

ENERGIZING THE FUTURE: IMPLEMENTING INTENTIONAL ISLANDING ON THE TEXAS POWER GRID

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Energizing the Future: Implementing Intentional Islanding on the Texas Power Grid

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As technology evolves and the electric load changes, electric grids need to be modified to accommodate new threats and resources. One such threat is the increase of natural disasters due to climate change. Electrical grids around the globe need to be carefully designed to withstand disasters such as hurricanes, tornadoes, blizzards, fires, and droughts. This paper focuses specifically on the Texas grid, as it is a stand-alone interconnection and has a synthetic model designed in PowerWorld to aid in the development of research. In the event of a natural disaster powerful enough to take out a few sizeable generators in one section of Texas, the whole state is vulnerable to blackout. In order to avoid this, Texas (and all grids) could implement intentional or “adaptive” islanding. The National Academies Report, *Enhancing the Resilience of the Nation's Electricity System*, describes adaptive islanding as, “The concept [of] predefining how to break apart the system in response to system events, by matching clusters of load and generation.”¹ The following paper includes simulations of such on the synthetic grid modeled in PowerWorld. The results show that islanding the Texas grid successfully protects the state from a complete blackout, and maintains full functionality for both halves in the absence of an event. Therefore, this paper concludes that all grids should prepare an islanding plan in case of a natural

disaster and coordinate with utilities to plan transmission lines which lend themselves to islanding.

ACKNOWLEDGEMENTS

On behalf of myself and the other undergraduate researchers, I would like to thank Dr. Overbye for giving us a chance to pursue our interest in power systems in a way that has real-world applications. His continued excitement towards our work has made research all the more rewarding, and we are all proud of what we have accomplished under his guidance.

I would also like to thank Adam Birchfield, a PhD student under Dr. Overbye, for developing and updating the synthetic model of Texas grid that we are using to test our research as well as for his help in learning the program.

CHAPTER I

INTRODUCTION

In 2017, Texas witnessed the devastation that can be caused by severe weather. Hurricane Harvey brought flood and ruin to coastal Texas cities. The damage caused by the storm was estimated to cost up to \$180 billion. On Monday August 28, almost 300,000 Texans were without power¹. Another frequent threat in Texas is winter ice storms. In 2011, the extreme ice caused 152 power generation plants to go offline in Texas, causing outages across the state.³ With the increasing frequency of severe weather as well as higher load demands, Texas needs a new strategy to avoid weather-related blackouts.

Effects of Severe Weather

Hurricanes and tornadoes are capable of knocking out power lines with their extreme wind speeds. The flooding from tropical storms can cause outages due to the water seeping into the electrical components at substations and plants, which then takes time to be either cleaned and dried or replaced. Customers can even have individual outages if the salt from flood water gets into their houses' meters. Blizzards can cause snow to pile up on power lines, weighing them down and breaking the pole or snapping the line. Ice storms can take out generators. Droughts can cause forest fires, or kill trees due to lack of water, providing a threat to lines located close enough to be taken down by a fallen tree. As you can imagine, natural disasters are the top causes for power outages across the globe.

Background Information

The following research, as mentioned previously, focuses on the Texas grid. Why only Texas? There are four major interconnections in North America, and Texas has its own. Not

surprisingly, this is historically due to Texas's desire to avoid federal regulations. The Texas interconnection has the same name as the agency that oversees it: the Electric Reliability Council of Texas, or ERCOT.

Current Methods (Grid Hardening)

Current methods of improving grid resilience are fairly intuitive. The national academies report states, "Building the transmission and distribution network to withstand greater physical stresses can help prevent or mitigate the catastrophic effects of major events."¹ This section refers to enhancing the robustness of the grid through physical means, often referred to as "grid hardening". First, tree trimming is enforced so that trees do not fall lines or cause shorts, especially when transmission lines sag during heavy loads. After the August 14, 2003 blackout in the Northeast United States, new standards for vegetation management were enforced.⁴ Undergrounding transmission and distribution lines is common in urban areas, and protects against storms. However, it is up to ten times as expensive to install, harder to repair, and is not immune to flooding from seismic disturbances. Building reinforced or dead-end towers is done to prevent the cascading effect of fallen poles. Most transmission line towers are unable to support broken lines, as they are made to have equal weight of the line on both sides to keep them upright. Therefore, dead-end towers exist to stop a domino effect of fallen lines. Another practice is to place redundant transmission lines, in case one is damaged. Cost must be considered when implementing all these solutions. With infinite money, for example, we could reinforce all the towers. Multiple papers have already been published on transmission line planning.^{4,5} However, most of these hardening methods are applied on a case by case basis rather than according to a large, pre-determined solution. This is why the focus of this paper is on intentional islanding, a technique which can be applied systematically, simulated, and studied.

CHAPTER II

METHODS

Previous Research: What Makes a Grid Resilient

Figure 1 shows a common graphic for illustrating grid resilience according to each phase of an event. It is called the “Resilience Trapezoid”. This particular image is from the IEEE paper: *Power Systems Resilience Assessment: Hardening and Smart Operational Enhancement Strategies*.⁷ This paper does an excellent job of describing each phase of the trapezoid and comparing to other grid resilience diagrams such as the “Resilience Triangle” which is limited to single-phase studies. On the topic of islanding, this paper concludes that, “Defensive islanding enhances the resilience of the system during extreme events (Phase I) by mitigating their impact on powersystem.” The important parts of this statement are that islanding is only helpful in Phase I, because it is implemented *during* an event to lessen the spread of negative effects. It has no direct contribution to the other two phases which take place *after* the event occurs. The other focus in this statement is the term “extreme events.” Because overloaded lines that are tripped during a standard event are reconnected soon after, the end of Phase I would look the same with or without islanding. In fact, islanding could even cause more lines to need reconnection. However, in an extreme event that knocks out enough generation and transmission to cause large blackouts, islanding could improve the resilience of Phase I by cutting the blackout area in half, or less.

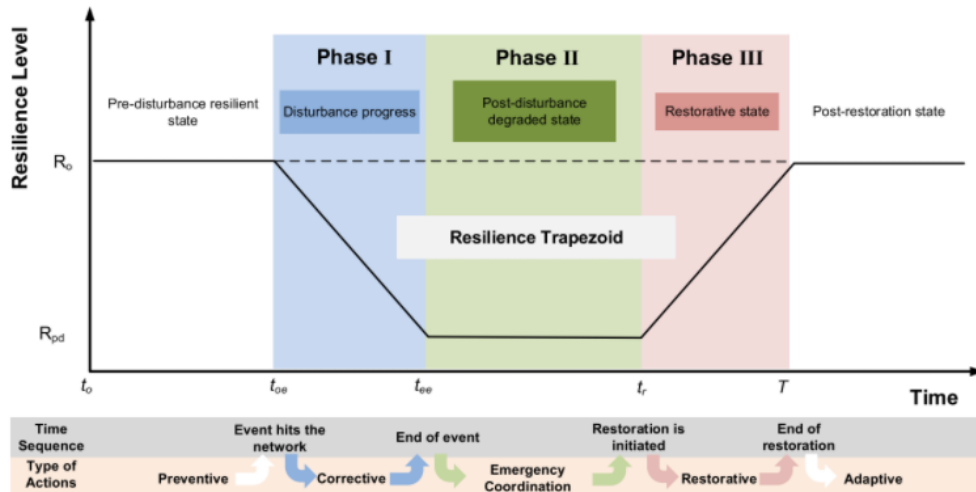


Figure 1. Conceptual resilience trapezoid associated to an event.⁷

The proposed islanding for the Texas grid is evaluated in Results section according to the standards set by previous resilience metrics, as described above. Islanding schemes are only recommended if they improve the overall resilience of the grid at the end of Phase I of the Resilience Trapezoid.

