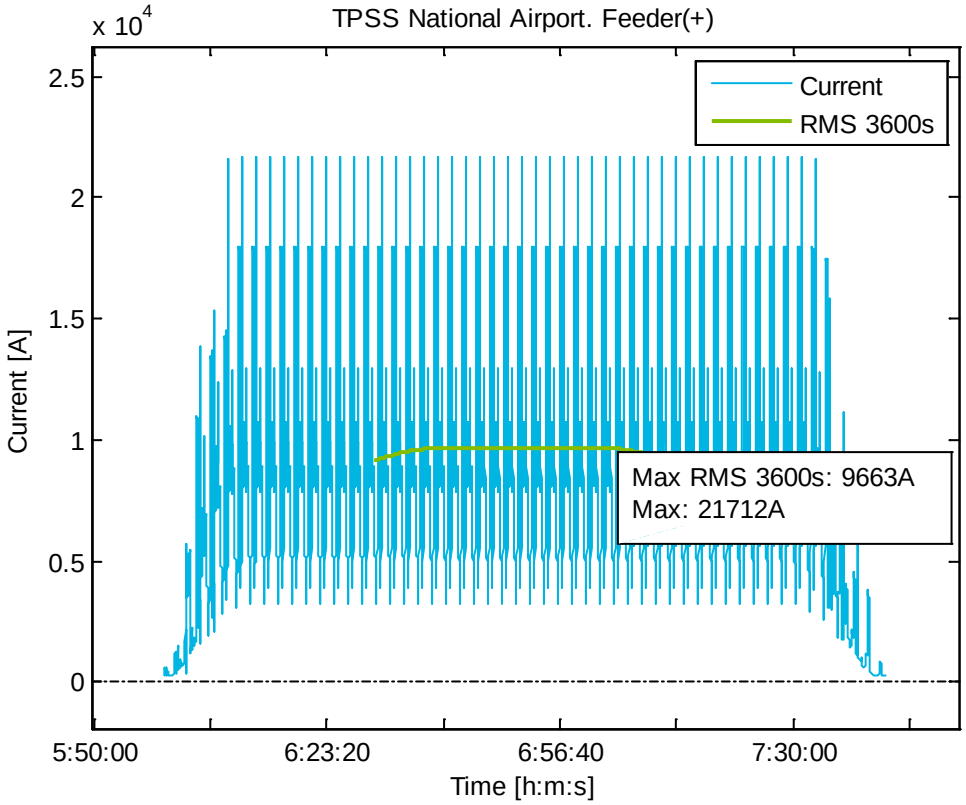


Figure 132. Upgraded system. National Airport Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

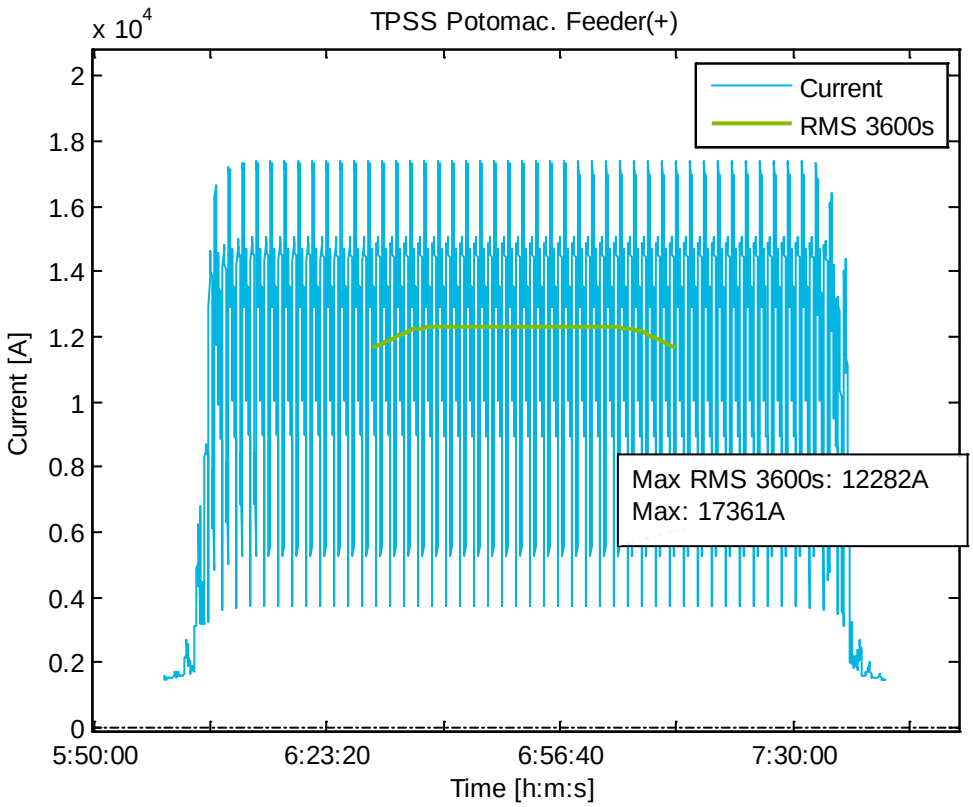


Figure 133. Upgraded system. Potomac Yard Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

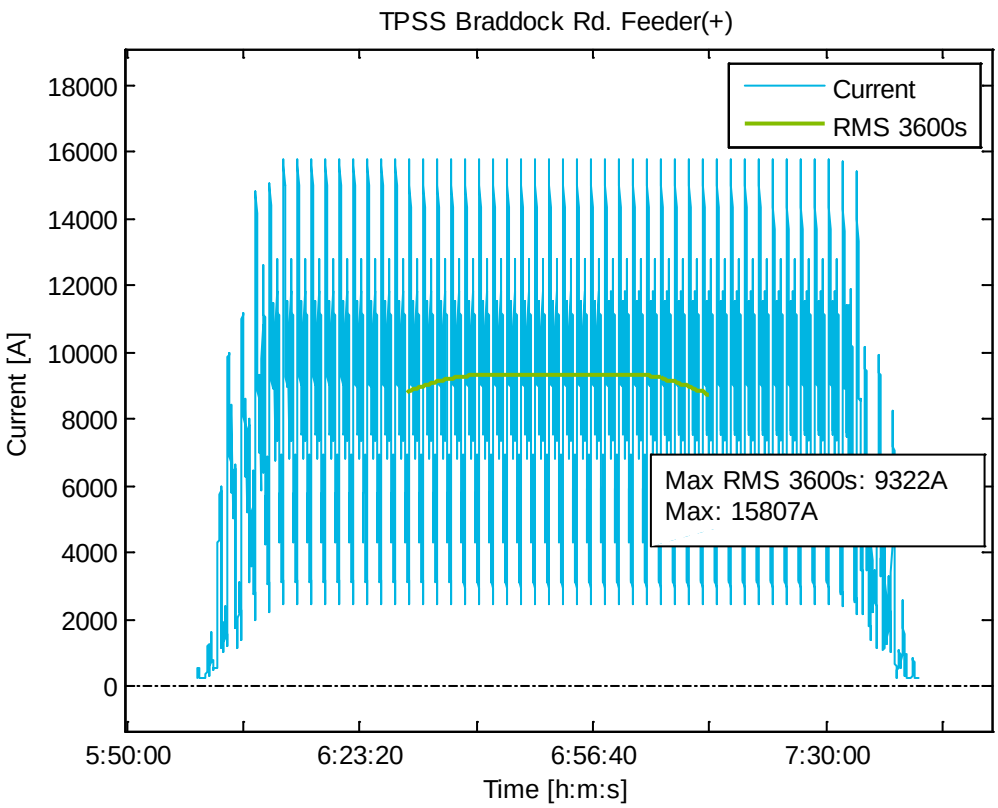


Figure 134. Upgraded system. Braddock Road Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

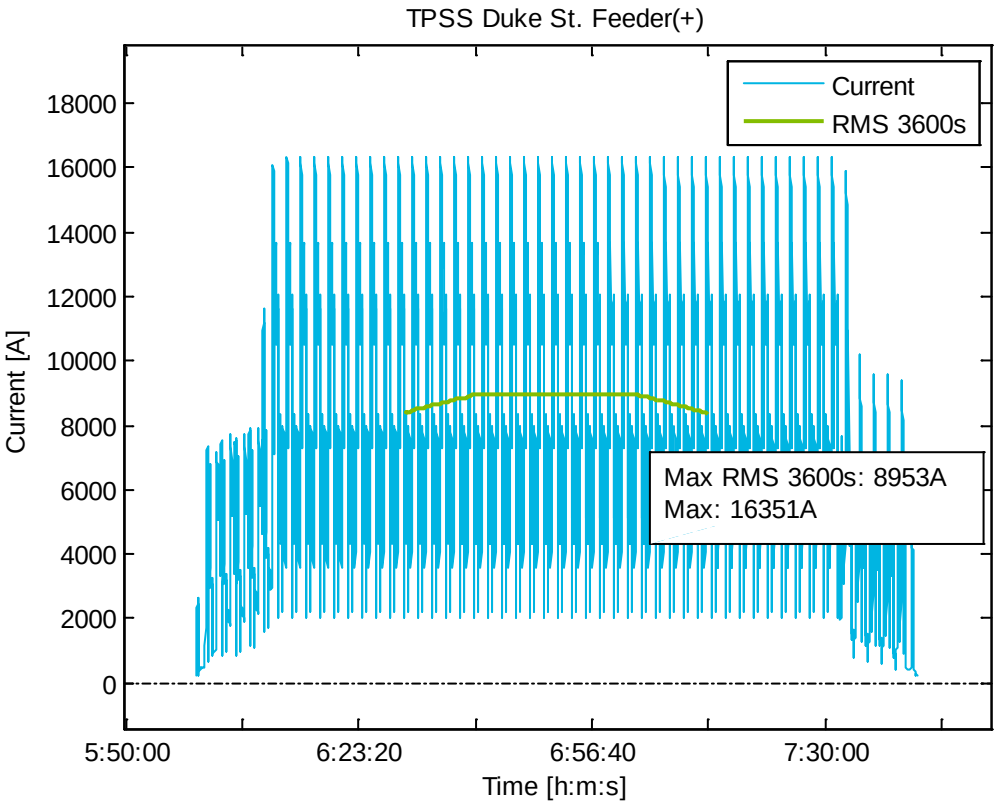


Figure 135. Upgraded system. Duke Street Substation Instant and RMS currents for Braddock Road Substation under abnormal operation.

