A Planning Model for Improving Phase Balance Through Inverter Reactive Power Control

Key Highlights

- Phase imbalance caused by the growth of distributed generation can increase technical losses and reduce the efficiency of three-phase motors.
- NRECA worked with Argonne National Laboratory to develop a phase balancing control method for distributed generation.
- A tool for testing the impacts of these kind of controls called "phaseBalance" is now available to the co-ops on NRECA's Open Modeling Framework (OMF) website, omf.coop.

What has changed?

Growth in distributed generation is likely to increase phase unbalance across the grid. As a consequence, grid efficiency and the stability of three-phase motors are vulnerable. A number of utilities have experienced motor burnout issues as a consequence of unbalance, a large financial liability.

To model what corrective approaches may alleviate this issue, NRECA was recently funded by the Argonne National Laboratory to work with them in building and testing a visualization and monetization software application called the "phaseBalance" evaluation tool. The program uses Gridlab-D and a newly-developed optimization technique to see if a distributed inverter control program would help the cooperative control unbalance. This evaluation tool also simulates the economic impacts of dispatching a group of these controls. The tool is now available to the co-ops, and in this advisory, we describe this tool and how it has been tested with cooperative partners and can be used.

What is the impact on cooperatives?

The phaseBalance tool will allow co-ops to evaluate the consequences of implementing a distributed Steinmetz control method to their specific feeders. The tool will enable its users not only to see how distributed generation impacts their feeder overall, but also the financial consequences of the control implementation.

Cooperatives are encouraged to try the tool, send NRECA feedback (via the email addresses at the end of this advisory), and consider using it to determine the long-term effects of distributed generation. The

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efforts to contain unbalance on our test feeders have thus far been very successful, and we expect that distributed inverter controllers, as applied to other co-ops' feeders, will be similarly promising. Feedback is always welcome, and we will continue to make updates to the tool to better serve cooperatives.

How the Model Works

The phaseBalance model operates by calculating a number of variables, including power factor and unbalance, when all distributed generation is turned off. It then calculates the same variables when distributed generation is operating at full capacity. Then, the model implements the distributed inverter control algorithm and runs a final calculation of how this algorithm affects the feeder.

The inverter control method manipulates the reactive power contributions from each of the inverters to improve the phase balance. It does this by calculating the Steinmetz circuit equivalent for the system and solving an AC optimal power flow to determine the correct settings for each of the inverters. For the full details on this control method, please see "Applying Steinmetz Circuit Design to Mitigate Voltage Unbalance using Distributed Solar PV" by Yao et al.

We use the OMF's existing feeder-manipulation libraries to add recorders and collectors, so that Gridlab-D can perform advanced energy flow calculations. While the actual system is naturally dynamic, the current system performs only one-time step to simplify the cost-benefit analysis.

Cooperative Test Partners

To test out the effectiveness of the control algorithm, we generated model results for circuits from three cooperative partners: Owen Electric Cooperative, Southwest Arkansas Electric Cooperative, and Northeast Oklahoma Electric Cooperative. We were able to demonstrate that the Steinmetz technique is effective is reducing phase unbalance under future distributed generation scenarios by 2 percent on average. In future work, we will be looking at ways that this and other inverter control techniques can be deployed simply and cost-effectively.

What do cooperatives need to know or do about it?

The PhaseBalance evaluation tool is hosted on NRECA's Open Modeling Framework (OMF) website. To access the OMF, go to omf.coop, log in (create a free account if you do not have one), and select phaseBalance from the "New Model" drop down menu. You can also run the model directly by navigating to https://www.omf.coop/newModel/phaseBalance/ts2019pb.

The OMF is a website developed by NRECA. It is comprised of a set of Python libraries for simulating power systems behavior with an emphasis on cost-benefit analysis of emerging technologies: distributed generation, storage, networked controls, etc.

