DEC 1613

Investigating Solutions To Voltage Increase On Distributed Generation Power Systems

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1. Introduction

1.1 Project Statement

As solar panels become cheaper and there is a larger push for green energy, more and more homeowners, farmers, and businesses are installing solar arrays to serve their electricity needs. Maquoketa Valley Energy Cooperative (MVEC) serves rural Iowa which has agricultural loads, residential loads, and some commercial loads spread across long, radial, single phase lines. With solar array installs currently reaching up to 110 kW on some of MVEC's feeders, and since MVEC has no say in the consumer's sizing of their solar array, they are concerned that too much solar in places could result in an excess of power being put back onto the grid which in turn could result in lines becoming overvoltaged which could lead to equipment damage. We were tasked with determining what solutions could reduce the potential overvoltages caused by solar and allow for an increase in the amount of Distributed Generation (DG) that MVEC's feeders can handle. Specifically, we tested if changing the solar inverter power factor settings would be able to sufficiently reduce the voltage on distribution lines away from the overvoltage conditions, and also if changing the voltage regulation at the substation would reduce the impact of voltage rise caused by DG.

1.2 Background

Due to tax credits and purchasing of excess power from DG in the United States, many homeowners, farmers, and businesses across the U.S. are finding it beneficial to install solar arrays and some may be tempted to oversize their new solar installations. As more and more solar arrays are installed on the same feeder, MVEC is concerned that during periods with high solar irradiance but low loads, particularly around noon, voltage increases could occur on feeder lines. The solar panels will be producing maximum power but the homes and farms may only require a small amount of power, since most people will be at work at noon during the week. This excess power has nowhere to go but back onto the power lines, which in some cases may drive the voltage on the lines outside of ANSI limits (ANSI standard C84.1 Range A, 114 V to 126 V, referred to the consumer side voltage). When overvoltages occur, damages to both grid and consumer equipment can occur. Additional distribution line equipment, line upgrades, or special settings on existing equipment will be needed to bring the voltage on the feeders back within acceptable voltage limits.

1.3 Data

The data we received from MVEC is based on Advanced Metering Infrastructure (AMI) data and Supervisory Control and Data Acquisition (SCADA) data for each substation and feeder system. Our AMI data is given in 1 day intervals starting on January 1st, 2015 and ending on December 31st, 2015. Every consumer on the system has 365 data points, resulting in 60,000-112,000 data points per substation. AMI data gives the daily KWh usage for each consumer on the feeder. The SCADA gives us the power output of each substation in 15 minute intervals for the entire year, resulting in ~35,000 data points per substation. The SCADA data was used to confirm that May 4th, 2015 was a relatively low load day while the AMI data was used to size consumers' solar arrays, as described in section 2.3.

MVEC also provided us with the base case model of each of the 3 substations in WindMil. Within these models, MVEC included each consumer's respective kW load at noon on May 4th, 2015, but no consumers were modeled as having a solar array.

2. Design/Process

2.1 Model Conditions And Assumptions

The system is modeled in the WindMil software and the base case of our model was provided by MVEC. The provided model is comprised of three separate substation systems (Backbone substation, Bernard substation, and Monmouth substation) and their component feeders, each of which was tested independently of the other two. The provided WindMil model included substation and individual consumer loads (in kWs and kVARs) for noon on May 4th, 2015 and included all line and equipment characteristics. MVEC's SCADA data shows that May 4th at noon represents a relatively low loaded day, and loads at noon tend to be at a daily low while solar irradiance is at its peak. Additionally, as shown in Figure 1, daily solar irradiance reaches a high plateau in late April through early August, meaning that a solar array's output will be at its summertime peak for May 4th.

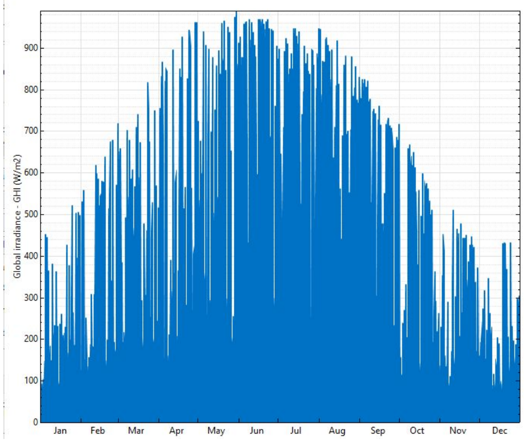


Figure 1: Graph of daily solar irradiance generated from National Renewable Energy Laboratory's (NREL) System Advisor Management (SAM) Software

These model conditions represent a worst case scenario, and therefore a good contingency to plan against. Periods of time with a higher load or lower solar irradiance will create less of a contingency since problems only worsen as generation increasingly exceeds the load consumption.

We created our test case under the following assumptions:

A. Consumer loads are at levels corresponding to noon on May 4th, 2015 to represent a low loaded day
B. May 4th is at a point when solar irradiance is essentially at a maximum for the

summer.

C. No solar arrays have been installed on the system prior to our analysis. All distributed generation on the model is specified and created by our team.
D. All consumers are equal candidates for any size of solar array, neglecting real world constraints of available space, pitch, and roof direction facing.
E. All solar arrays are operating at their nameplate AC power generating capacity. For the purpose of our analysis, the sun at noon is assumed to be free from cloud cover or other obscurations.
F. A contingency is only considered to have occurred if the overvoltage is on a line. An overvoltage on the consumer side of the local transformers is of no concern to our results.

2.2 Vulnerability Of A feeder - All Consumers Given A 3.3 kW Solar Array

This was a test to determine conditions which cause overvoltage and how vulnerable the system is to overvoltage. Using the SCADA data of the Backbone substation we were able to get the total amount of kilowatt load on the substation. Using this information we gave every consumer a 3.3 kW solar array. The amount of kilowatts produced was based on a 100 percent of the total kW load obtained from the SCADA data and distributed to every solar array evenly. While this test case cannot be considered a realistic scenario, it showed that distributed generation installed on a system must overproduce for the attached loads on that branch in order to create an overvoltage condition. Further results are described in detail in section 3.1.

2.3 Breaking The Model

Our second approach to applying solar to the consumers was to apply solar arrays to consumers on the ends of the lines with the solar arrays sized to an individual consumer’s energy consumption (Section 2.4 below). In most cases, applying correctly sized solar to the consumers on the ends of the lines did not result in overvoltage. In order to get the overvoltage that we required for our test cases, each array was increased by 2 kW until some part of the line was overvoltaged. This was repeated until all the end lines had a case of overvoltage.

2.4 Sizing Solar Arrays To Consumer Load

In order to model realistic situations, we determined that attempting to properly size the solar installations to each consumer’s individual needs was necessary. Using the AMI data provided by MVEC, we were able to look at each consumer’s daily kWh consumption during 2015. By finding the average monthly kWh consumptions of consumers over the six month period with the highest overall kWh consumption, we could find the minimum size solar array recommended for that particular consumer. To size the arrays, we took the approach of putting ourselves in the shoes of a consumer interested in sizing a solar array. We used Google to search for a way to size solar arrays and found the website http://www.wholesalesolar.com/solar-information/start-here/gridtie-calculator, where you enter your average monthly kWh usage, the percentage of power desired to come from solar (100% in our case), and the average number of peak sunlight hours over the year which is approximately 4.2 hours for the Anamosa/Cedar Rapids area according to NREL. The website then returns the minimum solar array size required by dividing the monthly kWh usage (altered by the percentage of power desired from solar) by 30 days per month, and dividing that number by the hours of peak sunlight (4.2 hours). We confirmed the mathematics of the website and got exactly the same results using hand calculations. We used each consumer's suggested minimum solar array size as the starting point for their solar array size.

