System Inertia Impact Due to High-Renewable Penetration

Final Presentation

Cal State LA Team:

Michael Carbajal
Kimberly Guido
Shuoran Liang
Manuel Rodriguez
Mayra Silva
Alexis Vargas

Faculty Advisor and Liaison:

Ayman Samaan PE MSEE

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Senior Design

SOUTHERN CALIFORNIA EDISON

Agenda

- Project Objective & Background
- Programmatic
- Case Development
- Case Study Analysis
- Economic Study
- Conclusion

Project Objective

Objective:
California passed the Senate Bill 100, targeting 100% carbon-free electricity by Dec 31, 2045. A study was conducted to simulate a high renewable impact study using PowerWorld Simulator software to provide a suitable recommendation that would help reduce greenhouse gasses into the atmosphere.

Team will Identify :

- Threshold for renewable penetration that can be connected in the CA system

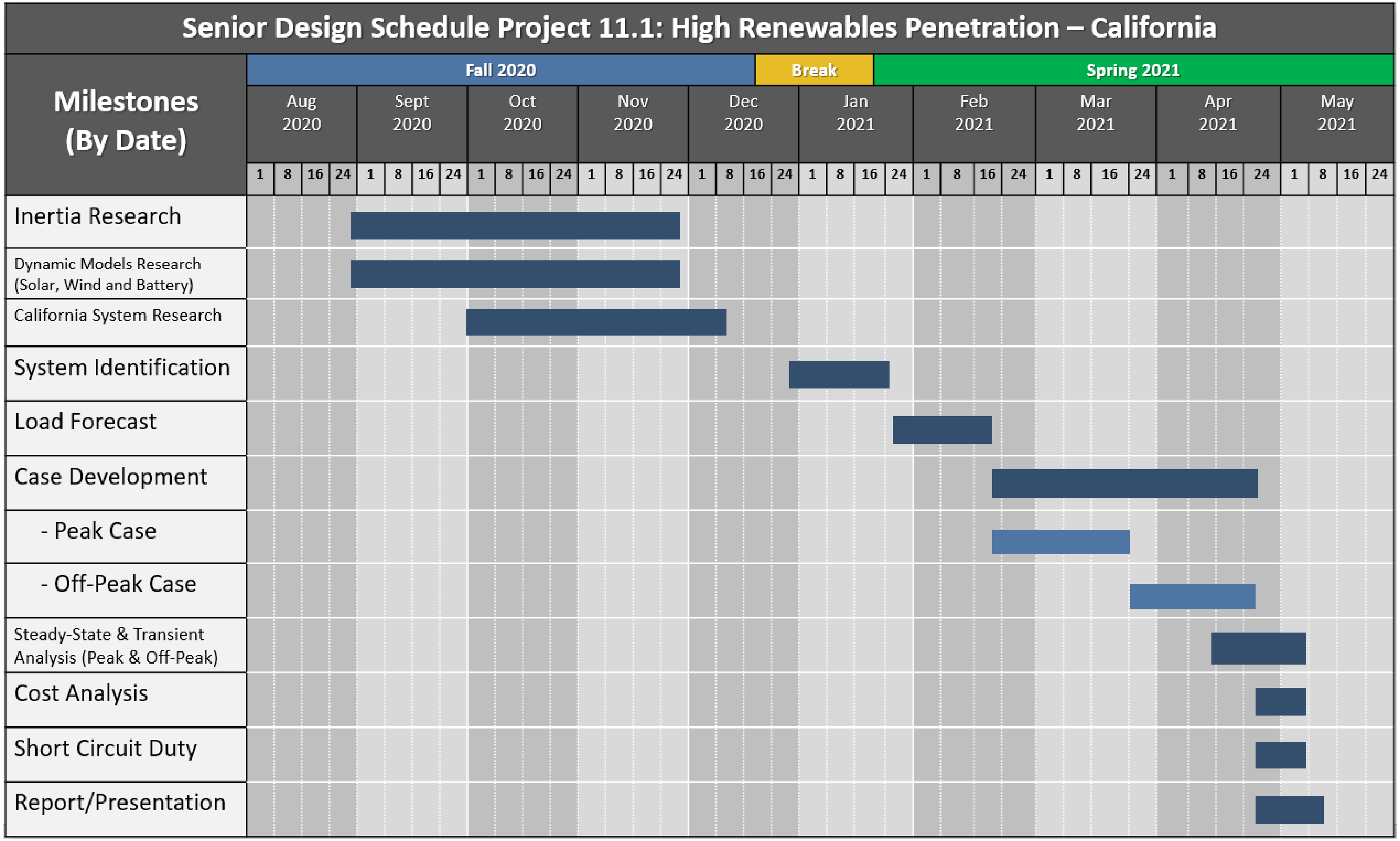
- Balance of load and resources for the on and off-peak case

- Impact of change in short circuit duty

- Evaluate the Cost and System upgrades needed

Work Breakdown Structure

- Study and Learn the existing case
- Determine the Case Assumption
- Identify the System Study scenarios
- Develop cases (on and off-peak cases)
- Short circuit duty
- Economic Analysis


Senior Design Schedule Project 11.1: High Renewables Penetration – California
Milestones (By Date)
Fall 2020
Break
Spring 2021
Aug 2020
Sept 2020
Oct 2020
Nov 2020
Dec 2020
Jan 2021
Feb 2021
Mar 2021
Apr 2021
May 2021
1 8 16 24
Inertia Research
Dynamic Models Research (Solar, Wind and Battery)
California System Research
System Identification
Load Forecast
Case Development
- Peak Case
- Off-Peak Case
Steady-State & Transient Analysis (Peak & Off-Peak)
Cost Analysis
Short Circuit Duty
Report/Presentation

