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WECC

2022 Underfrequency Load Shedding Program Assessment

Underfrequency Load Shedding Work Group

October 24, 2022

Executive Summary

The Underfrequency Load Shedding Program Assessment Report summarizes the modeling and study methodology including assumptions, the study cases used, and the simulation results composing the 2022 assessment of the WECC Off-Nominal Frequency Load Shedding Plan (WECC Plan) in accordance with the applicable requirements in NERC Standard PRC-006-5 and WECC Criterion PRC-006-WECC-CRT-3.1. The modeling data validation and the study simulations composing the assessment were performed by WECC Technical Staff under the direction and guidance of the WECC Underfrequency Load Shedding Work Group (UFLSWG) with oversight provided by the Studies Subcommittee (StS) under the Reliability Assessment Committee (RAC). PowerWorld Simulator Version 22 software platform was used for all steady-state and dynamic simulations composing this assessment.

During this assessment, performance of the WECC Plan was assessed under heavy load conditions in the 2021 HS3 operating case and light load conditions in the 2024 LSP1 scenario case. For both operating conditions, frequency performance was evaluated in the WECC Island (entire Western Interconnection footprint), the North Island and the South Island at 10%, 20%, and 25% generation-to-load imbalance levels using the criteria in D.B.3.1 and D.B.3.2 in NERC Standard PRC-006-5. The arrest in frequency decline, the frequency nadir, and the frequency recovery performance was monitored at 48 representative buses spanning the Western Interconnection, equally divided between the studied North and South islands.

V/Hz performance was monitored in all 25% imbalance levels and violations of the criteria in D.B.3.3 in NERC Standard PRC-006-5 are identified in this report. These V/Hz violations will be monitored in future assessments to establish validity.

The difference between the armed load that was available to be shed and the load shed during the 25% imbalance underfrequency simulations was used to evaluate the implemented (i.e., modeled) WECC Plan's adequacy and effectiveness. The amount of load that was armed to be shed but was not actually shed, was calculated. In this report, this value is called "available armed load margin" and indicates the adequacy of the WECC Plan's implementation. As noted in the previous assessment, the North Island has significantly less armed load margin than the South Island. This level of margin should be verified and compared in future UFLS assessments.

Finally, the 25% WECC Island and North Island imbalance simulations, under 2021 HS3 heavy load conditions, failed to run successfully. In both cases, extreme low voltages in multiple areas of the interconnection, as well as formation of additional islands, was observed. As a result, this 2022 UFLS Assessment demonstrates that the WECC Off-Nominal Frequency Load Shedding Plan may not conform to all applicable requirements in NERC Standard PRC-006-5.

The recommendations in this report follow:

1. Both the WECC and North Island simulations under 25% imbalance conditions in the 21 HS scenario failed to run the required amount of time and, therefore, did not produce meaningful results. The UFLSWG should investigate the cause and develop a Corrective Action Plan if the WECC Plan is insufficient.
2. While running the WECC and North Island simulations under 25% imbalance conditions in the 21 HS scenario identified in Recommendation 1, extreme low voltages in many areas were observed. The UFLSWG should determine whether these instances of low voltage could be remedied by modeling reactive devices that could operate in the time frame of the simulations.
3. V/Hz violations need to be addressed.
    a. Each PC should evaluate the affected units with violations in their control area and validate the behavior of the model. If model updates are required, these should be communicated to the necessary people.
4. The current UFLS Methodology Document, which outlines how the UFLS Assessment is performed, should be reviewed by the UFLSWG to address:
    a. Methods of causing imbalance (e.g., tripping generation, setting unit PGen to zero but allowing it to stay online, dynamically opening tie lines, adding load)
    b. Selection of generators to trip, including unit location, unit type (e.g., synchronous generator, IBR, must-runs)

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Purpose

The WECC Off-Nominal Frequency Load Shedding Plan (WECC Plan) was formalized and first approved in 1997 by the Western Systems Coordinating Council (WSCC), WECC's predecessor. A coordinated off-nominal frequency load shedding plan was originally developed by WSCC in the 1980s. This coordinated plan's design was updated in response to three system-wide disturbances that occurred in 1996 before its initial approval and adoption. The current WECC Plan was revised and approved in 2011 after the NERC Standard PRC-006-1 was approved in 2010. The current version of the NERC Standard PRC-006-5 was approved in 2021 and includes a WECC variance in Section D.B.

WECC has two documents associated with its Underfrequency Load Shedding (UFLS) program. The primary document is the WECC Plan, effective May 24, 2011. It is the comprehensive description of WECC's coordinated UFLS program and contains the background, design objectives, performance criteria, and the plan design details. The second document is WECC Criterion PRC-006-WECC-CRT-3.1, effective June 18, 2019, which was created to ensure consistent use of the WECC Plan among all applicable WECC entities and to coordinate the UFLS database maintenance and update requirements among these entities.

Planning Coordinators (PC) in the Western Interconnection have designated the Underfrequency Load Shedding Work Group (UFLSWG) to biennially assess the performance of the WECC Plan per the UFLSWG Charter and to help WECC Members meet their compliance with NERC Reliability Standard PRC-006-5. The activities and deliverables of the UFLSWG are overseen by the Studies Subcommittee (StS), which reports to the Reliability Assessment Committee (RAC). The biennial WECC Plan assessment is reviewed and approved by both the RAC and the Reliability Risk Committee (RRC).

Responsibilities of the UFLSWG, as identified in its charter, are to:

- Review UFLS data annually submitted by applicable WECC entities for consistency and accuracy of modeling (per requirements contained in PRC-006-WECC-CRT-3.1);
- Perform a biennial assessment of the WECC Plan to determine its effectiveness and adequacy in meeting the performance characteristics specified in PRC-006;
- Document the simulation results obtained from the biennial assessment in a report;
- Recommend improvements to the WECC Plan's design and implementation to the RRC and StS, based on findings of the biennial assessment; and
- Perform other tasks as assigned by the StS or the RRC.

Within the Western Interconnection, the way electrical islands are formed results in two islands: the North Island and the South Island. As a result, the WECC Plan includes two sub-area plans—one for each island in addition to the Primary plan. The Primary (aka WECC) plan and both sub-area plans—the Northwest Power Pool (NWPP) plan and the South Island Load Tripping Sub-area Plan (SILTP)—are detailed in Section E, items 1a, 1b, and 1c of the WECC Off-Nominal Frequency Load Shedding

Plan document. UFLS entities can adopt one plan or a combination of the three plans based on the location of their loads in the Western Interconnection. Most entities use one plan, but some UFLS entities' loads are located in more than one sub-region, so, they use more than one plan.

This report summarizes the modeling and study methods including assumptions, the study cases used, and the simulation results comprised in the 2022 assessment of the WECC Off-Nominal Frequency Load Shedding Plan in accordance with the applicable requirements in NERC Standard PRC-006-5 and WECC Criterion PRC-006-WECC-CRT-3.1.[1] The modeling data validation and the study simulations included in the assessment were performed by WECC Technical Staff under the direction and guidance of the WECC UFLS Work Group with oversight provided by the Studies Subcommittee (StS) under the Reliability Assessment Committee (RAC).

Study Methods

Performance of the WECC Plan was assessed under 2021 heavy summer (21HS) and 2024 light spring (24LSP) operating conditions by starting with the approved versions of the 21HS3A.sav and 24LSP1-SA.sav WECC base cases, respectively.

Software Platform and Dynamic Models

PowerWorld Simulator Version 22 was used for all steady-state and dynamic simulations in the studies performed for this assessment.

UFLS functionality was modeled in dynamic simulations by the lsdt9, lsdt1, and tlin1 models, which will automatically trip specified amounts of load at specific frequency levels. The WECC Plan also includes some automatic load restoration (reclosing) to arrest frequency overshoot, which, if actuated, would operate within the duration of the simulation run for the assessment.

UFLS Database Review

All data necessary to model the WECC Plan in dynamic simulations is contained in a UFLS database maintained by WECC staff. UFLS entities are asked to annually review this database and update it if necessary. The database is updated through a request from WECC to all UFLS entities to compile and submit their respective UFLS plan data and dynamic files using the data input form "Attachment A" of PRC-006-WECC-CRT-3.1. The "Attachment A" data input form is a spreadsheet that includes tabs where UFLS entities summarize their feeders and loads armed with UFLS relays, demonstrating that they provide automatic tripping of load in accordance with the UFLS program design. The database

[1] Compliance with NERC Reliability Standard PRC-006 and WECC Regional Criteria PRC-006-WECC-CRT requirements is the responsibility of NERC Registered Entities. WECC does not guarantee that this report or any analysis or information contained in it is sufficient for compliance with these or any other requirements. It is the responsibility of each NERC Registered Entity to ensure that it meets its compliance responsibilities as applicable.

update occurs once each calendar year and is completed by June 1 for Generator Owners and July 1 for the other UFLS entities in accordance with PRC-006-WECC-CRT-3.1. The UFLSWG reviews and updates the Attachment A template before each data request to ensure that the UFLS database contains the data necessary to model the UFLS program once the Attachment A data input forms are completed by the UFLS entities.

The UFLS database submissions are reviewed by the UFLSWG to ensure the WECC Master Dynamics File (MDF) accurately reflects the submitted UFLS plan data. Inconsistencies are reported back to the UFLS entities with a request to correct the errors in the MDF through the company's respective MOD-032 processes. The MDF contains data necessary to model the UFLS program for use in event analysis and assessments. Further, it is available to all PCs within the Western Interconnection.

The process for annual maintenance of the UFLS database described above, followed by the UFLSWG on behalf of all PCs within the Western Interconnection, is in accordance with PRC-006-WECC-CRT-3.1.

Island Formation in the Western Interconnection

PCs in the Western Interconnection have regularly participated in a joint regional review to identify the portions of the interconnection's Bulk Electric System (BES) that may form islands. The criteria used to identify the formation of plausible islands in the Western Interconnection includes:

a. Consideration of historical events,
b. System studies, and
c. Any portions of the BES designed to detach into islands because of Remedial Action Scheme (RAS) operation.

Based on these criteria, the consensus among PCs in the Western Interconnection is that the formation of two planned islands in the Western Interconnection—the North Island and the South Island—continues to be an adequate basis for the interconnection-wide coordinated UFLS program. Identification of both North and South islands is based on opening tie lines in the WECC Island—the entire Western Interconnection footprint—as further described below. The selection of islands in the Western Interconnection is therefore consistent with D.B.1 and D.B.2 in PRC-006-5.

As noted earlier, the WECC Plan was initially approved and adopted in 1997 in response to three system-wide disturbances that occurred in 1996. Since then, it has been periodically updated or refined to include two sub-area plans—the Northwest Power Pool (NWPP) plan and the South Island Load Tripping Sub-area Plan (SILTP)—that are fully coordinated with the primary (original) WECC area plan. After the 2011 disturbance event, the WECC UFLS Review Group (predecessor of the current WECC UFLS Work Group) evaluated the new island configurations that occurred during that disturbance (see 2013 UFLS Assessment). At the March 2014 meeting of the Planning Coordination Committee, the UFLS Review Group chair presented 14 potential BES island configurations based on the 2011 disturbance event, system studies, and RAS operation. The UFLSWG proposed, and the Planning Coordination Committee approved, that it is adequate to simulate the following planned islands in the 2015 UFLS Assessment:

- WECC Island;
- North Island; and
- South Island.

To date, the UFLSWG has not identified any other plausible island based on application of the island formation criteria. Therefore, like the 2015, 2017, and 2019 UFLS Assessments, the studies for this 2022 UFLS Assessment are also performed for the three planned islands noted above.

In the 2022 UFLS Assessment, dynamic simulations were run on all three specified islands in both WECC base cases identified earlier. The WECC Island is the entire Western Interconnection as represented in WECC base cases. The North and South islands are formed by starting with a WECC Island base case and splitting the Western Interconnection into two parts by opening the tie lines between the north and south halves. The WECC-1 RAS (aka NE/SE Separation Scheme) was designed to operationally perform this function. To form the North and South islands in the base case models, the following transmission elements were opened in accordance with the WECC-1 RAS (refer to Appendix E for details):

- Malin–Round Mountain #1 & #2 500 kV lines;
- Captain Jack–Olinda #1 500 kV line;
- Delta–Cascade #1 115 kV line;
- Pinto–Four Corners #1 345 kV line;
- Red Butte–Harry Allen #1 345 kV line;
- Walsenburg–Gladstone #1 230 kV line;
- Silver Peak–Control #1 & #2 55 kV lines;
- Summit/Drum–Cascade #1 60 kV and #1 & #2 115 kV lines;
- Robinson Summit–Harry Allen #1 500 kV line;
- Glen Canyon–Sigurd 230 kV line;
- Shiprock–Lost Canyon 230 kV line;
- Glade–Hesperus 115 kV line; and
- San Juan–Hesperus 345 kV line.

Generation–Load Imbalance

To simulate UFLS, a system event resulting in low frequency must be simulated; and to achieve a low frequency condition, it is necessary to simulate a case where generation in the interconnection is less than the load. In other words, there must be an imbalance between load and generation. In this assessment, the imbalance was calculated as described in D.B.3. in PRC-006-5 as:

$$\% \, Imbalance = \frac{(\text{Load} - \text{Actual Generation Output})}{\text{Load}}$$

where Actual Generation Output = Total On-line Generation Output Prior to the Outage—Generation Tripped. Imbalance levels of 10%, 20%, and 25% were simulated for this assessment. These three imbalance levels were simulated in each of the three islands in both base cases for a total of 18 simulations.

Frequency Performance and Monitored Buses

The frequency performance was evaluated for each of the three islands (WECC, North, and South) in both the 2021 heavy summer (21HS3) and the 2024 light spring (24LSP1-S) by applying the criteria noted in D.B.3.1 and D.B.3.2 in PRC-006-5. Specifically, this was done by monitoring the arrest in frequency decline, the frequency nadir, and the frequency recovery. The frequency was monitored at 48 representative buses in the Western Interconnection; 24 each in the North and the South islands. Within each island, the 24 monitored buses were equally divided among four sub-regions of the island. The six buses in each sub-region were selected to achieve both geographic and voltage-level diversity throughout the sub-region. The 48 monitored buses, at which frequency performance of the WECC Plan was verified, are tabulated in Tables 1 and 2.

Table 1: North Island Monitored Buses

Canada	MT/ID/WY	WA/OR	CO/UT/NV
Williston 500 kV	Garrison 500 kV	Coulee 500 kV	Valmy 345 kV
Nicola 500 kV	Midpoint 500 kV	John Day 500 kV	Terminal 345 kV
Langdon 240 kV	Bridger 345 kV	Bethel 230 kV	Daniels Park 230 kV
Kelly Lake 230 kV	Wyodak 230 kV	Boundary 115 kV	Sigurd 230 kV
Clover Bar 240 kV	Crossover 230 kV	Talbot Hill 115 kV	Hayden 230 kV
Muskeg River 72 kV	DRAM 138 kV	Port Angeles 69 kV	North 115 kV

Table 2: South Island Monitored Buses

N. California	S. California/Mexico	S. California/NV	AZ/NM
Red Mountain 500 kV	Vincent 500 kV	Harry Allen 500 kV	Moenkopi 500 kV
Midway 500 kV	Imperial Valley 500 kV	McCullough 500 kV	Rio Puerco 345 kV
Gregg 230 kV	Sylmar 230 kV	Victorville 500 kV	Gladstone 230 kV
Folsom 230 kV	Rosita 230 kV	Decatur 230 kV	Phoenix 230 kV
Newark 115 kV	Mesa Rim 69 kV	El Segundo 230 kV	Alomogordo 115 kV
Rector 66 kV	San Onofre 12.47 kV	Millers 57.5 kV	Tucson 47.2 kV

Functionally, the dynamic simulations for evaluating the frequency performance of the modeled Western Interconnection are achieved by tripping generation to form the target generation–load imbalance (10%, 20%, and 25%). After the generation is tripped, the simulation must run for 60 seconds to make sure that (1) the simulation is stable, (2) the frequency recovers to the required level specified in PRC-006, and (3) additional data checks can be performed, such as V/Hz (see next section). Frequency response plots were produced for each simulation run—at 48 buses for the WECC Island, and at 24 buses each for the North Island and South Island.

V/Hz Performance Check

This verification was performed at each generator bus and generator step-up transformer high-side bus by applying the V/Hz criteria noted in D.B.3.3 in PRC-006-5. That is, for each simulated event, V/Hz could not exceed 1.18 per unit for more than two seconds cumulatively and could also not exceed 1.10 per unit for more than 45 seconds cumulatively.

WECC Island Study

WECC 2021HS Case

Load = 175,979 MW Generation Output = 182,007 MW

W21HS Imbalance

Imbalance	Generation Tripped, MW		Imbalance
Target	Target	Actual	Actual
10%	23,626	24,284	10.4%
20%	41,224	41,383	20.1%
25%	50,023	50,076	25.0%

W21HS Frequency Performance

The frequency response plots are included in Appendix A. Frequency performance results from these plots for the 10% and 20% imbalance simulations meet requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5. However, the 25% imbalance simulation failed to run the required 60 seconds and failed at 47 seconds, shown in Figure 1. Additional results point to voltage collapse at lower voltage levels shown in Figure 2. Because of this, the WECC Plan does not meet the frequency performance requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5 for the 25% imbalance.

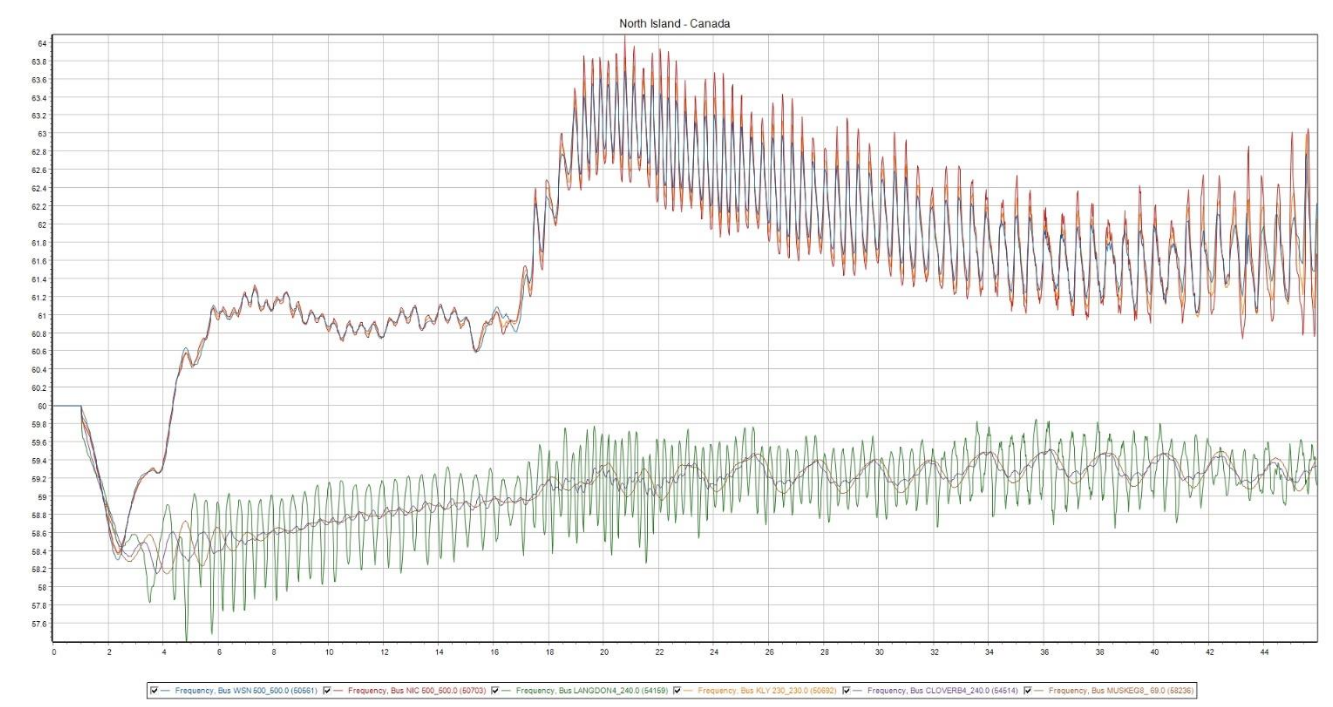


Figure 1: Unstable System

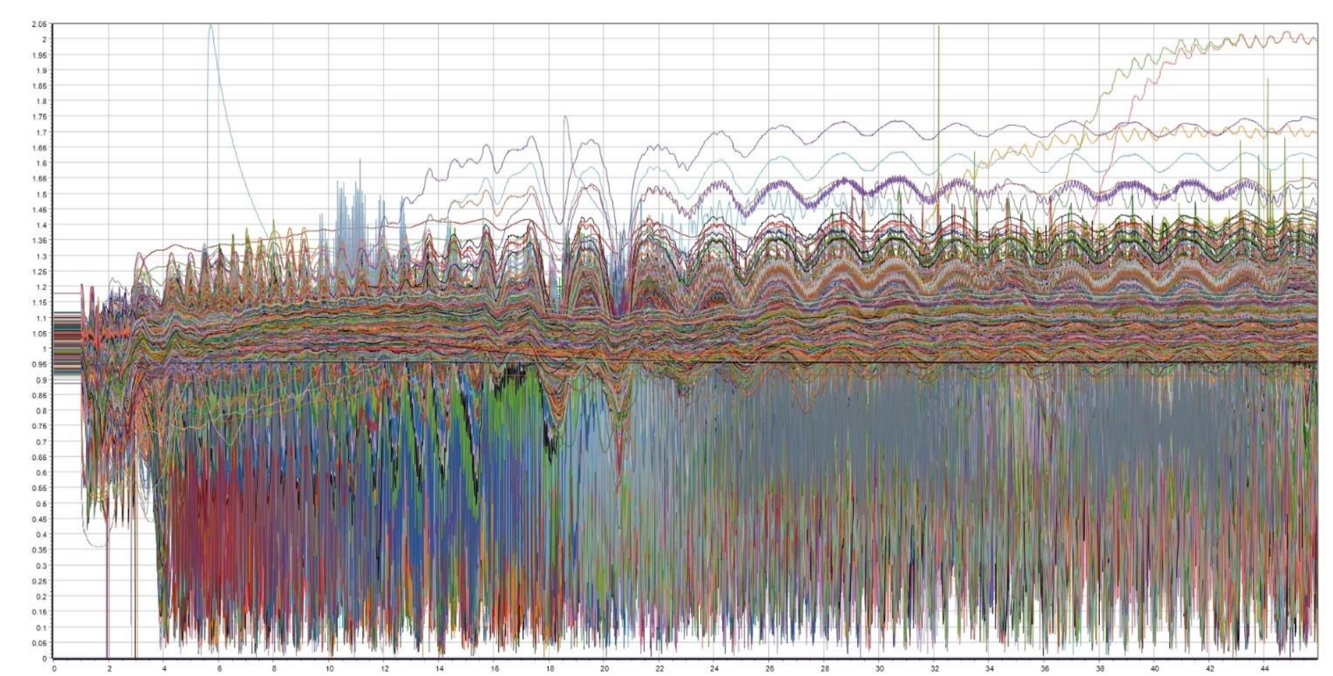


Figure 2: Sub-100kV Voltage

WECC 2024LSP Case

Load = 92,054 MW   Generation Output = 94,604 MW

W24LSP Imbalance

Imbalance	Generation Tripped, MW		Imbalance
Target	Target	Actual	Actual
10%	11,756	12,761	11.1%
20%	20,961	21,208	20.3%
25%	25,564	24,790	24.2%

W24LSP Frequency Performance

The frequency response plots are included in Appendix A. Frequency performance results from these plots for the 10%, 20%, and 25% imbalance simulations meet requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5.

North Island Study

North 2021HS Case

Load = 79,272 MW   Generation Output = 84,455 MW

N21HS Imbalance

Imbalance	Generation Tripped, MW		Imbalance
Target	Target	Actual	Actual
10%	13,110	13,162	10.1%
20%	21,037	23,659	23.3%
25%	25,001	26,487	26.9%

N21HS Frequency Performance

The frequency response plots are included in Appendix A. Frequency performance results from these plots for the 10% and 20% imbalance simulations meet requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5. However, the 25% imbalance simulation failed to run the required amount of time and failed at 35 seconds, shown in Figure 3. Additional results point to voltage collapse at lower voltage levels, shown in Figure 4. Because of this, the WECC Plan does not meet the frequency performance requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5 for the 25% imbalance.

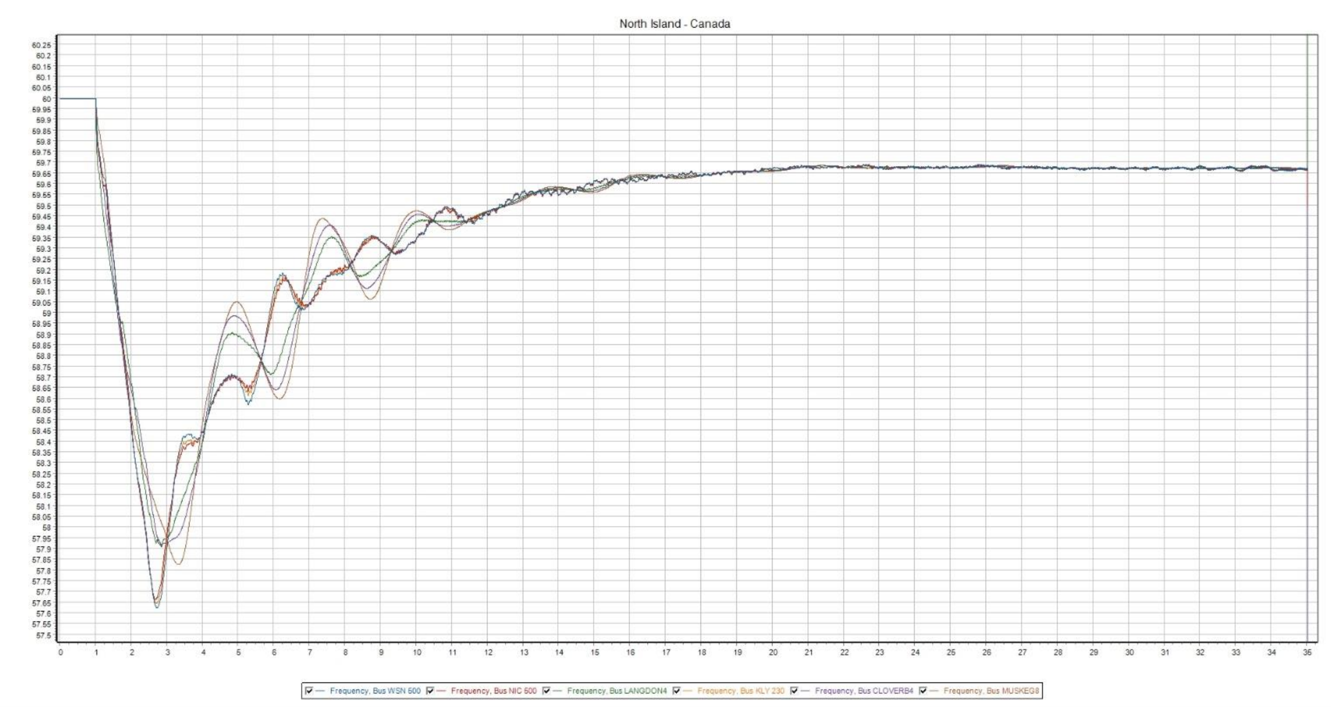


Figure 3: Simulation aborts at 35 seconds

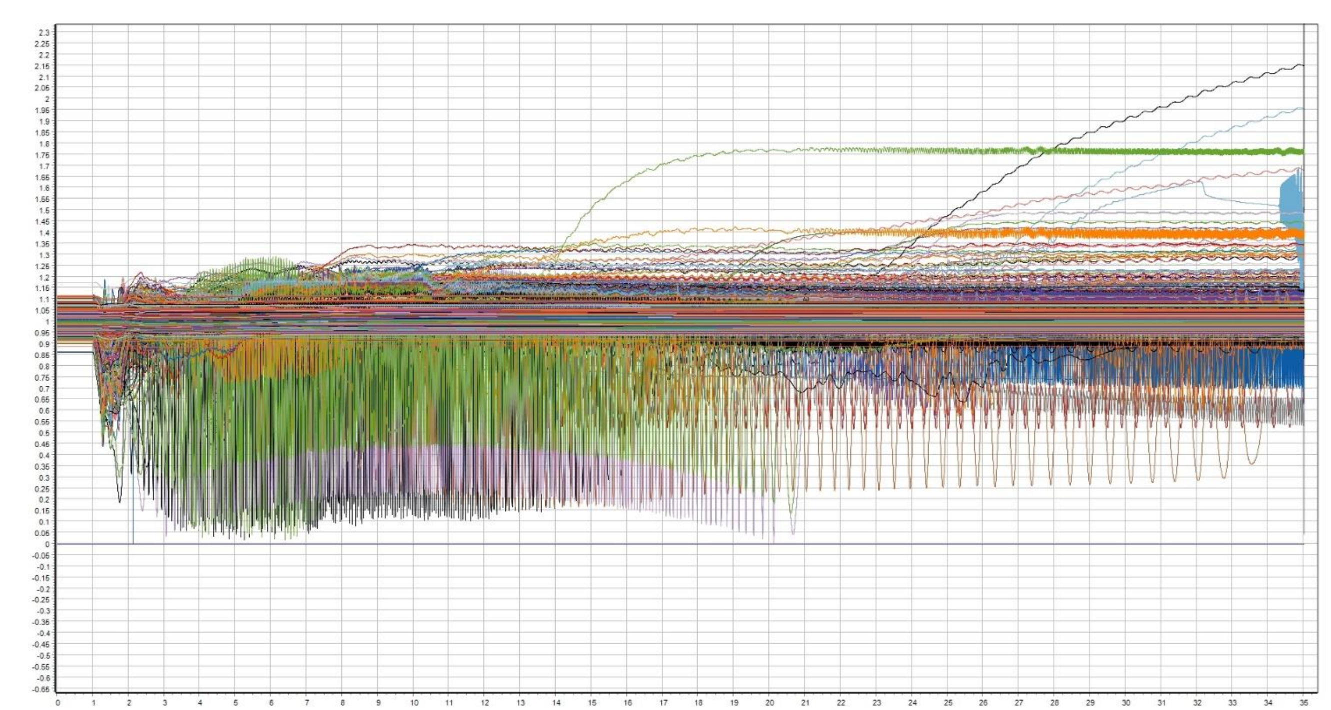


Figure 4: Sub-100kV Voltage

North 2024LSP Case

Load = 48,438 MW   Generation Output = 49,499 MW

N24LSP Imbalance

Imbalance	Generation Tripped, MW		Imbalance
Target	Target	Actual	Actual
10%	5,905	6,053	10.3%
20%	10,749	11,321	21.2%
25%	13,171	13,319	25.3%

N24LSP Frequency Performance

The frequency response plots are included in Appendix A. Frequency performance results from these plots for the 10%, 20%, and 25% imbalance simulations meet requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5.

South Island Study

South 2021HS Case

Load = 91,529 MW   Generation Output = 91,685 MW

S21HS Imbalance

Imbalance	Generation Tripped, MW		Imbalance
Target	Target	Actual	Actual
10%	9,308	9,346	10.0%
20%	18,461	18,654	20.2%
25%	23,038	23,274	25.3%

S21HS Frequency Performance

The frequency response plots are included in Appendix A. Frequency performance results from these plots for the 10%, 20%, and 25% imbalance simulations meet requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5.

South 2024LSP Case

Load = 43,313 MW   Generation Output = 44,826 MW

S24LSP Imbalance

Imbalance	Generation Tripped, MW		Imbalance
Target	Target	Actual	Actual
10%	5,844	5,768	9.8%
20%	10,175	10,127	19.9%
25%	12,341	12,239	24.8%

S24LSP Frequency Performance

The frequency response plots are included in Appendix A. Frequency performance results from these plots for the 10%, 20%, and 25% imbalance simulations meet requirements specified in D.B.3.1 and D.B.3.2 in PRC-006-5.

V/Hz Performance Check

A V/Hz performance check was done for the WECC, North, and South island simulations. This check is performed on synchronous generators and the high side terminals of generator step-up transformers because of the potential for high V/Hz levels to damage this equipment through elevated magnetic saturation. V/Hz is the voltage of the element (generator terminals or transformer high-side terminals), in per-unit, divided by the frequency at the same location, also in per-unit. This value is then evaluated relative to PRC-006-5, D.B.3.3:

V/Hz Threshold	Time Limit
1.18 per-unit	2.0 sec
1.1 per-unit	45.0 sec (Cumulative)

South Island

2021HS case: 25 criteria exceedances were flagged in the 2021 HS3 South Island 25% imbalance simulation. See Appendix E for WECC Power Flow Areas.

Area	Generator Bus	Violation
10	10261 Unit 1	1.18 pu 2 seconds
	10262 Unit 1	1.18 pu 2 seconds
16	160425 Unit PV	Both
	160435 Unit Q1	1.1 pu 45 seconds
	160902 Unit 1	Both
	160926 Unit 1	Both
	160930 Unit 1	Both
21	21458 Unit 1	Both
24	24026 Unit D1	1.1 pu 45 seconds
	24248 Unit EQ	1.1 pu 45 seconds
	24457 Unit 1	1.1 pu 45 seconds
	24491 Unit 1	1.1 pu 45 seconds
	24695 Unit EQ	Both
	24695 Unit EQ	Both
	29591 Unit 7	1.1 pu 45 seconds

Area	Generator Bus	Violation
	29592 Unit 1	1.1 pu 45 seconds
	29659 Unit EQ	1.1 pu 45 seconds
26	26026 Unit 1	1.18 pu 2 seconds

2024LSP case: Zero criteria exceedances were flagged in the 2024 LSP South Island 25% imbalance simulation.

North Island

2021HS case: 39 criteria exceedances were flagged in the 2021 HS North Island 20% imbalance simulation. The 25% imbalance simulation results are not reported below because of failure to run the entire 60 seconds. See Appendix E for WECC Power flow Areas.

Area	Generator Bus	Violation
40	44980 Unit 1	1.18 pu 2 seconds
	47688 Unit L	Both
	47924 Unit Z1	Both
	47974 Unit Z1	1.18 pu 2 seconds
50[2]	50306 Unit 1	1.18 pu 2 seconds
	50637 Unit 1	1.1 pu 45 seconds

[2] The area 50 (BC Hydro) representative indicated that a RAS is in place to trip 500 kV lines on over-voltage control, and this would remedy any V/Hz exceedances in the BC Hydro area.

Area	Generator Bus	Violation
	50640 Unit 4	1.1 pu 45 seconds
	51140 Unit 1	1.1 pu 45 seconds
54	56401 Unit G2	1.1 pu 45 seconds
	58030 Unit ST	1.1 pu 45 seconds
	59835 Unit G1	1.1 pu 45 seconds
	59935 Unit G2	1.1 pu 45 seconds
	560026 Unit G1	1.1 pu 45 seconds
	560894 Unit G1	1.1 pu 45 seconds
	561026 Unit G2	1.1 pu 45 seconds
	562026 Unit G3	1.1 pu 45 seconds
60	60188 Unit 1	Both
	60121 Unit 1	1.1 pu 45 seconds
	60345 Unit NT	1.1 pu 45 seconds
62	623581 Unit 1	1.18 pu 2 seconds
65	65583 Unit 1	Both

Area	Generator Bus	Violation
	65680 Unit 1	Both
	69517 Unit 1	1.1 pu 45 seconds
	69527 Unit 1	1.1 pu 45 seconds
73	79150 Unit 1	Both
	79151 Unit 3	Both
	79151 Unit 4	Both
	79153 Unit 7	Both
	79153 Unit 8	Both

2024LSP case: 17 criteria exceedances were flagged in the 2024 LSP North Island 25% imbalance simulation. See Appendix E for WECC Power flow Areas.

Area	Generator Bus	Violation
40	42997 Unit Z1	1.1 pu 45 seconds
	44980 Unit 1	1.1 pu 45 seconds
50	50295 Unit 2	1.1 pu 45 seconds
	50296 Unit 3	1.18 pu 2 seconds
	50297 Unit 4	1.18 pu 2 seconds
54	570008	1.1 pu 45 seconds
60	60314 Unit 1	Both
65	65391 Unit 1	Both
	65583 Unit 1	Both
	65778 Unit 1	1.1 pu 45 seconds
	67908 Unit 2	Both
	69020 Unit 1	1.1 pu 45 seconds
	69523 Unit 1	1.1 pu 45 seconds

WECC Island

2021HS case: Five criteria exceedances were flagged in the 2021 HS WECC Island 20% imbalance simulation. The 25% imbalance simulation results are not reported because of failure to run the entire 60 seconds. See Appendix E for WECC Power flow Areas.

Area	Generator Bus	Violation
26	26004 Unit 1	1.1 pu 45 seconds
	26005 Unit 2	1.1 pu 45 seconds
	26006 Unit 3	1.1 pu 45 seconds
	26026 Unit 1	1.18 pu 2 seconds
40	46188 Unit 9	1.1 pu 45 seconds

2024LSP case: 35 criteria exceedances were flagged in the 2024 LSP WECC Island 25% imbalance simulation. See Appendix E for WECC Power flow Areas.

Area	Generator Bus	Violation
24	24560 Unit 1	1.1 pu 45 seconds
	29418 Unit 2	1.1 pu 45 seconds
	29421 Unit 3	1.1 pu 45 seconds
	29425 Unit 4	1.1 pu 45 seconds
	29428 Unit 5	1.1 pu 45 seconds
	29434 Unit 8	Both
	29437 Unit 9	Both
	29591 Unit 7	1.1 pu 45 seconds

Area	Generator Bus	Violation
40	42997 Unit Z1	1.1 pu 45 seconds
	44980 Unit 1	1.1 pu 45 seconds
	47866 Unit Z1	1.1 pu 45 seconds
50	50172 Unit 1	1.1 pu 45 seconds
	50173 Unit 2	1.1 pu 45 seconds
	50174 Unit 3	1.1 pu 45 seconds
	50295 Unit 2	1.18 pu 2 seconds
	50296 Unit 3	1.18 pu 2 seconds
	50297 Unit 4	1.18 pu 2 seconds
	50500 Unit 6	1.1 pu 45 seconds
	50959 Unit 1	1.1 pu 45 seconds
	50960 Unit 2	1.1 pu 45 seconds
	50966 Unit 8	1.1 pu 45 seconds
54	560003 Unit G1	1.1 pu 45 seconds
	570008 Unit G1	1.1 pu 45 seconds

Area	Generator Bus	Violation
60	60314 Unit 1	Both
65	65391 Unit 1	Both
	65583 Unit 1	Both
	67908 Unit 2	Both
	69020 Unit 1	1.1 pu 45 seconds
	69523 Unit 1	1.1 pu 45 seconds

Armed Load Data Validation

As part of the validation check of UFLS data submittals received from the UFLS entities, the amount of load armed for each Load Shed Block of the WECC Plan was tabulated for both the 2021 Heavy Summer and the 2024 Light Spring cases. This benchmarks the consistency between actual implementation of the WECC Plan by UFLS entities compared to its design. The values in the Plan Design columns reflect the Primary WECC plan, NWPP sub-plan, and SILTP sub-plan descriptions in the WECC Plan and are tabulated here for easy comparison. The percentages in these columns are minimum requirements. The values in the "Modeled" columns of Table 3 and Table 4**Error! Reference source not found.** represent the amount of load armed for underfrequency shedding within the North and South islands—these percentages are the ratio of armed load shed data submitted by UFLS entities to the connected bus load in the case, computed for each Load Shed Block.

Table 3: Armed Load Shed Data Validation for the 2021 Heavy Summer Case

	Modeled Armed Load Validation 2021 Heavy Summer Case				
Load Shed Block	North Island (NWPP & WECC plans)			South Island (SILTP plan)	
	Plan Design NWPP	Plan Design	Modeled	Plan Design SILTP	Modeled
	n/a	n/a	n/a	~4.0% (DLT)	~0%
1	5.6% (59.3 Hz)	5.3% (59.1 Hz)	8.9% (≥ 59.1 Hz)	5.3% (59.1 Hz)	6.1% (59.1 Hz)

2	5.6% (59.2 Hz)	5.9% (58.9 Hz)	4.5% (≥ 58.9, < 59.1 Hz)	5.9% (58.9 Hz)	5.9% (58.9 Hz)
3	5.6% (59.0 Hz)	6.5% (58.7 Hz)	5.0% (≥ 58.7, <58.9 Hz)	6.5% (58.7 Hz)	6.7% (58.7 Hz)
4	5.6% (58.8 Hz)	6.7% (58.5 Hz)	5.5% (≥ 58.5, < 58.7 Hz)	6.7% (58.5 Hz)	6.5% (58.5 Hz)
5	5.6% (58.6 Hz)	6.7% (58.3 Hz)	3.4% (≥58.3, < 58.5 Hz)	6.7% (58.3 Hz)	6.4% (58.3 Hz)
< 58.3 Hz			1.6%		18.7%
TOTAL	28.0%	31.1%	28.9%	35.1%	50.3%
UF Stalling	6.0%	6.0%	4.0%	6.0%	6.2%

Table 4: Armed Load Shed Data Validation for the 2024 Light Spring Case

	Modeled Armed Load Validation 2024 Light Spring Case				
Load Shed	North Island (NWPP & WECC plans)			South Island (SILTP plan)	
	Plan Design NWPP	Plan Design WECC	Modeled	Plan Design SILTP	Modeled
	n/a	n/a	n/a	~4.0% (DLT)[3]	~0%
1	5.6% (59.3 Hz)	5.3% (59.1 Hz)	8.6% (≥ 59.1 Hz)	5.3% (59.1 Hz)	5.5% (59.1 Hz)
2	5.6% (59.2 Hz)	5.9% (58.9 Hz)	4.3% (≥ 58.9, < 59.1 Hz)	5.9% (58.9 Hz)	5.5% (58.9 Hz)
3	5.6% (59.0 Hz)	6.5% (58.7 Hz)	4.4% (≥ 58.7, <58.9 Hz)	6.5% (58.7 Hz)	6.2% (58.7 Hz)
4	5.6% (58.8 Hz)	6.7% (58.5 Hz)	4.6% (≥ 58.5, < 58.7 Hz)	6.7% (58.5 Hz)	5.7% (58.5 Hz)
5	5.6% (58.6 Hz)	6.7% (58.3 Hz)	2.6% (≥58.3, < 58.5 Hz)	6.7% (58.3 Hz)	5.1% (58.3 Hz)
< 58.3 Hz			1.2%		13.8%
TOTAL	28.0%	31.1%	23.7%	35.1%	41.8%
UF Stalling	6.0%	6.0%	3.7%	6.0%	4.1%

[3] Direct Load Tripping. Refers to approximately 709 MW of load in the PG&E control area that is armed to be directly tripped if all three 500 kV COI lines are lost and the NE/SE Separation Scheme is initiated. This load comprises CDWR pumps, Helms pumps, or PG&E load. The logic for this is built into the PG&E RAS controller.

North Island—Note that, in Table 3 and Table 4, the Total Armed Load modeled in the North Island falls short of what is required by plan design for both the 2021 Heavy Summer and 2024 Light Spring cases. Assuming the connected load in the North Island is almost equally distributed between the NWPP plan and WECC plan, the Total Armed Load, per plan design, would be 29.55% (average of 28.0% and 31.1%). In the 2021 Heavy Summer, the modeled Total Armed Load percentage is 28.9% and, in the 2024 Light Spring, it is 23.7%. This results in armed load **deficits of 0.7%** and **5.9%,** respectively.

South Island—Similarly, the Total Armed Load modeled in the South Island is much higher than what is required by plan design for both the 2021 Heavy Summer and the 2024 Light Spring cases—a **surplus of 15.2%** in the 2021 Heavy Summer **and 6.7%** in the 2024 Light Spring.

The Armed Load Data Validation also serves as the prerequisite step for performing the Armed Load Adequacy Check for the WECC Plan (see next section).

Armed Load Adequacy Check

This check provides another metric for evaluating the adequacy and effectiveness of the implemented (i.e., modeled) WECC Plan. Comparing the amount of actual load shed during the underfrequency event simulation with the amount of total armed load (i.e., maximum available load for shedding) in the model allows computing the remaining or unused armed load—available armed load margin—as an indicator of the adequacy of the WECC Plan's implementation. The difference between this section and the previous section is that this section shows how much load is armed and is still available to be shed in the specified simulations (unused armed load), while the previous section shows how much load is armed compared to what is required in the WECC Plan.

As shown in Table 5 and Table 6 below, the total armed load in the North Island has significantly lower margin compared to the others. Tables 7 and 8 are taken from the previous assessment report and are included only for the purpose of comparison. As in the current assessment, the North Island has lower margin compared to the others. This should be monitored and verified in future UFLS assessments since validated low margin would be a reasonable basis for making appropriate design adjustments to the WECC primary plan and NWPP sub-area plan to provide additional armed load in the North Island. Note that results for the WECC and North Island 25% simulations are not included in Table 5. These two dynamic simulations didn't finish but load was shed and the amount that was shed up to the point where the simulations stopped is provided in Footnote 4.