PowerWorld and the Texas Synthetic Grid Model

PowerWorld is, “an interactive power system simulation package designed to simulate high voltage power system operation.”⁹ Figure 2 shows a model of the Texas grid in PowerWorld which was developed by other researchers. It is similar to, but does not represent the actual ERCOT Texas grid. However, it is more than adequate to prove the advantages of defensive islanding. As seen in figure 2, the lines with arrows represent power lines and the direction of power flow. The gray boxes are buses which can represent generation, load, or both in one location. Generation creates power (MW) while load absorbs it. The simulator will run the power flow and adapt to any changes to the grid. The research described in this paper was conducted on the Texas synthetic grid model, which will be referred to as “TSG”.

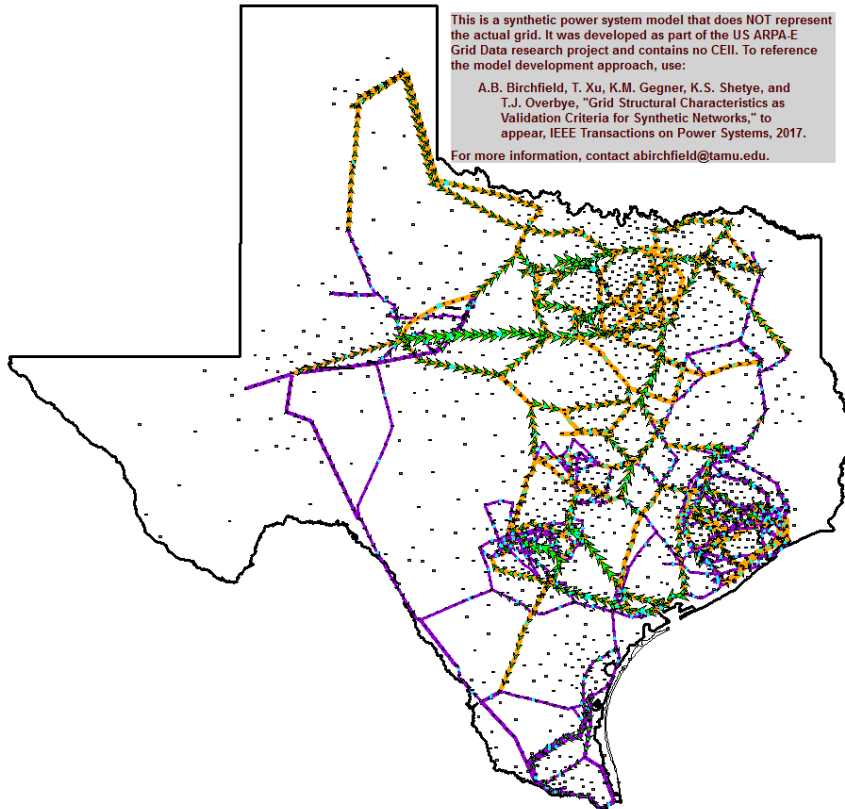


Figure 2. The synthetic model of the Texas grid in PowerWorld.

Transient Stability

Within PowerWorld, the Transient Stability add-on was used to simulate multiple lines opening at once to create islands. Figure 3 shows the set-up to split the Texas grid in two by opening 15 lines between the North and South halves of the state. The “Object Pretty” section shows the names of the buses which the line connects. The description, “OPEN BOTH” instructs the simulator to open both ends of the line at the specified time, which is set to 1 second for all the lines. This simulation is able to gather data on transmission and bus parameters such as frequency, per unit voltage and current, rotor angle, and real and reactive power. Plots and analysis of these items are discussed in the results section.

Transient Contingency Elements

Insert Clear All Insert Apply/Clear/Open Time Shift (seconds) 0.000

Records Set Columns

	Object Pretty	Time (Cycles)	Time (Seconds)	Object	Description	Enabled
1	Line WACO 1 0 TO WACO 2 0 CKT 1	60.0	1.000000	Branch '5137' '5388' '1'	OPEN BOTH	CHECK
2	Line THORNTON 0 TO GROESBECK 0 CKT 1	60.0	1.000000	Branch '5011' '5054' '1'	OPEN BOTH	CHECK
3	Line SAN SABA 0 TO BUCHANAN DAM 2 0 CKT 1	60.0	1.000000	Branch '3025' '3101' '1'	OPEN BOTH	CHECK
4	Line RIESEL 1 1 TO MART 0 CKT 1	60.0	1.000000	Branch '5359' '5276' '1'	OPEN BOTH	CHECK
5	Line RIESEL 1 0 TO CORSICANA 2 0 CKT 1	60.0	1.000000	Branch '5358' '5179' '1'	OPEN BOTH	CHECK
6	Line MARQUEZ 0 TO JEWETT 2 0 CKT 1	60.0	1.000000	Branch '8010' '8103' '1'	OPEN BOTH	CHECK
7	Line LUFKIN 3 0 TO WILLIS 2 0 CKT 1	60.0	1.000000	Branch '8004' '7150' '1'	OPEN BOTH	CHECK
8	Line LOMETA 0 TO GOLDTHWAITE 1 2 CKT 1	60.0	1.000000	Branch '3029' '5241' '1'	OPEN BOTH	CHECK
9	Line JEWETT 1 1 TO FRANKLIN 1 CKT 1	60.0	1.000000	Branch '8068' '8083' '1'	OPEN BOTH	CHECK
10	Line GOLDTHWAITE 1 0 TO MARBLE FALLS 2 0 CKT 1	60.0	1.000000	Branch '5239' '6210' '1'	OPEN BOTH	CHECK
11	Line GATESVILLE 2 0 TO VALLEY MILLS 0 CKT 1	60.0	1.000000	Branch '5182' '5314' '1'	OPEN BOTH	CHECK
12	Line DEL RIO 0 FROM EAGLE PASS 0 CKT 1	60.0	1.000000	Branch '3050' '4014' '1'	OPEN BOTH	CHECK
13	Line CROCKETT 0 TO LOVELADY 0 CKT 1	60.0	1.000000	Branch '8118' '8014' '1'	OPEN BOTH	CHECK
14	Line COPPERAS COVE 0 TO GOLDTHWAITE 1 0 CKT 1	60.0	1.000000	Branch '5451' '5239' '1'	OPEN BOTH	CHECK
15	Line CLIFTON 2 0 TO WOODWAY 0 CKT 1	60.0	1.000000	Branch '5407' '5470' '1'	OPEN BOTH	CHECK

Figure 3. Transient stability set-up

CHAPTER III

RESULTS

North and South Islands

To create successful islands, it is necessary to consider a number of things: the amount of load vs generation in an area (so the island is self-sustaining), the total amount of load and generation in an area (so the island is not too small or large relative to the other), and the number of transmission lines that need to be opened in order to create the island (the least number is best). After analysis of the obstacles described, and some guess and check, the islands shown in figure 4 were obtained. The northern island contains the major cities Dallas and Fort Worth, 898 buses, and 27,779 MW of generation. The southern island contains the cities Houston, Austin, and San Antonio, 1,102 buses, and 40, 985 MW of generation. When power flow analysis is run on the grid, the islands are self-sustaining.