TPSS Currents for National Airport Emergency Operation

Both instant current and RMS are represented from **Figure 136** to **Figure 139** for all the TPSS under study for National Airport emergency operation for the upgraded system.

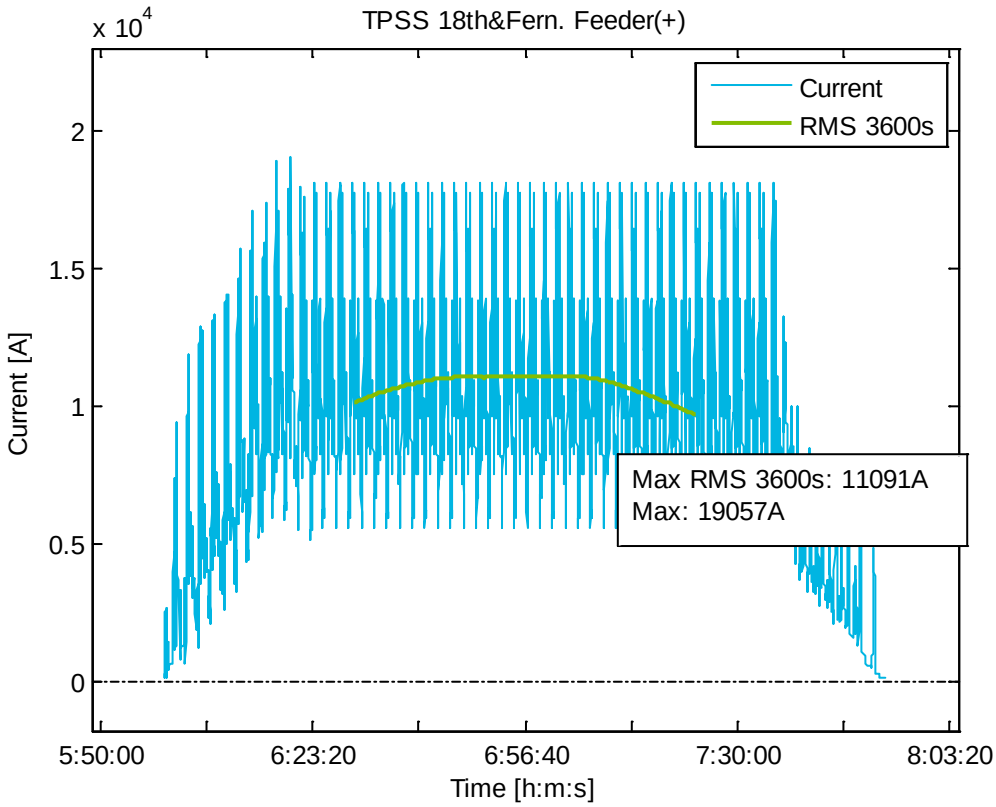


Figure 136. Upgraded system. 18th and Fern Substation Instant and RMS currents for National Airport under emergency operation.

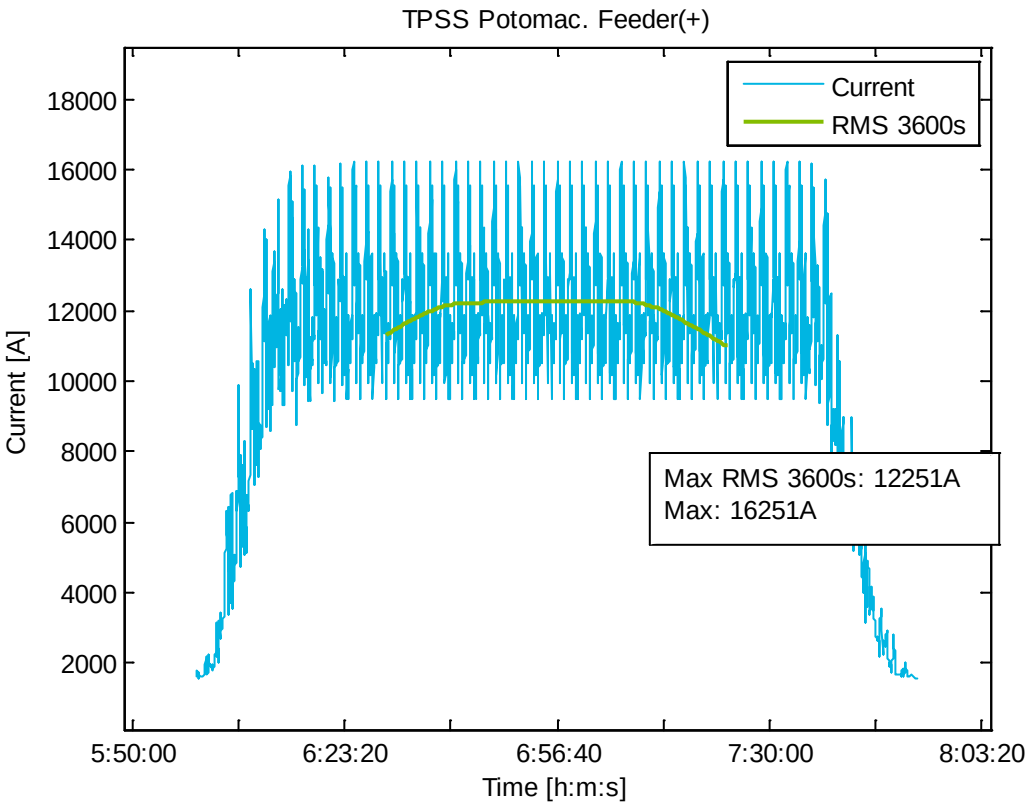


Figure 137. Upgraded system. Potomac Yard Substation Instant and RMS currents for National Airport under emergency operation.

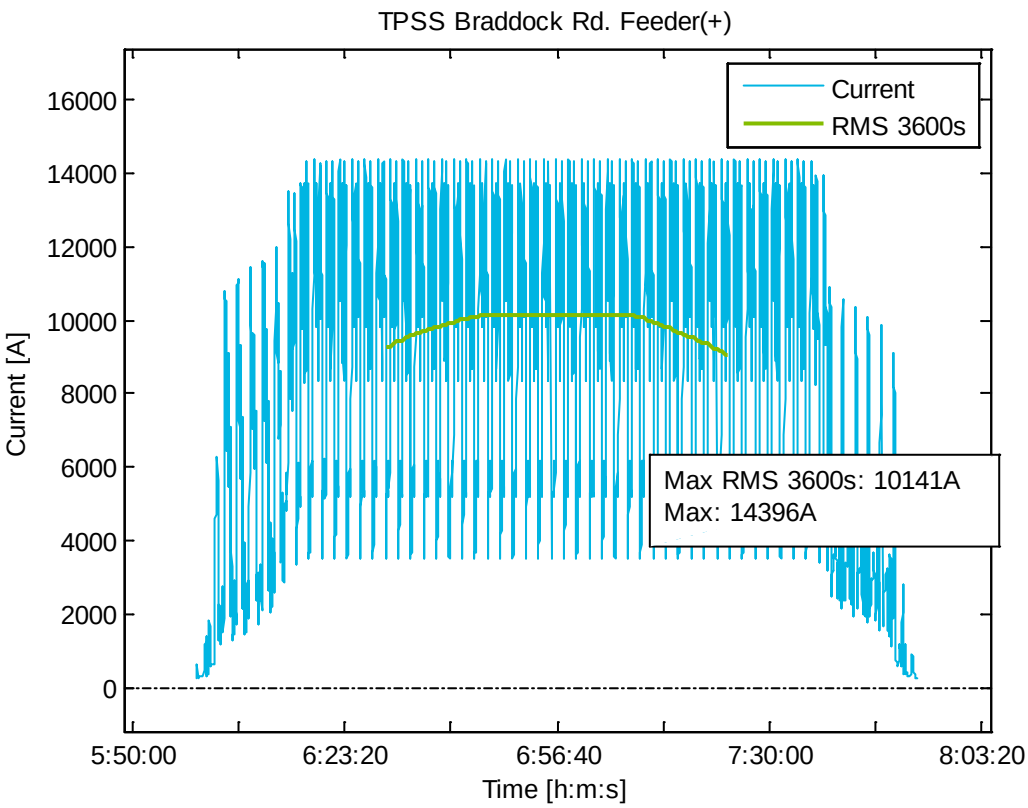


Figure 138. Upgraded system. Braddock Road Substation Instant and RMS currents for National Airport under emergency operation.