Table 5: Armed Load Adequacy for the 2021HS Case

Island				25% Imbalance		
	Total (MW)	Armed (MW)	Armed (% of Total)	Shed (MW)	Shed (% of Armed)	Plan Margin %
WECC	175,979	80,605	44.8%			20.2%

North	78,283	25,625	32.7%	Simulations Incomplete[4]		7.9%
South	97,696	54,980	56.3%	26,106	47.5%	52.5%

Table 6: Armed Load Adequacy for the 2024LSP Case

Island				25% Imbalance		
	Total (MW)	Armed (MW)	Armed (% of Total)	Shed (MW)	Shed (% of Armed)	Plan Margin %
WECC	92,054	34,253	37.2%	18,230	53.2%	46.8%
North	48,696	14,355	29.5%	10,529	73.3%	26.7%
South	43,358	19,898	45.9%	10,335	51.9%	48.1%

Table 7: Armed Load Adequacy for 2019HS Case

Island				25% Imbalance		
	Total (MW)	Armed (MW)	Armed (% of Total)	Shed (MW)	Shed (% of Armed)	Plan Margin %
WECC	172,836	73,044	42.3%	49,925	68.35%	31.65%
North	75,712	22,863	30.2%	21,604	94.5%	5.5%
South	97,124	50,181	51.7%	30,353	60.5%	39.5%

Table 8: Armed Load Adequacy for 2019LSP Case

Island				25% Imbalance		
	Total (MW)	Armed (MW)	Armed (% of Total)	Shed (MW)	Shed (% of Armed)	Plan Margin %
WECC	9,5071	36,765	38.7%	29,014	78.9%	21.1%
North	50,442	14,743	29.2%	13,147	89.2%	10.8%
South	44,629	22,021	49.3%	30,353	68.0%	32.0%

[4] Both the WECC and North island 25% imbalance simulations in the 2021 HS failed to complete, so these numbers are not meaningful. For the sake of completeness, they are presented here:

Island	Shed (MW)	Shed (% of Armed)
WECC	62,943	79.8
North	23,614	92.1

Findings and Conclusions

This assessment of the WECC UFLS Plan was unable to demonstrate that it meets some of the performance characteristics defined in PRC-006-5. Specifically, PRC-006-5, D.B.3. requires it to maintain a steady-state frequency condition between 59.3 and 60.7 Hz under generation-to-load imbalance conditions of up to 25% within identified islands for 60 seconds or until steady-state conditions are achieved. In both the WECC and North Island 25% heavy summer imbalance scenarios, the software that was used for this assessment was either unable to complete the simulation to 60 seconds or provide meaningful results. The underlying cause has not been fully determined, but some of the symptoms are extreme low voltages, voltage collapse in multiple low voltage pockets (Figure 2), and formation of islands (Figure 1), in addition to the North and South islands in the WECC and North Island 25% heavy summer imbalance scenarios.[5]

As shown in the Armed Load Adequacy Check section of this report, the North Island has a much lower armed load margin than the South Island in the 25% imbalance simulations, particularly under heavy load conditions. None of the imbalance simulations resulted in 100% of the armed load being shed, but as this level of load shed is approached, the addition of more armed load or WECC Plan design adjustments should be considered.

V/Hz results were tabulated for the 25% imbalance simulations for all but the 21HS WECC and North Islands. For these two scenarios, which stopped prematurely, V/Hz results would have been meaningless, so results were taken from the 20% imbalance simulations.

[5] In the 25% WECC and North island imbalance cases in heavy summer conditions, several additional islands were formed within the North Island area. Plot information suggests that the following three sub-islands were formed: BC Hydro, Idaho/Utah/Colorado, NW/WAPA UM.

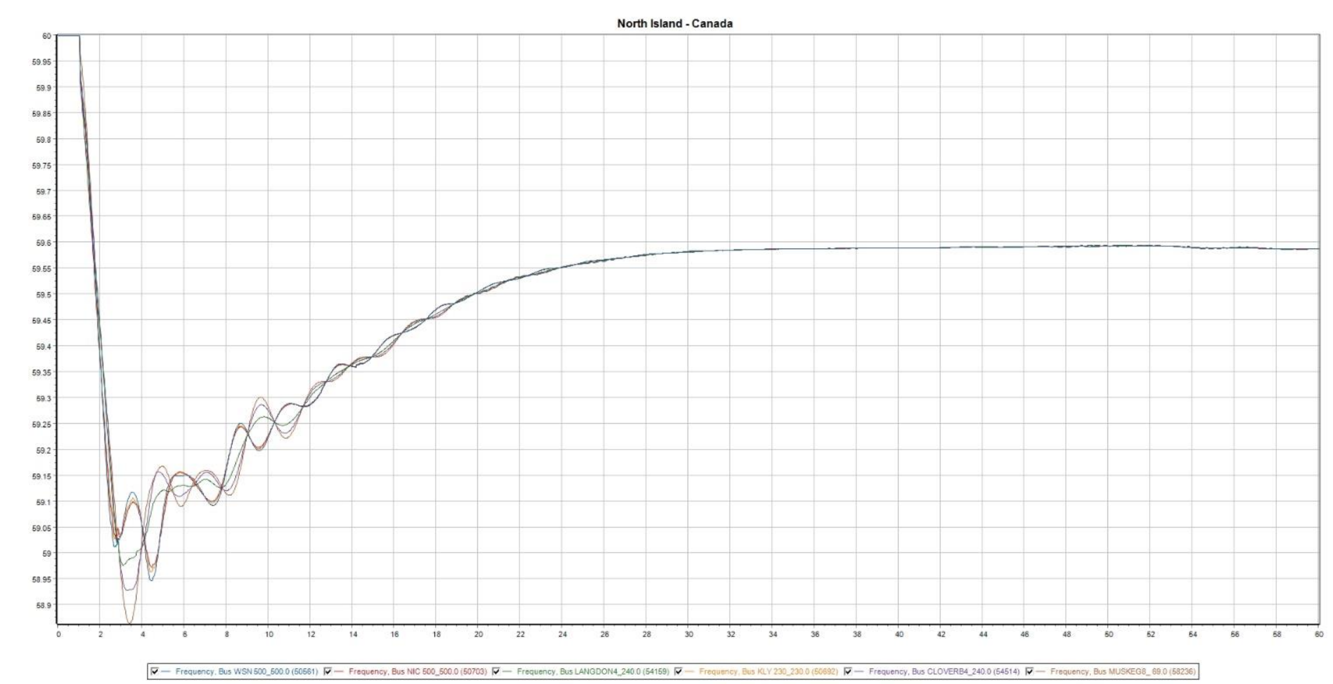
Recommendations

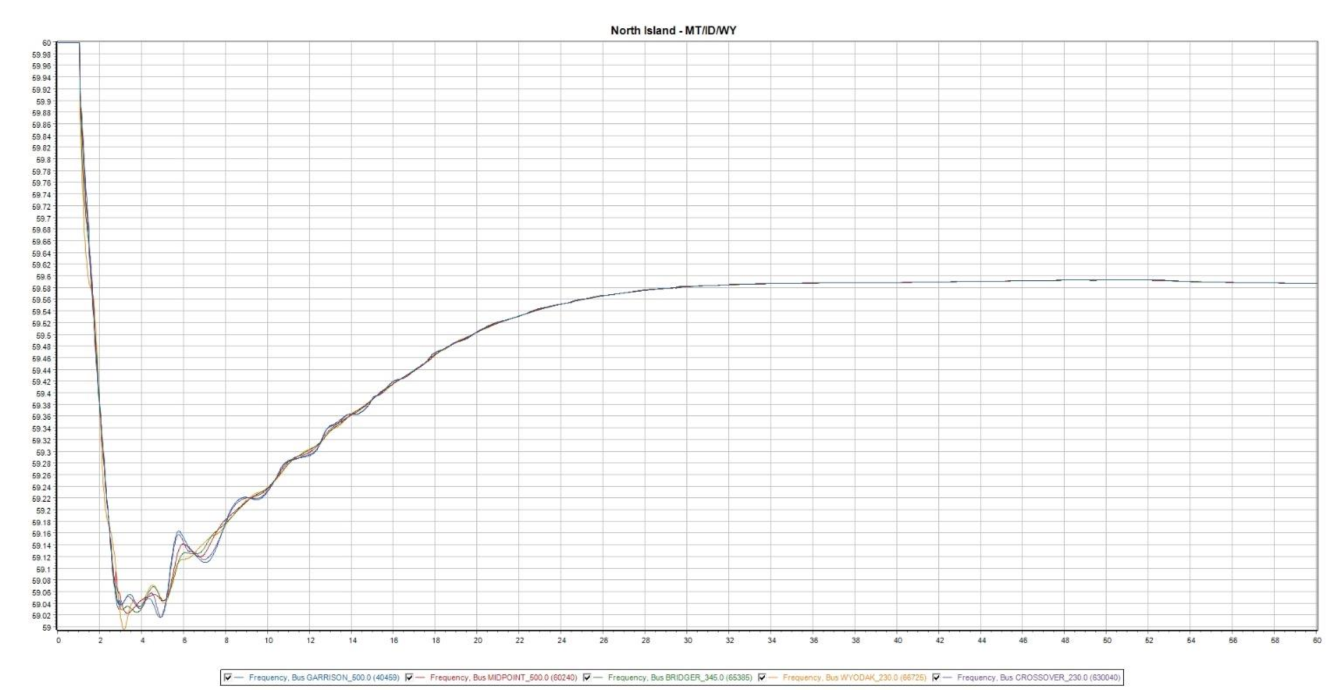
Due to findings and results in this assessment of the WECC Plan, the following recommendations are made:

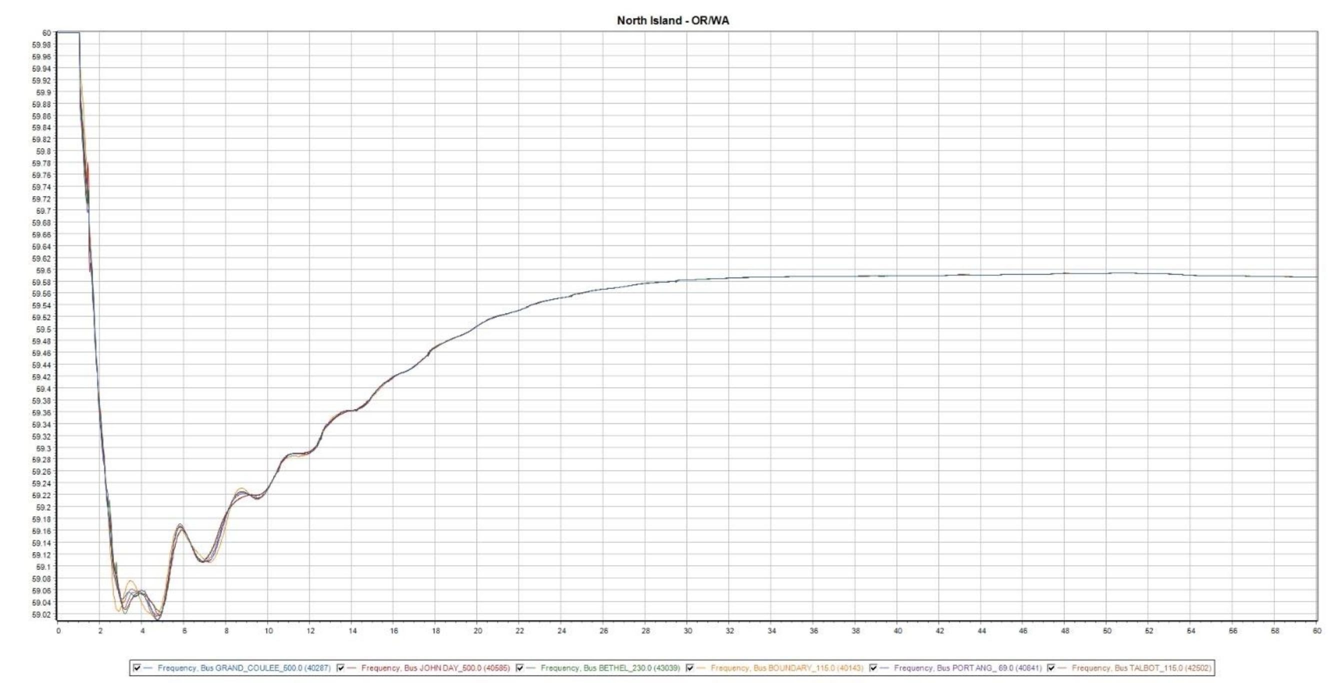
1. Both the WECC and North Island simulations under 25% imbalance conditions in the 21 HS scenario failed to run the required amount of time and therefore didn't produce meaningful results. The UFLSWG should investigate the cause and develop a Corrective Action Plan if the WECC Plan is determined to be insufficient.
2. While running the WECC and North Island simulations under 25% imbalance conditions in the 21 HS scenario identified in Recommendation 1, extreme low voltages in many areas were observed. The UFLSWG should determine whether these instances of low voltage could be remedied by modeling reactive devices that could operate in the time frame of the simulations.
3. V/Hz violations need to be addressed.
    a. Each PC should evaluate the affected units with violations in their control area and validate the behavior of the model. If model updates are required, these should be communicated to the necessary people.
4. The current UFLS Methodology Document, which outlines how the UFLS Assessment is performed, should be reviewed by the UFLSWG to address:
    a. Methods of causing imbalance (e.g., tripping generation, setting unit PGen to zero but allowing it to stay online, dynamically opening tie lines, adding load); and
    b. Selection of generators to trip, including unit location, unit type (e.g., synchronous generator, IBR, must-runs).

Appendix A—Frequency Performance—WECC Island

21HS—10%



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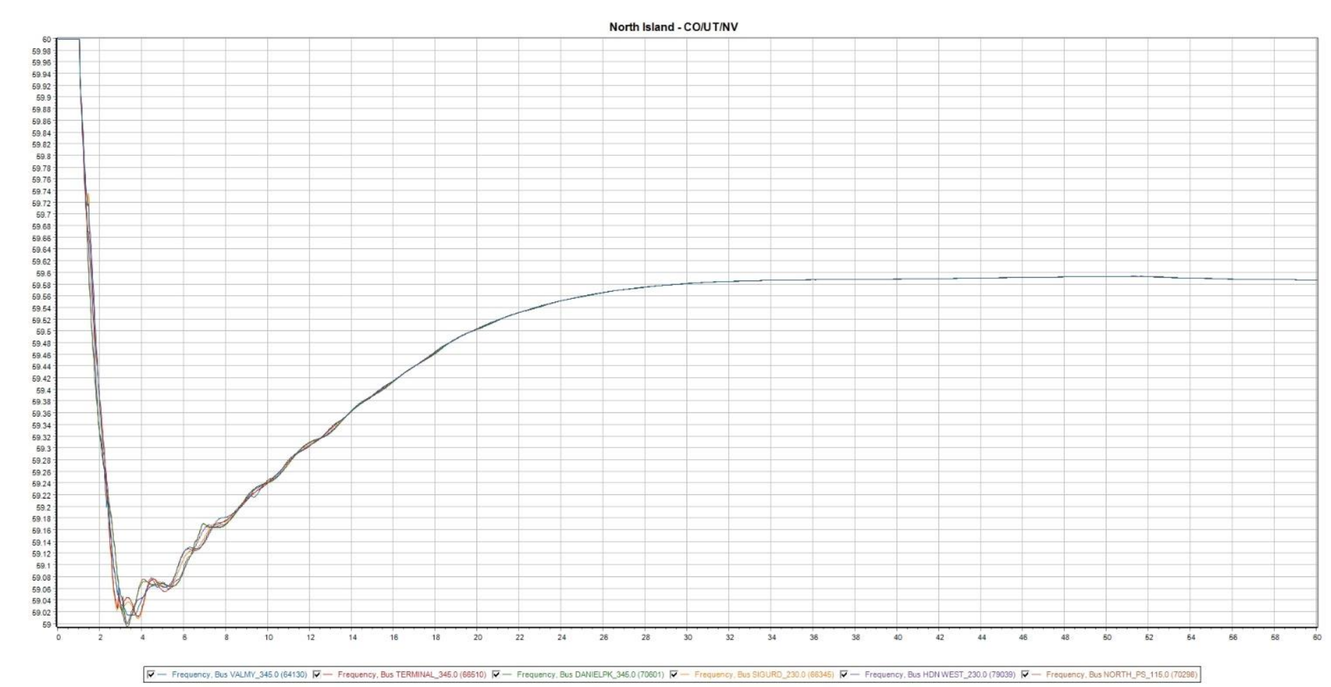
Frequency, Bus JOHN DAY_500.0 (40585)
Frequency, Bus BETHEL_230.0 (43039)
Frequency, Bus BOUNDARY_115.0 (40143)
Frequency, Bus PORT ANG_69.0 (40841)
Frequency, Bus TALBOT_115.0 (42502)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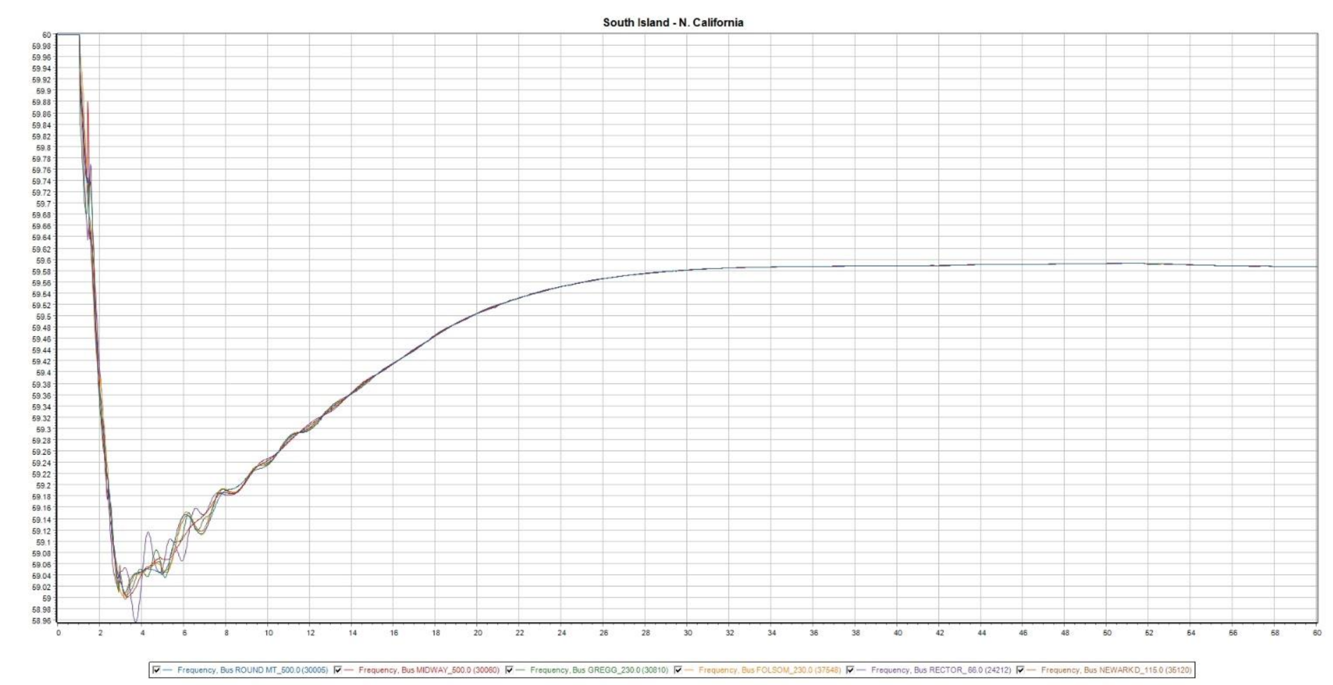
Frequency, Bus TERMINAL_345.0 (66510)
Frequency, Bus DANIELPK_345.0 (70601)
Frequency, Bus SIGURD_230.0 (66345)
Frequency, Bus HDN WEST_230.0 (79039)
Frequency, Bus NORTH_PS_115.0 (70298)


South Island - N. California
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Frequency, Bus MIDWAY_500.0 (30060)
Frequency, Bus GREGG_230.0 (30810)
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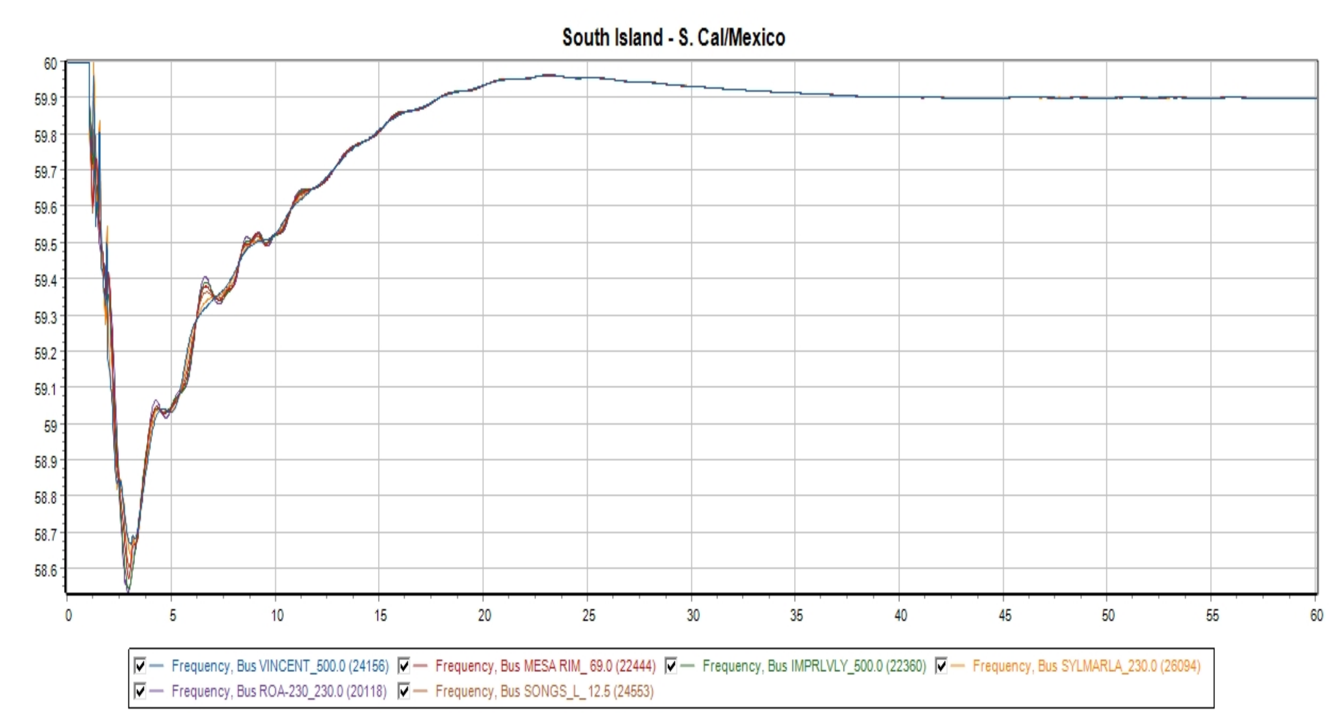
Frequency, Bus RECTOR_66.0 (24212)
Frequency, Bus NEWARKD_115.0 (35120)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59.9
59.8
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59
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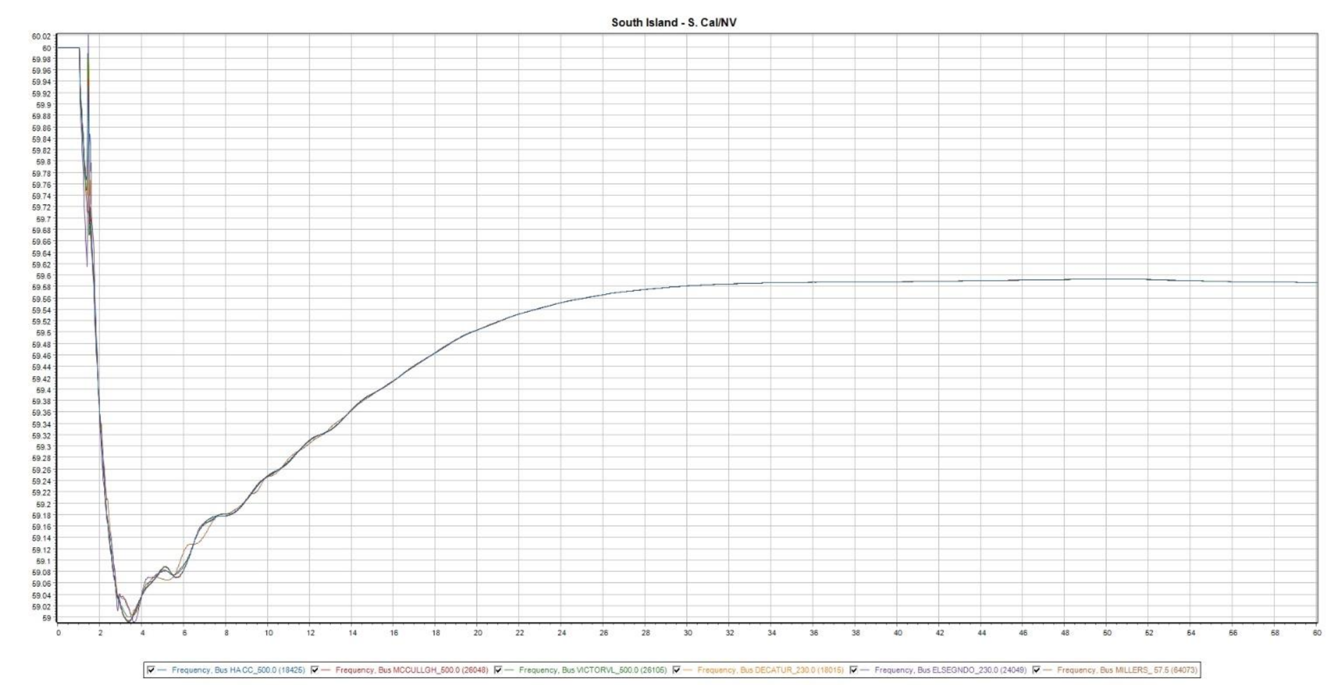
25
30
35
40
45
50
55
60
Frequency, Bus VINCENT_500.0 (24156)
Frequency, Bus MESA RIM_ 69.0 (22444)
Frequency, Bus IMPRLVLY_500.0 (22360)
Frequency, Bus SYLMARLA_230.0 (26094)
Frequency, Bus ROA-230_230.0 (20118)
Frequency, Bus SONGS_L_ 12.5 (24553)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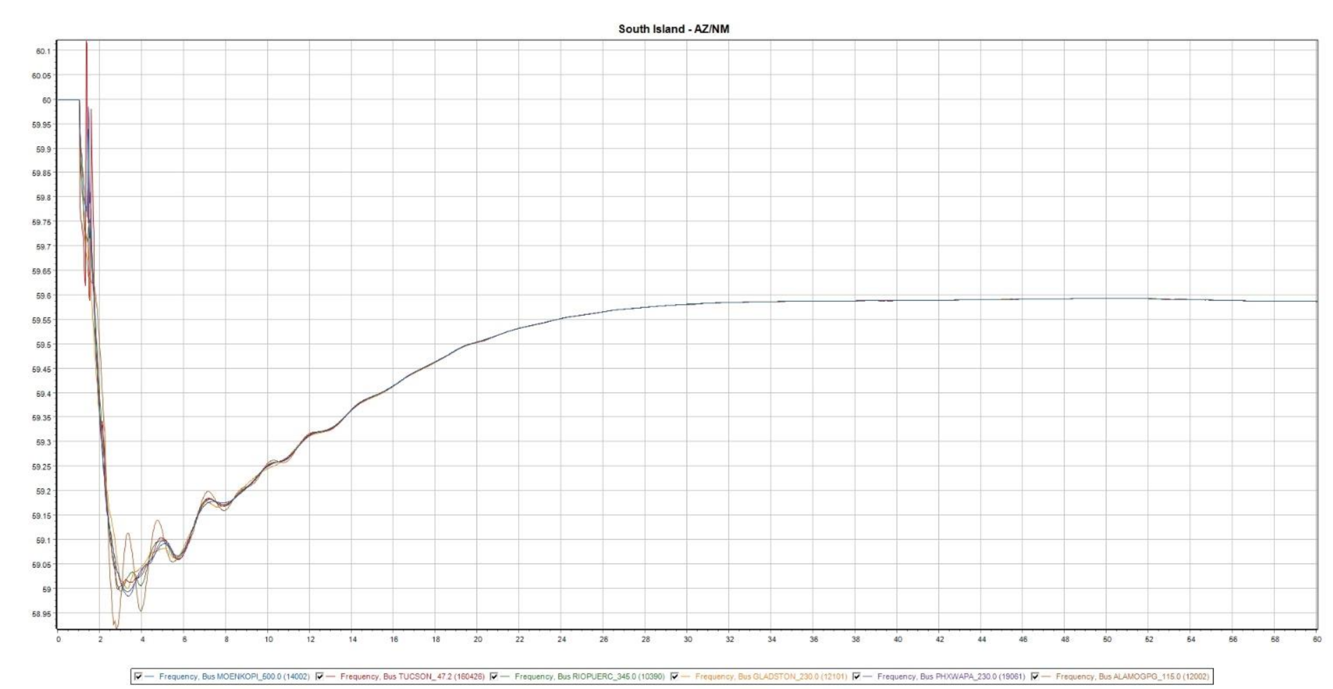
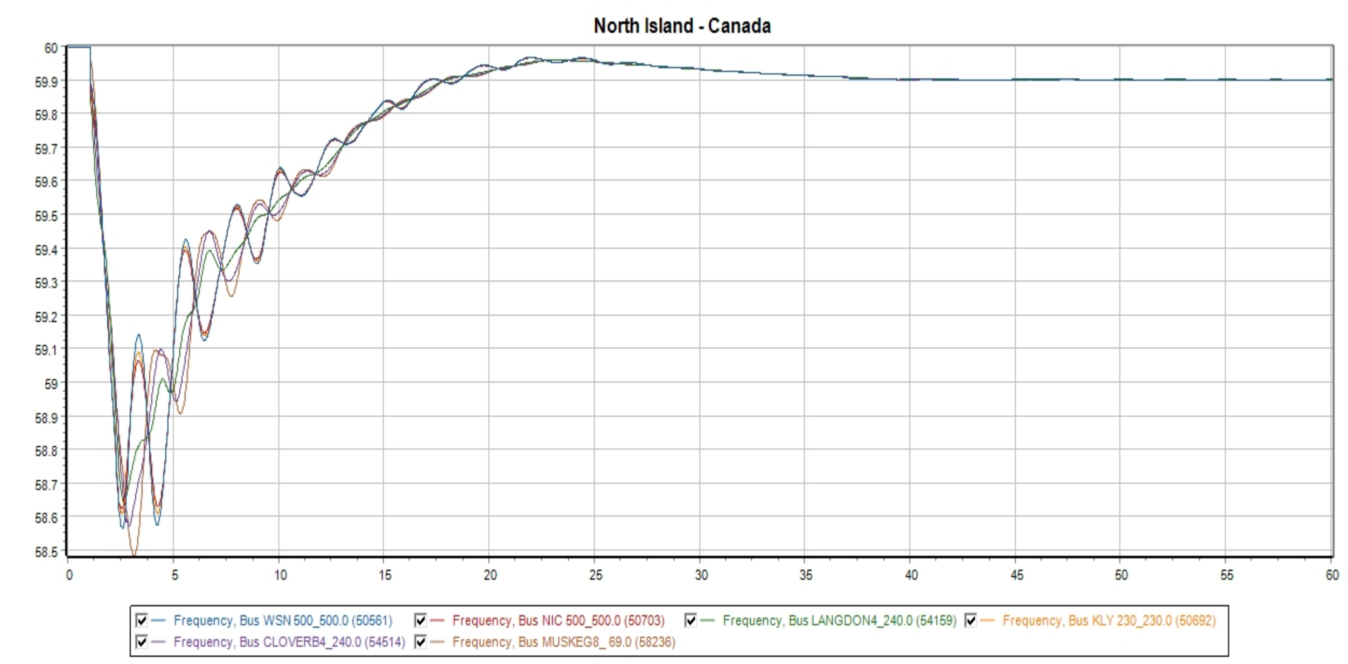
Frequency, Bus MCCULLGH_500.0 (26048)
Frequency, Bus VICTORVL_500.0 (26105)
Frequency, Bus DECATUR_230.0 (18015)
Frequency, Bus ELSEGNDO_230.0 (24049)
Frequency, Bus MILLERS_ 57.5 (64073)


South Island - AZ/NM
Frequency, Bus MOENKOPI_500.0 (14002)
Frequency, Bus TUCSON_47.2 (160426)
Frequency, Bus RIOPUERC_345.0 (10390)
Frequency, Bus GLADSTON_230.0 (12101)
Frequency, Bus PHXWAPA_230.0 (19061)
Frequency, Bus ALAMOGPG_115.0 (12002)

21HS—20%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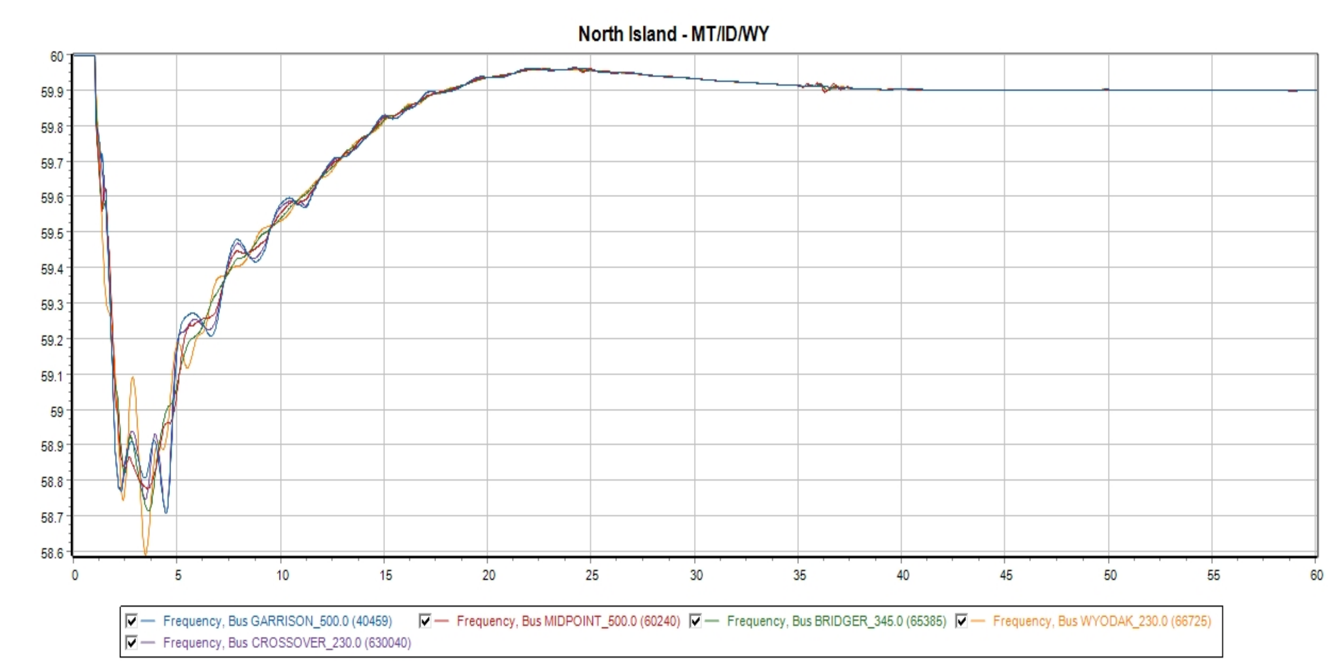
60
Frequency, Bus WSN 500_500.0 (50561)
Frequency, Bus NIC 500_500.0 (50703)
Frequency, Bus LANGDON4_240.0 (54159)
Frequency, Bus KLY 230_230.0 (50692)
Frequency, Bus CLOVERB4_240.0 (54514)
Frequency, Bus MUSKEG8_ 69.0 (58236)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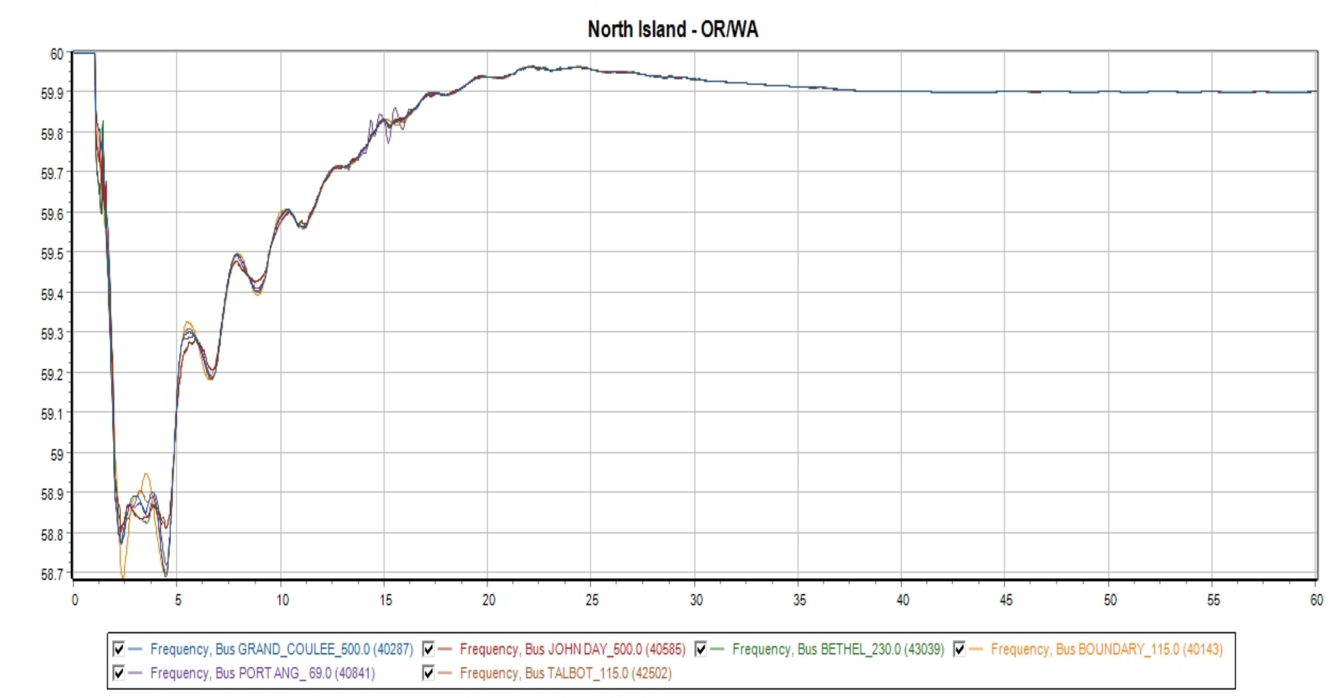
Frequency, Bus GARRISON_500.0 (40459)
Frequency, Bus MIDPOINT_500.0 (60240)
Frequency, Bus BRIDGER_345.0 (65385)
Frequency, Bus WYODAK_230.0 (66725)
Frequency, Bus CROSSOVER_230.0 (630040)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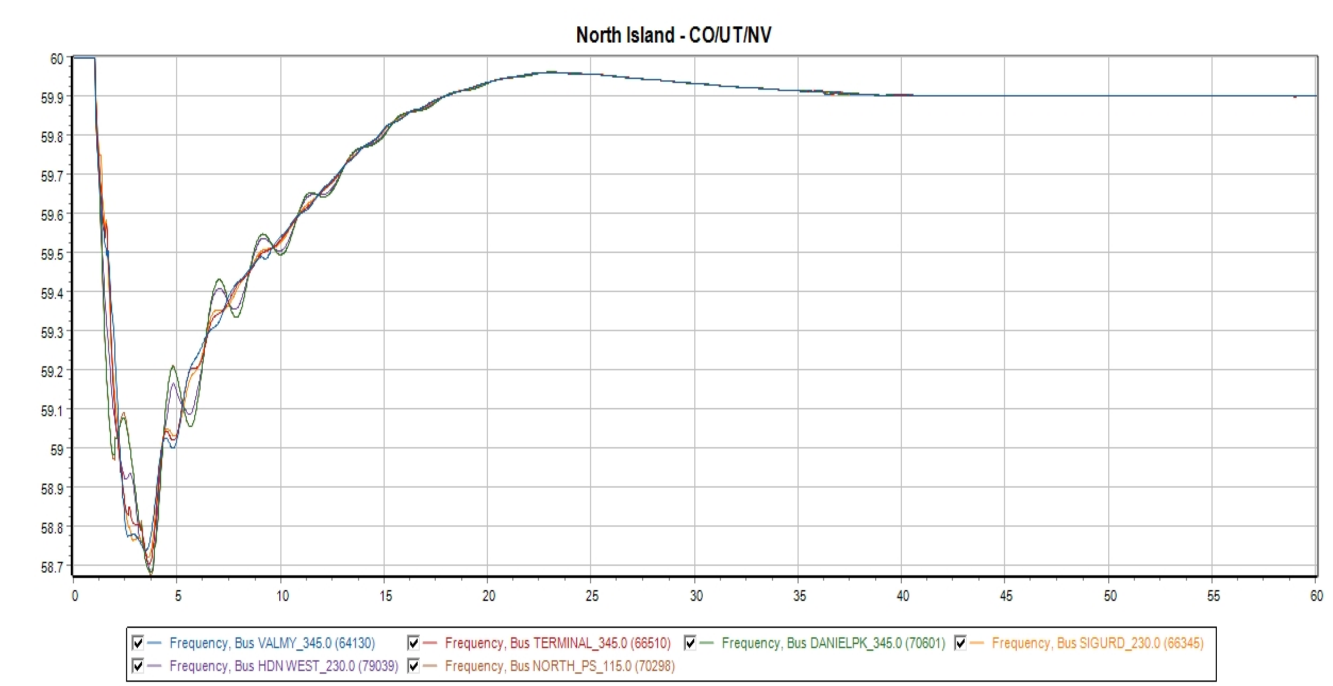
Frequency, Bus GRAND_COULEE_500.0 (40287)
Frequency, Bus JOHN DAY_500.0 (40585)
Frequency, Bus BETHEL_230.0 (43039)
Frequency, Bus BOUNDARY_115.0 (40143)
Frequency, Bus PORT ANG_ 69.0 (40841)
Frequency, Bus TALBOT_115.0 (42502)


