

Western Area Power Administration Sierra Nevada Region

2012 Annual Transmission System Assessment Study Plan

April 2012

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Introduction

The Western Area Power Administration – Sierra Nevada Region’s (WASN) transmission system annual assessment will be conducted to provide a transmission plan spanning at least ten years (2013 thru 2022) and be consistent with meeting the requirements of NERC Transmission Planning Standards TPL-001 thru TPL-004. This is a technical analysis of WASN’s transmission system and not of the load-serving entities and generation resources associated with it, but their interaction with the WASN transmission system will be investigated. The assessment will focus on the ability of WASN’s transmission system to reliably accommodate power imported on the California-Oregon Transmission Project 500 kV line and power generated by the U.S. Bureau Of Reclamation’s Central Valley Project hydro generation plants to supply load within the cities of Redding and Roseville as well as in the Sacramento Area and beyond. Critical system conditions will be analyzed. Where potential reliability problems are identified, mitigation measures will be identified to maintain required system performance. Mitigation measures will include proposed new transmission projects or other mitigation measures such as operating procedures including operating nomograms and Special Protection Schemes.

This Study Plan is a guide for coordinating the base case modeling assumptions, conducting the technical analysis, preparing documentation and reports including proposing new transmission projects or other mitigation measures. While this assessment is the basis of a ten-year transmission plan for maintaining system reliability, emphasis is placed on the first 5 years (2013-2017) of the plan where the interconnected transmission system reliability is addressed and potential performance deficiencies are identified and corresponding projects that resolve these problems are developed. As required, analysis out to the year 2022 will be analyzed to identify potential reliability concerns, which may require longer lead-times associated with significant 230 kV and 500 kV systems reinforcements.

This assessment will build on previous assessments, but also not duplicate previous assessments such that if there is no significant change being planned to the system, therefore no change in the assessment would be expected. To this extent, additional contingencies and system scenario’s will be investigated that have not been in previous assessments. These scenarios could involve other utilities transmission projects as well as different resource scenarios.

Specifically, an assessment of WASN’s transmission facilities will be performed to identify reliability problems within the years 2013 to 2022 delivering transmission service obligations. For each identified potential reliability problem directly associated with WASN’s transmission system and obligations to transport power through its transmission system, a mitigation plan will be proposed. As appropriate, alternative mitigation plans will be developed to determine the preferred engineering and economical mitigation plan. Existing transmission projects will be investigated to verify their continuing need and operation date.

Responsibilities and Objectives

With coordination and input from surrounding and interconnected utilities, WASN is responsible for performing a system assessment and developing a transmission plan of its transmission facilities covering the next 10 years. WASN will perform the following:

- As needed, revise power flow base cases obtained through the California Independent System Operator (CAISO), Pacific Gas and Electric (PG&E) and Western Electricity Coordinating Council (WECC) that model the 10 year span of the studies under various seasonal and load conditions;
- Conduct transmission system studies and benchmark the performance of WAPA's transmission facilities;
- Identify potential reliability problems for the 5 and 10-year planning horizons based on NERC Transmission Planning Standards and their requirements;
- Propose mitigation plans to address potential reliability problems for years 2013 to 2022; and
- Disseminate a report on the assessment to the WECC Reliability Coordinator as well as those utility entities within California or adjacent to it where the assessment results are relevant to the planning and operation of their electric transmission systems.

The projects proposed in the transmission plan will accomplish the following objectives:

- Comply with NERC Transmission Planning Standards TPL-001 thru TPL-004 and associated Requirements;
- Provide reliable transmission service to electric customers whose power is transmitted over WASN transmission lines;
- Maintain acceptable system voltages and reactive power support, thermal loadings on transmission facilities and synchronism of generator units directly connected to WASN's transmission system;
- Include planned transmission system additions and upgrades and verify their continued need and initial operation date;
- Support coordinated operation with interconnected and parallel utilities transmission systems; and
- Follow-up on the results and findings of various previous and on-going transmission planning studies

Reliability Standards

NERC Transmission Planning Standards TPL-001, TPL-002, TPL-003 and TPL-004 (included in Attachment 2) and their requirements will be the basis for establishing completion of this annual assessment.

Standard TPL-001-0 — System Performance Under Normal (No Contingency) Conditions (Category A)

Standard TPL-002-0 — System Performance Following Loss of a Single Bulk Electric System Element (Category B)

Standard TPL-003-0 — System Performance Following Loss of Two or More Bulk Electric System Elements (Category C)

Standard TPL-004-0 — System Performance Following Extreme Events Resulting in the Loss of Two or More Bulk Electric System Elements (Category D)