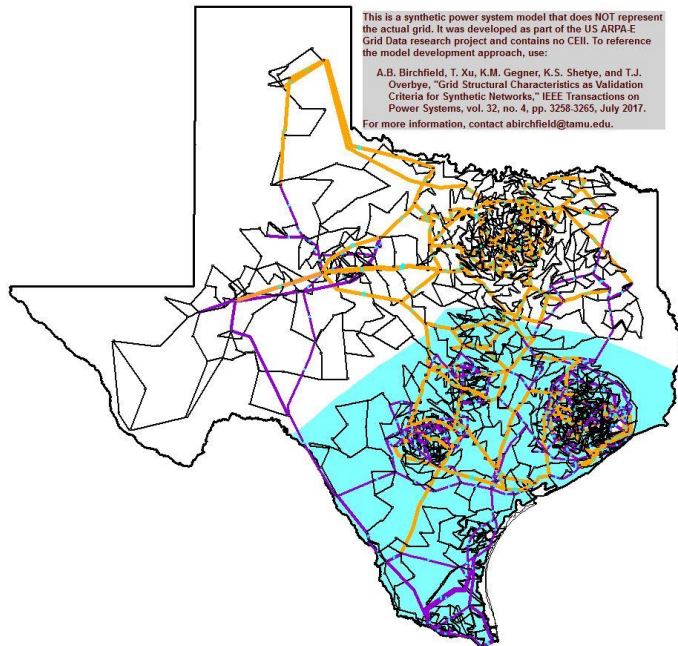


Figure 4. Color indicating the boundary of North and South islands.

Frequency and Voltage P.U.

Before using the islands to prevent a state-wide blackout, it is essential to prove that the islands can handle the initial separation and then remain stable while operating independently. Running transient stability on the islands provided data on many metrics. The most important, which are discussed here, are frequency and per-unit voltage. In North America, all power grids operate at a frequency of 60 Hz. Faults or events in the grid can cause fluctuation in which the frequency will either oscillate and eventually taper back to 60 Hz, or diverge because the disruption was too extreme. Separating the islands from each other inevitably causes some fluctuation in frequency and per unit voltage. Fortunately, the transient stability results show that this case is within an acceptable amount, and the frequency and voltage stabilize after approximately 20 seconds. Figure 5 shows the frequency of some randomly selected buses in the North island and the South island. Figure 6 shows the frequency at all buses on the grid model, with the frequency of both islands plotted together for comparison. Figure 7 shows the per unit voltage at all buses. The separation of the islands occurs at 1 second in the simulation.

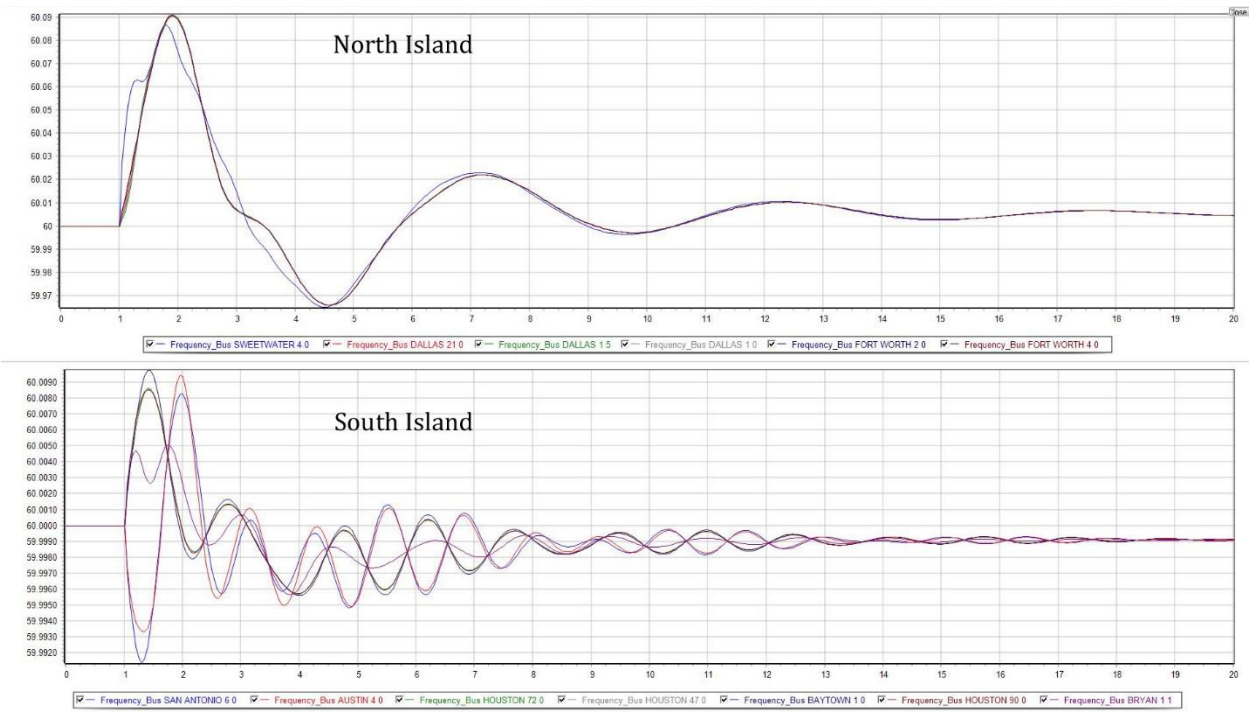


Figure 5. Frequency of some buses in North and South islands.