Project Background

- Importance of System Inertia

- Renewable Energy & Inverter-Based Resource

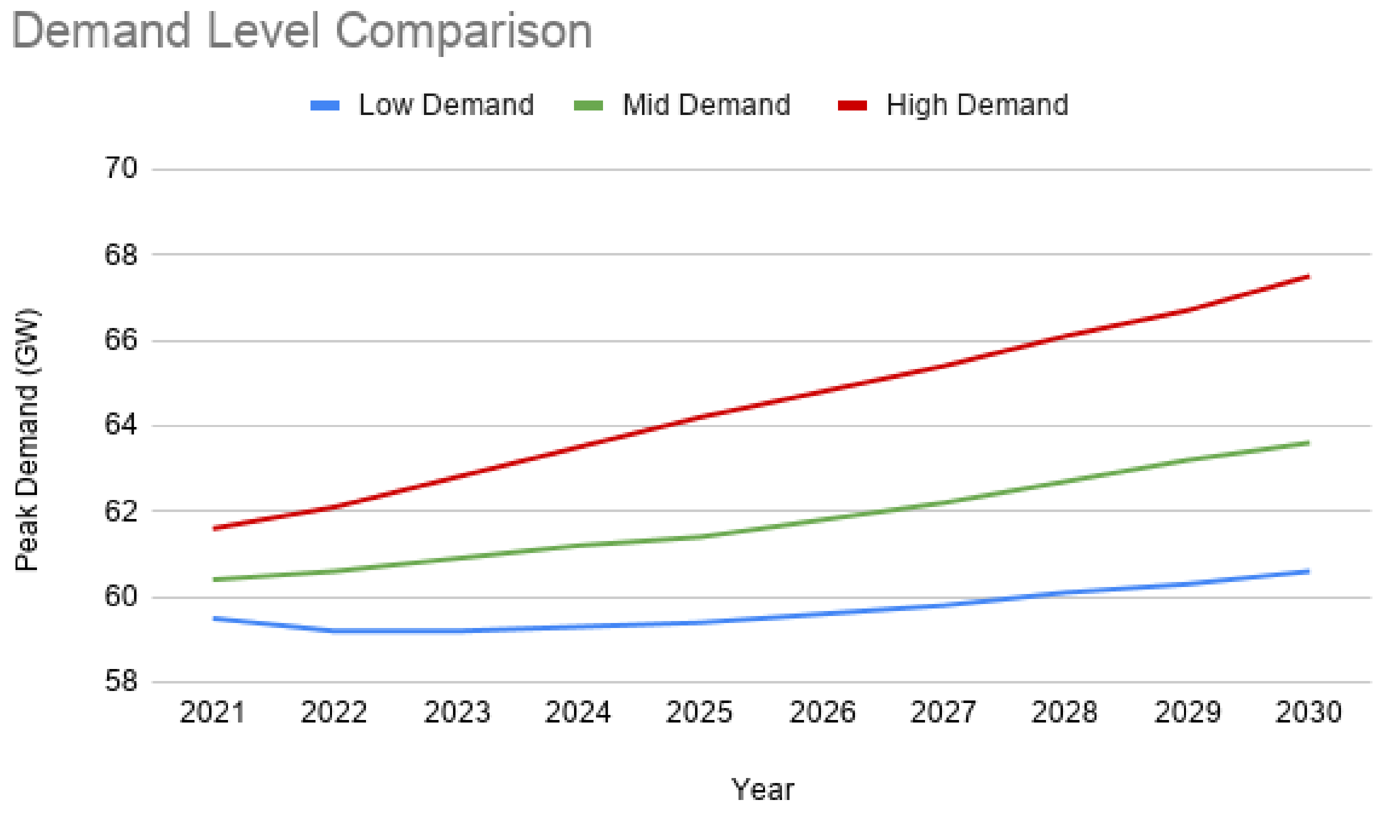
-WEEC & NERC System Performance Requirements

2017 California Electric Grid

In this case we see:

- Existing TL, Load, and Generation
- Solved existing issues before modifying the case to 2045
- load and gen in this case to see if it meets the 2045 load forecast

2045 Load Forecast



The 2045 forecasted load was referenced from a 10-year planning horizon provided from the California Energy Commission.

The California Mid-Demand load forecast included:

- Economic & demographic data
- Transportation electrification
- Self-generation
- Electricity rates
- Climate change impact

2045 Load Forecast (Cont.)

$$F = P(1 + i)^{n}$$

Calculation:

$$1 + i = \left(\frac{F}{P}\right)^{\frac{1}{n}} = \left(\frac{63637\ MW_{\ Year\ 2030}}{60495\ MW_{\ Year\ 2021}}\right)^{\frac{1}{9\ years}} = 1.005642$$

Annual Load Growth Factor:

$$F = P(1.005642)^{28\ years} = P(1.170618)$$

Case Modification

- From the equation used, we determined to compensate for 11 GW growth from 67 GW (2017) to 78 GW (2045).

- To simulate California's 2045 peak demand case, the totality of the supply and demand of the power system was monitored by observing the slack bus.

Existing Generator Type	Power Generated (GW)
Natural Gas	39.5
Coal	0.4
Nuclear	0
Water	8.3
Solar	5.2
Wind	3.9
Imports	10.5
Total	**67.8**