North Island - CO/UT/NV
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58.8
58.7
0 5 10 15 20 25 30 35 40 45 50 55 60
Frequency, Bus VALMY_345.0 (64130)
Frequency, Bus TERMINAL_345.0 (66510)
Frequency, Bus DANIELPK_345.0 (70601)
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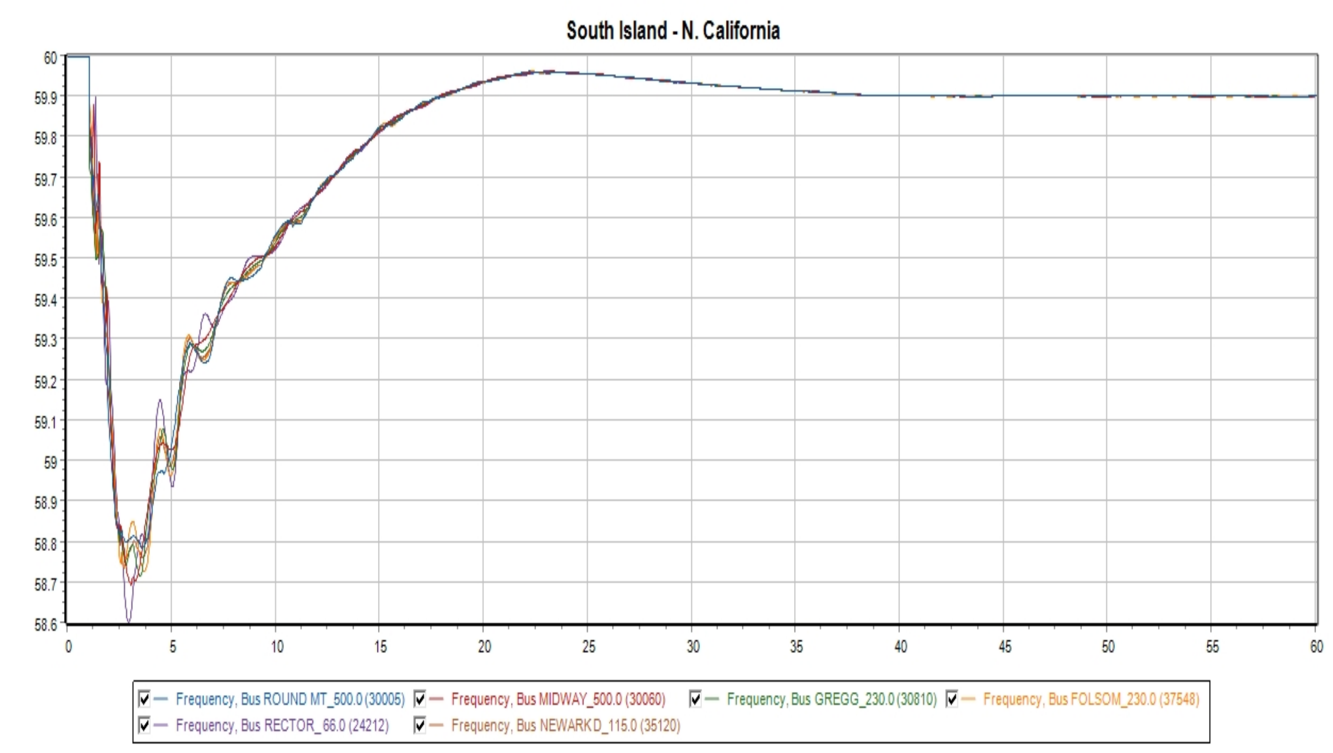
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Frequency, Bus ROUND MT_500.0 (30005)
Frequency, Bus MIDWAY_500.0 (30060)
Frequency, Bus GREGG_230.0 (30810)
Frequency, Bus FOLSOM_230.0 (37548)
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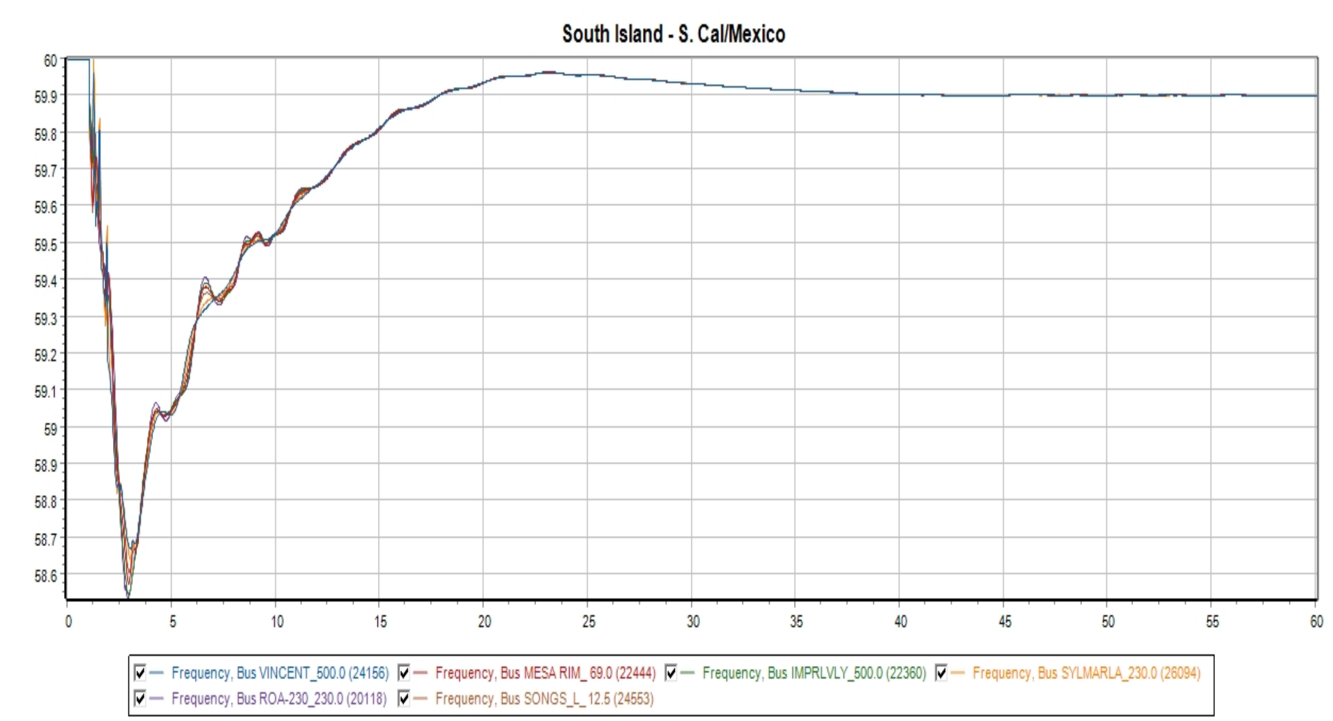
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Frequency, Bus VINCENT_500.0 (24156)
Frequency, Bus MESA RIM_ 69.0 (22444)
Frequency, Bus IMPRLVLY_500.0 (22360)
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Frequency, Bus ROA-230_230.0 (20118)
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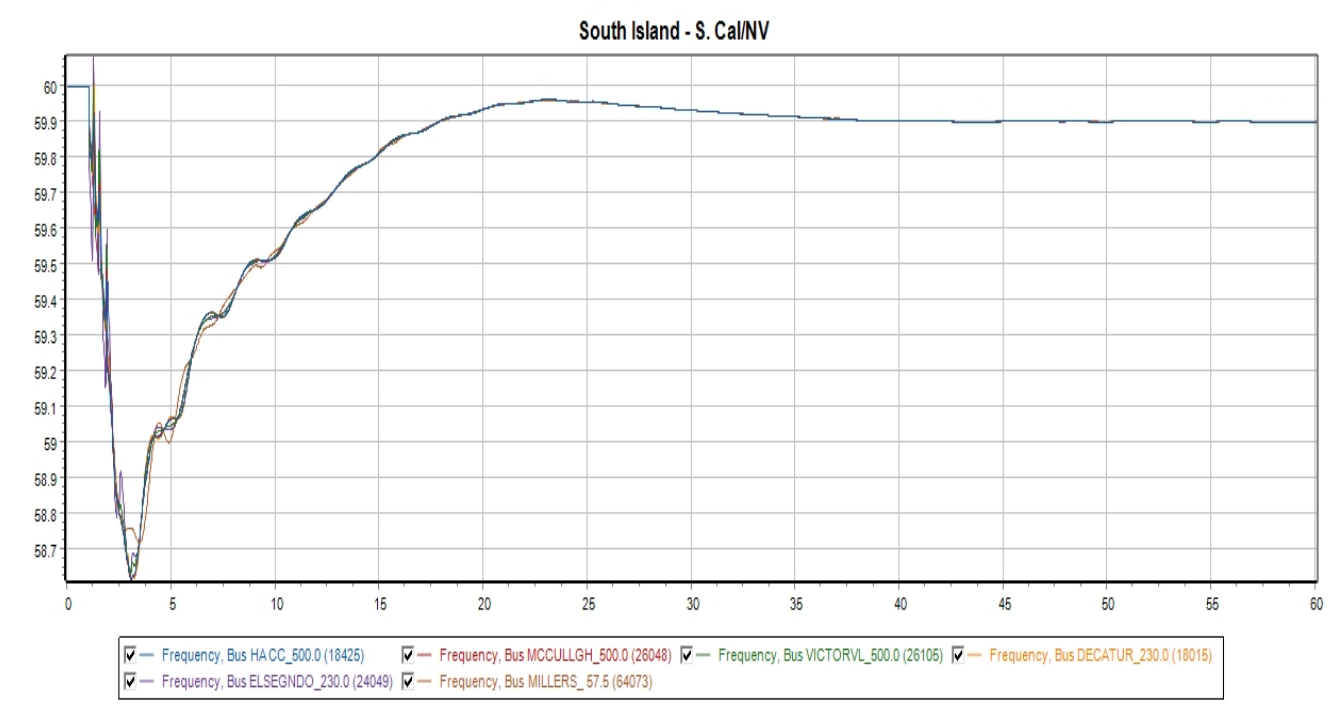
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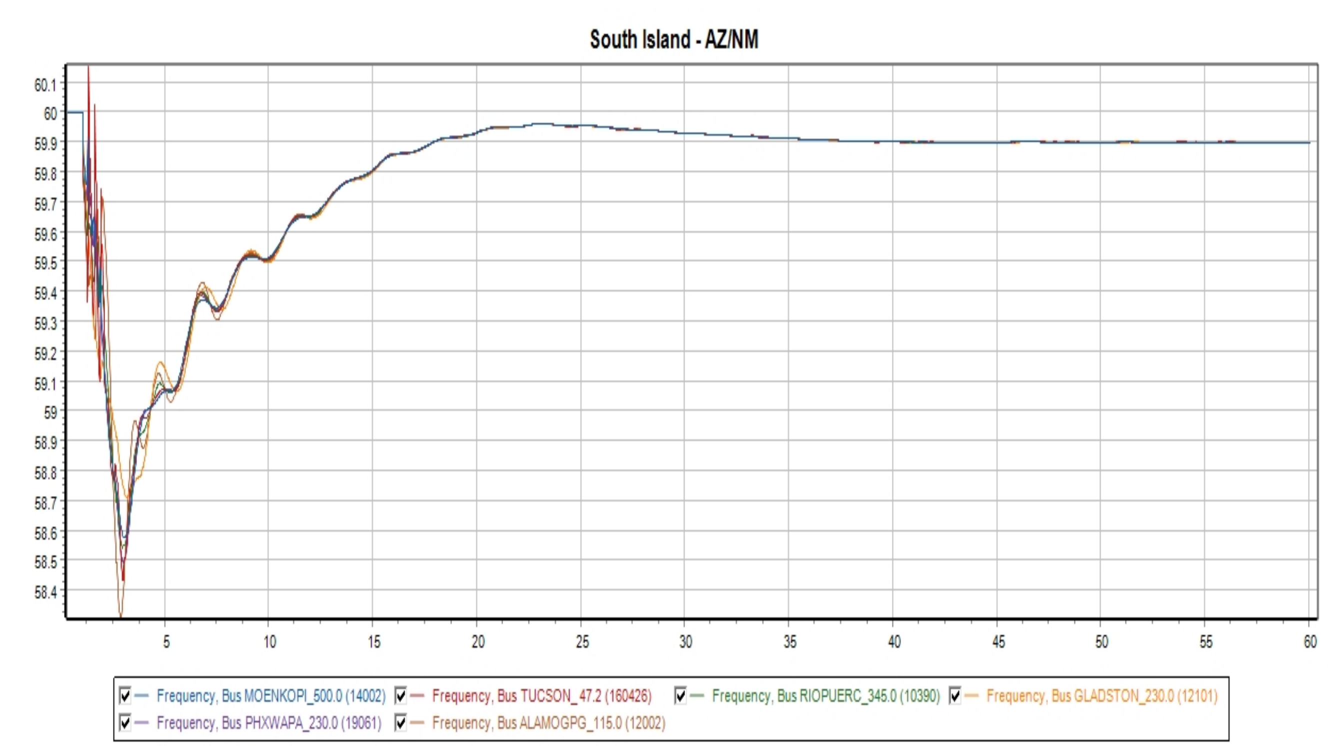
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Frequency, Bus RIOPUERC_345.0 (10390)
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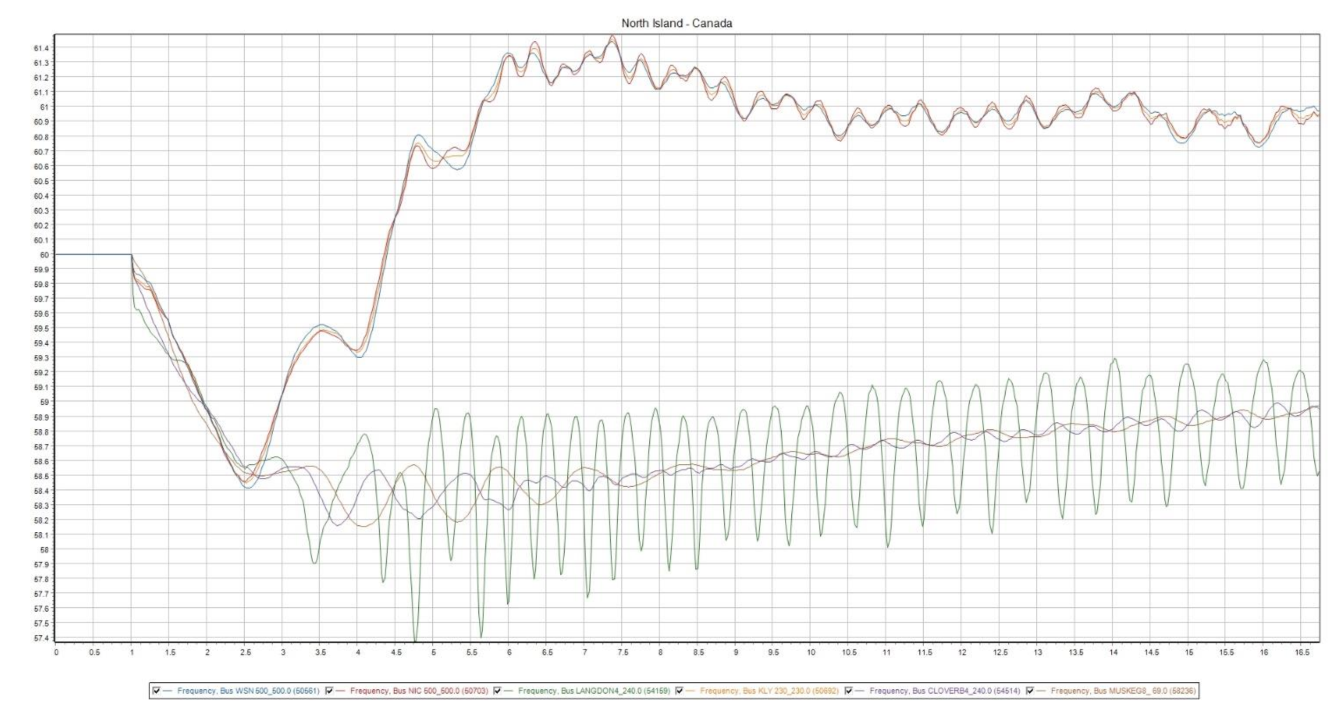
Frequency, Bus ALAMOGPG_115.0 (12002)

21HS—25%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Frequency, Bus NIC 500_500.0 (50703)
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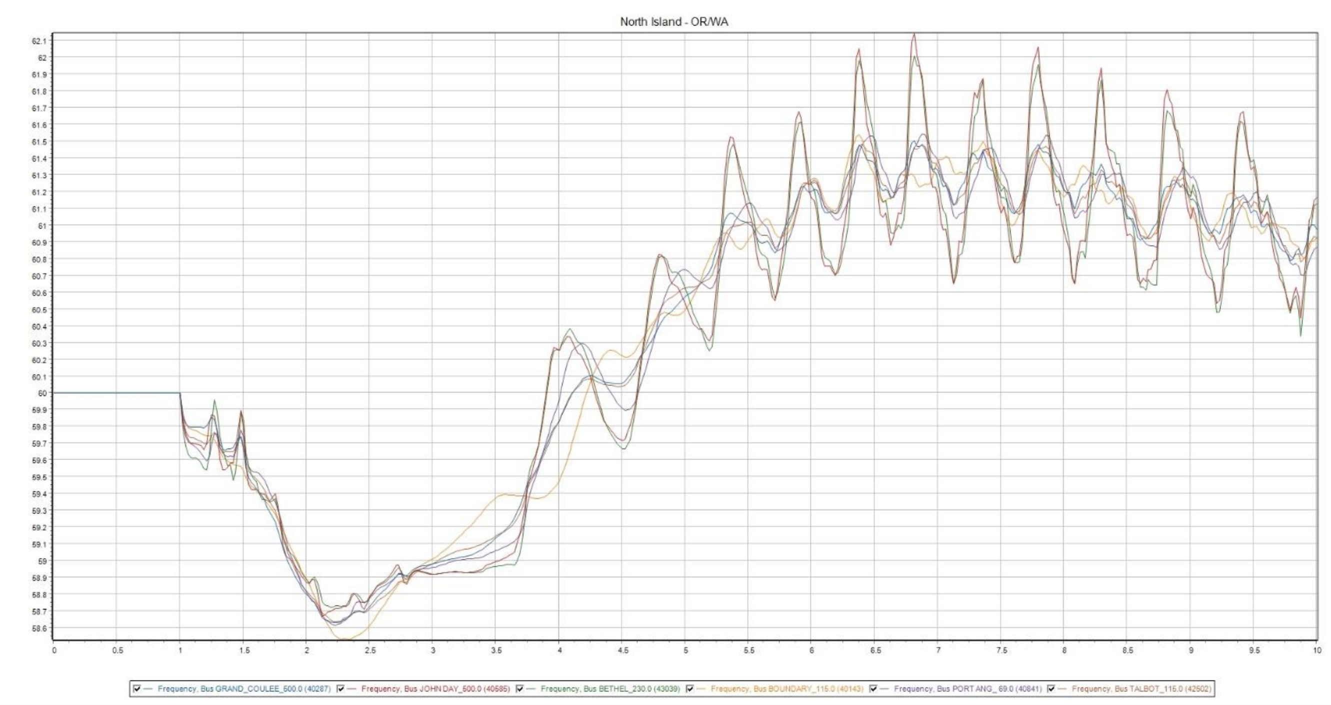
Frequency, Bus KLY 230_230.0 (50692)
Frequency, Bus CLOVERB4_240.0 (54514)
Frequency, Bus MUSKEG8_ 69.0 (58236)


North Island - MT/ID/WY
Frequency, Bus GARRISON_500.0 (40459)
Frequency, Bus MIDPOINT_500.0 (60240)
Frequency, Bus BRIDGER_345.0 (65385)
Frequency, Bus WYODAK_230.0 (66725)
Frequency, Bus CROSSOVER_230.0 (630040)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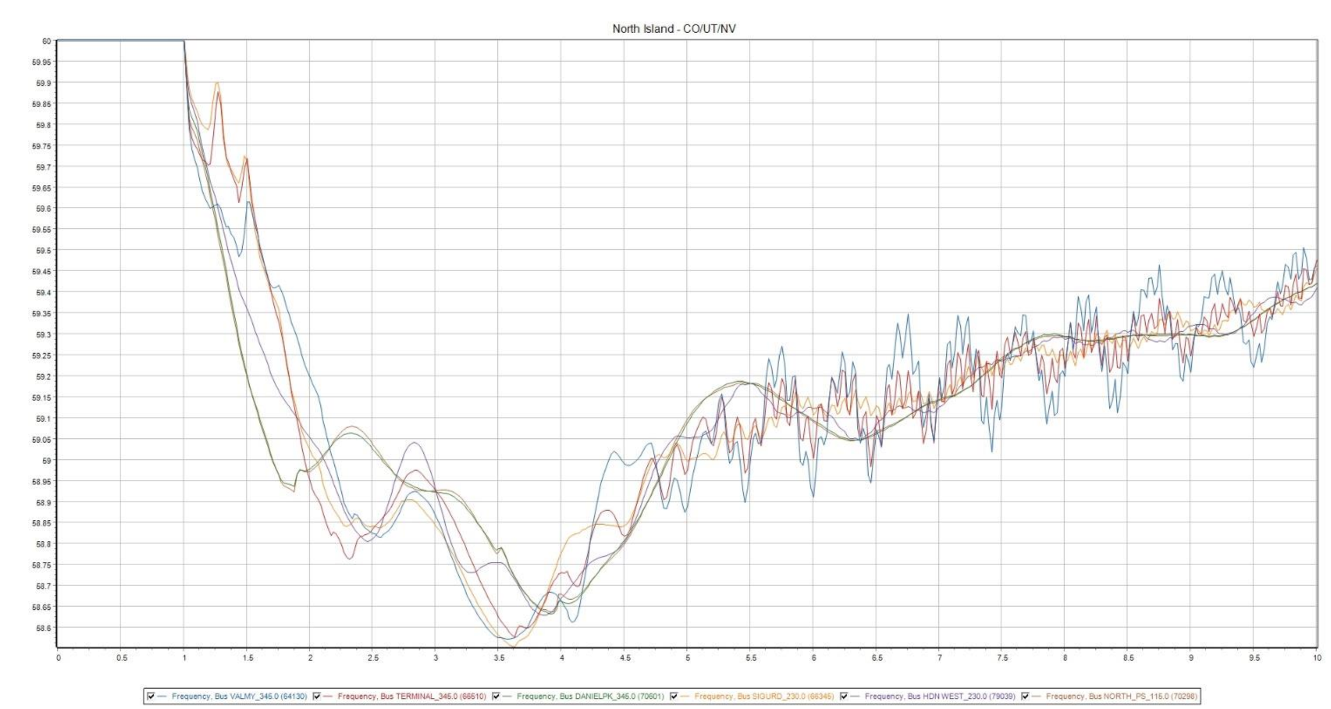
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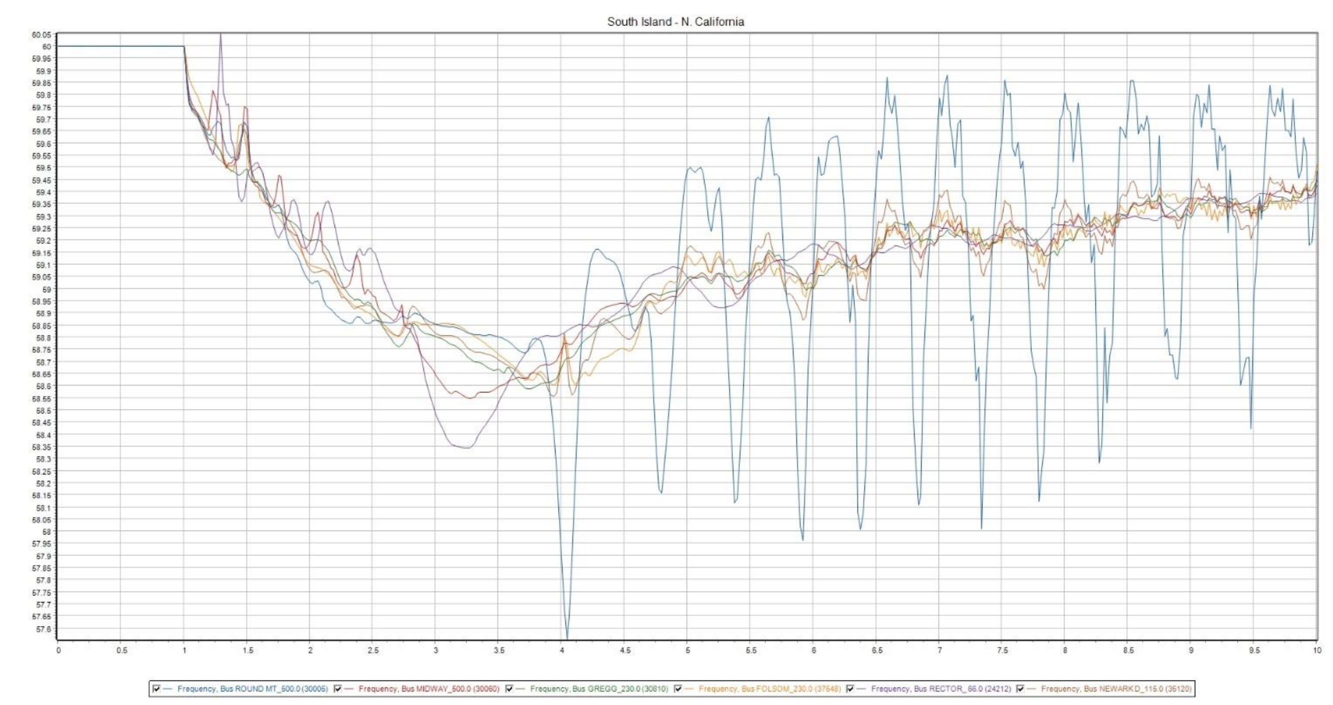
Frequency, Bus SIGURD_230.0 (66346)
Frequency, Bus HDN WEST_230.0 (79039)
Frequency, Bus NORTH_PS_115.0 (70298)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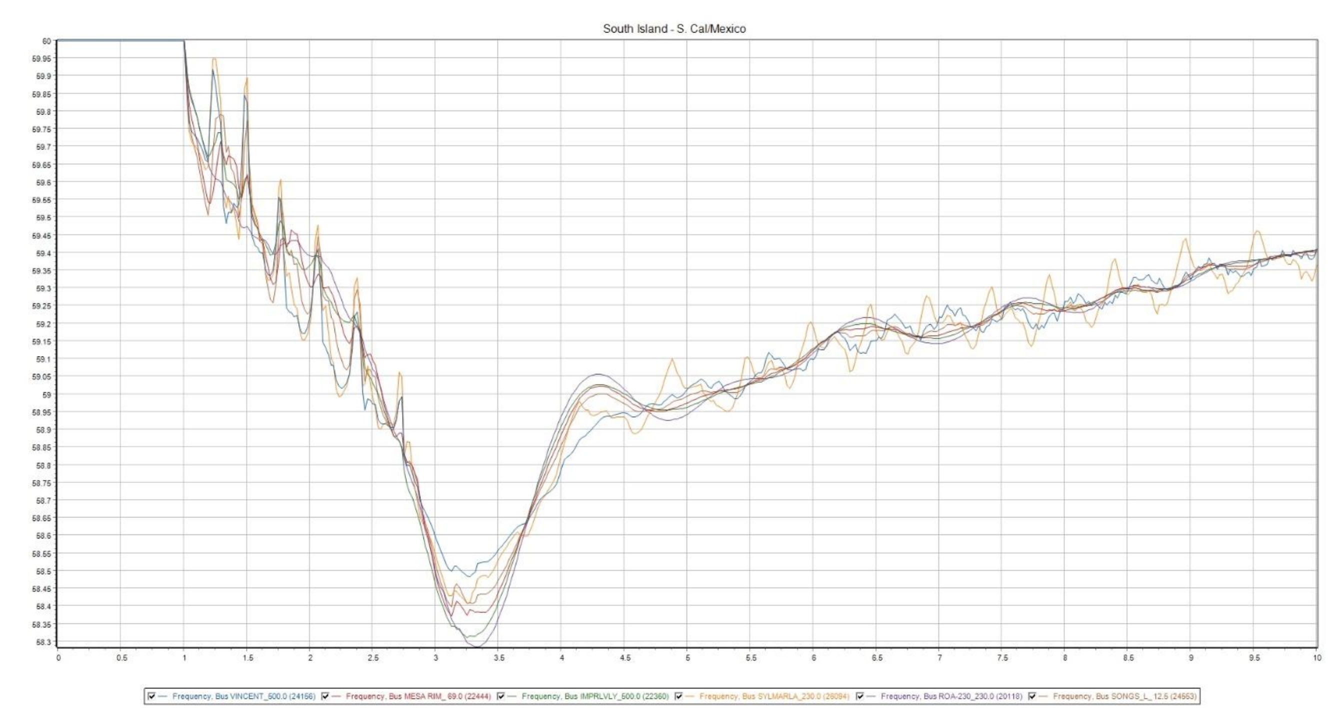
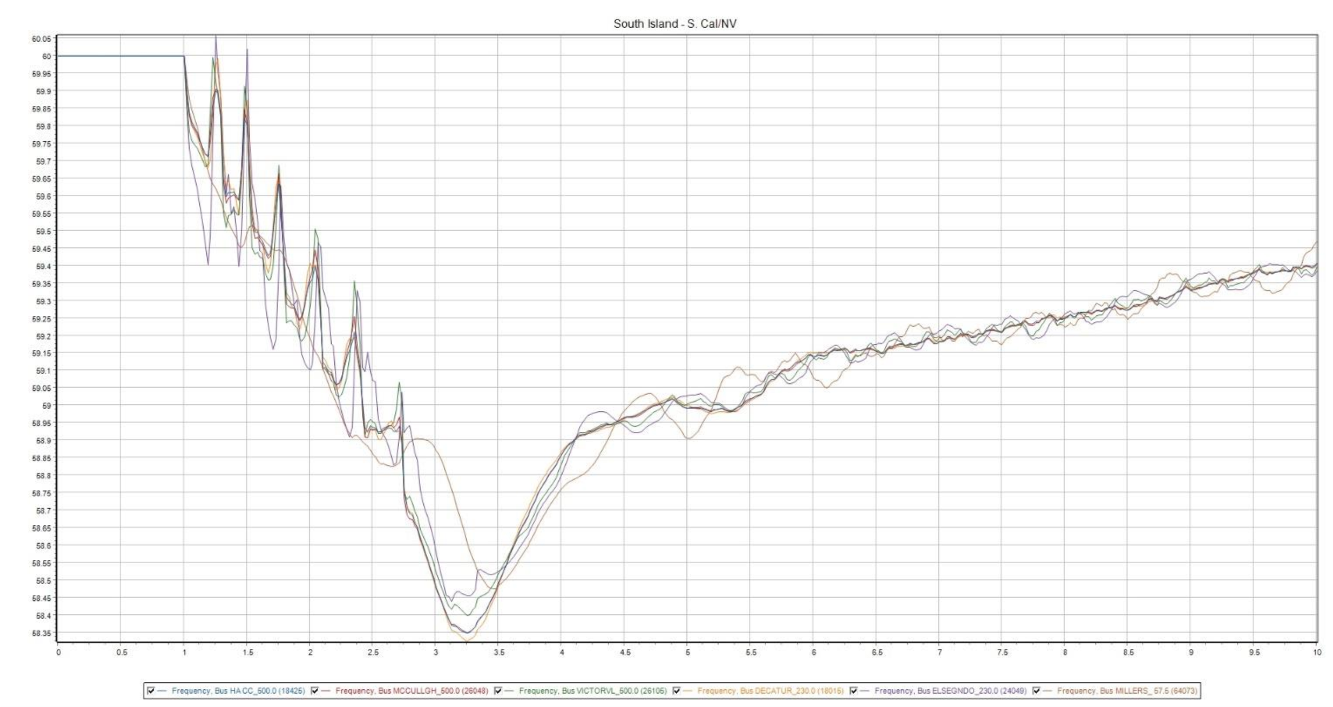
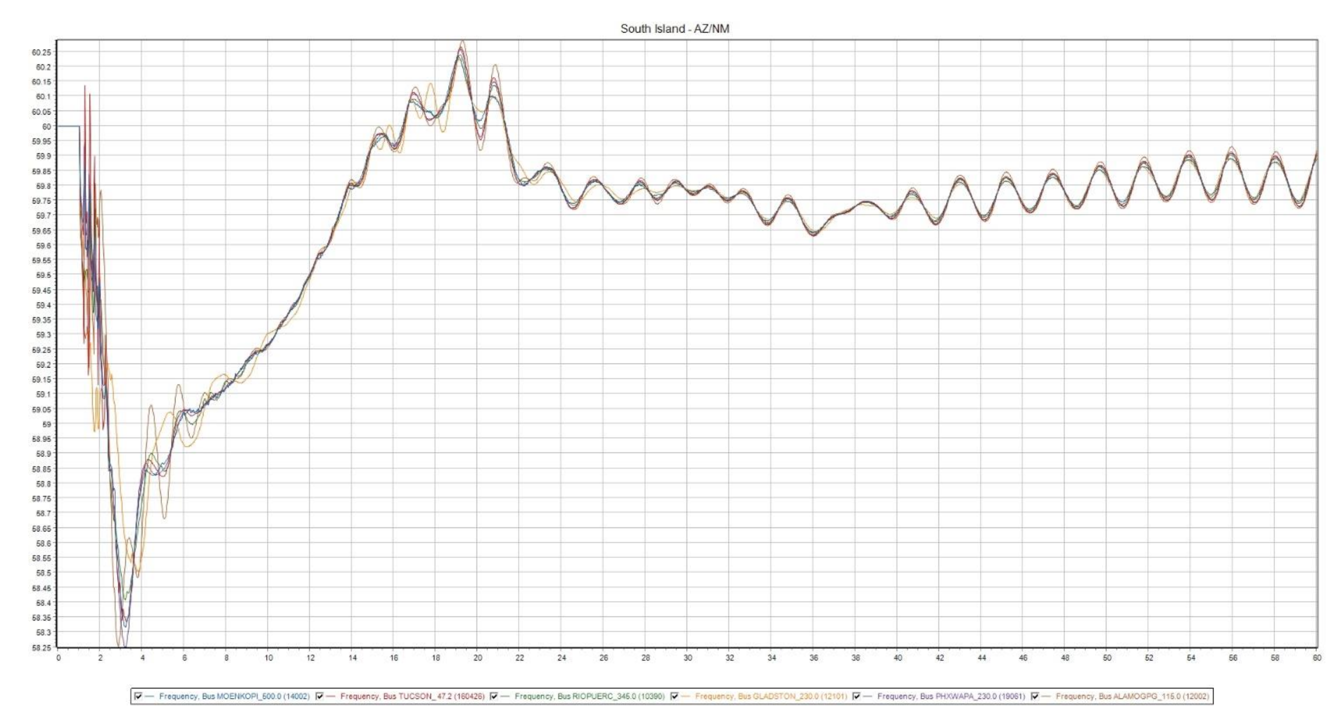
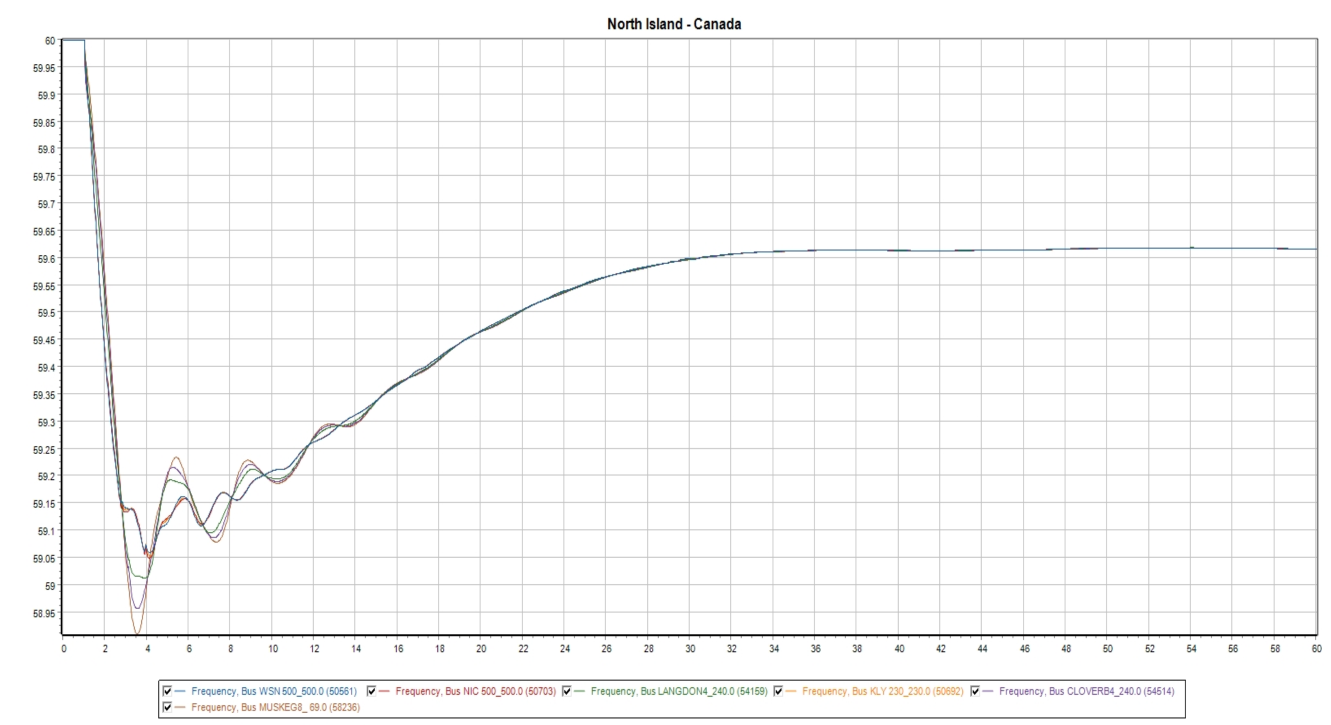
Frequency, Bus MIDWAY_500.0 (30060)
Frequency, Bus GREGG_230.0 (30810)
Frequency, Bus FOLSOM_230.0 (37548)
Frequency, Bus RECTOR_66.0 (24212)
Frequency, Bus NEWARKD_115.0 (35120)

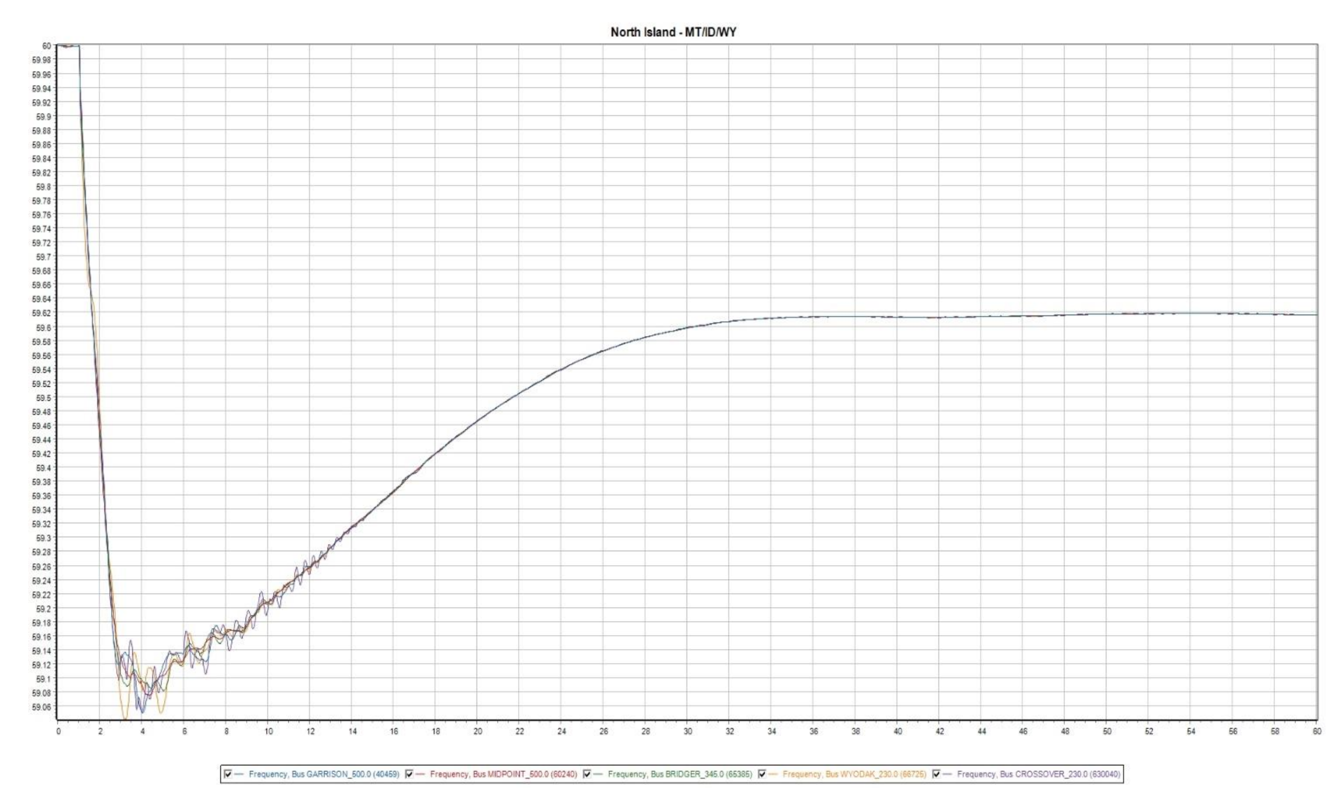

South Island - S. Cal/Mexico
Frequency, Bus VINCENT_500.0 (24156)
Frequency, Bus MESA RIM_ 69.0 (22444)
Frequency, Bus IMPRLVLY_500.0 (22360)
Frequency, Bus SYLMARLA_230.0 (26094)
Frequency, Bus ROA-230_230.0 (20118)
Frequency, Bus SONGS_L_ 12.5 (24553)

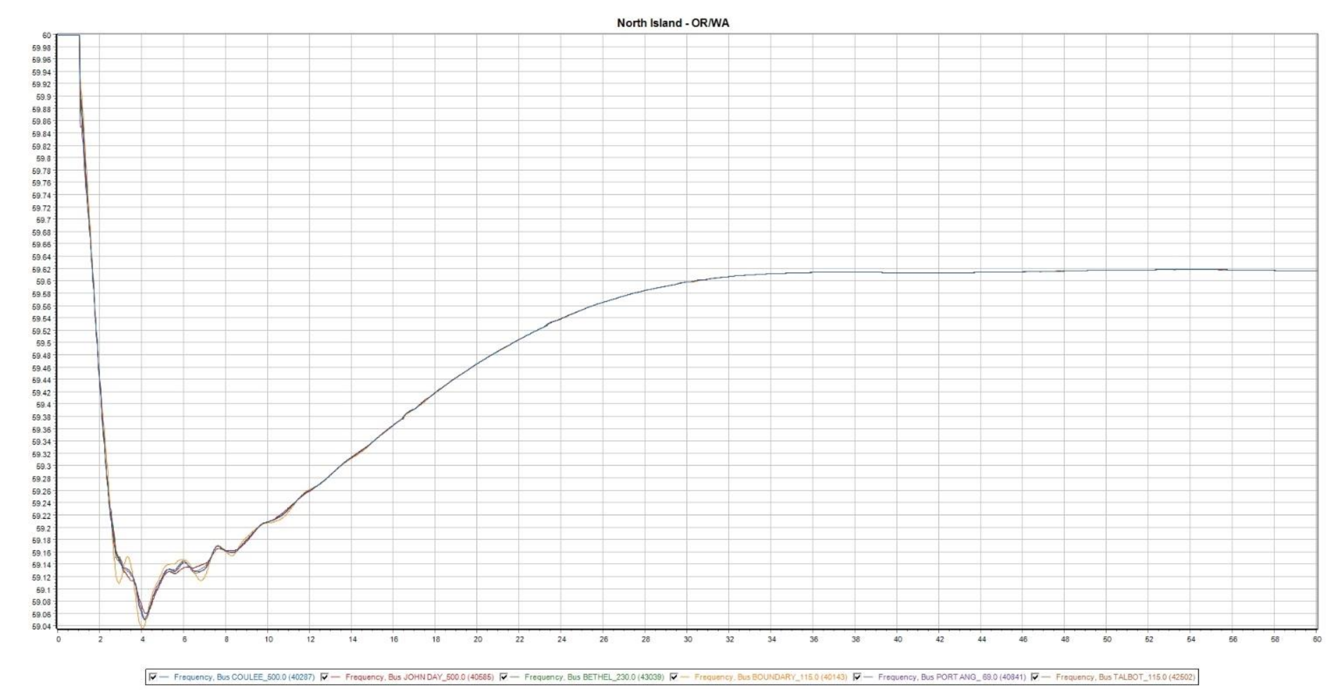

South Island - S. Cal/NV
Frequency, Bus HA CC_500.0 (18426)
Frequency, Bus MCCULLGH_500.0 (26048)
Frequency, Bus VICTORVL_500.0 (26105)
Frequency, Bus DECATUR_230.0 (18015)
Frequency, Bus ELSEGNDO_230.0 (24049)
Frequency, Bus MILLERS_ 57.5 (64073)

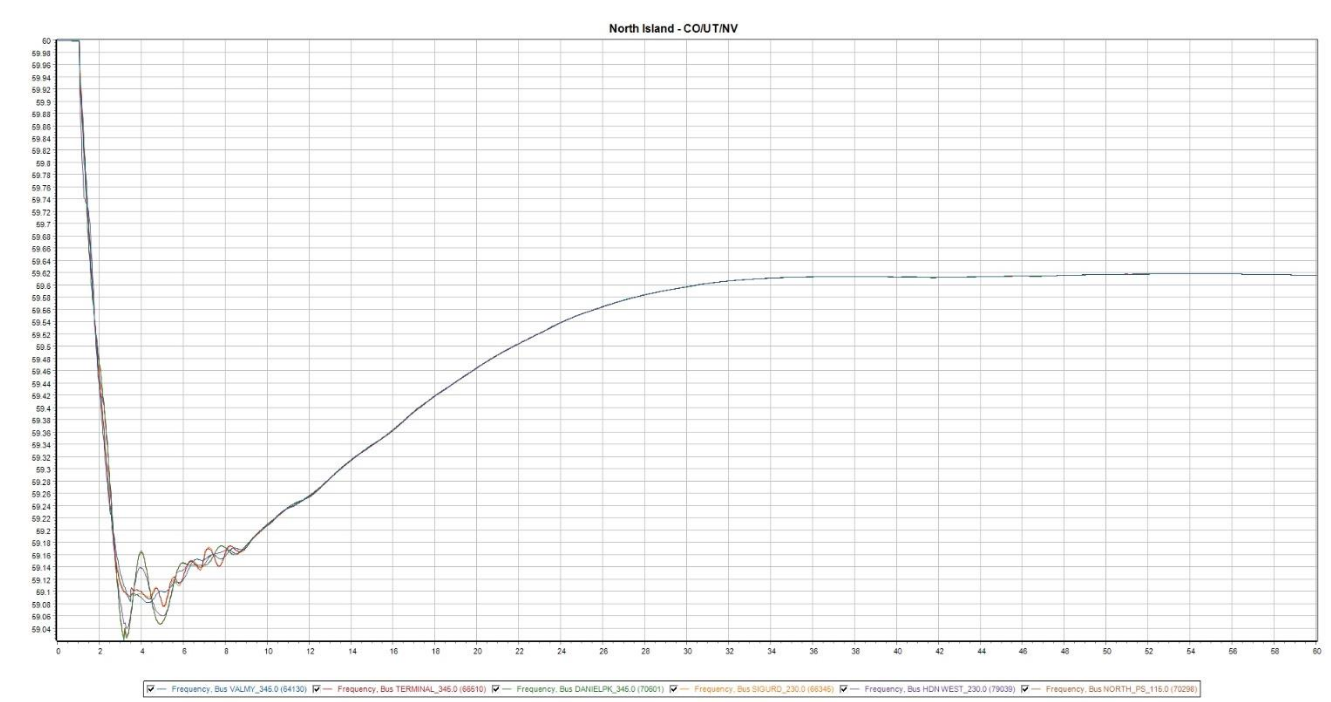

South Island - AZ/NM
Frequency, Bus MOENKOPI_500.0 (14002)
Frequency, Bus TUCSON_ 47.2 (160426)
Frequency, Bus RIOPUERC_345.0 (10390)
Frequency, Bus GLADSTON_230.0 (12101)
Frequency, Bus PHXWAPA_230.0 (19061)
Frequency, Bus ALAMOGPG_115.0 (12002)