2.5 Voltage Regulation/ Load Tap Changing Transformer (LTC)

This was a test to decrease the substation voltage from 125 V to offset the voltage rise. In order to bring the voltage down we considered a LTC transformer to change the voltage of all three phases. Another way to accomplish this is to put a voltage regulator on each phase individually just outside the substation. In the model, adding a regulator after the substation provided the voltage control abilities we desired, with the results discussed below in section 3.2.

2.6 Inverter/Smart Inverter testing

To test the effects of different solar inverter power factors on the overvoltage conditions in the model, we changed the solar generator settings in WindMil to reflect the adjusted real power production and power factor setting. When at unity power factor (1.0 PF), the apparent power is purely real power, meaning the generator kW setting is the generator kVA. To calculate each generator's kW after a power factor change, we took the apparent power of the solar generator (the solar arrays kW production at overvoltage conditions) and multiplied it by the magnitude of the desired power factor. We then replaced the solar generator kW value with this new, adjusted value and replaced the unity power factor setting with the desired power factor. WindMil automatically generates the imaginary power value (kVAR value). All solar arrays were adjusted to have to same power factor setting before running the simulation.

To confirm the effectiveness of our solution, we tested the power factor settings in two cases per substation model: the three substations modeled with solar generators at overvoltage conditions at the ends of the lines/branches and also on a per-branch basis, where we modeled only one branch at a time with solar generators causing overvoltage on that particular branch.

2.7 Rebreaking The Model After Inverter Change

While leaving the power factor at the new value, we increased the solar array's total kW by 2 kW per solar array, running the simulation, and repeating until a branch reached overvoltage conditions again.

3. Results

3.0 Color Scheme

In the following images, an element (line, transformer, generator, consumer, etc) shown in a dark blue color is has an overvoltage condition. We are only concerned about MVEC’s lines being overvoltaged and we are not concerned by any consumers (denoted by houses) or solar arrays (denoted by the generator symbol of a squiggly line inside a circle) being overvoltaged. An overvoltage condition is marked by the color of the line changing from black (normal conditions: 118 V to 126 V) to blue (exceeding 126 V). A power factor below 0.8 leading or lagging will result in the consumer or line being colored with a teal color as seen in the below figure. We are not concerned with solving power factor issues for this project, only the overvoltage conditions.

3.1 Vulnerability Testing - Backbone Example

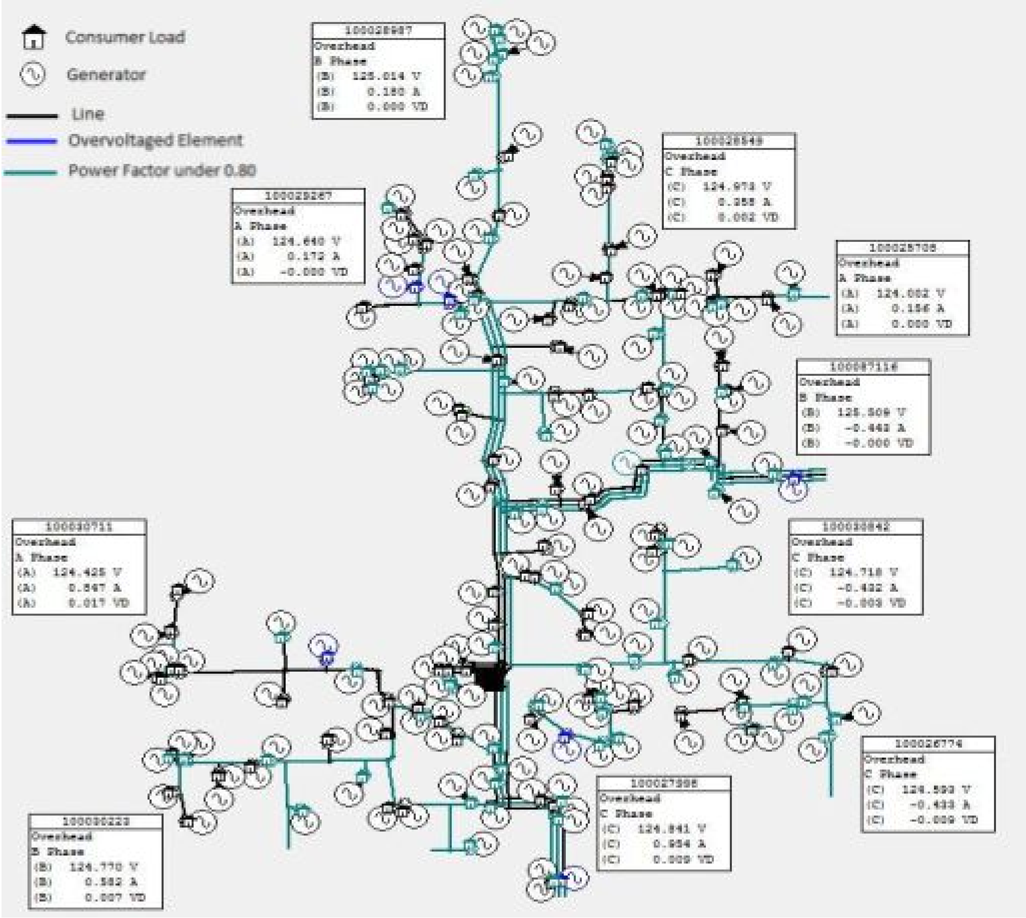


Figure 2: Backbone substation with 100% solar array penetration

This test gave us valuable information into what causes overvoltages to occur. We found that even when 100 percent of the load is generated by solar arrays and distributed evenly across all consumers (for Backbone substation, each solar array is producing 3.3 kW at a unity power factor) there is not an overvoltage problem. This tells us that there needs to be an excess of power generated in an area to cause overvoltage.