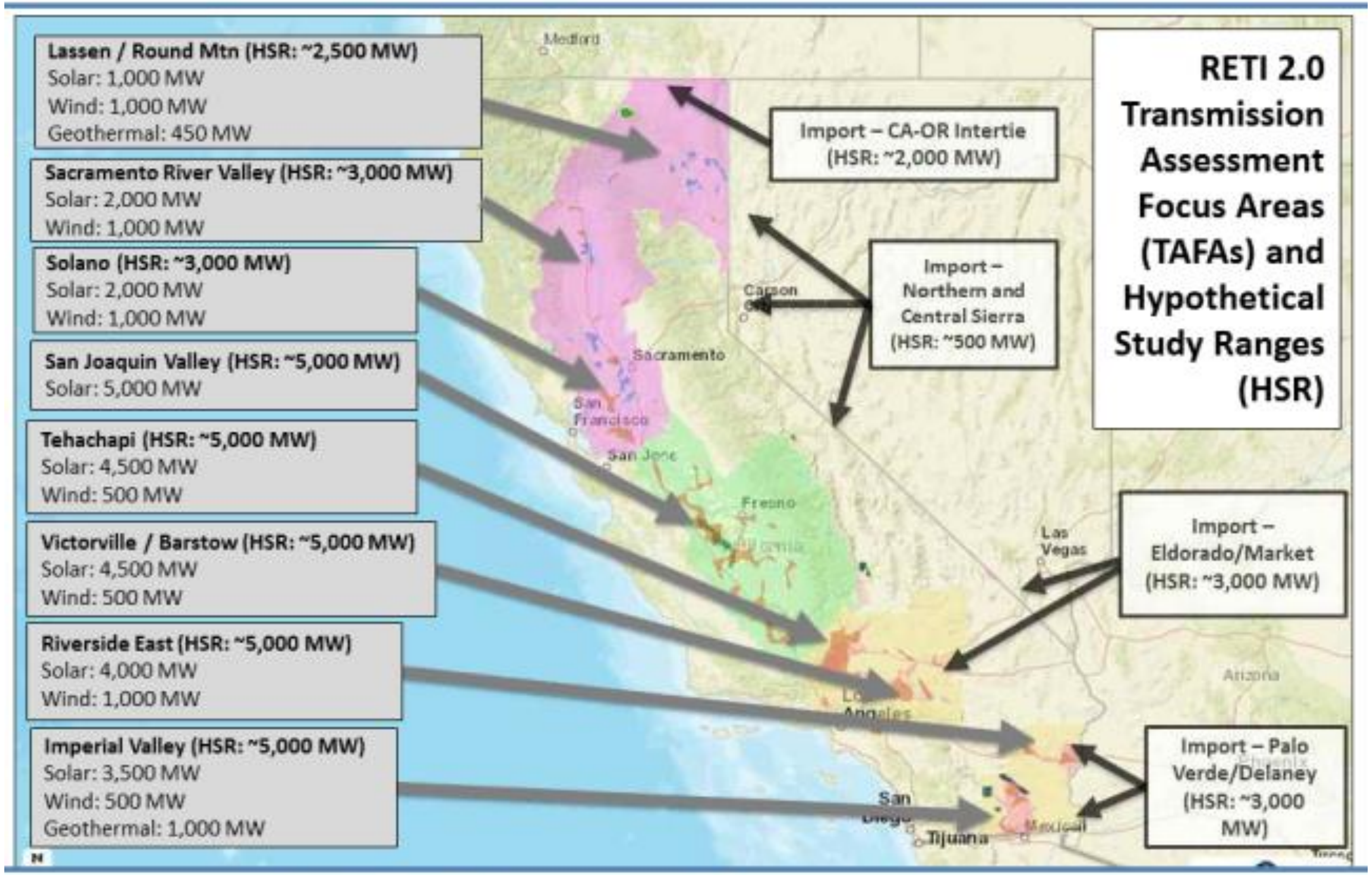
California Renewable Energy

- The Renewable Energy Transmission Initiative shows us the locations of where the different types of new renewable construction were appropriate.

- The team decided to model solar photovoltaic and battery storage units for simulation.

- A total of 10 GW of solar and 30.6 GW of battery energy storage models were newly added in the simulation.

In-state and import-export TAFA map



California Public Utilities Commission
California Energy Commission
California ISO

New Renewable Resources

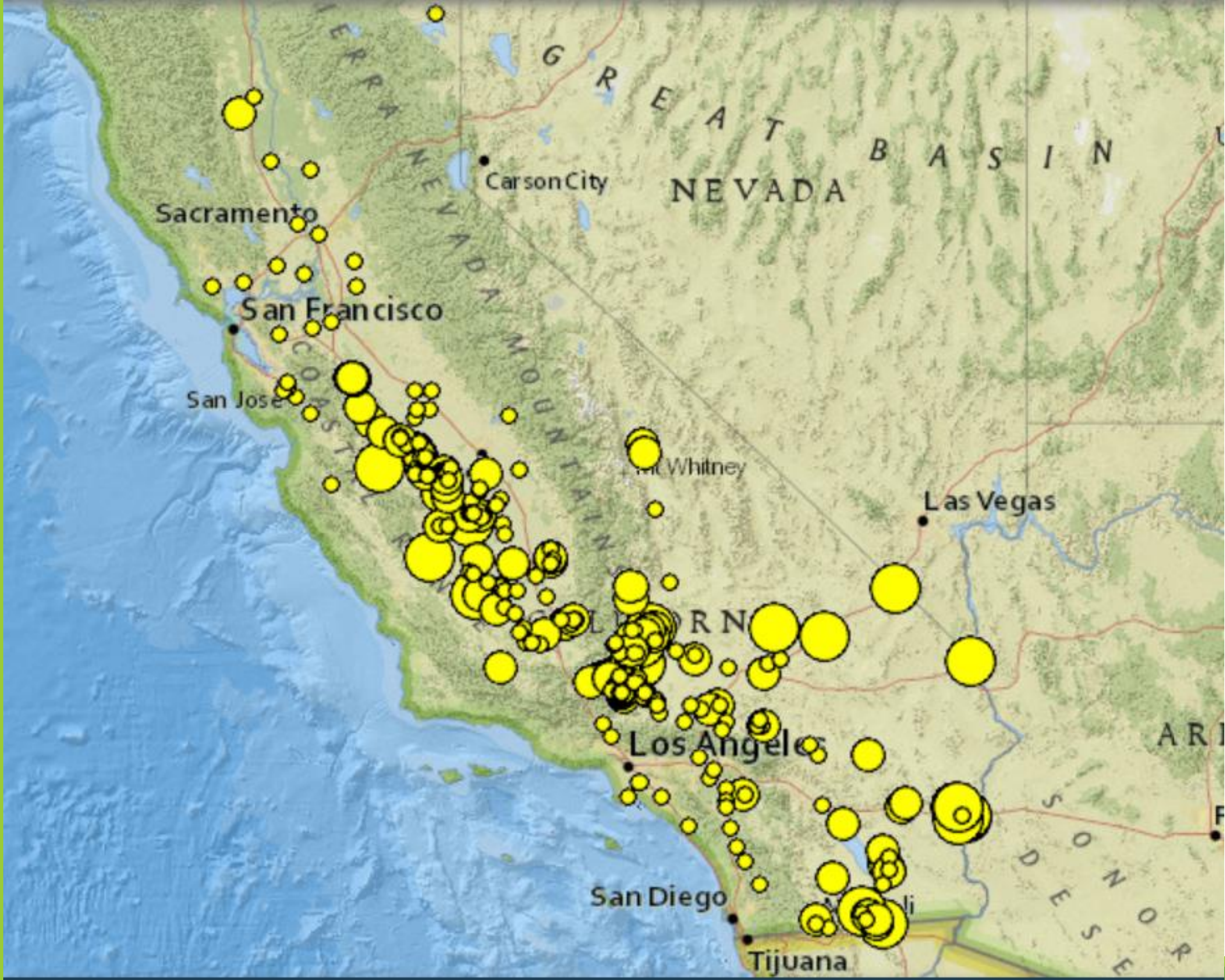
- The team modeled new photovoltaic generation according to this map.