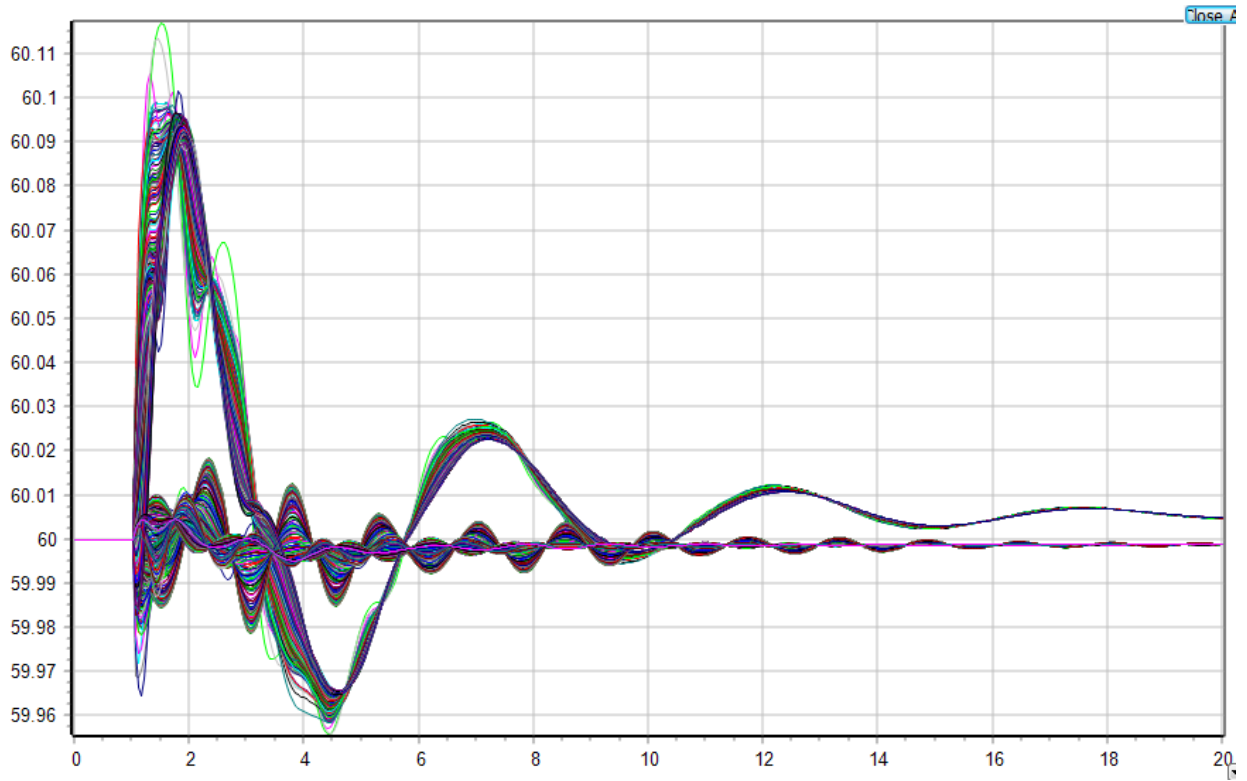


Figure 6. Frequency at all buses.

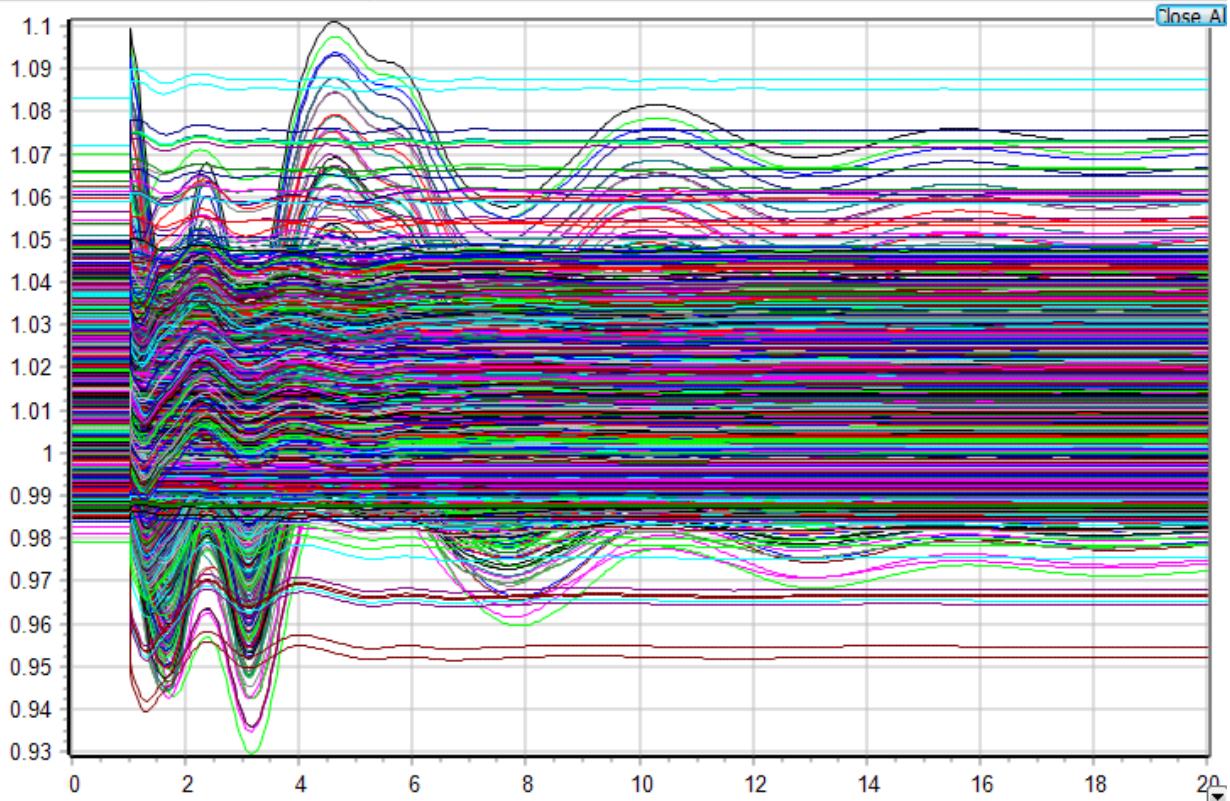


Figure 7. V pu at all buses.

From these figures, it is apparent that the North island experiences a more extreme reaction to the separation of the grid. Its maximum frequency reaches an average of 60.1 Hz, while that of the South island reaches only 60.02 Hz. Figure 5 also shows that the two islands do not stabilize around the same final frequency. While the South island almost returns to the ideal 60 Hz, the North island is slightly higher at 60.005 Hz. This supports the conclusion that the North island is less optimal, with a poorer matchup of load and generation. It also the smaller island, with about 2/3 the amount of MW generation that South island has, so it is more vulnerable to fluctuation. However, these are all acceptable results for a power grid and will not cause any major issues to the overall functionality. Another interesting result of this simulation is that the North island frequency and Vpu oscillate at a much slower rate than that of the South island before stabilizing.

Blackout Simulation

When simulating an extreme weather event, for example a tornado, in Northeast Texas by taking out three high-voltage lines connected to large generators, the entire TSG (Texas synthetic grid) immediately blacks out. However, once the islands are created and stabilized, the same removal of generation only causes a blackout in the North island. This is shown in Figures 8 and 9 which are contour maps of the TSG with blue being above 60 Hz and red below. Figure 10 shows the frequency of some buses in each island. At 10 seconds, when the North island frequency drops significantly (and therefore blacks out), the South island's frequency is unaffected and continues stabilizing.

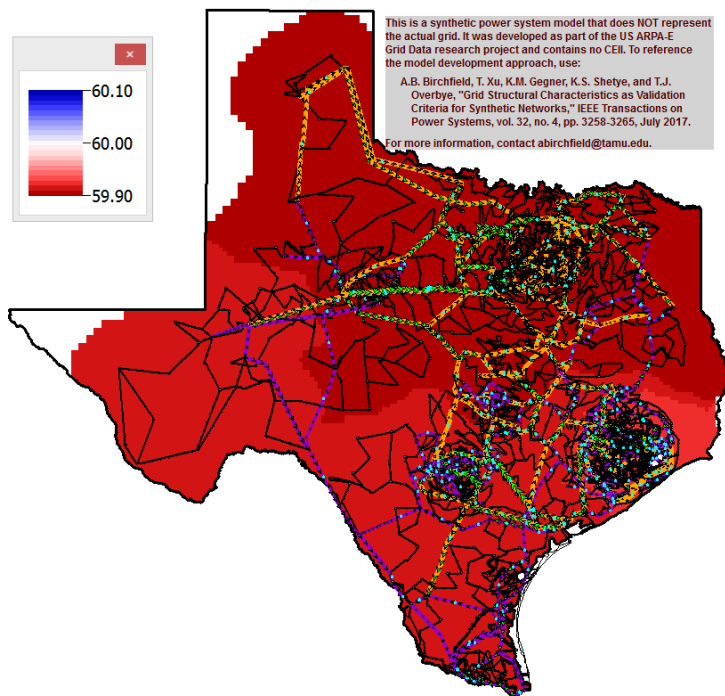


Figure 8. Blackout due to generation loss in Northeast.