Table I. Transmission System Standards – Normal and Emergency Conditions

Category	Contingencies	System Limits or Impacts		
	Initiating Event(s) and Contingency Element(s)	System Stable and both Thermal and Voltage Limits within Applicable Rating ^a	Loss of Demand or Curtailed Firm Transfers	Cascading Outages
A No Contingencies	All Facilities in Service	Yes	No	No
B Event resulting in the loss of a single element.	Single Line Ground (SLG) or 3-Phase (3Ø) Fault, with Normal Clearing: 1. Generator 2. Transmission Circuit 3. Transformer Loss of an Element without a Fault	Yes Yes Yes Yes	No ^b No ^b No ^b No ^b	No No No No
	Single Pole Block, Normal Clearing ^e : 4. Single Pole (dc) Line	Yes	No ^b	No
C Event(s) resulting in the loss of two or more (multiple) elements.	SLG Fault, with Normal Clearing ^e : 1. Bus Section	Yes	Planned/ Controlled ^c	No
	2. Breaker (failure or internal Fault)	Yes	Planned/ Controlled ^c	No
	SLG or 3Ø Fault, with Normal Clearing ^e , Manual System Adjustments, followed by another SLG or 3Ø Fault, with Normal Clearing ^e : 3. Category B (B1, B2, B3, or B4) contingency, manual system adjustments, followed by another Category B (B1, B2, B3, or B4) contingency	Yes	Planned/ Controlled ^c	No
	Bipolar Block, with Normal Clearing ^e : 4. Bipolar (dc) Line Fault (non 3Ø), with Normal Clearing ^e :	Yes	Planned/ Controlled ^c	No
	5. Any two circuits of a multiple circuit towerline ^f	Yes	Planned/ Controlled ^c	No
	SLG Fault, with Delayed Clearing ^e (stuck breaker or protection system failure): 6. Generator	Yes	Planned/ Controlled ^c	No
7. Transformer	Yes	Planned/ Controlled ^c	No	
8. Transmission Circuit	Yes	Planned/ Controlled ^c	No	
9. Bus Section	Yes	Planned/ Controlled ^c	No	

Standard TPL-001-0 — System Performance Under Normal Conditions

<p>D^d Extreme event resulting in two or more (multiple) elements removed or Cascading out of service.</p>	<p>3Ø Fault, with Delayed Clearing^e (stuck breaker or protection system failure):</p> <table border="0"> <tr> <td>1. Generator</td> <td>3. Transformer</td> </tr> <tr> <td>2. Transmission Circuit</td> <td>4. Bus Section</td> </tr> </table> <hr/> <p>3Ø Fault, with Normal Clearing^e:</p> <ol style="list-style-type: none"> 5. Breaker (failure or internal Fault) 6. Loss of towerline with three or more circuits 7. All transmission lines on a common right-of way 8. Loss of a substation (one voltage level plus transformers) 9. Loss of a switching station (one voltage level plus transformers) 10. Loss of all generating units at a station 11. Loss of a large Load or major Load center 12. Failure of a fully redundant Special Protection System (or remedial action scheme) to operate when required 13. Operation, partial operation, or misoperation of a fully redundant Special Protection System (or Remedial Action Scheme) in response to an event or abnormal system condition for which it was not intended to operate 14. Impact of severe power swings or oscillations from Disturbances in another Regional Reliability Organization. 	1. Generator	3. Transformer	2. Transmission Circuit	4. Bus Section	<p>Evaluate for risks and consequences.</p> <ul style="list-style-type: none"> ▪ May involve substantial loss of customer Demand and generation in a widespread area or areas. ▪ Portions or all of the interconnected systems may or may not achieve a new, stable operating point. ▪ Evaluation of these events may require joint studies with neighboring systems.
1. Generator	3. Transformer					
2. Transmission Circuit	4. Bus Section					

- a) Applicable rating refers to the applicable Normal and Emergency facility thermal Rating or system voltage limit as determined and consistently applied by the system or facility owner. Applicable Ratings may include Emergency Ratings applicable for short durations as required to permit operating steps necessary to maintain system control. All Ratings must be established consistent with applicable NERC Reliability Standards addressing Facility Ratings.
- b) Planned or controlled interruption of electric supply to radial customers or some local Network customers, connected to or supplied by the Faulted element or by the affected area, may occur in certain areas without impacting the overall reliability of the interconnected transmission systems. To prepare for the next contingency, system adjustments are permitted, including curtailments of contracted Firm (non-recallable reserved) electric power Transfers.
- c) Depending on system design and expected system impacts, the controlled interruption of electric supply to customers (load shedding), the planned removal from service of certain generators, and/or the curtailment of contracted Firm (non-recallable reserved) electric power Transfers may be necessary to maintain the overall reliability of the interconnected transmission systems.
- d) A number of extreme contingencies that are listed under Category D and judged to be critical by the transmission planning entity(ies) will be selected for evaluation. It is not expected that all possible facility outages under each listed contingency of Category D will be evaluated.
- e) Normal clearing is when the protection system operates as designed and the Fault is cleared in the time normally expected with proper functioning of the installed protection systems. Delayed clearing of a Fault is due to failure of any protection system component such as a relay, circuit breaker, or current transformer, and not because of an intentional design delay.
- f) System assessments may exclude these events where multiple circuit towers are used over short distances (e.g., station entrance, river crossings) in accordance with Regional exemption criteria.

Study Assumptions

The annual transmission planning process starts with the development of power flow base cases that model WASN's transmission system within Northern California as well within the WECC reliability area. This section discusses the assumptions used in developing the power flow base cases for this study.

