ECEN 615 FALL 2025 DESIGN PROJECT: SOLUTION

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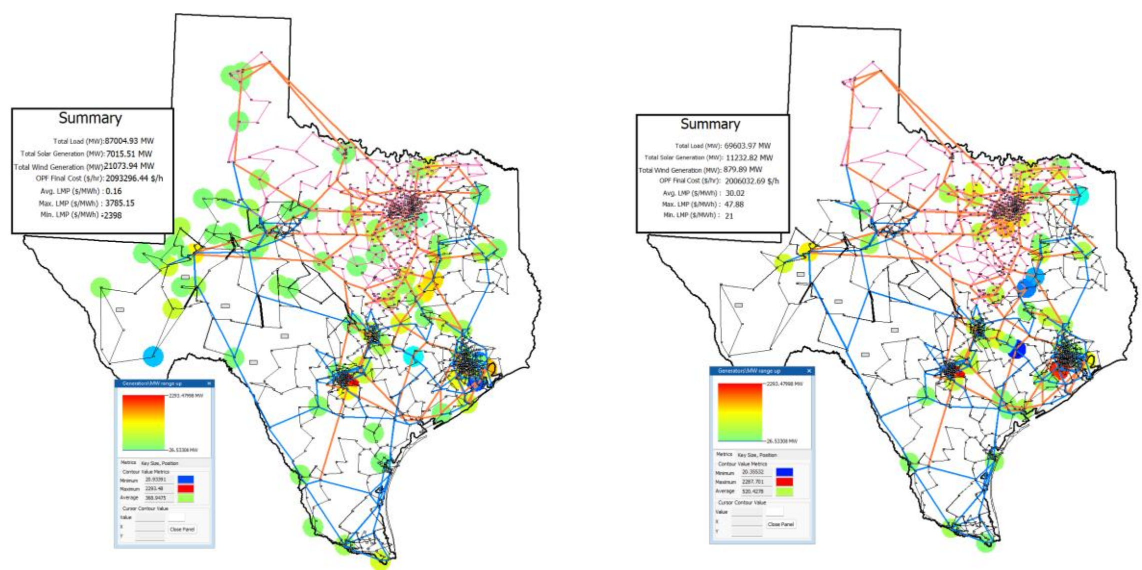
Introduction and Initial Exploration

The general approach I took to this design project was to first try to understand the Texas 2k bus system a little better, and gain an understanding of the best places to interconnect the new loads. Then, I took a look at a few alternative different design approaches and evaluated them based on the estimated cost. Finally, I picked the alternative that looked best, set up all of the new equipment, and made design tweaks until all of the scenarios + contingencies were satisfied.