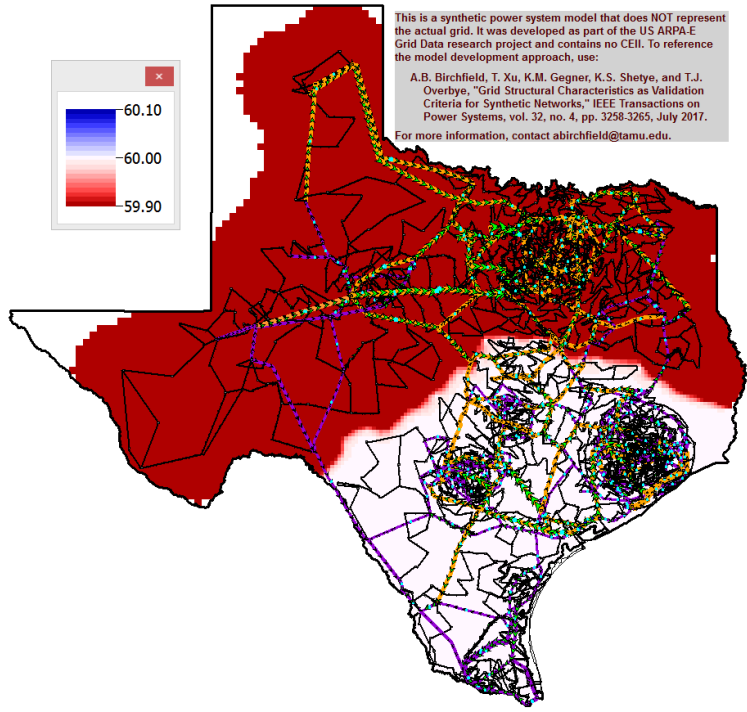


Figure 9. Blackout reduced by islanding.

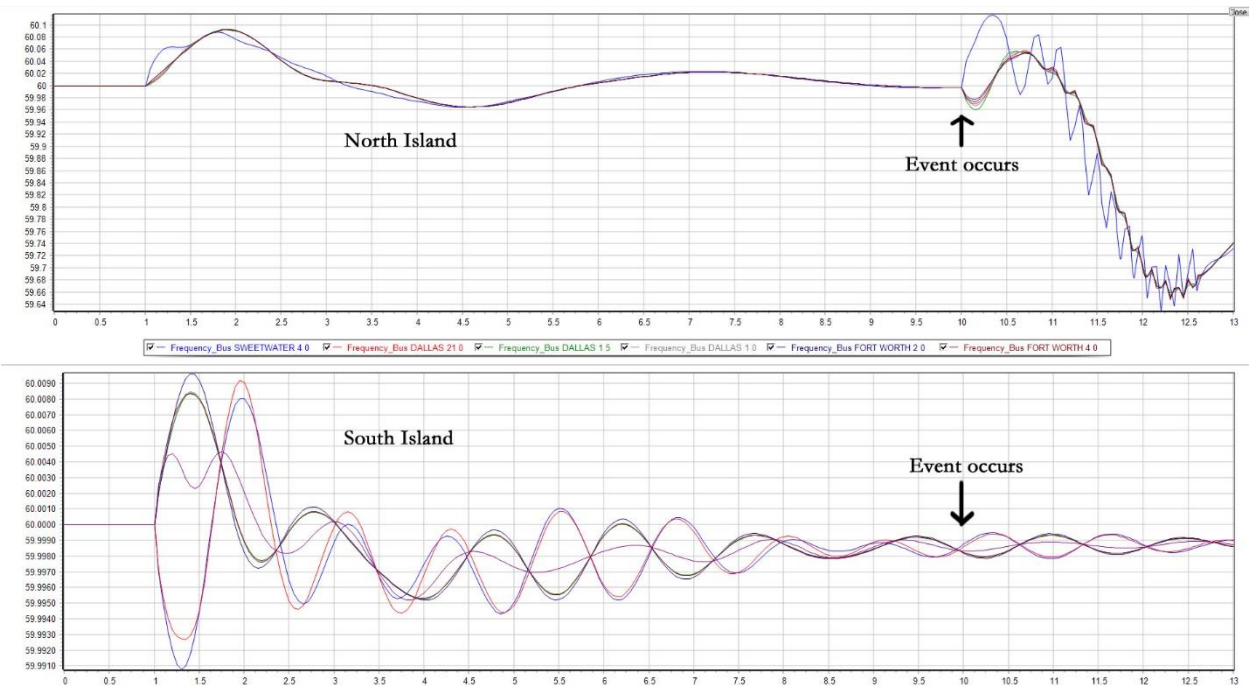


Figure 10: Frequency of North (blackout) vs South (unaffected) islands

Although no blackout at all is preferred, it is clearly preferable for half the state to survive. Having the other half functioning is also extremely helpful in restarting the half that is blacked-out. The half with power can reconnect to the other side when the weather event is over and provide power to generators to restart that section of the grid. By creating more than two islands, even more of the state could be saved from blackout by the same event. There are countless ways to implement islanding to protect the grid.

Fail-to-Island Scenario

An important thing to consider when islanding is: What if it doesn't work? The reason to implement islanding is to prevent a blackout based on upcoming weather conditions. However, it would be even worse to cause a blackout by trying to use islanding and failing. This is a potential issue if one of the lines necessary to separate the islands fails to open. In that case, the two halves will be mostly separated, becoming unstable at their own pace, and essentially playing tug-o-war with the attached line. If the line opens, the islands can continue to stabilize as separate entities. The longer the line stays closed, however, the more unstable the entire grid becomes, which puts it in an even more vulnerable position for when the natural disaster hits. Figures 11 and 12 show the effects of high voltage and low voltage line failing to open, respectively.

