METRO GOLD LINE
FOOTHILL EXTENSION – SEGMENT 1

TRACTION POWER LOAD-FLOW STUDY REPORT

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June 10, 2011

Metro

REVISION RECORD

Revision no.	Revision Date	Page(s) Affected	Comments
0	July 5, 2010	All	Initial Issue
1	December 28, 2010	All	Updated alignment and TPSS data
2	March 6, 2011	All	Add 2 more substations
3	June 10, 2011	All	Presents results if additional TPSS were not provided

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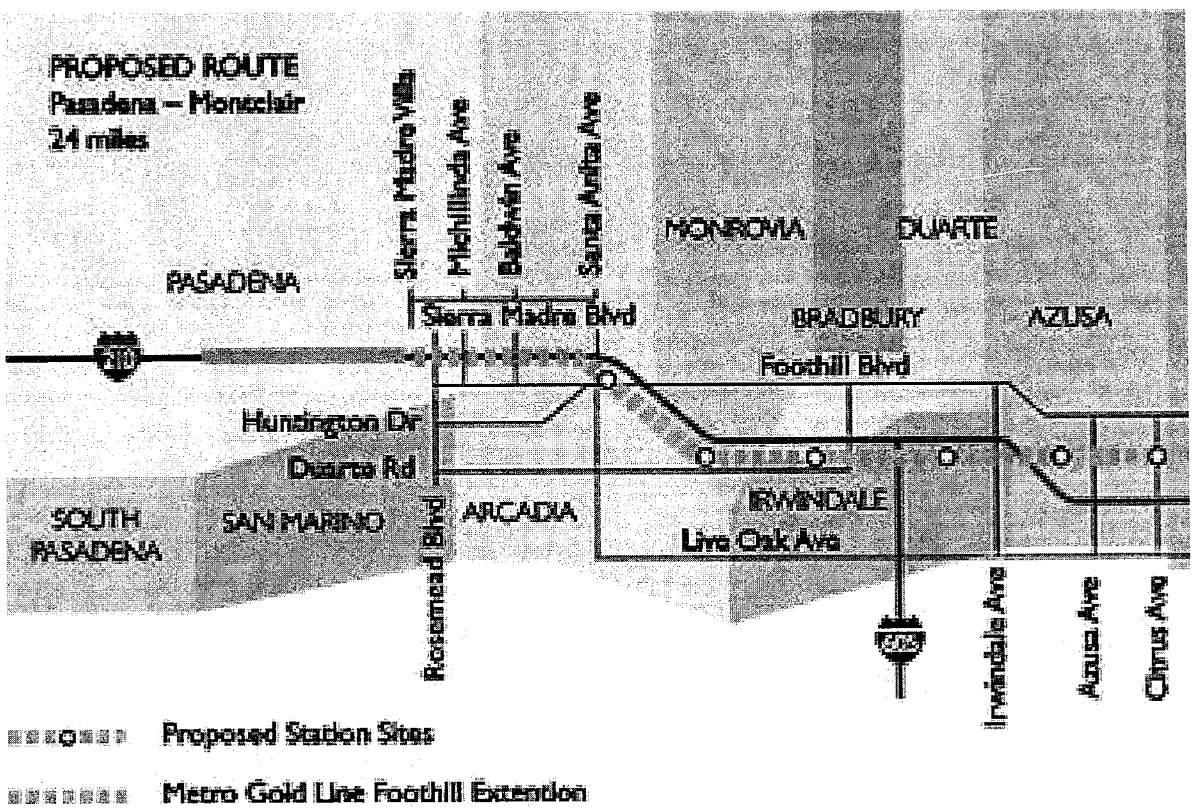
1.0 INTRODUCTION

1.1 Overview of the Project

The Foothill Extension, is an approximate 11-mile east-west light rail extension of the Pasadena Gold Line (PGL). The alignment generally follows the foothills of the San Gabriel Mountains from east Pasadena to Azusa. The Project begins just east of the existing PGL Sierra Madre Villa station in Pasadena and runs along the former Burlington Northern Santa Fe (BNSF) railroad Pasadena Subdivision, generally paralleling Interstate 210 (I-210).

The Foothill Extension will connect the historic downtowns of Arcadia, Monrovia, Duarte, Irwindale, and Azusa (see Figure 1).

Figure 1 - Gold Line Foothill Extension Proposed Alignment



1.2 Purpose of This Report

The purpose of this report is to determine the traction power requirements of Segment 1, including traction power substation size and locations. This report updates the original Construction Authority Traction Power Load Flow Report of December 2006, with revised substation locations and TPS characteristics for Segment 1.

2.0 APPROACH TO THE STUDY

2.1 General

This section of the report addresses the approach used in the Traction Power System Study.

2.2 Approach

The following are the principal steps used in performing the study:

- Review and incorporate the requirements and characteristics of the current design of the Foothill Extension and PGL Phase 1.
- Gather the necessary input data. This data includes typical characteristics of traction power substations, overhead catenary system, positive feeder and negative-return cables for the Foothill Extension, plus details of the vehicles, track, plan and profile, and alignment speeds. This data also includes similar existing parameters for the PGL Phase 1.
- Select a series of scenarios for the study to reflect relevant normal and contingency operating conditions in accordance with Metro Design Criteria, Section 9.18.
- Run a series of preliminary simulations for the scenarios selected.
- Analyze the results.
- Iteratively adjust TP System configuration until the system performs satisfactorily.

2.3 Foothill Extension Substation Sites

Table 1 lists the planned substation sites. Refer to the Advanced Conceptual Engineering alignment plan and profile drawings for details.

Table 1 - Substation Sites

Substation Name	Approximate Stationing	Location
Michilinda	0866+28	At Michilinda Avenue, Pasadena
Baldwin	0919+00	Adjacent to LA Arboretum off Baldwin Avenue
Joseph	0987+00	West of the 1st st/Santa Clara crossing, South of the alignment.
Los Robles	1036+00	Wasteland, North of the alignment, East of Alta Vista Wash.
Yard	1117+00	Foothill Maintenance & Storage Facility East of California.
Bus Center	1208+00	North of the alignment, West of the I-605 overpass.
Irwindale	1289+00	Irwindale Avenue.
Virginia	1345+00	South of the alignment, East of Virginia Avenue.
Soldano	1382+54	Soldano Avenue, Azusa
Citrus	1424+00	Citrus Avenue.

2.4 Selection of Scenarios

Scenarios were selected as indicated below to satisfy the purpose of this study, and to reflect operating conditions during normal weekday peak service periods and contingency power outage conditions as follows:

Normal Operating Conditions. Normal operating conditions refers to the TP system in its normal operating configuration with all substations in service, all incoming utilities energized, and all DC feeder breakers in their normal operating positions. The following normal operating conditions were simulated:

- Simultaneous starting of two trains at each station used by Foothill Extension trains (except terminus stations) at full performance, with all other trains operating at their normal schedules[1].

Contingency Operating Conditions. The following contingency operating conditions were simulated:

- One substation out-of-service and simultaneous acceleration of two trains (reflective of a line current limit of 1,400 Amps, as implemented on Metro P2550 and P3010 vehicles), located close to the out-of-service substation, with all other trains operating at their normal schedules[2].

2.5 Evaluation of Results

The following results of the TP System Study were analyzed to determine the adequacy of the traction power system:

Voltage at Trains. Low voltage conditions at trains may have a significant impact on train performance. This critical condition was evaluated for each scenario by comparing train voltage to the minimum permissible voltage of 525 VDC.

Substation Loadings. The root-mean-square (rms) and peak loadings of each substation were compared to the simulated substation ratings for each scenario. Substation peak load was determined by analysis of detailed output files of TOM.

For the purposes of this study, substation peak loads of less than 300% of full service current were ignored. Substations can withstand loads below 300% for more than a minute.

1 Used to verify substation peak current ratings.
2 Used to verify substation continuous and peak current ratings, and minimum traction voltage.

3.0 SYSTEMS DATA

3.1 General

This section of the report presents the following system data used in the study:

- System voltage limitations
- Traction power network characteristics
- Vehicle characteristics
- Train operations

3.2 System Voltage Limitations

The substations will be rated and located to satisfy the following voltage conditions under all train operating conditions:

- Maximum Voltage: 950 VDC
- Minimum Permissible Train Voltage: 525 VDC

3.3 Traction Power Network Characteristics

The traction power network characteristics define the impedance, interconnections, and configuration of the network including transformers, rectifiers, running rails, contact and messenger wires, DC positive feeder cables, and negative-return cables.

The existing PGL utilizes conventional 1.5 MW diode rectifier substations. For the Foothill Extension, similar rectifier substations were assumed.