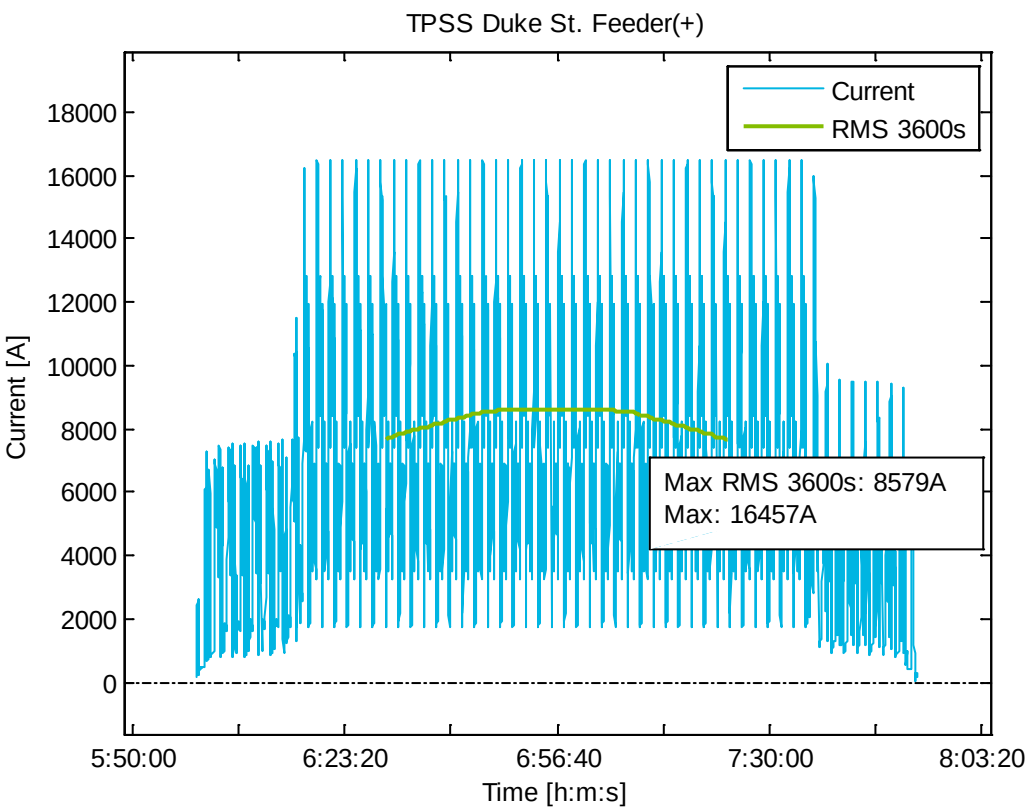


Figure 139. Upgraded system. Duke Street Substation Instant and RMS currents for National Airport under emergency operation.

TPSS Currents for Potomac Yard Emergency Operation

Both instant current and RMS are represented from **Figure 140** to **Figure 143** for all the TPSS under study for Potomac Yard emergency operation for the upgraded system.

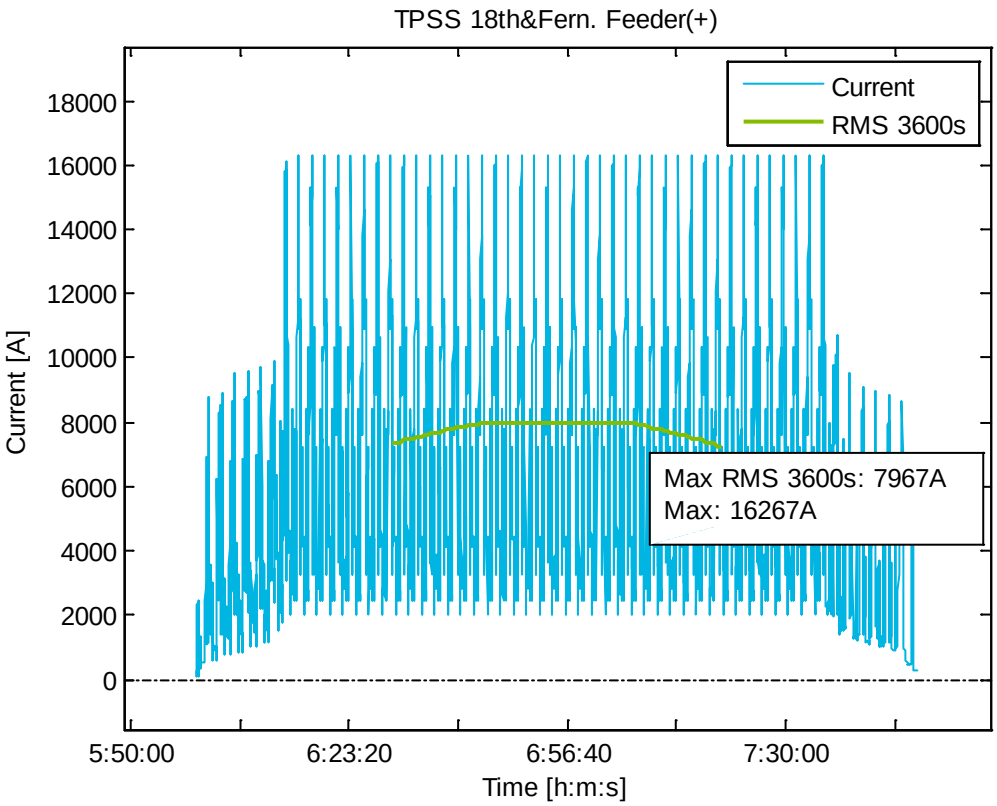


Figure 140. Upgraded system. 18th and Fern Substation Instant and RMS currents for Potomac Yard under emergency operation.

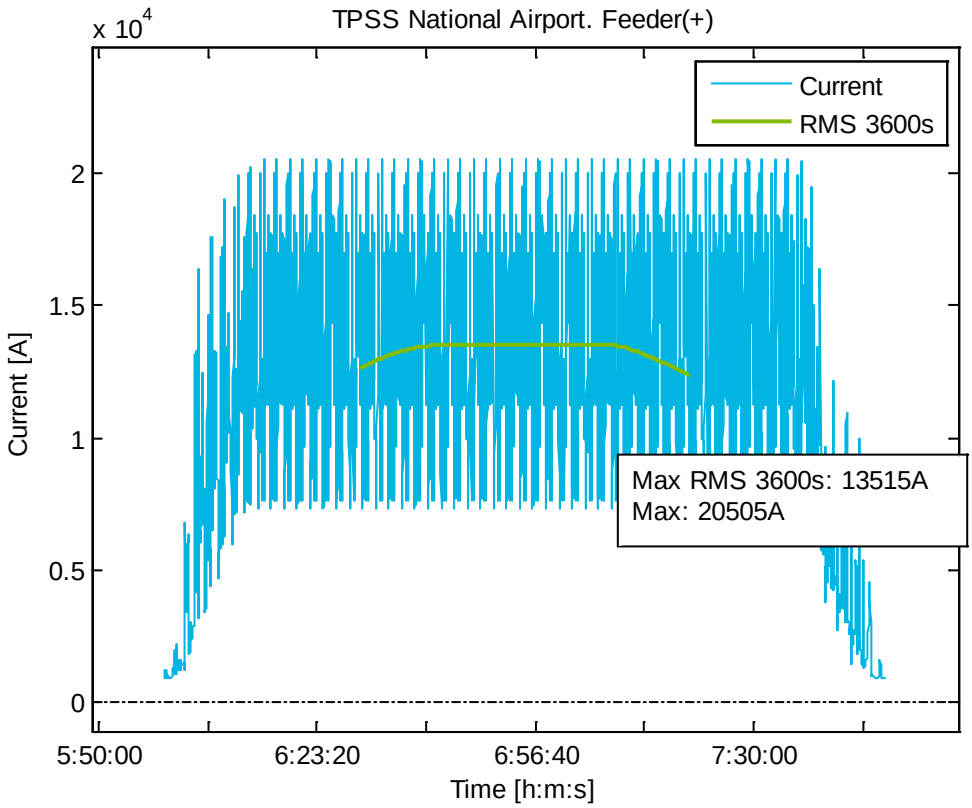


Figure 141. Upgraded system. National Airport Substation Instant and RMS currents for Potomac Yard under emergency operation.

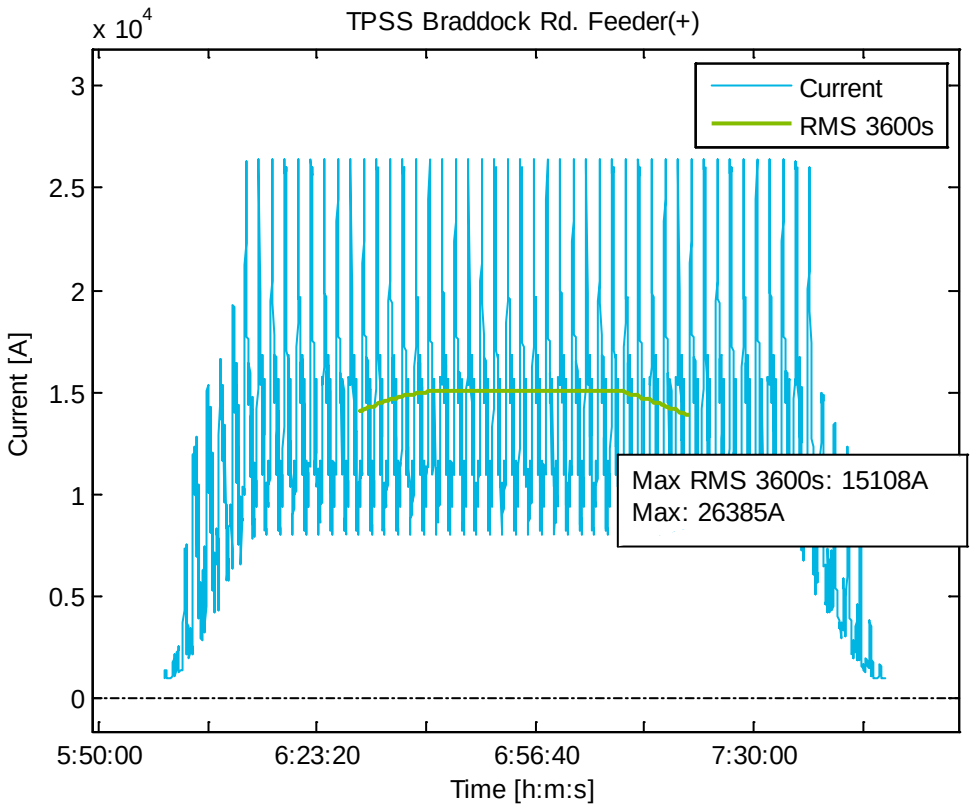


Figure 142. Upgraded system. Braddock Road Substation Instant and RMS currents for Potomac Yard under emergency operation.