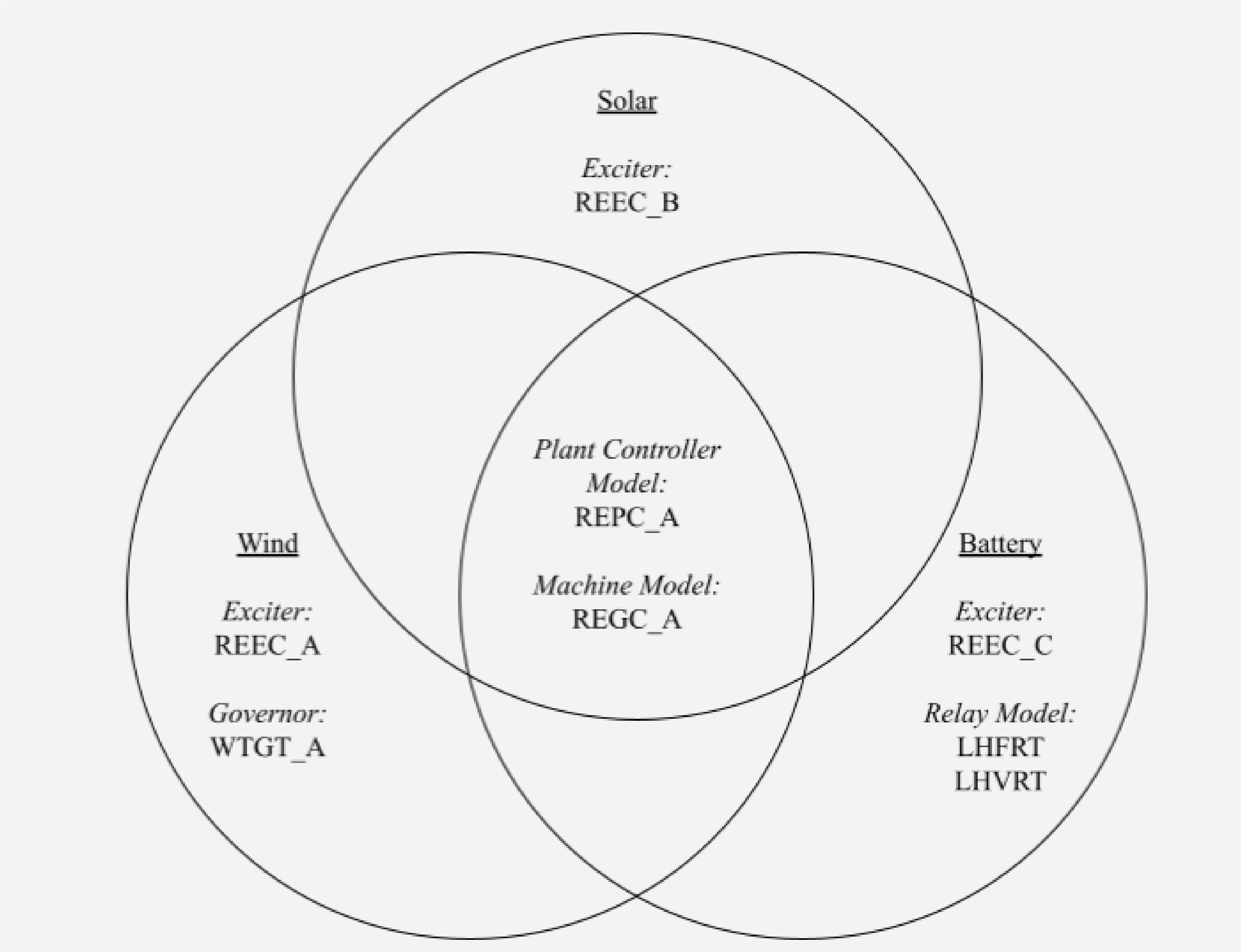
- New battery storage were modeled mostly in urban areas since photovoltaic generation was not appropriate.

Photovoltaic CEC

Displaying: MW

- 1 - 20 MW
- 21 - 200 MW
- 201 - 2,400 MW



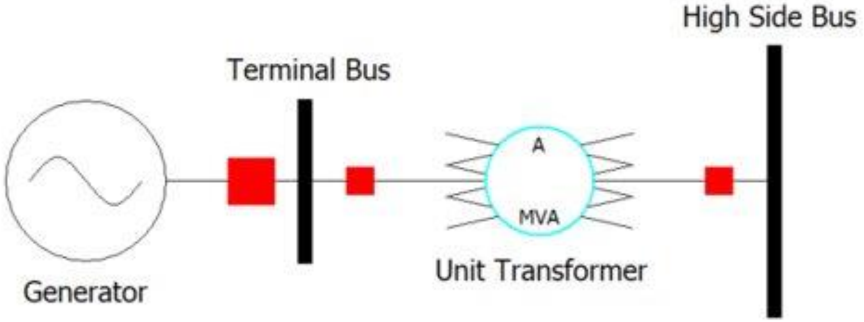


Generator Modeling

- Dynamic Modeling

- Generic WECC Models

- Real and Reactive Power Parameters



Case Study Analysis

Steady-State Analysis

Transient Analysis

Fault Analysis

Steady-State Analysis

- Evaluated the system under normal condition to ensure system reliability

- Conducted a contingency analysis to identify system violation in accordance with the NERC requirement TPL-001-4

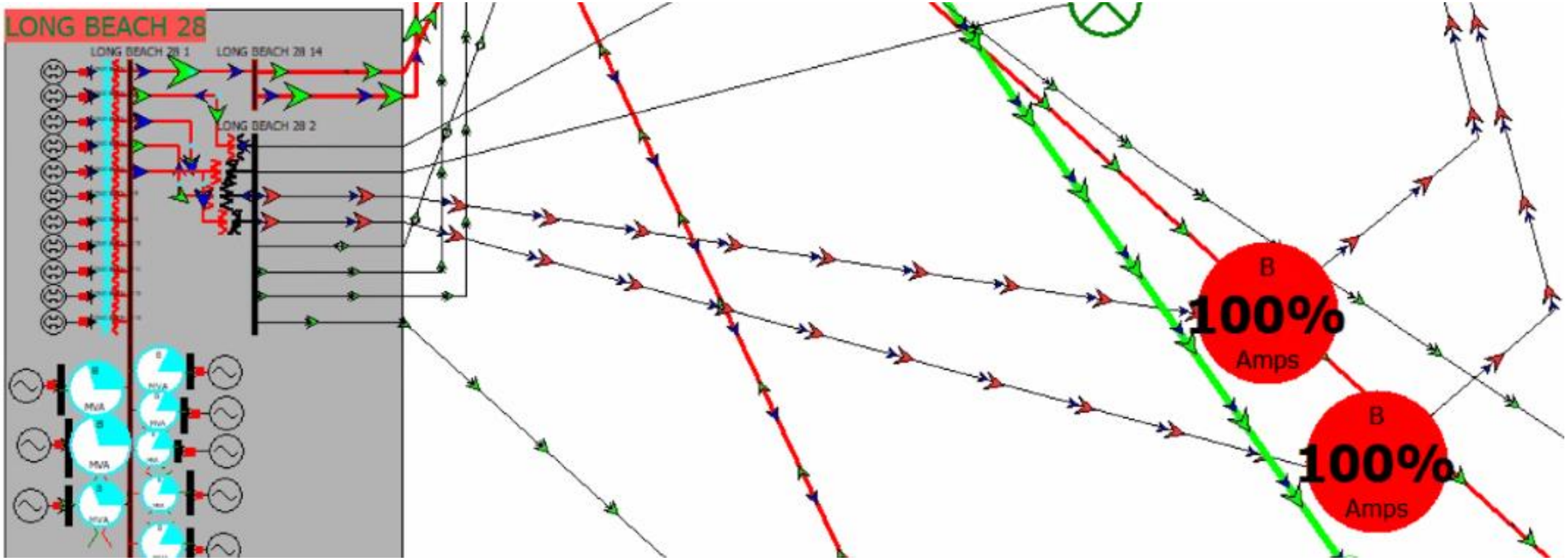
  -Bus Voltage within (0.9 - 1.1 P.U Voltage)

