Investigating Solutions to Voltage Increase on Distributed Generation Power Systems

Dec1613
Adam Beck - Team Leader
Matthew Ladd - Webmaster/Key Concept Holder
Trevor Andersen - Communications Leader

Advisors - Anne Kimber, Zhaoyu Wang
Client - Maquoketa Valley Rural Electric Cooperative (MVEC)

Email - dec1613@iastate.edu
Website - http://dec1613.sd.ece.iastate.edu

Background

MVEC serves a mostly rural area of Iowa (agricultural loads, residential loads, and commercial loads)

MVEC has 36 substations with 118 feeders, some of which consist of long, single phase, radial lines which are fairly low loaded

Tax credits and support for green energy are causing an increase in Distributed Generation, namely solar arrays, on MVEC's distribution systems

With tax credits being based on the size of the solar array installed, homeowners and farmers may be tempted to oversize their solar arrays and sell power back onto the grid (at MVEC's avoided cost rate)

The average currently installed solar array size is 15kW, with the largest being 110kW

MVEC has no say in the sizing of the solar, entirely based on customer decision

Project Importance

Solar is becoming cheaper and more accessible for average consumers and Investment Tax Credits make installing panels even more economical, up to 46% of cost

Power systems are traditionally modeled and designed for one directional flow, and are not well equipped to deal with distributed generation of any kind

Solar technology has evolved much faster than the grid technology that accommodates it and there aren't established solutions

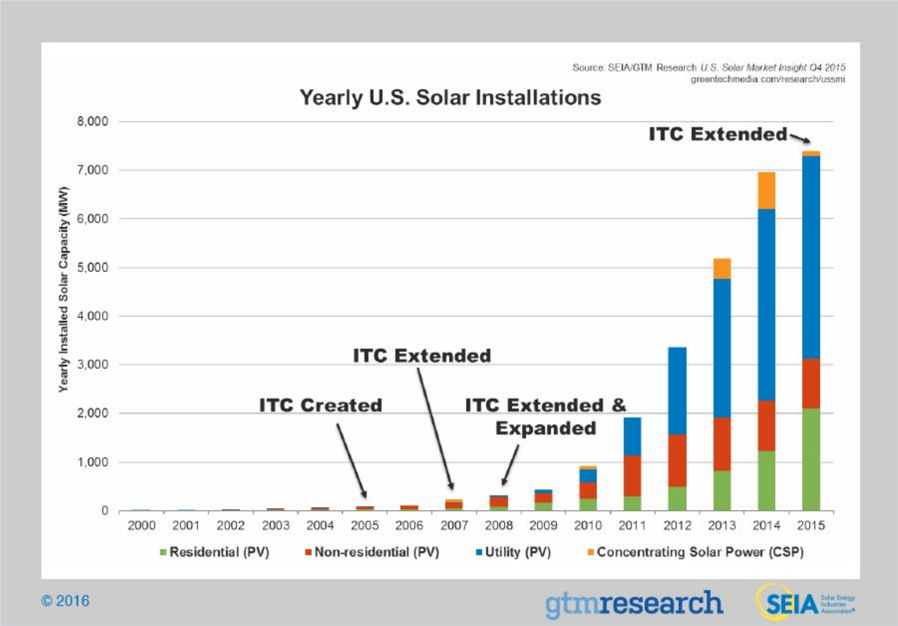


Figure 1: Yearly Solar Installations
Solar Energy Industries Association: www.seia.org/research-resources/solar-industry-data

Why It’s Happening

When loads are low on cool, sunny days around noon (most residential customers aren’t home), solar panels are sending most of the energy generated back onto the grid. With too many kW being put back onto the grid, we see a rise in voltage on MVEC’s lines.

Simply Put:

|P|=|V||I|*PF

V=IR

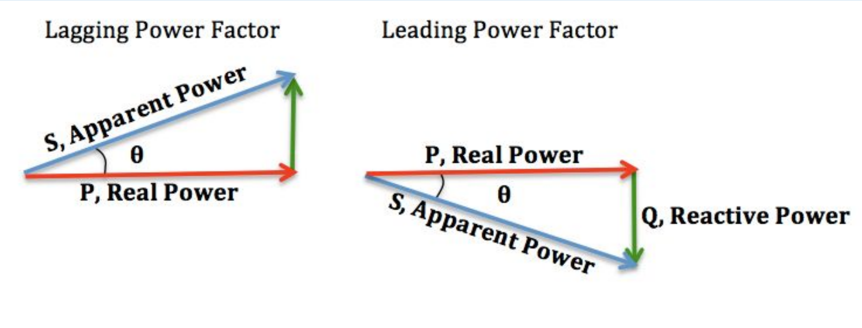


Figure 2: Lagging Power Factor vs Laeading Power Factor: https://en.wikipedia.org/wiki/Power_factor

Project Scope

1. Task was to assess the vulnerability to overvoltage of the substation feeders by applying a spread out percentage of the load across all consumers evenly.
2. Finding the worst case scenario for location of solar arrays and sizing them for overvoltage conditions.
3. Testing what Load Tap Changer/voltage regulator settings could fix this overvoltage issue.
4. Finally testing the power factor control of inverters/smart inverters to reduce the voltage.

In summary the project scope was to find a worst case scenario and solve the overvoltage issue.

Our Data

From MVEC we received a model of three substations and their feeders. It is on this model that our tests were performed. Models included each consumer’s kW and kVAR load at noon.