Transformer-Rectifier Unit Ratings. The transformer-rectifier units were simulated with the following characteristics typical of traction power substations[3]:

- Continuous Rating: 1.5 MW
- Configuration: 12-pulse Rectifier
- Duty Rating: Extra-Heavy Duty Traction (150% for 2 hours, 300% for 1 minute, 450% for 15 seconds)
- Substations:
  - Type: Diode rectifier
  - Light-Load Voltage (1% load): 820 VDC

Substation Locations. The substation locations are based upon the current PGL system, plus currently planned additional substations and proposed sites as listed in Section 2.3.

3 Typical substation characteristics, similar to existing PGL substations.

Running Rail Characteristics. For expediency, it was assumed that all running rails are available for traction return purposes. It is unlikely that a Contractor's design for the Foothill Extension would employ single rail track circuits outside of interlockings.

- Resistance of one rail: 0.00904 ohms/1000 ft.
- Resistance of one track: 0.00452 ohms/1000 ft.

Overhead Contact System (OCS). The characteristics of various OCS elements are as follows[4]:

Contact Wire:

- Size: 350 kcmil
- Type: HD copper, grooved
- DC Resistance at 20°C: 0.03051 ohms/1000 ft
- Adjusted for 75°C: 0.03711 ohms/1000 ft
- Adjusted for 20% Worn Wire: 0.04638 ohms/1000 ft

Messenger Wire:

- Size: 500 kcmil
- Type: HD copper, stranded
- DC Resistance at 20°C: 0.02220 ohms/1000 ft
- Adjusted for 75°C: 0.02675 ohms/1000 ft

Due to voltage limitations, a double-messenger OCS system had to be simulated between the Yard and Irwindale TPSS.

Substation Feeder Cables. The characteristics of the substations' positive and negative feeder cables are as follows[5]:

Positive Feeder Cables:

- Size: 750 kcmil
- Type: Copper, stranded
- DC Resistance at 25°C: 0.0148 ohms/1000 ft
- Cables per Track, per Direction: 2

4 Based upon Metro Design Criteria, Section 9.18.5.H.7.
5 Typical configuration for a 1.5MW substation. Feeder lengths were estimated from the alignment drawings.

- Length: 500 ft

Negative-Return Cables:

- Size: 750 kcmil
- Type: Copper, stranded
- DC Resistance at 25°C: 0.0148 ohms/1000 ft
- Cables per Track: 3
- Length: As for Positive Feeders

3.4 Vehicle Characteristics

This simulation utilizes the propulsion, auxiliary power, and physical configuration of the Siemens P2000 car as an example of a modern AC-propulsion LRV[6].

Siemens P2000 Metro LRV

- Tare Weight: 51.0 tons
- AW2 Weight: 64.1 tons
- Auxiliary Power: 40 kW/car
- Service Acceleration Rate: 3.0 mphps to 20 mph, 1.6 mphps to 55 mph
- Normal Service Deceleration Rate: 2.5 mphps
- Maximum Speed: 55 mph (imposed by signaling system)
- Propulsion Type: 2 AC PWM inverters and 4 motors per car
- Regeneration Voltage: 950 VDC
- Minimum Permissible Train Voltage: 525 VDC[7]
- Tractive Effort Curve: See Figure 2
- Braking Effort Curve: See Figure 3

3.5 Operations Data

The following operational assumptions were made in the operating plan:

- Intermediate Station Dwell: 20 seconds

6 The Foothill Extension is planned to receive P3010 vehicles. The characteristics of this vehicle are unknown at present, but are specified to be similar to the P2000 vehicles.

7 The propulsion system can operate down to 450 vdc.

- Terminal Station Dwell: 3 minutes

The following service pattern was simulated:

- 5 minute headway, 3 car trains

3.6 Switch Heater Load

No switch heater loads were simulated.

3.7 Alignment Data

Alignment data (grade, station locations, and curve data) was assembled from the current Foothill Extension and PGL designs.

3.8 Cab Speed Data

Maximum train speeds were based upon the alignment civil and curve speeds.

Figure 2 - P2000 Tractive Effort Curve

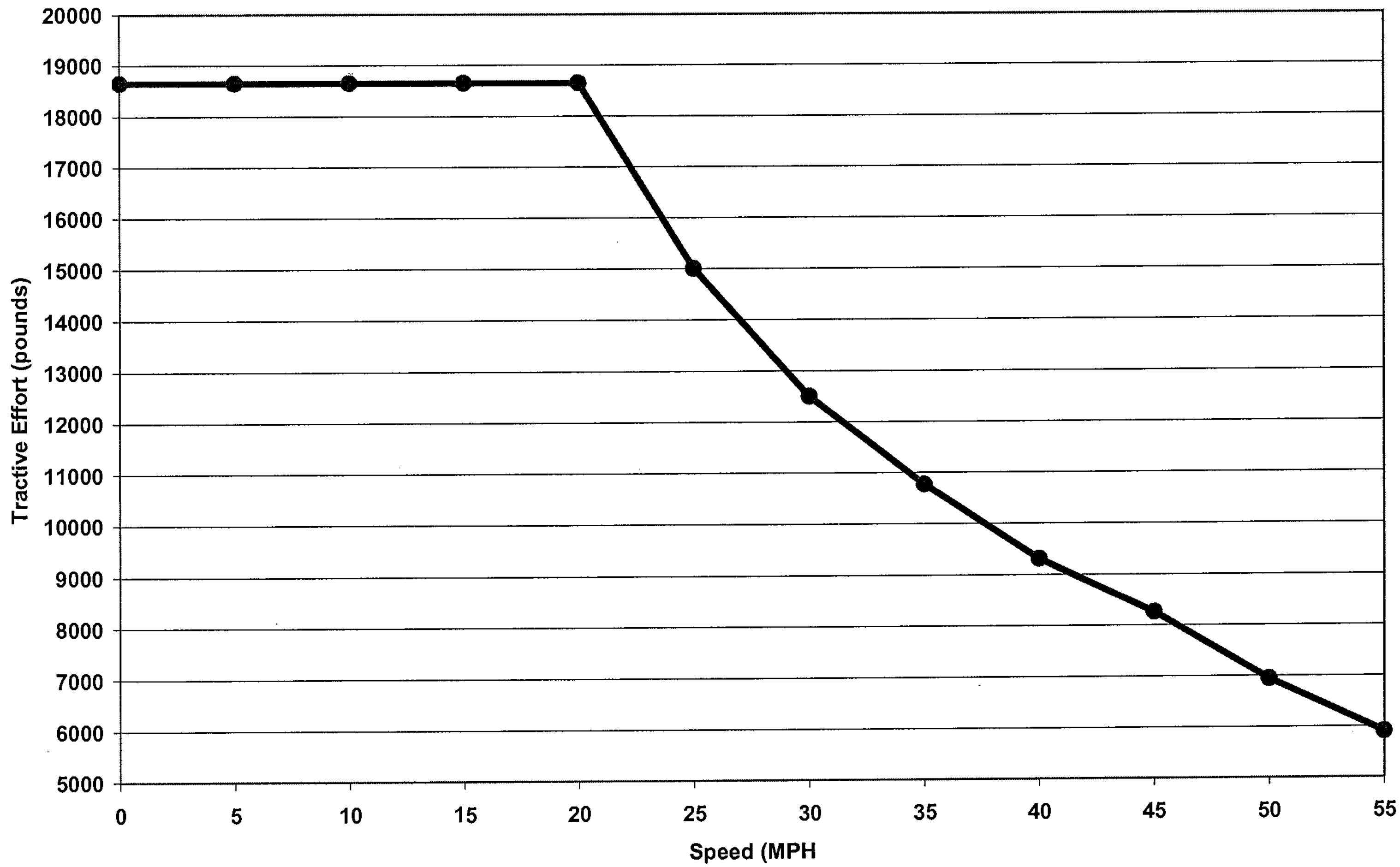
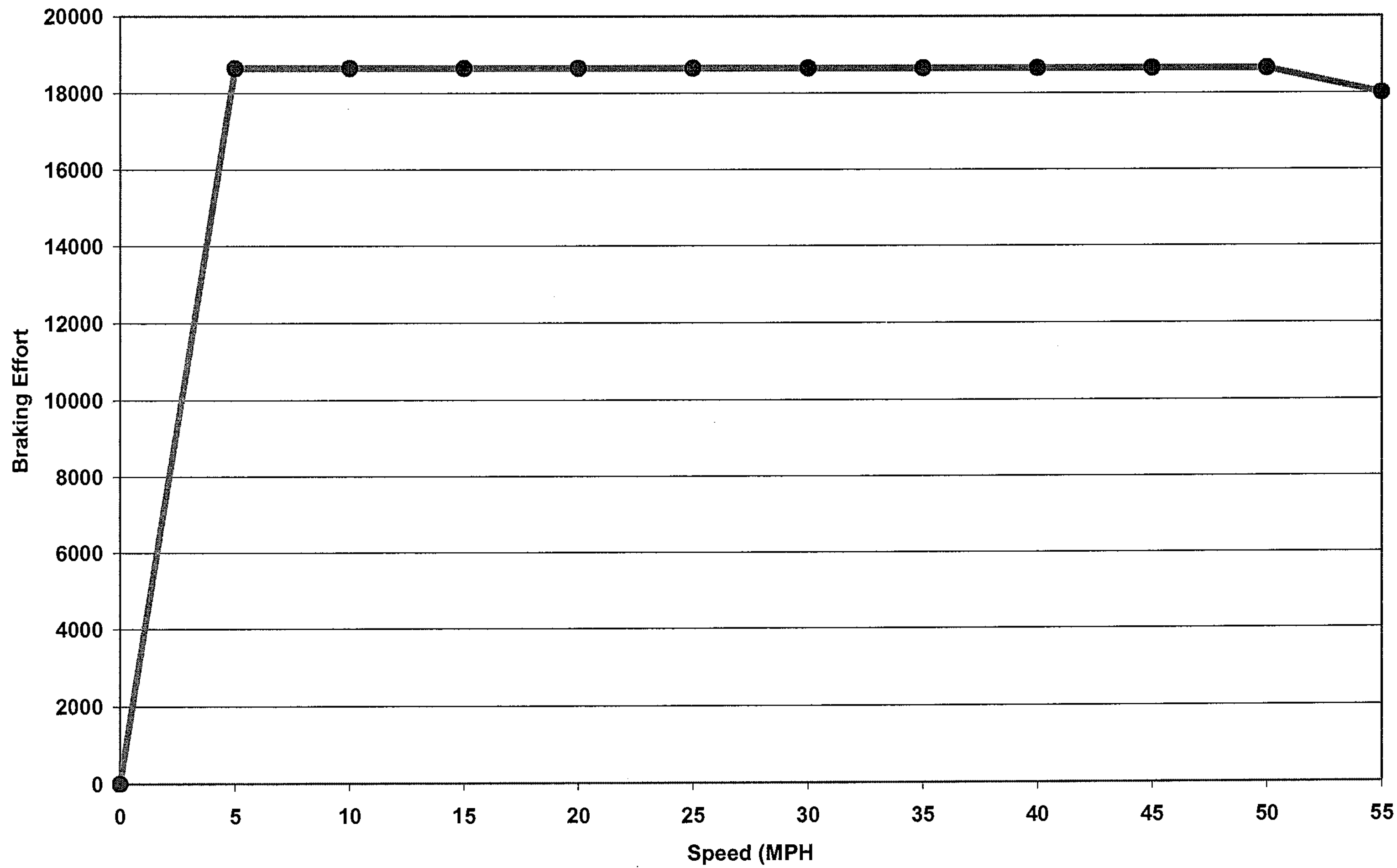