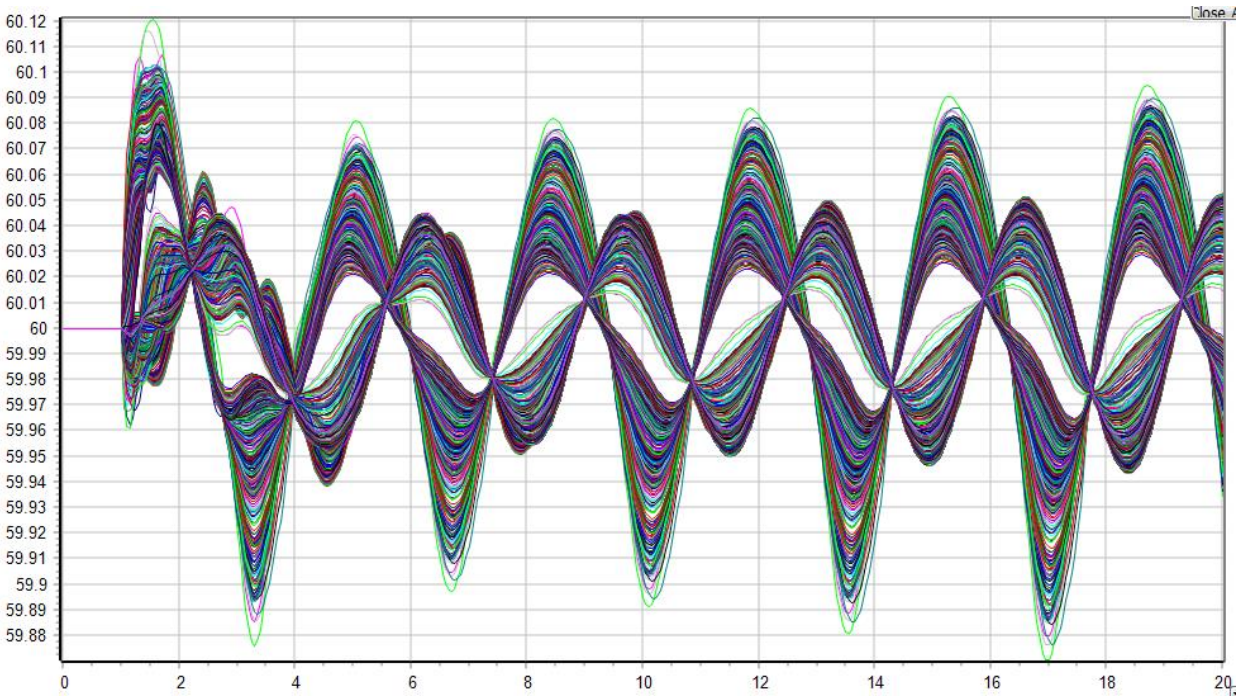


Figure 11: Frequency when a high voltage line fails to open.

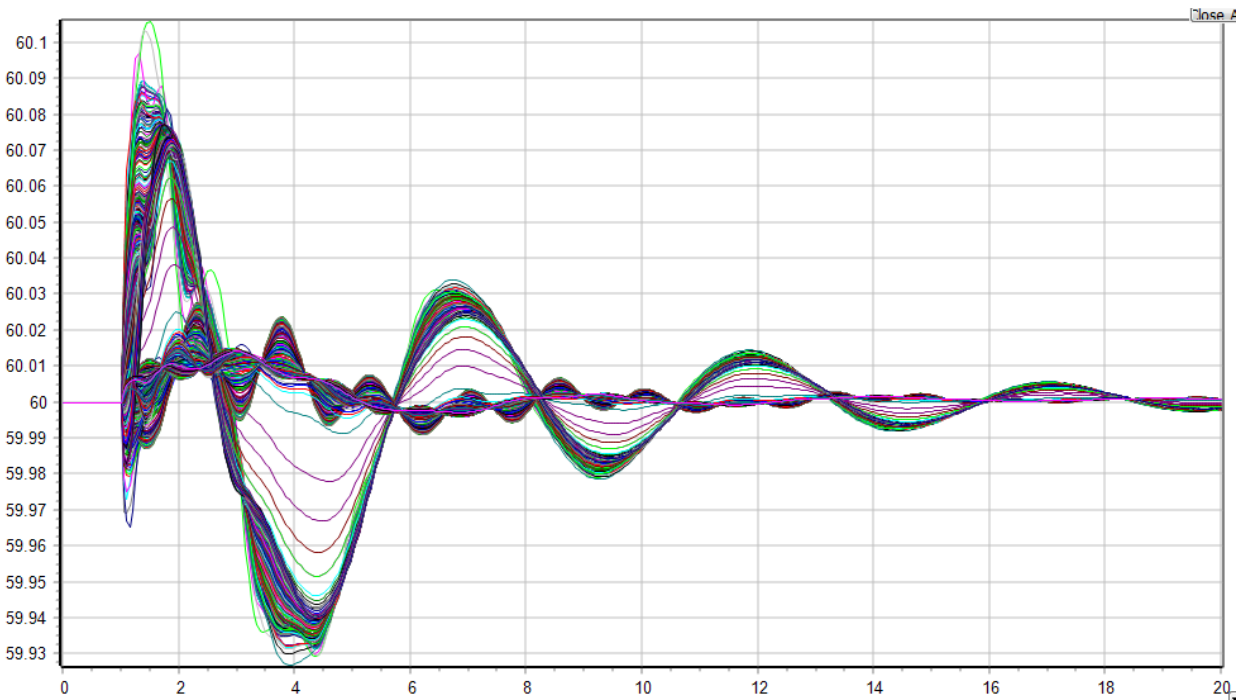


Figure 12: Frequency when a low voltage line fails to open.

For context, the low-voltage line was carrying 67 MW before islanding, and the high voltage line was carrying 560 MW. The graph of frequency when the low-voltage line fails to

open looks similar to when all lines open. This shows that the case is able to recover, and takes only a few seconds longer to stabilize than in the case of completely successful islanding. In the high-voltage case of Figure 11, however, it is clear that the island “tug-o-war” is happening, with increasing magnitude as time progresses. These results suggest that high-voltage lines should be given the most attention when implementing islanding, and should be confirmed as opened with priority over smaller lines.

Choosing Where to Island: Interface study

The predetermined island scenario discussed in this paper is just one example of how to set up islands on the Texas grid. It is also possible to island the grid in an East-West configuration rather than North-South, to have more than two islands, etc. Therefore, the above example of a successful island was used to conduct a study to help inform the future placement of islands. Using the interface tool in PowerWorld, the net power (MW) across the interface of the two islands can be observed. To clarify, this is the power flow across the islands before they are split apart. The flow across the interface afterwards should of course be zero. In the unaltered case used in the rest of this paper, the net flow across the islands from North to South is 41.3 MW (before separation). Although many of the individual lines connecting the two halves carry more than 41 MW, the total transfer when added together is relatively small, which is why this area is suitable for islanding. A small power exchange between the interface of islands means that they are well suited to operate independently. To determine what range of power across the interface is acceptable for islanding, some generation in Houston and Dallas on the TSG was incrementally adjusted to alter the net power transfer. Figure 13 shows how the interface flow (MW) affects the maximum frequency reached by either island before stabilizing. Figure 14 shows how the interface flow affects the equilibrium frequency to which the islands stabilize.

Ideally, both islands would stabilize to 60 Hz. For the case used in the rest of this paper (41 MW interface flow), the South island stabilizes to 60 Hz, and the North is slightly higher at 60.005 Hz. However, Figure 14 shows that larger interface flows cause the islands to stabilize farther from 60 Hz and farther from each other. This causes issues for reconnecting the islands. Another metric to consider is the time required for islands to stabilize. However, this study showed that interface flow did not affect stabilization time.