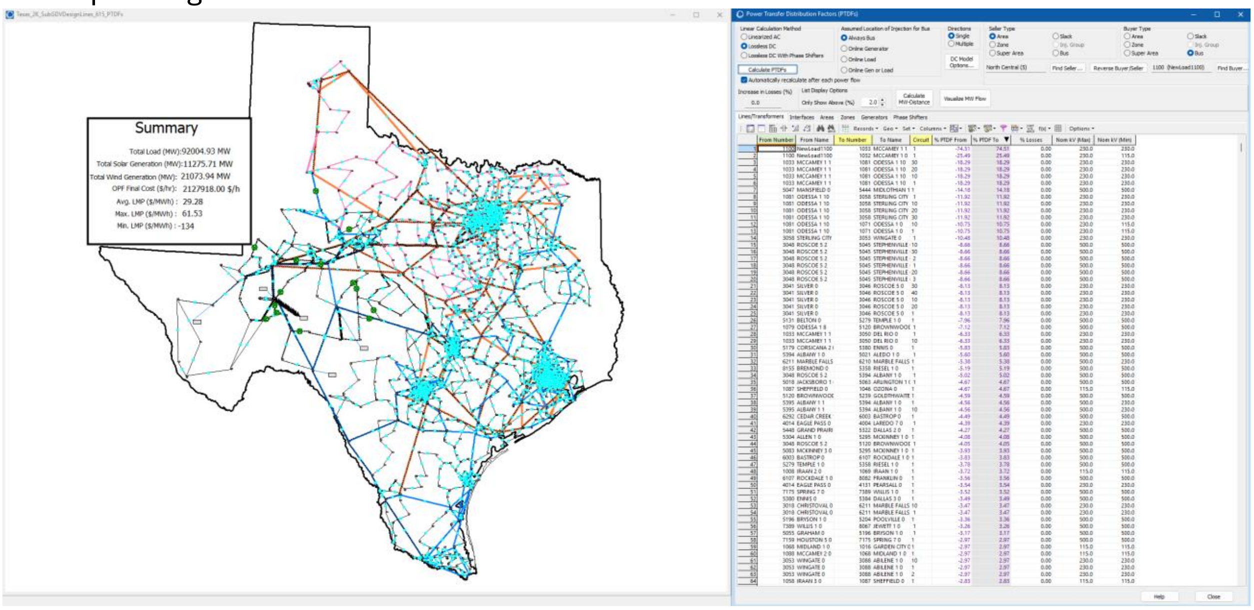
The first question I wanted to answer was, where is all this generation for these loads going to come from? By contouring the available Generation MW range up across the four different scenarios, I was able to get a better idea of where the available MWs might come from. Here is what that contouring looked like for the first two cases, A and B:



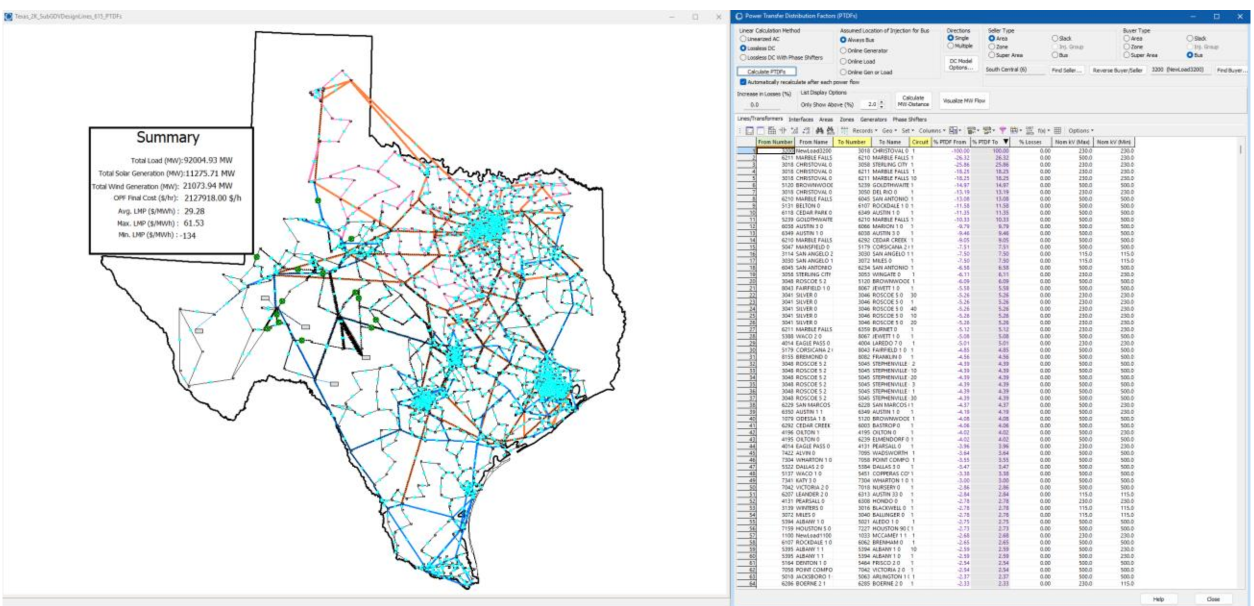
Gen MW Range Up Contours, Scenarios A and B

From looking at these cases, it was quickly apparent that most available generation was going to be coming from these areas: North Central, South Central, and Far West. I also noticed a lot of the Far West generation was renewable, so it would be important to have other resources available for the scenarios when those generators were producing less.