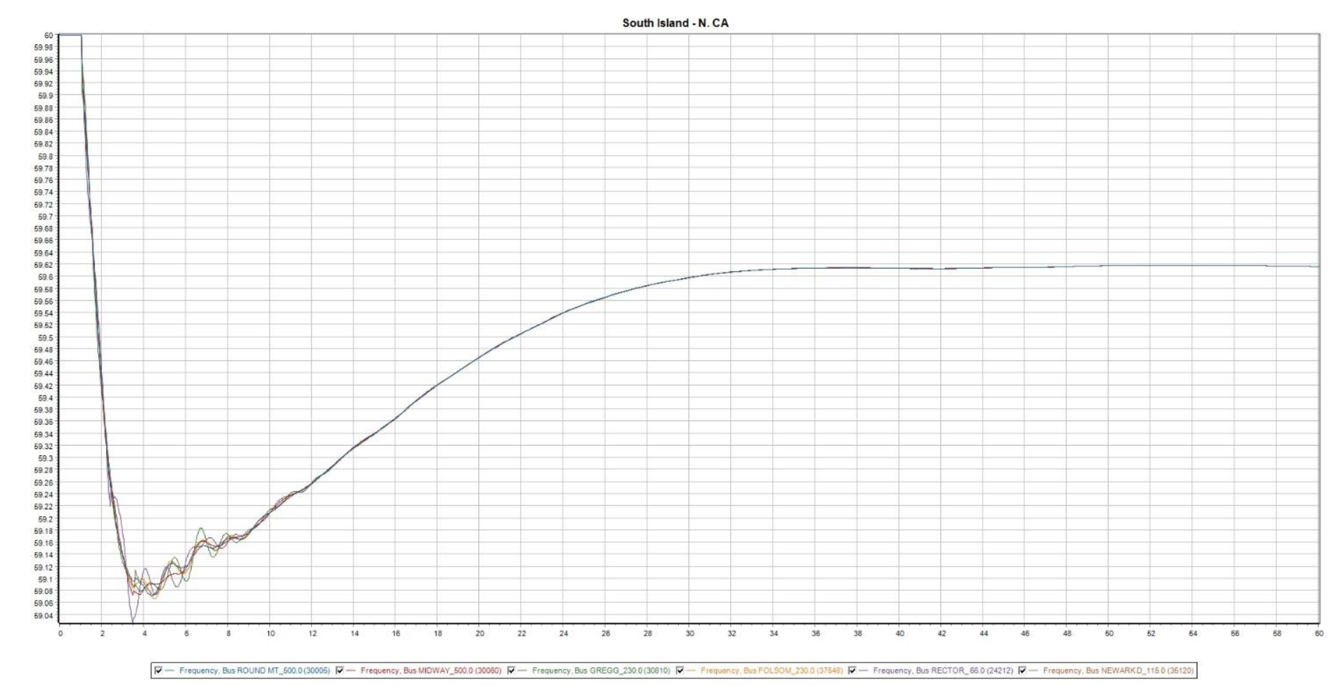
24LSP—10%

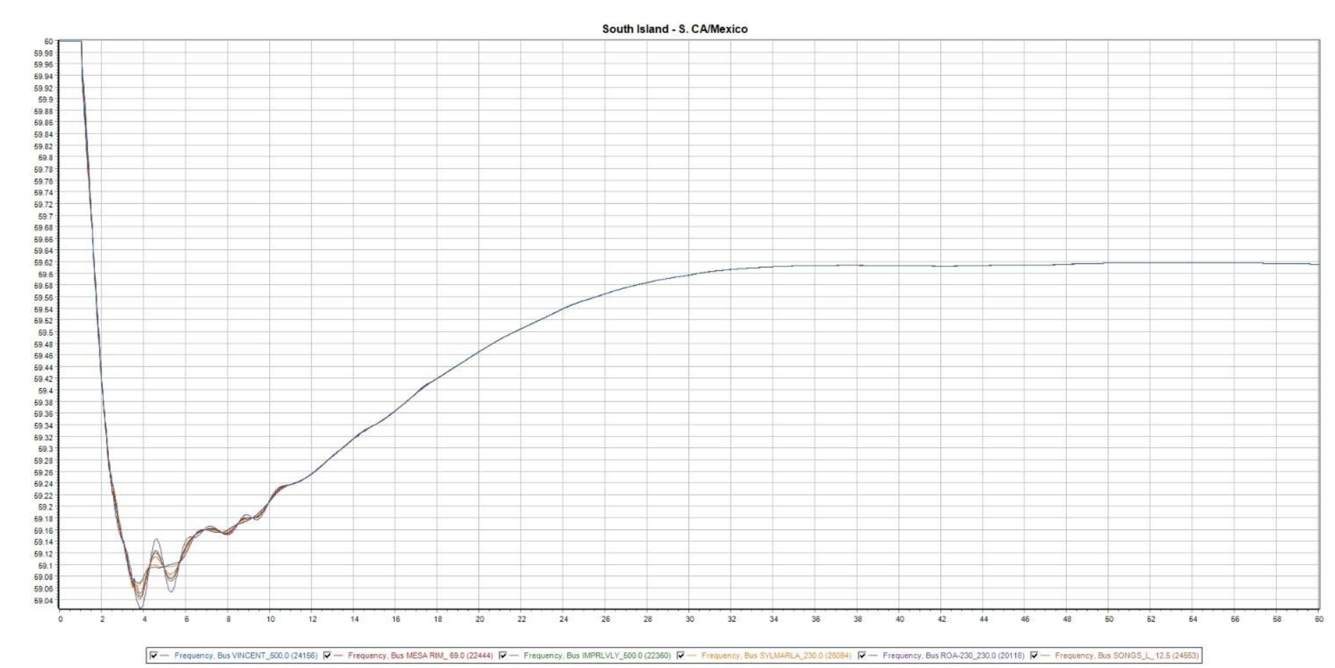

North Island - Canada
Frequency, Bus WSN 500_500.0 (50561)
Frequency, Bus NIC 500_500.0 (50703)
Frequency, Bus LANGDON4_240.0 (54159)
Frequency, Bus KLY 230_230.0 (50692)
Frequency, Bus CLOVERB4_240.0 (54514)
Frequency, Bus MUSKEG8_ 69.0 (58236)

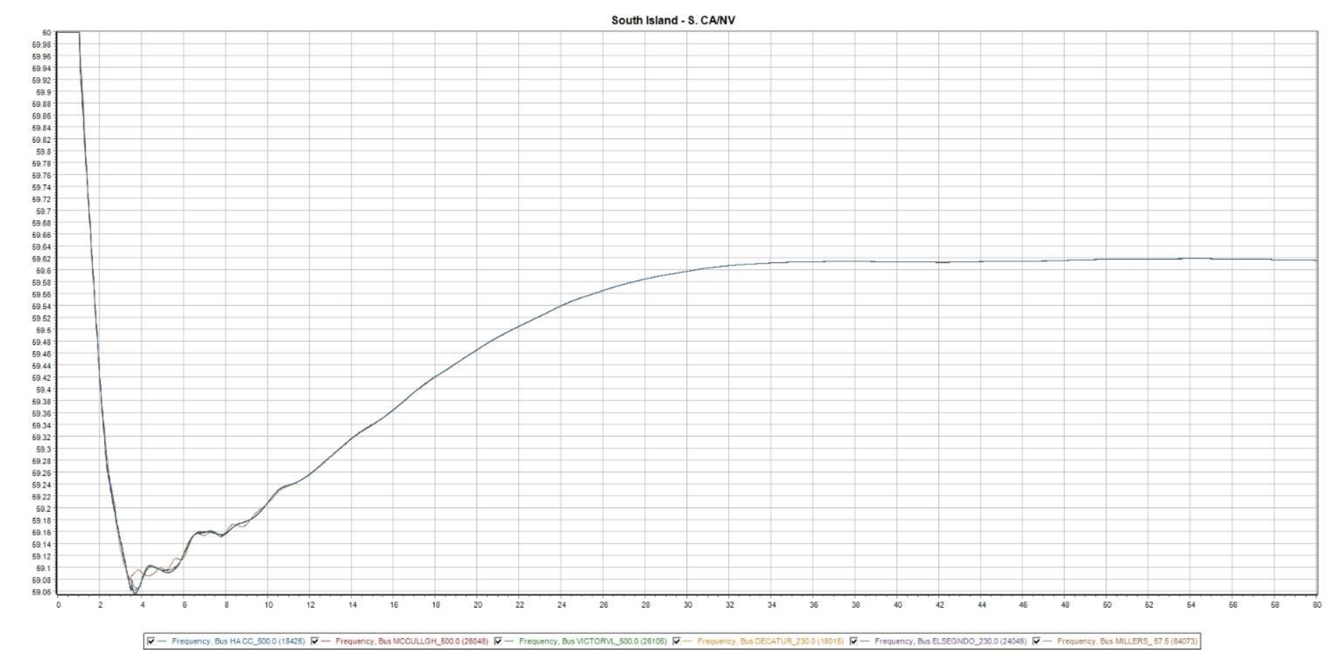

North Island - MT/ID/WY
Frequency, Bus GARRISON_500.0 (40459)
Frequency, Bus MIDPOINT_500.0 (60240)
Frequency, Bus BRIDGER_345.0 (65385)
Frequency, Bus WYODAK_230.0 (66725)
Frequency, Bus CROSSOVER_230.0 (630040)

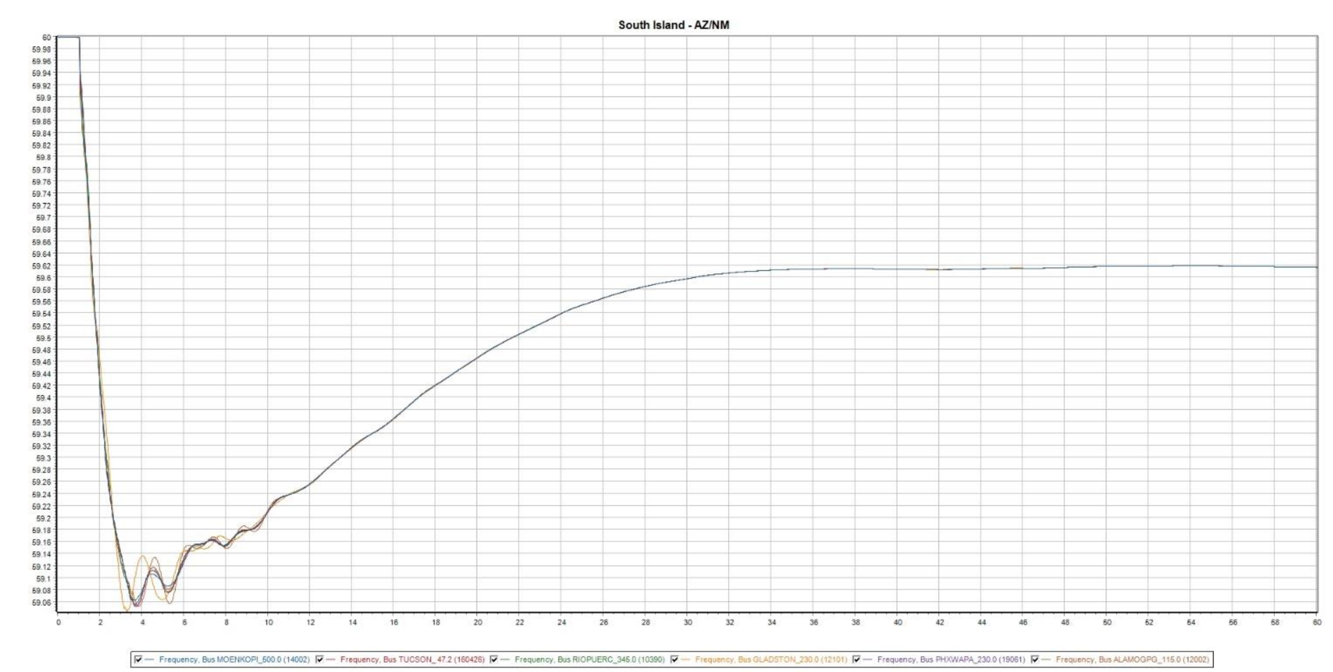

North Island - OR/WA
Frequency, Bus COULEE_500.0 (40287)
Frequency, Bus JOHN DAY_500.0 (40585)
Frequency, Bus BETHEL_230.0 (43039)
Frequency, Bus BOUNDARY_115.0 (40143)
Frequency, Bus PORT ANG_ 69.0 (40841)
Frequency, Bus TALBOT_115.0 (42502)


North Island - CO/UT/NV
Frequency, Bus VALMY_345.0 (64130)
Frequency, Bus TERMINAL_345.0 (66510)
Frequency, Bus DANIELPK_345.0 (70601)
Frequency, Bus SIGURD_230.0 (66345)
Frequency, Bus HDN WEST_230.0 (79039)
Frequency, Bus NORTH_PS_115.0 (70298)

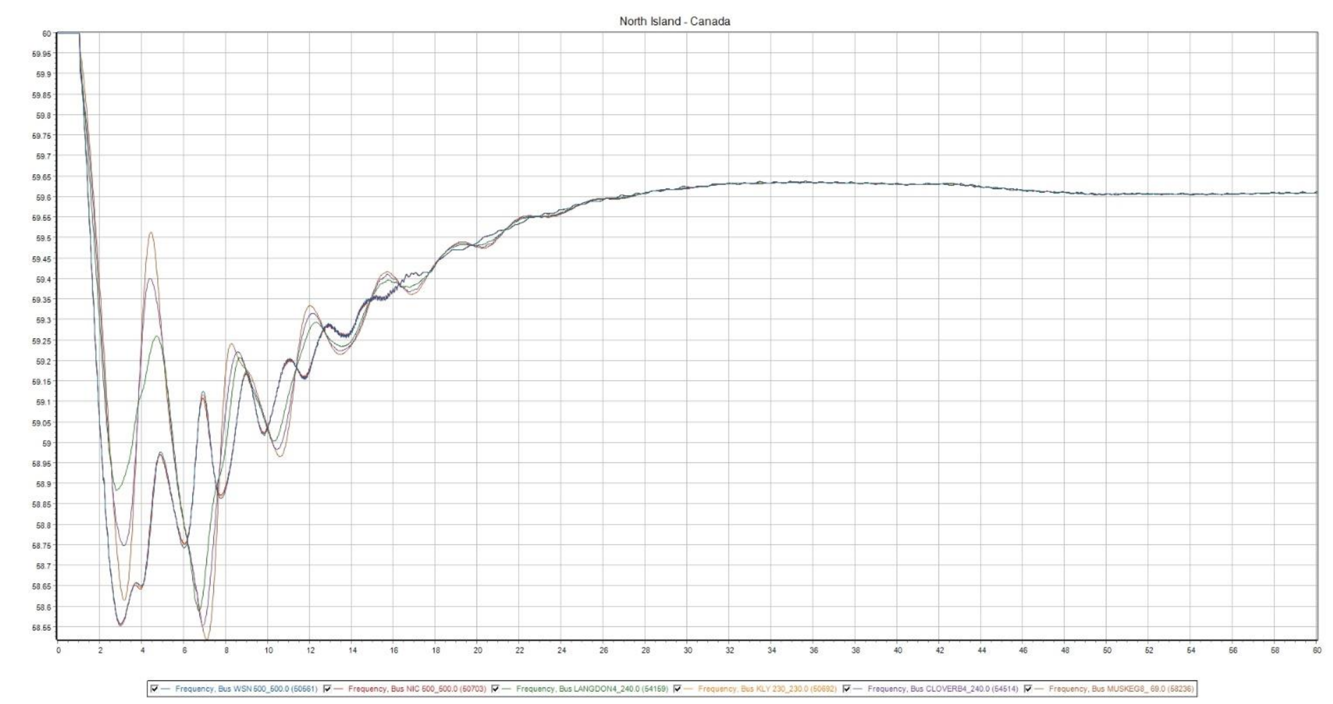

South Island - N. CA
Frequency, Bus ROUND MT_500.0 (30005)
Frequency, Bus MIDWAY_500.0 (30060)
Frequency, Bus GREGG_230.0 (30810)
Frequency, Bus FOLSOM_230.0 (37548)
Frequency, Bus RECTOR_66.0 (24212)
Frequency, Bus NEWARKD_115.0 (35120)

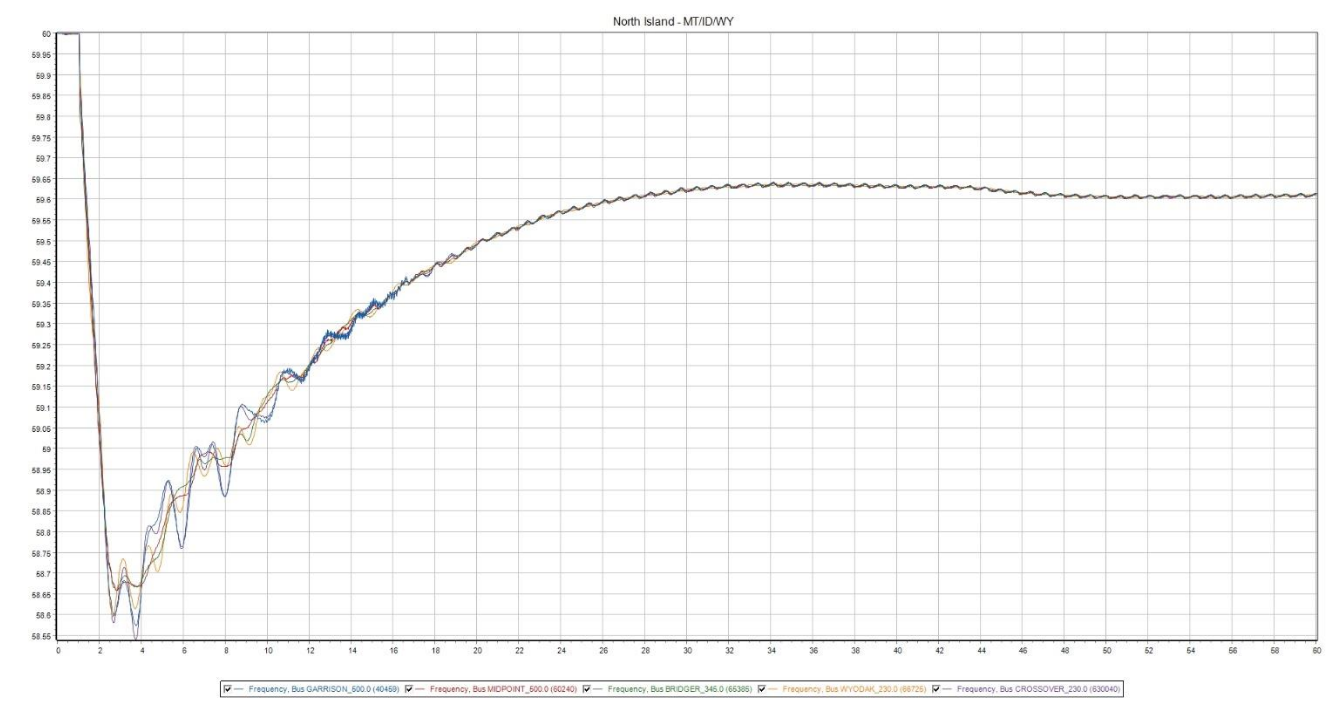

South Island - S. CA/Mexico
Frequency, Bus VINCENT_500.0 (24156)
Frequency, Bus MESA RIM_ 69.0 (22444)
Frequency, Bus IMPRLVLY_500.0 (22360)
Frequency, Bus SYLMARLA_230.0 (26094)
Frequency, Bus ROA-230_230.0 (20118)
Frequency, Bus SONGS_L_ 12.5 (24553)

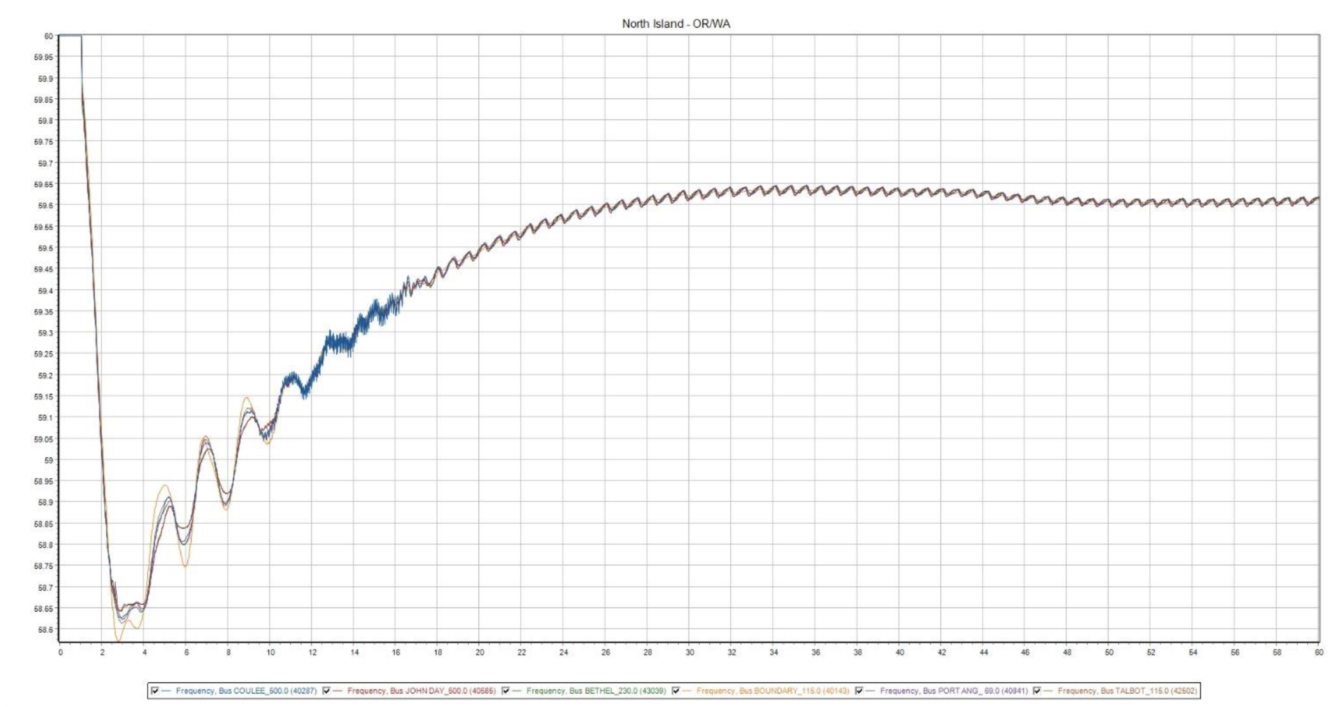

South Island - S. CA/NV
Frequency, Bus HA CC_500.0 (18425)
Frequency, Bus MCCULLGH_500.0 (26048)
Frequency, Bus VICTORVL_500.0 (26105)
Frequency, Bus DECATUR_230.0 (18015)
Frequency, Bus ELSEGNDO_230.0 (24049)
Frequency, Bus MILLERS_ 57.5 (64073)

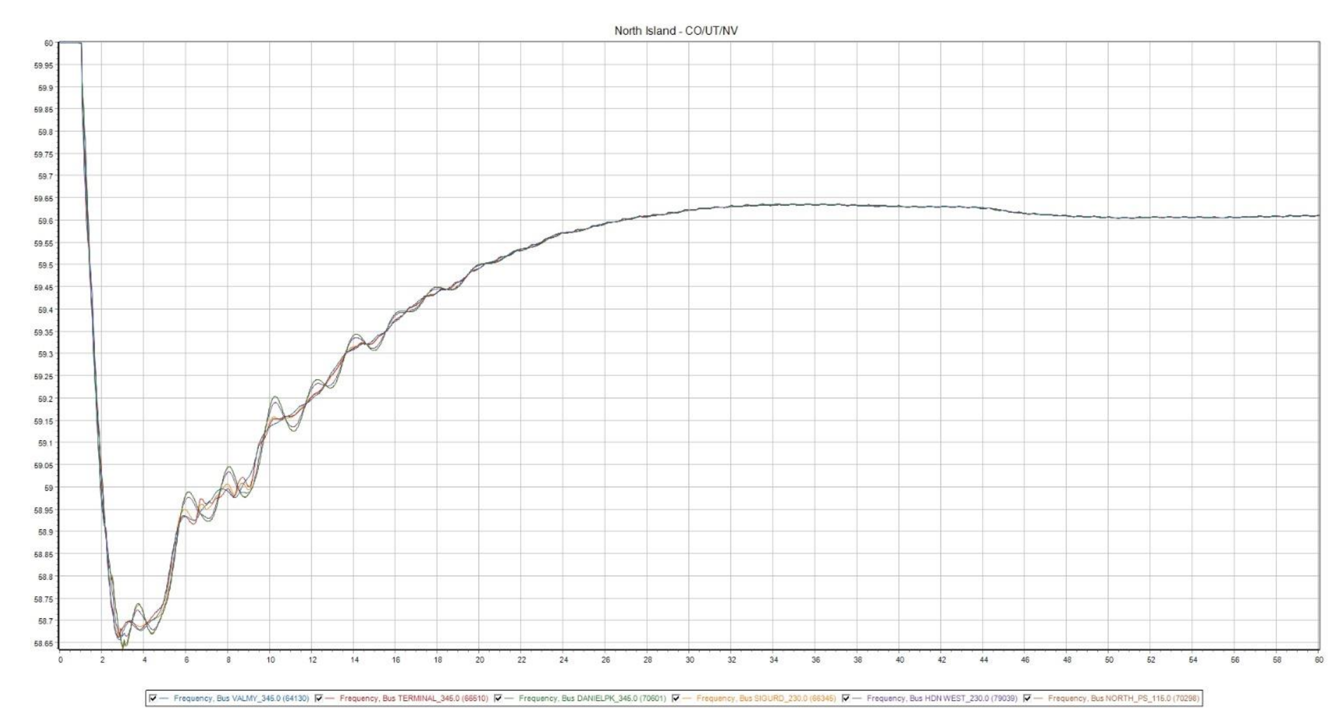

South Island - AZ/NM
Frequency, Bus MOENKOPI_500.0 (14002)
Frequency, Bus TUCSON_ 47.2 (160426)
Frequency, Bus RIOPUERC_345.0 (10390)
Frequency, Bus GLADSTON_230.0 (12101)
Frequency, Bus PHXWAPA_230.0 (19061)
Frequency, Bus ALAMOGPG_115.0 (12002)

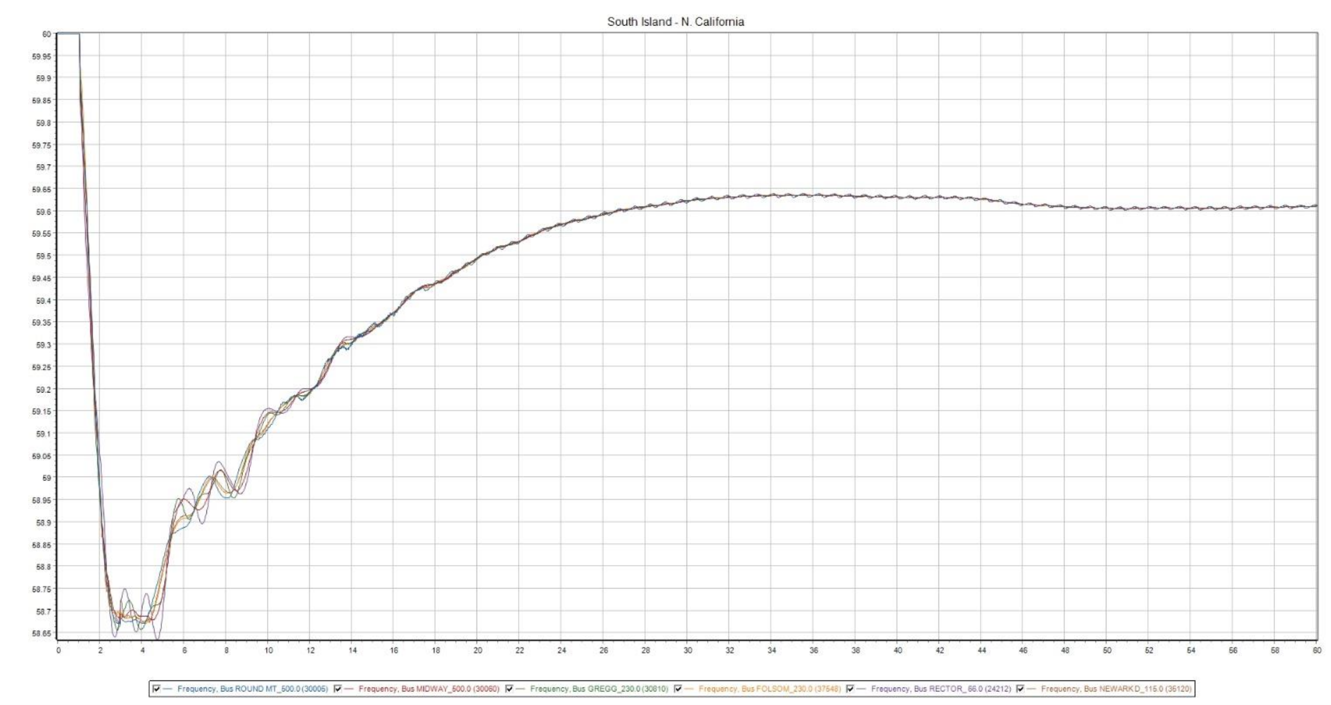
24LSP—20%

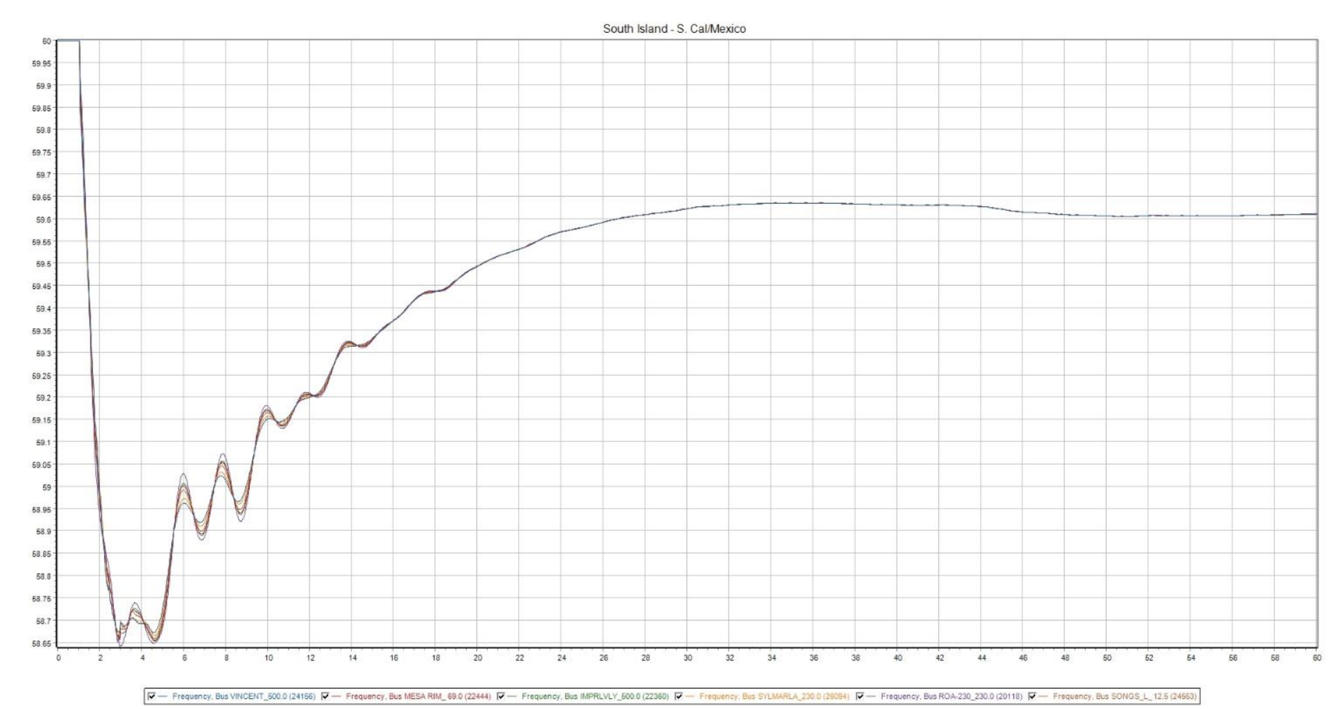

North Island - Canada
Frequency, Bus WSN 500_500.0 (50561)
Frequency, Bus NIC 500_500.0 (50703)
Frequency, Bus LANGDON4_240.0 (54159)
Frequency, Bus KLY 230_230.0 (50692)
Frequency, Bus CLOVERB4_240.0 (54514)
Frequency, Bus MUSKEG8_ 69.0 (58236)

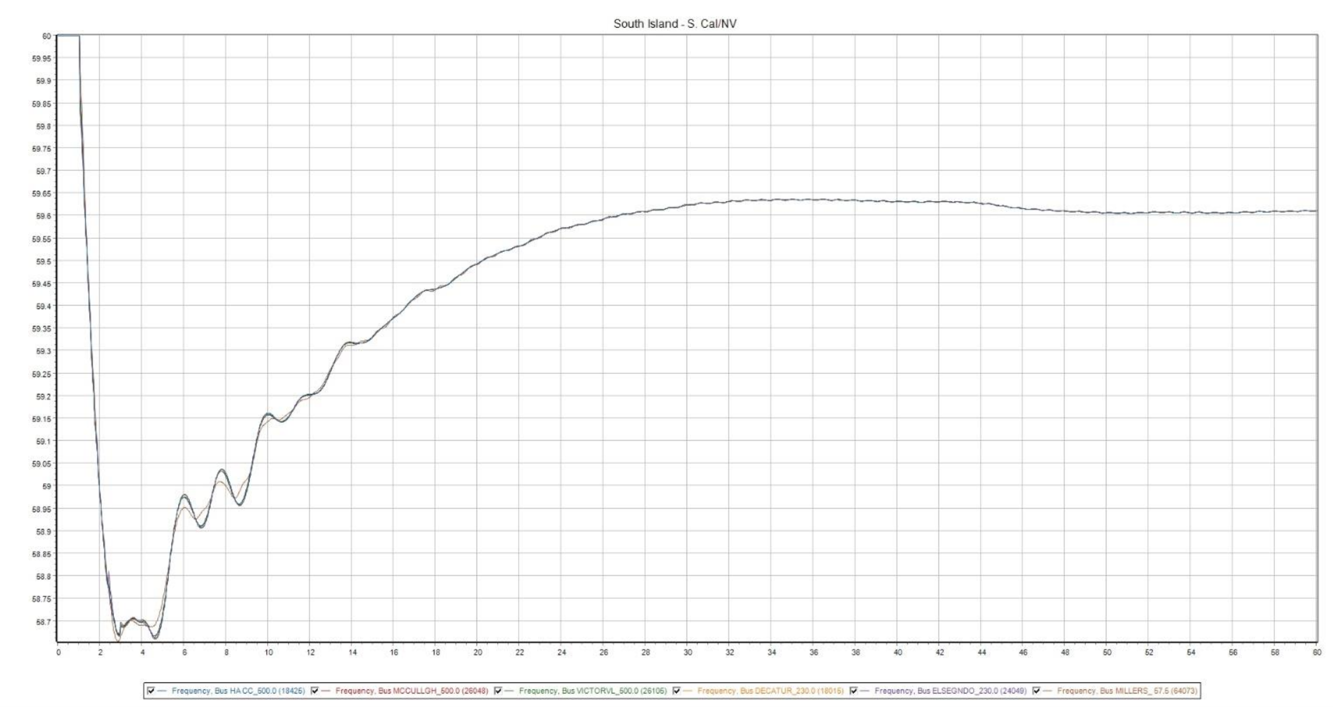

North Island - MT/ID/WY
Frequency, Bus GARRISON_500.0 (40459)
Frequency, Bus MIDPOINT_500.0 (60240)
Frequency, Bus BRIDGER_345.0 (65385)
Frequency, Bus WYODAK_230.0 (66725)
Frequency, Bus CROSSOVER_230.0 (630040)

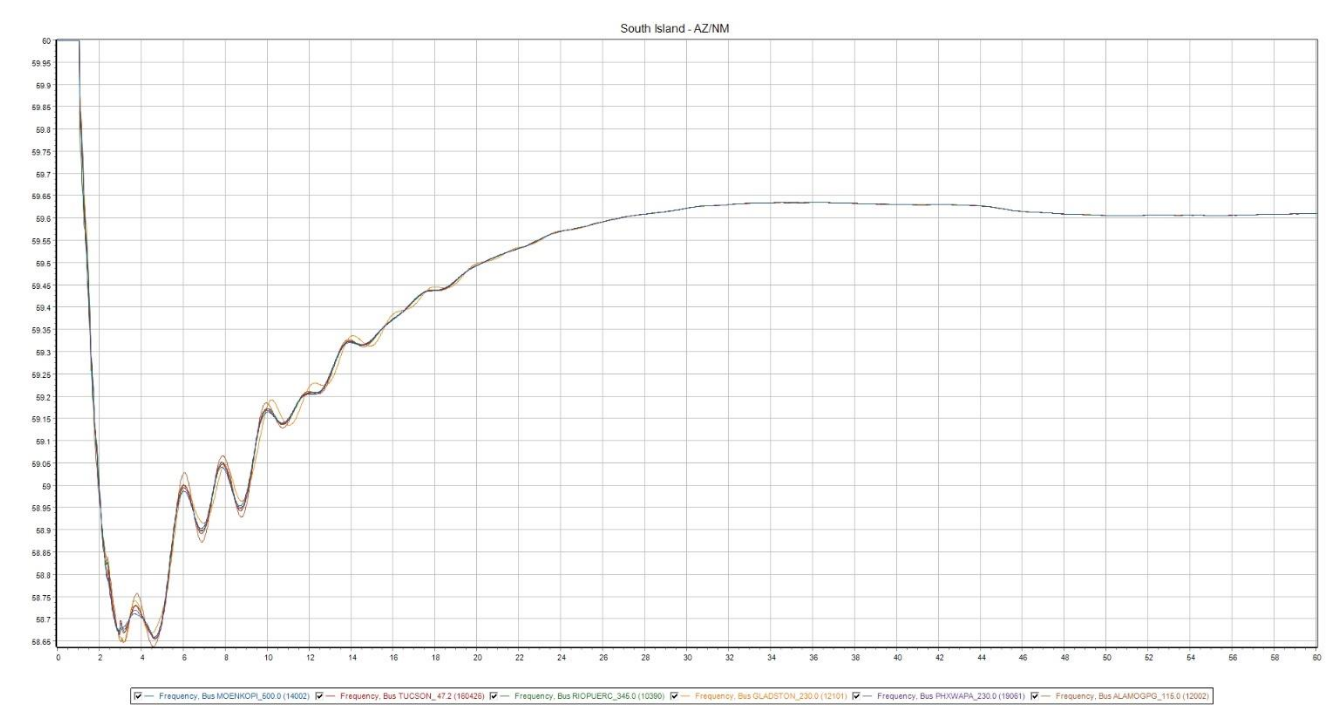

North Island - OR/WA
Frequency, Bus COULEE_500.0 (40287)
Frequency, Bus JOHN DAY_500.0 (40585)
Frequency, Bus BETHEL_230.0 (43039)
Frequency, Bus BOUNDARY_115.0 (40143)
Frequency, Bus PORT ANG_ 69.0 (40841)
Frequency, Bus TALBOT_115.0 (42502)


North Island - CO/UT/NV
Frequency, Bus VALMY_345.0 (64130)
Frequency, Bus TERMINAL_345.0 (66510)
Frequency, Bus DANIELPK_345.0 (70601)
Frequency, Bus SIGURD_230.0 (66345)
Frequency, Bus HDN WEST_230.0 (79039)
Frequency, Bus NORTH_PS_115.0 (70298)

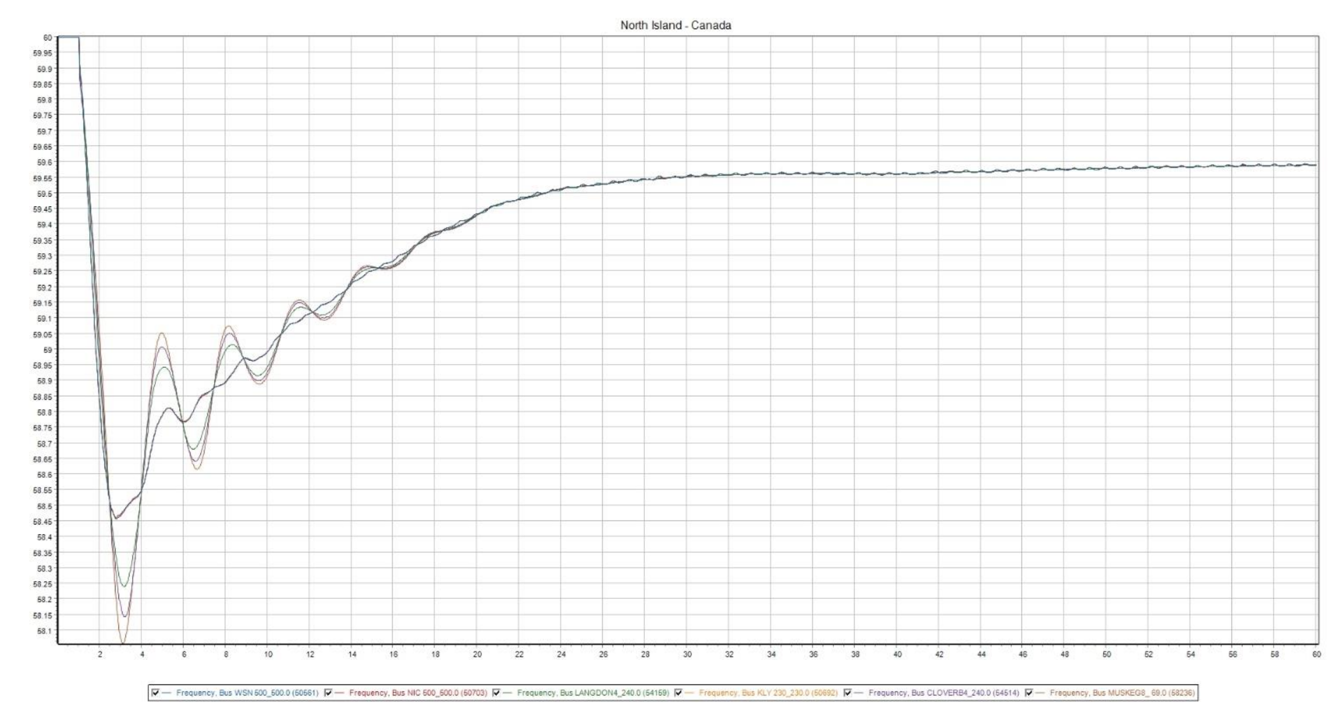

South Island - N. California
Frequency, Bus ROUND MT_500.0 (30005)
Frequency, Bus MIDWAY_500.0 (30060)
Frequency, Bus GREGG_230.0 (30810)
Frequency, Bus FOLSOM_230.0 (37548)
Frequency, Bus RECTOR_66.0 (24212)
Frequency, Bus NEWARKD_115.0 (36120)

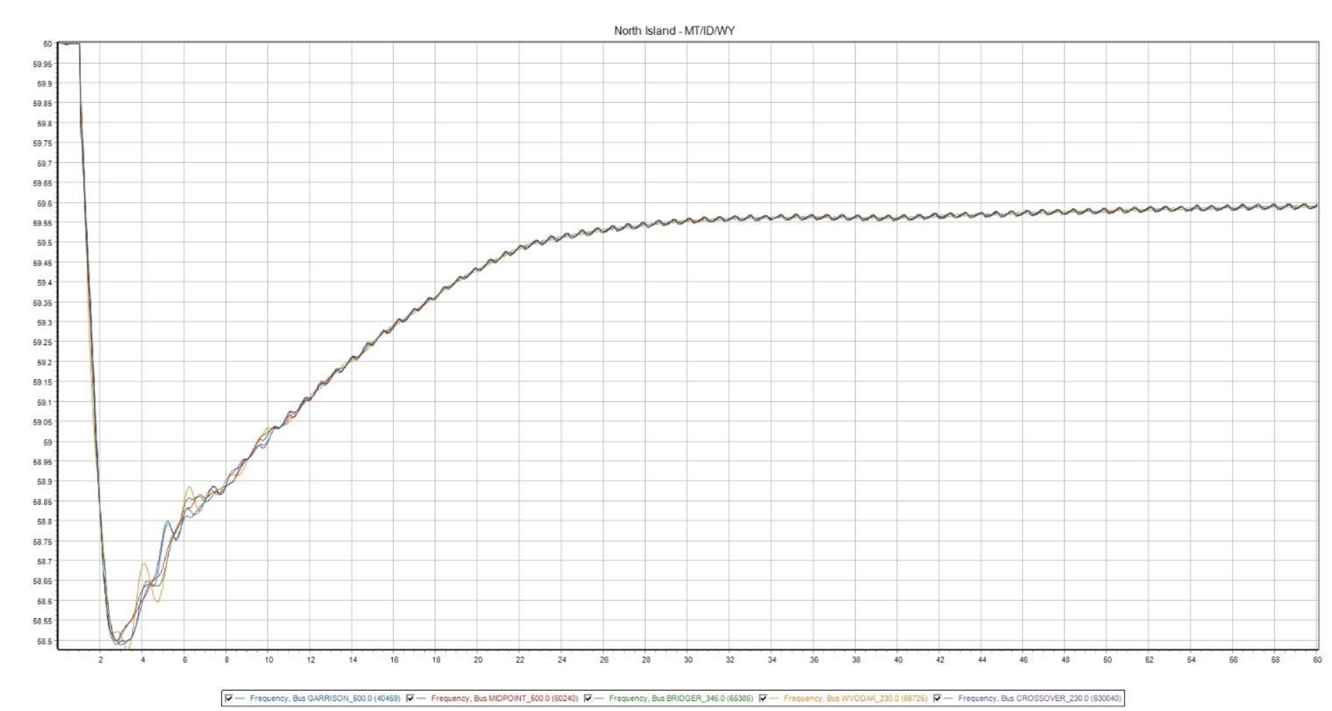

South Island - S. Cal/Mexico
Frequency, Bus VINCENT_500.0 (24156)
Frequency, Bus MESA RIM_69.0 (22444)
Frequency, Bus IMPRLVLY_500.0 (22360)
Frequency, Bus SYLMARLA_230.0 (26094)
Frequency, Bus ROA-230_230.0 (20118)
Frequency, Bus SONGS_L_12.5 (24553)

