Modeling and Comparison of Solutions to Renewable-caused Instability

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I. Introduction

Decarbonizing electricity production is a critical step on the fight against climate change. Solar and wind power are growing in popularity as a source of cheap, carbon-free electricity. However, they also make the grid more sensitive to contingencies making blackouts more likely. In this study, 5 proposed solutions to this problem were modeled and compared (fig. 1)

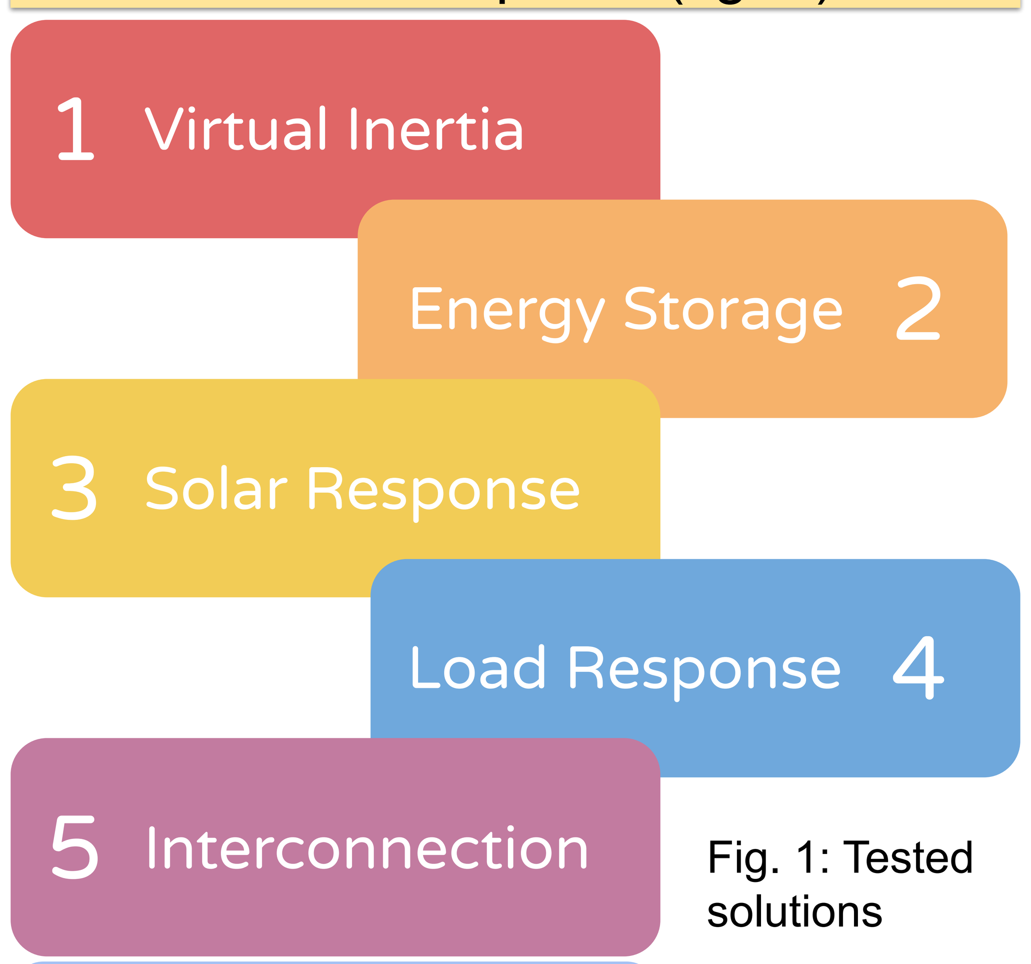


Fig. 1: Tested solutions

II. Modeling

The system was modeled with MATLAB and Simulink. It was broken up into 3 buses, representing smaller regions of the electric grid. In each bus, a load consumed a randomly generated amount of power, supplied by 20% gas and 80% solar power, shown in fig. 2. The 3 buses were connected with transmission lines, shown in fig. 3. To determine the system's stability, each trial, a sudden spike in power consumption was applied in a chosen bus, causing a disturbance in the system frequency. The difference between the initial and minimum frequency reached by the system was then used as a measure for the system stability.