Figure 3 - P2000 Braking Effort Curve



4.0 FINDINGS

4.1 General

This section of the report presents the findings of the TP System Study. The findings include results for evaluating the following:

- The adequacy of traction voltage.
- The adequacy of substation capacity.

The findings were based on simulations run under both normal and contingency operating conditions.

4.2 Train Performance Simulation Results

Output of the TPS portion of the model are provided in Table 2.

Table 2 - Train Performance Simulation Results

Train Operation		Distance (miles)	Time (minutes)[8]	Speed (mph)	Energy (kwh)
Foothill Extension Northbound					
Sierra Madre	to Arcadia	3.10	4.18	44.60	4.94
Arcadia	to Monrovia	1.67	2.57	39.08	15.20
Monrovia	to Duarte	2.03	2.95	41.17	36.70
Duarte	to Irwindale	2.05	3.04	40.60	36.24
Irwindale	to Azusa Alameda	1.58	2.49	38.05	25.95
Azusa Alameda	to Azusa Citrus	0.86	1.35	38.04	21.29
Foothill Extension Southbound					
Azusa Citrus	to Azusa Alameda	0.86	1.67	30.75	9.17
Azusa Alameda	to Irwindale	1.58	2.49	38.15	16.87
Irwindale	to Duarte	2.05	3.01	40.90	14.63
Duarte	to Monrovia	2.03	2.94	41.37	11.87
Monrovia	to Arcadia	1.67	2.57	39.01	28.66
Arcadia	to Sierra Madre	3.10	4.20	44.40	67.03

4.3 Analysis

4.3.1 Simulation of Normal Operating Conditions

A series of traction power simulations were performed with all TP substations in service and with simultaneous starting of trains at full performance from each station, except terminal stations as follows:

8 For this report, trains were operated in "all-out" mode. That is, at full service acceleration and deceleration. Runtimes are not applicable for timetable analysis or fleet size calculations.

- Simultaneous start from stations (Run series 3B###)[9].

Refer to Table 3 for the train voltages under simultaneous-start at stations operating conditions. The worst-case train voltage was 535 volts (see Figure 4) that occurred on the Southbound track at Milepost 20.353, near Monrovia station for case reference 3Bmon (simultaneous start at Monrovia station). This result confirms that adequate train voltage is being maintained under normal operations.

The simulated rms and peak currents under normal conditions were compared to the rated rms and 300% peak currents at each substation location to determine their adequacy. Peak loads below 300% of rated current were ignored.

Simulations indicated that the worst-case substation rms load is 62% of continuous rating (i.e. just under 1.0 MW), which occurred at Irwindale substation (see Figure 5) for case reference 3Baza (simultaneous start from Azusa Alameda station). This result confirms that the proposed 1.5 MW substation rating is adequate for this service pattern.

Peak loading of substations was less than 300% for all substations.

9 "###" is a 3-letter variable, used to designate the station at which simultaneous start occurs.

Figure 4 - Train voltage for Case 3Bmon (Normal operations, simultaneous start at Monrovia station)