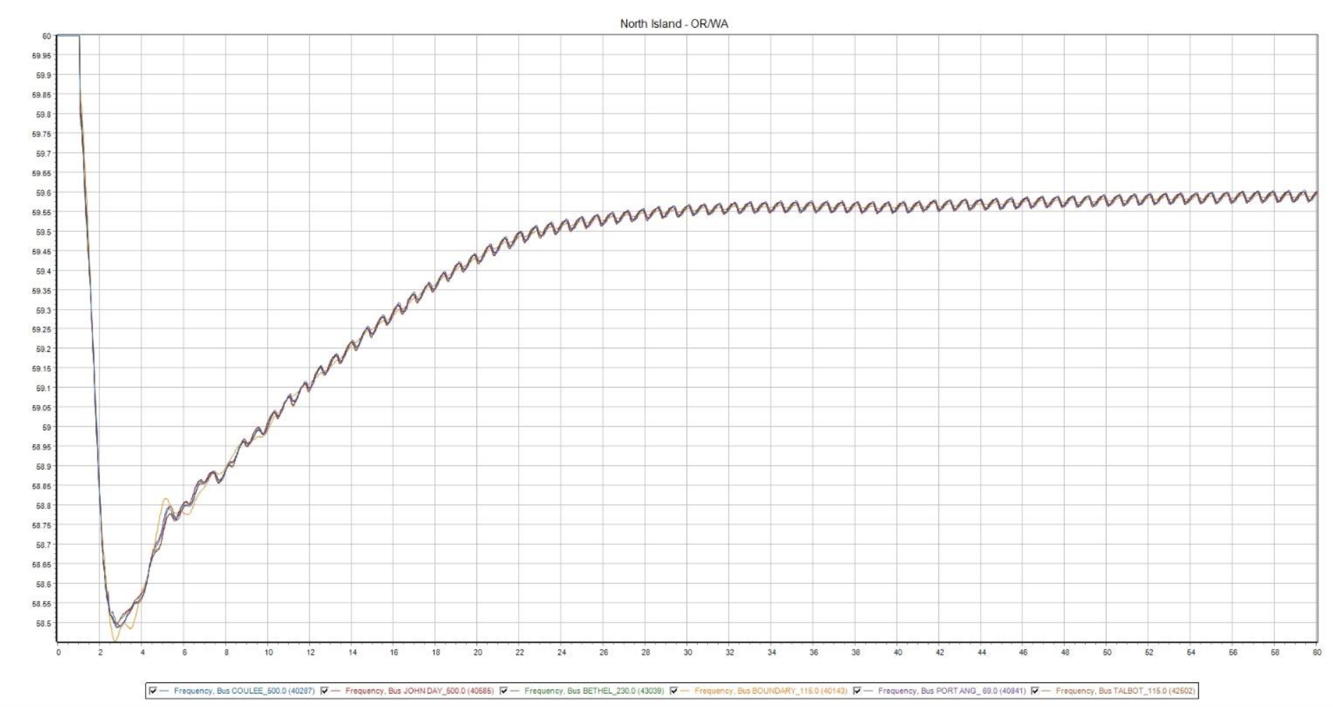

South Island - S. Cal/NV
Frequency, Bus HA CC_500.0 (18425)
Frequency, Bus MCCULLGH_500.0 (26048)
Frequency, Bus VICTORVL_500.0 (26105)
Frequency, Bus DECATUR_230.0 (18015)
Frequency, Bus ELSEGNDO_230.0 (24049)
Frequency, Bus MILLERS_ 57.5 (64073)

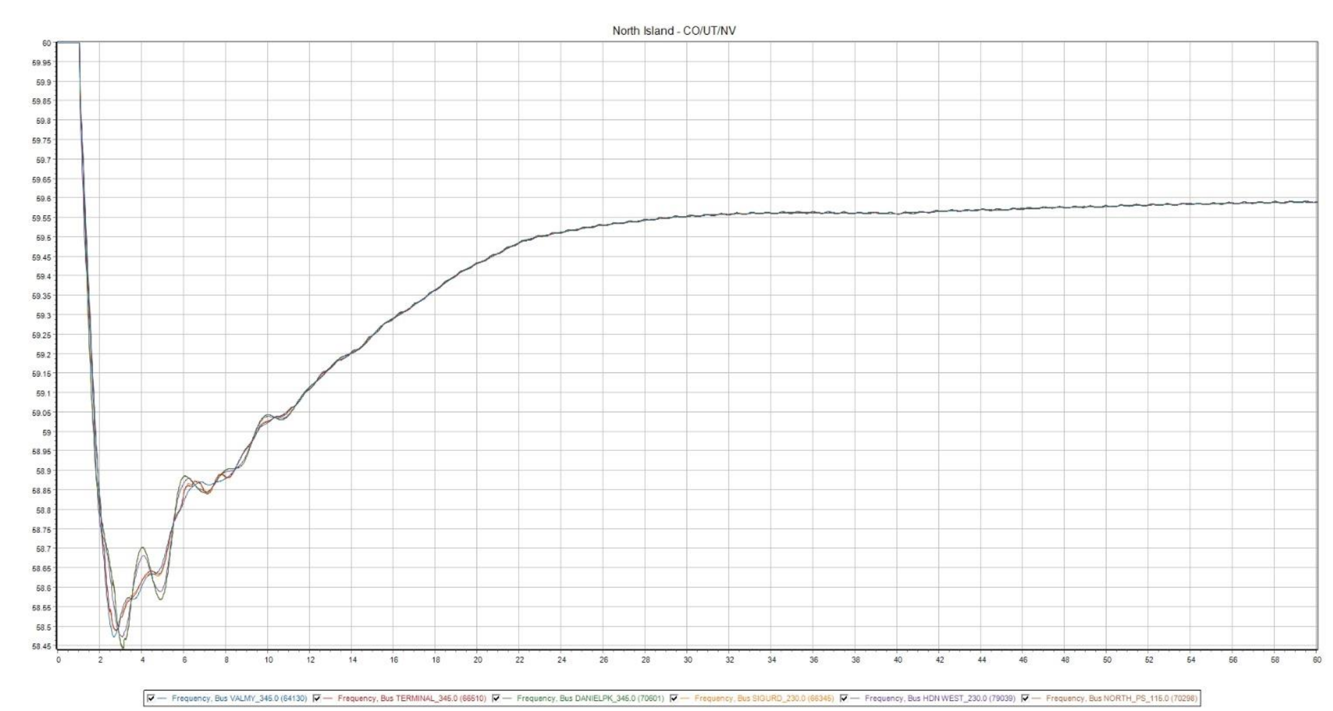

South Island - AZ/NM
Frequency, Bus MOENKOPI_500.0 (14002)
Frequency, Bus TUCSON_47.2 (160426)
Frequency, Bus RIOPUERC_345.0 (10390)
Frequency, Bus GLADSTON_230.0 (12101)
Frequency, Bus PHXWAPA_230.0 (19061)
Frequency, Bus ALAMOGPG_115.0 (12002)

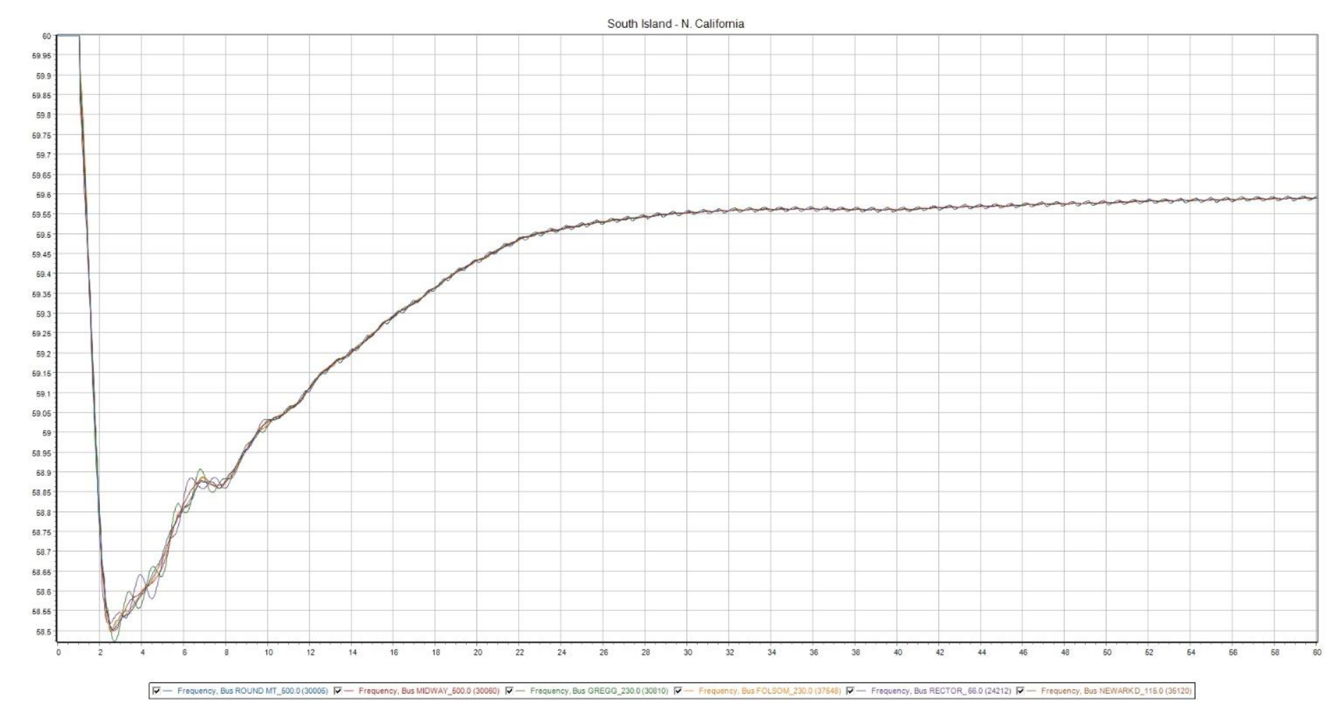
24LSP—25%

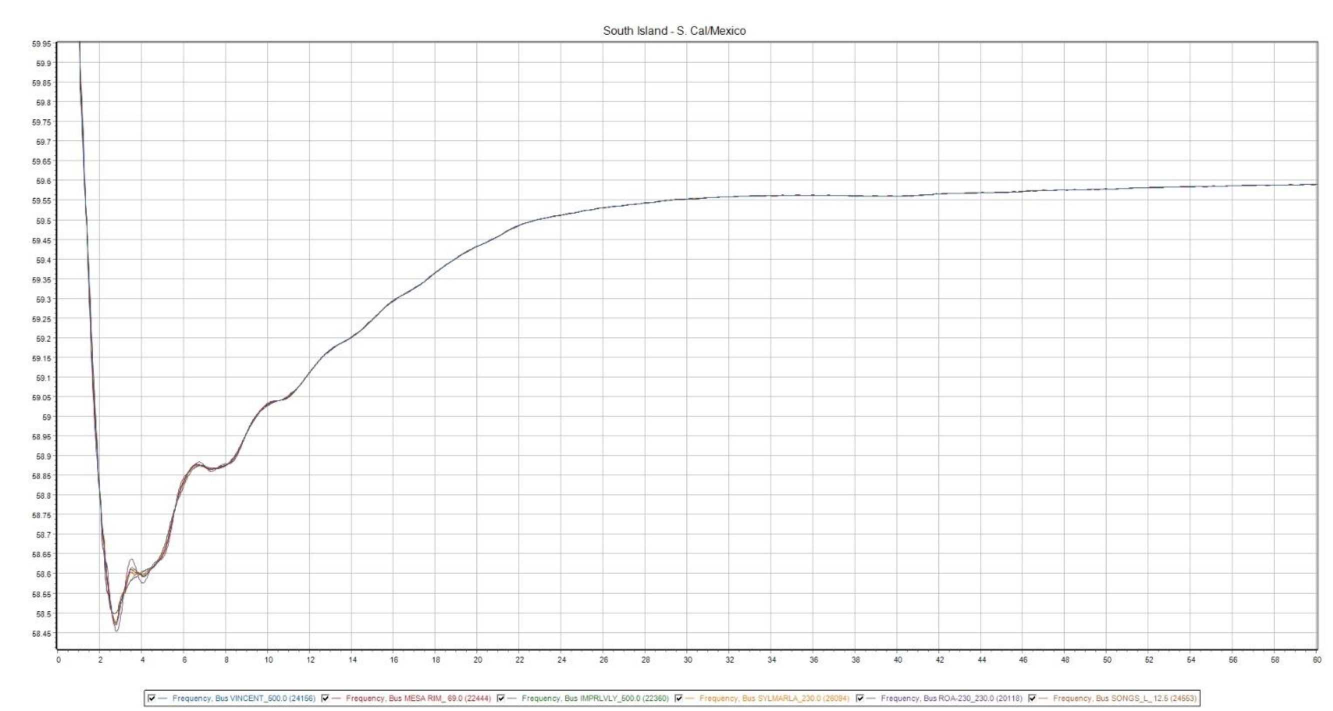

North Island - Canada
Frequency, Bus WSN 500_500.0 (50561)
Frequency, Bus NIC 500_500.0 (50703)
Frequency, Bus LANGDON4_240.0 (54159)
Frequency, Bus KLY 230_230.0 (50692)
Frequency, Bus CLOVERB4_240.0 (54514)
Frequency, Bus MUSKEG8_ 69.0 (58236)

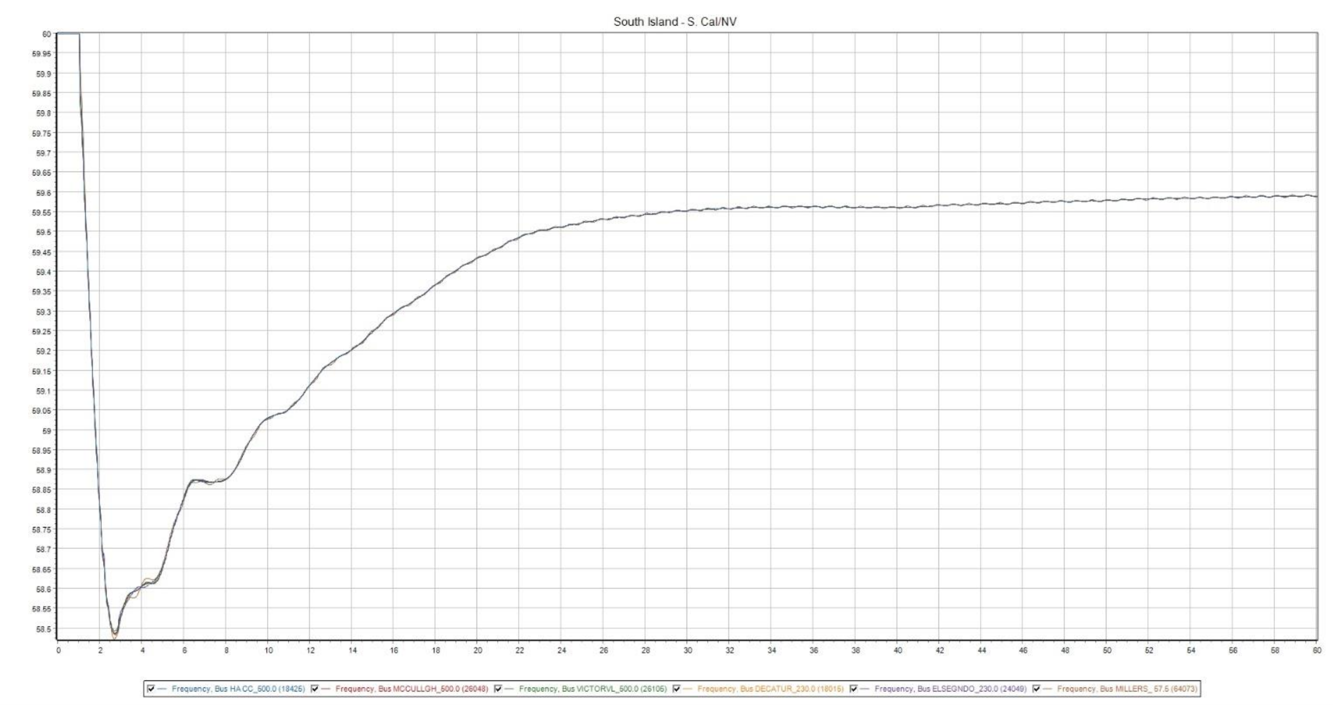

North Island - MT/ID/WY
Frequency, Bus GARRISON_500.0 (40459)
Frequency, Bus MIDPOINT_500.0 (60240)
Frequency, Bus BRIDGER_345.0 (65385)
Frequency, Bus WYODAK_230.0 (66725)
Frequency, Bus CROSSOVER_230.0 (630040)

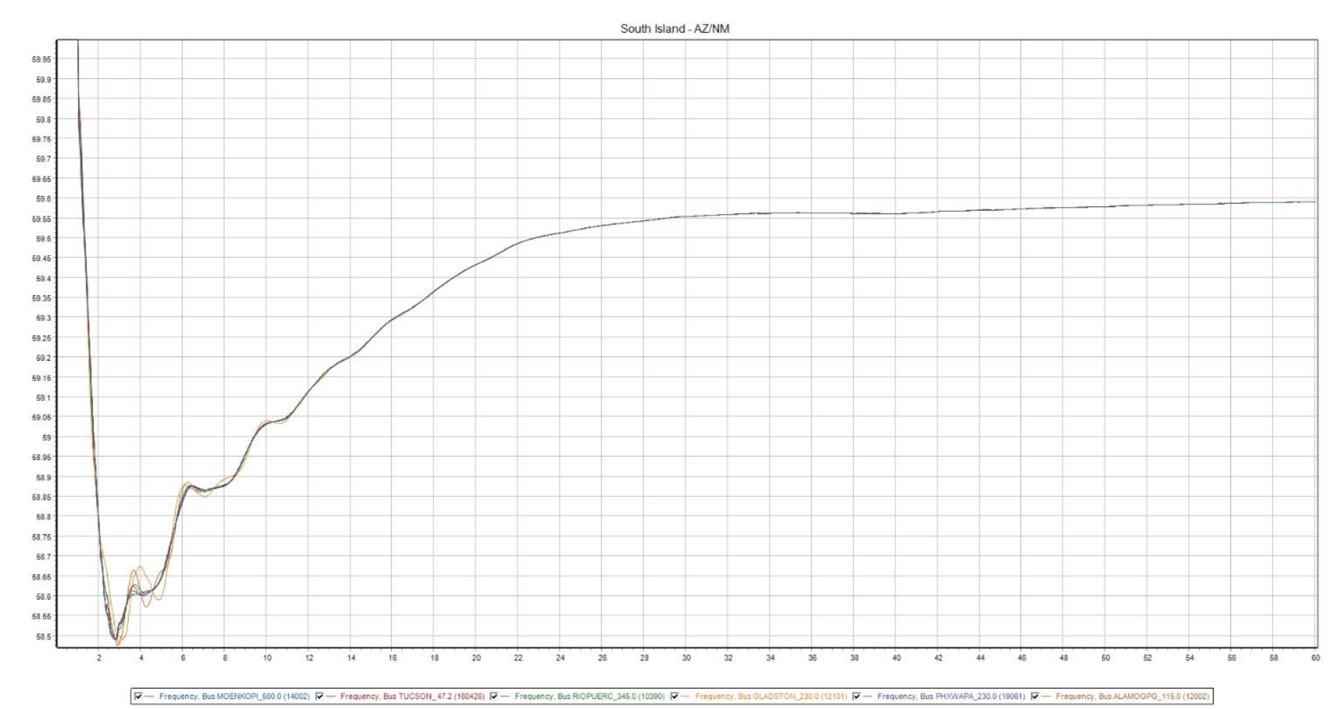

North Island - OR/WA
Frequency, Bus COULEE_500.0 (40287)
Frequency, Bus JOHN DAY_500.0 (40585)
Frequency, Bus BETHEL_230.0 (43039)
Frequency, Bus BOUNDARY_115.0 (40143)
Frequency, Bus PORT ANG_ 69.0 (40841)
Frequency, Bus TALBOT_115.0 (42502)


North Island - CO/UT/NV
Frequency, Bus VALMY_345.0 (64130)
Frequency, Bus TERMINAL_345.0 (66510)
Frequency, Bus DANIELPK_345.0 (70601)
Frequency, Bus SIGURD_230.0 (66345)
Frequency, Bus HDN WEST_230.0 (79039)
Frequency, Bus NORTH_PS_115.0 (70298)


South Island - N. California
Frequency, Bus ROUND MT_500.0 (30005)
Frequency, Bus MIDWAY_500.0 (30060)
Frequency, Bus GREGG_230.0 (30810)
Frequency, Bus FOLSOM_230.0 (37548)
Frequency, Bus RECTOR_66.0 (24212)
Frequency, Bus NEWARKD_115.0 (36120)

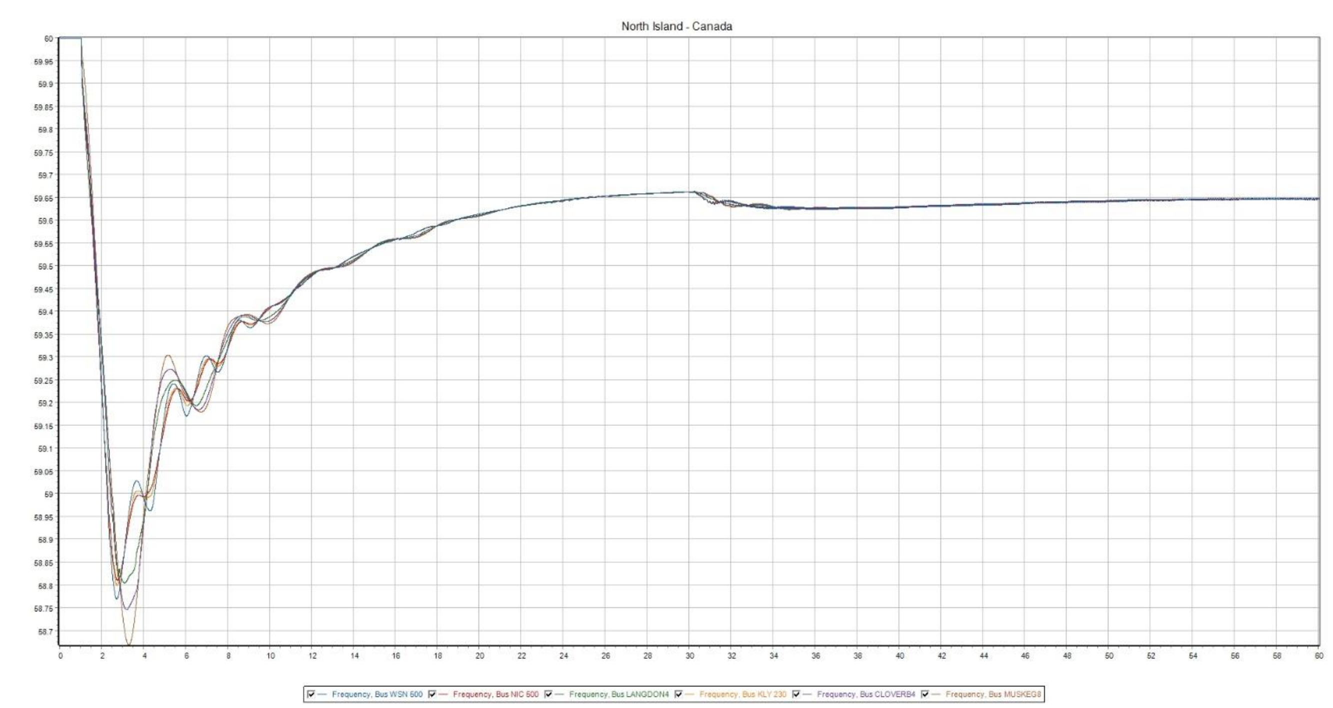

South Island - S. Cal/Mexico
Frequency, Bus VINCENT_500.0 (24156)
Frequency, Bus MESA RIM_ 69.0 (22444)
Frequency, Bus IMPRLVLY_500.0 (22360)
Frequency, Bus SYLMARLA_230.0 (26094)
Frequency, Bus ROA-230_230.0 (20118)
Frequency, Bus SONGS_L_12.5 (24553)

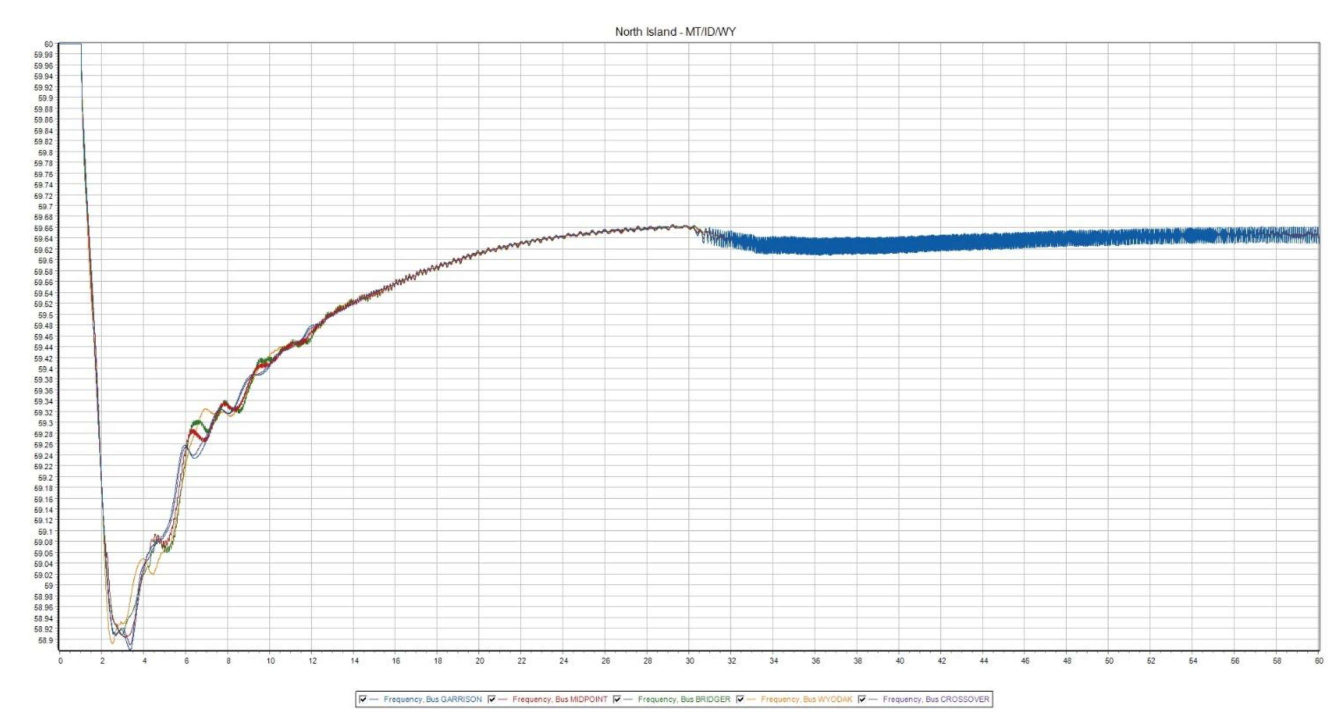

South Island - S. Cal/NV
Frequency, Bus HA CC_500.0 (18425)
Frequency, Bus MCCULLGH_500.0 (26048)
Frequency, Bus VICTORVL_500.0 (26105)
Frequency, Bus DECATUR_230.0 (18015)
Frequency, Bus ELSEGNDO_230.0 (24049)
Frequency, Bus MILLERS_ 57.5 (64073)

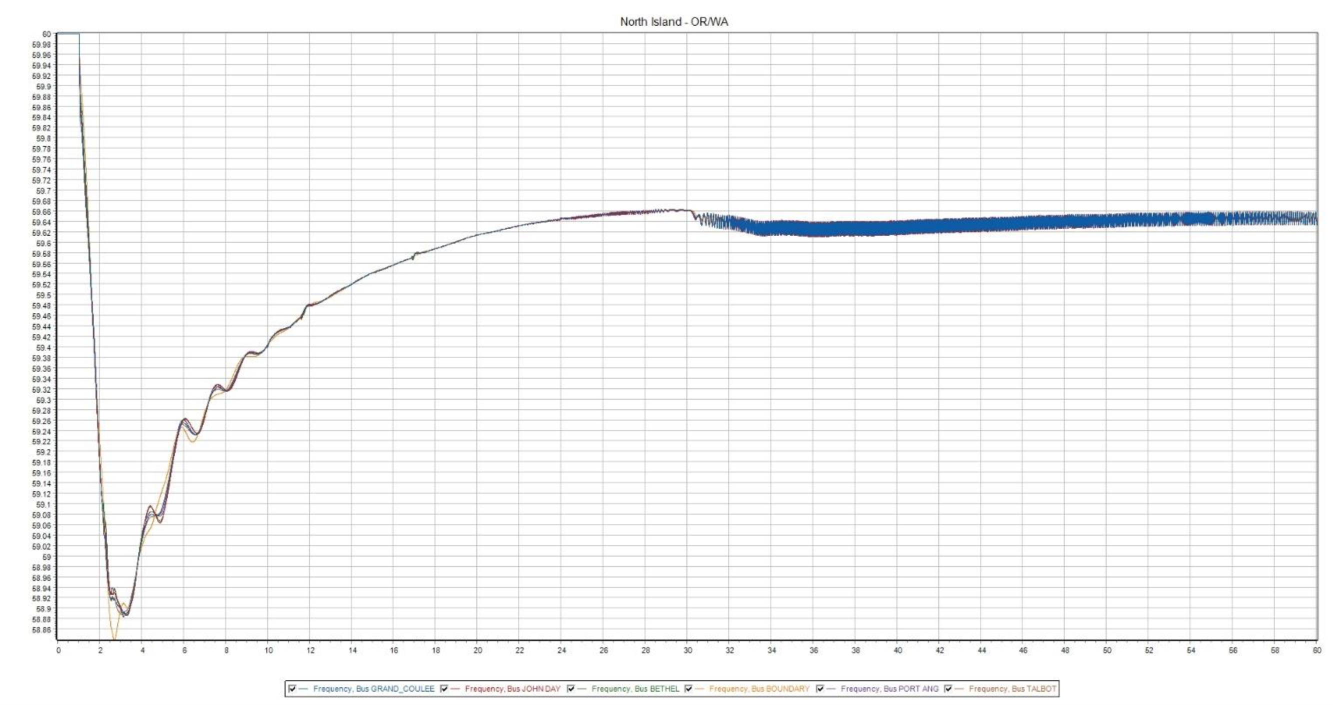

South Island - AZ/NM
Frequency, Bus MOENKOPI_500.0 (14002)
Frequency, Bus TUCSON_ 47.2 (160426)
Frequency, Bus RIOPUERC_345.0 (10390)
Frequency, Bus GLADSTON_230.0 (12101)
Frequency, Bus PHXWAPA_230.0 (19061)
Frequency, Bus ALAMOGPG_115.0 (12002)

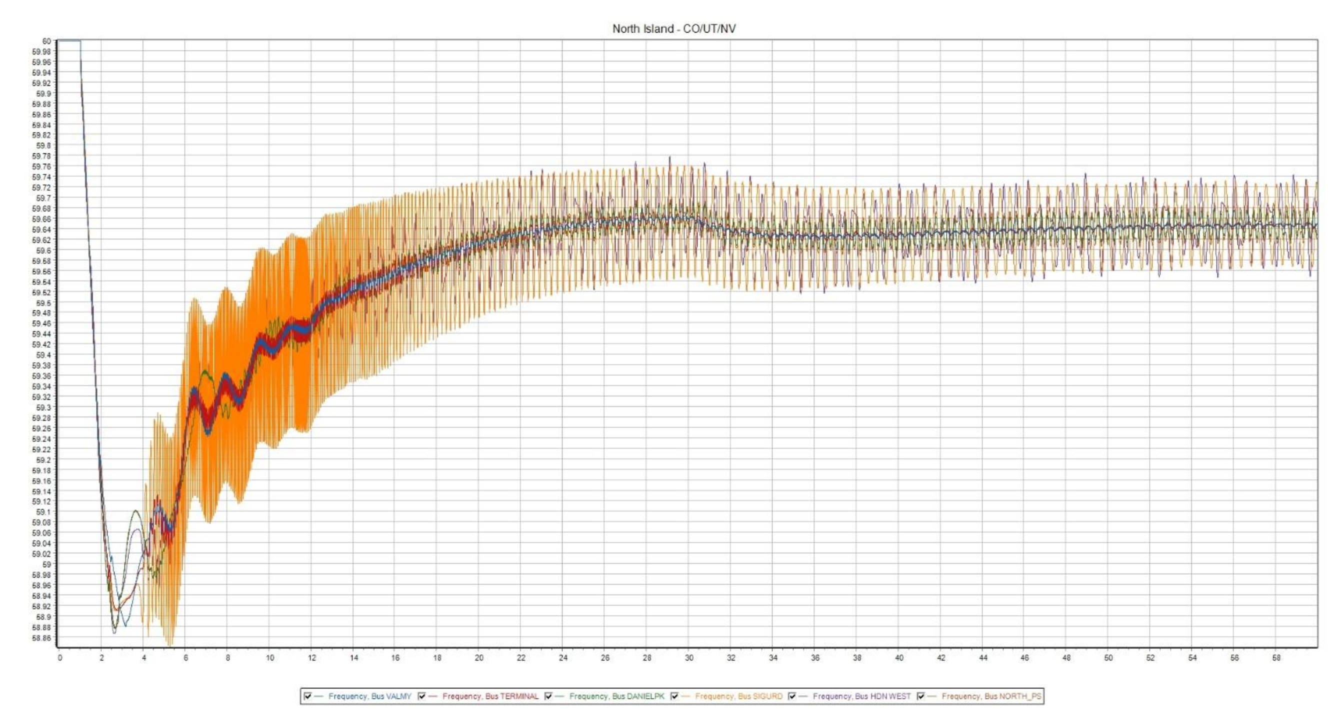
Appendix B—Frequency Performance—North Island

21HS—10%

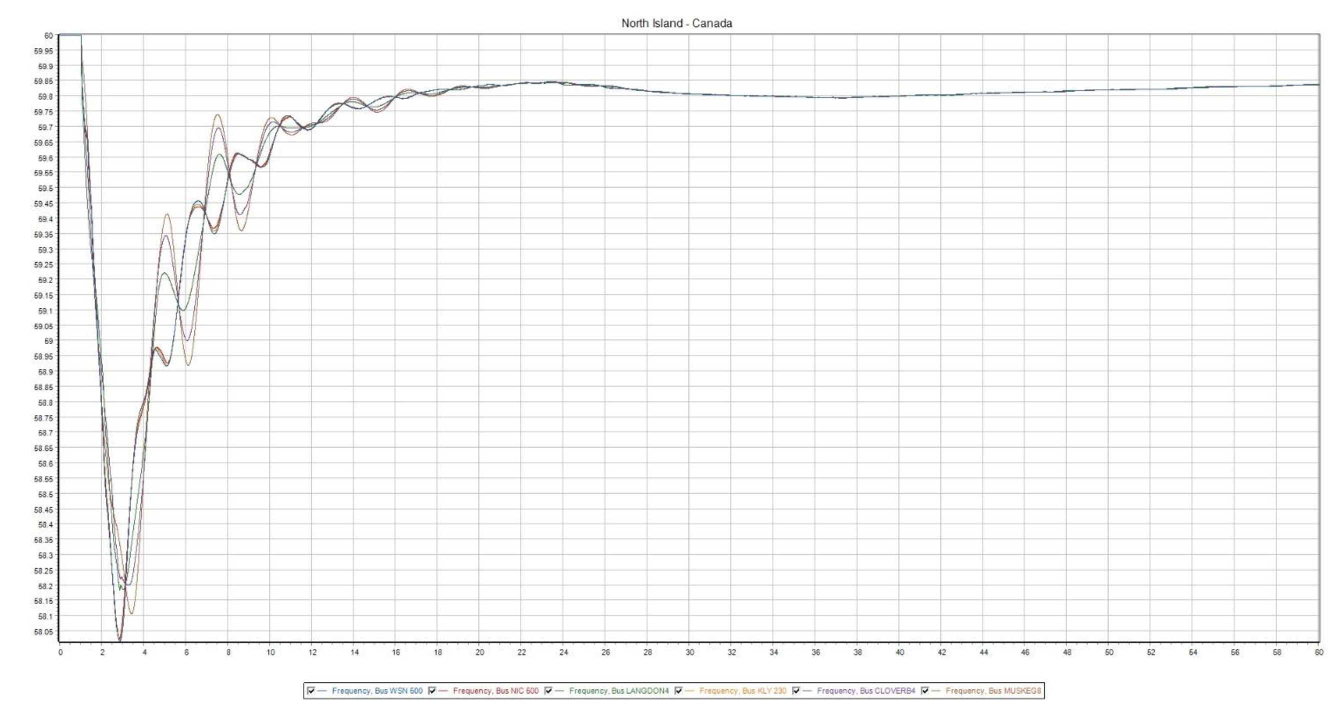


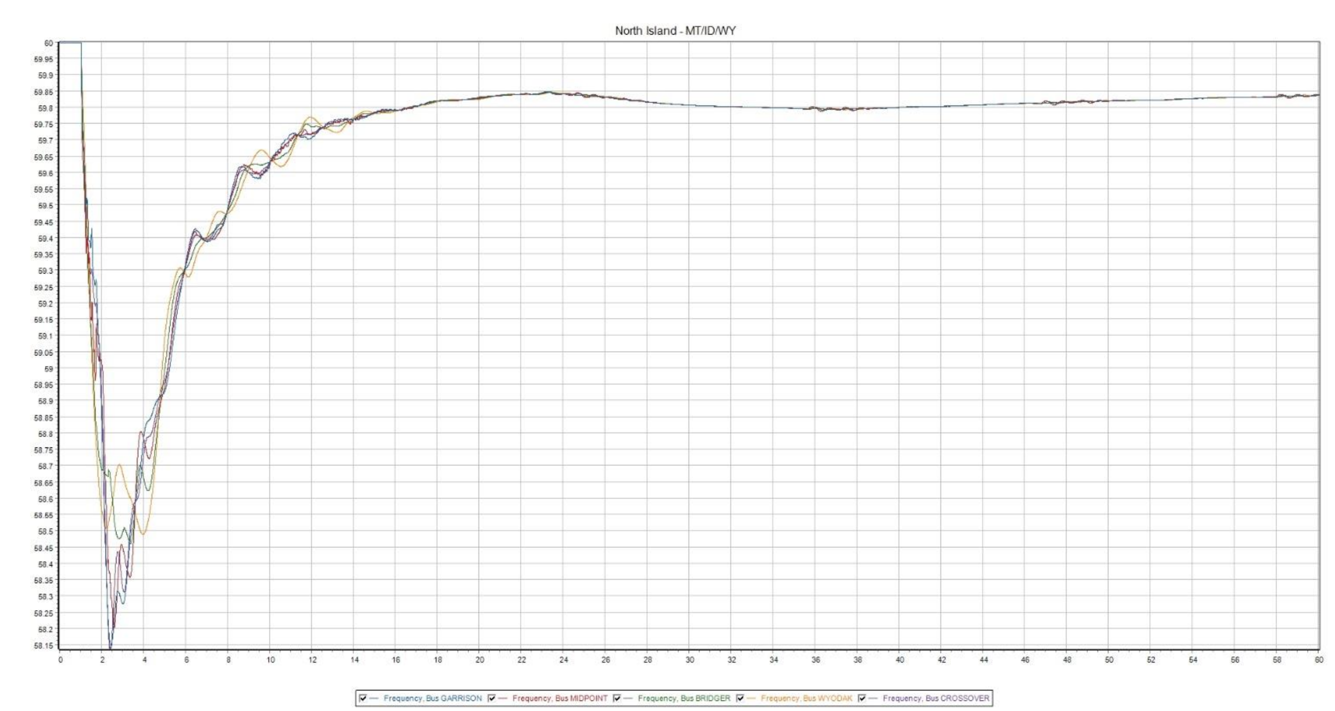


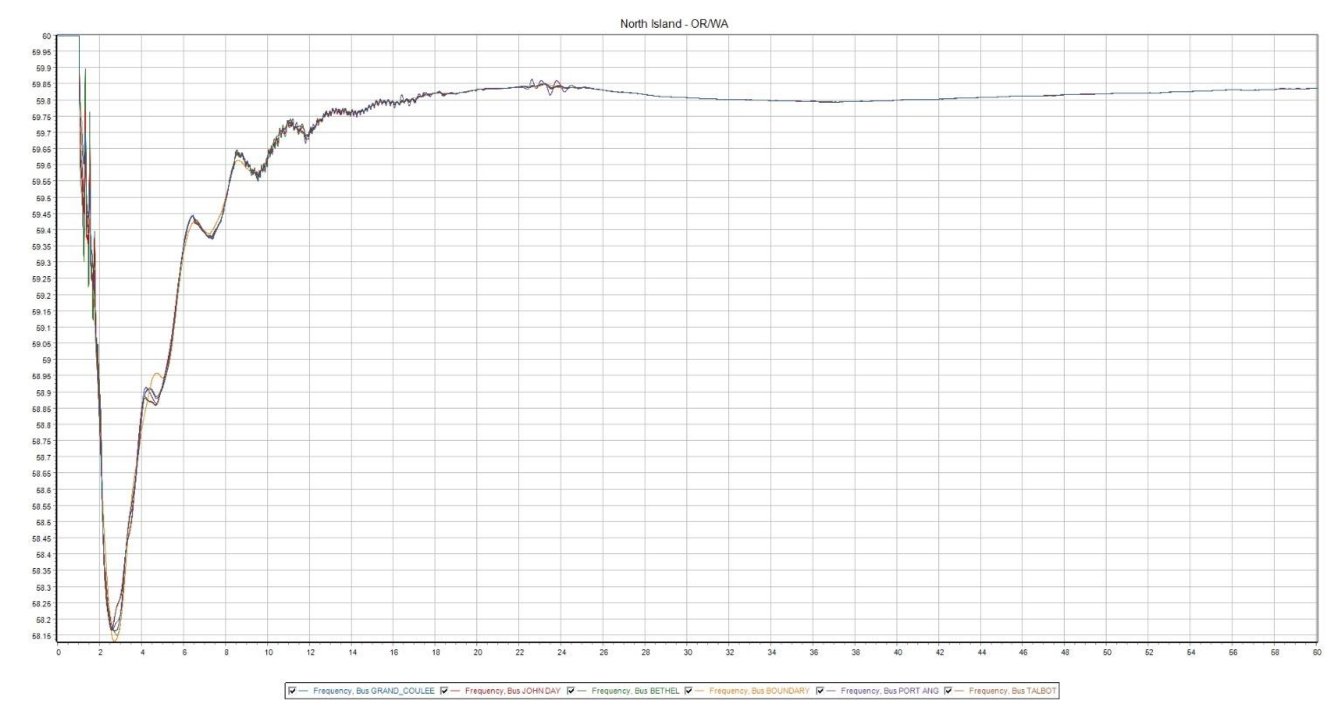

North Island - OR/WA
Frequency, Bus GRAND_COULEE
Frequency, Bus JOHN DAY
Frequency, Bus BETHEL
Frequency, Bus BOUNDARY
Frequency, Bus PORT ANG
Frequency, Bus TALBOT

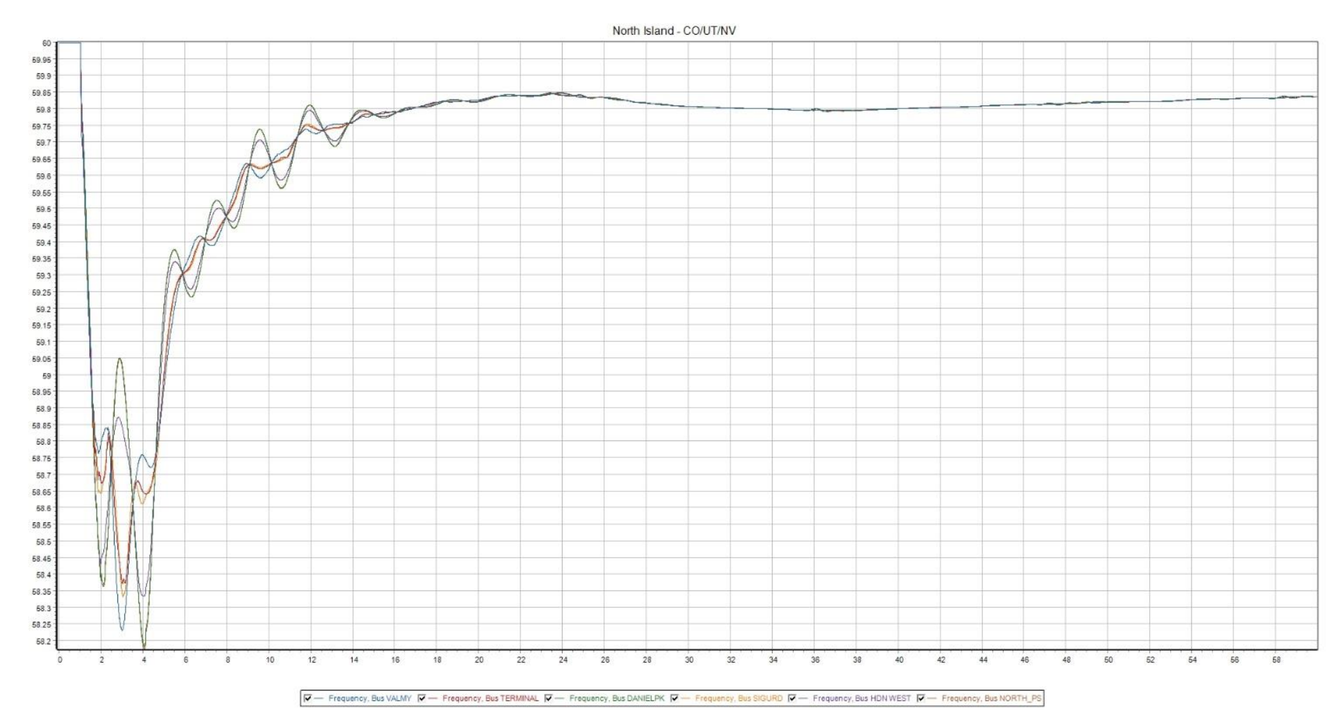

North Island - CO/UT/NV
Frequency, Bus VALMY
Frequency, Bus TERMINAL
Frequency, Bus DANIELPK
Frequency, Bus SIGURD
Frequency, Bus HDN WEST
Frequency, Bus NORTH_PS