A. Base Cases Developed for Transmission System Assessment

Power flow base cases for this annual assessment are derived from base cases developed by PG&E and by WECC members through WECC. The local area power flow cases developed by PG&E and distributed through the California Independent System Operator (CAISO) represent the Northern Valley portion of California's Central Valley area with transmission and generation representation of Northern California. PG&E base cases for Northern California with transmission system representation for the entire WECC area will also be used to assess system performance 5 and 10 years out. Specifically, the base cases were developed through review and any required revision by WASN, those entities that supply and receive power over WASN's transmission system and other utilities within Northern California as well as within the WECC area. This review and revision was conducted through PG&E and the CAISO. The transmission system configuration was updated to reflect, according to the projected year of operation, new planned transmission system reinforcements expected to be approved and become operational. The cases include WASN transmission facilities updated to reflect any recent changes to the configuration of the transmission system as well as voltage support devices at WAPA owned and/or operated substations. Voltage support devices include shunt reactors, shunt capacitors and series capacitors. In general, the North Valley power flow cases include forecasted 1-in-10-year summer peak forecasted load and the WECC system-wide cases include forecasted 1-in-5-year summer peak load.

Historically, maximum power flow through WASN's transmission system has occurred during summer peak load conditions when pre-dominant power flow through the 500 kV transmission system in California is from North to South. This flow along with near maximum hydro power generation in Northern California model the most stressed conditions on the WASN transmission system. The 2008 thru 2011 WASN Annual Transmission Assessments support this conclusion.

However, there are system conditions that occur during other seasons or load conditions that warrant investigation. These include summer off-peak conditions with lower load, spring peak load conditions when loads are lower and maximum hydro power is available or during winter peak when loads are lower, hydro power is minimal and the direction of pre-dominant power flow through the 500 kV transmission system in California is in a South to North direction. To address this issue and as needed to adequately assess the reliability of WASN's transmission system, additional seasonal WECC base cases will be utilized. These WECC cases were developed by WECC members with representation of the entire WECC area.

Base cases that will be utilized for this annual transmission assessment are summarized in Table 1.

Table 1: List of Study Base Cases Derived from PG&E Annual Assessment Base cases and WECC Base Cases

PG&E power flow base cases distributed through the CAISO

- 2011HS2A with TSS and OC comments reviewed and incorporated.
- 2013 PG&E Area Base Cases for the Northern Sacramento Valley area with Northern California modeling 1-in-10 summer peak loads
- 2013 PG&E Area Base Cases for the Northern Valley Area within Northern California modeling winter peak loads
- 2014 Light Autumn WECC approved case with TSS and OC comments reviewed and incorporated.
- 2015 PG&E Area Base Cases for the Northern Sacramento Valley area with Northern California modeling 1-in-10 summer peak loads
- 2016 Spring off-peak WECC approved case with TSS and OC comments reviewed and incorporated
- 2015, 2017, 2018, 2019, 2022 Heavy Summer WECC approved case with TSS and OC comments reviewed and incorporated.
- 2017 Heavy and Light Winter WECC approved case with TSS and OC comments reviewed and incorporated
- 2018 Heavy Winter and Heavy Spring WECC approved case with TSS and OC comments reviewed and incorporated
- 2019 Heavy Winter WECC approved case with TSS and OC comments reviewed and incorporated
- 2021 Summer Peak Load PG&E Base Case modeling WECC
- 2021 Spring Off-Peak Load PG&E Base Case modeling WECC
- 2022 Heavy Winter and Light Spring WECC approved case with TSS and OC comments reviewed and incorporated

See Attachment 1 for a diagram of the WAPA-SNR system within Northern California.

The base cases include transmission projects approved by the CAISO consistent with CAISO criteria for modeling new transmission projects. Some specific projects modeled include the Sacramento Voltage Support Project, the Redding Business Development Projects, the Folsom Loop Project and the Re-configuration of the Shasta 230 kV Bus Project.

Please note that these base cases are considered a “base” starting point when studying a particular area. Other electric load, generation, or import-export scenarios may be studied to determine their influence on system performance.

B. Electric Demand and Power Factor Assumptions and Methodology

Base case assumptions for electric demand and power factor will represent projected

summer peak load conditions as reported by WASN’s Load Serving Entities (LSE) (the cities of Redding, Roseville, Lawrence Livermore Lab, Ames Research etc.) consistent with the California Energy Commission’s (CEC) Integrated Energy Policy Report (IEPR) which includes load projections for all of Northern California as well as separately for public and privately owned electric utilities. Electric demand and power factor assumptions for the WECC system-wide base cases will incorporate a 1-in-5 year adverse weather assumption based on ambient temperature. Similarly, the PG&E North Valley area base cases incorporate a 1-in-10 year adverse weather assumption. Additional information on the electric demand forecast is listed below:

Load in MW represented in summer peak load power flow cases (4)

<u>Year</u>	<u>2013</u>	<u>2017</u>	<u>2022</u>
SMUD	3390	3007	3241
City of Redding(3)	295	210	310
City of Roseville	380	415	443
MID	736	746	827
WASN Direct Service(1)	205	196	192
Total Northern California Area Load (2)	25043	28,559	30,417

(1) Includes the Tracy Pumping Plant, City of Shasta Lake, Lawrence Livermore Lab

(2) Includes - PG&E, SVP, SMUD, MID, TID, WAPA Direct Svc, LMUD, NCPA, Roseville, Redding, CDWR and Other Muni's

(3) Redding includes load at Knauf

(4) Forecasted 1-in-10 year load for the Sacramento Valley was used when appropriate. In several years forecasted load was greater than Load Serving Capability load, in which case load was adjusted while monitoring WAPA’s Elverta bus voltage. WASN is not an LSE and has no obligation to support the load of adjacent Sacramento Valley LSE’s.