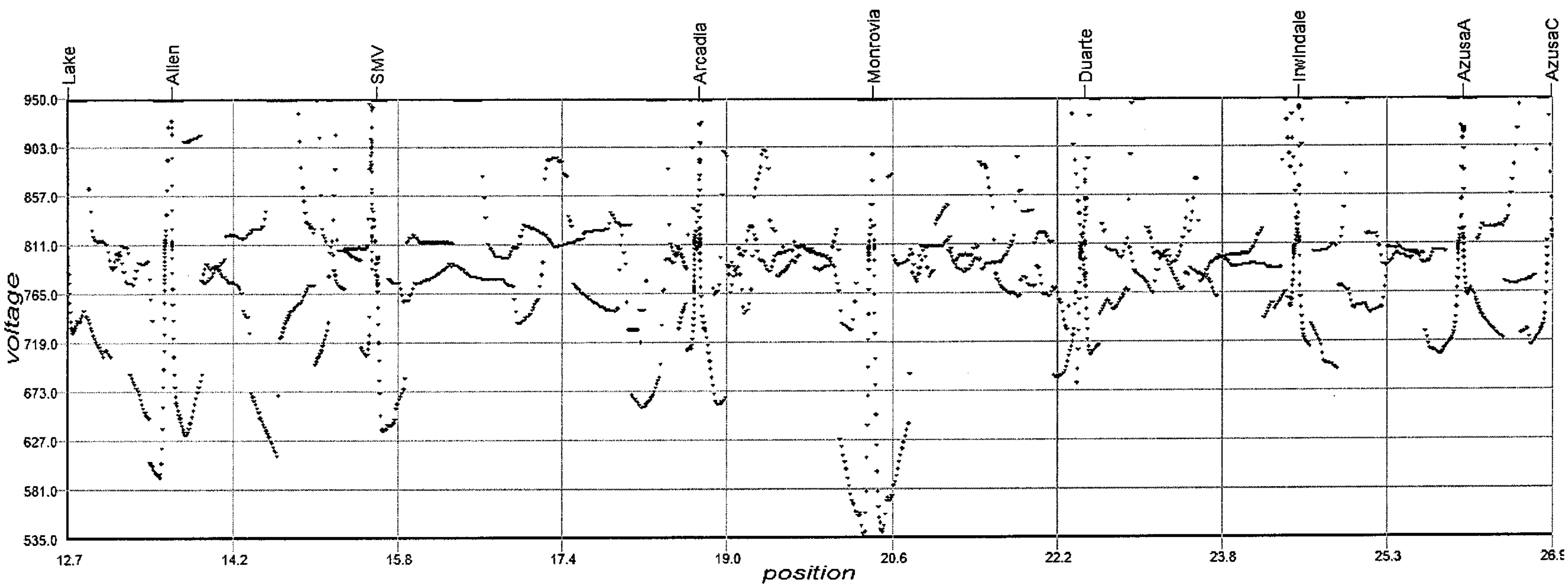
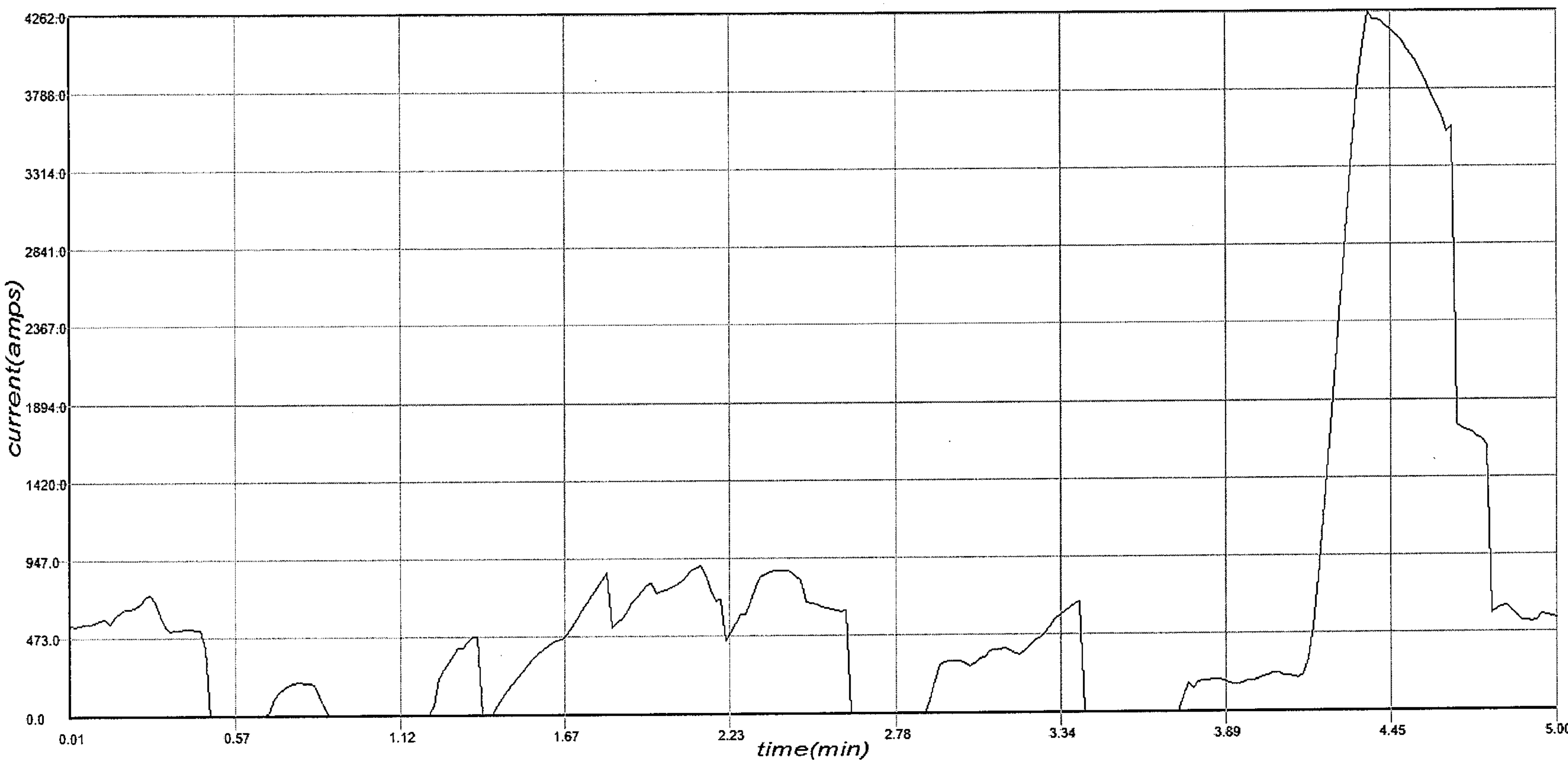


Figure 5 - Irwindale Substation Load for Case 3Baza (Normal operations, simultaneous start at Azusa Alameda station)



4.3.2 Simulation of Contingency Operating Conditions

A series of traction power simulations were performed with each TP substation out of service as follows:

- Simultaneous start from nearest station (Run series 3B##)[10]

During simulation, it was found that generally the in-built system performance (i.e. line current limit) of the propulsion system compensated for line voltage drop and enabled stable system performance.

Refer to Table 7 for the train voltages under contingency (TPSS outage) operating conditions. The worst-case train voltage was 525 volts (see Figure 6), which occurred on the Northbound track, at Milepost 20.263, near Monrovia station for case reference 3B04 (Los Robles substation out of service). This result indicates acceptable train voltage.

The simulated rms currents were compared to the rated rms currents at each substation location to determine their adequacy. Also, the simulated peak currents under baseline and simultaneous-start operating conditions were compared to the rated 300% peak currents at each substation location to determine their adequacy. Peak loads below 300% were ignored.

Contingency operations simulations indicated that the worst-case rms load is 69% of continuous rating (i.e. just over 1.0 MW), which occurred at Soldano substation (see Figure 7) for case reference 3B10 (Citrus substation out of service). This indicates that substation ratings are adequate.

Peak loading of substations was less than 300% for all cases and all substations.

10 "##" is a 2-number variable, used to designate the out-of-service substation.

Figure 6 - Train voltage for Case 3B04 (Los Robles Substation out of service)

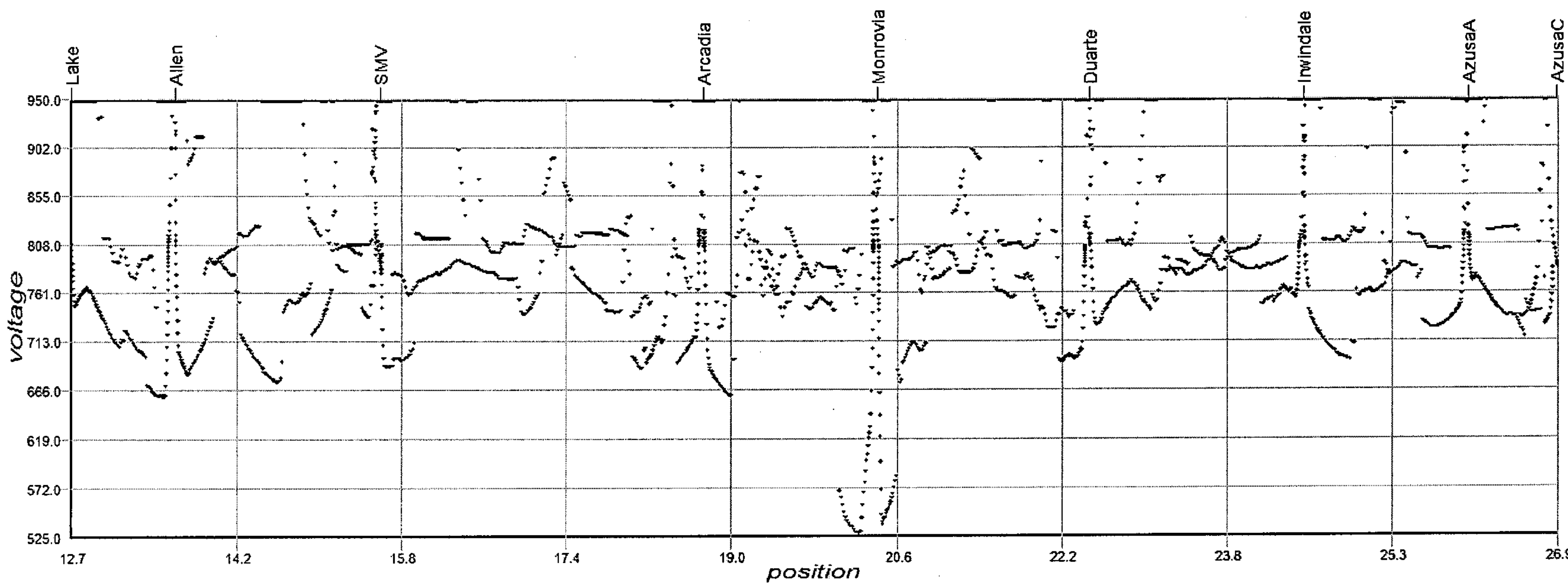


Figure 7 - Virginia Substation load for Case 3B10 (Citrus substation out of service)