AMI data showing daily kWh usage for each meter on the system for a year. (~40,000 data points per feeder). Individual daily kWh usage ranges between ~900 kWh and ~0.2kWh

SCADA data showing substation information in 15 minute increments (~35,000 data points per substation)

Our Approach to Properly Sizing Solar to Consumer

Analyze each consumer’s AMI data

Determine average monthly kWh usage over 6 month period

Assumed 100% of load desired to be fed from solar array (Worst case)

http://www.wholesalesolar.com/solar-information/start-here/gridtie-calculator

Divide avg. daily kWh usage by avg. hours of peak daylight (roughly 4.2 hours)

Result is minimum solar array size assuming Unity Power Factor (Results were verified)

Massive range in kW sizes, from 0.1 kW to about 65 kW

Model Conditions and Assumptions

Loads are modelled for noon at May 4th, 2015. May 4th is a relatively low loaded day while solar irradiance has already peaked for the summer, remaining peaked until late august.

Assuming solar is producing at nameplate AC values

All consumers are candidates for any size of solar

No solar is currently installed on any feeders

Line voltages are referred to customer side voltages for ease of understanding the effects on customers

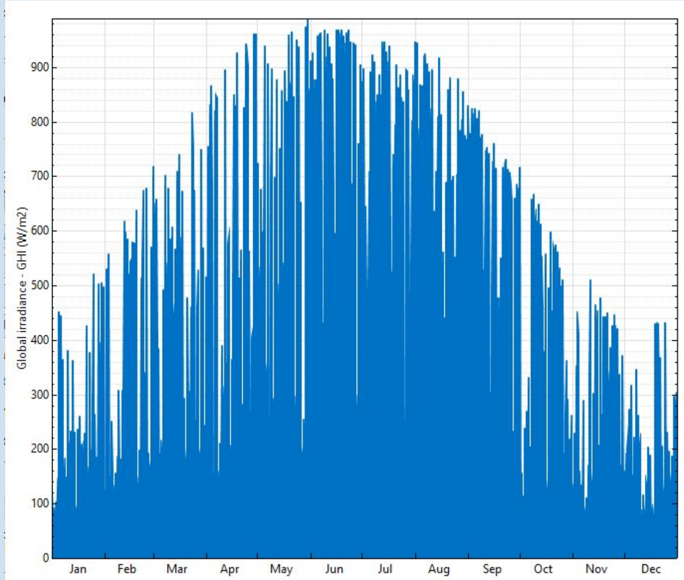


Figure 3: Daily Solar Irradiance for 2015
From NREL System Advisor Model software

What You Will See

- A substation (Backbone) with all consumers having 100% of the load of the substation equally distributed among all solar arrays (3.3kW)

- A substation (Backbone) with solar on the ends of lines, sized to overvoltage conditions
    - With a voltage regulator at the substation reducing voltage out to 123V

- A different substation (Bernard) with solar on the ends, sized to overvoltage conditions
    - A specific branch with solar properly sized to consumers’ needs at Unity PF, then 0.95 leading PF
    - The entire feeder with solar at 0.95 leading PF

Backbone Vulnerability

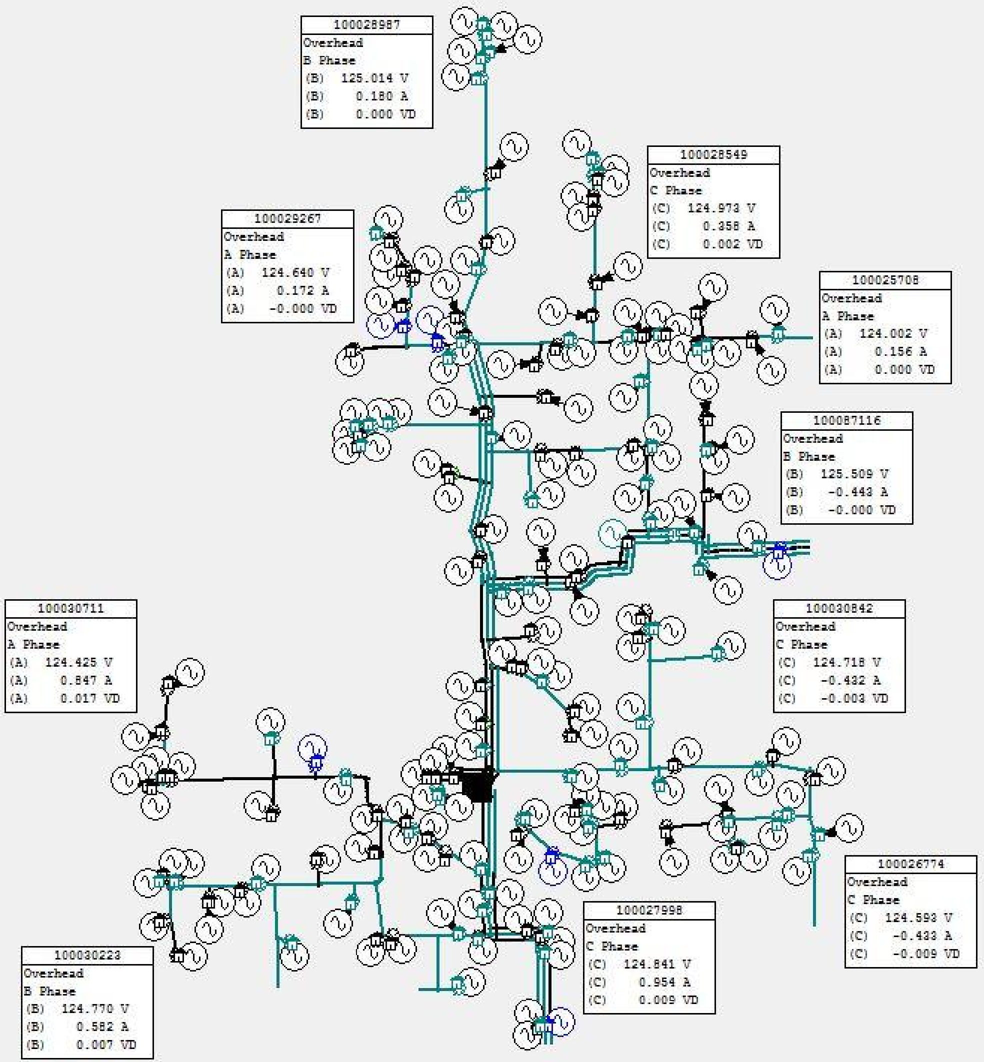
100% of load generated by solar spread across all customers.