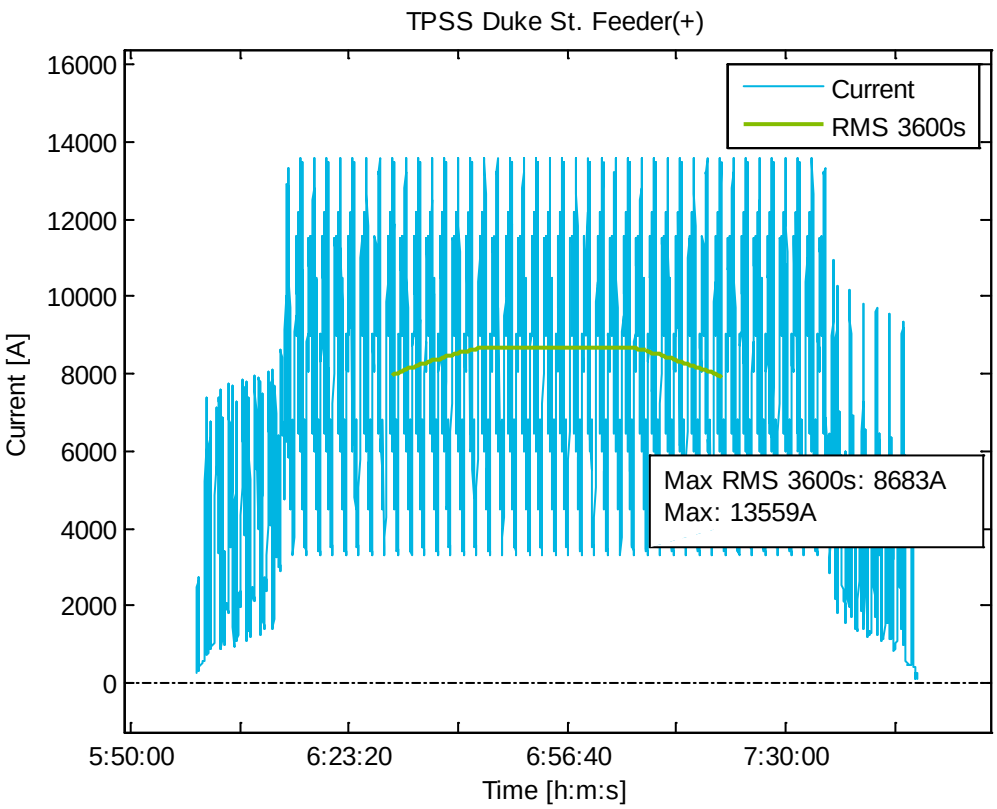


Figure 143. Upgraded system. Duke Street Substation Instant and RMS currents for Potomac Yard under emergency operation.

TPSS Currents for Braddock Road Emergency Operation

Both instant current and RMS are represented from **Figure 144** to **Figure 147** for all the TPSS under study for Braddock Road emergency operation.

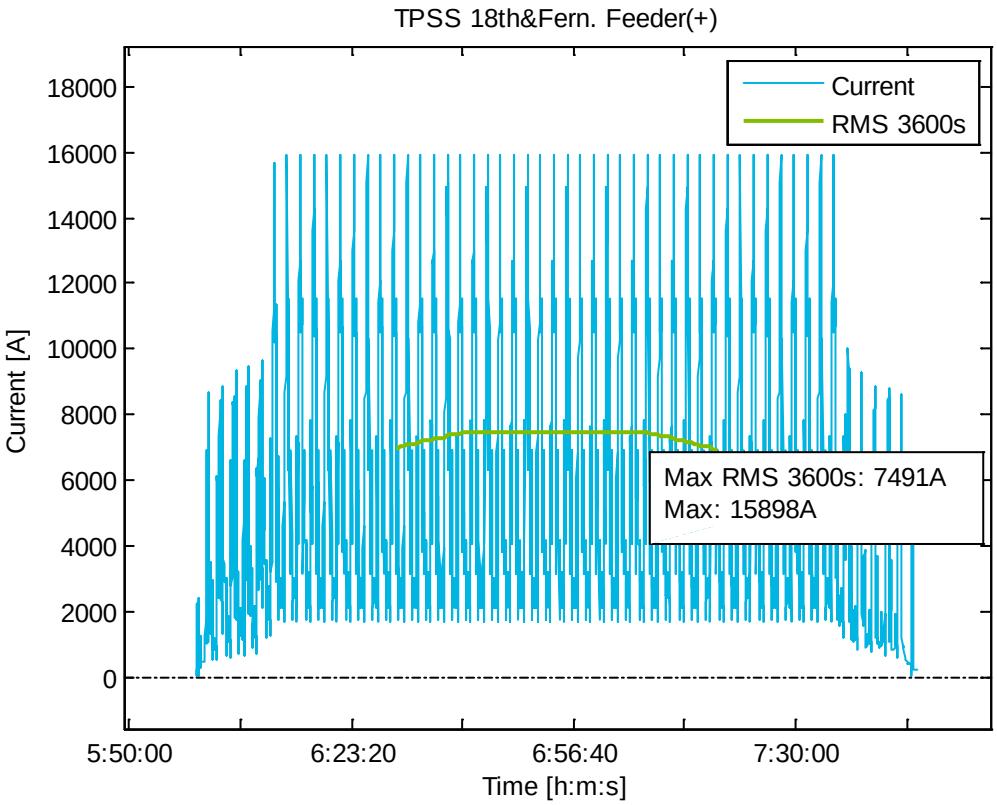


Figure 144. Upgraded System. 18th and Fern Substation Instant and RMS currents for Braddock Road under emergency operation.

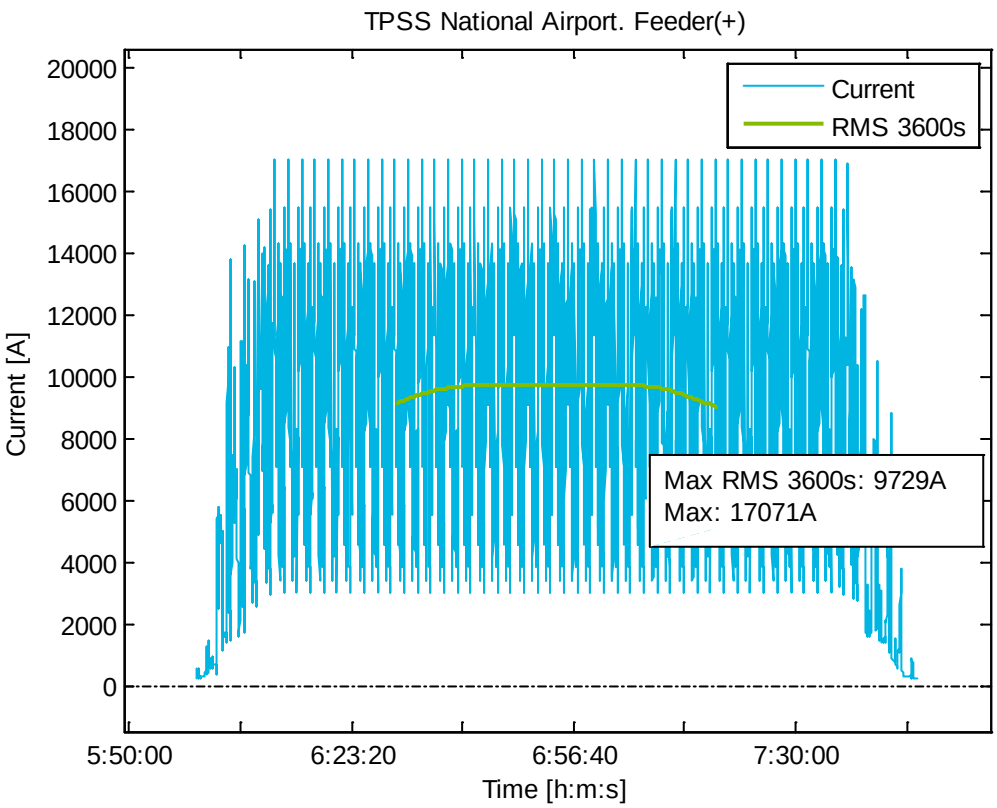


Figure 145. Upgraded system. National Airport Substation Instant and RMS currents for Braddock Road under emergency operation.