  -Power Flow on the Transmission Lines / Transformer within rating limits

    - Limit A: Normal (Continuous) Rating

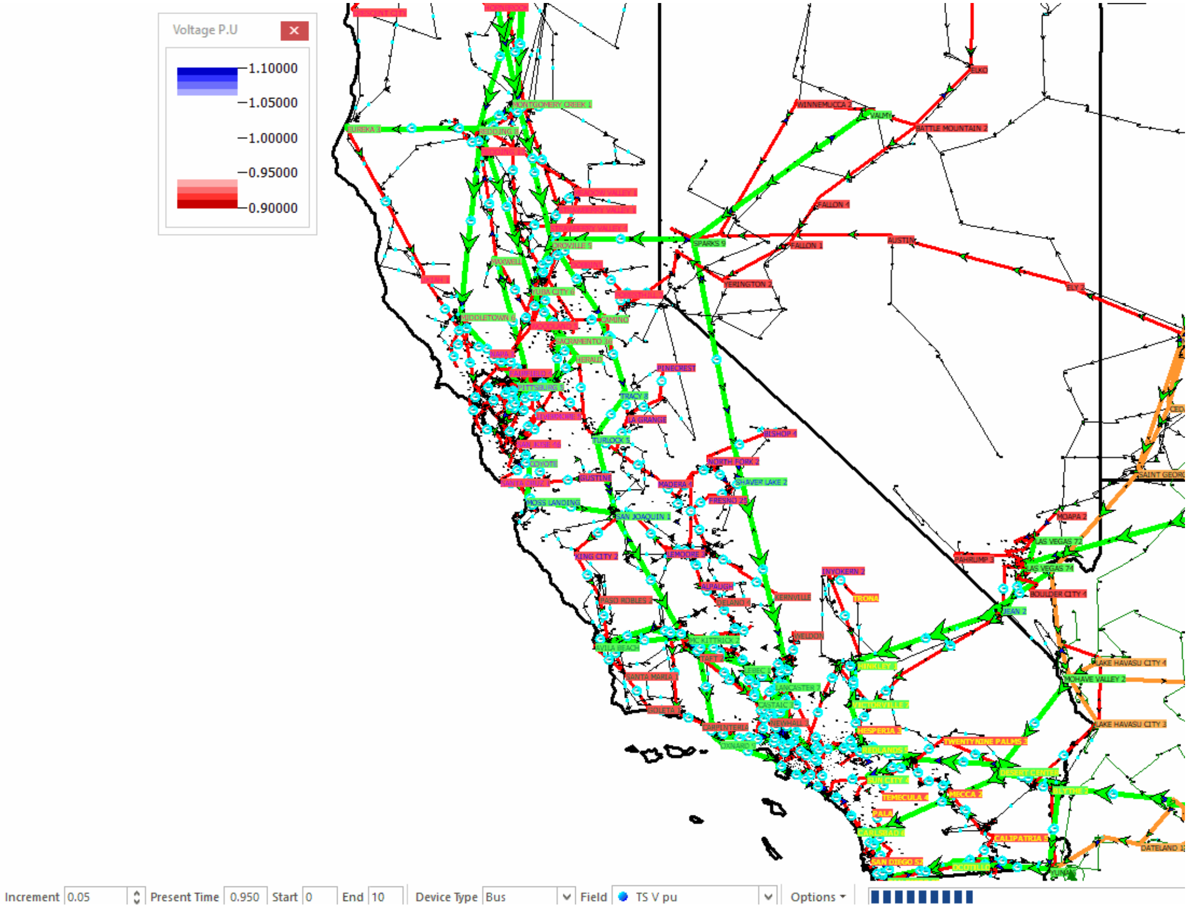
    - Limit B: Emergency Rating (Approximately 130% Limit A Rating)

Transmission Overload Due to a Contingency



An example of 2 Transmission Line Violations due to a line outage.

Bus Voltage P.U. during Contingency



- This visual is an example of how a bus (e.g., substation facility) is to rise/decrease in P.U. Voltage during a contingency.

Battery Storage as a Solution

- Battery resources utilized in areas where solar projects are not available.

- Battery resources were mainly used in congested areas and used as solution to mitigate etc...

- Battery helps solve power flow issues. These issues include Low Bus Voltage and Overloaded Transmission lines.

Proposed Solution for Violations

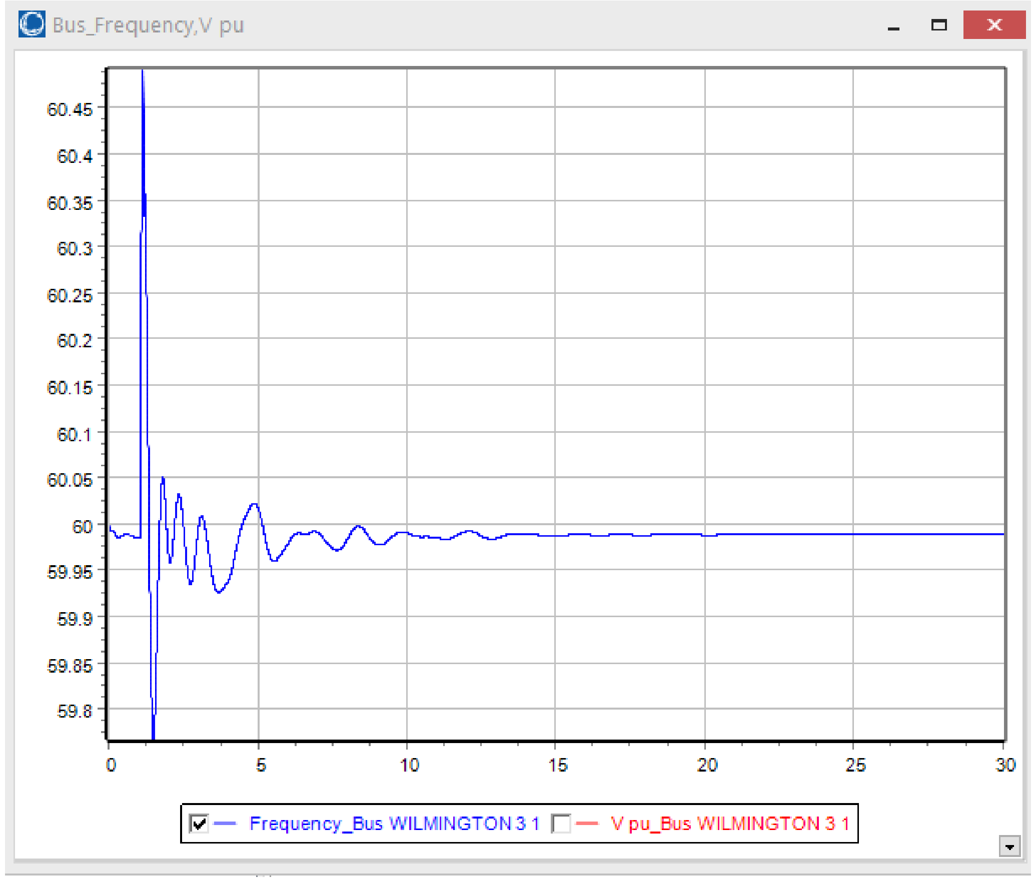
Violations by type and solutions to mitigate them:

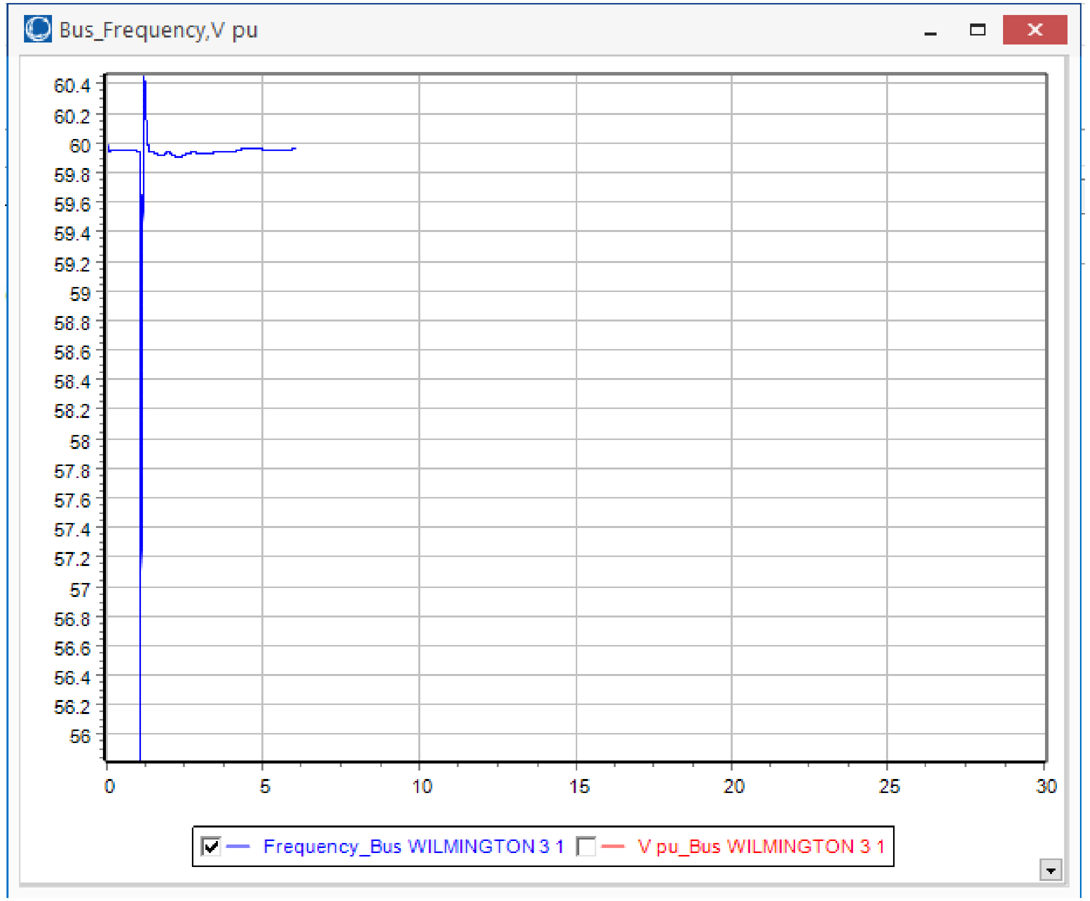
- 82 Voltage Violations (These included Low/High Voltage)
  - Fixed with 32 Shunts.
  - Fixed with 11 Batteries
- 112 Transmission Line overloads (Over the Limit B's Rating)
  - Fixed with 36 Double circuit Lines.
  - Fixed with 17 Batteries.

Transient Analysis

- Tests whether a power system can return to a stable state after major interruption.
- In our case we simulated a fault to occur at 50% of our most critical transmission lines.
- Helped us determine when our case is most reliable by testing frequency on critical bus.

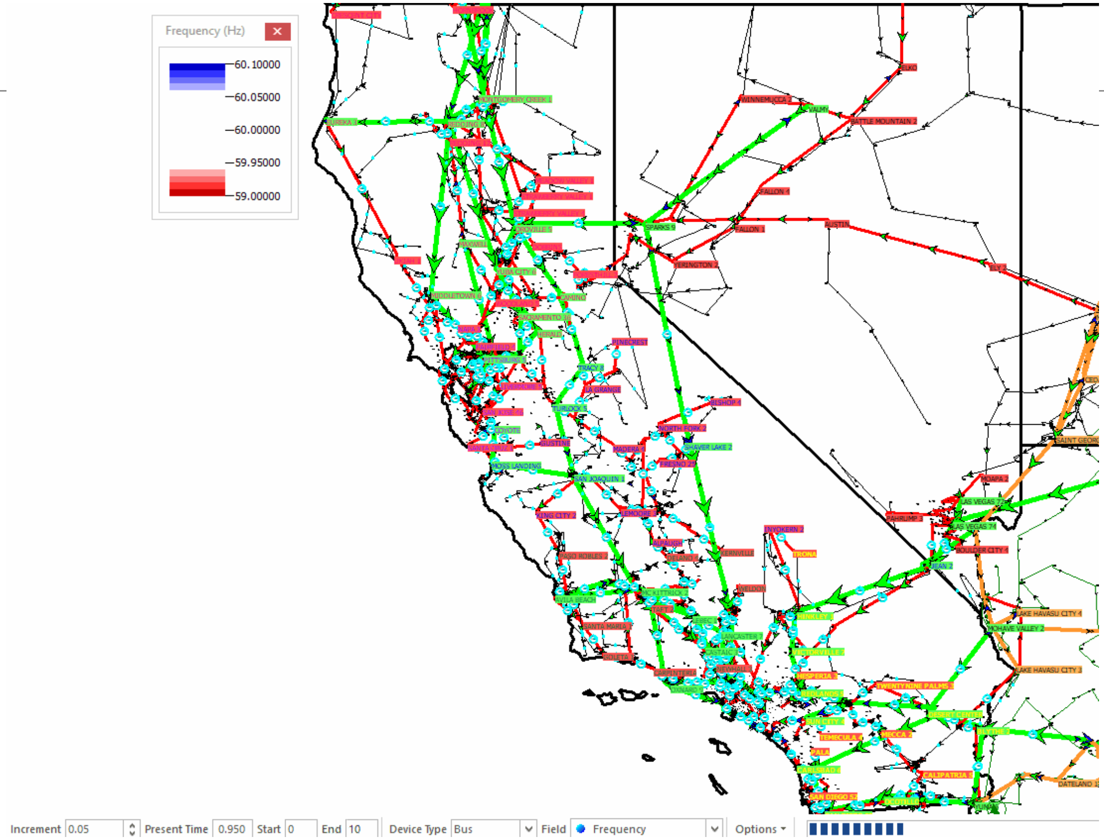
Frequency results after inserting fault on 765kV line





80% vs 81% renewable penetration with same fault inserted.