3.2 Voltage Regulation/LTC Transformer At The Substations

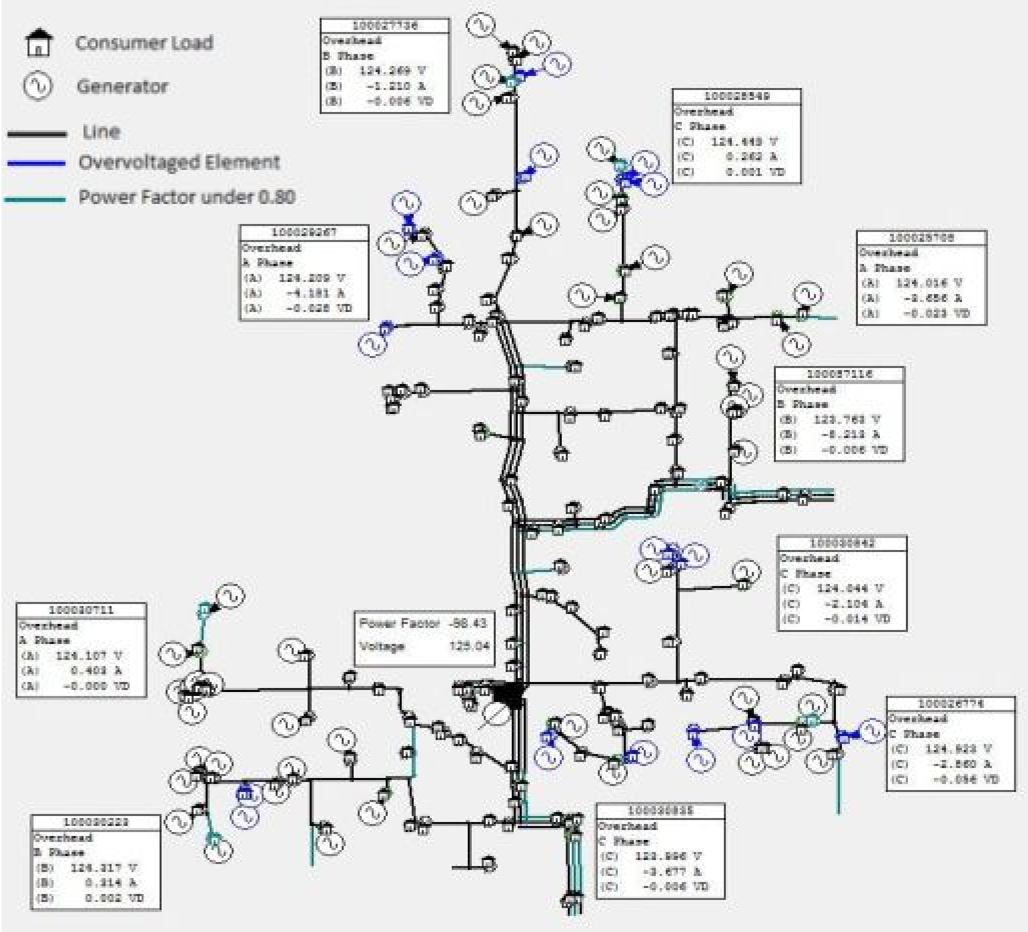


Figure 3: Backbone substation after solar arrays are modeled with a voltage regulator set to 123 V at the substation

For the Backbone and Monmouth substations, setting the substation voltage level to 123 V, instead of the current 125 V, would provide enough of a voltage reduction on the lines that the solar array-induced voltage rise would not cause overvoltage. This is not the best option for a solution since MVEC's rates for buying the power depends on the voltage at which it is bought, increasing at lower voltages. Thus by decreasing the voltage level to 123 V, MVEC's cost to purchase the power increases, which in turn would result in the rates increasing for the consumers which would be unfair to the consumers who are not participating in the solar power production.

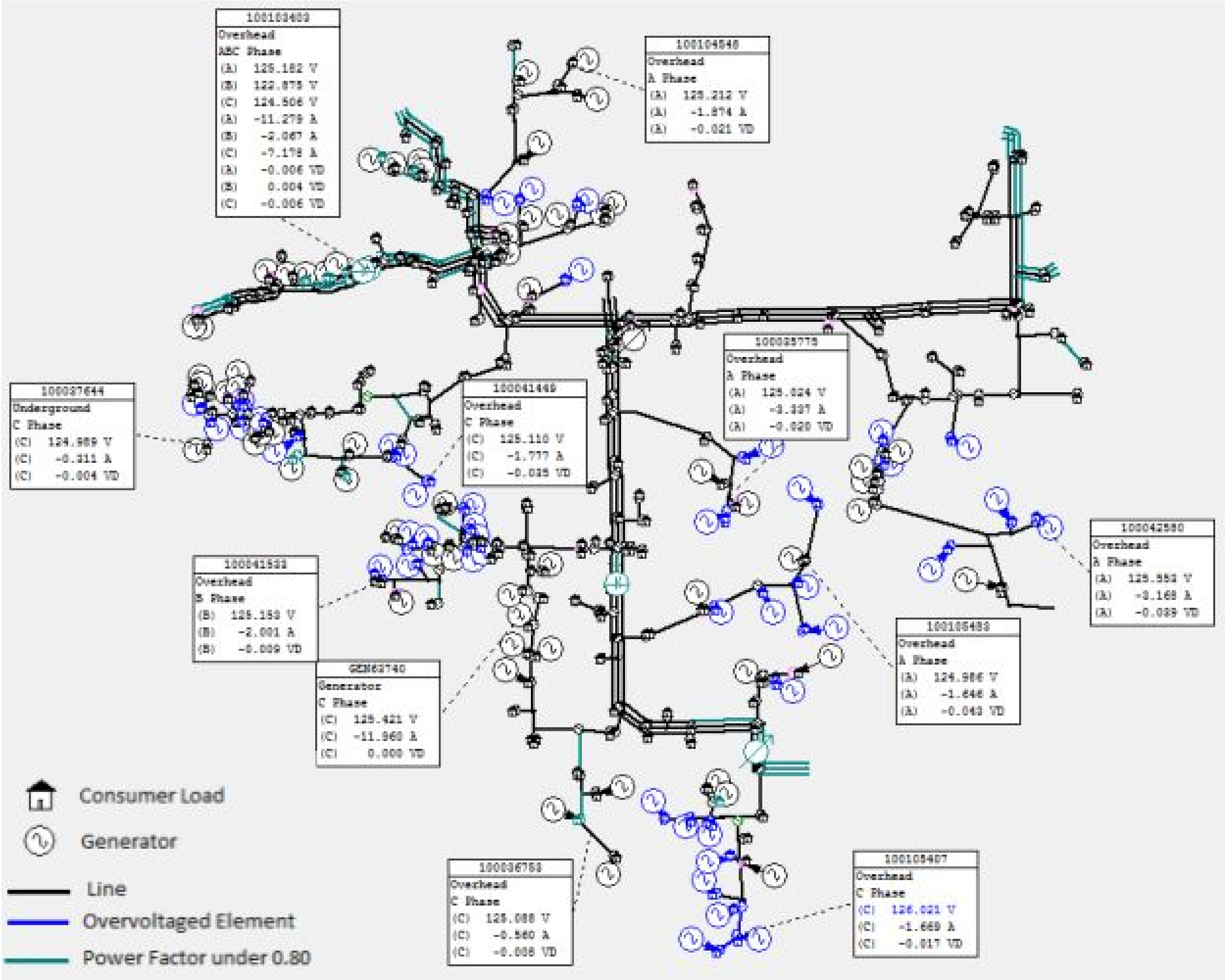


Figure 4: Bernard substation with voltage regulator set to 124 V at the substation

With solar arrays sized to overvoltage conditions on the Bernard substation, changing the voltage regulation at the substation to 124 V, as shown in the above figure, reduces the overvoltage issues at all lines except for the southern most line (later referred to as Line 5). Line 5 is being affected by the upstream regulator, which is set to 125 V. Reducing the voltage setting at this existing voltage regulator to 124 V would reduce the overvoltage on Line 5 and result in all lines being below the 126 V limit.

3.3 Inverter Settings

3.3.0 Why A Leading Power Factor Was Used

At unity power factor, a solar array will produce only real power (kW). The solar array will be only producing power, which means supplying voltage and current to the consumer and to the grid. However, as too much voltage is being put back onto the grid, we see the overvoltage problems begin to occur. To reduce the voltage being supplied, the current will have to increase to maintain a constant apparent power level. This is done by having the solar inverter consume

VARs, or have a leading power factor. The result is a positive real power (kW) and a negative reactive power (kVARS). To confirm this, we tested a lagging power factor of 0.95 and a leading power factor of 0.95 on a modeled solar array. The result was that the 0.95 lagging power factor further increased line voltages even further while the leading power factor reduced line voltages. The following tables give an overview of the results of our power factor analysis. Section 3.3.1 gives a more in depth analysis of our results.