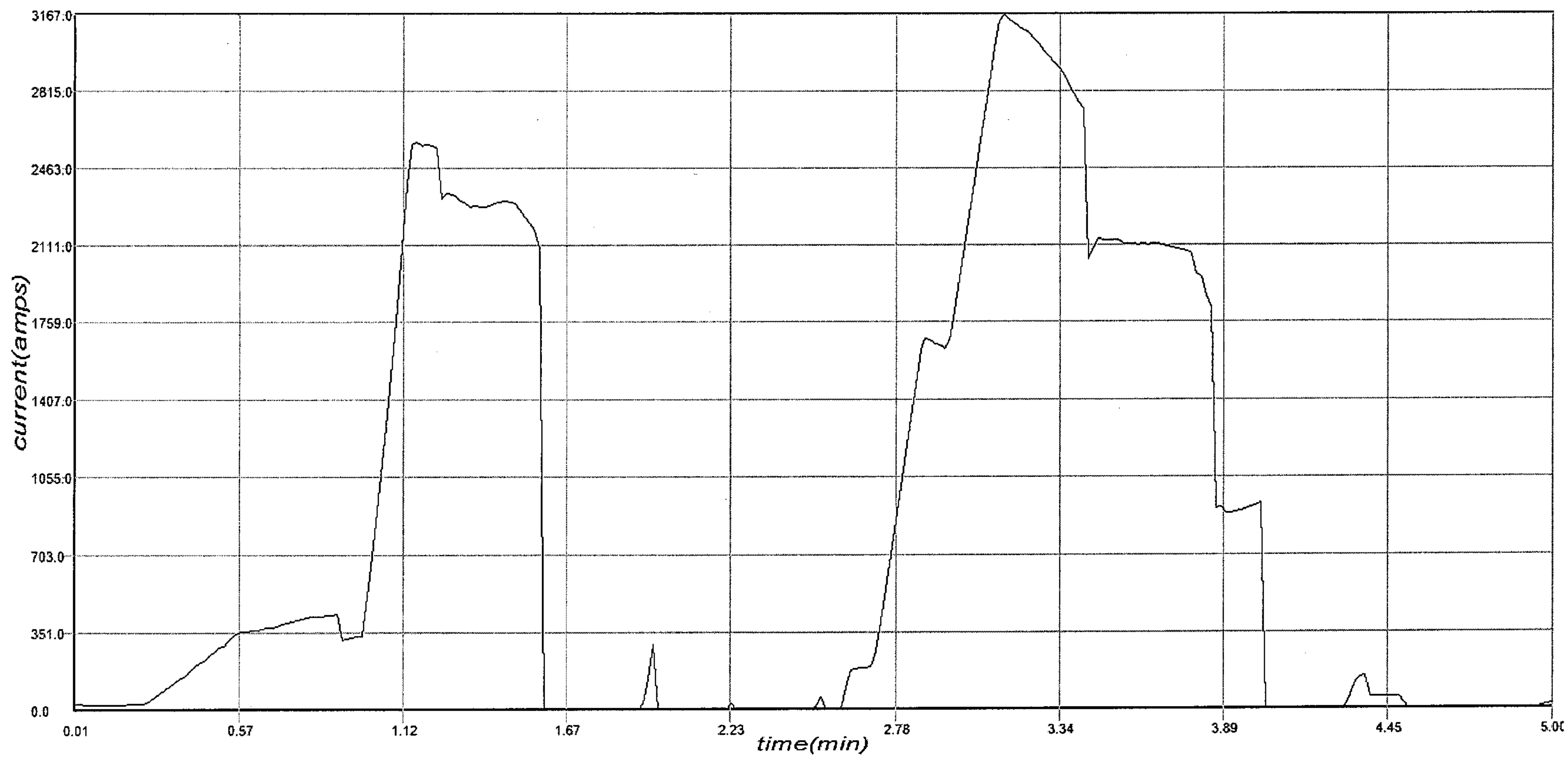


Table 3 - Summary of Results from Load-Flow Simulations with all Substations in Service[11]

Normal Operation, Simultaneous Starts at Station

Case #	Location of Simultaneous Start	Substation rms Loads (% capacity)		Substation Peak Load (Maximum Peak)		Minimum Train Voltage & Location
3Bsmv	SMV Station	Titley	52%	Titley	<300%	594 VDC on the Southbound track, at Milepost 20.353 (near Monrovia station)
		Michilinda	33%	Michilinda	<300%	
		Baldwin	28%	Baldwin	<300%	
		Joseph	45%	Joseph	<300%	
		Los Robles	41%	Los Robles	<300%	
		Yard	50%	Yard	<300%	
		Bus Center	59%	Bus Center	<300%	
		Irwindale	48%	Irwindale	<300%	
		Virginia	35%	Virginia	<300%	
		Soldano	37%	Soldano	<300%	
		Citrus	43%	Citrus	<300%	
3Barc	Arcadia Station	Titley	48%	Titley	<300%	540 VDC on the Northbound track, at Milepost 20.491 (near Monrovia station)
		Michilinda	32%	Michilinda	<300%	
		Baldwin	30%	Baldwin	<300%	
		Joseph	59%	Joseph	<300%	
		Los Robles	52%	Los Robles	<300%	
		Yard	55%	Yard	<300%	
		Bus Center	46%	Bus Center	<300%	
		Irwindale	44%	Irwindale	<300%	
		Virginia	37%	Virginia	<300%	
		Soldano	43%	Soldano	<300%	
		Citrus	38%	Citrus	<300%	

11 Shaded lines indicate worst-case rms load for each substation for all 3B### runs.

Case #	Location of Simultaneous Start	Substation rms Loads (% capacity)	Substation Peak Load (Maximum Peak)	Minimum Train Voltage & Location
3Bmon	Monrovia Station	Titley 53%	Titley <300%	535 VDC on the Southbound track, at Milepost 20.353 (near Monrovia station)
		Michilinda 34%	Michilinda <300%	
		Baldwin 30%	Baldwin <300%	
		Joseph 54%	Joseph <300%	
		Los Robles 53%	Los Robles <300%	
		Yard 57%	Yard <300%	
		Bus Center 42%	Bus Center <300%	
		Irwindale 42%	Irwindale <300%	
		Virginia 35%	Virginia <300%	
		Soldano 41%	Soldano <300%	
		Citrus 35%	Citrus <300%	
3Bdua	Duarte Station	Titley 50%	Titley <300%	593 VDC on the Southbound track, at Milepost 20.353 (near Monrovia station)
		Michilinda 32%	Michilinda <300%	
		Baldwin 29%	Baldwin <300%	
		Joseph 48%	Joseph <300%	
		Los Robles 39%	Los Robles <300%	
		Yard 50%	Yard <300%	
		Bus Center 61%	Bus Center <300%	
		Irwindale 48%	Irwindale <300%	
		Virginia 29%	Virginia <300%	
		Soldano 39%	Soldano <300%	
		Citrus 35%	Citrus <300%	
3Birw	Irwindale Station	Titley 44%	Titley <300%	602 VDC on the Southbound track, at Milepost 20.353 (near Monrovia station)
		Michilinda 28%	Michilinda <300%	
		Baldwin 29%	Baldwin <300%	
		Joseph 49%	Joseph <300%	
		Los Robles 43%	Los Robles <300%	
		Yard 41%	Yard <300%	
		Bus Center 45%	Bus Center <300%	
		Irwindale 61%	Irwindale <300%	
		Virginia 34%	Virginia <300%	
		Soldano 38%	Soldano <300%	
		Citrus 35%	Citrus <300%	

Case #	Location of Simultaneous Start	Substation rms Loads (% capacity)	Substation Peak Load (Maximum Peak)	Minimum Train Voltage & Location
3Baza	Azusa Alameda Station	Titley........ 47% Michilinda .... 29% Baldwin........ 29% Joseph........ 50% Los Robles .... 44% Yard........ 46% Bus Center .... 46% Irwindale .... 62% Virginia .... 41% Soldano........ 57% Citrus........ 41%	Titley .... <300% Michilinda........ <300% Baldwin .... <300% Joseph .... <300% Los Robles........ <300% Yard .... <300% Bus Center........ <300% Irwindale .... <300% Virginia........ <300% Soldano........ <300% Citrus .... <300%	570 VDC on the Southbound track, at Milepost 20.353 (near Monrovia station)

Table 4 - Summary of Results from Load-Flow Simulations for Contingency Operations[12]