Peak Case



Frequency Stability in California after inserting line fault

Off-Peak Case

- The off peak case represent 2:00 AM during Winter, it has a lighter load than peak time.
- The off-peak case would going to be 40% of load from the peak case.
- Solar PV generator will not be available.
- Battery that is supporting the system during peak time will be in charging mode.

Off-Peak Case

Off-Peak Load (GW)	
Load in the case	31.2
Charging mode Batteries	11.1
Total Load	42.3

Off-Peak Generation (GW)	
Renewable energy	16.7
Gas Units	12.1
Intertie from other states	11.5
Battery	2
Total Generation	42.3

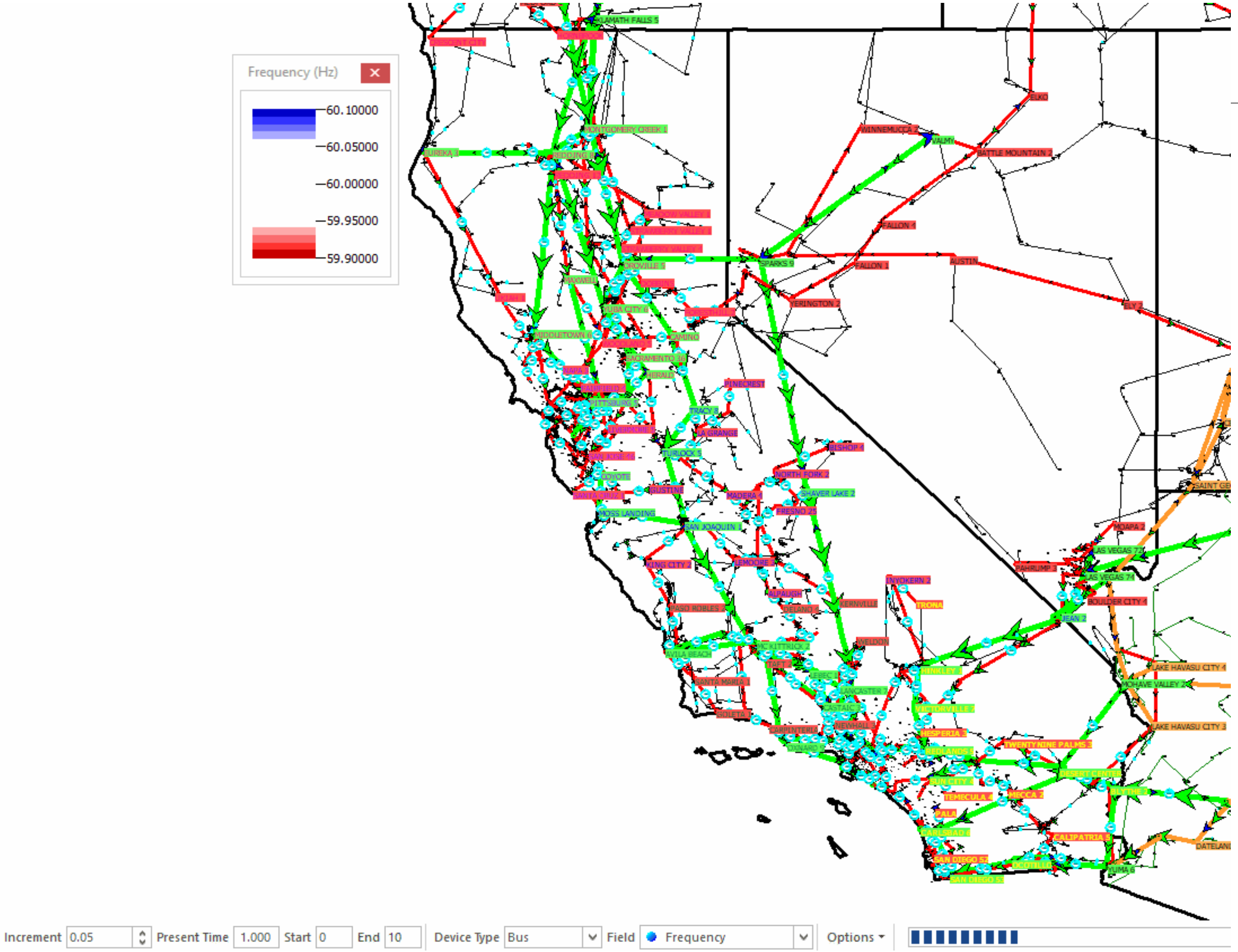
The battery will act like a load during charging mode.

All the battery in the same bus will be combined into one load.

Battery storage supporting during off-peak time to balance the load and resources.

During off-peak season, the renewable energy mix can go as high as 72% and still need to have 28% of Gas Unit.