Each solar array is 3.3kW

Color Scheme:

Blue -> Overvoltage

Turquoise -> Power Factor below 0.8

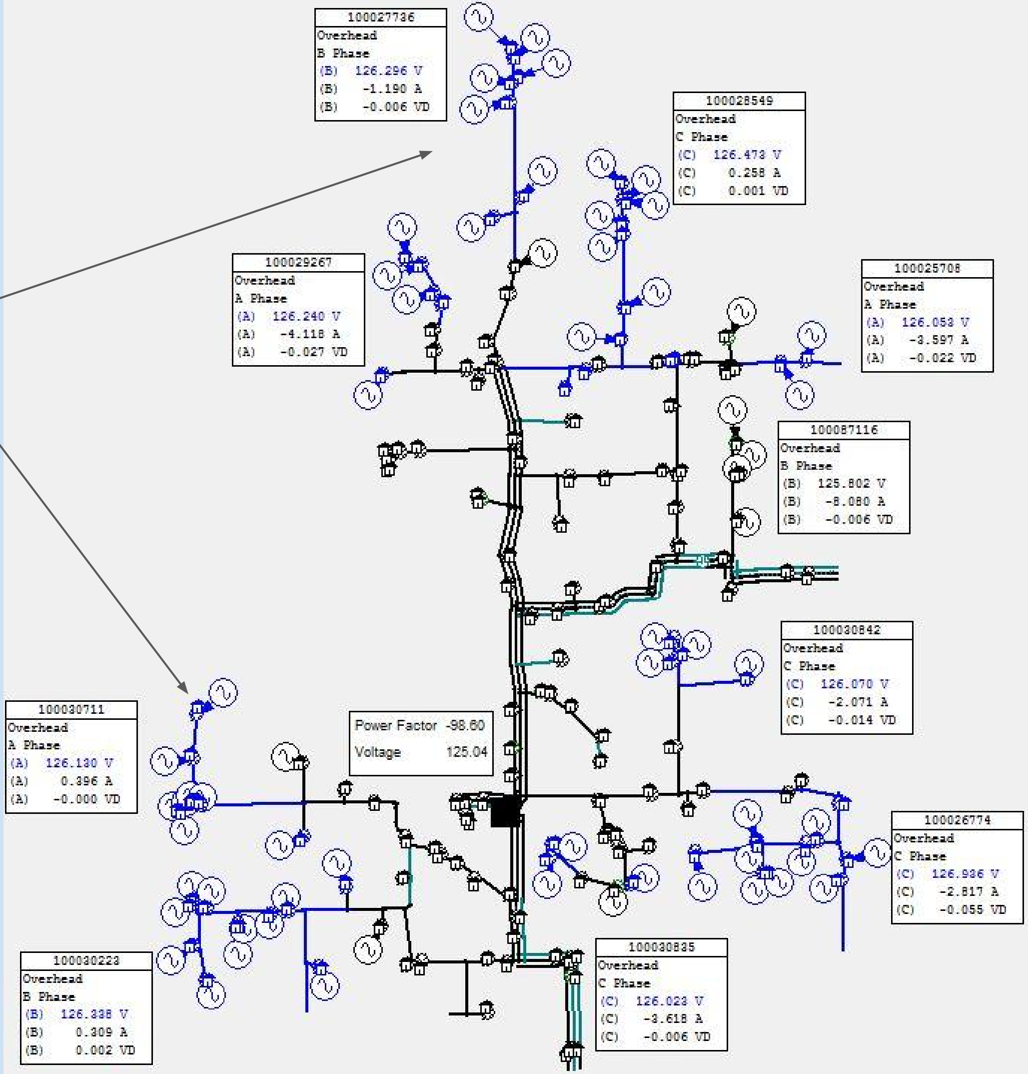


Backbone End Of Line Generators

Feeders with overvoltage to apply fixes to.

Two lines overvoltaged with recommended minimum size solar array.

The other ends were upped by 2kW on each solar array of the non-overvoltaged branches until they became overvoltaged.