21HS—20%

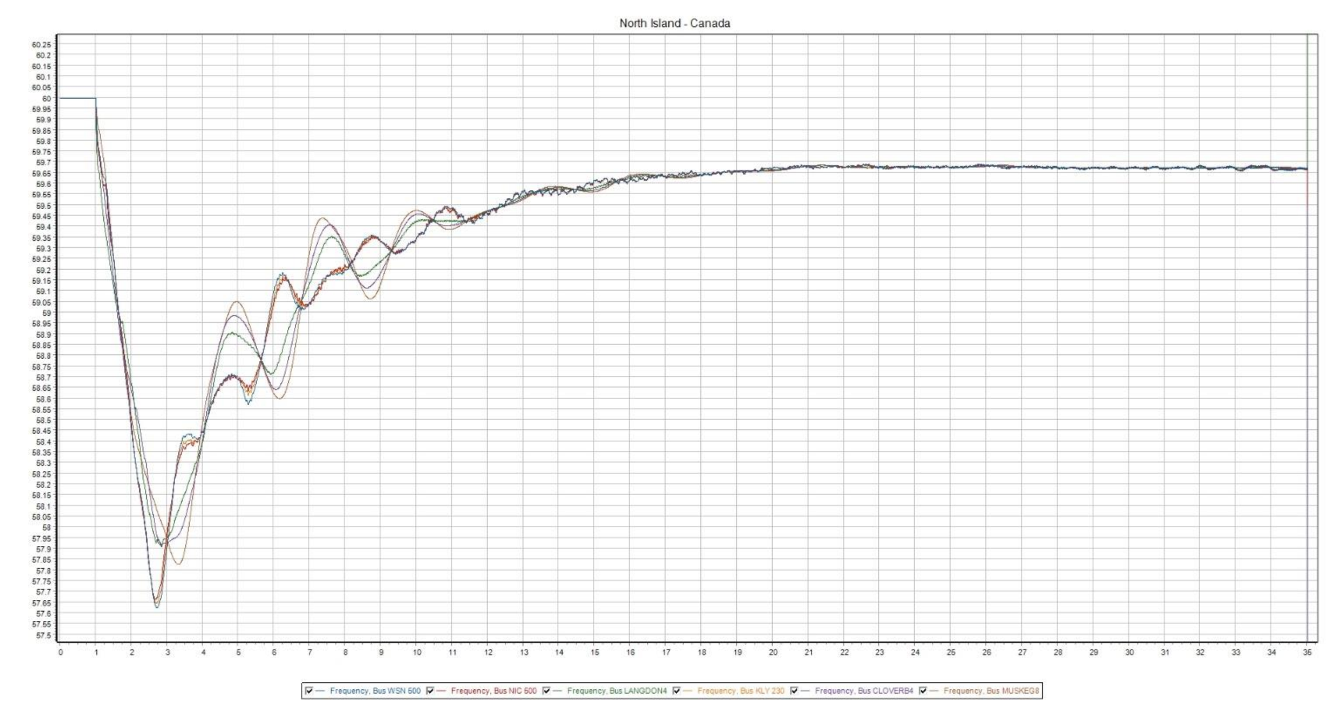

North Island - Canada
Frequency, Bus WSN 600
Frequency, Bus NIC 600
Frequency, Bus LANGDON4
Frequency, Bus KLY 230
Frequency, Bus CLOVERB4
Frequency, Bus MUSKEG8

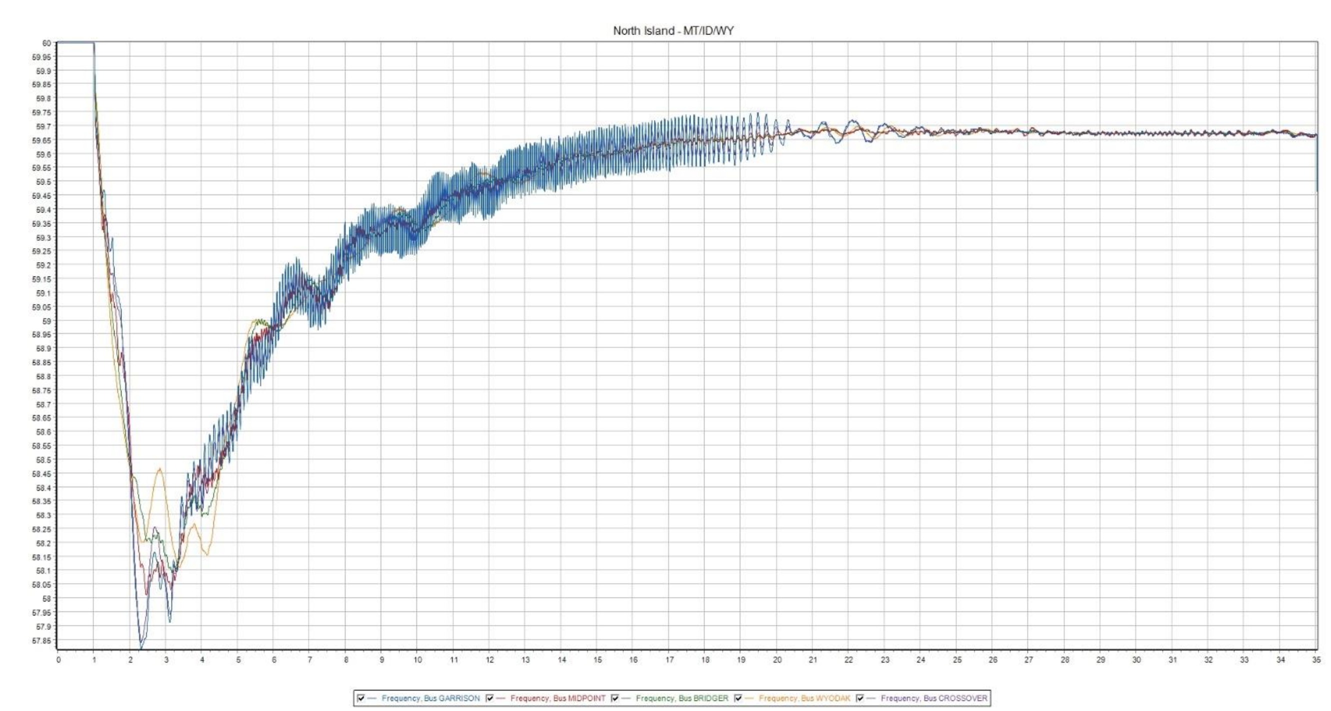

North Island - MT/ID/WY
Frequency, Bus GARRISON
Frequency, Bus MIDPOINT
Frequency, Bus BRIDGER
Frequency, Bus WYODAK
Frequency, Bus CROSSOVER

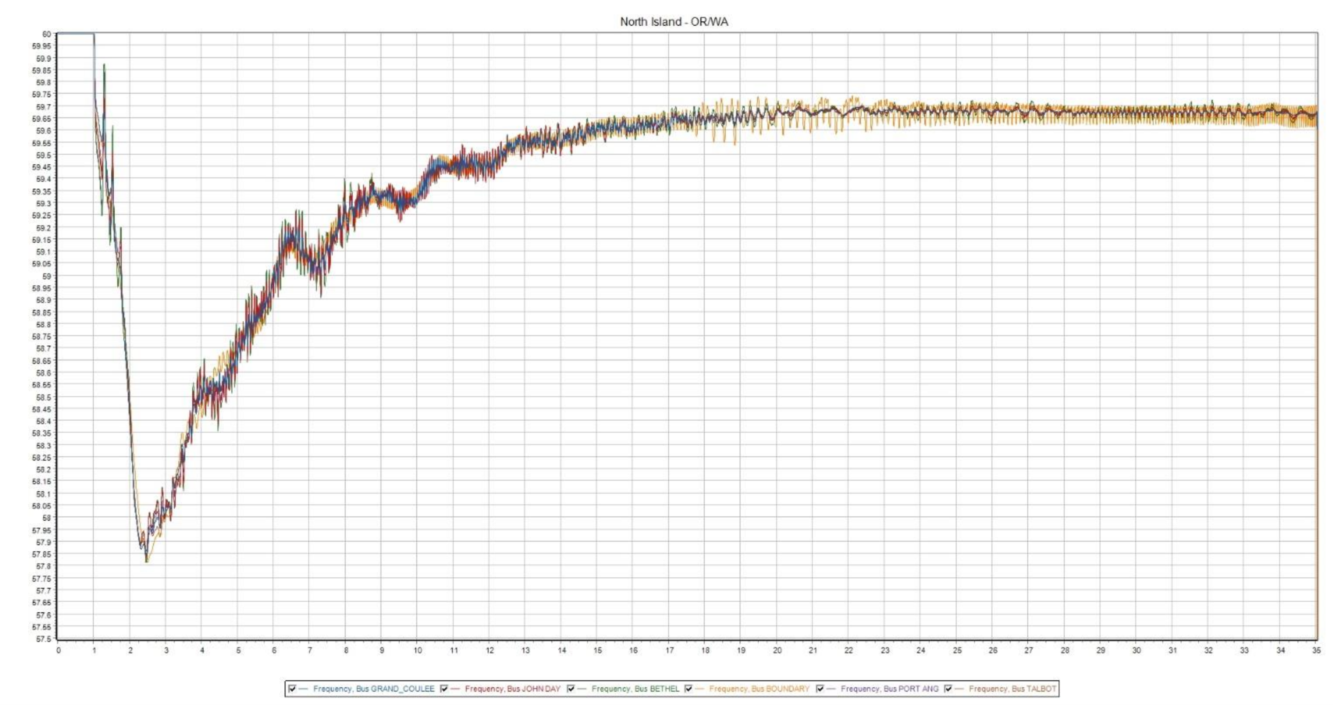

North Island - OR/WA
Frequency, Bus GRAND_COULEE
Frequency, Bus JOHN DAY
Frequency, Bus BETHEL
Frequency, Bus BOUNDARY
Frequency, Bus PORT ANG
Frequency, Bus TALBOT

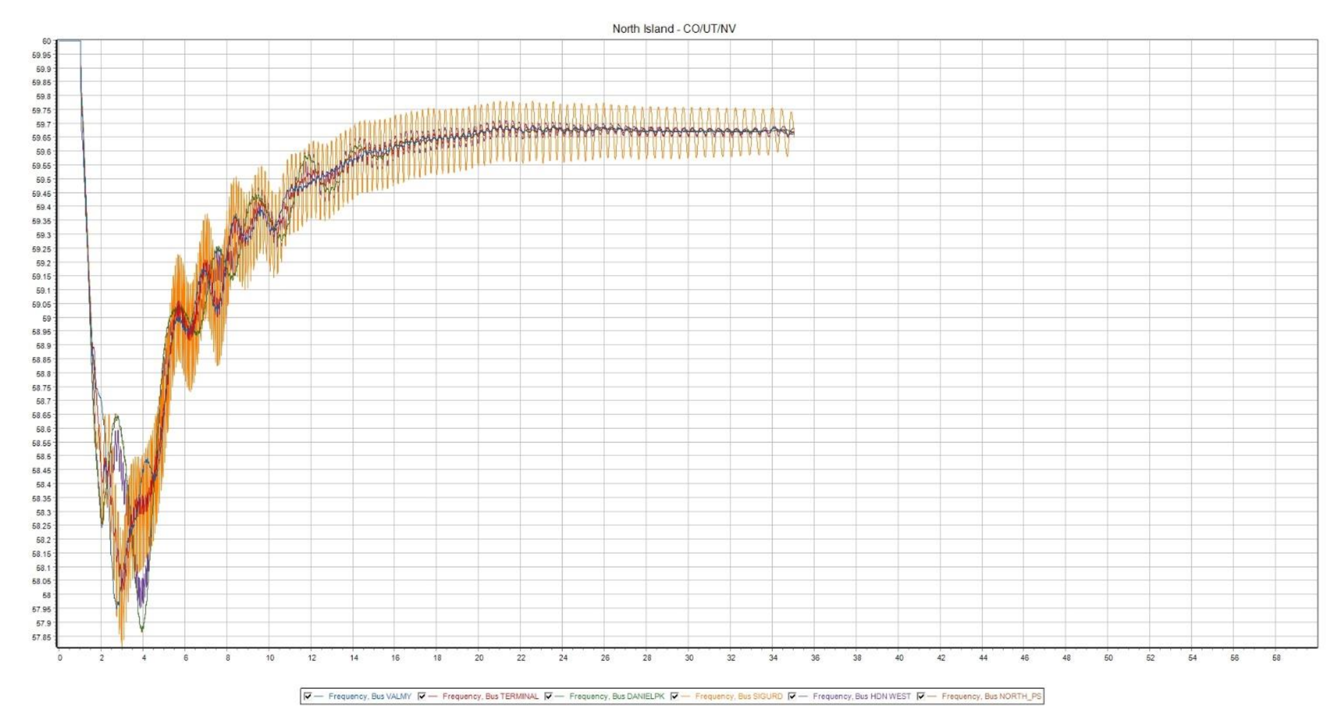

North Island - CO/UT/NV
Frequency, Bus VALMY
Frequency, Bus TERMINAL
Frequency, Bus DANIELPK
Frequency, Bus SIGURD
Frequency, Bus HDN WEST
Frequency, Bus NORTH_PS

21HS—25%

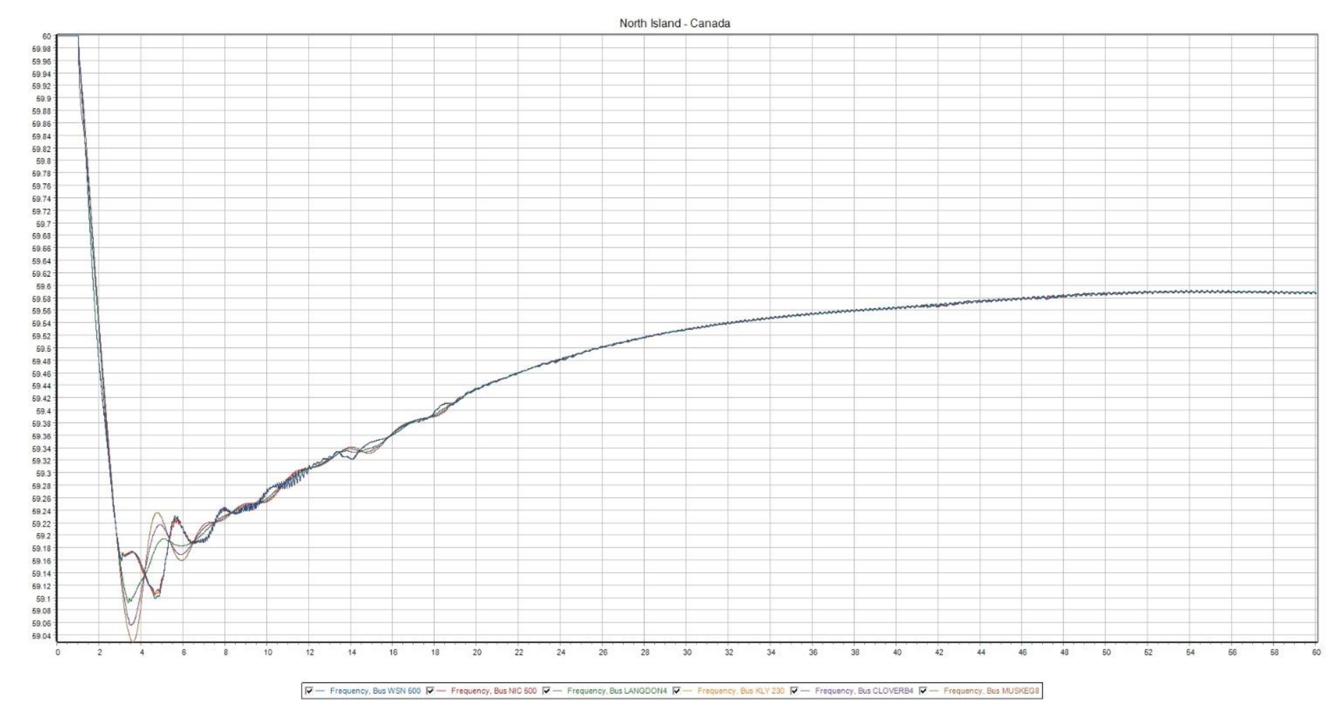

North Island - Canada
Frequency, Bus WSN 500
Frequency, Bus NIC 500
Frequency, Bus LANGDON4
Frequency, Bus KLY 230
Frequency, Bus CLOVERB4
Frequency, Bus MUSKEG8

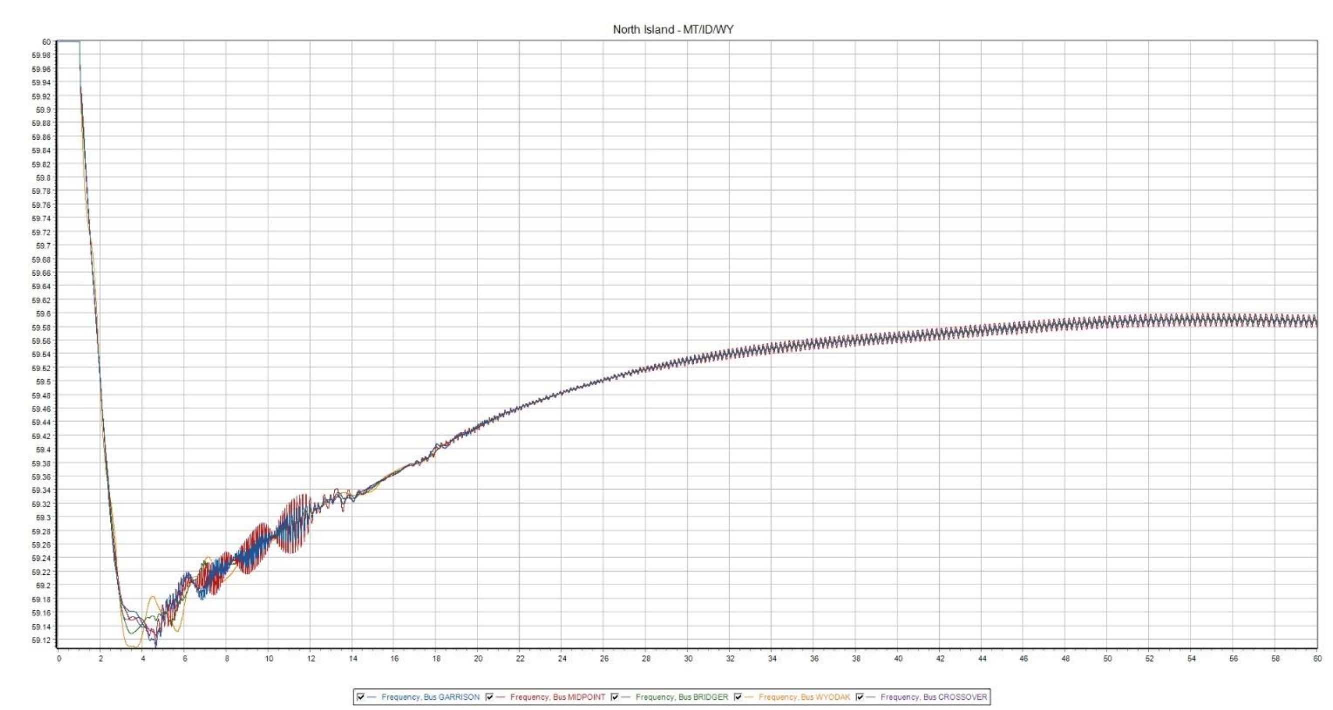

North Island - MT/ID/WY
Frequency, Bus GARRISON
Frequency, Bus MIDPOINT
Frequency, Bus BRIDGER
Frequency, Bus WYODAK
Frequency, Bus CROSSOVER

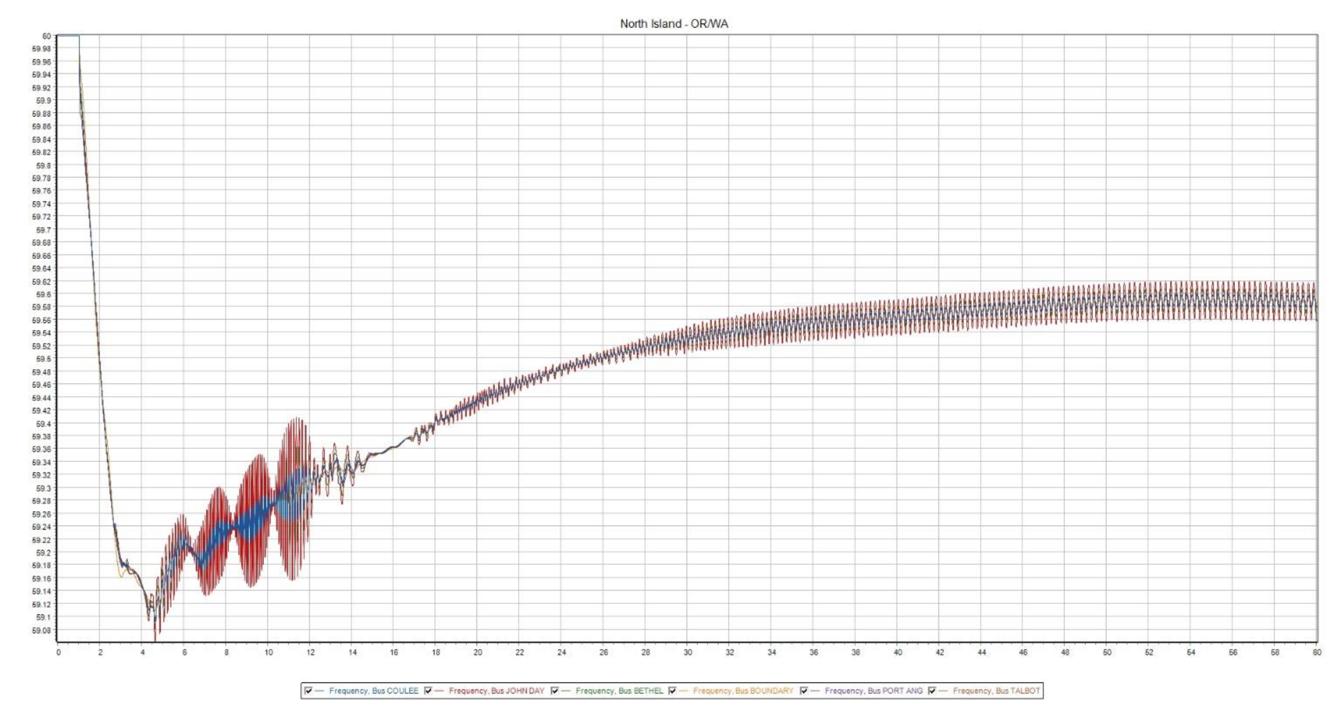

North Island - OR/WA
Frequency, Bus GRAND_COULEE
Frequency, Bus JOHN DAY
Frequency, Bus BETHEL
Frequency, Bus BOUNDARY
Frequency, Bus PORT ANG
Frequency, Bus TALBOT

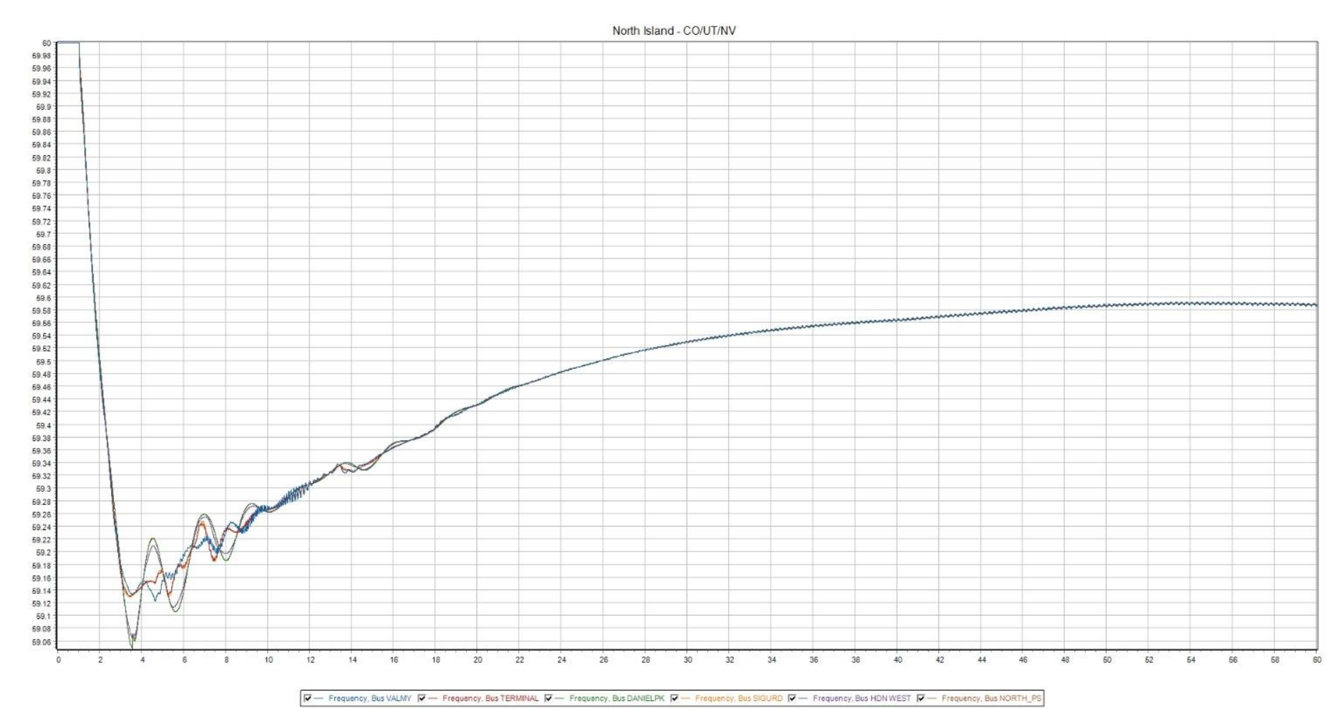

North Island - CO/UT/NV
Frequency, Bus VALMY
Frequency, Bus TERMINAL
Frequency, Bus DANIELPK
Frequency, Bus SIGURD
Frequency, Bus HDN WEST
Frequency, Bus NORTH_PS

24LSP—10%

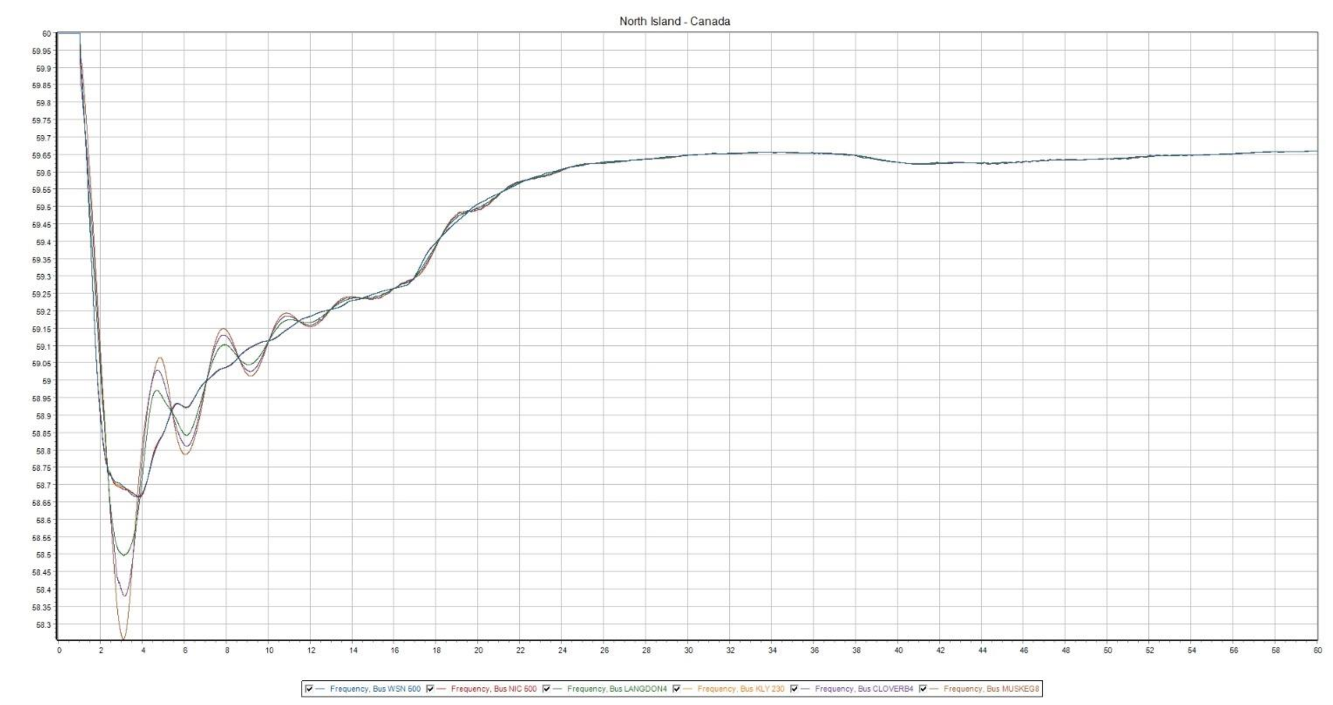

North Island - Canada
Frequency, Bus WSN 500
Frequency, Bus NIC 500
Frequency, Bus LANGDON4
Frequency, Bus KLY 230
Frequency, Bus CLOVERB4
Frequency, Bus MUSKEG8

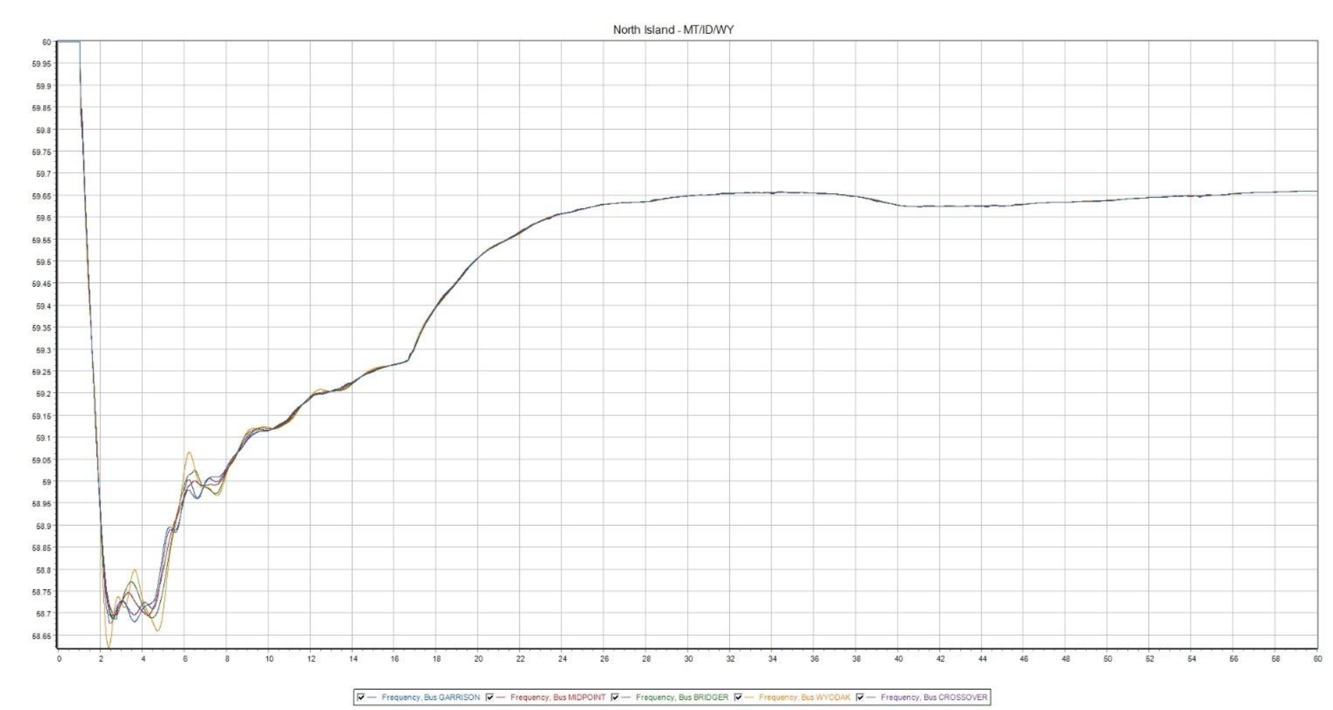

North Island - MT/ID/WY
Frequency, Bus GARRISON
Frequency, Bus MIDPOINT
Frequency, Bus BRIDGER
Frequency, Bus WYODAK
Frequency, Bus CROSSOVER

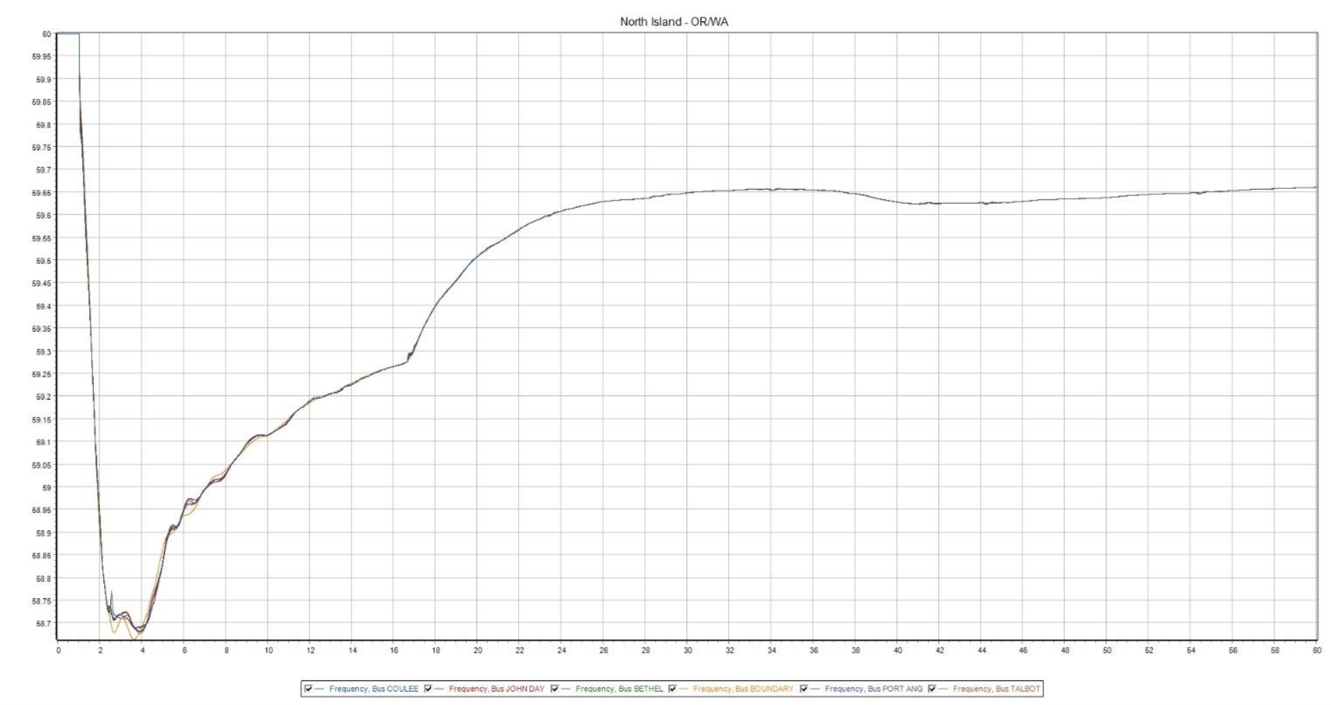

North Island - OR/WA
Frequency, Bus COULEE
Frequency, Bus JOHN DAY
Frequency, Bus BETHEL
Frequency, Bus BOUNDARY
Frequency, Bus PORT ANG
Frequency, Bus TALBOT

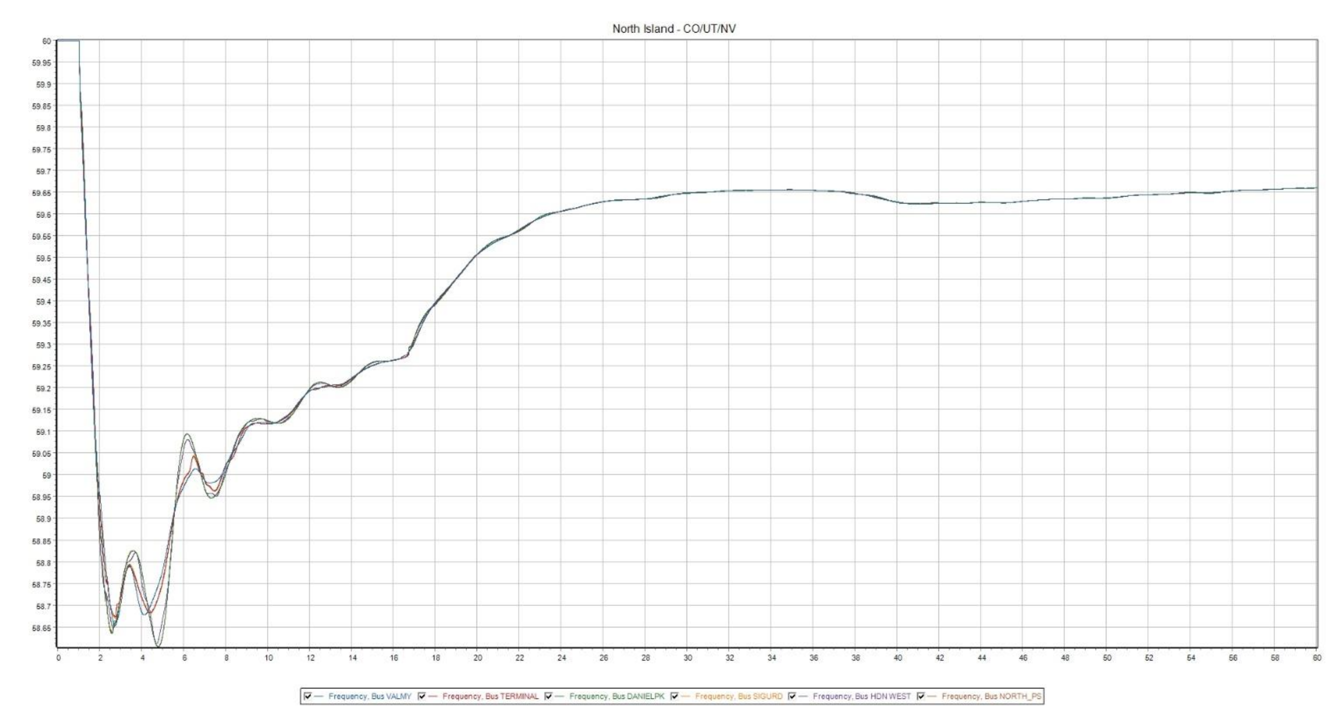

North Island - CO/UT/NV
Frequency, Bus VALMY
Frequency, Bus TERMINAL
Frequency, Bus DANIELPK
Frequency, Bus SIGURD
Frequency, Bus HDN WEST
Frequency, Bus NORTH_PS

24LSP—20%

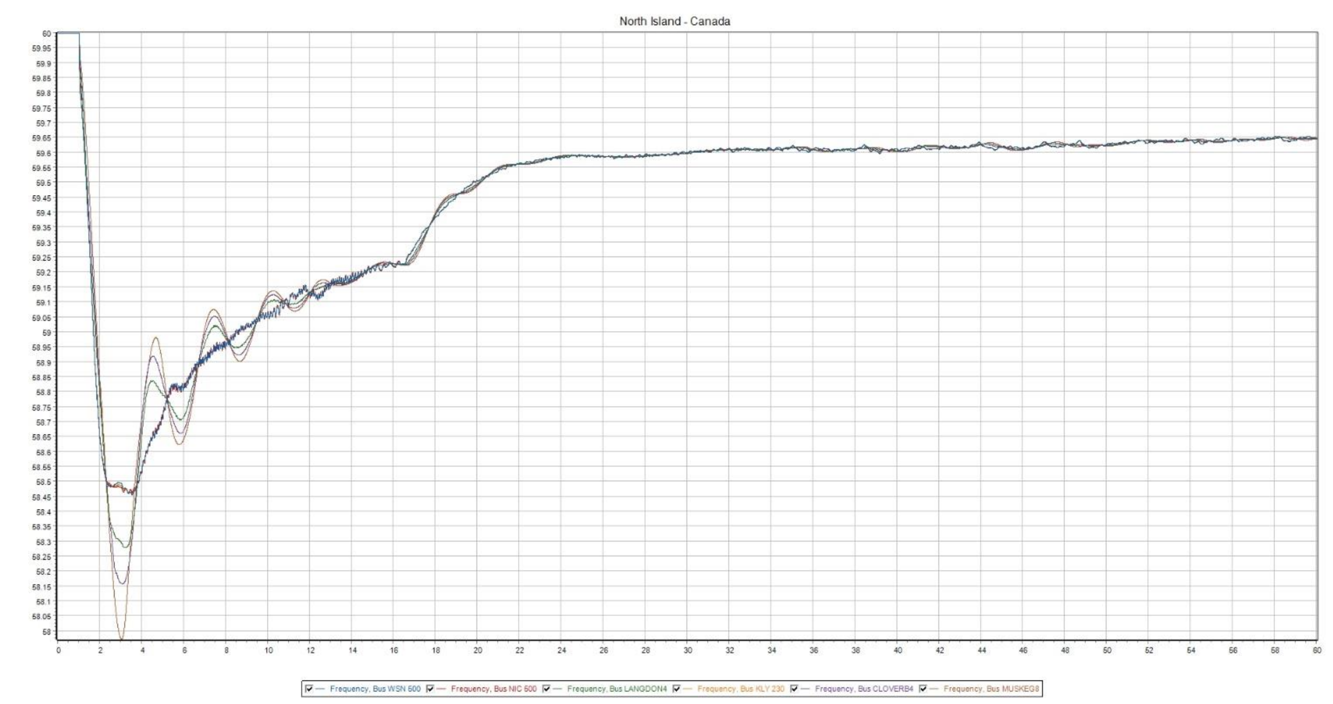

North Island - Canada
Frequency, Bus WSN 500
Frequency, Bus NIC 500
Frequency, Bus LANGDON4
Frequency, Bus KLY 230
Frequency, Bus CLOVERB4
Frequency, Bus MUSKEG8

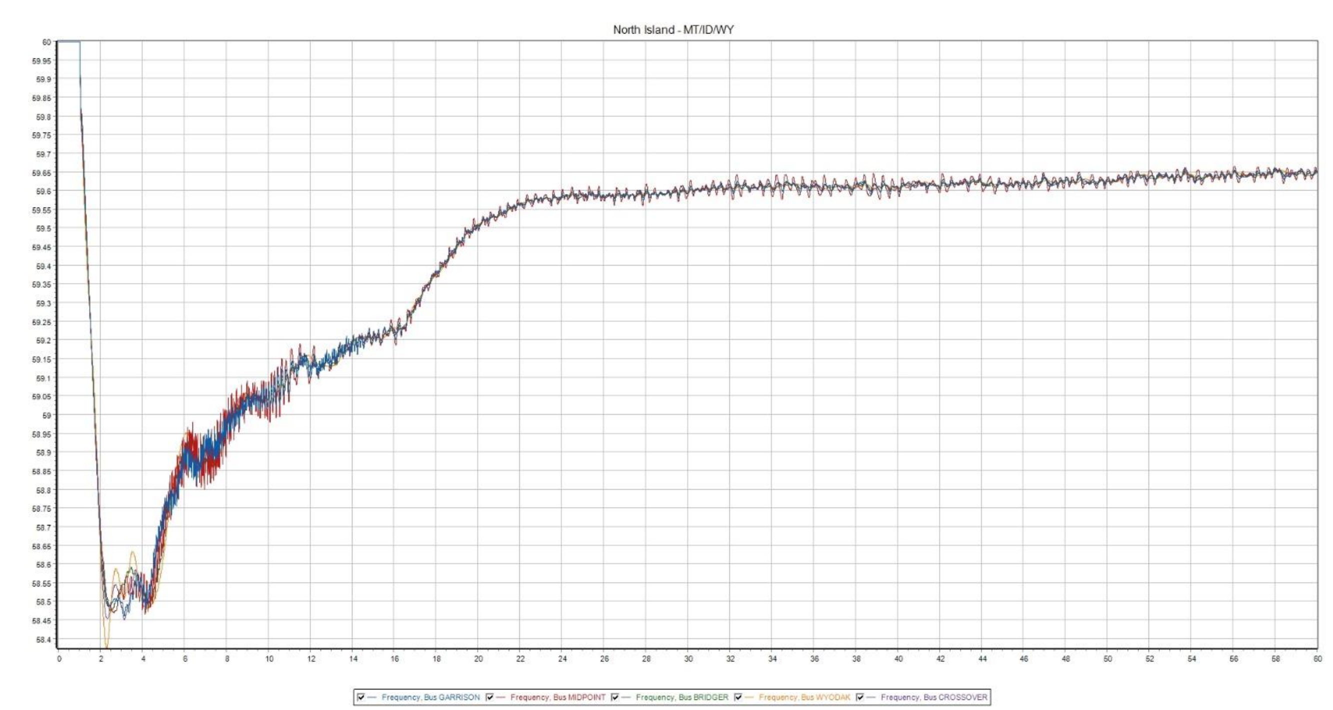

North Island - MT/ID/WY
Frequency, Bus GARRISON
Frequency, Bus MIDPOINT
Frequency, Bus BRIDGER
Frequency, Bus WYODAK
Frequency, Bus CROSSOVER