Off-Peak Transient Study

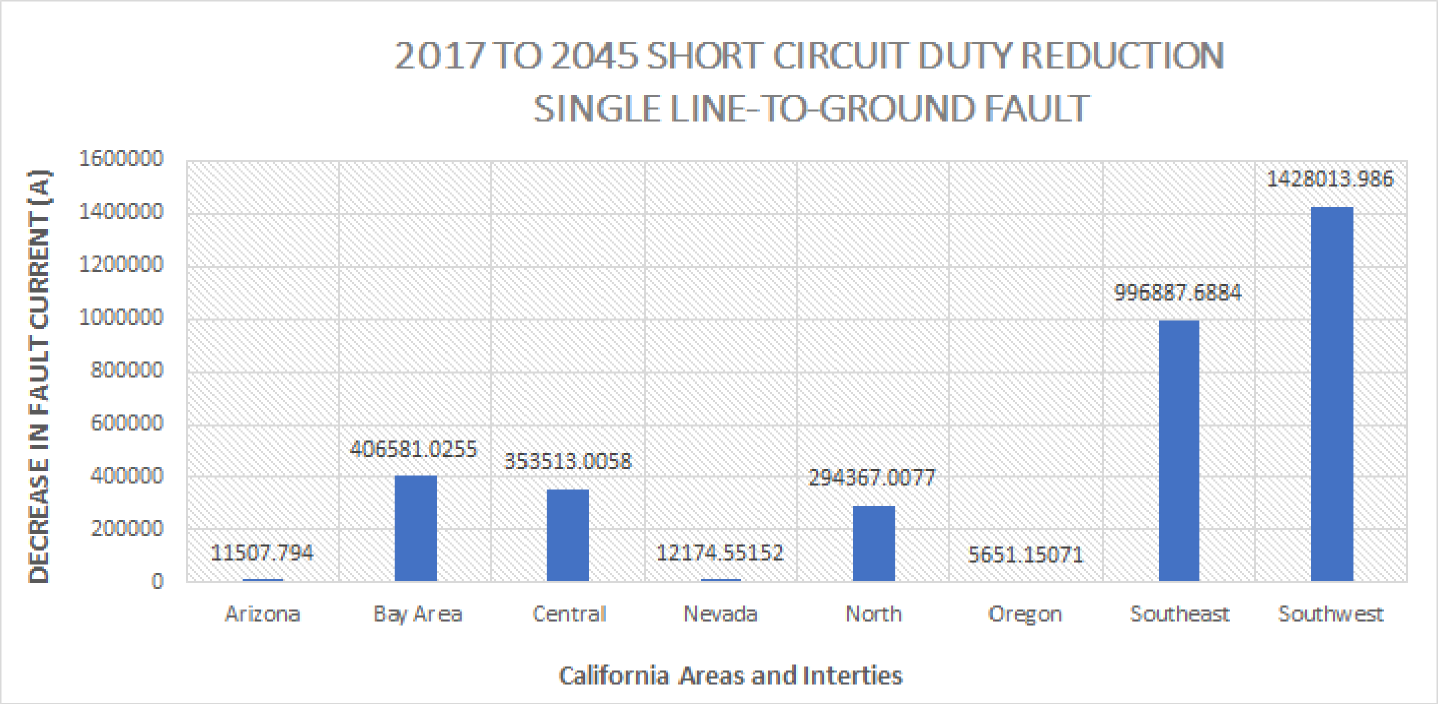


Frequency stability after inserting line fault

Fault Analysis – Short Circuit Duty

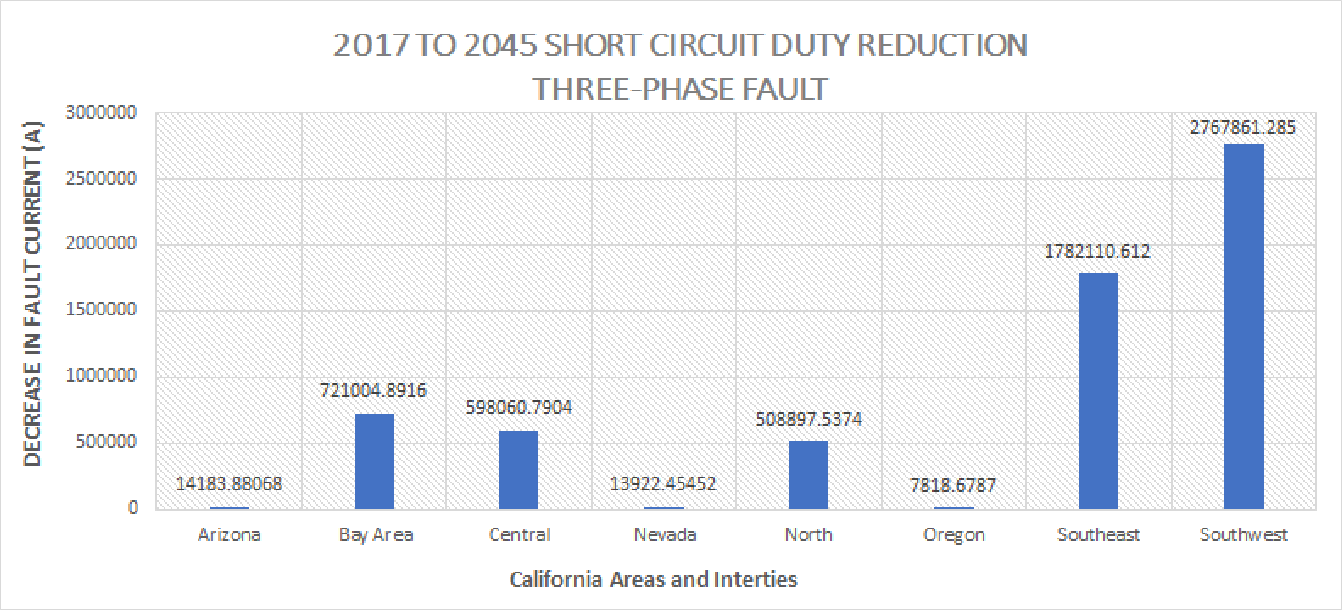
Area	2017 Single Line-to-Ground Current Mangitude (A)	2045 Single Line-to-Ground Current Mangitude (A)	Single Line-to-Ground Current Change (A)
Southwest	110448.1867	93144.66472	17303.52202
Southwest	86378.19777	73987.15999	12391.03778
Southwest	86378.19777	73987.15999	12391.03778
Southwest	68078.38169	57268.0993	10810.28239
Southeast	43870.28268	33522.54096	10347.74172

- What is a SLG Fault?
  - Most common type of faults & least disruptive
- Why is it important to us?
  - Testing if the protection settings are suitable for a high-renewable grid
- What do these graphs mean?
  - Southeast & Southwest need better protection relay settings



Fault Analysis – Short Circuit Duty

Area	2017 Three-Phase Current Mangitude (A)	2045 Three-Phase Current Mangitude (A)	Three-Phase Current Change (A)
Southwest	105000.3097	82419.4403	22580.86943
Southwest	79550.44618	64394.88415	15155.56203
Southwest	79550.44618	64394.88415	15155.56203
Southwest	80623.58606	66824.65131	13798.93475
Southwest	80623.58606	66824.65131	13798.93475



- What is a 3-Phase Balanced Fault?
  - Most critical fault, least common fault
- Why is it important to us?
  - Yields highest short-circuit current values
- What do these graphs mean?
  - Southeast & Southwest need better protection relay settings

Fault Analysis Conclusion

-California areas such as Southeast and Southwest have a total reduction of 1.7 GA and 2.7 GA.

-Short circuit analysis showed a decreased fault current in the areas where the gas resources were mostly retired

-We recommend **Southeast** and **Southwest** areas need further review in regards to the protection settings.

Transmission Line & Voltage **Total**

- To achieve a 2045 goal was determined that the system will require the addition of 36 new transmission lines along with a few shunt capacitors and reactors for a cost of $20 Billion.
- The study also included the additional voltage support will be required for a total of 32 cap banks and 8 SVCs for a total cost of $32 Million.
- The final overall cost is $40 Billion. The team utilized both the 2021 PG&E and SCE Proposed Generator Interconnection Unit Cost Guide found on the CAISO website.

Conclusion

- On-Peak :

80% is the threshold for Renewable Penetration

- Off-Peak :

Stagger the battery charging in the case

- Short Circuit Duty:

Further evaluation in protection setting for the SE and SW areas of CA

- Renewable Dynamic Model:

Need further improvement to represent the actual generator model

- Cost Analysis:

Total of$40 Billion

Thank you for your time.