C. Major Path Flow Assumptions

The summer peak base cases modeled approximately 4,800 MW flowing north-to-south on the California-Oregon Intertie, COI (Path 66). The flow on the Midway-Vincent 500 kV lines (Path 26) at Midway Substation was modeled at 4,000 MW (North-to-South), but varied as necessary to balance loads and resources in Northern California. The Pacific DC Intertie (PDCI) was modeled as indicated in the table below. Table 2 summarizes the major path flow assumptions.

Table 2: Major Intertie and Path Flow Summary

Path or Intertie	Path Flow (MW)		Path Rating (MW)
	Summer/Spring	Winter	
WECC Path 66 California- Oregon Intertie (COI)	4,800 (North to South)	3,675 (South to North)	4,800 (North to South) 3,675 (South to North)
WECC Path 26 Midway-Vincent 500 kV	4,000 (North to South)	Varied to balance loads and resources in No. California	4,000 (North to South) 3,000 (South to North)
WECC Path 15 Midway-Los Banos	Varied to balance loads and resources in No. California	5,400 (South to North)	3,265 (North to South) 5,400 (South to North)
WECC Path 65 Pacific DC Intertie (PDCI)	3,100 (North to South)	2,200 (South to North)	3,100

D. Generation Assumptions

Assumptions on existing generation facilities such as capability and output levels will be developed based on historical dispatch generation data for Northern California. Northern California hydro generation will be assumed available at historical output (about 86%) during peak system demand conditions. Both hydro and thermal generation within local areas, and generation external to a local area that has an effect on local area reliability will be varied as necessary to identify the most restrictive system conditions and related reliability problems.

For new generation proposals, WASN will utilize the CAISO's approach on the modeling of new generation in power flow cases including the following stages of generation development:

- Level 1: Under construction
- Level 2: Regulatory approval (local agency approval for < 50MW)
- Level 3: Application under review
- Level 4: Starting application process
- Level 5: Press release only

For the five-year planning cases, new generation proposals that are under construction (Level 1) will be modeled in the initial power flow case. With the recent developments of generation procurement, in addition to modeling the Level 1 generation projects, generation projects that have received a power purchasing agreement will also be modeled with the Level 1 generation projects in the base cases.

For ten-year planning cases, only generation that is under construction or has received regulatory approval (Levels 1 and 2) will be modeled in the area of interest of

the initial power flow case. If additional generation is required to achieve an acceptable initial power flow case, generation from Levels 3 and 4 that have received CAISO preliminary approval can be used – but only if they are outside the area of study, so that their impact on the facility addition requirements will be minimized.

All generators with online dates of May or earlier will be modeled in the summer peak case for that year. All generators with online dates of June or later will be modeled in the season following their planned operation date.

The generation pattern and level of generation modeled in power flow base cases will be representative of recent utility information provided for both PG&E and WECC seasonal base cases representing peak and off-peak load conditions. Information on proposed new generation development is available on the California Energy Commission's web site at: http://www.energy.ca.gov/sitingcases/all_projects and on the CAISO's web site at: <http://www.caiso.com/docs/2002/06/11/2002061110300427214.html> .

As deemed necessary, sensitivity studies reflecting various generation patterns that could influence system reliability will be analyzed.

System Assessment

The WASN transmission system will be evaluated against NERC's Planning Standards listed below.

Category A (NERC Planning Standard TPL-001): All Facilities in Service, (N-0)

Category B (NERC Planning Standard TPL-002): Single Element Outage, (N-1)

Category C (NERC Planning Standard TPL-003): Double Element Outages, (N-2)

Category D (NERC Planning Standard TPL-004): Extreme Events (N-2 plus) covering the contingencies included for Categories B and C above.

The various contingencies analyzed as associated with NERC Planning Standards will be listed in the study report.

Assessment Study Scope

The assessment process will test the WASN transmission system against NERC Planning Standards. This process will evaluate the transmission grid for the following:

- Thermal Loading and Voltage Limits
- Transient Stability

- Voltage Stability – Post Transient Voltage
- Proposed new transmission projects
- Transmission Upgrades to support import of generation from Renewable Resources

A. Thermal Loading and Voltage Limits

A thermal loading assessment will be performed on all WASN transmission facilities. This analysis will examine thermal loadings under normal and contingency conditions. Should a WAPA transmission facility be determined to exceed its thermal capability normally or during contingency conditions, WAPA will address the thermal loading with a mitigation plan.

WASN will examine system voltages to determine if they stay within acceptable post transient and steady state limits. As with the thermal loading assessment, the analysis will include examining base case (normal) conditions and contingency conditions.