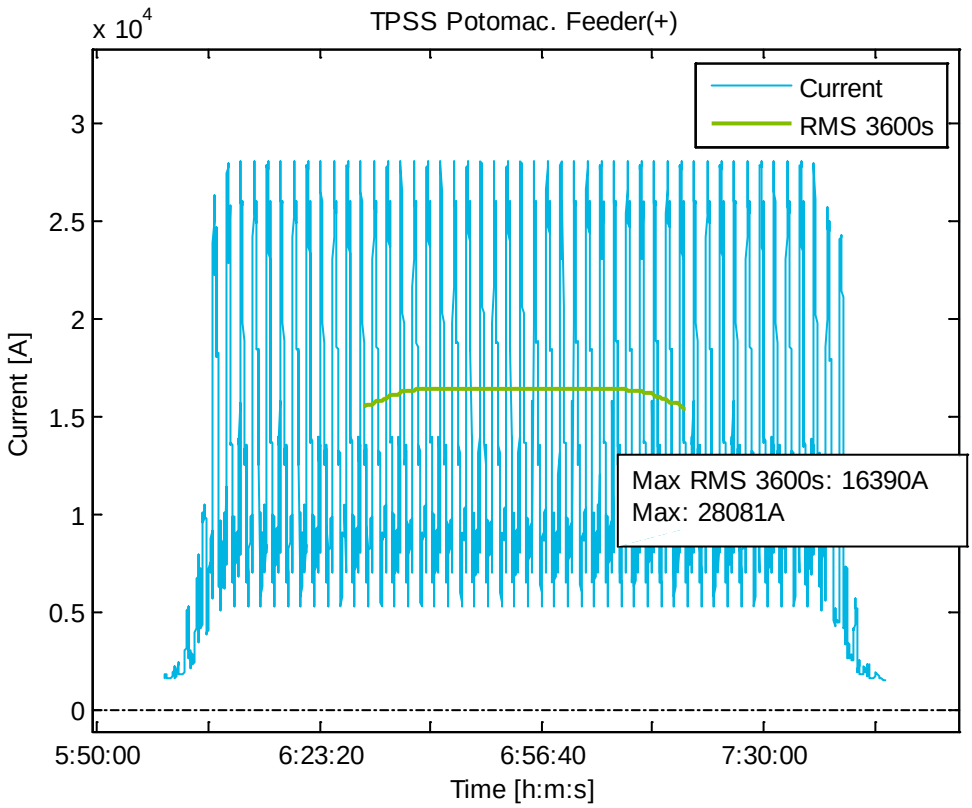


Figure 146. Upgraded system. Potomac Yard Substation Instant and RMS currents for Braddock Road under emergency operation.

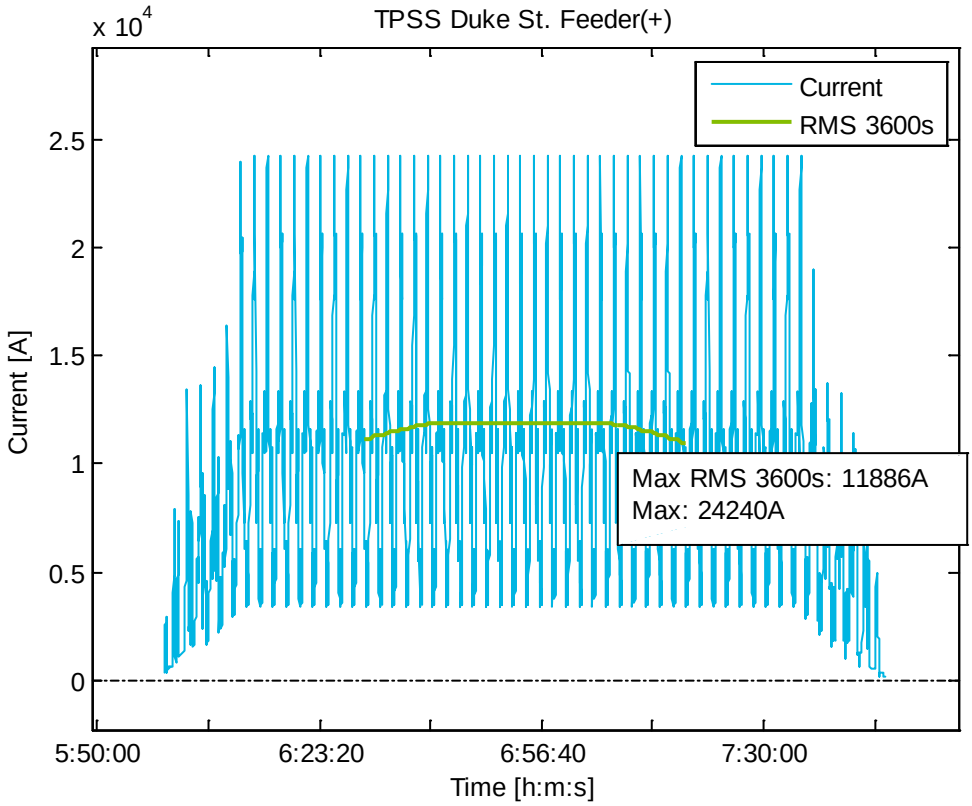


Figure 147. Upgraded system. Duke Street Substation Instant and RMS currents for Braddock Road under emergency operation.

Appendix 3.

Currents vs Voltages Graphs.

A3

Appendix 3. Currents vs Voltages Graphs.

Current System

Currents vs Voltages at trains for Normal Operation

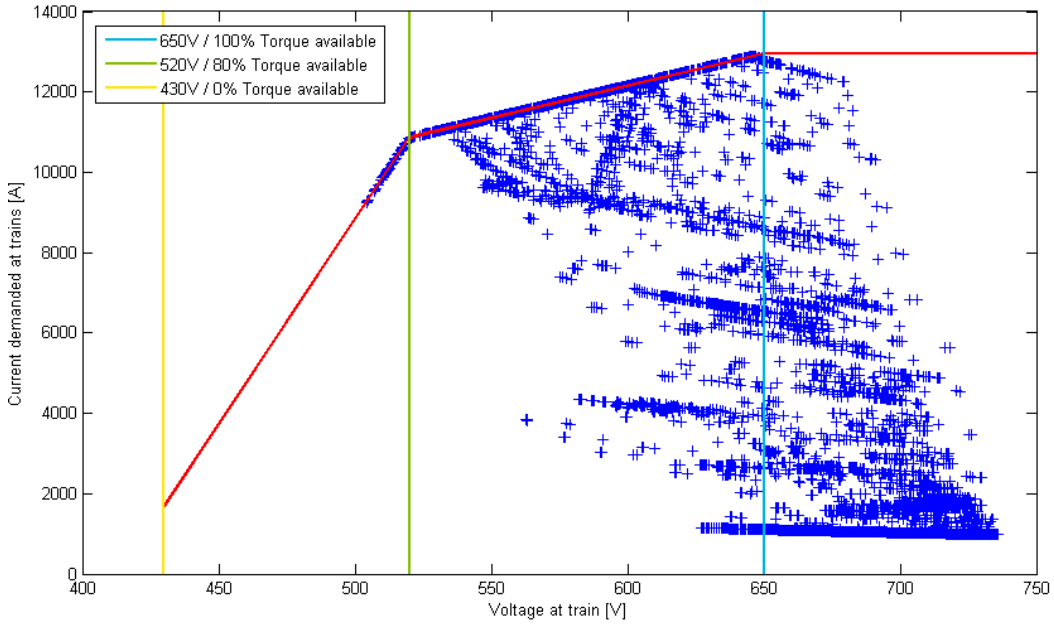


Figure 148. Currents vs Voltages under normal operation.

Currents vs Voltages at trains for National Airport Substation Abnormal Operation

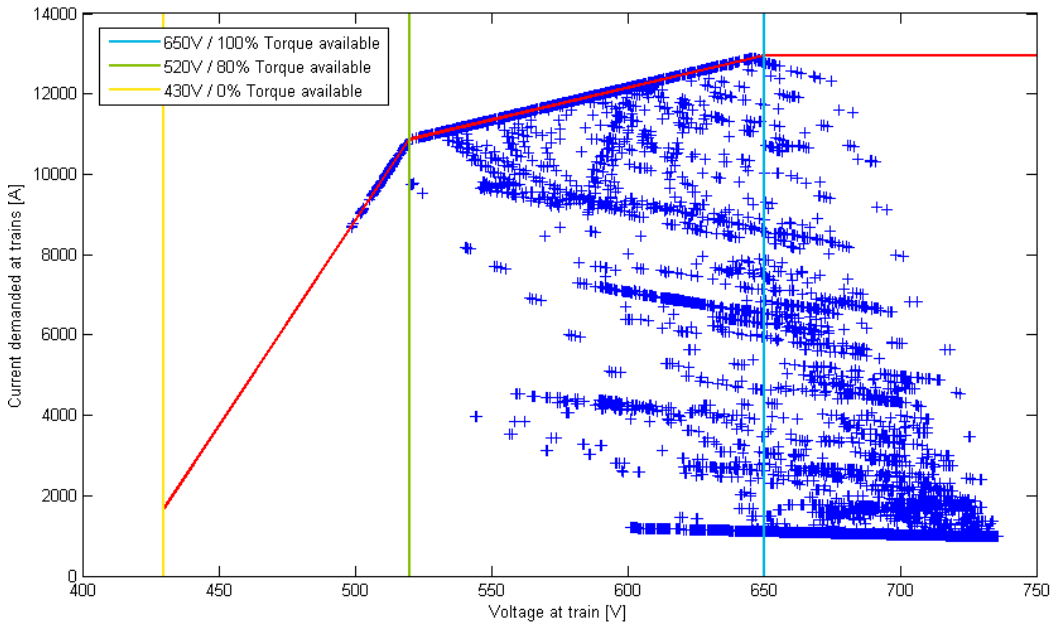


Figure 149. Currents vs Voltages under National Airport substation abnormal operation.