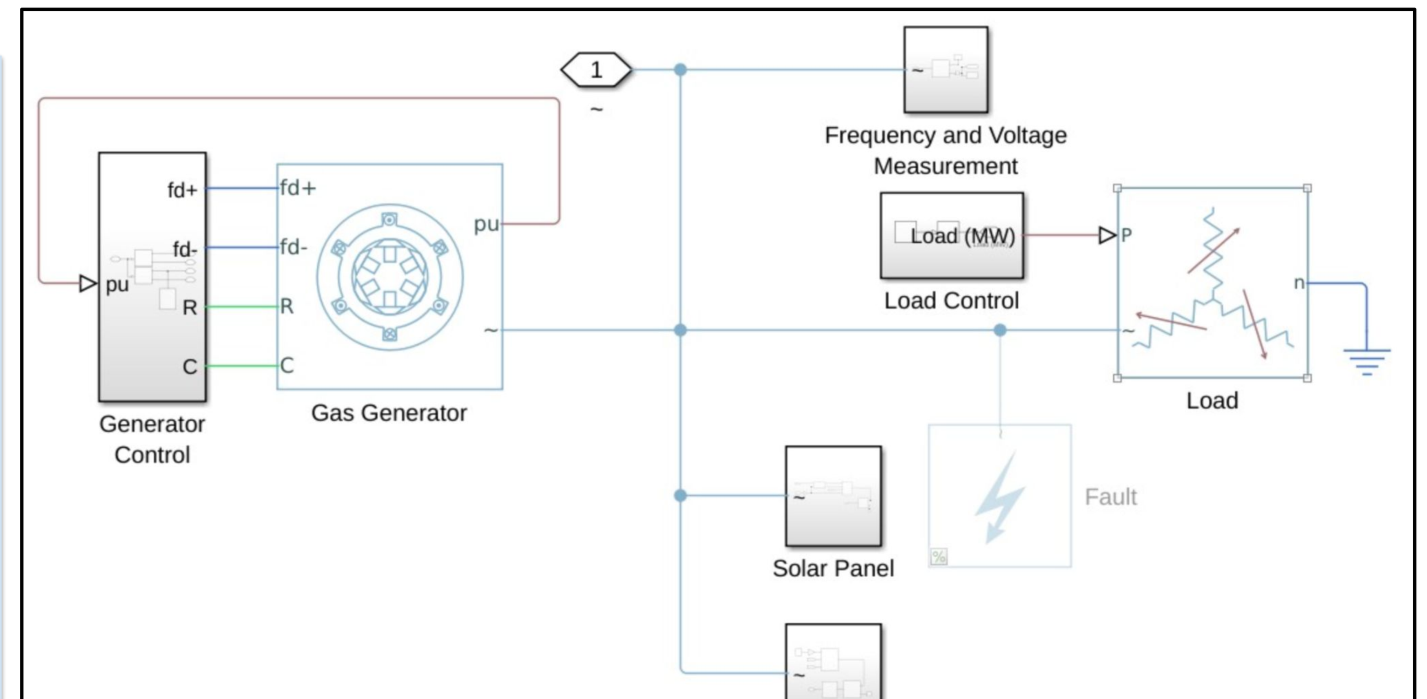