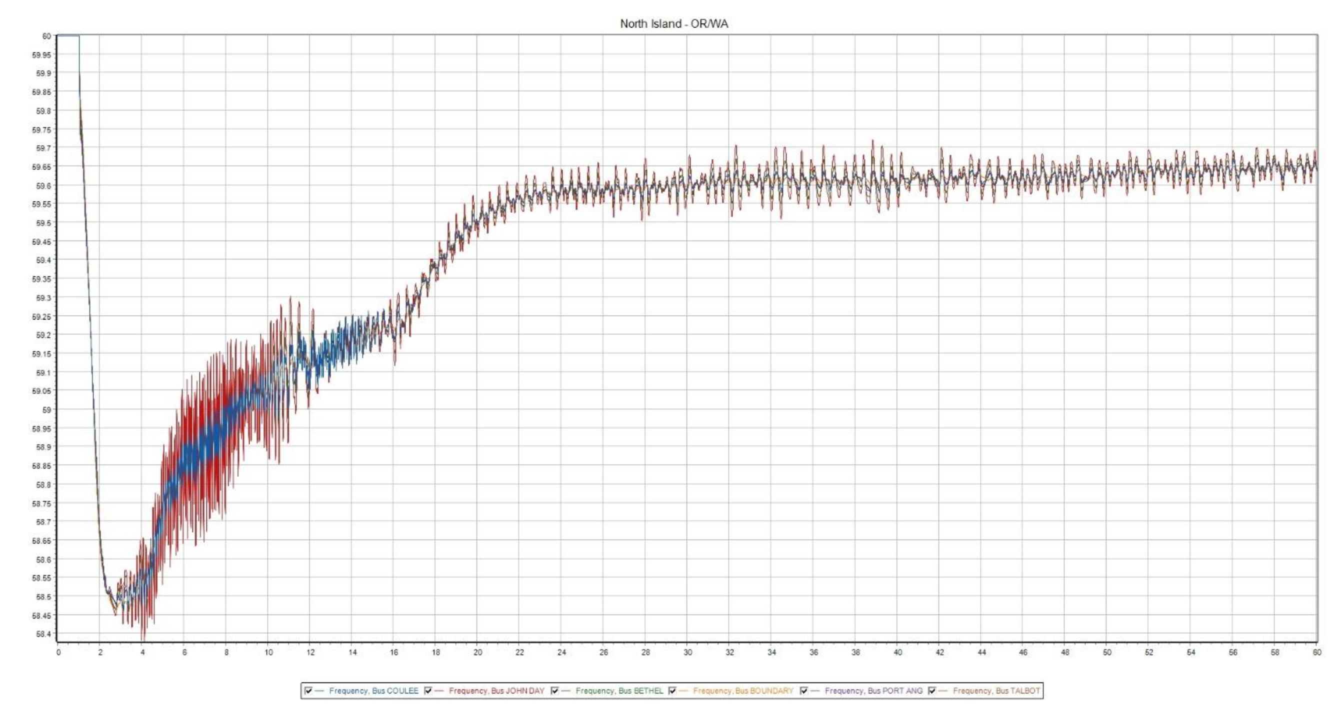

North Island - OR/WA
Frequency, Bus COULEE
Frequency, Bus JOHN DAY
Frequency, Bus BETHEL
Frequency, Bus BOUNDARY
Frequency, Bus PORT ANG
Frequency, Bus TALBOT

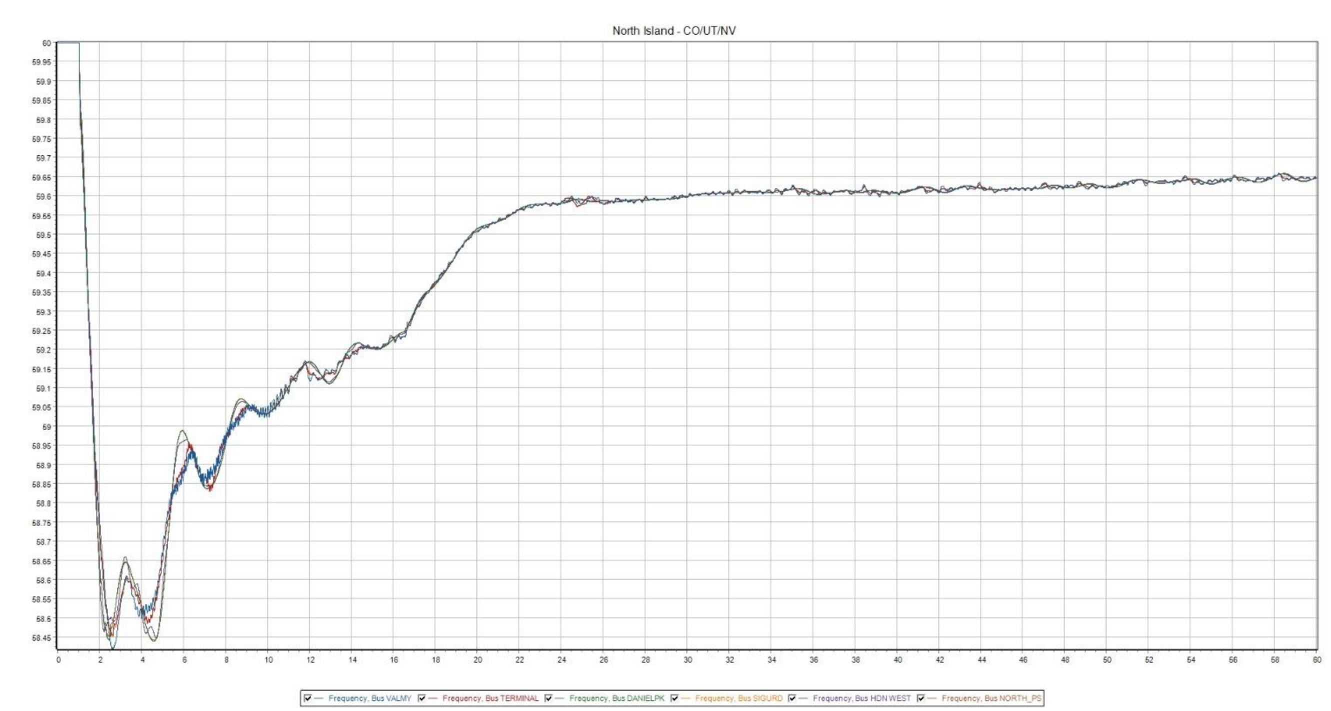

North Island - CO/UT/NV
Frequency, Bus VALMY
Frequency, Bus TERMINAL
Frequency, Bus DANIELPK
Frequency, Bus SIGURD
Frequency, Bus HDN WEST
Frequency, Bus NORTH_PS

24LSP—25%


North Island - Canada
Frequency, Bus WSN 500
Frequency, Bus NIC 500
Frequency, Bus LANGDON4
Frequency, Bus KLY 230
Frequency, Bus CLOVERB4
Frequency, Bus MUSKEG8

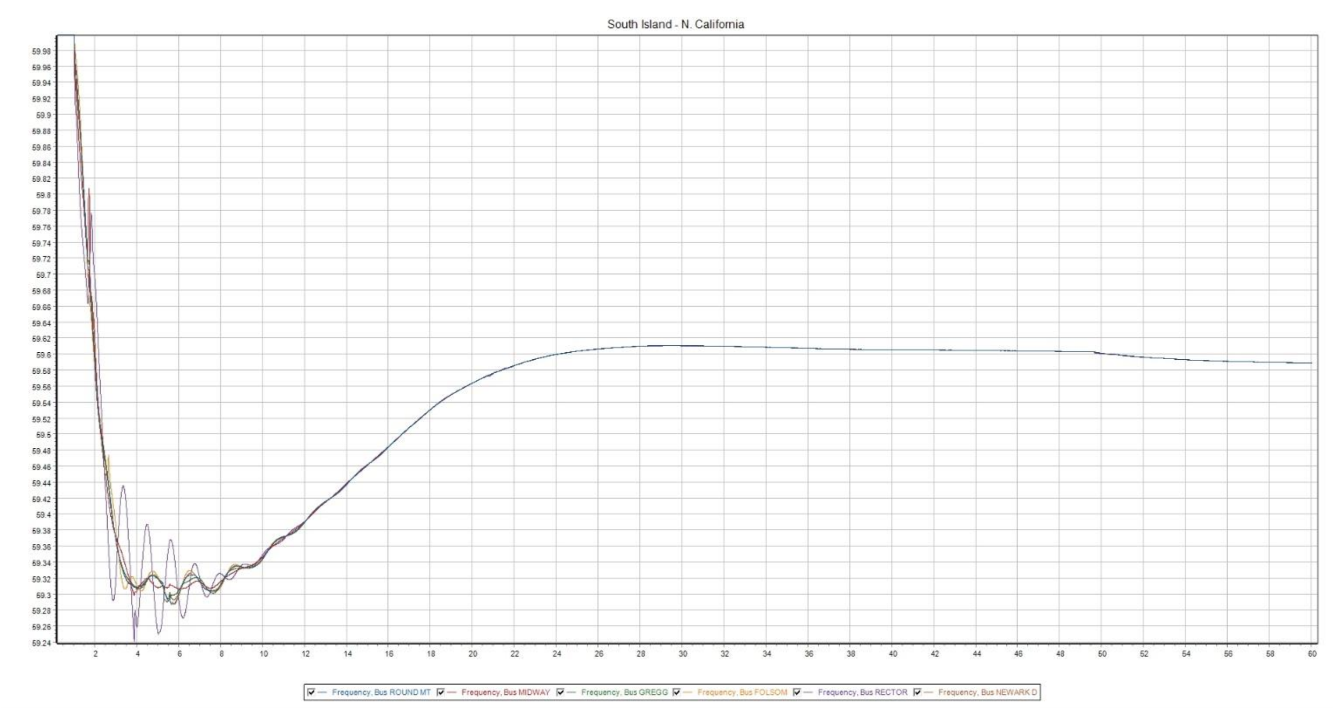

North Island - MT/ID/WY
Frequency, Bus GARRISON
Frequency, Bus MIDPOINT
Frequency, Bus BRIDGER
Frequency, Bus WYODAK
Frequency, Bus CROSSOVER

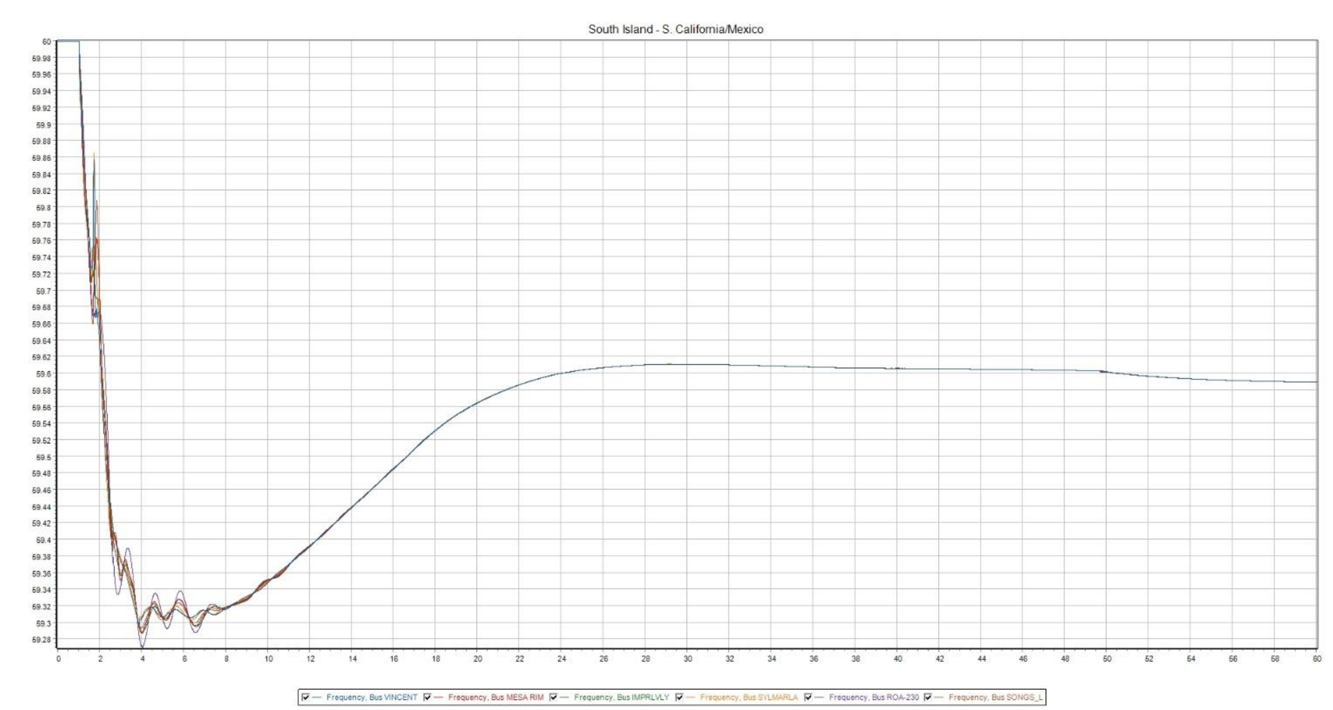

North Island - OR/WA
Frequency, Bus COULEE
Frequency, Bus JOHN DAY
Frequency, Bus BETHEL
Frequency, Bus BOUNDARY
Frequency, Bus PORT ANG
Frequency, Bus TALBOT

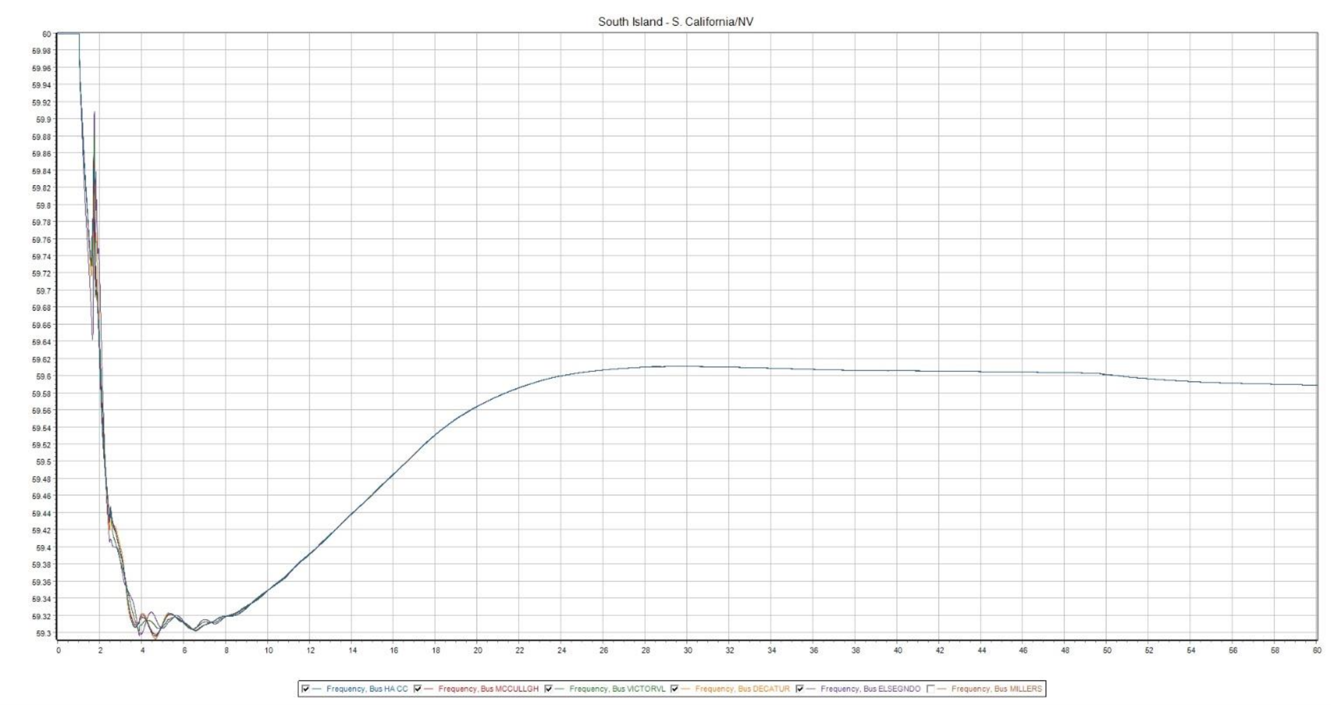

North Island - CO/UT/NV
Frequency, Bus VALMY
Frequency, Bus TERMINAL
Frequency, Bus DANIELPK
Frequency, Bus SIGURD
Frequency, Bus HDN WEST
Frequency, Bus NORTH_PS

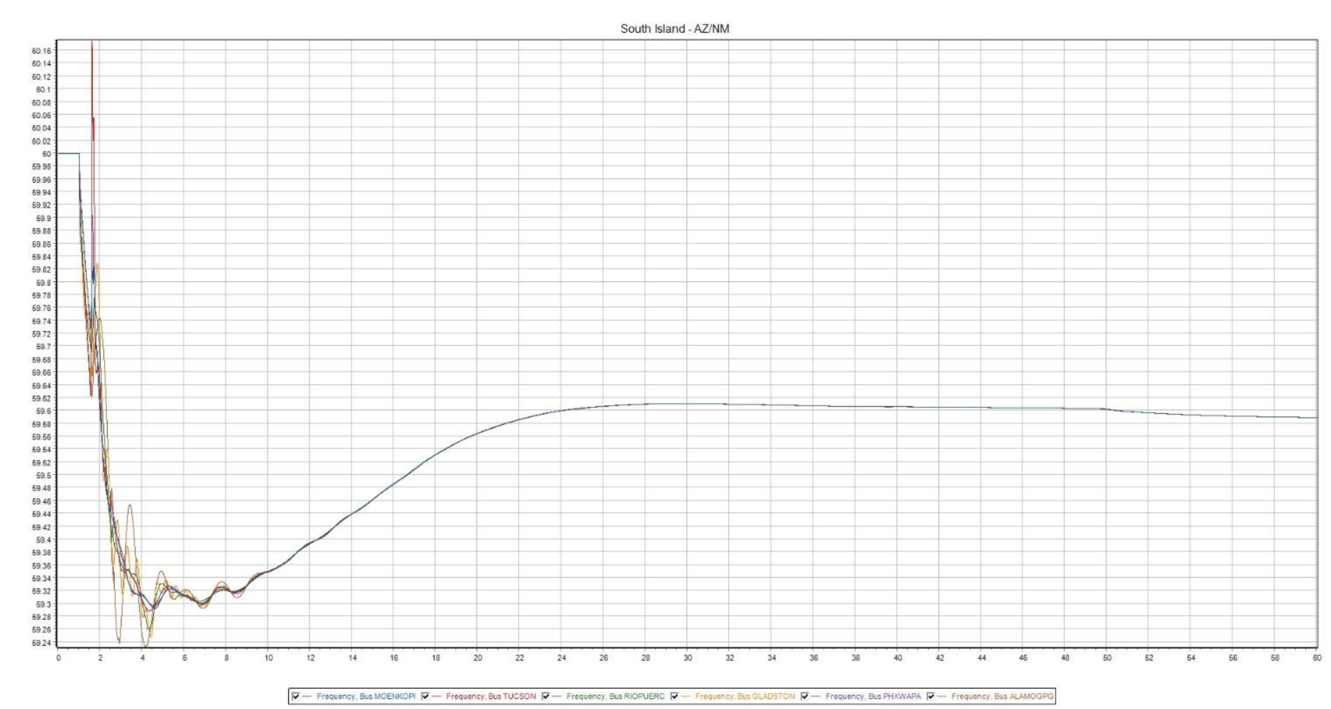
Appendix C—Frequency Performance—South Island

21HS—10%

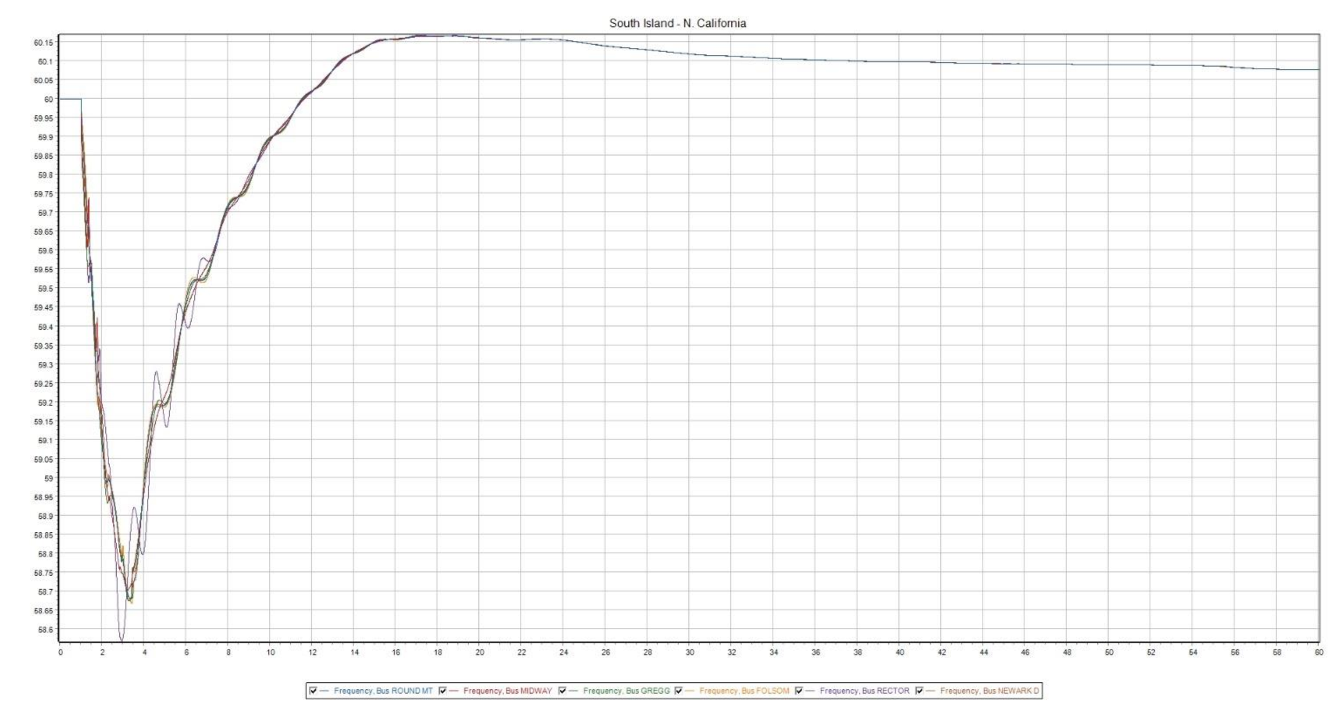


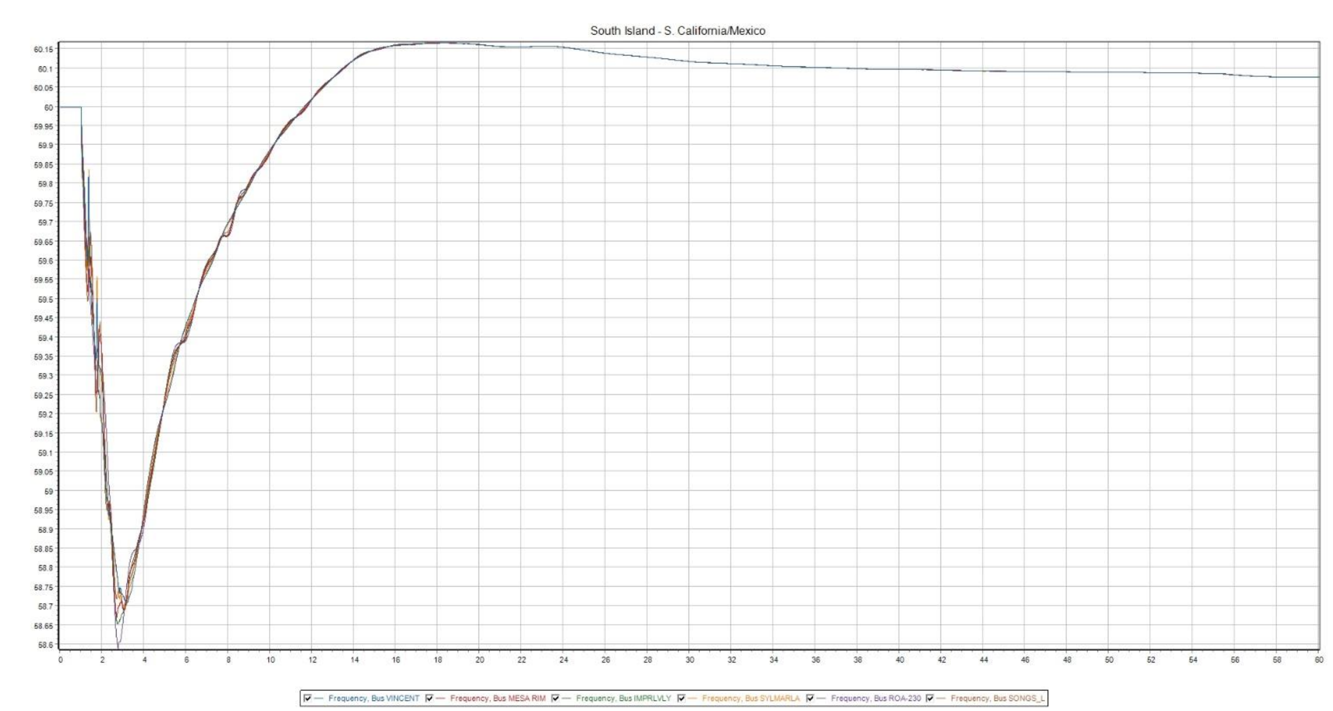


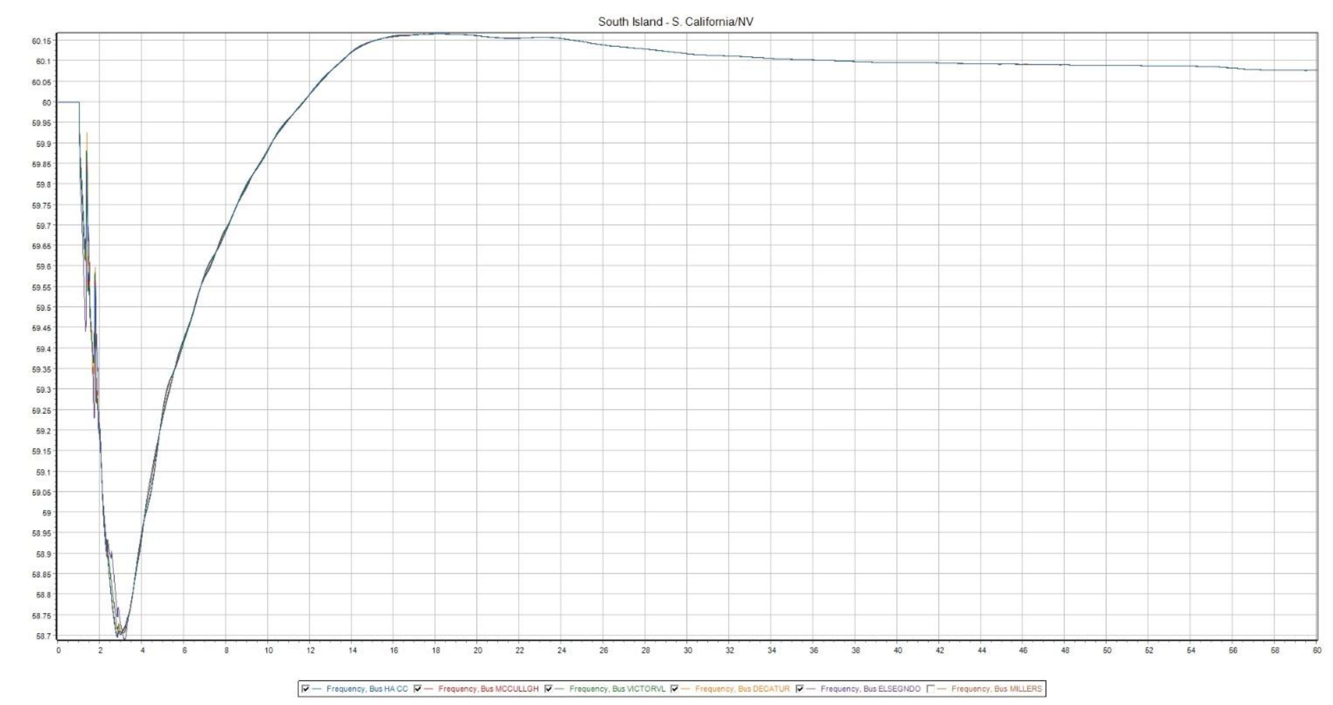

South Island - S. California/NV
Frequency, Bus HA CC
Frequency, Bus MCCULLGH
Frequency, Bus VICTORVL
Frequency, Bus DECATUR
Frequency, Bus ELSEGNDO
Frequency, Bus MILLERS

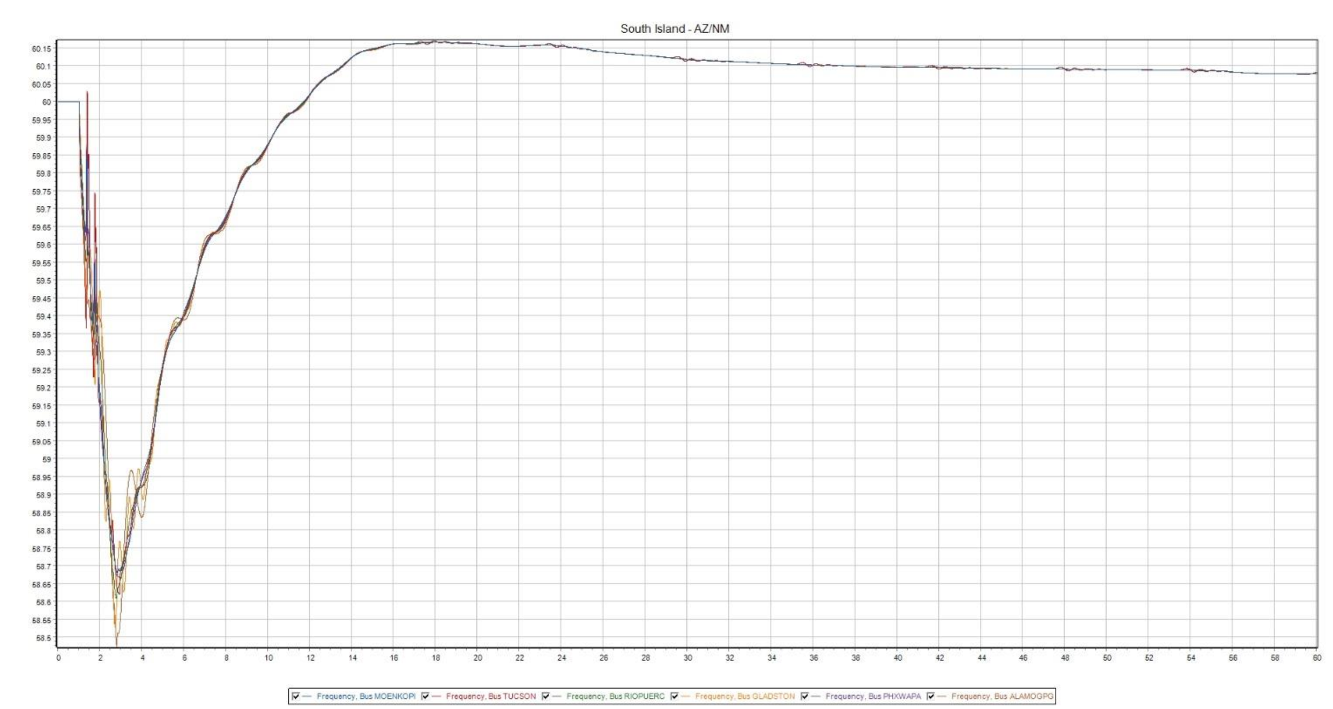

South Island - AZ/NM
Frequency, Bus MOENKOPI
Frequency, Bus TUCSON
Frequency, Bus RIOPUERC
Frequency, Bus GLADSTON
Frequency, Bus PHXWAPA
Frequency, Bus ALAMOGPG

21HS—20%

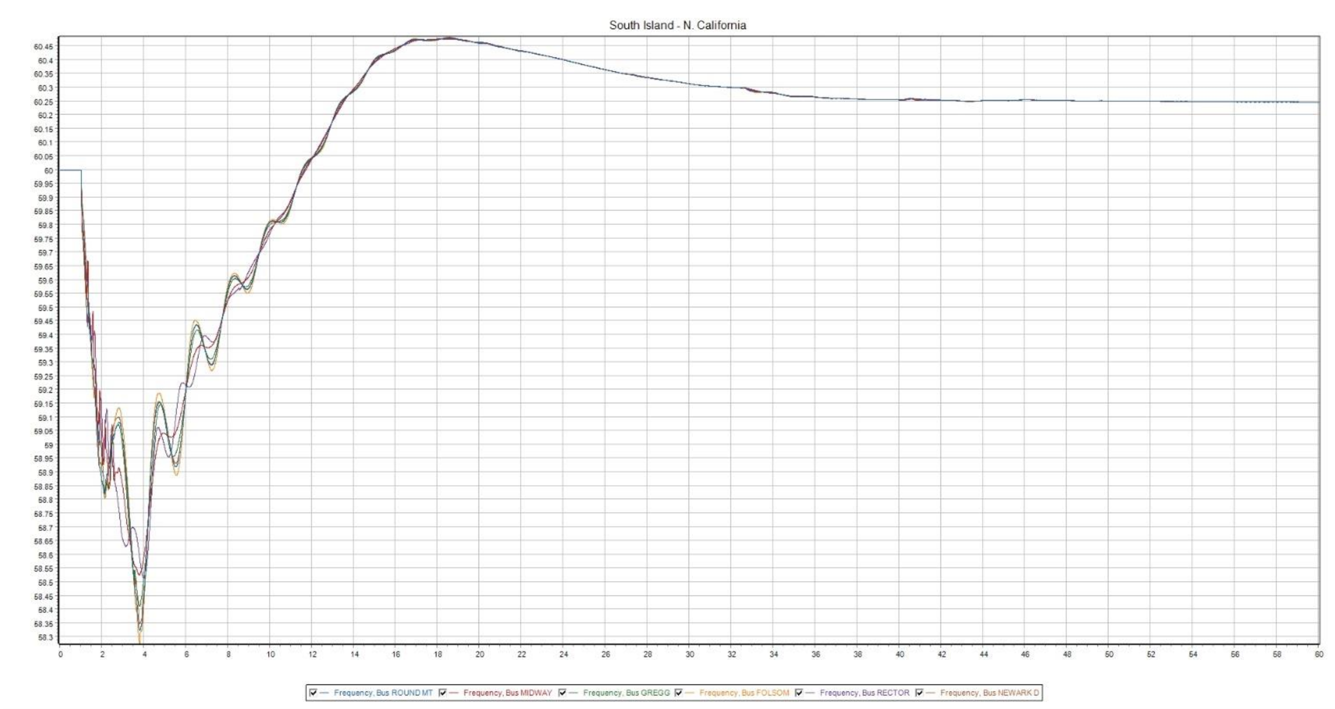

South Island - N. California
Frequency, Bus ROUND MT
Frequency, Bus MIDWAY
Frequency, Bus GREGG
Frequency, Bus FOLSOM
Frequency, Bus RECTOR
Frequency, Bus NEWARK D

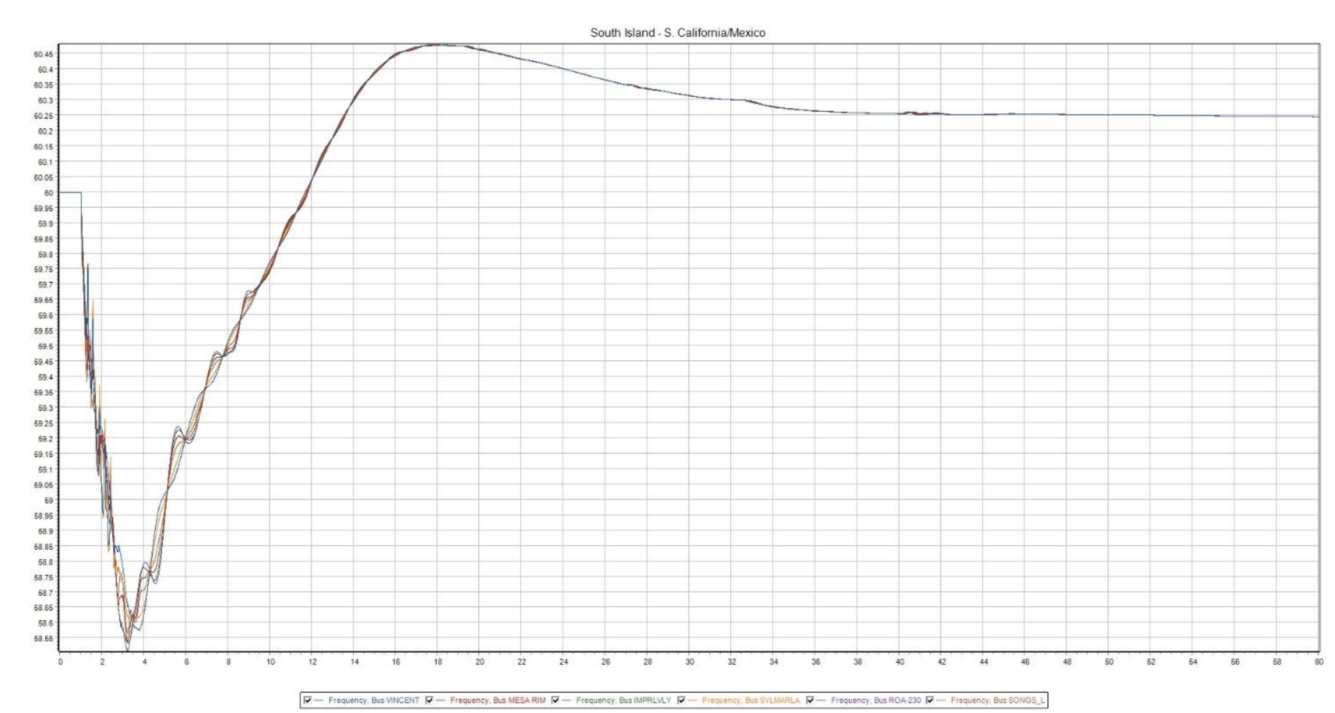

South Island - S. California/Mexico
Frequency, Bus VINCENT
Frequency, Bus MESA RIM
Frequency, Bus IMPRLVLY
Frequency, Bus SYLMARLA
Frequency, Bus ROA-230
Frequency, Bus SONGS_L

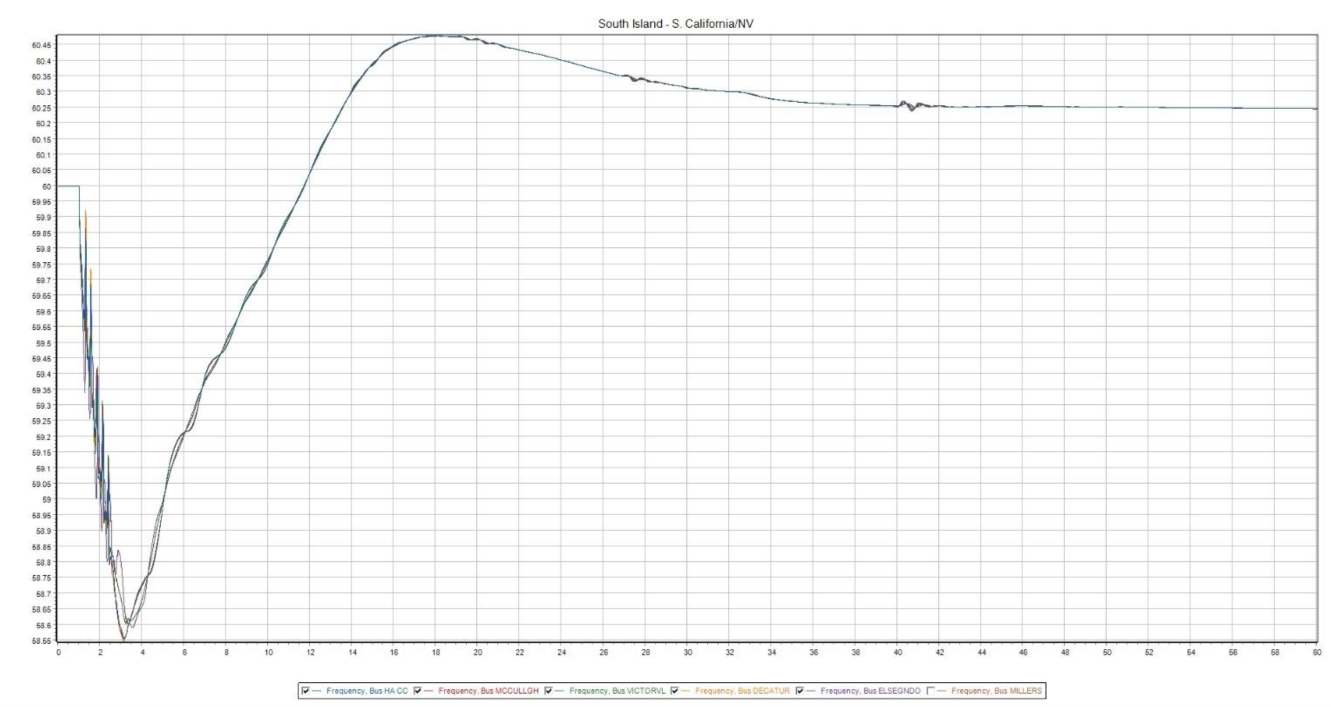

South Island - S. California/NV
Frequency, Bus HA CC
Frequency, Bus MCCULLGH
Frequency, Bus VICTORVL
Frequency, Bus DECATUR
Frequency, Bus ELSEGNDO
Frequency, Bus MILLERS

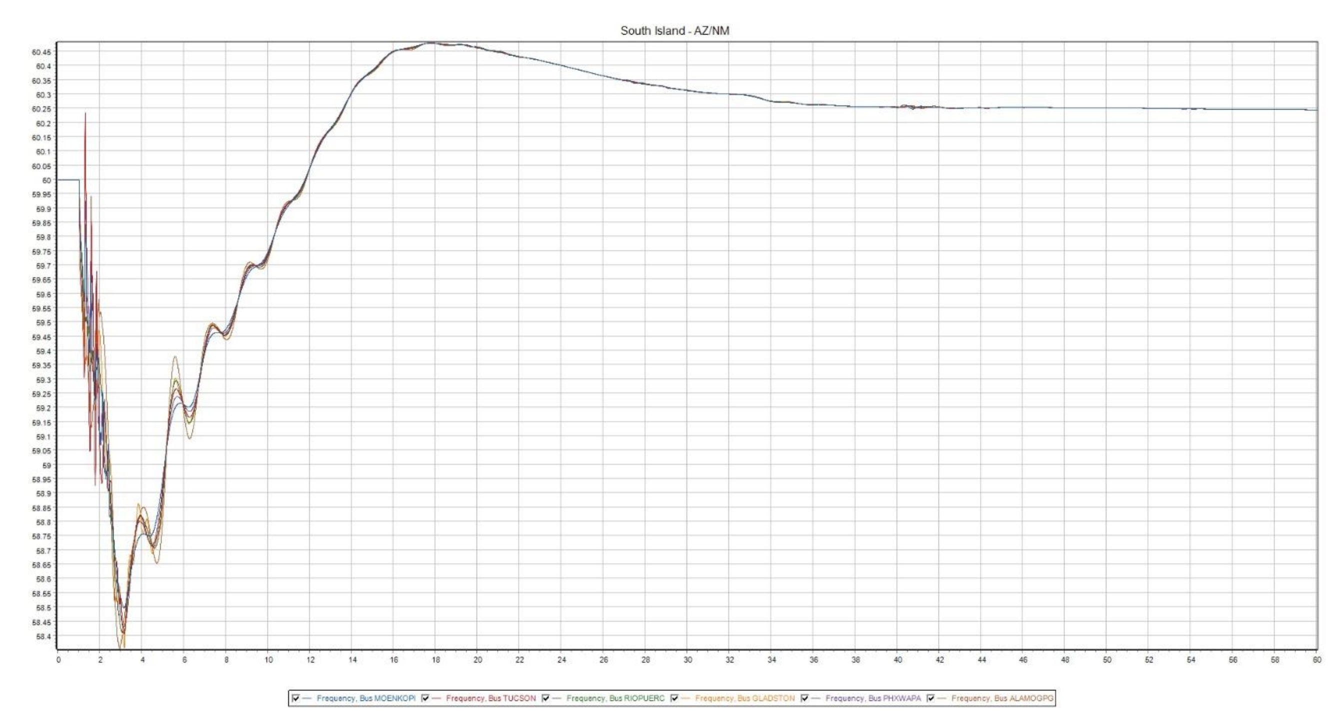

South Island - AZ/NM
Frequency, Bus MOENKOPI
Frequency, Bus TUCSON
Frequency, Bus RIOPUERC
Frequency, Bus GLADSTON
Frequency, Bus PHXWAPA
Frequency, Bus ALAMOGPG