Next, I tried to get a feel for where most of this power would be flowing in from for each of these different areas, both in terms of the transmission lines as well as the most promising substations to expand and hook into for the new loads. I did this by doing a simple connection of each load to its nearest substation, and then running PTDFs for each load, importing from each of the 3 different areas. A couple of examples for a load and its corresponding area PTDFs are below:



PTDF, Load: 1100, Area: North Central



PTDF, Load: 3200, Area: South Central

The pattern from these PTDFs seemed to indicate the high utilization of the existing 500kV lines running East to West through North Texas (no big surprises there), as well as some of the 230kV lines coming from the South and East. From these PTDFs it became clearer that the major substations that would make the most sense to connect to would be ODESSA, CHRISTOVAL, and DEL RIO.

Comparing and Choosing a Transmission Buildout Strategy

I considered a few different ways of approaching the new transmission buildout:

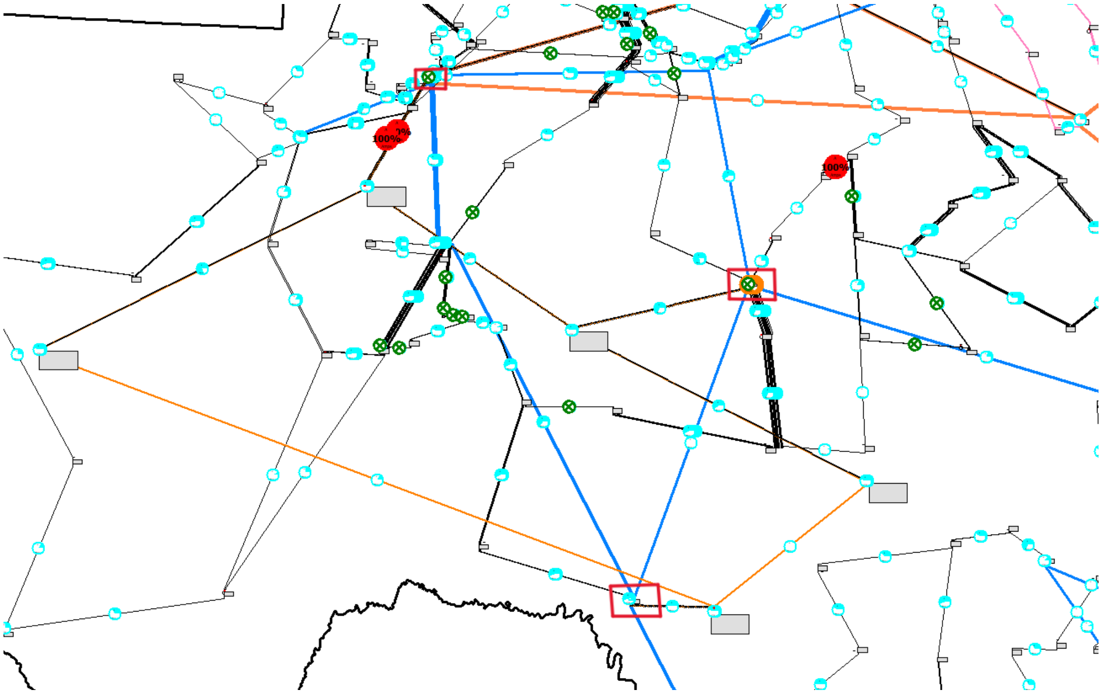
1. Connect each load to the best available substation and continue to reinforce, adding transmission where needed
2. Hub-and-spoke model: build a large central substation to send transmission to from the 3 major substations in the area, and connect out to each new load substation
3. Build a high capacity 500kV closed loop ring or transmission corridor