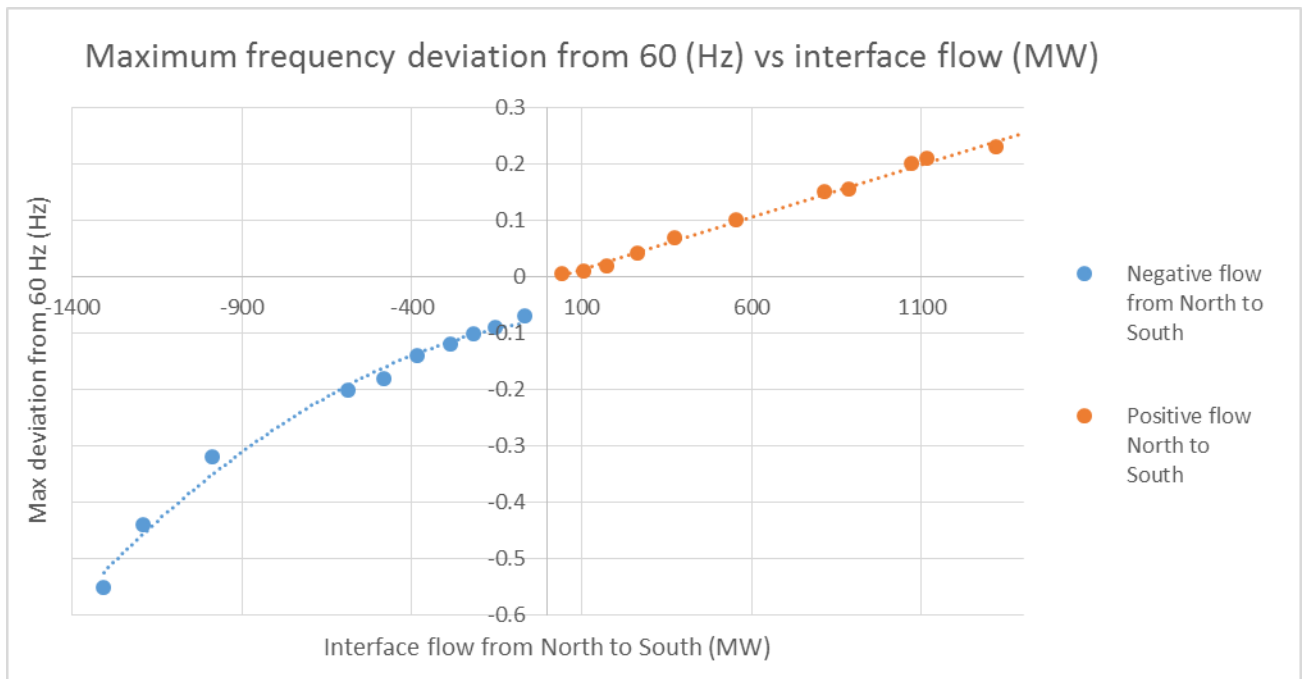


Figure 13: Maximum frequency observed (Hz) vs interface flow (MW).

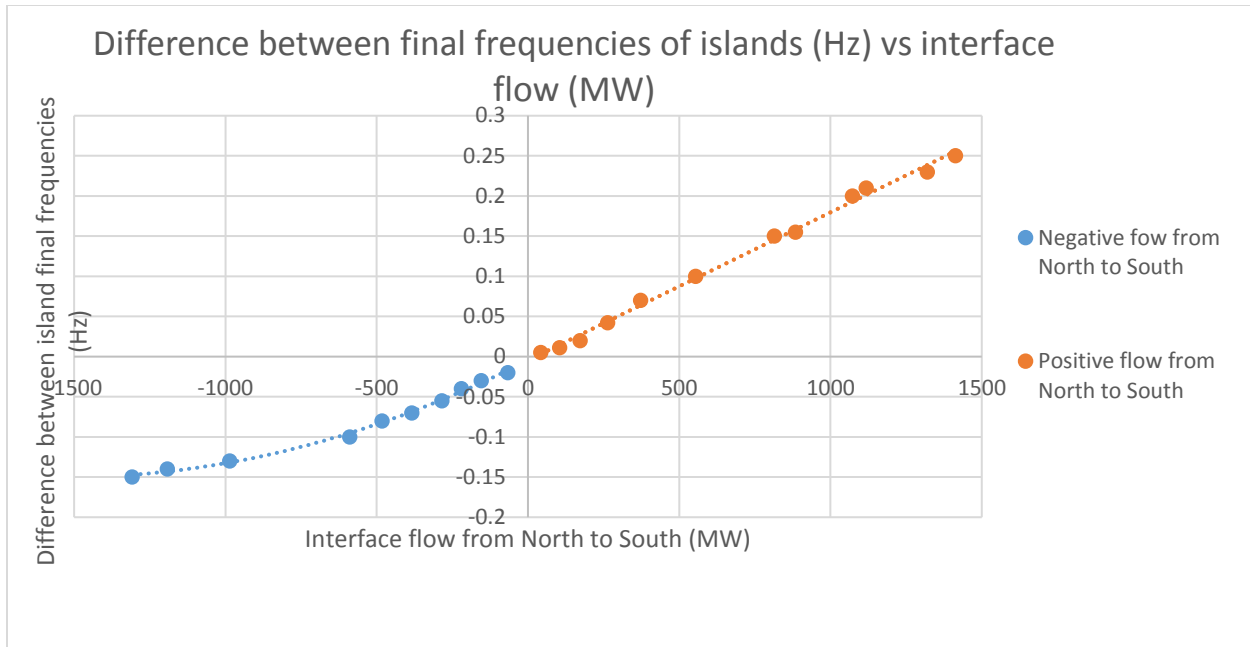


Figure 14: Difference between equilibrium frequencies of islands (Hz) vs interface flow (MW).

Beyond an interface flow of around -1350 MW from North to South, the North island of the TSG fails to stabilize and blacks out. This number is about 4.7% of the North island's total generation capacity. Figures 14 and 15 show a linear trend in frequency deviation until the interface flow approaches the point of blackout. Figure 15 shows the frequency of the islands when starting with an interface flow of -1200 MW. Although the plot exhibits undesirable traits such as the frequency deviations mentioned above, both islands eventually stabilize. Figure 16 shows the frequency of the islands when starting with an interface flow of -1450 MW. Note the difference in scale between Figure 15 and 16: In Figure 16, the North island reaches frequencies above 70 Hz. This, along with the abrupt spikes rather than smooth oscillations, indicates a blackout.