To run a simulation, a few things are required that are listed in the full documentation for the model:

https://github.com/dpinney/omf/wiki/Models-~-phaseBalance

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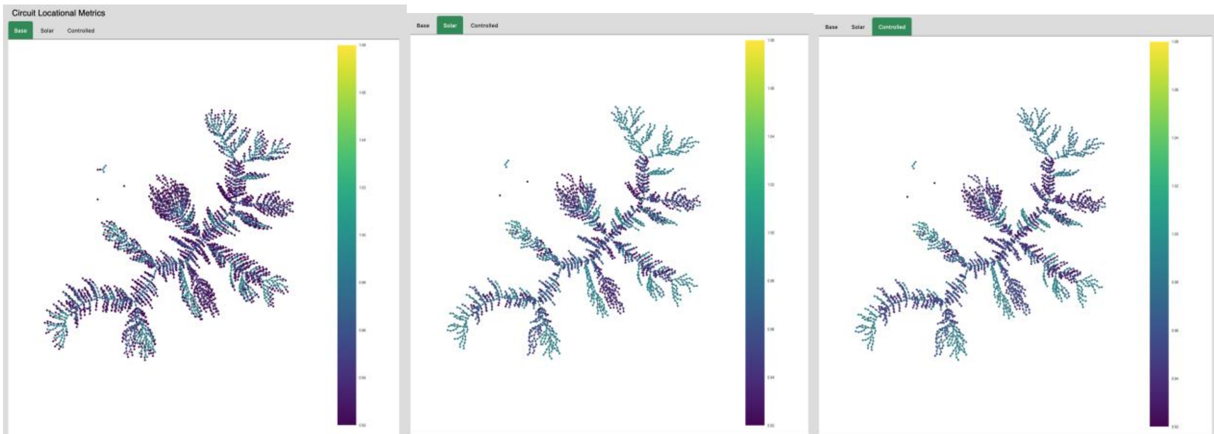
Once the required parameters and input files are loaded, the simulation can be run and will return results as follows:

1. A visual "before" and "after" diagram of the feeder, graphing the unbalance when there is no solar generation (left), full solar generation (center), and after implementing controller (right).



2. A summary of how Gridlab-D calculates the load, distributed generation, losses, all VARs, and power factor in each case. Assumed net metering when calculating energy revenue.

Feeder Power Summary

	Base Case	With Solar	Controlled Solar
Load (kWh)	7,437,015.00	7,437,015.00	7,437,015.00
Distributed Generation (kWh)	0.00	1,771,000.00	1,771,000.00
Losses (kWh)	366,615.48	304,685.52	286,535.02
VARs	4,163,707.17	4,033,110.64	4,719,987.32
Power Factor	0.87	0.81	0.77

3. A summary of inverter outputs in volt amps, giving the user a detailed look into how the controller is manipulating each inverter. All results are searchable and sortable.

Inverter Power Outputs

Search:

	Uncontrolled Solar			Controlled Solar		
Name	AB (VA)	BC (VA)	AC (VA)	AB (VA)	BC (VA)	AC (VA)
test_solar_inverter_1	3000-0j	-0+0j	-0+0j	3000-4084.51j	-0+0j	-0+0j
test_solar_inverter_10	1000-0j	-0+0j	-0+0j	1000-4084.51j	-0+0j	-0+0j
test_solar_inverter_100	-0+0j	-0+0j	1000-0j	-0+0j	-0+0j	1000+9949.87j
test_solar_inverter_101	2000-0j	-0+0j	-0+0j	2000-4084.51j	-0+0j	-0+0j

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4. A summary of how every three-phase motor on the feeder is affected by each case. Unbalance is calculated as specified by the user, and then motor efficiency is calculated using a polynomial fit to calculations posted by the EERE. The tables are sortable and searchable.

Three Phase Motor Loads Voltage and Imbalance

Base

Search:

Name	Total kW	Total VARs	A (V)	B (V)	C (V)	Unbalance	Motor Efficiency
R1-12-47-1_load_11	27,251.01	10,638.45	262.70	252.34	245.47	2.36	98.29
R1-12-47-1_load_19	43,110.30	16,829.70	269.38	265.19	263.20	0.79	99.58
R1-12-47-1_load_20	32,165.10	12,556.86	262.58	258.94	257.20	0.72	99.62
R1-12-47-1_load_4	25,017.30	9,766.47	263.69	253.38	246.54	2.33	98.32
R1-12-47-1_load_5	90,979.80	23,805.75	266.58	256.40	249.66	2.29	98.36
R1-12-47-1_load_6	47,354.10	18,486.51	267.02	256.88	250.16	2.24	98.41

Solar

Search:

Name	Total kW	Total VARs	A (V)	B (V)	C (V)	Unbalance	Motor Efficiency
R1-12-47-1_load_11	27,251.01	10,638.45	264.09	254.86	246.63	2.60	98.03
R1-12-47-1_load_19	43,110.30	16,829.70	269.99	266.19	263.74	0.88	99.52
R1-12-47-1_load_20	32,165.10	12,556.86	263.11	259.80	257.67	0.80	99.58
R1-12-47-1_load_4	25,017.30	9,766.47	265.07	255.89	247.69	2.58	98.06
R1-12-47-1_load_5	90,979.80	23,805.75	267.95	258.88	250.79	2.54	98.10
R1-12-47-1_load_6	47,354.10	18,486.51	268.38	259.35	251.29	2.48	98.16

Controlled

Search:

Name	Total kW	Total VARs	A (V)	B (V)	C (V)	Unbalance	Motor Efficiency
R1-12-47-1_load_11	27,251.01	10,638.45	263.04	248.57	251.73	0.36	99.82
R1-12-47-1_load_19	43,110.30	16,829.70	269.64	263.73	265.81	0.07	99.95
R1-12-47-1_load_20	32,165.10	12,556.86	262.81	257.67	259.48	0.12	99.93
R1-12-47-1_load_4	25,017.30	9,766.47	264.02	249.63	252.76	0.34	99.83
R1-12-47-1_load_5	90,979.80	23,805.75	266.91	252.70	255.80	0.34	99.83
R1-12-47-1_load_6	47,354.10	18,486.51	267.36	253.19	256.28	0.29	99.85

The model outputs also include a table with detailed monthly power, energy, and cost data with and without the virtual batteries impact. Additional details about the model can be found at https://github.com/dpinney/omf/wiki/Models-~-phaseBalance.

Detailed Scenario Analysis

By using the inputs on the following page, the distributed inverter control algorithm dramatically reduced the amount of unbalance on the system. Losses decreased by 6 percent (from the "Solar" to "Controlled" cases), but more importantly, the largest unbalance recorded on three phase motors dropped from 2.60 to 0.37, dramatically reducing the risk of motor burnout and increasing efficiency.

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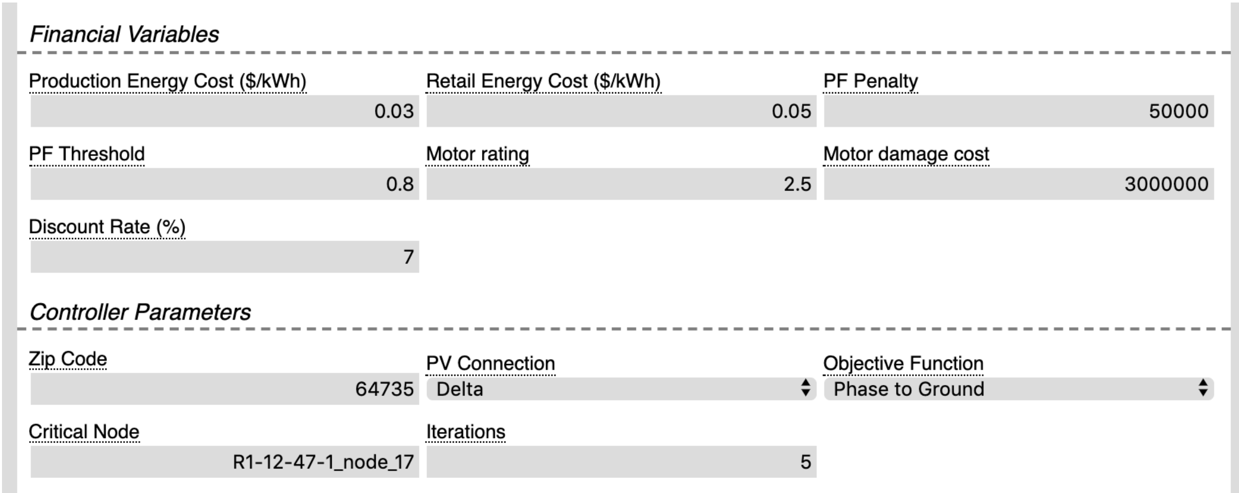

The financial and control inputs for test case.

The feeder is an example taken from a collection of taxonomic feeders from the Pacific Northwest National Laboratory (PNNL). Solar panels were then added to the example feeder.

Additional Resources

- Try out the model: https://www.omf.coop/newModel/phaseBalance/ts2019pb
- Documentation for the model: https://github.com/dpinney/omf/wiki/Models-~-phaseBalance
- Open Modeling Framework (OMF): https://www.omf.coop
- More information about the OMF: https://www.cooperative.com/programs-services/bts/open-modeling-framework/Pages/default.aspx

Contacts for Questions

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