I decided against the additive approach, #1, because it wasn't quite clear how to calculate what the estimated cost might be before I started building, and seemed a little riskier (I did end up with a final solution that looks similar to what you might come up with using this approach, I just found it easier to pick a clear starting point and subtract elements to optimize). Comparing the Hub-and-Spoke model to the 500kV loop, I came to the conclusion that the loop would be cheaper (and also easier to optimize). I also was concerned that a Hub-and-Spoke approach would result in a single point of failure with one large substation, not great from a reliability standpoint. Here are the estimated costs, calculated from rough area estimates of the load spacing, alongside the final actual costs:

Component	**Hub-and-Spoke (Estimate)**	**500 kV Closed Loop (Estimate)**	**500 kV Closed Loop (Actual)**	**500 kV Open Loop (Actual)**
Substations	$14,000,000.00	$70,000,000.00	$56,000,000.00	$56,000,000.00
Transformers	$72,000,000.00	$120,000,000.00	$168,000,000.00	$168,000,000.00
Transmission Lines	$3,631,000,000.00	$3,040,000,000.00	$3,016,200,000.00	$2,739,600,000.00
Total Capital Cost	$3,717,000,000.00	$3,230,000,000.00	$3,240,200,000.00	$2,963,600,000.00

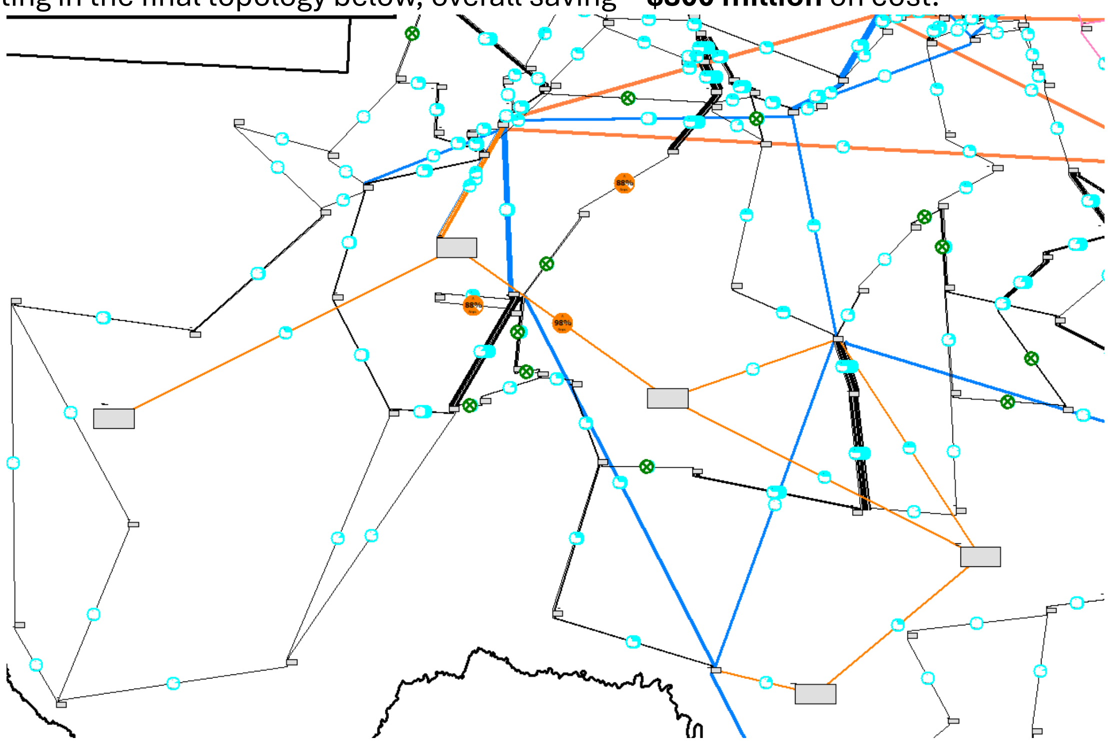
Design and Simulation Results

The design approach I took was to first upgrade all of the load substations to accept 500kV, and made sure to add 2 transformers per upgrade to cover N-1 contingencies. I then upgraded two of the three substations mentioned above (CHRISTOVAL and DEL RIO) to 500kV, since the ODESSA substation already had a 500kV bus available. I then built a 500kV transmission ring loop connecting all 5 loads, with 500kV feed lines going from each substation to the nearest load, adding lines as necessary until the base case solved without any overflows. Here's what the project looked like at this stage (connected substations boxed in red):



Initial Closed Loop Ring Solution, Feed Substations Highlighted

At this point, the solution was able to provide power to the loads, but it wasn't robust enough for the N-1 contingencies, and also not cost optimal due to the one very long 200+ mile 500kV line. (I also later realized it would have violated the 200-mile maximum ROW length anyways). After some iterations, I was able to remove this long transmission line by adding some additional redundant circuits between the loads and the feed substations, resulting in the final topology below, overall saving ~**$300 million** on cost:

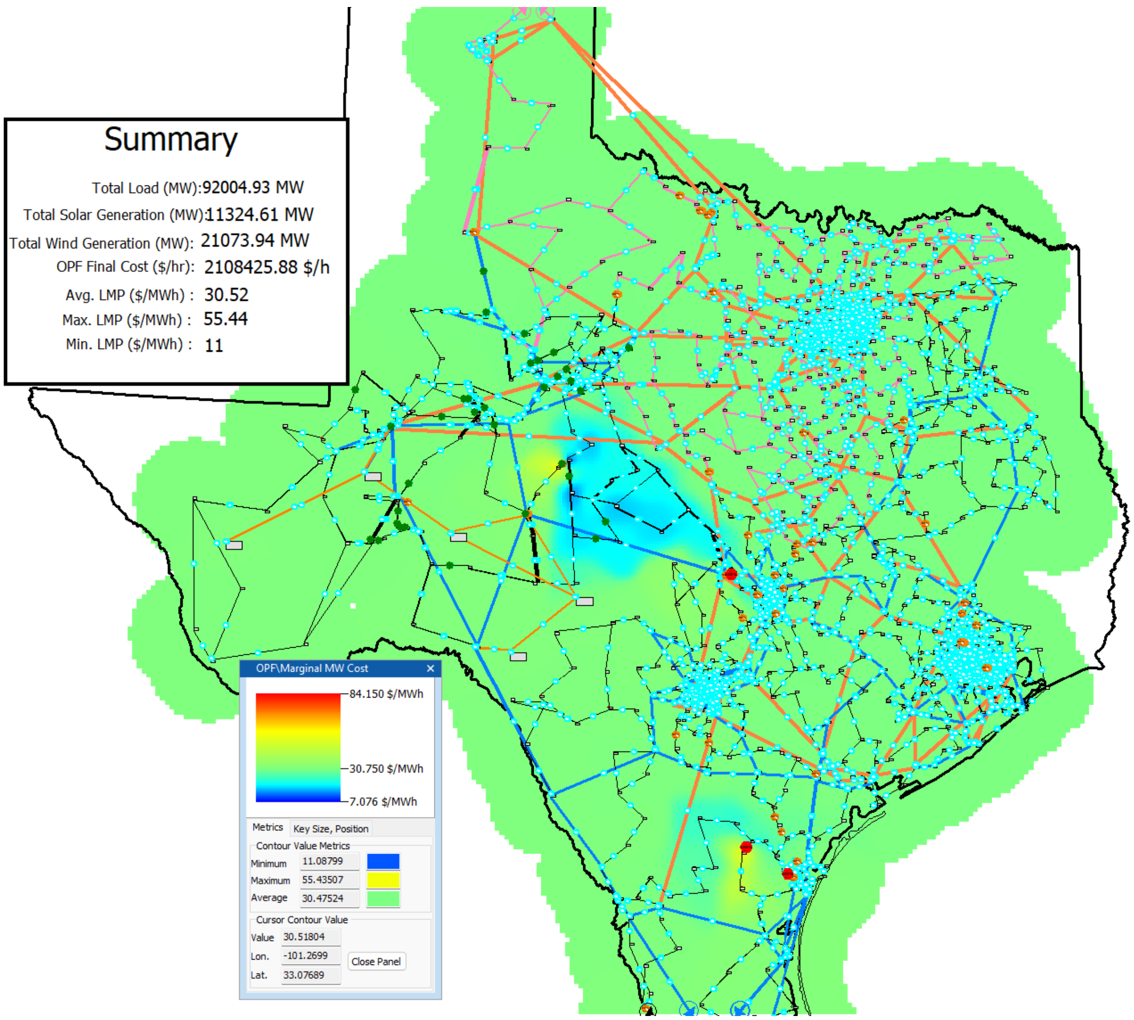


Final Optimized Open Loop Topology

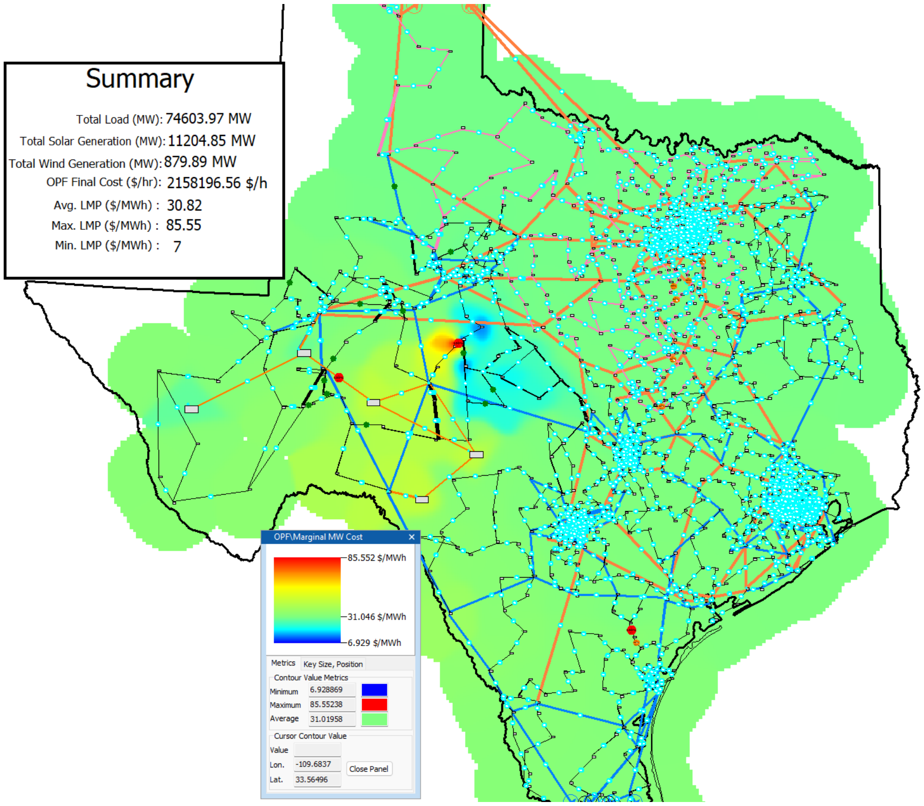
For handling contingencies, it was necessary to add 3 parallel 500kV circuits to the North ODESSA link, and 2 parallel 500kV for the South DEL RIO link. For the CHRISTOVAL East substation, I used a triangular connection pattern for second load since the distances were similar, to distribute the lines out a bit more geographically.