B. Transient Stability

Transient stability assessments will be conducted in accordance with the WECC Stability Standards for selected contingency conditions. The scope of these studies will be sufficient to establish the existence of any stability problems. A transient stability contingency list can be reviewed within Attachment 4. The analysis will follow the latest transient stability modeling methodology recommended by the WECC. Transient stability analysis will include modeling the impact of either a three-phase fault on the mentioned facilities with normal clearing times and any associated remedial action schemes or a single-phase to ground fault with delayed clearing.

Transient stability studies will focus on the 500 kV system (California/Oregon Transmission Project), but also will assess the 230 kV systems between Olinda, Cottonwood, O'Banion, Roseville and Elverta Substations as determined by their location between generation resources and load centers as well as being between generation sub-regional generation resources such as Northern California hydro and San Francisco Bay Area thermal generation.

C. Voltage Stability – Post Transient Voltage

Voltage stability studies will be performed in accordance with the Guide to WECC/NERC Planning Standards I.D: Voltage Support and Reactive Power under normal and contingency conditions. For voltage stability analysis, a 1-in-10 year adverse weather-load condition will be used. The voltage stability assessment consists of two components: Reactive margin and power margin. The reactive margin will be achieved by keeping the load level constant to determine how much reactive margin can be obtained at a given point in the network. Power margin is achieved by increasing the local load level from that in the reactive margin portion incrementally up until the system collapses. When analyzing voltage stability, the WECC requires a 5% increase in load for single contingencies (Category B) and 2.5%

for double contingencies (Category C). These percent increases in load amount to margin between where normal and contingency related operations are expected and where voltage instability is projected to occur.

Post-transient voltage analysis will be conducted at points where the WASN transmission system connects to customer load-serving points such as for the Cities of Redding and Roseville as well as connections to the Sacramento Municipal Utility District (SMUD) and USBR Pumps at Tracy as well as recognition of the 500 and 230 kV connections to PG&E's system at Cottonwood and Tracy Substations.

Annual Transmission Assessment Report

The WASN 2012 Annual Transmission Assessment will document compliance with NERC Transmission Planning Standards, the study assumptions used, study methodologies, study results, conclusions, recommendations, and proposed mitigation measures to resolve reliability issues and any other relevant information required to meet NERC Standards. Mitigation measures can include transmission reinforcement projects, re-rating of transmission facilities, special protection systems, or operating procedures. The information will include when mitigation is needed and how it will be achieved.

Study Schedule

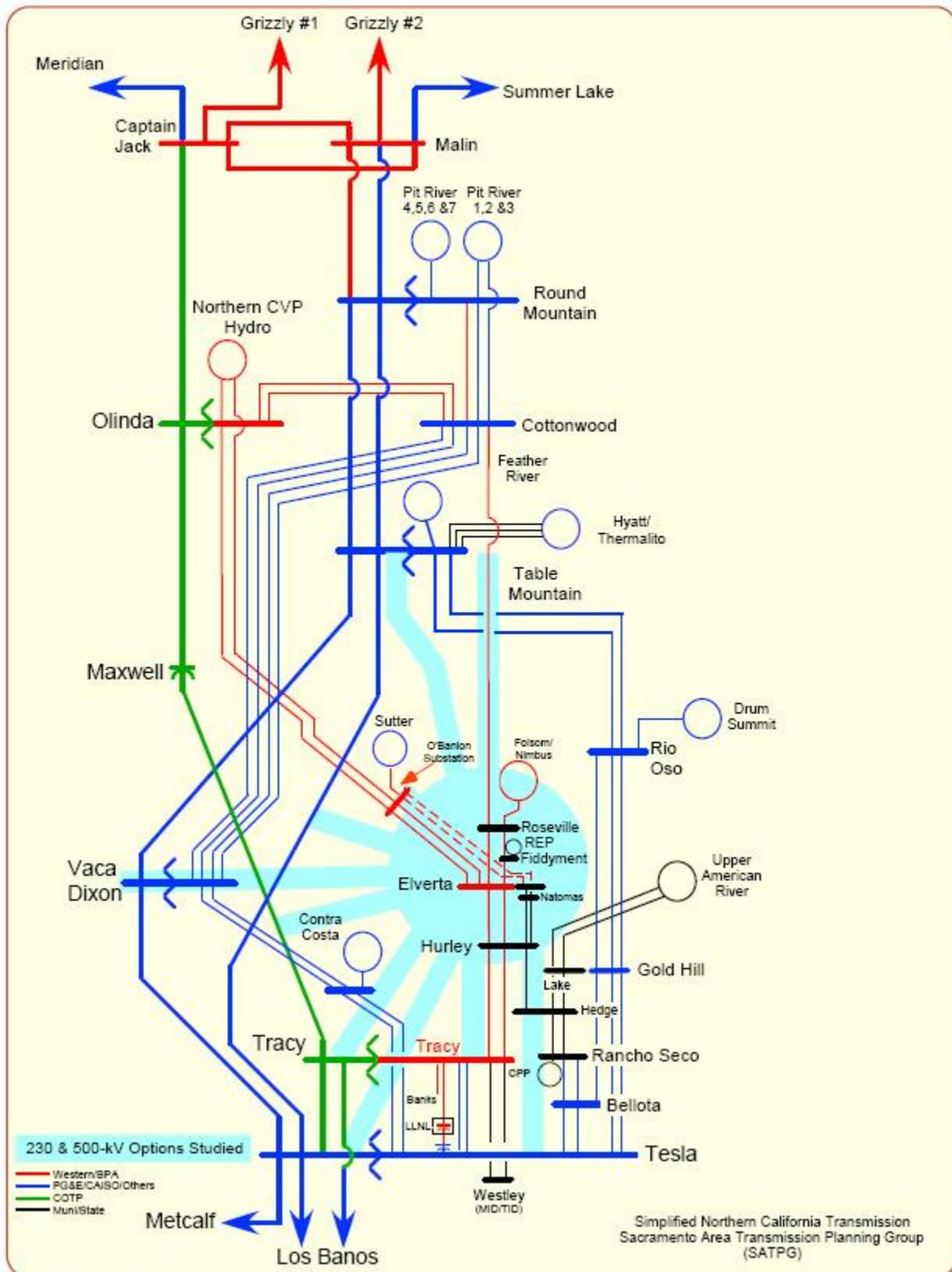
Table 3 – Below is WASN's study schedule to conduct the 2009 Annual Assessment.