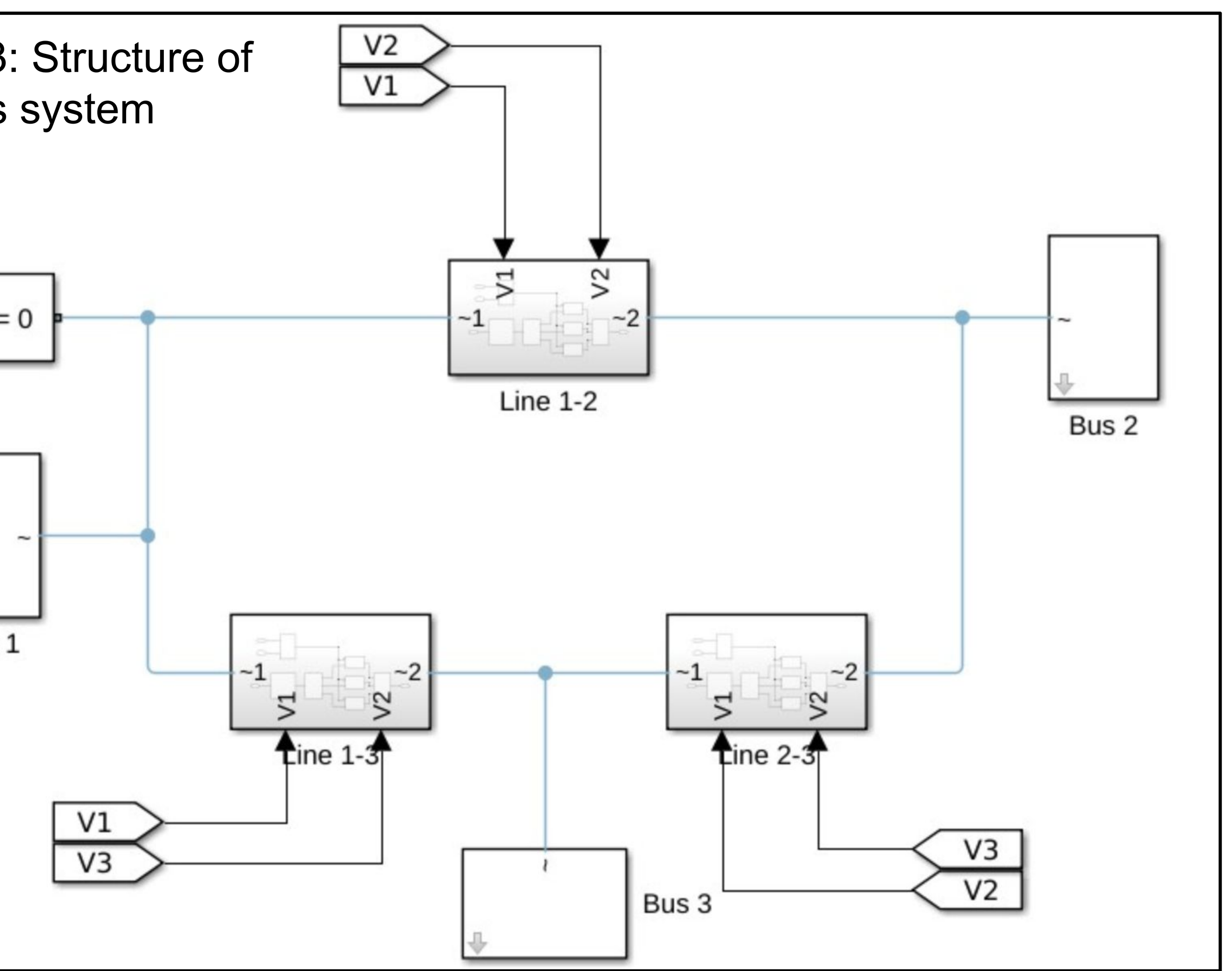