Table 1: Backbone substation analysis results

Backbone Line Segments	Average kW increase per array from suggested size to reach overvoltage (kW)	Minimum Solar Array	Maximum Solar Array	Multiplier (applied to kW value at 0.95 leading PF) required to reach overvoltage again
Entire Substation	8.18 kW	0.07 kW	85 kW	1.61
End of Line 1	4.5 kW	6 kW	65 kW	2.33
End of Line 2	33 kW	40 kW	95 kW	2.46
End of Line 3	11.75 kW	12 kW	61 kW	1.82
End of Line 4	41 kW	41 kW	51 kW	1.56
End of Line 5	5 kW	3 kW	33 kW	1.6
End of Line 6	44 kW	49 kW	72 kW	1.81
End of Line 7	7 kW	7 kW	23 kW	1.28
End of Line 8	0 kW	6.6 kW	35.5 kW	1.57
End of Line 9	31.5 kW	32 kW	39 kW	1.93
End of Line 10	0 kW	.07 kW	47 kW	1.39

Table 2: Bernard substation analysis results

Bernard Line Segments	**Average kW increase per array from suggested size to reach overvoltage (kW)**	**Minimum Solar Array Size (at unity PF)**	**Maximum Solar Array Size (at unity PF)**	**Multiplier (applied to kW value at 0.95 leading PF) required to reach overvoltage again**
Entire Substation	3.14 kW	0.5 kW	67 kW	1.58
Solar on Line 1 Only	0 kW	0.5 kW	62.5 kW	1.16
Solar on Line 2 Only	19.25 kW	25 kW	30 kW	1.42
Solar on Line 3 Only	5 kW	6 kW	21.5 kW	1.87
Solar on Line 4 Only	36 kW	36.5 kW	43.5 kW	3 Phase Line overvoltages
Solar on Line 5 Only	6.14 kW	5 kW	30 kW	1.42
Solar on Line 6 Only	45 kW	47 kW	70 kW	1.83
Solar on Line 7 Only	15 kW	15.5 kW	82 kW	1.63
Solar on Line 8 Only	4 kW	1.5 kW	24.5 kW	1.41
Solar on Line 9 Only	2.86 kW	4 kW	33.5 kW	1.89
Solar on Line 10 Only	15 kW	23 kW	57 kW	1.40
Solar on Line 11 Only	2.09 kW	3.5 kW	30 kW	1.40

Table 3: Monmouth substation analysis results

Branch	Average kW increase per array from suggested size to reach overvoltage (kW)	Min Solar Array (kW)	Max Solar Array (kW)	Multiplier (applied to kW value at 0.95 leading PF) required to reach overvoltage again
Whole System	2.50	2.83	56.37	1.5
Northeast	1.15	2.85	30	1.55
East	1.52	7.21	15.00	1.6
Southeast	6.45	3.75	24.00	1.7
South	1.44	6.34	17.61	1.5
Southwest	2.42	3.00	56.37	1.65
West	6.65	5.50	43.70	1.9
Northwest	0	2.85	30	1.45
North	0	2.83	13.34	1.4

3.3.1 Backbone Substation Detailed Results

A. <u>Entire System</u>

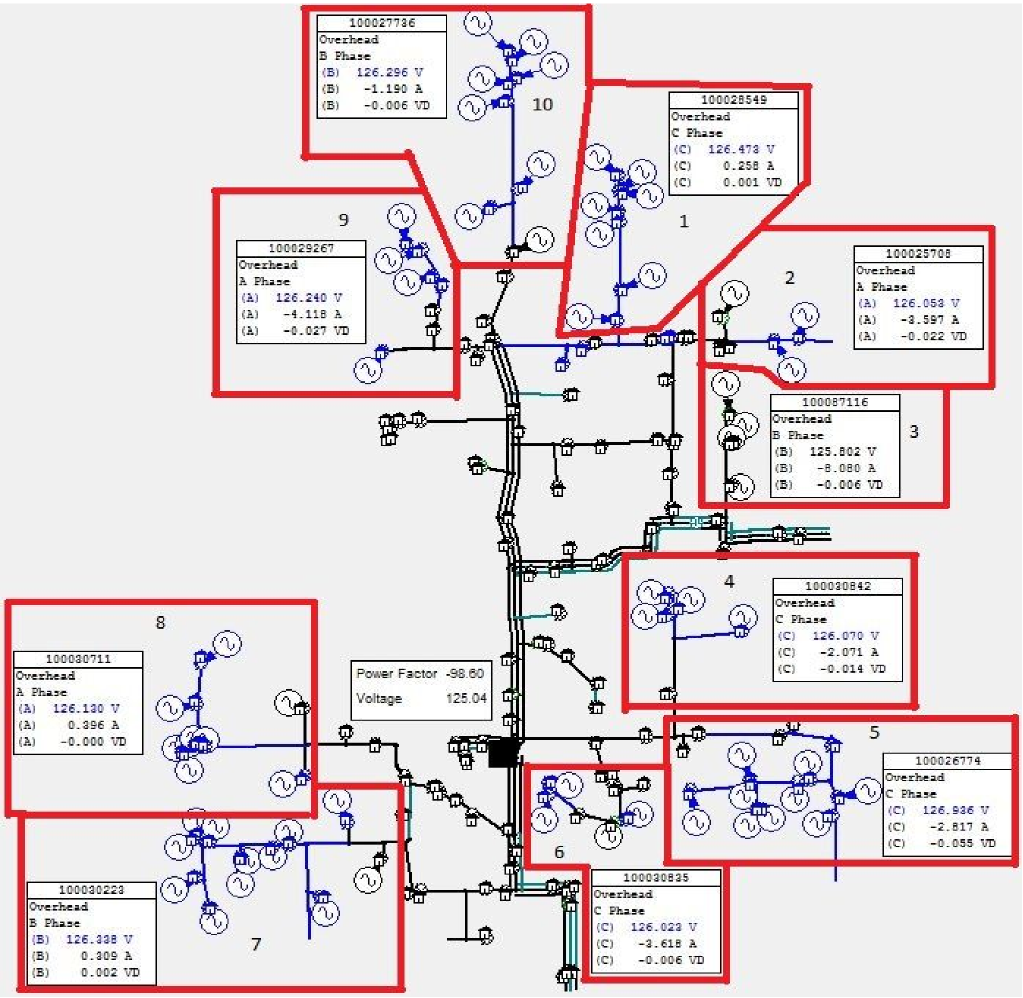


Figure 5: Backbone substation line segment definitions

Above is the WindMil model of the Backbone substation with solar added and set to overvoltage conditions. Each end of line has been numbered and the borders marked in red boxes. The smallest solar array added was 0.07 kW and the largest was 85 kW. The average solar array size for this system is approximately 20.7 kW. To reach the overvoltage conditions for the entire system, an average of 8.18 kW was added to each solar array's recommended minimum size. A note that the end of line 3 does not have an overvoltage case in the entire system. This was determined to be acceptable because there was some coupling with other lines that would boost or reduce the voltage of the lines, and that to attain an overvoltage case would require a lot more over sizing of the solar arrays not only on that part of the line but other parts as well which had already reached the overvoltage state.

With the overvoltage case found. The power factor of the generators in WindMil were changed to 0.975 leading power factor. This fixed all overvoltage cases except the end of line 5. Next the power factor was changed to 0.95 leading and this resulted in no overvoltage conditions. It took, on average, an 11 kW increase per solar array to reach overvoltage conditions with the 0.95 leading power factor in place. The exact data and numbers can be found in Appendix 3.

B. End Of Line 1

When looking at this branch individually, it required between a 4 and 5 kW oversizing of each solar array on the branch to get overvoltage. The minimum amount of solar was 6 kW and the maximum was 65 kW. A power factor of 0.95 leading was successful in keeping the branch within voltage limits. It took on average 2.33 times more kW at 0.95 leading power factor to re-overvoltage the branch.

C. End Of Line 2

In order to get overvoltage for this branch with the entire system being used required that the solar sizes be oversized by 23 kW per solar array on this branch. When looking at the individual branch by itself it required 33 kW of oversizing to achieve overvoltage. The minimum of this branch (when looking at it by itself) was 40 kW and the maximum was 95 kW. A power factor of 0.95 leading was able to bring the end of the line back out of overvoltage. It then required an increase to the kilowatts by 2 to 3 times more at 0.95 leading power factor to re-overvoltage the end of the line. A note to make here is that before getting the end of the line to overvoltage a line in the three phase in a different part overvoltages first.