Backbone Voltage Regulator Set to 123V

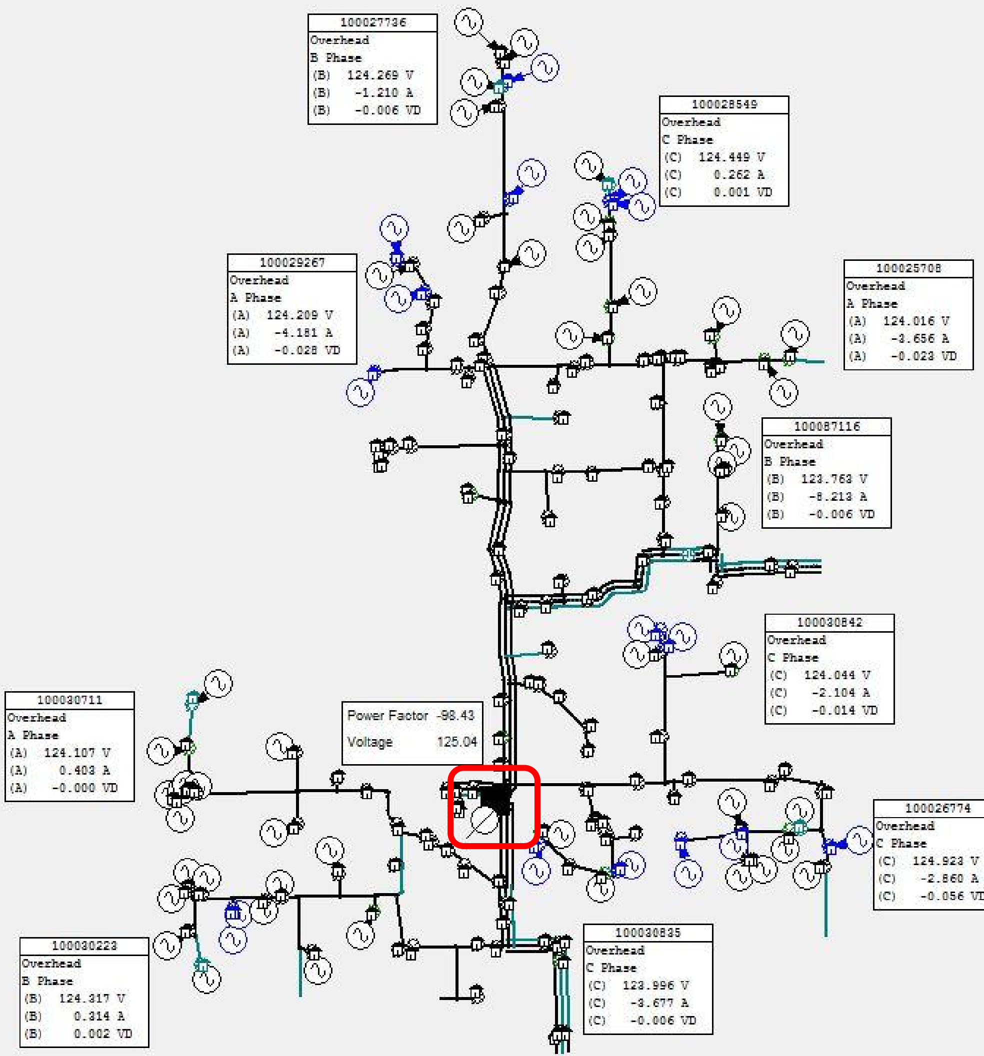
Same generator values as previous slides at unity PF

Substation voltage reduced to 123V from the standard 125V by use of voltage regulator

No lines are overvoltaged (blue)

Again, MVEC is only concerned with the lines being overvoltaged, not each customer

Substation voltage regulation worked for the 3 substations tested

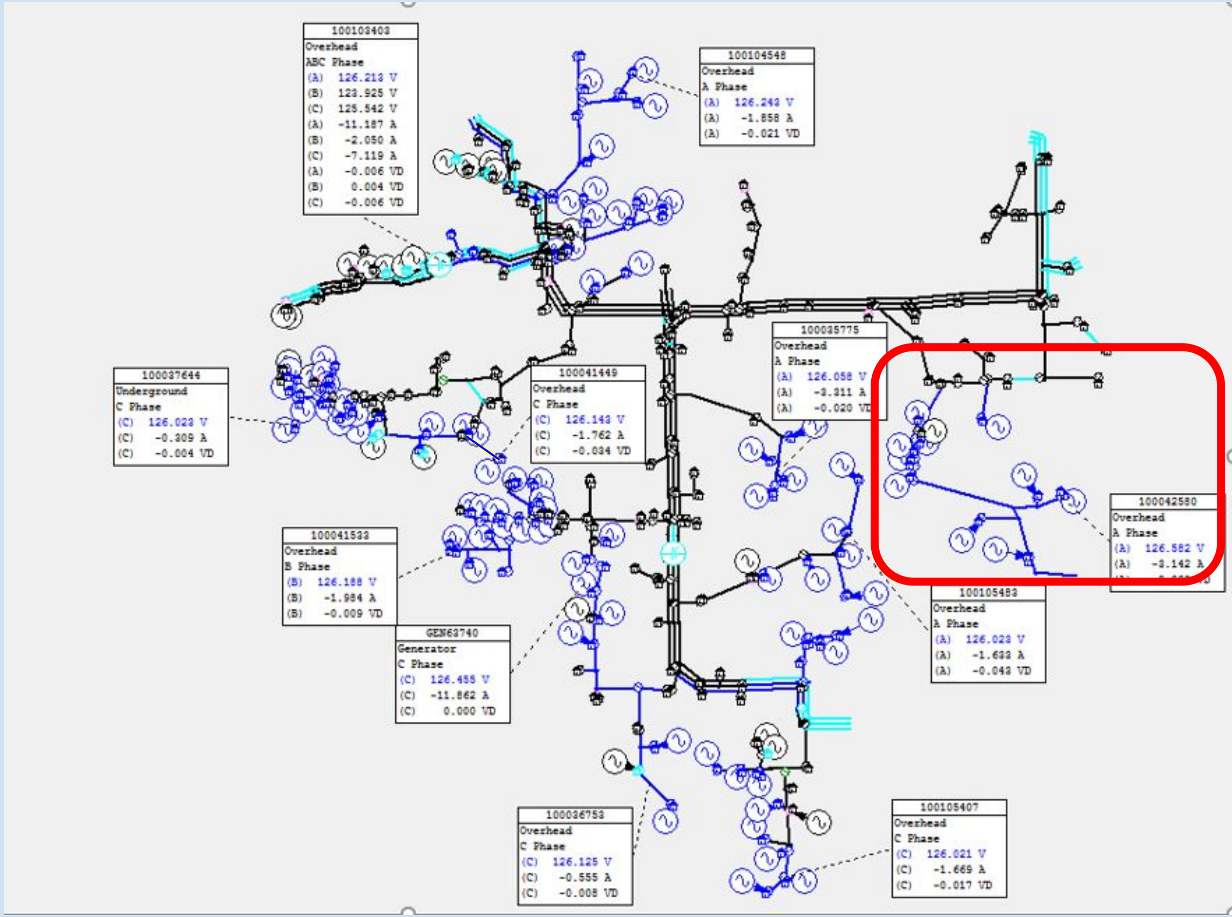


Bernard Substation Overvoltage

Bernard substation model at significant overvoltage conditions.