Currents vs Voltages at trains for Potomac Yard Substation Abnormal Operation

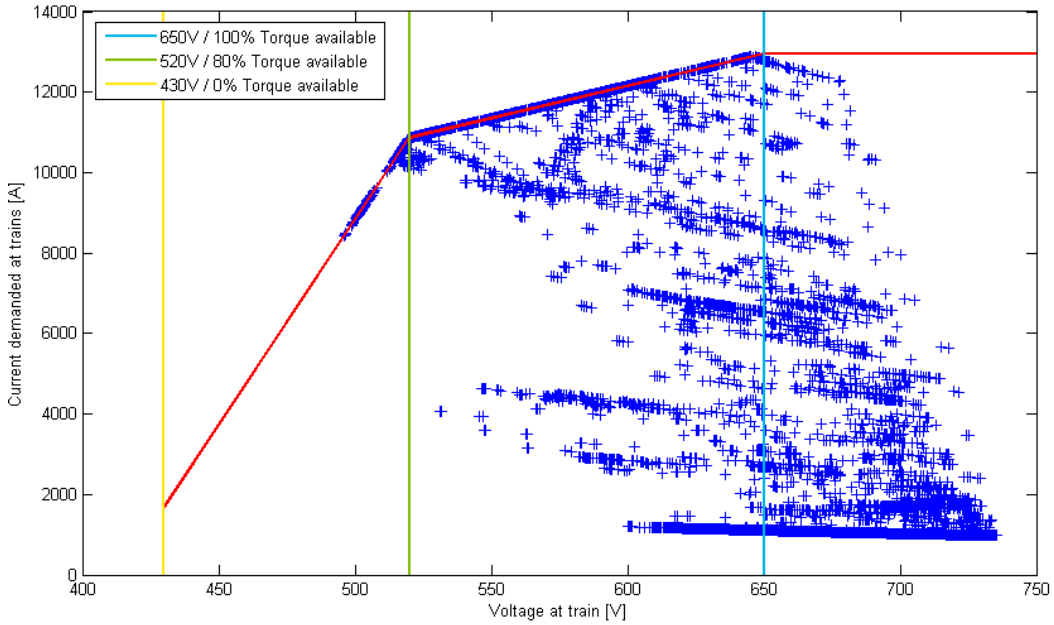


Figure 150. Currents vs Voltages under Potomac Yard substation abnormal operation.

Currents vs Voltages at trains for Braddock Road Substation Abnormal Operation

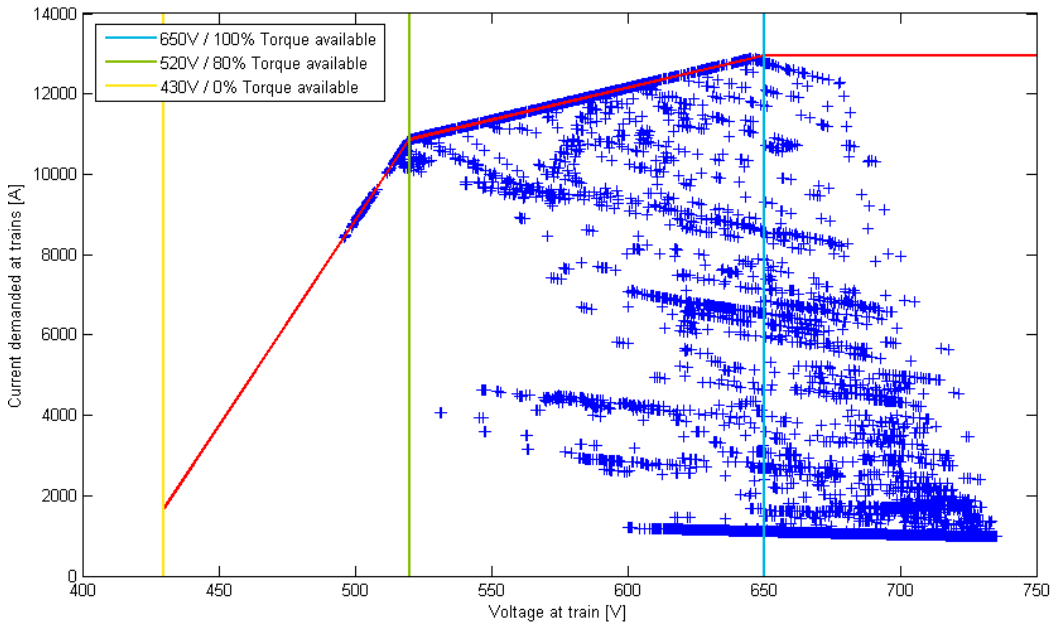


Figure 151. Currents vs Voltages under Braddock Road substation abnormal operation.

Currents vs Voltages at trains for National Airport Substation Emergency Operation

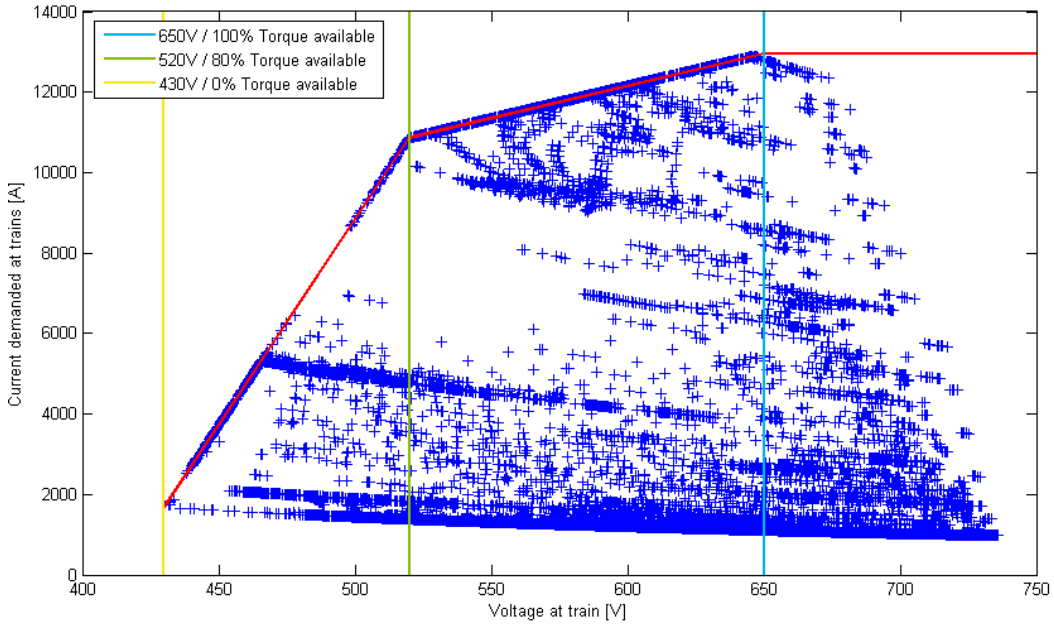


Figure 152. Currents vs Voltages under National Airport substation emergency operation.

Currents vs Voltages at trains for Potomac Yard Substation Emergency Operation

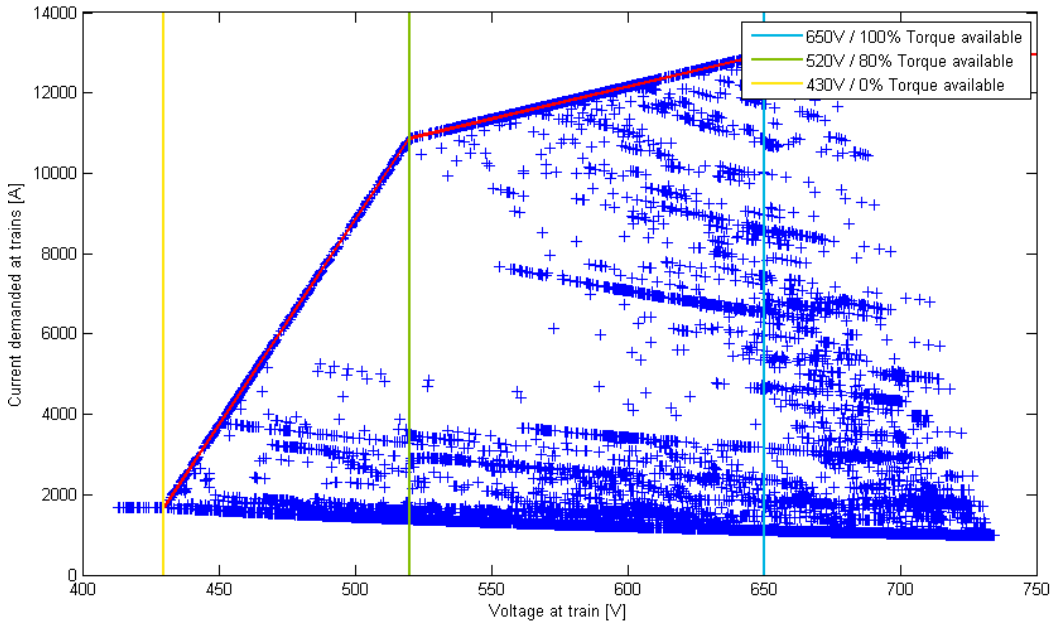


Figure 153. Currents vs Voltages under Potomac Yard substation emergency operation.