Case #	Substation Out-of-Service	Adjacent Substations	Substation rms Loads (% capacity)	Substation Peak Load (Maximum Peak)	Minimum Train Voltage & Location
3B99	Titley	Craig & Michilinda	Michilinda 50%	Michilinda <300%	565 VDC on the Southbound track, at Milepost 15.578 (near Sierra Madre Villa station)
			Baldwin 29%	Baldwin <300%	
			Joseph 39%	Joseph <300%	
			Los Robles 35%	Los Robles <300%	
			Yard 45%	Yard <300%	
			Bus Center 54%	Bus Center <300%	
			Irwindale 41%	Irwindale <300%	
			Virginia 29%	Virginia <300%	
			Soldano 34%	Soldano <300%	
			Citrus 32%	Citrus <300%	
3B01	Michilinda	Titley & Baldwin	Titley 62%	Titley <300%	528 VDC on the Northbound track, at Milepost 15.812 (near Sierra Madre Villa station)
			Baldwin 42%	Baldwin <300%	
			Joseph 43%	Joseph <300%	
			Los Robles 38%	Los Robles <300%	
			Yard 48%	Yard <300%	
			Bus Center 54%	Bus Center <300%	
			Irwindale 57%	Irwindale <300%	
			Virginia 35%	Virginia <300%	
			Soldano 41%	Soldano <300%	
			Citrus 37%	Citrus <300%	
3B02	Baldwin	Michilinda & Joseph	Titley 54%	Titley <300%	594 VDC on the Southbound track, at Milepost 20.353 (near Monrovia station)
			Michilinda 42%	Michilinda <300%	
			Joseph 53%	Joseph <300%	
			Los Robles 42%	Los Robles <300%	
			Yard 50%	Yard <300%	
			Bus Center 57%	Bus Center <300%	
			Irwindale 49%	Irwindale <300%	
			Virginia 35%	Virginia <300%	
			Soldano 44%	Soldano <300%	
			Citrus 37%	Citrus <300%	

12 Shaded lines indicate worst-case rms load for each substation for all 3B## runs.

Case #	Substation Out-of-Service	Adjacent Substations	Substation rms Loads (% capacity)	Substation Peak Load (Maximum Peak)	Minimum Train Voltage & Location
3B03	Joseph	Baldwin & Los Robles	Titley....44% Michilinda....32% Baldwin....45% Los Robles....63% Yard....45% Bus Center....49% Irwindale....47% Virginia....37% Soldano....39% Citrus....36%	Titley....<300% Michilinda....<300% Baldwin....<300% Los Robles....<300% Yard....<300% Bus Center....<300% Irwindale....<300% Virginia....<300% Soldano....<300% Citrus....<300%	528 VDC on the Northbound track, at Milepost 18.808 (near Arcadia station)
3B04	Los Robles	Joseph & Yard	Titley....45% Michilinda....30% Baldwin....30% Joseph....67% Yard....61% Bus Center....50% Irwindale....46% Virginia....38% Soldano....38% Citrus....33%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Yard....<300% Bus Center....<300% Irwindale....<300% Virginia....<300% Soldano....<300% Citrus....<300%	525 VDC on the Southbound track, at Milepost 20.263 (near Monrovia station)
3B05	Yard	Los Robles & Bus Center	Titley....43% Michilinda....27% Baldwin....27% Joseph....43% Los Robles....47% Bus Center....66% Irwindale....45% Virginia....27% Soldano....33% Citrus....31%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Los Robles....<300% Bus Center....<300% Irwindale....<300% Virginia....<300% Soldano....<300% Citrus....<300%	579 VDC on the Southbound track, at Milepost 20.359 (near Monrovia station)

Case #	Substation Out-of-Service	Adjacent Substations	Substation rms Loads (% capacity)	Substation Peak Load (Maximum Peak)	Minimum Train Voltage & Location
3B06	Bus Center	Yard & Irwindale	Titley....43% Michilinda....27% Baldwin....26% Joseph....41% Los Robles....35% Yard....63% Irwindale....59% Virginia....29% Soldano....34% Citrus....31%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Los Robles....<300% Yard....<300% Irwindale....<300% Virginia....<300% Soldano....<300% Citrus....<300%	551 VDC on the Southbound track, at Milepost 22.289 (near Duarte station)
3B07	Irwindale	Bus Center & Virginia	Titley....37% Michilinda....25% Baldwin....26% Joseph....44% Los Robles....40% Yard....40% Bus Center....63% Virginia....58% Soldano....50% Citrus....36%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Los Robles....<300% Yard....<300% Bus Center....<300% Virginia....<300% Soldano....<300% Citrus....<300%	546 VDC on the Northbound track, at Milepost 24.604 (near Irwindale station)
3B08	Virginia	Irwindale & Soldano	Titley....35% Michilinda....24% Baldwin....25% Joseph....43% Los Robles....37% Yard....38% Bus Center....45% Irwindale....61% Soldano....60% Citrus....40%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Los Robles....<300% Yard....<300% Bus Center....<300% Irwindale....<300% Soldano....<300% Citrus....<300%	663 VDC on the Southbound track, at Milepost 20.359 (near Monrovia station)

Case #	Substation Out-of-Service	Adjacent Substations	Substation rms Loads (% capacity)	Substation Peak Load (Maximum Peak)	Minimum Train Voltage & Location
3B09	Soldano	Virginia & Citrus	Titley....33% Michilinda....22% Baldwin....28% Joseph....41% Los Robles....34% Yard....37% Bus Center....42% Irwindale....63% Virginia....54% Citrus....51%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Los Robles....<300% Yard....<300% Bus Center....<300% Irwindale....<300% Virginia....<300% Citrus....<300%	634 VDC on the Southbound track, at Milepost 25.880 (near Azusa Alameda station)
3B10	Citrus	Soldano	Titley....35% Michilinda....24% Baldwin....25% Joseph....43% Los Robles....37% Yard....37% Bus Center....42% Irwindale....52% Virginia....44% Soldano....69%	Titley....<300% Michilinda....<300% Baldwin....<300% Joseph....<300% Los Robles....<300% Yard....<300% Bus Center....<300% Irwindale....<300% Virginia....<300% Soldano....<300%	614 VDC on the Southbound track, at Milepost 26.889 (near Azusa Alameda station)

5.0 ANALYSIS OF PERFORMANCE WITHOUT ADDITIONAL SUBSTATIONS

5.1 Description

The following provides analysis of system performance and capacity if the substations at Michilinda and Soldano were not provided.

All other factors, data and requirements remain as per the main report.

5.2 Analysis

5.2.1 Simulation of Normal Operating Conditions

A series of traction power simulations were performed with all TP substations in service and with simultaneous starting of trains at full performance from each station, except terminal stations as follows:

- Simultaneous start from stations (Run series 3D###)[13].

The analysis indicated that even with all substations in service, the system cannot maintain traction voltage in compliance with Metro criteria. Specifically, for Run series 3Daza (simultaneous start from Azusa Alameda station), the minimum train voltage was 407 volts (see Figure 8). The latter case, in particular, reflects a voltage condition significantly below what Metro trains can accept and thus indicates that operation would be significantly affected, with trains shutting-down temporarily.

5.2.2 Simulation of Contingency Operating Conditions

A series of traction power simulations were performed with each TP substation out of service as follows:

- Simultaneous start from nearest station (Run series 3D##)[14]

The analysis indicated that of the nine conditions simulated, all but two resulted in voltages below acceptable criteria. Moreover, two simulations showed very poor performance (likely to lead to frequent shut-down of LRVs due to low voltage) and two were highly unstable (voltages were too low to stabilize the system at any voltage). Table 5 provides a summary of the results. Figures 9 through 15 provide graphs of train voltage for these simulations.

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13 "###" is a 3-letter variable, used to designate the station at which simultaneous start occurs.
14 "##" is a 2-number variable, used to designate the out-of-service substation.

Table 5 - Summary of Results from Load-Flow Simulations for Contingency Operations

Case #	Substation Out-of-Service	Adjacent Substations	Minimum Train Voltage & Location	Notes
3D99	Titley	Craig & Baldwin	174 VDC	Highly unstable
3D01	Baldwin	Titley & Joseph	410 VDC	Very poor
3D02	Joseph	Baldwin & Los Robles	520 VDC	Below Criteria
3D03	Los Robles	Joseph & Yard	523 VDC	Below Criteria
3D04	Yard	Los Robles & Bus Center	578 VDC	Acceptable
3D05	Bus Center	Yard & Irwindale	511 VDC	Below Criteria
3D06	Irwindale	Bus Center & Virginia	533 VDC	Acceptable
3D07	Virginia	Irwindale & Citrus	424 VDC	Very poor
3D08	Citrus	Irwindale	220 VDC	Highly unstable

Figure 8 - Train voltage for Case 3Daza (Simultaneous start from Azusa Alameda station)