All solar is at Unity PF

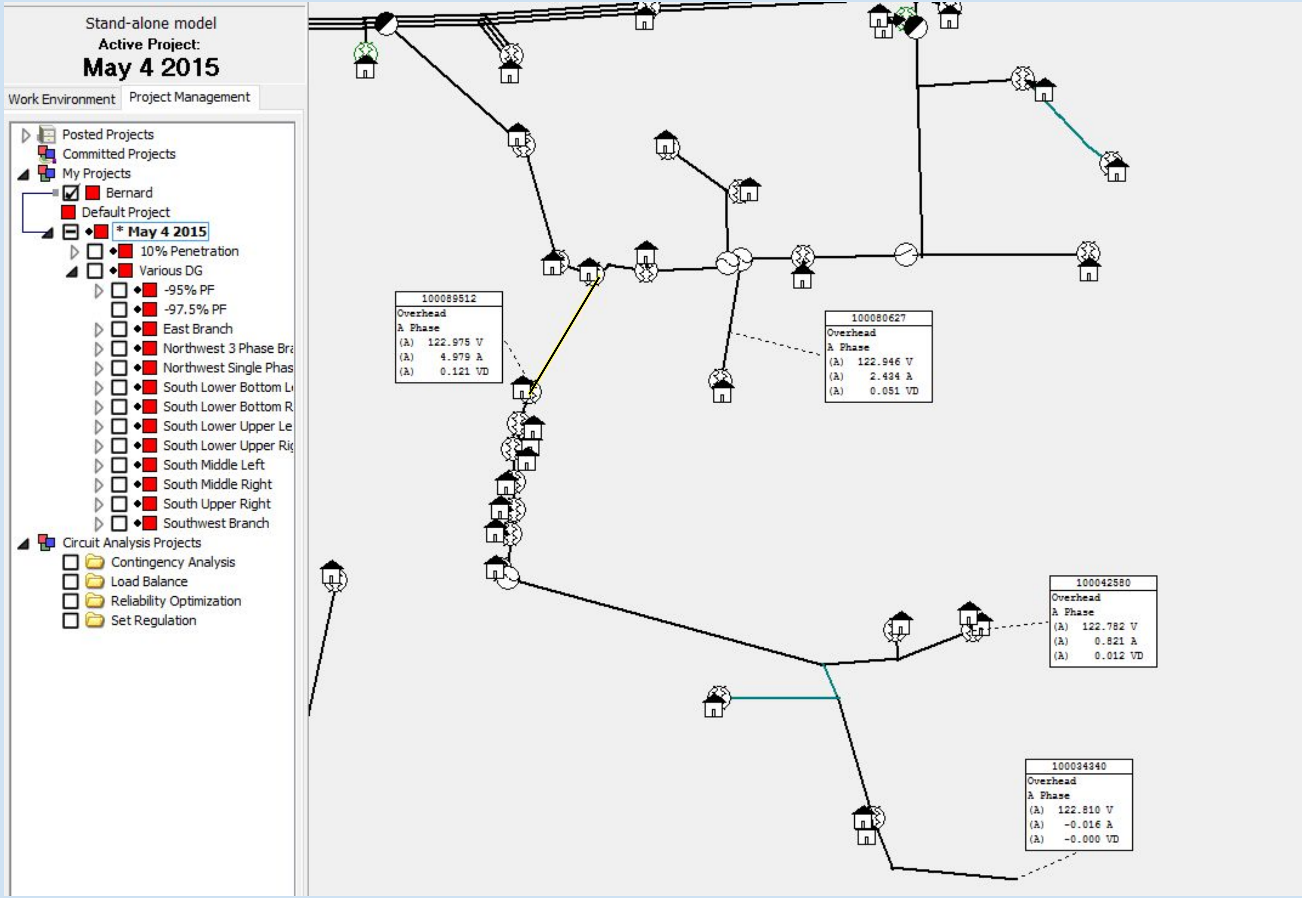
We'll look more specifically into the branch in the red box



Blue-->Overvoltage
Cyan-->Power Factor below 0.8

Initial Bernard East Branch Voltage Conditions

We see that without any solar arrays on the Bernard system, the voltages at this East Branch are right around 123V, comfortably within MVEC's range of 118V to 126V