Table 3: Study Schedule¹

Reference #	Milestone	Date
1	Draft a Study Plan	April 16, 2012
2	Acquire Study Data (Power Flow and Dynamic)	May 1, 2012
3	Perform Analysis	Aug. 1, 2012
4	Put Together Assessment Report and Related Documentation	Sept. 1, 2012
5	Perform Additional Analysis and Documentation as Needed	Oct, 1, 2012
6	Finalize 2012 Transmission Assessment Report	Nov. 1, 2012

¹ This Study Schedule is a working document and can be revised from time to time.

Attachment 1: Simplified Diagram of the Western Area Power Administration – Sierra Nevada Region Transmission System



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Attachment 2: North American Electric Reliability Corporation (NERC) Planning Standards

The NERC Planning Standards available on the NERC web site at <http://www.nerc.com/page.php?cid=2>

Attachment 3: Contingencies Studied

The following list of contingencies were included for thermal, voltage, post-transient and transient stability. For transient stability analysis and while Table 1 within the NERC Planning Standards TPL-001 thru 004 allow for simulating a single-line to ground(SLG) fault for certain contingencies, this WASN transmission assessment was conducted simulating 3-phase faults for all of the contingencies studied, but included SLG faults for some contingencies to verify that this type of fault would produce less of an impact to system reliability. The fault was applied on the leading bus. For example, a 3-phase fault was applied at Captain Jack for a fault on the Captain Jack to Olinda 500 kV line that's results in an outage of the line after the fault is cleared in 4 cycles.

Event resulting in the loss of a single element – NERC Level B

- Captain Jack – Olinda 500 kV
- Olinda – Tracy 500 kV
- Folsom Power Plant Units 1, 2 or 3
- Nimbus Power Plant Units 1 or 2
- Roseville Generation Units Rep1, 2 or 3
- Roseville Generation CT's 1 or 2
- Sutter Power Plant Units 1, 2, or 3
- Airport – Cottonwood 230 kV
- Cottonwood – Round Mountain 230 kV
- Cottonwood – Roseville 230 kV
- Cottonwood – Shasta 230 kV overlapping with Shasta Units 1 & 2
- Cottonwood – Shasta 230 kV overlapping with Shasta Units 3 & 4
- Elverta WAPA – Hurley 230 kV
- Fiddymment – Elverta WAPA 230 kV
- Fiddymment – Roseville 230 kV
- Flanagan – Keswick 230 kV
- Folsom – Lake 230 kV
- Folsom – Nimbus 115 kV
- Folsom – Orangevale 230 kV
- Folsom – Roseville 230 kV
- Goldhill – Lake 230 kV
- Keswick – Airport 230 kV
- Keswick – JF Carr 230 kV
- Keswick – O'Banion 230 kV
- Keswick – Spring Creek 230 kV overlapping with Spring Creek Unit 1
- O'Banion – Elverta WAPA 230 kV
- O'Banion – Natomas 230 kV
- Olinda – Cottonwood 230 kV
- Olinda – Keswick 230 kV
- Olinda – O'Banion 230 kV
- Rancho Seco – Bellota 230 kV
- Roseville – Elverta WAPA 230 kV

- Roseville – Folsom 230 kV
- Shasta – Flanagan 230 kV
- Sutter – O’Banion 230 kV and Sutter Power Plant
- Trinity – JF Carr 230 kV overlapping with Trinity Units 1 & 2
- Tracy – Hurley 230 kV
- Tracy – Lawrence Livermore 230 kV
- Tracy – Tesla 230 kV
- Tracy – Wesley 230 kV
- Olinda 500/230 kV Transformer Bank
- Roseville 230/60 kV Transformer Bank
- Tracy 500/230 kV Transformer Bank