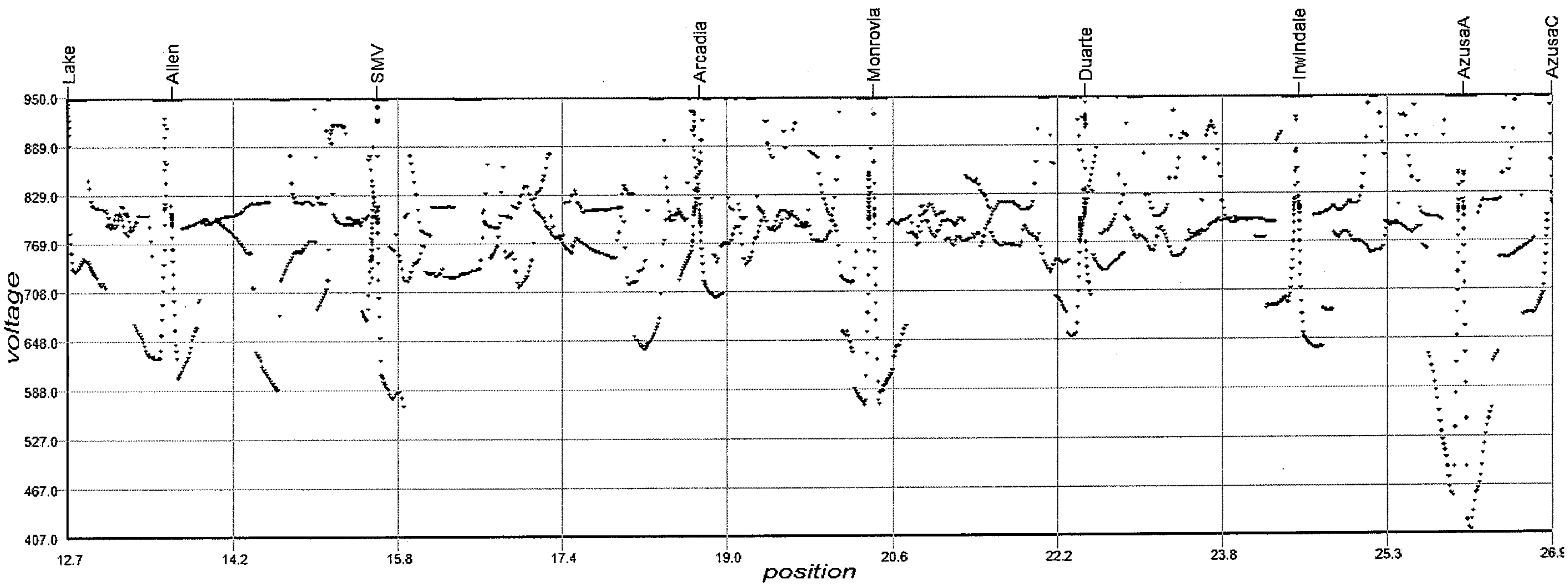

Figure 9 - Train voltage for Case 3D99 (Titley Substation out of service)

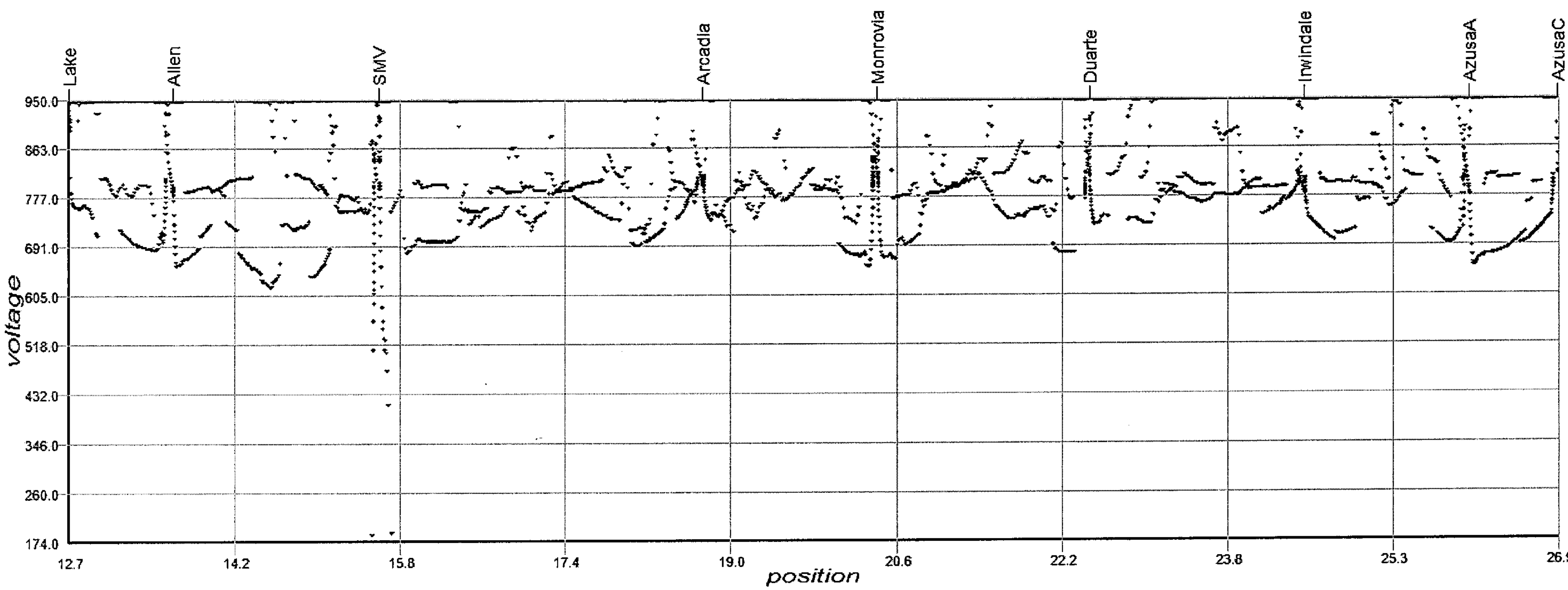

Figure 10 - Train voltage for Case 3D01 (Baldwin Substation out of service)

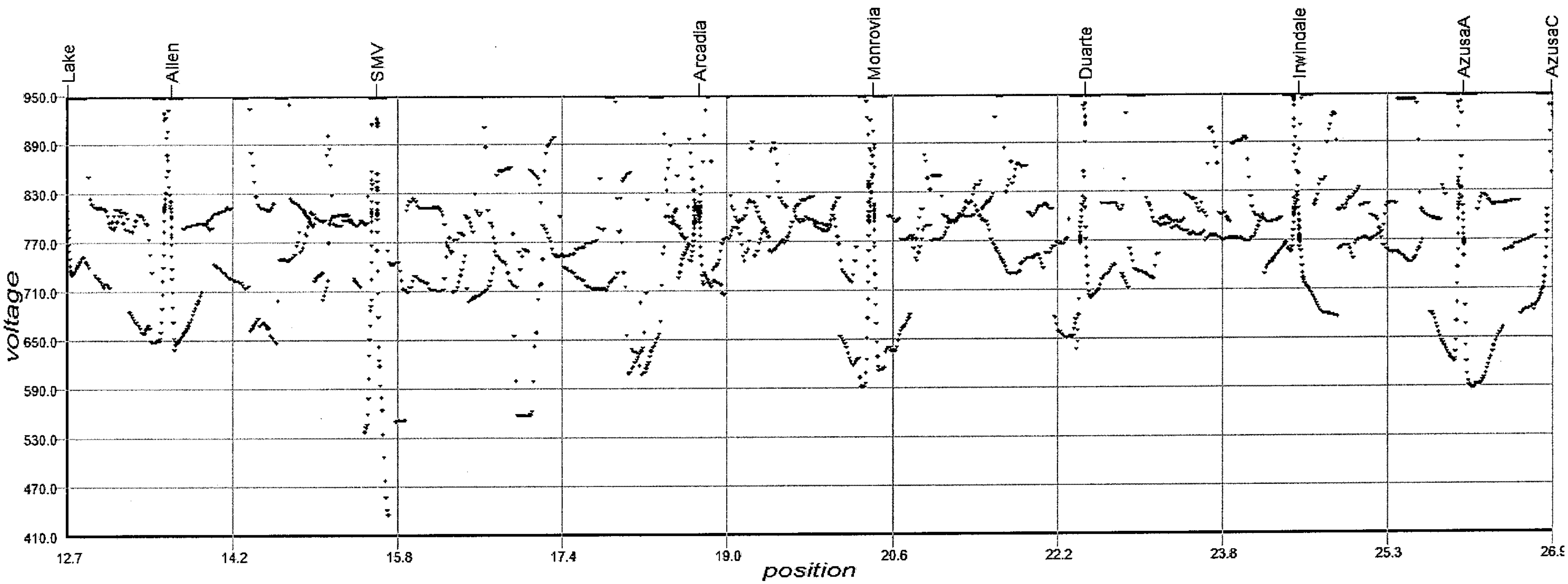

Figure 11 - Train voltage for Case 3D02 (Joseph Substation out of service)