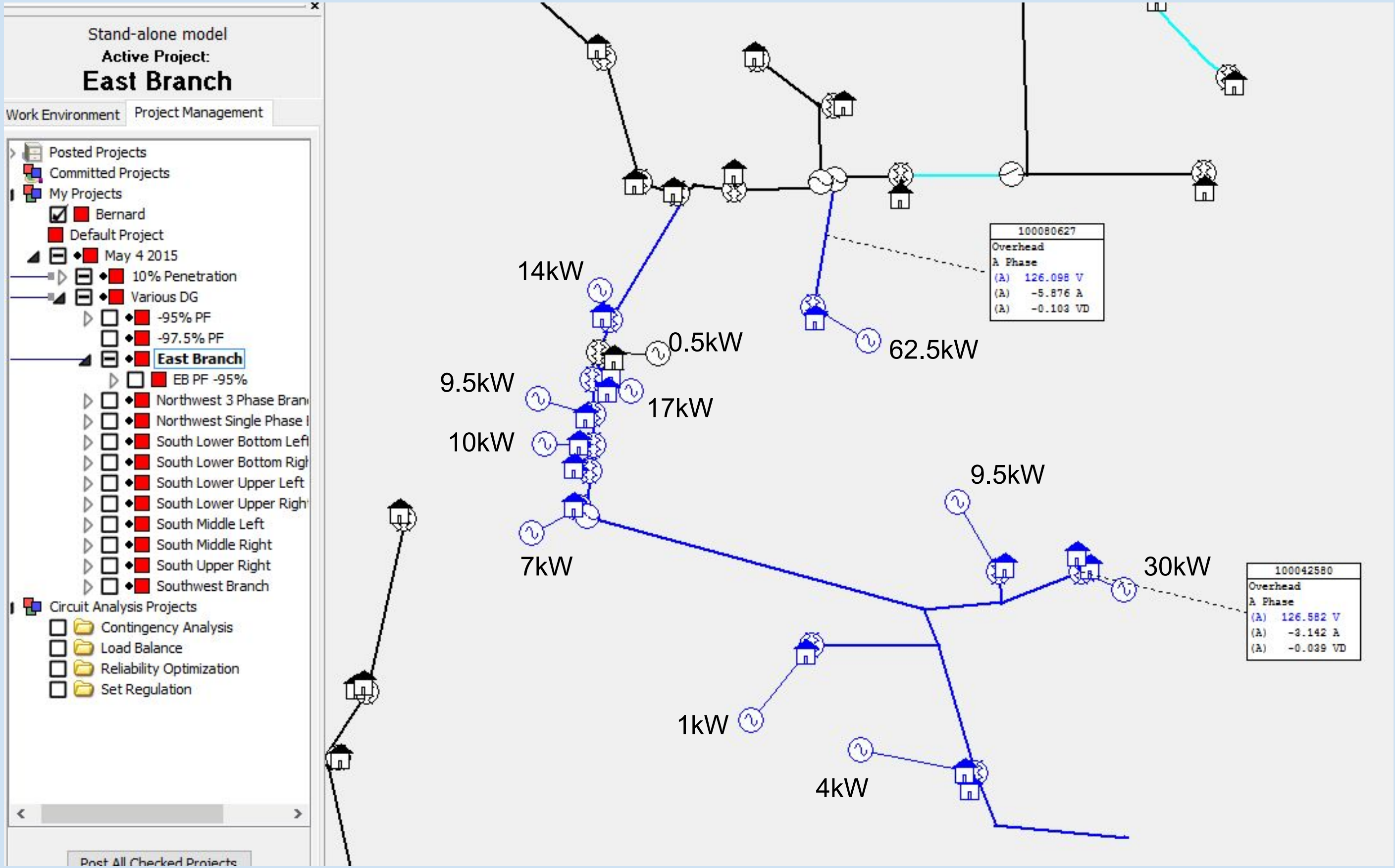
Bernard East Branch at Unity PF

All other generators removed from Bernard System

Generators sized to consumer's monthly kWh usage

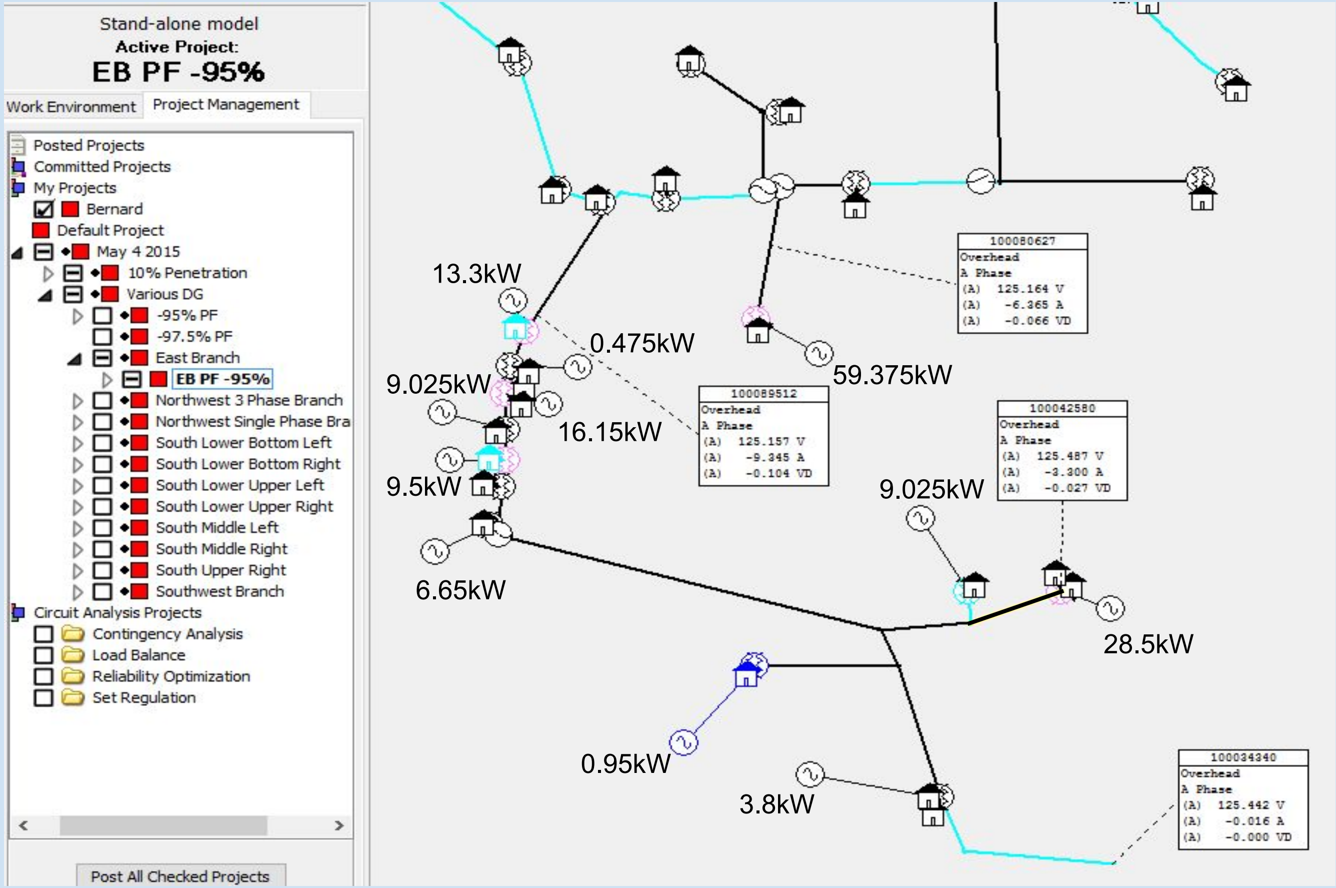
All generators have Unity PF

Removing the 62.5kW generator brings voltage back below 126V



Bernard East Branch at 0.95 leading PF

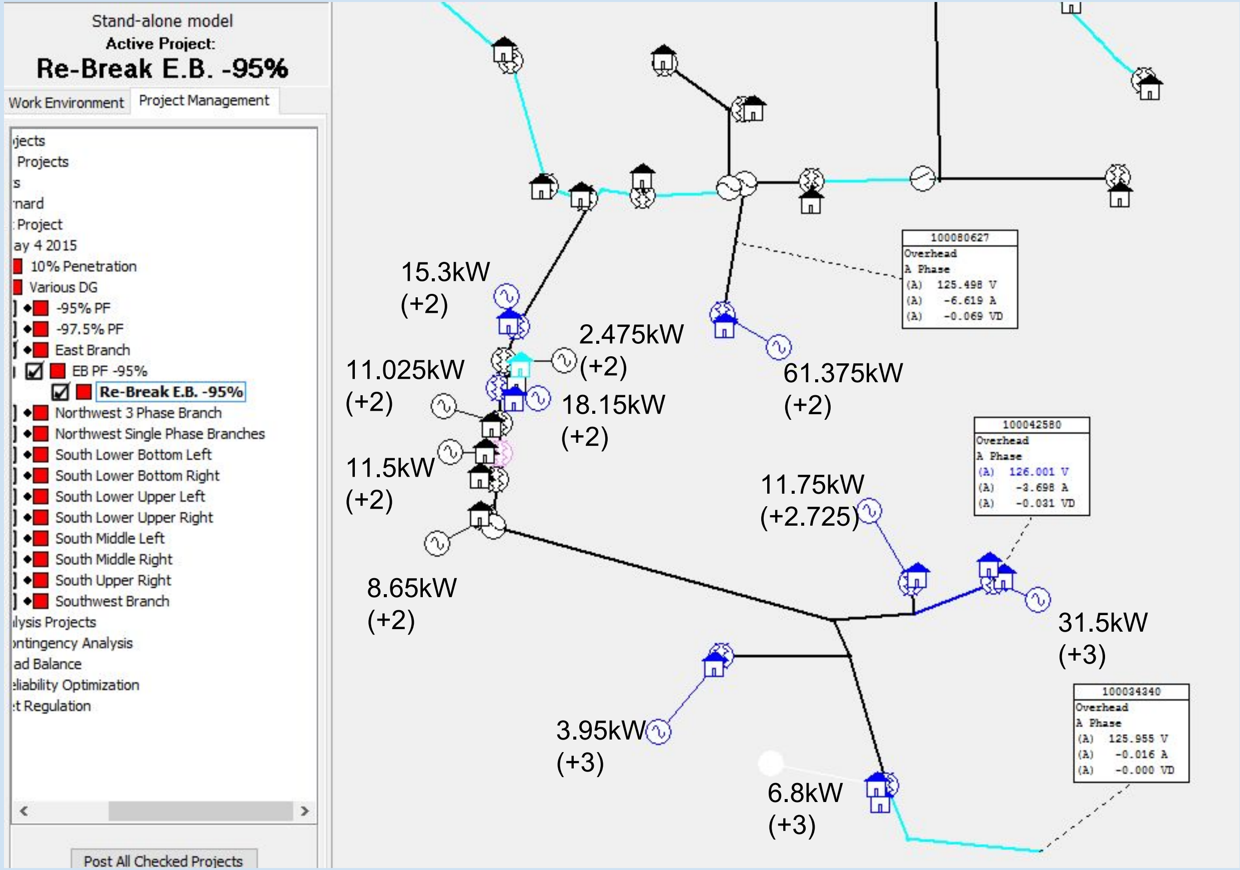
With the generator kW and kVAR values changed to reflect a 0.95 leading Power Factor, the voltages have fallen below the 126V limit



Bernard East Branch at 0.95 Leading PF at Overvoltage

To test the effectiveness of the 0.95 leading Power Factor fix, the kW value of each generator was increased 1kW at a time until a section of line overvoltaged.

As seen, an increase of 3kW at the end of the lines and 2kW elsewhere with the Power Factor remaining at 0.95 leading results in a slight overvoltage.