D. End Of Line 3

In order to get this line to overvoltage it required on average 11.75 kW of oversizing each array. The sizes of the solar arrays were 12 kW and 61 kW. A power factor of 0.95 leading was successful in going back to non-overvoltage conditions. It then required a 1.2 or 2 times increase to re-overvoltage the end of the line.

E. End Of Line 4

In order to get this line to overvoltage it required approximately 16kW of oversizing the solar to reach overvoltage for the entire system. When looking at the individual branch it required around 41 kW of each solar array to be oversized. The minimum for this branch was 41 kW and the maximum was 51 kW solar arrays. 0.95 leading power factor was enough to reduced the voltage back into ANSI limits. It then required on average a 1.56 times more kilowatts per solar array at 0.95 leading power factor to re-overvoltage the end of the line.

F. End Of Line 5

When looking at the entire system it required around a 3 kW oversizing of every solar array to cause overvoltage. However, when looking at the end of the line by itself it required 5 kW of oversizing to reach overvoltage. The smallest array was 3 kW and the largest was 33 kW. 0.95 leading power factor was a fix to the overvoltage. It required on average a 1.6 times increase to the kilowatts at 0.95 power factor to reach overvoltage again.

G. End Of Line 6

It required 21 kW of oversizing each solar array in terms of the entire system to get overvoltage. When looking at the end of the line individually it required 44 kW of oversizing to become overvoltage. The smallest array was 49 kW and the maximum size was 72 kW. 0.95 leading power factor brought the voltage below 126 V. To get the voltage back over 126 V the kilowatts needed to be increased on average 1.81 times at 0.95 leading power factor.

H. End Of Line 7

This end of line required on average 7 kW of oversizing each solar array to reach the overvoltage condition. The minimum solar size was 7 kW and the maximum was 23 kW. 0.95 leading power factor was able to correct the overvoltage. It required on average a 1.28 times increase to each solar arrays kilowatts at 0.95 leading power factor to re-overvoltage the end of the line.

I. End Of Line 8

This end of line was one of the two cases that the line overvoltage at the correctly sized solar arrays. The smallest array size was 6.6 kW and the largest array size was 35.5 kW. A power factor of 0.95 leading reduced the voltage under 126 V. When increasing the kilowatts at 0.95 leading power factor by 1.57 times per solar array it brought the voltage back over 126 V.

J. End Of Line 9

When looking at the system as a whole it required an oversizing of the solar arrays on average 29.5 kW to reach overvoltage. However, when looking at the branch individually it required 31.5 kW oversizing to obtain overvoltage. The smallest array size was 32 kW and the largest was 39 kW. A power factor of 0.95 was successful in reducing the voltage to approved values. It required on average it required a 1.93 times increase to the kW of each solar array to bring the voltage back into overvoltage at 0.95 leading power factor.

K. End Of Line 10

This is the second of the two cases that required no oversizing of the solar arrays to reach overvoltage. The smallest solar array was 0.07 kW and the largest solar array was 47 kW. A 0.95 leading power factor fixed the overvoltage. On average (excluding the abnormally small solar array) it required 1.39 times kilowatts to be added at 0.95 leading power factor to each solar array to obtain overvoltage again.

3.3.2 Bernard Substation Detailed Results

A. With Solar Generators Placed At The Ends Of Lines Throughout The Entire Substation Model:

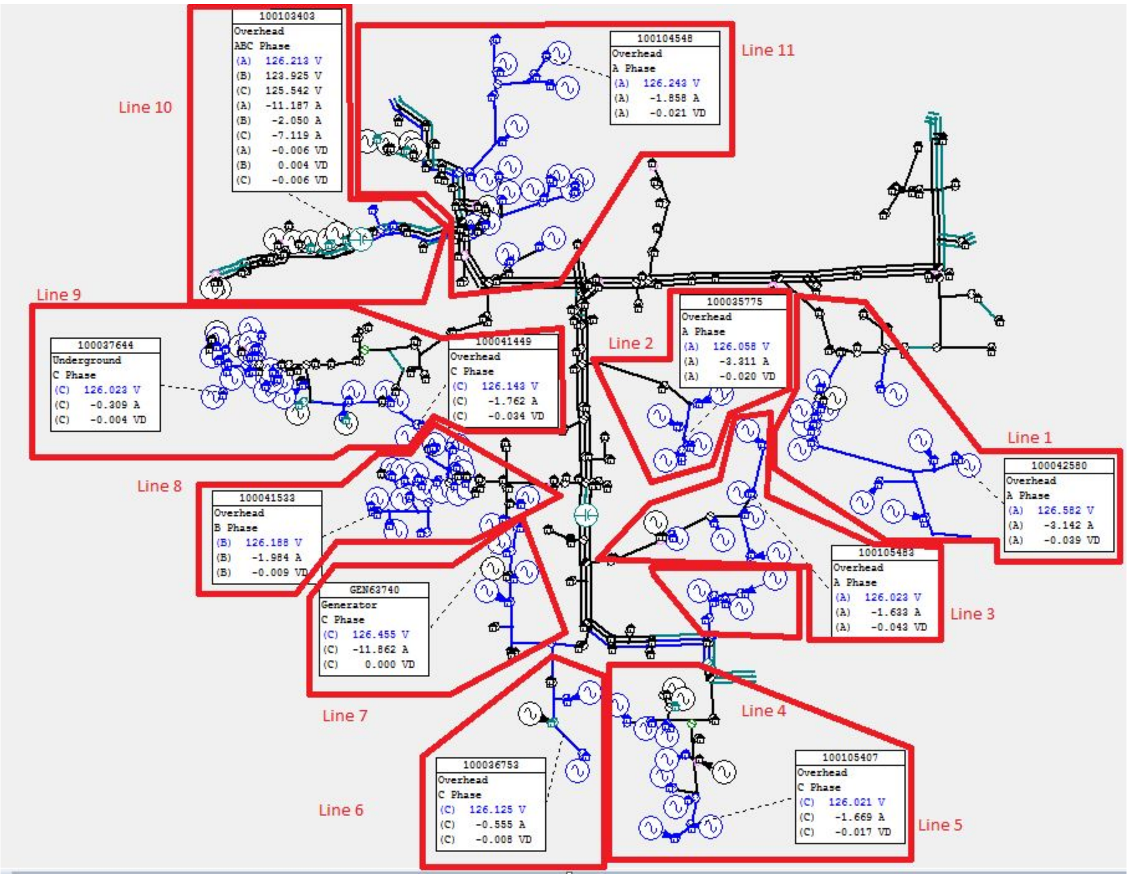


Figure 6: Bernard substation line segment definitions

While causing the overvoltages on the lines in the case of solar generators placed near the ends of the lines across the entire substation model, lines 1, 7, 10, and 11 overvoltage at the recommended minimum solar array sizes, but causing overvoltage on the remaining lines required fairly significant oversizing of the solar arrays. The smallest solar array size was 0.5kW, the largest being 67 kW and the average solar array size in this model was about 15 kW. Dependence was also discovered between several of the lines in the southern portion of the model, and the voltages would change on several lines when one solar array output was varied. This will be further discussed in Appendix 2.

When analyzing solar arrays only on one line at a time, all lines required oversizing of solar arrays to reach overvoltage except for Line 1, which still overvoltaged at minimum recommended array sizes.