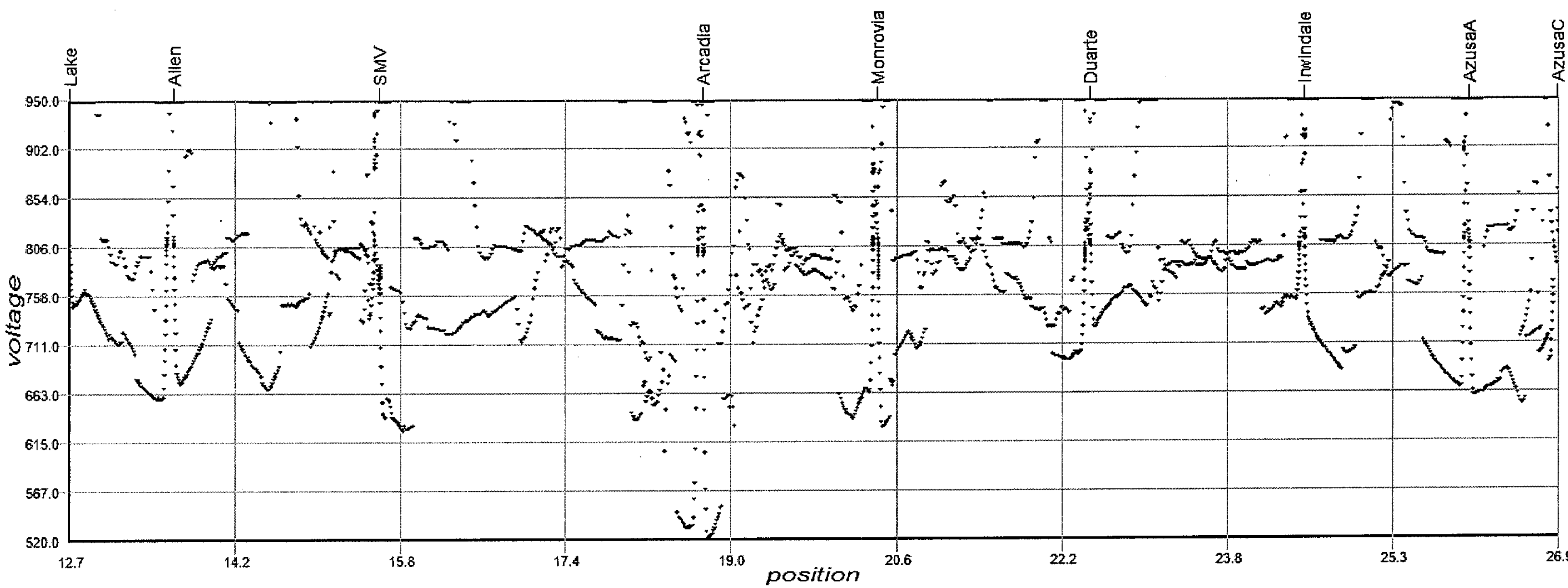

Figure 12 - Train voltage for Case 3D03 (Los Robles Substation out of service)

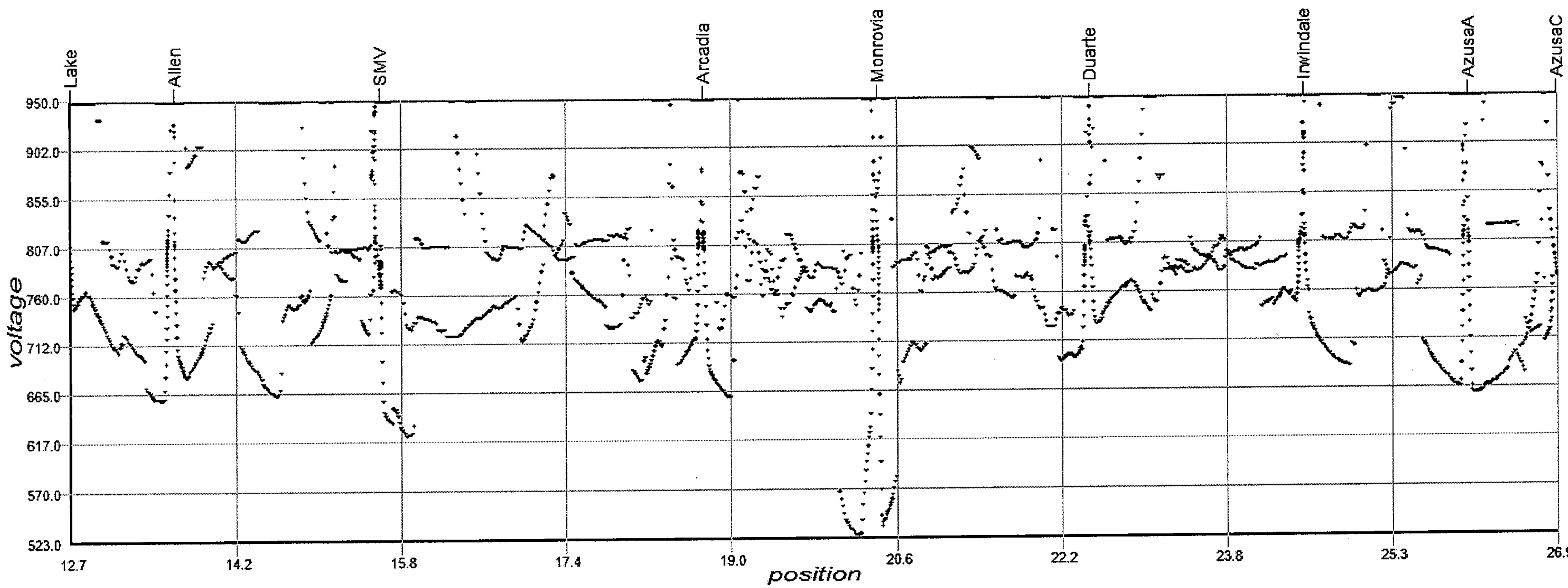

Figure 13 - Train voltage for Case 3D05 (Bus Center Substation out of service)

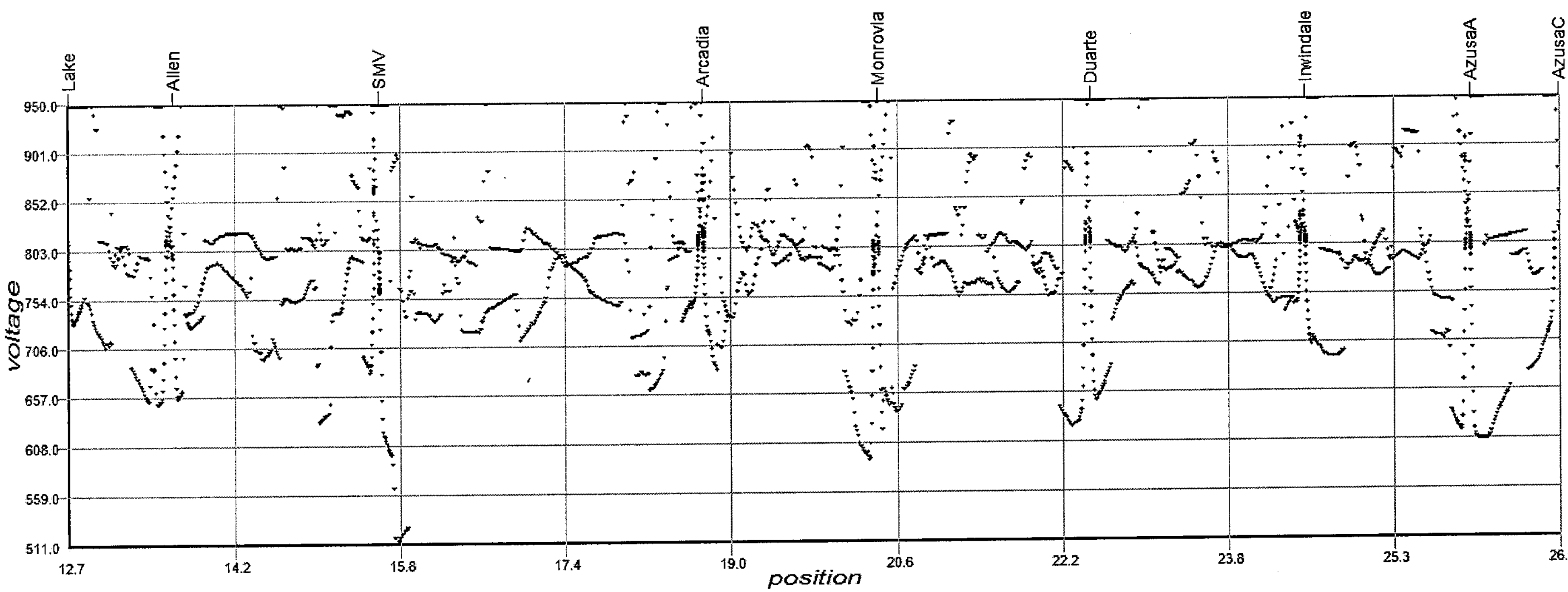

Figure 14 - Train voltage for Case 3D07 (Virginia Substation out of service)