Event(s) resulting in the loss of two or more (multiple) elements – NERC Level C

- Cottonwood 230 kV bus section
- Elverta 230 kV bus section
- Keswick 230 kV bus section
- Tracy 230 kV bus section
- Cottonwood – Shasta #1 & #2 230 kV
- Elverta - Hurley #1 & #2 230 kV
- O’Banion – Elverta #1 & #2 230 kV
- O’Banion – Elverta and O’Banion – Keswick 230 kV
- O’Banion – Elverta and O’Banion – Natomas 230 kV
- Olinda – Cottonwood #1 & #2 230 kV
- Olinda-Cottonwood 230 kV & Captain Jack-Olinda 500 kV
- Olinda-OBanion 230 kV & Olinda-Tracy 500 kV
- Rancho Seco – Bellota #1 & #2 230 kV
- Roseville – Elverta & Fiddymont – Elverta 230 kV
- Roseville – Elverta & Fiddymont – Roseville 230 kV
- Sutter-O’Banion – Keswick- O’Banion 230 kV
- Tracy – Hurley #1 & #2
- Tracy-Hurley 230 kV & Olinda-Tracy 500 kV
- Tracy – Tesla #1 & #2 230 kV
- Keswick – JF Carr #1 & #2 230 kV
- Over-lapping Tracy 500/230 kV transformer & Olinda 500/230 kV transformer
- Airport-CottonwoodX-FailAirport-1182
- Airport-CottonwoodX-FailAirport-2182
- Airport-CottonwoodX-FailCottonwood-352
- Airport-KeswickX-FailAirport-2082
- Airport-KeswickX-FailAirport-2086
- Airport-KeswickX-FailKeswick
- J.F.Carr #1-KeswickX-FailCarr-482-Whiskey
- J.F.Carr #1-KeswickX-FailKeswick-Whiskey
- J.F.Carr #1X-Keswick-FailCarr-482-Whiskey
- J.F.Carr #2X-Keswick-FailCarr-582-Whiskey
- J.F.Carr #2-KeswickX-FailKeswick
- Elverta1-HurleyX-FailElverta

- Elverta1-Hurley-FailHurley
- Elverta-RosevilleX-FailElverta
- Elverta-RosevilleX-FailRoseville-182
- Elverta-RosevilleX-FailRoseville-582
- Elverta2-HurleyX-FailElverta
- Elverta2-HurleyX-FailHurley
- ElvertaEAST-BUS
- Elverta-West-BUS
- Fiddymment-ElvertaX-FailElverta
- Fiddymment-ElvertaX-FailFiddymment-1182
- Fiddymment-ElvertaX-FailFiddymment-1582
- Fiddymment-RosevilleX-FailFiddymment-1182
- Fiddymment-RosevilleX-FailFiddymment-1482
- Fiddymment-RosevilleX-FailRoseville-782
- Fiddymment-RosevilleX-FailRoseville-1282
- Flanagan-KeswickX-FailFlanagan-182-fln-
- Flanagan-KeswickX-FailFlanagan-382-fln-
- Flanagan-KeswickX-FailKeswick-fln-Whiskey
- FolsomX-Lake-FailFolsom
- FolsomX-Lake-FailLake-5242
- FolsomX-Lake-FailLake-5236
- FolsomX-NIM-FailFolsom-562
- FolsomX-Orangevale-FailFolsom
- FolsomX-Orangevale-FailOrangevale
- FolsomX-Roseville-FailFolsom
- FolsomX-Roseville-FailRoseville-1182
- FolsomX-Roseville-FailRoseville-782
- Keswick-Redding#1X-FailKeswick-566
- Keswick-Redding#1X-FailRedding#1-3635
- Keswick-Redding#2X-FailKeswick-666
- Keswick-Redding#2X-FailEUR-3231
- KnaufX-Keswick-FailKeswick-462
- KnaufX-Keswick-FailKeswick-466
- KnaufX-Keswick-FailKnauf-TB42
- KnaufX-Keswick-FailKnauf-TB62
- LLL230-115-LLN424X-FailLLL230-115-662
- LLL230-115-LLN424X-FailLLN424-652
- LLL230-115-LLN424X-FailLLN424-952
- New Melones-BellotaX-FailBellota
- New Melones-BellotaX-FailNew Melones
- New Melones-WilsonX-FailNew Melones
- New Melones-WilsonX-FailWilson
- O'Banion-Elverta1X-FailElverta
- O'Banion-Elverta1X-FailO'Banion-1086
- O'Banion-Elverta1X-FailO'Banion-1182
- O'Banion-Elverta2X-FailElverta