Currents vs Voltages at trains for Braddock Road Substation Emergency Operation

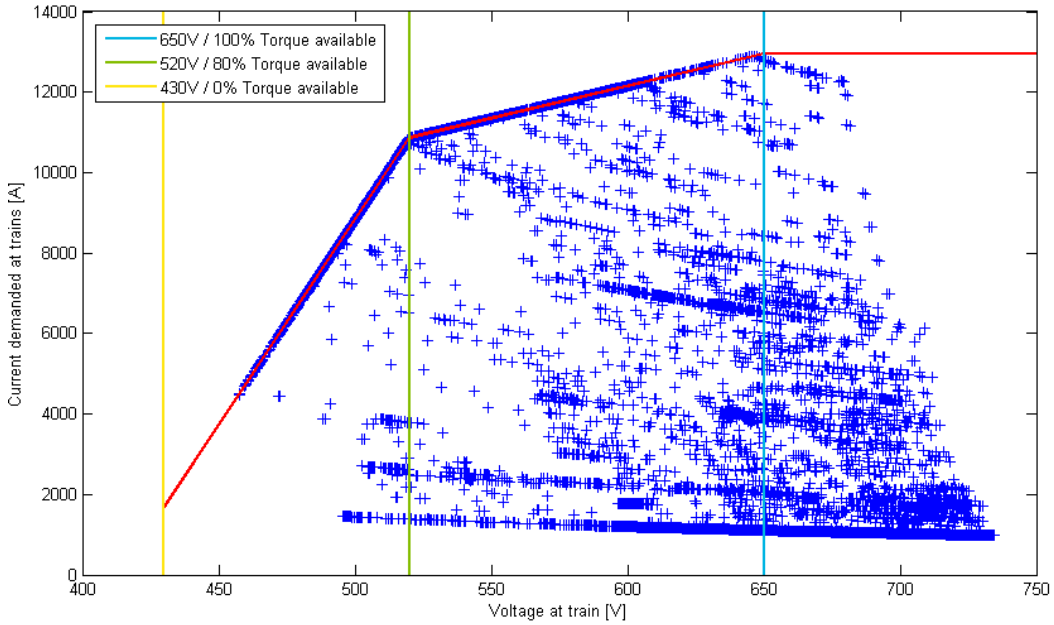


Figure 154. Currents vs Voltages under Braddock Road substation emergency operation.

Upgraded System

Currents vs Voltages at trains for Normal Operation

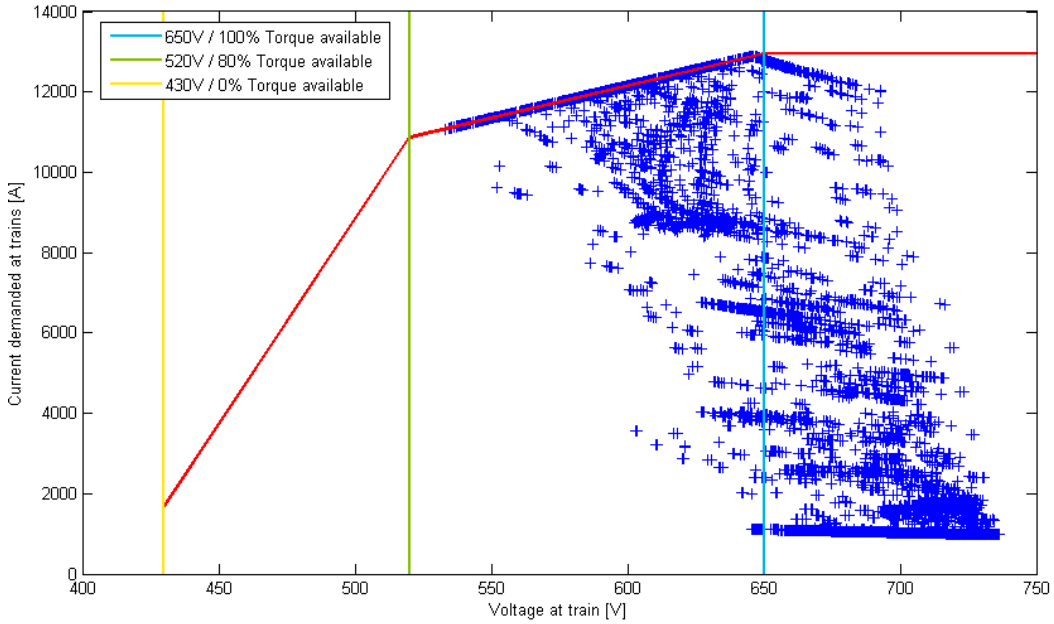


Figure 155. Currents vs Voltages under normal operation.

Currents vs Voltages at trains for National Airport Substation Abnormal Operation

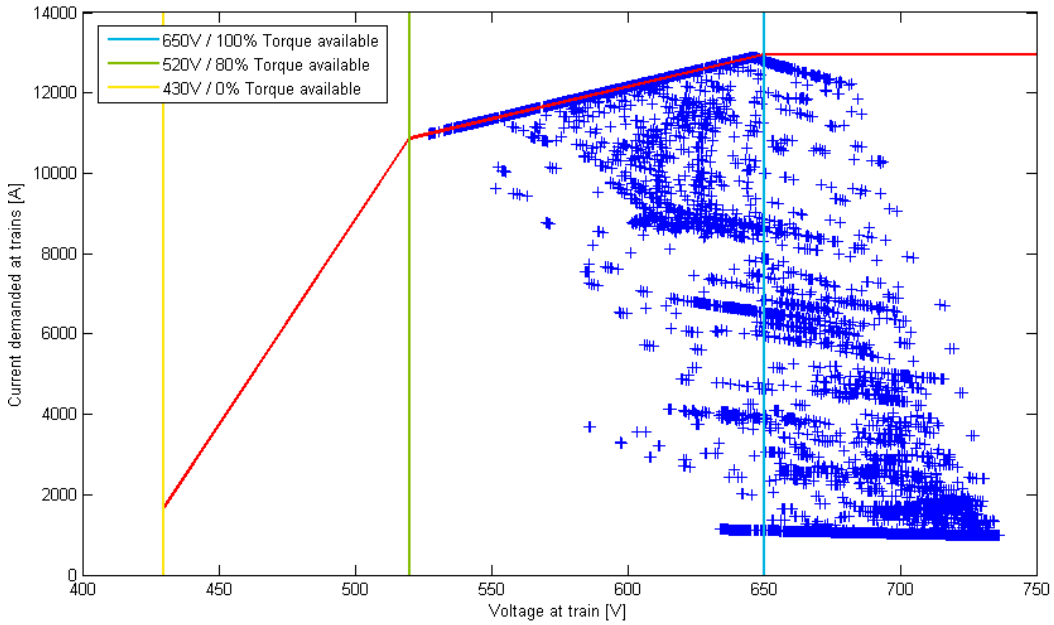


Figure 156. Currents vs Voltages under National Airport substation abnormal operation.

Currents vs Voltages at trains for Potomac Yard Substation Abnormal Operation

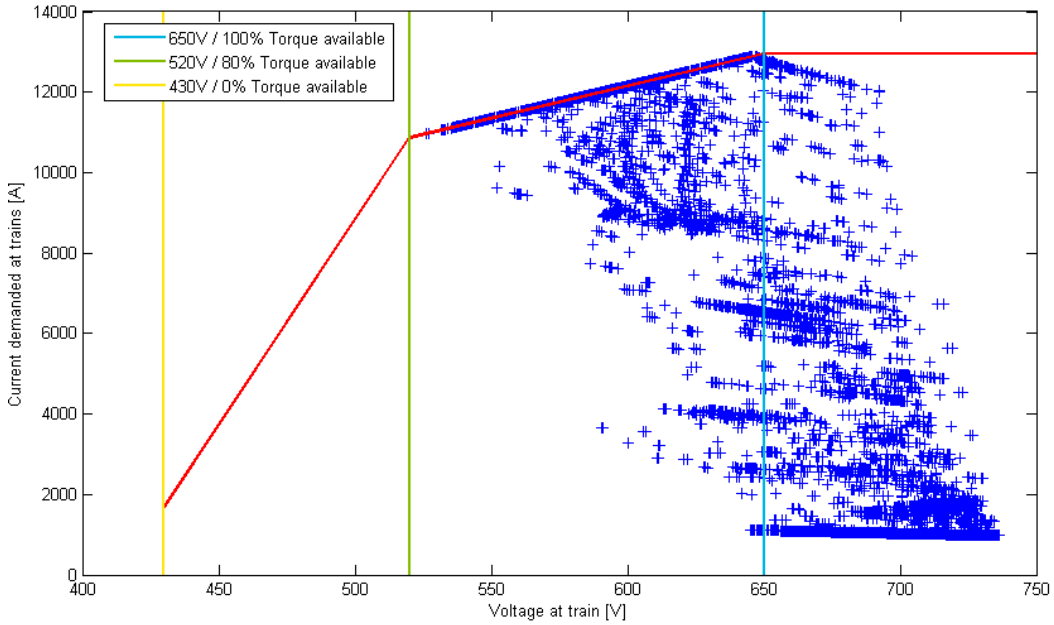


Figure 157. Currents vs Voltages under Potomac Yard substation abnormal operation.

