



Effects of dynamic power electronic load models on power systems analysis using ZIP-E loads

Final Project Report

T-70G

Power Systems Engineering Research Center
*Empowering Minds to Engineer
the Future Electric Energy System*



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PSERC Publication 24-10

December 2024

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Acknowledgements

We wish to thank Carmen Cardozo, Gilles Torresan of RTE for engaging technical discussions.

Executive Summary

Power grids are seeing more devices connected at the load level in the form of power electronics: e.g., data centers, electric vehicle chargers, and battery storage facilities. Therefore it is necessary to perform power system analysis with load models that capture these loads' behavior, which has historically not been done. Instead, static ZIP loads, which have constant impedance, constant current, and constant power components, have for the most part been the industry standard for load modeling analysis of power systems.

It has been posited in the research community that these new power electronic loads should be modeled as constant power loads, as the converter acts as a firewall between the network and the load. While we think that this is a suitable modeling choice for slower time scales, we think that this is a very strict modeling requirement during transient events for time domain simulations: it is hard to control voltage and current quickly enough to ensure that constant real power is delivered to the load for all time. Furthermore, constant power load models are well known to induce unstable operating conditions.

To this end, we propose ZIP-E loads, a composite load model that has a ZIP load with a dynamic power electronic, or E, load model. We model the E load as a grid following converter that consumes, instead of delivers, real and reactive power.

We believe that ZIP-E loads provide a flexible alternative for load modeling during fast time scales: ZIP-E loads adopt i.) the common industry practice of ZIP loads, ii.) the notion that power electronic loads will behave as constant power loads in steady state, iii.) an energy buffer so the constant power constraint of the load is relaxed during transient events, and iv.) a physical representation of power electronic loads capturing the dynamics of new loads being incorporated into the grid.

For now, we do not incorporate motors as loads for two primary reasons: i.) we seek to identify the modeling impact of changing constant power, or P loads, to E loads, and ii.) most modern motor loads are interfaced with variable frequency drives, which inherently have a power electronics interface of the form we choose to model here.

In addition, by modeling loads in this way, we consider fast dynamics on both generation and load, meaning that fast line dynamics could be relevant. We investigate their effect as well.

Therefore, this research is guided by the following questions:

1. What, if any, qualitative differences are there between the conclusions of small signal stability analyses of power systems that use ZIP versus ZIP-E load models?
2. Can ZIP-E loads influence inverter current dynamics in ways not otherwise manifested by ZIP models?

To address these questions, we perform studies with load comparisons: we compare ZIP to ZIP-E loads (a ZIP-E load with no constant power portion) to assess the effect of modeling real life power electronic loads as constant power loads versus E loads.

Loads overall have a total real power consumption of P_0 , which is split among each of the ZIP-E components. For the analysis of ZIP to ZI-E loads, we increase the P (for ZIP) and E (for ZI-E) percentage of the load in 0.1 point increments from 0 to 1, while keeping the Z to I ratio constant.

We perform small signal and transient analysis of the IEEE WSCC 9 Bus test case with ZIP and ZIP-E load models, using both static and dynamic pi line models, while changing the loading of the network. That is, the default network has a nominal operating condition for the nominal load. We take this value and scale it by a factor *load scale* in order to change the operating condition of the network, resulting in a more heavily or more lightly loaded system.

Therefore, given an operating condition of the system by *load scale*, we run a small signal and transient analysis of that operating condition for each load and line model.

For the small signal analysis, we conclude that ZIP loads destabilize networks significantly faster than corresponding ZIP-E loads. We found that at higher loading conditions, the choice of load model had a larger effect on the overall placement of eigenvalues: eigenvalues moved more as a function of load model at higher loading conditions. For the transient stability analysis, results showed significantly larger oscillations for ZIP loads relative to ZI-E loads. Further, we find that a higher network loading condition is correlated with a higher sensitivity to load model choice.

In general, these results suggest that the constant power portion of the ZIP load has a large destabilizing effect and can generally overestimate instability, and that attention should be drawn to load model choice if operating near a stability boundary.

To summarize, our contributions are:

1. An analysis on load model effects on small-signal and transient stability of the IEEE WSCC 9 Bus Test Case.
2. A series of recommendations for load models for static and dynamic power system simulation studies.
3. ZIP loads with larger constant power portions induce larger oscillations in transient simulations relative to ZI-E loads which are significantly more dampened and converge more regularly.
4. ZIP_E_loads.jl - A software package for modeling ZIP-E loads compatible with PowerSimulationsDynamics.jl, a Julia-based open source simulation software for small signal, phasor, and EMT analysis of power systems.
5. An analysis of dq-abc signal relationships.

Future work includes:

1. Further studies with a larger test case.
2. Decreasing grid strength to study subsynchronous oscillations.
3. Changing generation location and portfolio to study its impact on small signal and transient analysis.

Project Publications:

- [1] Gabriel E. Colón Reyes, Reid Dye, Claire Tomlin, Duncan Callaway, “Effects of dynamic power electronic load models on power systems analysis using ZIP-E loads,” *accepted to North American Power Symposium*, October 2024.

Student Theses:

- [1] Gabriel E. Colón Reyes. High-fidelity modeling for modern power systems analysis and stability. PhD candidate at UC Berkeley. Expected graduation date May 2025.