- O'Banion-Elverta2X-FailO'Banion-2182
- O'Banion-Elverta2X-FailO'Banion-2086
- O'Banion-ElvertaSX-FailElvertaS
- O'Banion-ElvertaSX-FailO'Banion-A-4086
- O'Banion-ElvertaSX-FailO'Banion-A-4182
- O'Banion-KeswickX-FailKeswick-fln-Whiskey
- O'Banion-KeswickX-FailO'Banion-1082
- O'Banion-KeswickX-FailO'Banion-1086
- O'BanionX-Natomas-FailNatomas-400
- O'BanionX-Natomas-FailNatomas-410
- O'BanionX-Natomas-FailO'Banion-3086
- O'BanionX-Natomas-FailO'Banion-3182
- O'BanionX-Olinda-FailO'Banion-2082
- O'BanionX-Olinda-FailO'Banion-2086
- O'BanionX-Olinda-FailOlinda-186
- O'BanionX-Olinda-FailOlinda-286
- O'BanionX-Sutter-FailO'Banion-3082
- O'BanionX-Sutter-FailO'Banion-3086
- O'BanionX-Sutter-FailSutter
- Olinda1X-Cottonwood-FailCottonwood-332
- Olinda1X-Cottonwood-FailOlinda-282
- Olinda1X-Cottonwood-FailOlinda-286
- Olinda2X-Cottonwood-FailCottonwood-332
- Olinda2X-Cottonwood-FailOlinda-182
- Olinda2X-Cottonwood-FailOlinda-186
- OlindaX-Keswick-FailKeswick-fln-Whiskey
- OlindaX-Keswick-FailOlinda-282
- OlindaX-Keswick-FailOlinda-386
- Round MountainX-Cottonwood1-FailCottonwood1
- Round MountainX-Cottonwood1-FailRound Mountain
- RosevilleX-Cottonwood-FailCottonwood-362
- RosevilleX-Cottonwood-FailRoseville-284
- RosevilleX-Cottonwood-FailRoseville-382
- Spring CreekX-Keswick-FailKE
- Spring CreekX-Keswick-FailSpring Creek
- ShastaX-Cottonwood1-FailCottonwood
- ShastaX-Cottonwood1-FailShasta
- ShastaX-Cottonwood2-FailCottonwood
- ShastaX-Cottonwood2-FailShasta-A
- ShastaX-Flanagan-FailFlanagan-482
- ShastaX-Flanagan-FailFlanagan-282
- ShastaX-Flanagan-FailShasta
- TrinityX-Carr-FailCarr-Whiskey
- TrinityX-Carr-FailTrinity-982
- TrinityX-Carr-FailTrinity-1082
- Tracy1X-Hurley-FailHurley

- Tracy1X-Hurley-FailTracy
- Tracy2X-Hurley-FailHurley
- Tracy2X-Hurley-FailTracy
- TracyX-LLL-FailLLL
- TracyX-LLL-FailTracy
- TracyX-Tesla1-FailTesla
- TracyX-Tesla1-FailTracy
- TracyX-Tesla2-FailTesla
- TracyX-Tesla2-FailTracy
- TracyX-Wesley1-FailTracy
- TracyX-Wesley1-FailWesley-2358
- TracyX-Wesley1-FailWesley-2359
- TracyX-Wesley2-FailTracy
- TracyX-Wesley2-FailWesley-2361
- TracyX-Wesley2-FailWesley-2362
- ElvertaERTA-BUS-TIE-182
- Tracy-BUS-TIE-1082
- ElvertaERTA-BUS-TIE-1182
- Cottonwood 472 stuck BKR
- Cottonwood 482 stuck BKR

Note: An X indicates location of the fault applied

Extreme event resulting in two or more (multiple) elements removed of Cascading out of service – NERC Level D

- Sutter Power Plant Units 1, 2, and 3 entire power plant outage
- Shasta – Cottonwood #1 & #2 and Shasta – Flanagan and Flanagan – Keswick 230 kV
- Keswick – Airport and Flanagan – Keswick and Keswick – Olinda and Keswick – O’Banion
- Keswick – Olinda and Keswick – O’Banion and Shasta – Cottonwood #1 & #2
- Cottonwood – Olinda #1 & #2 and Shasta – Cottonwood #1 & #2 230 kV and Captain Jack – Olinda 500 kV
- Cottonwood – Olinda #1 & #2 and Keswick – O’Banion 230 kV and Captain Jack – Olinda 500 kV
- Cottonwood – Olinda #1 & #2 and Keswick – O’Banion 230 kV and Olinda – Tracy 500 kV
- O’Banion – Elverta #1 & #2 and Cottonwood – Roseville 230 kV
- Cottonwood – Roseville and Roseville – Elverta and Fiddymment – Elverta 230 kV
- O’Banion – Elverta #1 & #2 and Roseville – Elverta and Fiddymment – Elverta 230 kV
- Tracy – Hurley #1 & #2 230 kV and Olinda – Tracy 500 kV

In addition, circuit breaker failure was analyzed for each of the following substations. For some, the failure of a circuit breaker to clear a faulted transmission line resulted in the outage of two lines. In some cases, failure of a circuit breaker to open resulted in the outage of multiple transmission lines and part or all of one voltage level at a substation. In addition, some of the outages

modeling failure of a circuit breaker to open also included failure of the primary protection system and therefore the dynamic stability simulation included a longer period of time to clear the fault as well as the impacted transmission, generation and substation facilities.

- Airport 230 kV
- JF Carr 230 kV
- Elverta 230 kV
- Fiddymment 230 kV
- Flanagan 230 kV
- Folsom 230 kV
- Keswick 230 kV
- O'Banion 230 kV
- Olinda 230 kV
- Roseville 230 kV
- Shasta 230 kV
- Tracy 230 kV