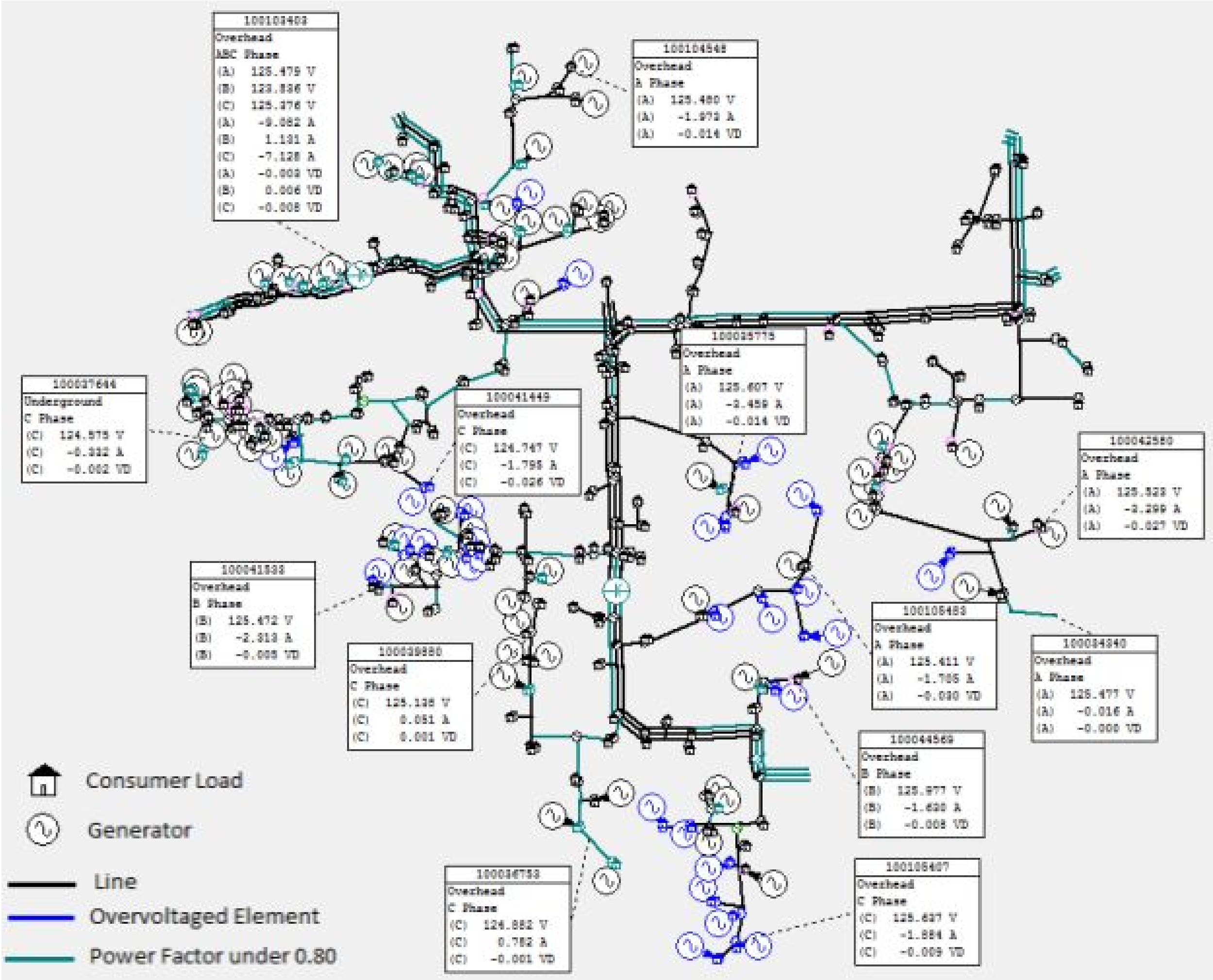


Figure 7: Bernard substation with 0.95 leading power factor applied to solar arrays. No overvoltage on lines

Also under these overvoltage conditions, the power factors at each solar generator were changed first to 0.975 leading and while this solution reduced most of the overvoltage conditions, it did not solve them all. Changing the power factor to 0.95 leading (as shown in the above figure) did effectively reduce all of the overvoltages, and in most cases, reduced the line voltages a good amount below the 126 V limit. With the power factor set to 0.95 leading, it took, on average, an increase of 1.5 times the kW value at 0.95 leading power factor to the power output at each solar generator to cause overvoltage to occur again.

B. Solar On East Branch Only (Line 1)

This line reached overvoltage at recommended minimum solar array sizes, with the sizes ranging from 0.5 kW to 62.5 kW. Changing the power factor from unity to 0.95 leading reduced the voltages back within limits and allows for an average increase of 1.1 times the kW output before overvoltage is reached again.

C. Solar On South Branch Upper Right Only (Line 2)

   To overvoltage this line, significant oversizing of the solar arrays was required (an average of triple the recommended solar array sizes). At overvoltage, the solar arrays were sized between 25 kW and 30 kW. Changing the power factor to 0.95 leading reduced the voltages successfully and allows for an average increase of 1.4 times the kW output before overvoltage is reached again.

D. Solar On South Branch Middle Right Only (Line 3)

   To overvoltage this line, an average kW increase of 1.6 kW to each solar array's suggested kW size was required, with the sizes ranging from 6 kW to 88.5 kW. Changing the power factor to 0.95 leading reduced the voltages successfully. To get back to overvoltage levels, an average increase of 1.8 times the kW value of each solar array was required.

E. Solar On South Branch Lower Upper Right Only (Line 4)

   To cause overvoltage on this line, an average increase of 11 times each suggested array's kW value was required, with sizes ranging from 36.5 kW to 43.5 kW, which is highly unlikely to occur due to the low loads on this line. This large oversizing and the location of this line proved to be problematic when changing the power factors to 0.95 leading. While the power factor reduced the voltages on the line to within the limits, the voltage on the 3 phase line that this line branches off of reached overvoltage slightly further down the line. Due to the excessive oversizing of the solar arrays, this is marked as an outlier and a highly unlikely scenario, but MVEC should be aware of this issue and monitor this section of the southern 3 phase line.

F. Solar On South Branch Lower Bottom Right Only (Line 5)

   To overvoltage this line, the initial kW size of each solar array was increased an average of 1.5 times the suggested kW size, with sizes ranging from 5 kW to 30 kW. Changing the power factor to 0.95 leading reduced the voltages successfully and allowed for an average increase of 1.4 times the kW value of each solar array before overvoltage was reached again.

G. Solar On South Branch Lower Bottom Left Only (Line 6)

   An average increase of 5.5 times the recommend solar array sizes were required to reach overvoltage conditions on this branch, with sizes ranging from 47 kW to 70 kW. Changing the inverter power factor from unity to 0.95 leading reduced the voltages successfully and allows for an average kW increase of 1.8 times the kW value of each solar array before overvoltage is reached again.

H. Solar On South Branch Lower Upper Left Only (Line 7)

   To overvoltage this branch, an average increase of 1.7 times the suggested solar array kW size was required, with sizes ranging from 15.5 kW to 82 kW. Changing the power factor from unity to 0.95 leading reduced the voltages successfully and allows for an average solar array kW increase of 1.6 times the previous kW amount at each solar array.

I. Solar On South Branch Middle Left Only (Line 8)

   An average increase of 1.5 times the suggested minimum solar array size per solar array was required to reach overvoltage on this branch, with solar array sizes ranging from 1.5 kW to 24.5 kW. Changing the power factor to 0.95 leading reduced the voltages successfully and to reach overvoltage conditions again, each solar array kW value had to be increased to 1.4 times the kW value at 0.95 leading power factor.