21HS—25%

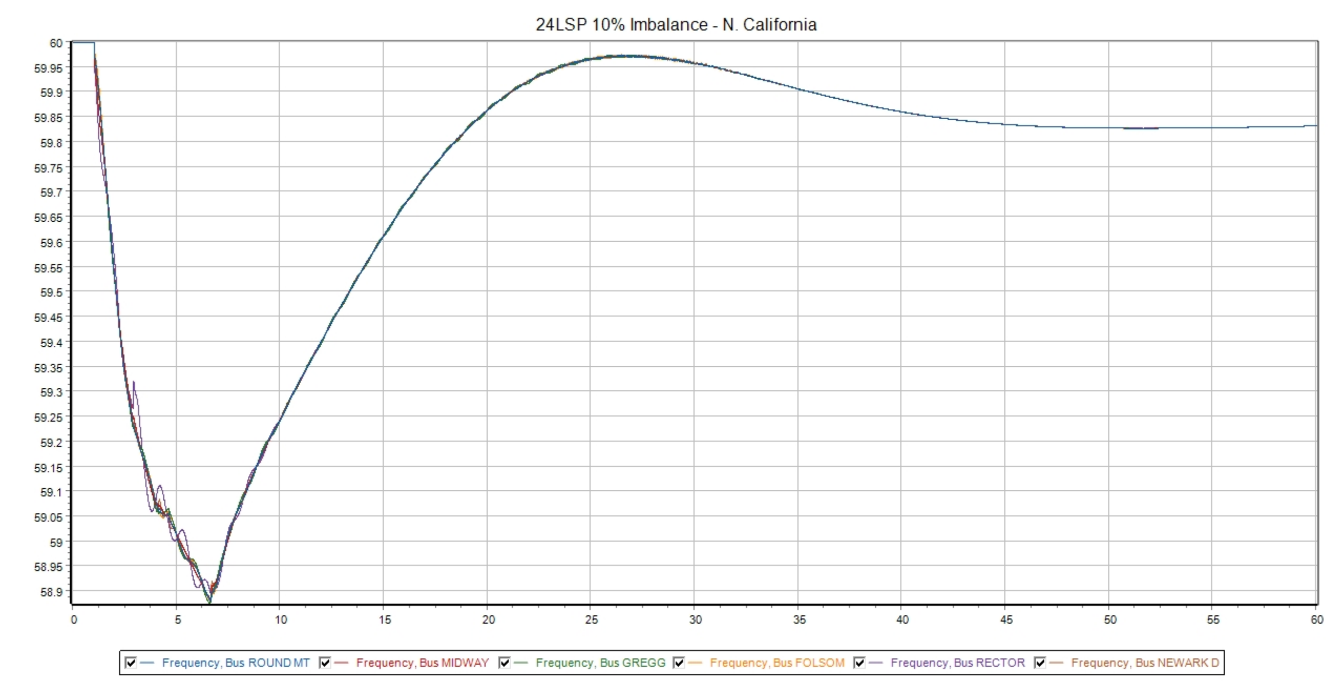

South Island - N. California
Frequency, Bus ROUND MT
Frequency, Bus MIDWAY
Frequency, Bus GREGG
Frequency, Bus FOLSOM
Frequency, Bus RECTOR
Frequency, Bus NEWARK D

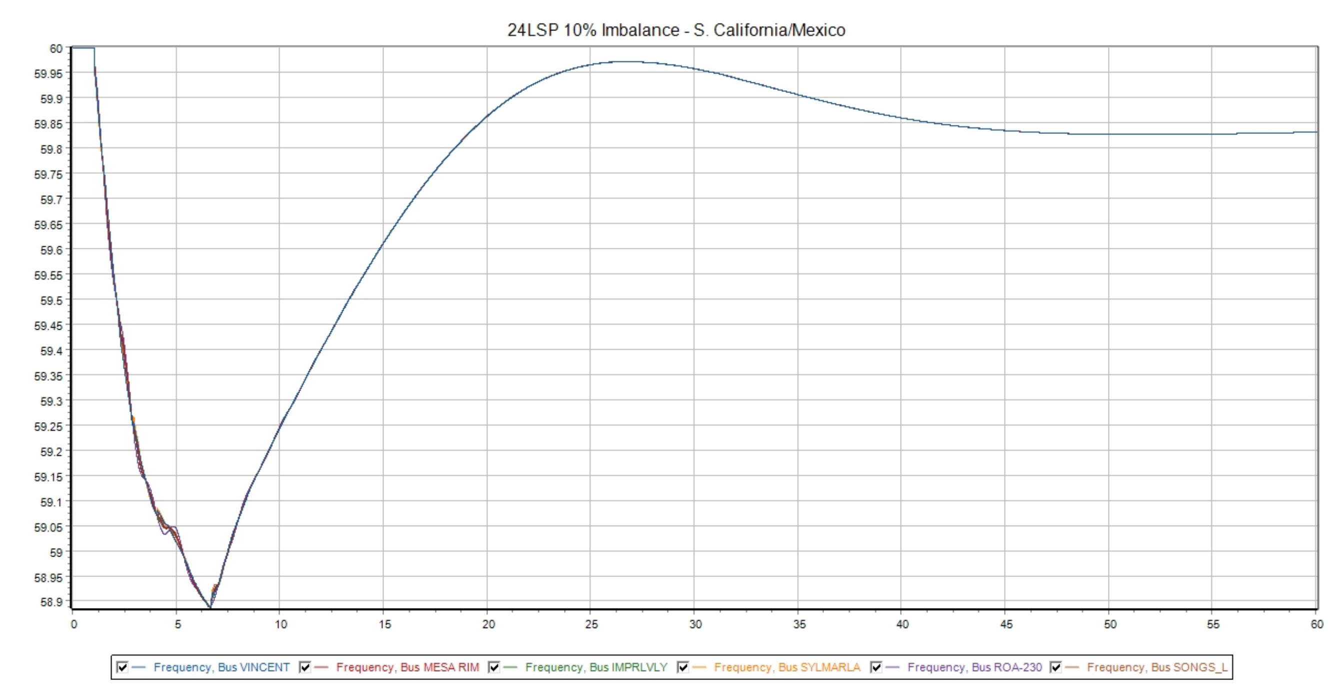

South Island - S. California/Mexico
Frequency, Bus VINCENT
Frequency, Bus MESA RIM
Frequency, Bus IMPRLVLY
Frequency, Bus SYLMARLA
Frequency, Bus ROA-230
Frequency, Bus SONGS_L

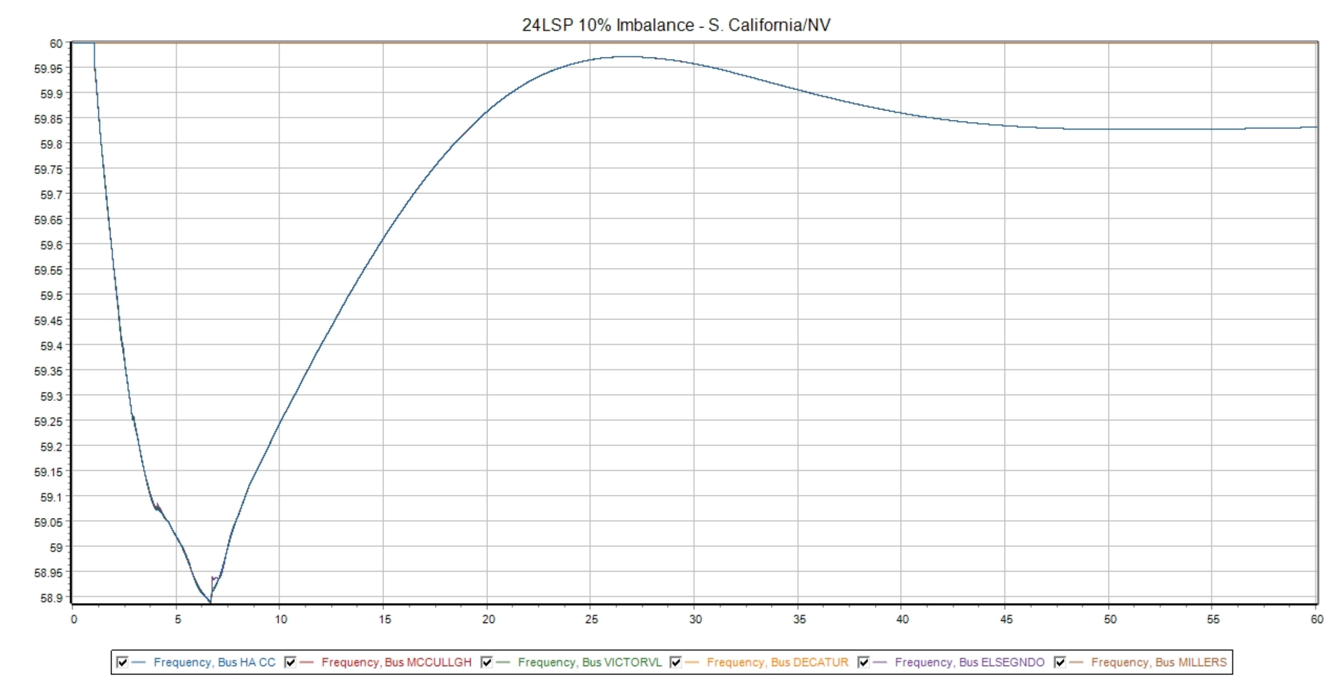

South Island - S. California/NV
Frequency, Bus HA CC
Frequency, Bus MCCULLGH
Frequency, Bus VICTORVL
Frequency, Bus DECATUR
Frequency, Bus ELSEGNDO
Frequency, Bus MILLERS

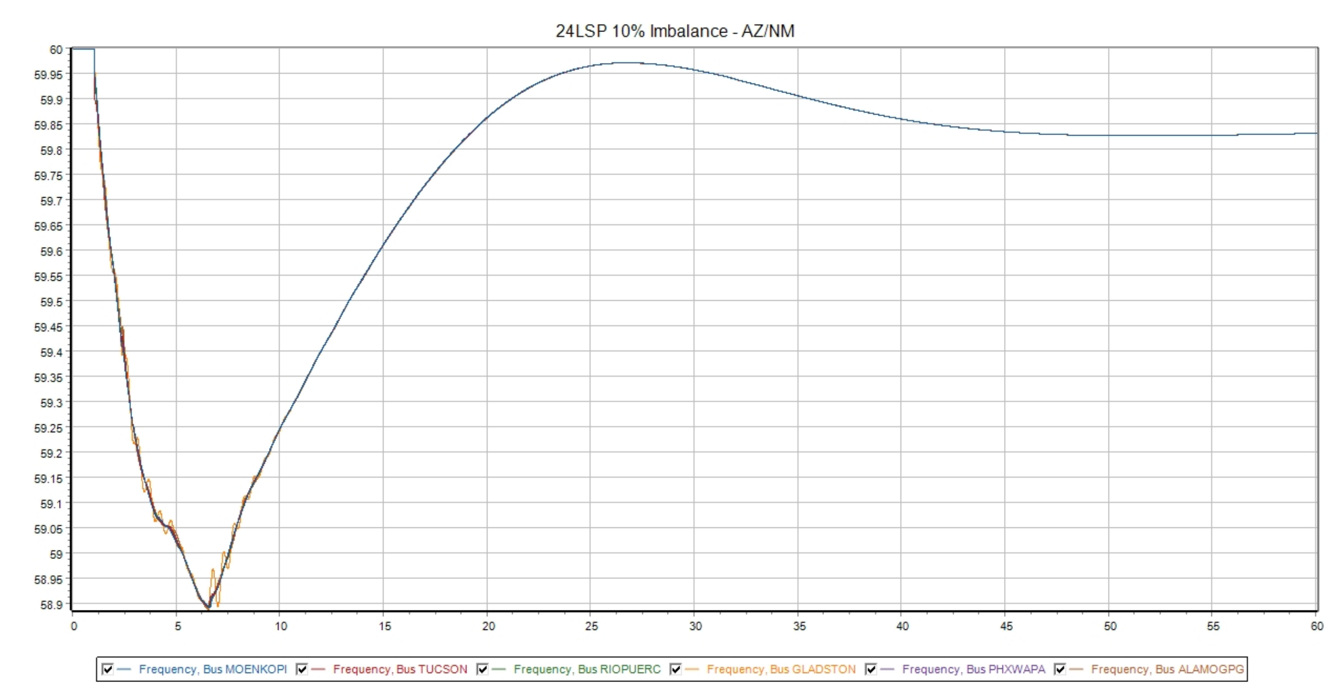

South Island - AZ/NM
Frequency, Bus MOENKOPI
Frequency, Bus TUCSON
Frequency, Bus RIOPUERC
Frequency, Bus GLADSTON
Frequency, Bus PHXWAPA
Frequency, Bus ALAMOGPG

24LSP—10%

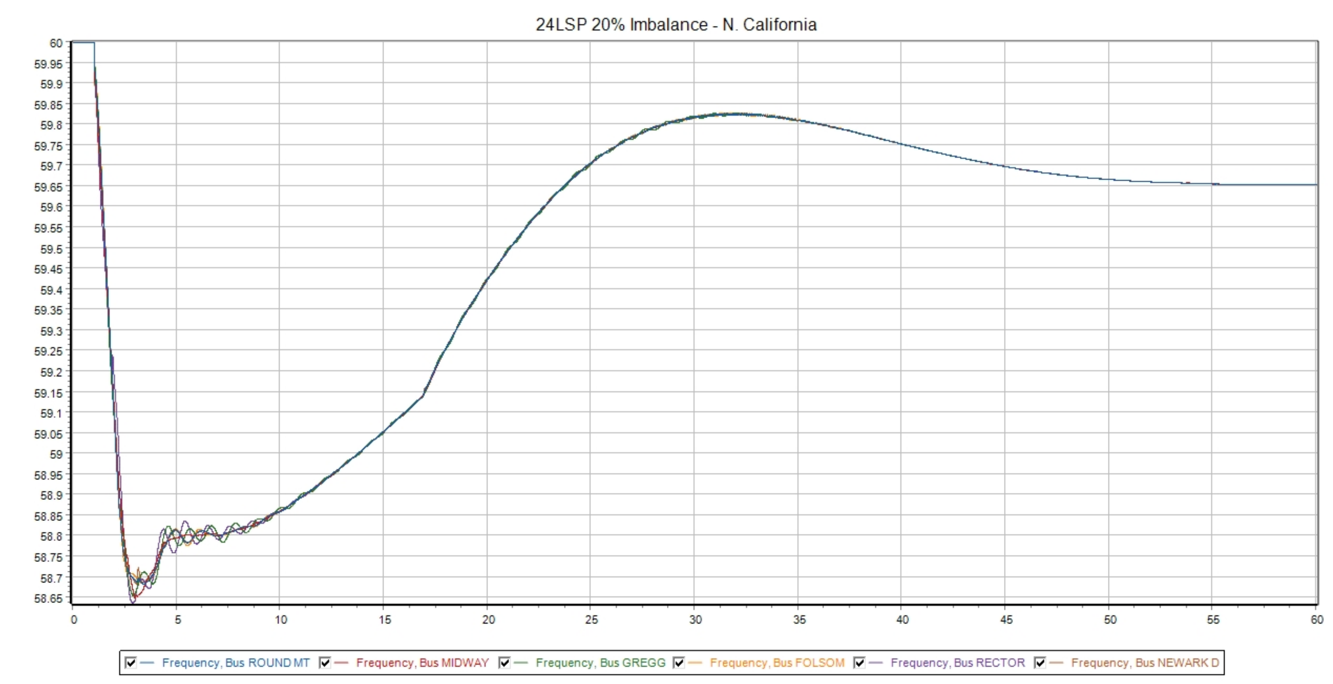

24LSP 10% Imbalance - N. California
60
59.95
59.9
59.85
59.8
59.75
59.7
59.65
59.6
59.55
59.5
59.45
59.4
59.35
59.3
59.25
59.2
59.15
59.1
59.05
59
58.95
58.9
0
5
10
15
20
25
30
35
40
45
50
55
60
Frequency, Bus ROUND MT
Frequency, Bus MIDWAY
Frequency, Bus GREGG
Frequency, Bus FOLSOM
Frequency, Bus RECTOR
Frequency, Bus NEWARK D

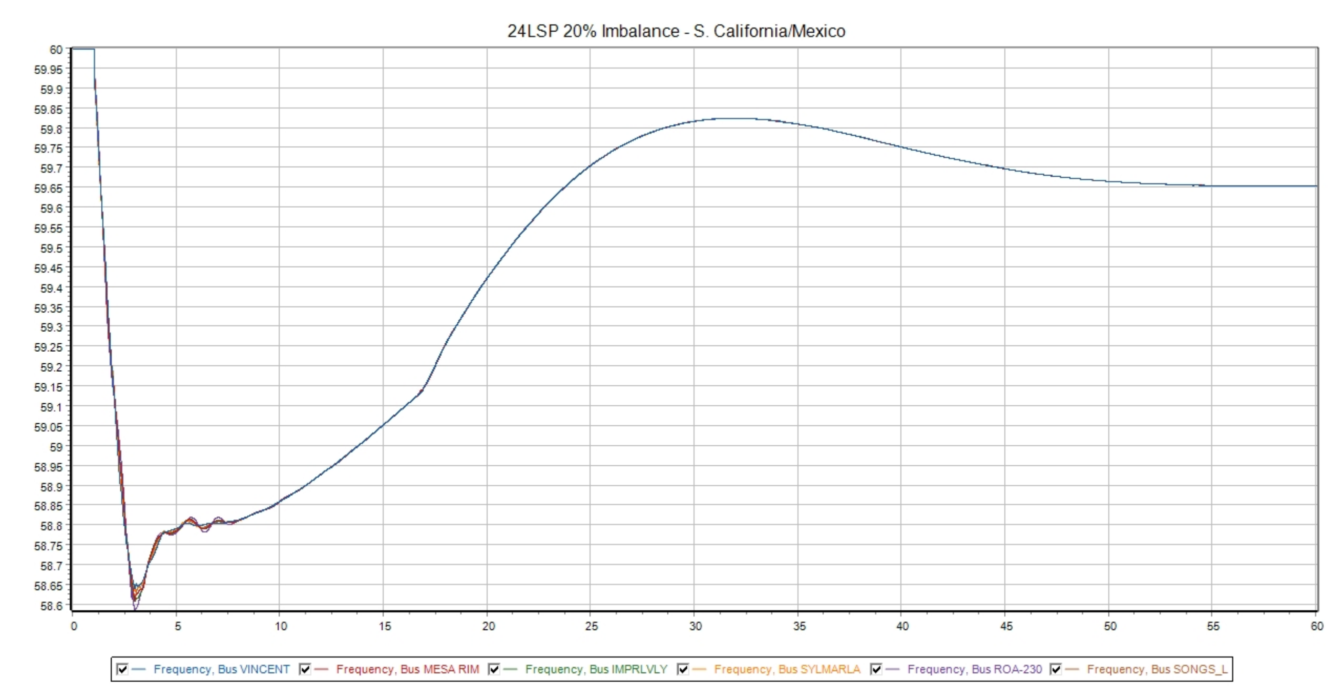

24LSP 10% Imbalance - S. California/Mexico
60
59.95
59.9
59.85
59.8
59.75
59.7
59.65
59.6
59.55
59.5
59.45
59.4
59.35
59.3
59.25
59.2
59.15
59.1
59.05
59
58.95
58.9
0
5
10
15
20
25
30
35
40
45
50
55
60
Frequency, Bus VINCENT
Frequency, Bus MESA RIM
Frequency, Bus IMPRLVLY
Frequency, Bus SYLMARLA
Frequency, Bus ROA-230
Frequency, Bus SONGS_L

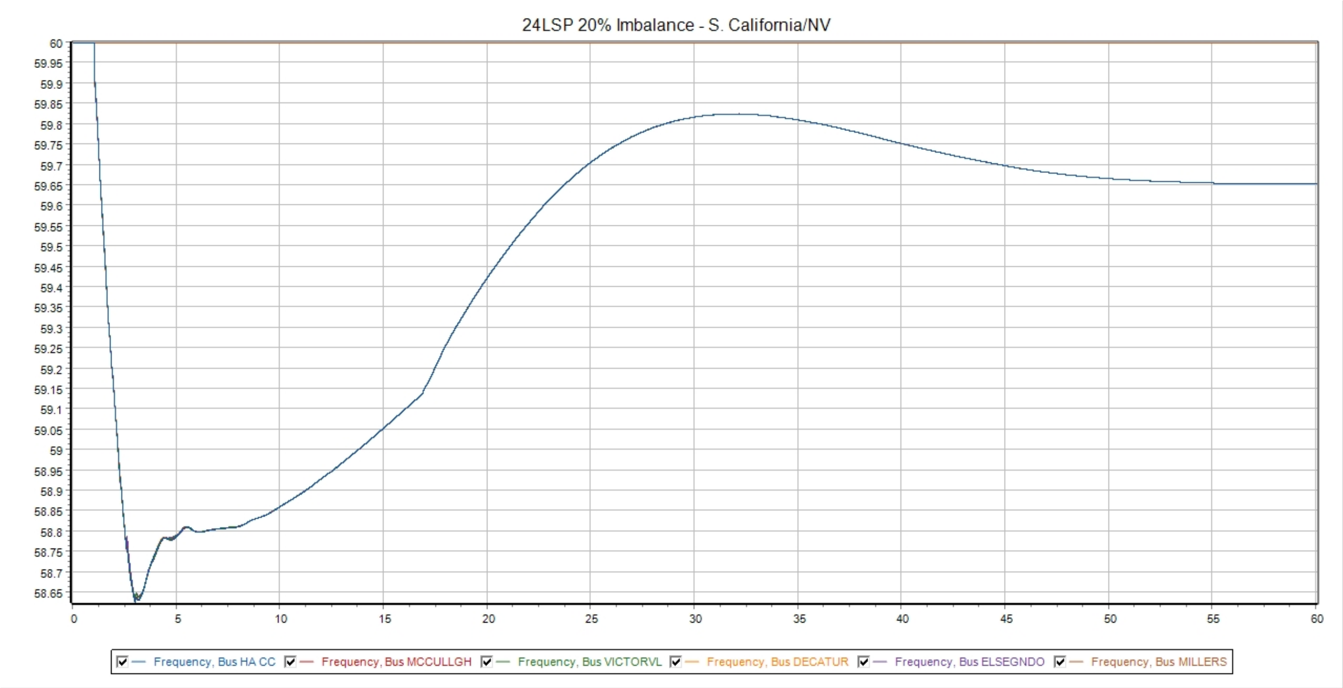

24LSP 10% Imbalance - S. California/NV
Frequency, Bus HA CC
Frequency, Bus MCCULLGH
Frequency, Bus VICTORVL
Frequency, Bus DECATUR
Frequency, Bus ELSEGNDO
Frequency, Bus MILLERS

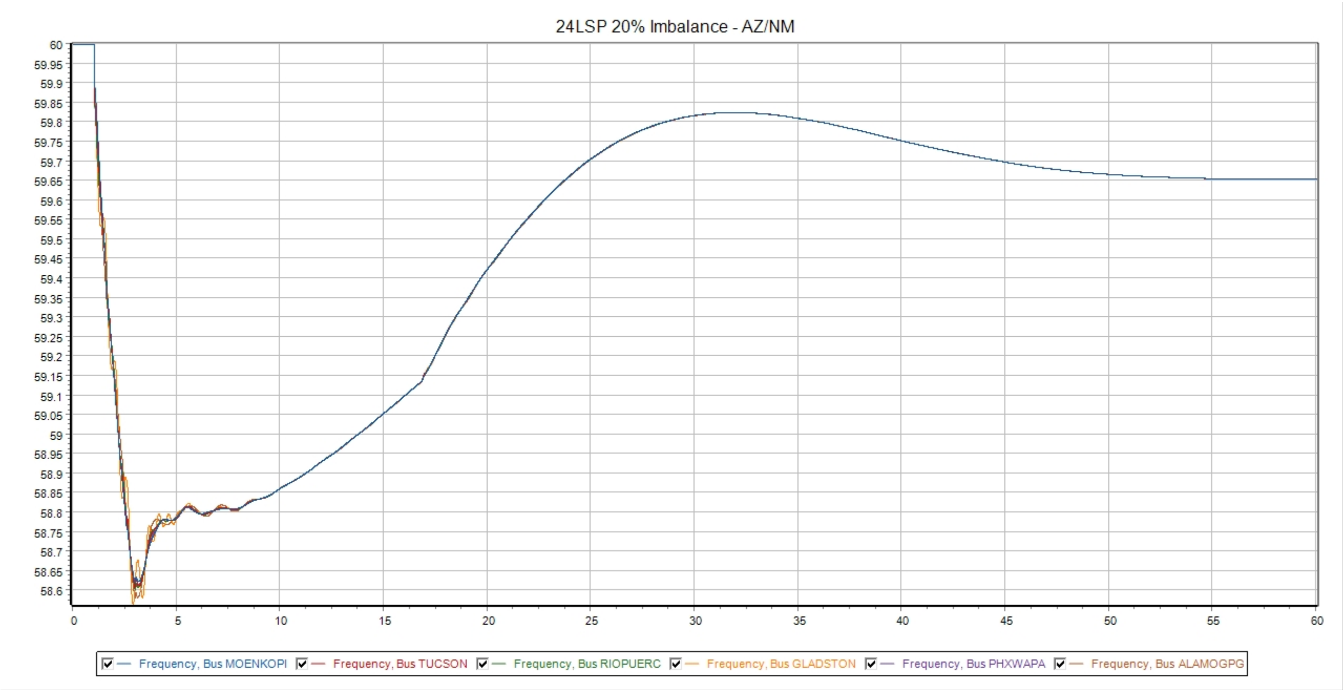

24LSP 10% Imbalance - AZ/NM
Frequency, Bus MOENKOPI
Frequency, Bus TUCSON
Frequency, Bus RIOPUERC
Frequency, Bus GLADSTON
Frequency, Bus PHXWAPA
Frequency, Bus ALAMOGPG

24LSP—20%

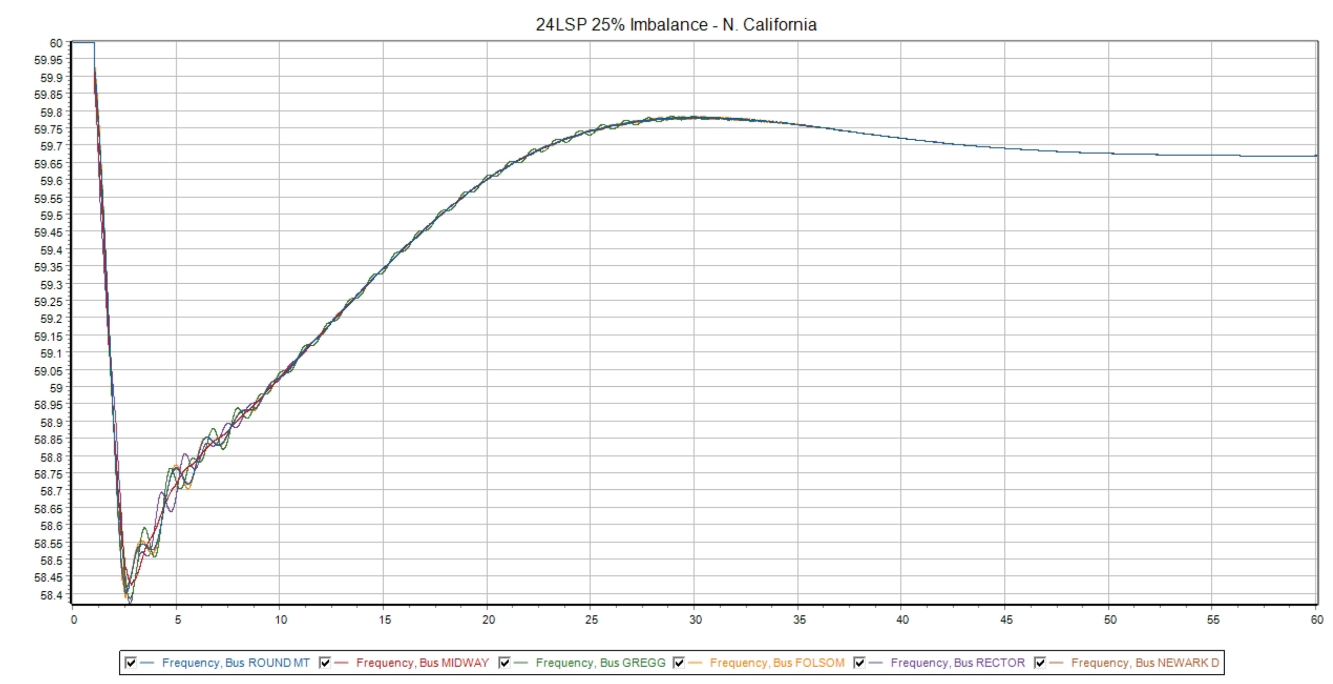

24LSP 20% Imbalance - N. California
Frequency, Bus ROUND MT
Frequency, Bus MIDWAY
Frequency, Bus GREGG
Frequency, Bus FOLSOM
Frequency, Bus RECTOR
Frequency, Bus NEWARK D

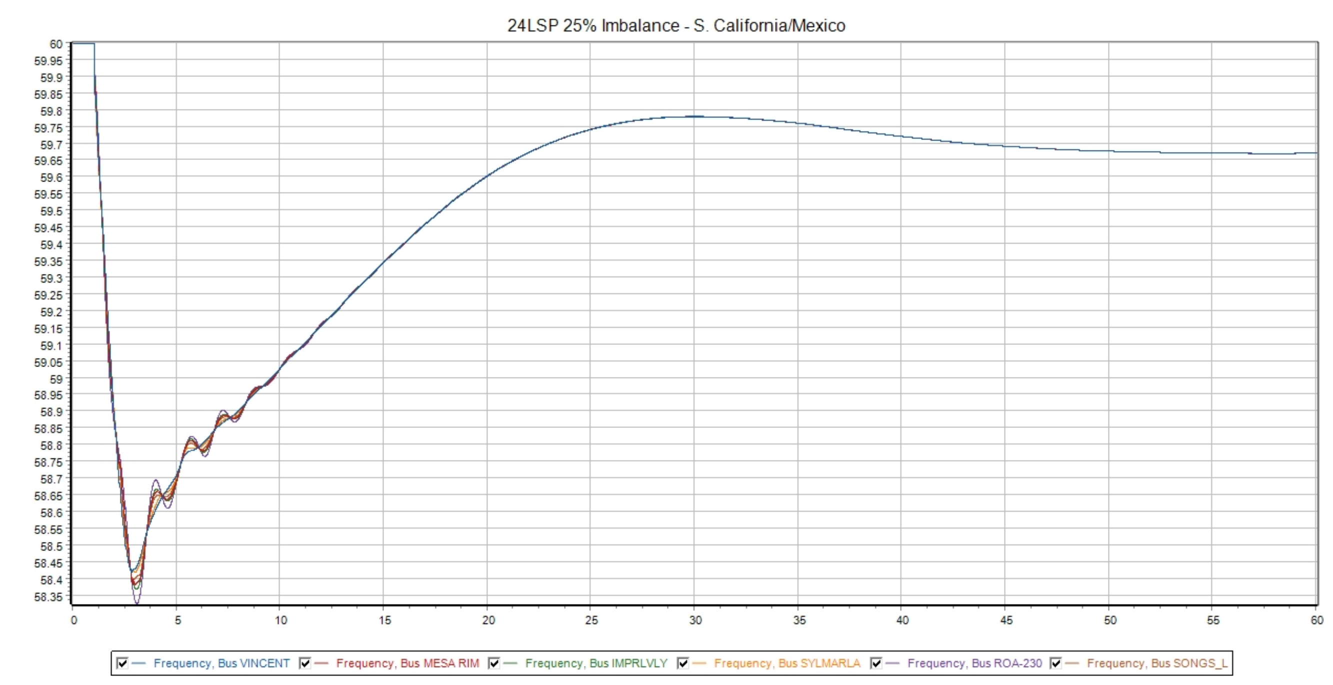

24LSP 20% Imbalance - S. California/Mexico
Frequency, Bus VINCENT
Frequency, Bus MESA RIM
Frequency, Bus IMPRLVLY
Frequency, Bus SYLMARLA
Frequency, Bus ROA-230
Frequency, Bus SONGS_L


24LSP 20% Imbalance - S. California/NV
Frequency, Bus HA CC
Frequency, Bus MCCULLGH
Frequency, Bus VICTORVL
Frequency, Bus DECATUR
Frequency, Bus ELSEGNDO
Frequency, Bus MILLERS


24LSP 20% Imbalance - AZ/NM
Frequency, Bus MOENKOPI
Frequency, Bus TUCSON
Frequency, Bus RIOPUERC
Frequency, Bus GLADSTON
Frequency, Bus PHXWAPA
Frequency, Bus ALAMOGPG

24LSP—25%


24LSP 25% Imbalance - N. California
60
59.95
59.9
59.85
59.8
59.75
59.7
59.65
59.6
59.55
59.5
59.45
59.4
59.35
59.3
59.25
59.2
59.15
59.1
59.05
59
58.95
58.9
58.85
58.8
58.75
58.7
58.65
58.6
58.55
58.5
58.45
58.4
0
5
10
15
20
25
30
35
40
45
50
55
60
Frequency, Bus ROUND MT
Frequency, Bus MIDWAY
Frequency, Bus GREGG
Frequency, Bus FOLSOM
Frequency, Bus RECTOR
Frequency, Bus NEWARK D


24LSP 25% Imbalance - S. California/Mexico
60
59.95
59.9
59.85
59.8
59.75
59.7
59.65
59.6
59.55
59.5
59.45
59.4
59.35
59.3
59.25
59.2
59.15
59.1
59.05
59
58.95
58.9
58.85
58.8
58.75
58.7
58.65
58.6
58.55
58.5
58.45
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0
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35
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45
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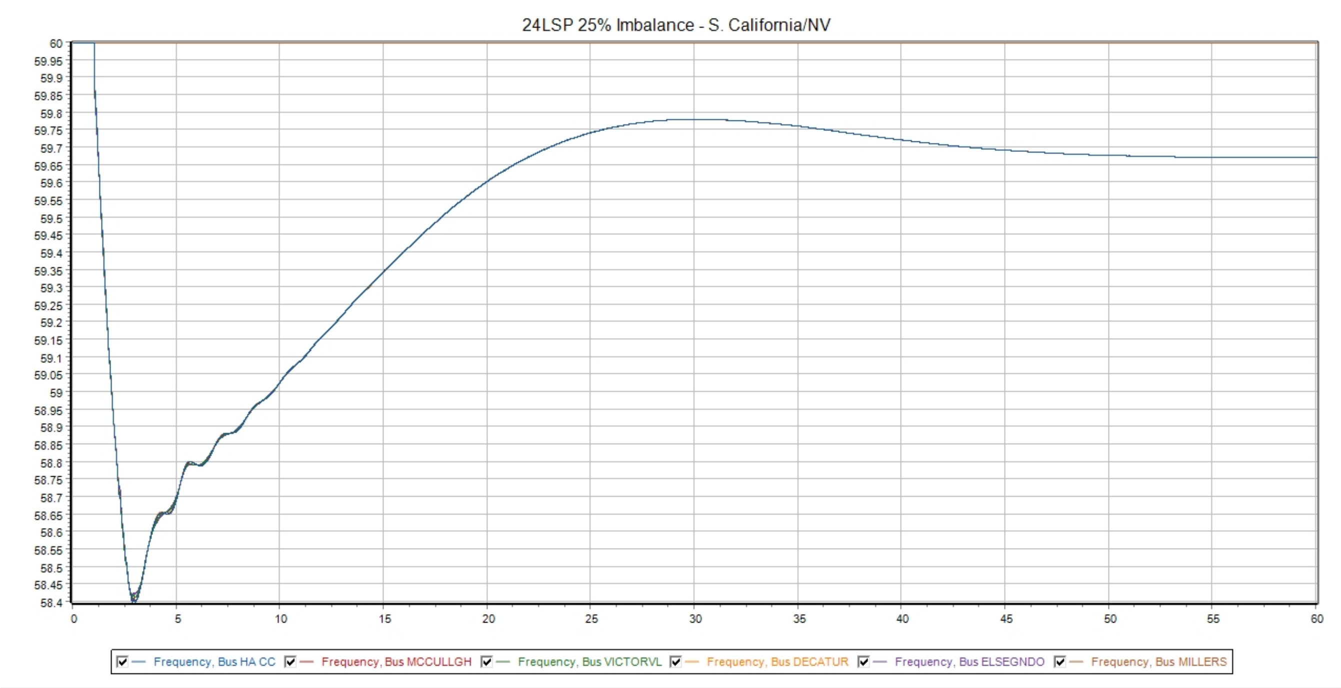
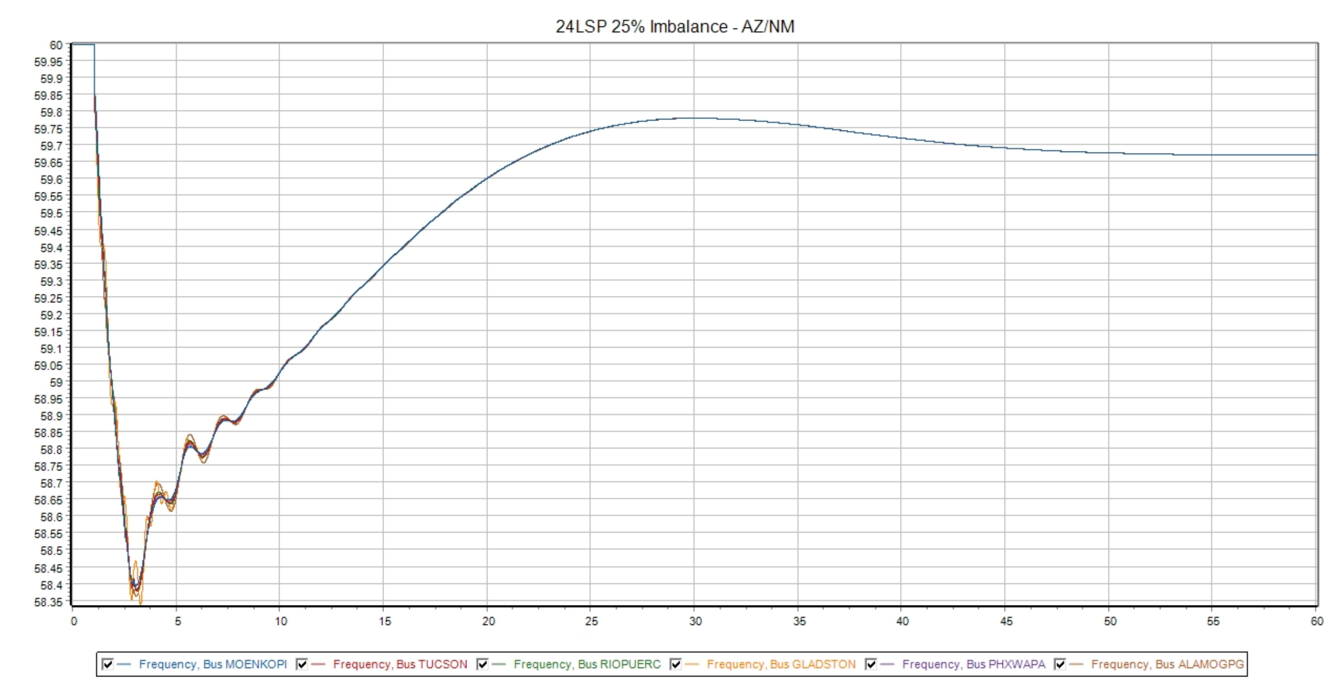
55
60
Frequency, Bus VINCENT
Frequency, Bus MESA RIM
Frequency, Bus IMPRLVLY
Frequency, Bus SYLMARLA
Frequency, Bus ROA-230
Frequency, Bus SONGS_L


24LSP 25% Imbalance - S. California/NV
Frequency, Bus HA CC
Frequency, Bus MCCULLGH
Frequency, Bus VICTORVL
Frequency, Bus DECATUR
Frequency, Bus ELSEGNDO
Frequency, Bus MILLERS


24LSP 25% Imbalance - AZ/NM
Frequency, Bus MOENKOPI
Frequency, Bus TUCSON
Frequency, Bus RIOPUERC
Frequency, Bus GLADSTON
Frequency, Bus PHXWAPA
Frequency, Bus ALAMOGPG

Appendix D—WECC Power Flow Areas

Area #	Area Name
South Island	
10	New Mexico
11	El Paso
14	APS
15	SRP
16	TEP
17	AEPCO
18	Nevada
19	WAPA L.C.
20	Mexico-CFE
21	IID
22	SDGE
24	So. Ca. Edison
26	LADWP
30	PG&E
North Island	
40	Northwest
50	B.C. Hydro
52	Fortis BC
54	Alberta
60	Idaho
62	Montana

63	WAPA U.W.
64	Sierra
65	PACE
70	PSCO
73	WAPA R.M.

Appendix E—WECC NE/SE Separation Scheme

The Western Interconnection is designed to detach into North and South islands as a result of the WECC-1 Remedial Action Scheme (RAS). Depending on the region and the company referring to it, this scheme has many names, including NE/SE separation scheme, the COI RAS, PACI RAS, AC RAS, Four Corners Scheme, and Pacific Intertie Transfer Trip Scheme. WECC-1 is installed to prevent overload, low voltage, and instability in the connected system should one or more lines between John Day, Buckley, Marion in the north, and Vincent in the south trip for whatever reason. In addition, selected 500-kV lines north of John Day, Buckley, and Marion have line loss logic to initiate WECC-1 for specific operating conditions. The separation cut-plane is shown in Figure 5.

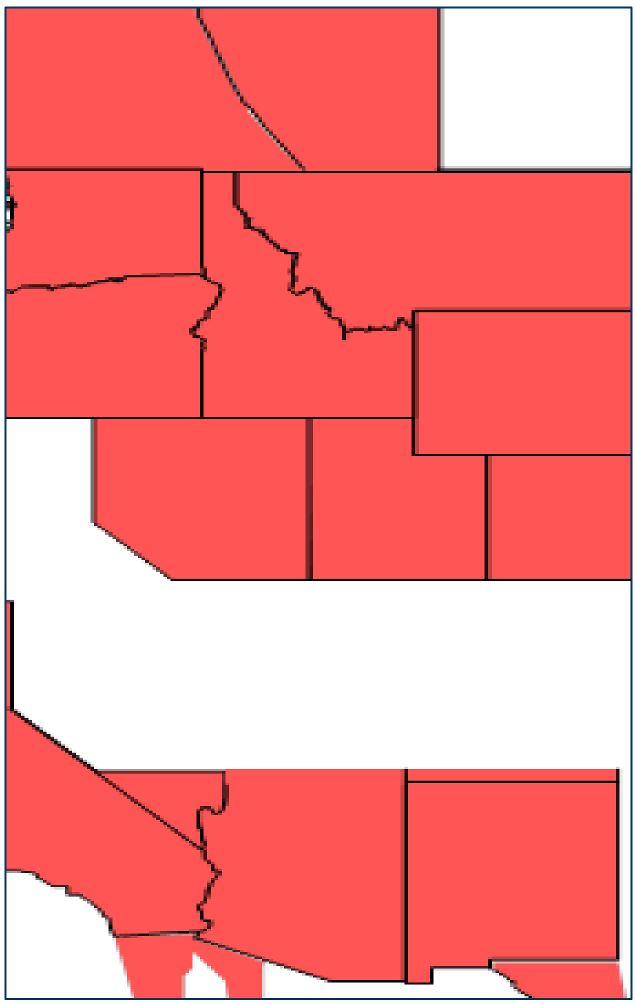


Figure 5: Separation Cut-plane

The separation occurs between the following entities:

- BPA and PG&E on the COI at Malin and Round Mountain Substations;
- BPA and WASN at Captain Jack and Olinda Substations;
- PG&E and PACW at Cascade Substation;

- PG&E and NVEN (SPPC) at NVE's California, Truckee, and North Truckee Substations;
- NVEN (SPPC) and SCE at NVE's Silver Peak Substation;
- NVEN (SPPC) and NVES (NEVP) at NVE's Robinson Summit Substation;
- PACE and APS at Four Corners;
- PACE and NVES (NEVP) at Red Butte and Harry Allen; and
- Tri-State and PNM at the Gladstone Substation.

To complete the separation between the North and South islands, WACRSP and WARM trips the following:

- Glen Canyon-Sigurd 230-kV line;
- Shiprock-Lost Canyon 230-kV line;
- Glade- Hesperus 115-kV line; and
- San Juan-Hesperus 345-kV line.