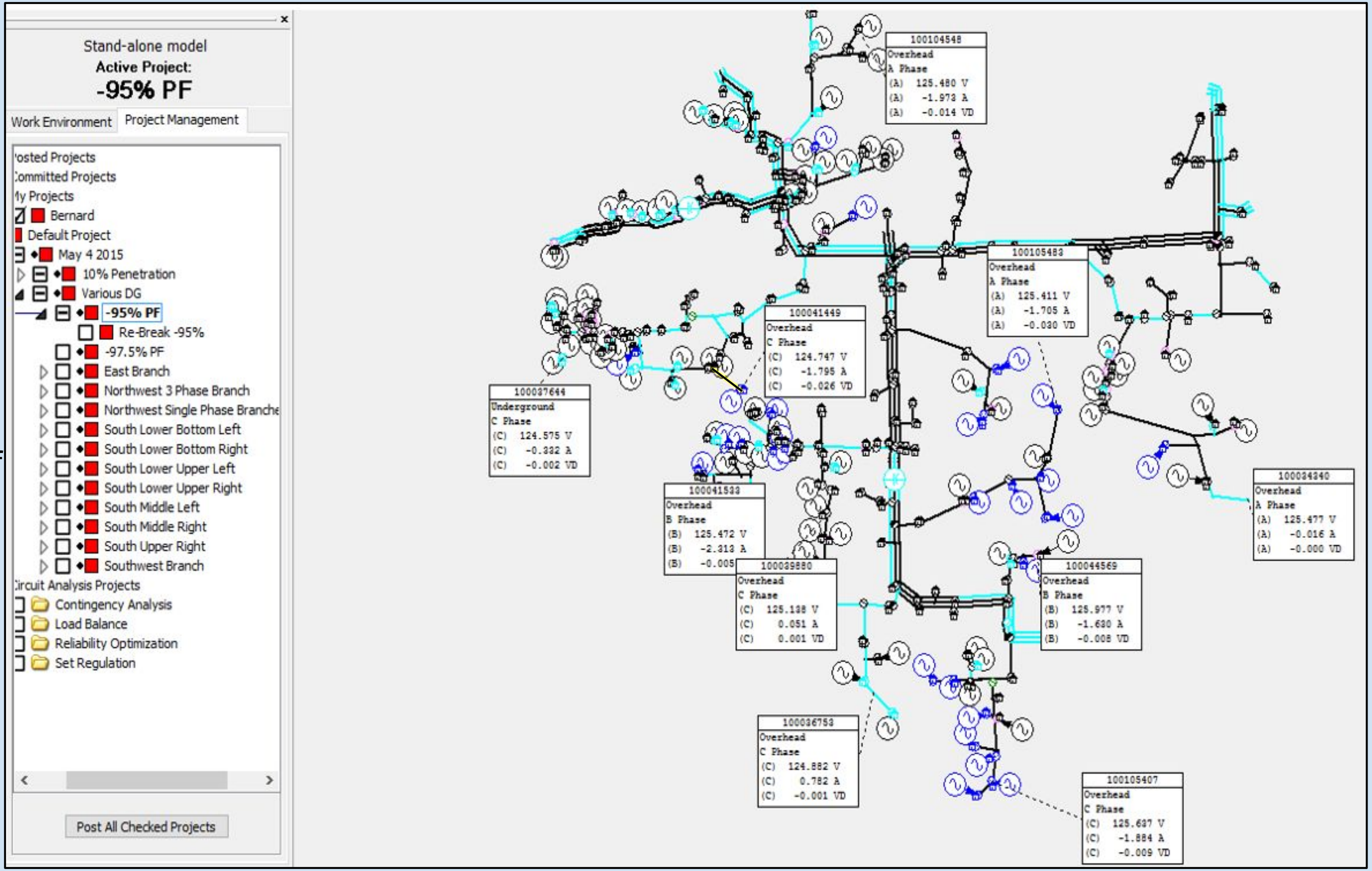


Bernard With All Generators at 0.95 Leading PF

With the generator kW and kVAR values changed to reflect a 0.95 leading Power Factor on the generators, we see that all lines have been reduced below the upper voltage limit of 126V

MVEC will need to be aware of a <0.8 Power Factor value at the substation.

Blue-->Overvoltage
Cyan-->Power Factor below 0.8
Ignore Yellow



Solutions

Substation voltage regulation below 124V cost more to both customer and MVEC and are only effective in some situations.

Curtailment of solar output is effective at reducing voltage, but is not desirable for the customer, as they lose the option to sell power back to MVEC.

Solar inverters set to a 0.95 leading PF were able to solve all the overvoltage conditions we created on the model. This is a small change compared to that of other parts of the US. For example, California and Hawaii require their smart inverters to be able to go between 0.85 PF leading and lagging.

However, the constantly changing state of the solar industry and the complex nature of power flow makes it much more desirable to have the variety of possible settings and options (grid-follow technology, autonomous PF control, autonomous Watt/VAR control) provided by a smart inverter to prevent an unforeseen problem.

Smart Inverter Information

Hawaii standard interconnection agreement
https://www.hawaiianelectric.com/clean-energy-hawaii/producing-clean-energy/standard-interconnection

List of smart inverters that fit Hawaii's grid interconnection agreement and Rule 14H
https://www.hawaiianelectric.com/Documents/clean_energy_hawaii/list_of_advanced_legacy_equipment.pdf#page=4

Example of smart inverters that fit Hawaii's grid interconnection agreement and Rule 14H
http://www.sma-america.com/products/solarinverters/sunny-boy-3000tl-us-3800tl-us-4000tl-us-5000tl-us-6000tl-us-7000tl-us-7700tl-us.html

Questions?

Email - dec1613@iastate.edu
Website - http://dec1613.sd.ece.iastate.edu