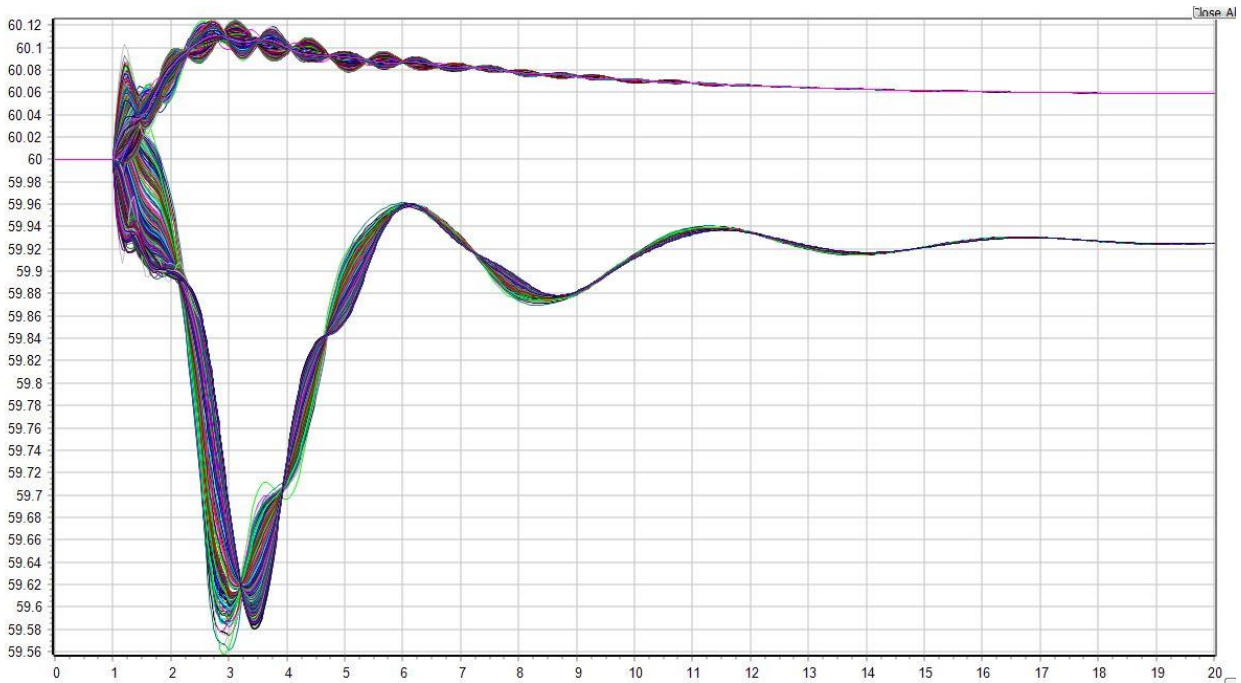


Figure 15: Islanding frequency response with initial interface flow of -1200 MW

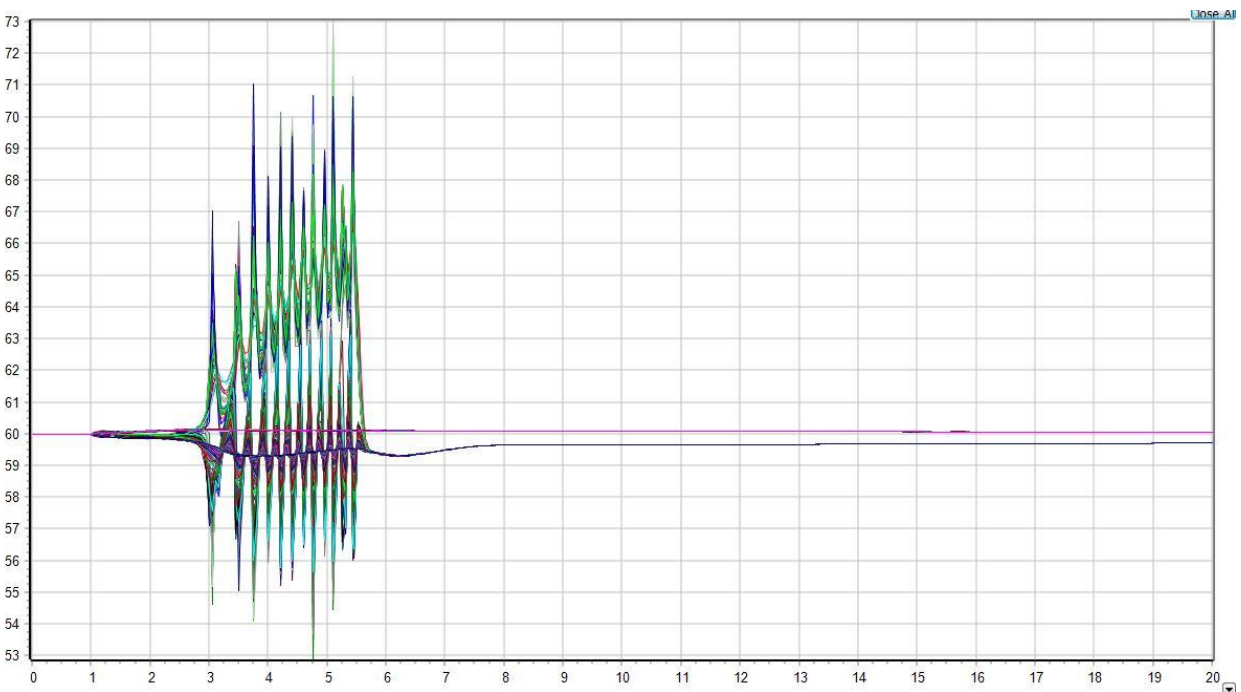


Figure 16: Islanding frequency response with initial interface flow of -1450 MW

Using the above data and ERCOT's tolerance for underfrequency¹⁰, the following criteria were created: The interface flow should not cause islands to reach 0.4 Hz above or below 60 Hz

at any time during stabilization, the islands should not reach equilibrium frequencies more than 0.4 Hz apart from each other, and the magnitude of interface flow into the smallest island (MW) should be less than 4.5% of that island's generation capacity. Figures 13 and 14 show that the islanding scenario discussed in the paper blacks out before reaching the frequency thresholds when the flow is negative for North to South. This is why the 4.5% metric had to be created. If the interface flow is positive (flowing into the larger island), then the first frequency threshold reached is "Maximum deviation from 60 Hz" at an interface flow of 1770 MW, according to the trendline. Therefore, for this scenario on the TSG, the interface study concludes that the net interface flow between the two islands can be no more than 1350 MW into the North island or 1770 MW into the South island.

CHAPTER IV

CONCLUSION

Islanding Texas

The results of the islanding study on the TSG proved that a system with the approximate size and set-up as the Texas grid can be successfully islanded by following a few key parameters. While stabilizing after separation, the islands' frequencies should not reach 0.4 Hz above or below 60 Hz, and should not finish stabilizing more than 0.4 Hz apart from each other. This can be predicted using the interface flow between the two islands before separation. Also, the magnitude of interface flow into the smallest island should be less than 4.5% of that island's generation capacity. Priority should be given to opening high-voltage lines over low-voltage lines when implementing islanding. Finally, the islands should be created having common patterns of severe weather in mind. With these items in consideration, the actual Texas grid could be improved to include predetermined islands. ERCOT should then advise utilities to place their new transmission lines in a way that avoids intersecting the island divide, to avoid extra complication. This paper has shown that creating islands can save a Texas-like grid from complete blackout in the case of extreme weather events, which grow more common each day. Therefore, it is in the state's best interest to immediately implement the capability to island.

Future Research: Adaptive Islanding

The type of islanding discussed in this paper can be called "predetermined islanding," meaning that in the event of severe weather or natural disaster, the grid is split into islands that have been decided beforehand. That is, the boundaries for the islands are already known along with the amount of load and generation in each. "Adaptive islanding," however, tends to refer to

the idea of creating islands in-the-moment based on weather data. Researches have already tested an algorithm on a simplified model of the Great Britain power grid^{7,8}. However, as they mention, there are limitations to this approach such as the computing power needed to find the best scenario, and issues with solutions based on inaccurate weather data. When successful, however, adaptive islanding would be more efficient and less strenuous for the grid than predetermined islanding. Therefore, the next step for the study of islanding the Texas grid is undoubtedly to create algorithms and test the benefits and limitations of adaptive islanding.

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