Currents vs Voltages at trains for Braddock Road Substation Abnormal Operation

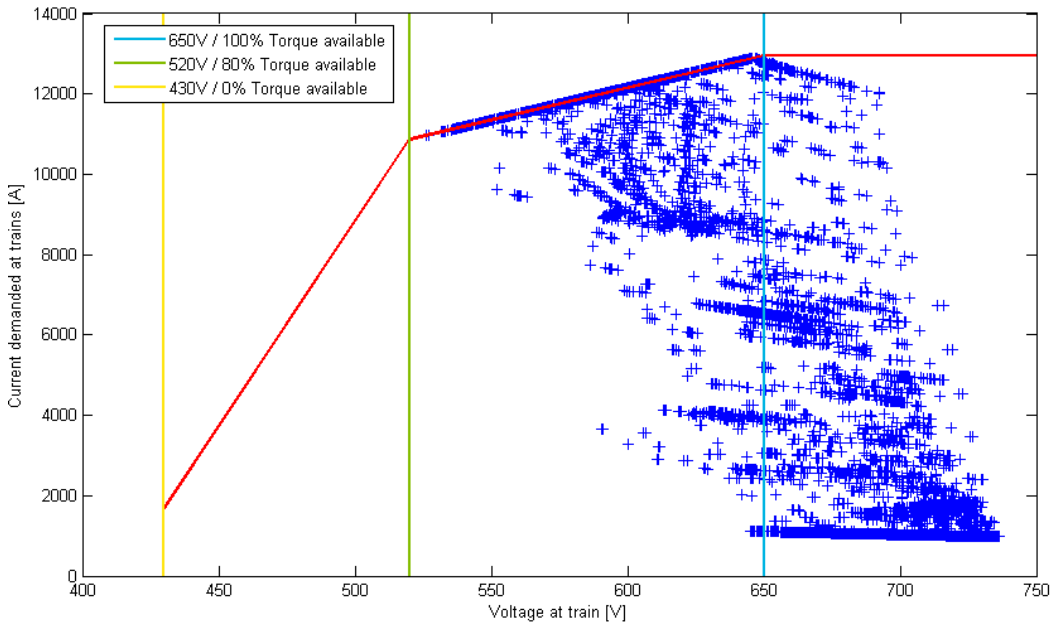


Figure 158. Currents vs Voltages under Braddock Road substation abnormal operation.

Currents vs Voltages at trains for National Airport Substation Emergency Operation

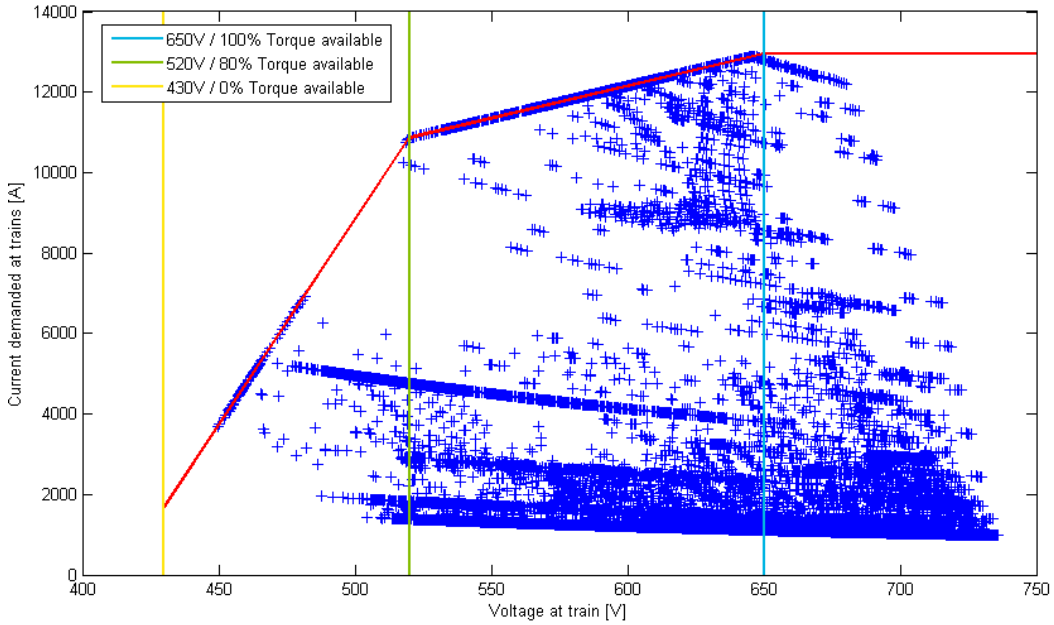


Figure 159. Currents vs Voltages under National Airport substation emergency operation.

Currents vs Voltages at trains for Potomac Yard Substation Emergency Operation

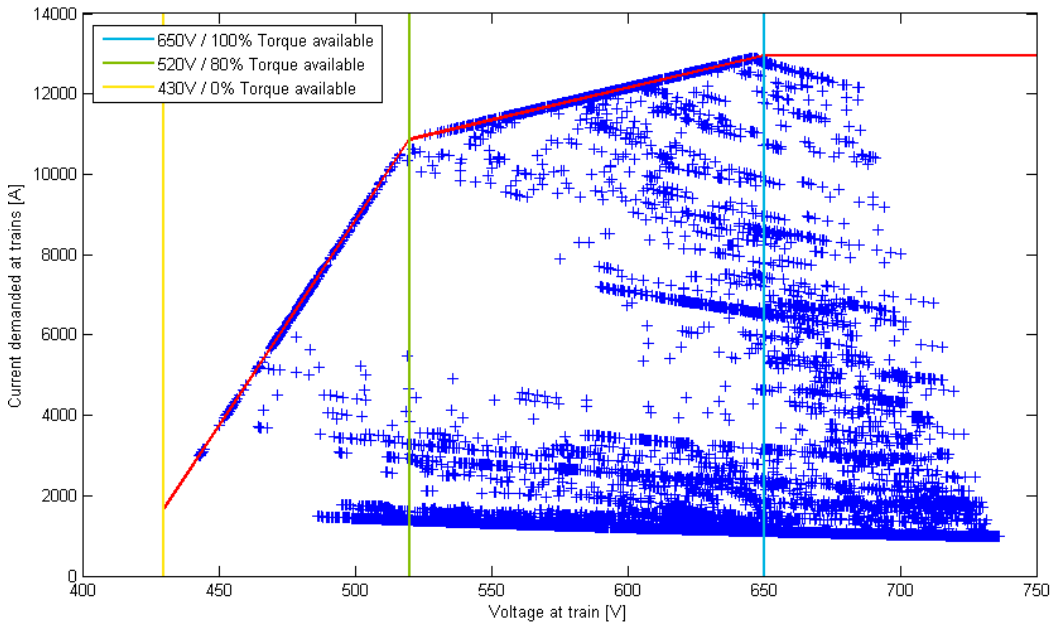


Figure 160. Currents vs Voltages under Potomac Yard substation emergency operation.

Currents vs Voltages at trains for Braddock Road Substation Emergency Operation

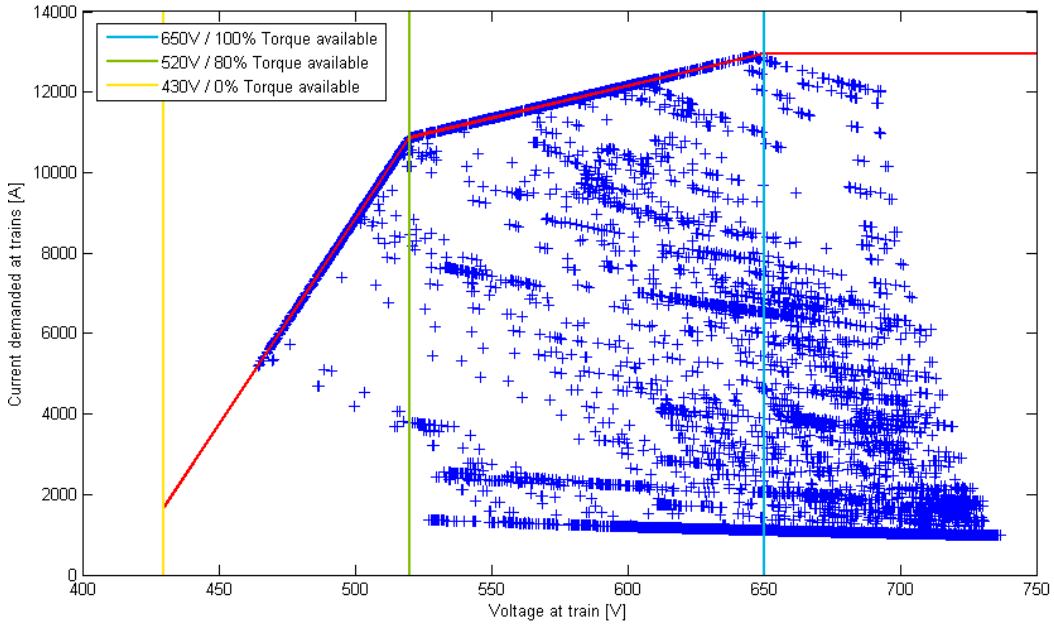


Figure 161. Currents vs Voltages under Braddock Road substation emergency operation.

About AECOM

AECOM (NYSE: ACM) is built to deliver a better world. We design, build, finance and operate infrastructure assets for governments, businesses and organizations in more than 150 countries.

As a fully integrated firm, we connect knowledge and experience across our global network of experts to help clients solve their most complex challenges.

From high-performance buildings and infrastructure, to resilient communities and environments, to stable and secure nations, our work is transformative, differentiated and vital. A Fortune 500 firm, AECOM companies had revenue of approximately US$19 billion during the 12 months ended June 30, 2015.

See how we deliver what others can only imagine at aecom.com and @AECOM.

Contact

Jorge Garzón
Head of Rail Systems Department
Madrid Transportation Design Center
Europe
T +34-915-487-790
E jorge.garzon@aecom.com

aecom.com