Scenario Results

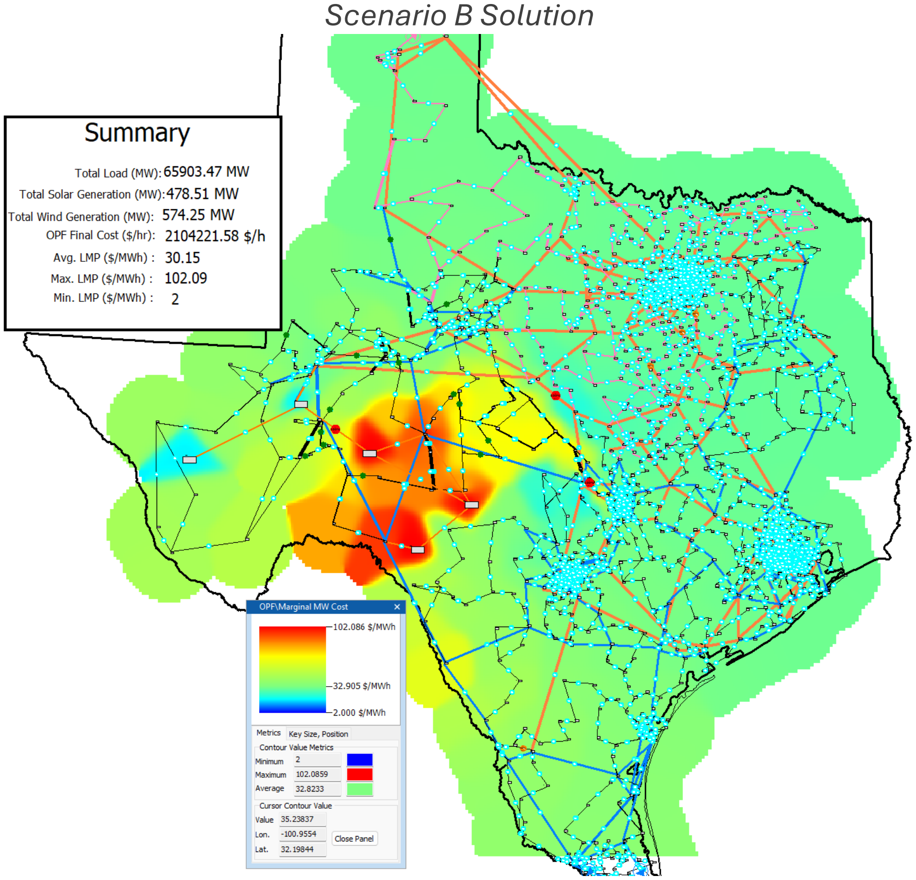
I ran the design above in each scenario and verified that it worked for each contingency by manually opening/closing the new transmission lines one at a time and re-running the DCOPF. I observed that all lines appeared to be within tolerance and the average LMPs appeared to be reasonable for most of the cases (the exception being the low generation scenario C, but I mainly was concerned that the design would be able to pull enough power from the other areas). Below are the base case results with line pie charts and LMP contours for each scenario:



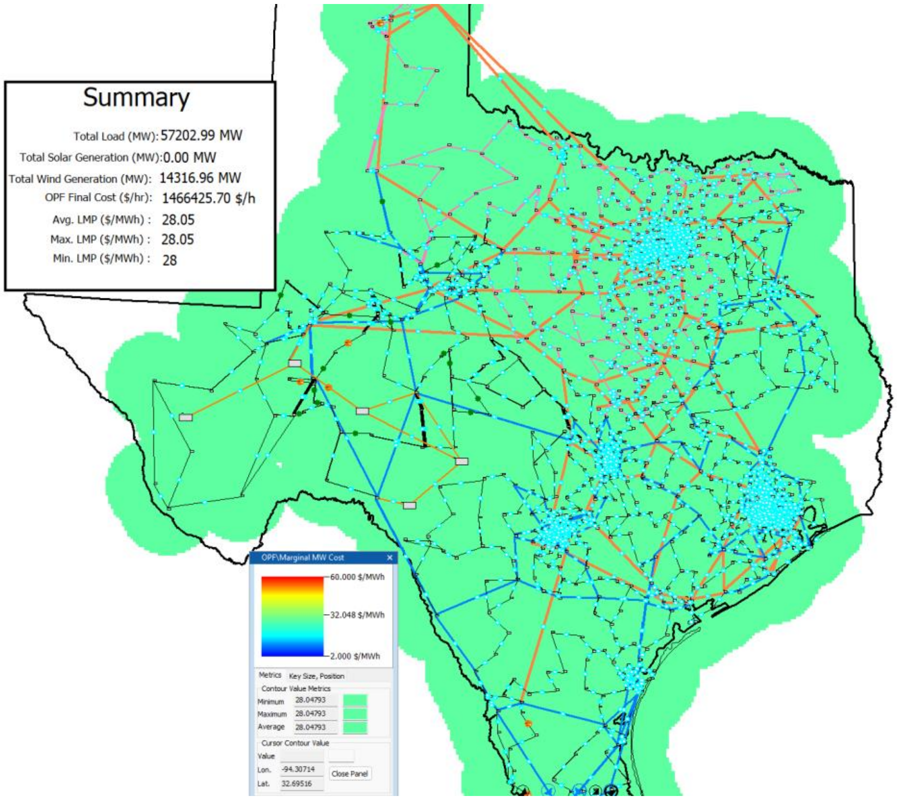
Scenario A Solution



Scenario B Solution



Scenario C Solution



Scenario D Solution

It can be seen that the LMPs are worst in Scenario C when renewable generation is low, but the power is still well balanced and no lines are exceeding 100% of their ratings. One other thing I noticed was that there were certain cases where opening a line may have actually made the LMPs and OPF final cost even better, however, this also appears to reduce reliability (since any N-1s are now N-1-1).

Final Cost Calculations

Total Transmission Capital Cost: From the table above, the total is **$2,963,600,000**

OPF Final Costs per Scenario: From the summary boxes:

Scenario 1: $2,108,425.88 /hr
Scenario 2: $2,158,196.56 /hr
Scenario 3: $2,104,221.58 /hr
Scenario 4: $1,466,425.70 /hr

Calculating the Total Yearly Production Cost:

Sum of Hourly Costs:

$2,108,425.88 + $2,158,196.56 + $2,104,221.58 + $1,466,425.70 = **$7,837,269.72 /hr**

Total Yearly Production Cost:

$7,837,269.72 /hr * 2190 hr/year = **$17,163,620,686.80**

The objective function uses 12.9% of the new transmission capital cost.

$2,963,600,000 * 0.129 = **$382,204,400**

Calculating Final Objective Function Value:

Total Yearly Production Cost	$17,163,620,686.80
+ Weighted Transmission Cost	$382,204,400.00
Final Objective Function	**$17,545,825,086.80**

Conclusion and Closing Thoughts

The project's final objective function cost came out to around $17.5 billion, which seems competitive with other optimized solutions considering that the LMPs in most of the scenarios are low even with contingencies, and the minimal components necessary were used (sticking with a 500kV standard for simplicity). There may have been even more cost savings that could be achieved by paring down the design even further and switching out to 230kV lines/transformers if necessary. But this would also have introduced more complexity, may have caused some back and forth battling with contingency line overloads, and also in general leaves less headroom available for future expansion, which I would imagine is an important consideration in real-world transmission planning. Overall, I am happy with how my solution turned out. I enjoyed the project, the course, and the opportunity to get more hands on with PowerWorld!

Link to Google Drive Folder with additional project files:
https://drive.google.com/drive/folders/1q8kZ7O9CI_Sgn4EE1F1jgDXkne4TeeVU?usp=sharing