J. Solar On Southwest Branch Only (Line 9)

To reach overvoltage conditions on this branch, each solar array kW value had to be increased an average of 1.2 times the suggested minimum solar array size, with sizes now ranging from 4 kW to 33.5 kW. Changing the power factor from unity to 0.95 leading successfully reduced the voltage. To reach overvoltage on the lines again, each solar array kW value, on average, was increased by about 1.8 times the new kW value at 0.95 leading power factor.

K. Solar On Northwest 3 Phase Only (Line 10)

An average increase of 1.6 times the suggested minimum solar array size at unity power factor was required to cause overvoltage on this branch, with sizes ranging from 23 kW to 57 kW. Changing the power factor to 0.95 leading successfully lowered the voltages, and it takes an average increase of 1.4 times the kW value at 0.95 leading power factor to reach overvoltage on the line.

L. Solar On Northwest Single Phase Only (Line 11)

An average increase of about 1.2 times the suggested minimum solar array sizes were required to reach overvoltage on this section of the feeder. Changing the power factor from unity to 0.95 leading successfully reduced the voltages and on average it took an increase of about 1.4 times the kW value per solar array to reach overvoltage conditions again.

3.3.3 Monmouth Substation Detailed Results

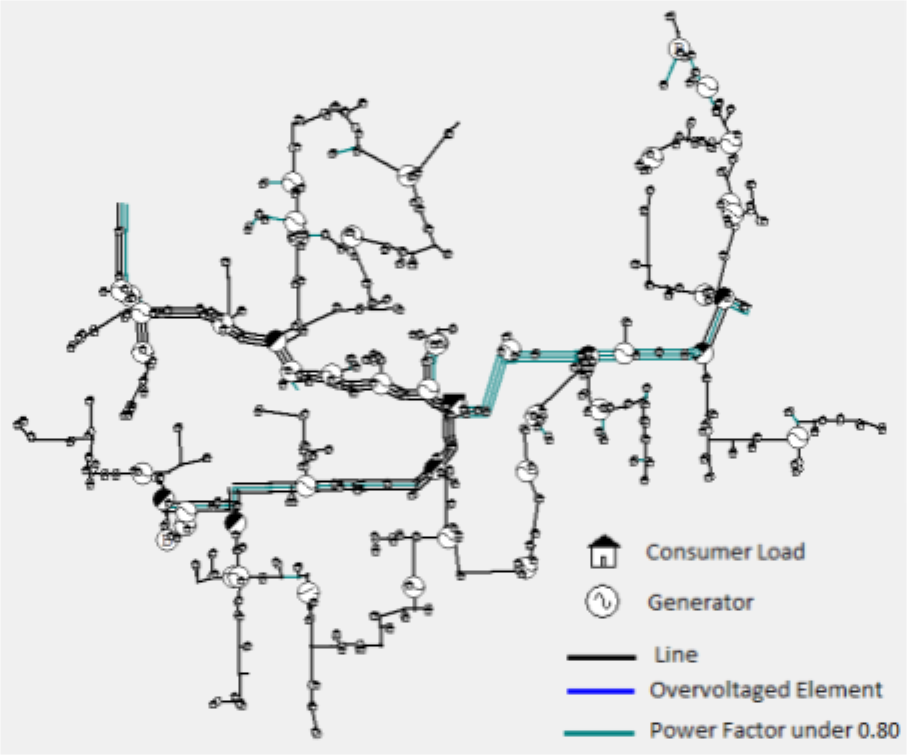


Figure 8: Monmouth substation and feeders base case

A. <u>Entire System</u>

The Monmouth system has a relatively smaller load on the system when compared to the other two systems Bernard and Backbone, with a total substation load of 238 kW for May 5th 2015. In general, the further from the substation a solar array is, the easier it will overvoltage. The smallest solar array modeled on this system is a 1 kW and the largest is 43.5 kW. The average solar array size is 6 kW. To analyse this system, it is broken up into 8 different subsystems, defined as follows:

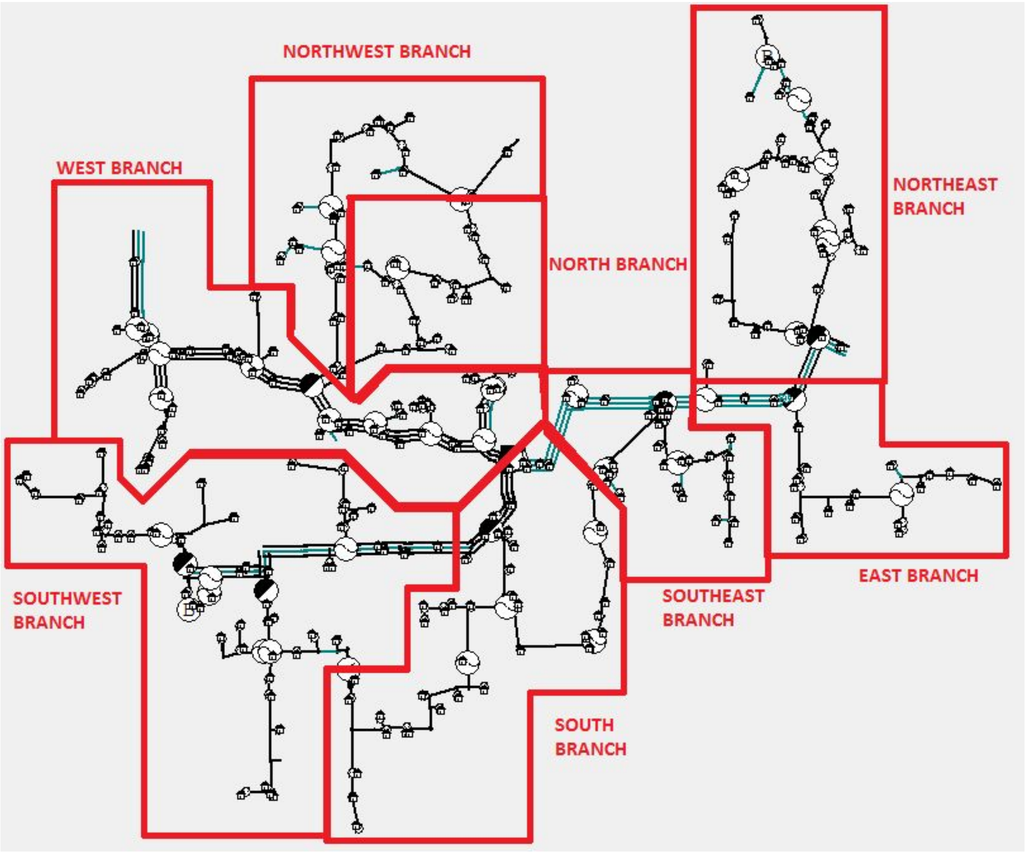


Figure 9: Monmouth system banch definitions

The branches were split up in this manner under the criteria of geographic nearness, and also dependance on phases. The South, Southwest, East, Northeast, North, and Northwest branches overvoltaged at the suggested kW levels for distributed generation.

A few peculiarities of this system was observed. The Southeast branch seems to be close enough to the substation where even large distributed generation on the system will not cause an overvoltage on the system. Similarly, the west branch of the system is situated on a three-phase line. Three phase lines are found to be very resistant to overvoltage conditions and require extremely large DG penetration to result in a line overvoltage.

Finally, a last peculiarity is the interconnection between the Northwest and the North branches. The North branch is on the B-phase and the Northwest branch is on the C-phase. High DG penetration on the Northwest branch will actually cause the voltage on the North branch to decrease and vice versa. This will be further discussed in appendix 2.

Information about the levels at which the system overvoltaged can be found in appendix 3.