Fig. 2: Structure of a bus

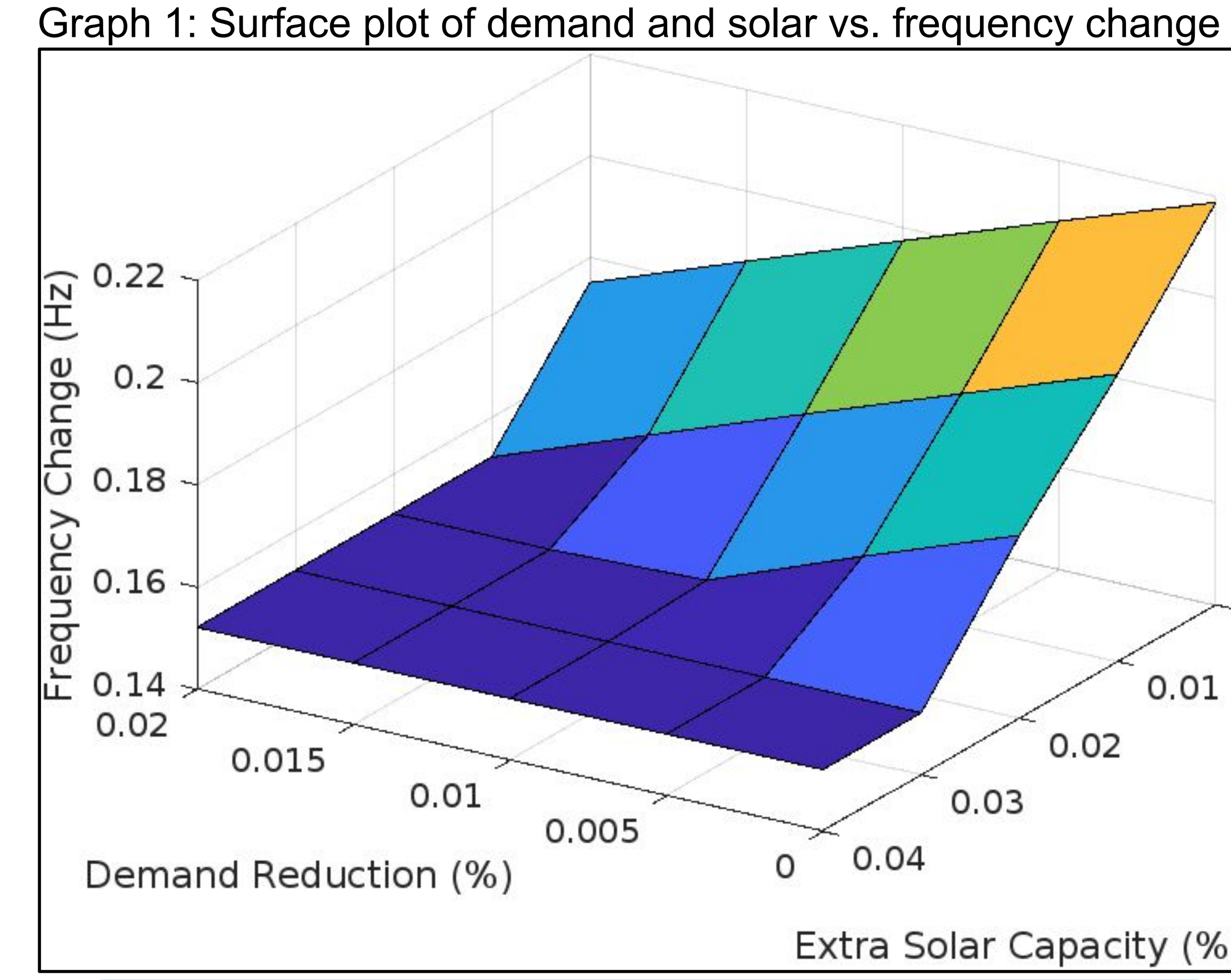
Fig. 3: Structure of 3-bus system



III. Data

Trials were divided into 10 groups, one for each pair of the 5 solutions. Between trials in a group, the amount of both solutions were varied between 5 values, for 25 total combinations/trials. For solutions other than virtual inertia, the maximum power capacity (as a percent of bus load) was varied, while for virtual inertia, the inertia constant of the gas generator was varied. As an example, in graph 1, the demand and solar response trial group data is shown.

Graph 1: Surface plot of demand and solar vs. frequency change



IV. Data Analysis

Regression was used to quantify how effective each individual solution was in improving the system's stability, as well as each solution's interaction with the other solutions. The results of the regression are shown below in table 2, with a more negative coefficient indicating greater effectiveness. Regression was also directly performed on individual solutions to better determine the individual effectiveness of each solution. (Table 1)

Table 1: Individual regression coefficients for each solution

Solution	Coefficient
demand	-2.17681
transmission	0.74455
storage	-2.23575
inertia	-0.05109
solar	-2.20267

Table 2: Regression coefficients for each trial group

Solution 1	Solution 2	Solution 1 Coefficient	Solution 2 Coefficient	Interaction Coefficient
transmission	demand	0.6795	-1.9572	-9.3409
demand	storage	-2.1829	-2.2401	-2.3206
demand	inertia	-1.5529	-0.04764	0.4832
demand	solar	-2.1566	-2.147	-7.8543
transmission	storage	0.7022	-1.938	-8.0487
transmission	inertia	0.8246	-0.04775	-0.7614
transmission	solar	0.6827	-1.6285	-7.7770
storage	inertia	-1.6151	-0.05325	-4.3372
storage	solar	-2.2209	-2.1573	-6.2868
inertia	solar	-0.05004	-1.4531	-0.4581

V. Implications and Next Steps

Comparing the regression coefficients for each trial group, several conclusions can be made:

- The effectiveness of demand response, solar response, and energy storage were found to be similar, suggesting that the relative effectiveness of these solutions should be given lower priority than other factors (e.g. cost and location)
- Stronger interconnections between the buses unexpectedly decreased system stability, likely a sign of modeling error, but also potentially lower individual effectiveness than other methods, more detailed modeling is needed to test this
- Interconnection however, significantly improved the effectiveness of other solutions when combined with them, suggesting that it should be mainly used in systems where a substantial amount of other solutions are already present
- Virtual inertia synergized incredibly well with energy storage, possibly due to statistical error, more research needed
- Demand and inertia were detrimental to each other when combined, so this pair of solutions should be avoided

Further modeling studies—adding elements such as wind turbines, finer modeling of inverters, etc—are needed to determine if these results still apply in more realistic scenarios.

VI. Acknowledgements and References

Special thanks to Erin Angell and Victor Meyerfreund for helping make this project possible.

The Simulink model, gathered data, and code used for regression analysis can be found at https://github.com/PatXue/Electric-Grid-Stability-Modeling-AAR

Works Cited:

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