After the whole system reached an overvoltage condition by adding progressively more and higher power solar arrays, a power factor of 0.975 leading was tried. At this level, while some overvoltage conditions were solved, it was not universal across the system. By decreasing the power factor to 0.95 leading solved any remaining overvoltage conditions. An increase of 2 kW across the whole system began to create an overvoltage condition again after the power factor was decreased.

B. Northeast Branch

The Northeast branch required an oversizing of around 1.1 times in order to create a significant overvoltage on the line when it was the only branch with DG modeled. At this level, the overvoltage condition could be solved with a 0.95 leading power factor.

C. East Branch

The east branch was difficult to overvoltage due to its proximity to a three-phase line and the relatively short length of line leading to it. An average increase of 1.3 times the suggested amount was required to create any overvoltage. At that level, a power factor of 0.975 leading was sufficient to solve the overvoltage condition. After the power factor was applied, the DG installed on the system were increased by 1.6 times before another overvoltage condition was observed.

D. Southeast Branch

The Southeast branch showed a significant resistance to overvoltage conditions, requiring an oversizing of roughly twice the suggested size of solar array before an overvoltage condition occurs at the branch. The solar arrays ranged in size from 3.75 kW to 24 kW, with an average of 10 kW. The overvoltage conditions were solved with an applied power factor of 0.95, and another kw increase of 1.5 time was required to create an overvoltage.

E. South Branch

The South branch readily overvoltaged at 1.2 times the suggested solar array levels. The south branch has relatively high suggested solar array sizes, with a range of 6 kW to 18 kW and an average of 12 kW. The overvoltage conditions were solved by an applied power factor of 0.95 leading. After the power factor was applied, it took an increase of 1.5 times the suggested solar array size to create a new overvoltage condition.

F. Southwest Branch

The Southwestern branch overvoltaged with an increase of on average 1.3 times to the suggested solar array size. The range of solar array sizes was from a minimum of 3 kW and a maximum of 56.7 kW. A power factor of 0.95 leading was applied and found to solve the overvoltage problems created by the DG penetration. After the power factor was applied, an average increase of 1.65 to the suggested solar array size caused an overvoltage condition to occur again.

G. West Branch

The west branch lies almost completely on a three-phase line. As such, it is incredibly resistant to increased voltages due to distributed generation. DG modeled on this line were increased to 3 times the suggested solar array size, and still overvoltage conditions only occurred on the consumer side of the transformers.

H. Northwest Branch

This line reached overvoltage at recommended minimum solar array sizes, with the sizes ranging from 2.85 kW to 30 kW. Changing the power factor from unity to 0.95 leading reduced the voltages back within limits and allows for an average increase of 1.4 times the kW output before overvoltage is reached again.

I. North Branch

This line reached an overvoltage condition at the recommended solar array size with solar arrays between 3.4 kW and 14.05 kW. Decreasing the power factor to 0.975 leading solved the overvoltage problems sufficiently on the branch. At this level, it took an oversizing of solar arrays of on average 1.45 times to reach an overvoltage condition again.

3.4 Re-Overvoltage With Inverter Settings

In general for all systems a 1.5 times increase to the kW output per solar array was required to cause overvoltage after the 0.95 leading power factor was implemented. This means that only a very significant increase in distributed generation will cause a further problem after the 0.95 leading power factor is applied to the solar arrays. Per Appendix 2, solar inverters with a capability of 0.85 power factor leading and lagging are common. This means that with the implementation of smart inverters on all solar installations on all three systems, a capability of 0.85 leading power factor would be more than adequate to handle a very large injection of distributed generation onto the system.

Appendix 1: Alternative Designs and Approaches

In the early stages of our project, we had planned to test the effects of 5 different solutions we could apply to the model. We planned to test the effects of Load Tap Changing transformers at the substations, consumer side voltage regulation (regulators at each consumer regulating from the consumer back towards the grid), capacitor banks, inverter power factor changes/smart inverters, and batteries. As we progressed with the project, we determined that adding capacitor banks would only result in further increasing the voltage on lines so capacitor banks were removed from the list of options to test. As we dove deeper into the capabilities of WindMil during the second semester, we quickly discovered that WindMil does not have a way to model battery storage or consumer side voltage regulation, and so these were removed from our scope. This left us with testing Load Tap Changing transformers and inverter power factor settings. To model the Load Tap Changing transformer, we modeled a voltage regulator at the substation as explained above in this paper. As for studying smart inverter capabilities, we were only able to go as far as researching the newest technologies, as discussed in Appendix 2.

As we started to attempt to cause overvoltages on the system, we were initially finding the consumers with the largest loads and sizing them with their minimum recommended solar array size to handle 100% of their load and working down through the consumers by max load. About 5 weeks into the second semester of doing this, we met with MVEC and determined that this was not the most effect way to cause overvoltages as the large load consumers were spread throughout the models and not frequently at the ends of lines and we weren't achieving many overvoltages. We then switched to the method we used during this report, which was starting with consumers at the ends of lines and working in and oversizing until overvoltage was reached.

Appendix 2: Additional Resources and Considerations

A2.1 Smart Inverter Capabilities

Solar power is becoming a big factor in power generation due to its lack of fuel costs and environmental friendliness. Because of an exponentially growing rate of solar installations, power companies are working to find ways to protect the grid from the adverse effects caused by solar. Grid follow capabilities are common on smart inverters and allow the inverters to read the grid and make changes to the inverter output to help keep the grid stable.

To prevent frequent nuisance trips of the solar arrays during grid frequency or voltage issues, smart inverters are being designed with the ability to ride through brief disturbances on the grid, which in turn helps stabilize the grid. When there is a lot of power being supplied by solar and then suddenly all of that power trips off due to a momentary frequency or voltage disturbance, the grid will see a large loss of power and a large loss of voltage, which could result in cascading outages.

Overproduction and overvoltage are also recurring issues. To compensate for this, some countries implement a curtailment ability in smart inverters which detects when the grid is at overvoltage conditions and the inverters will either switch off completely for a brief period of time or reduce the output kW being supplied. This is not a favorable technique in the U.S. as consumers want to be paid for their excess production and not have it just be cut off. This leads to the autonomous power factor control capabilities that allow smart inverters to read the grid and its voltage and power factor and adjust its own power factor to reduce output voltage and help keep the grid more stable.

While there are a great many smart inverters currently on the market, an example of smart inverters that we looked into are the SMA Sunny Boy series string inverters. For more information on these please visit the following website:
http://www.sma-america.com/home-systems/overview.html

A2.2 Hawaii Interconnection Agreement And Rule 14H

Hawaii has a very detailed interconnection agreement and Rule 14H which in depth describes the requirements of any solar inverters that are to be connected to the grid to ensure maximum stability. For more details on this please visit the website below, as it has a lot of good information.
https://www.hawaiianelectric.com/clean-energy-hawaii/producing-clean-energy/standard-interconnection

A2.3 Power Factor Issues At Substation

Although outside the scope of this project, a consequence of uniformly lowering power factors on solar installations results in a decrease of power factor at the substation. The power factor was found to go as low as 0.71 on the Backbone substation. This happens as a result of a leading power factor consuming kVARs at every smart inverter. Which causes the need for those kVARs to be supplied from the substation resulting in the lowering of the power factor. It is especially important to ensure that substation power factor does not drop too far, and further research would be required to address this issue as part of any overvoltage solution scheme.

A2.4 Consumer Side Voltage Regulation

Although consumer side voltage regulation was considered as a possible solution, WindMil does not have the capability of simulating voltage regulators from the consumer back towards the regulator. Regulators modeled in WindMil only work in one direction, with voltage flowing from the substation to the consumer. If voltage regulators were to be considered again, a different modelling software would be required. Such regulators are made by Cooper Industries.

A2.5 Power Coupling

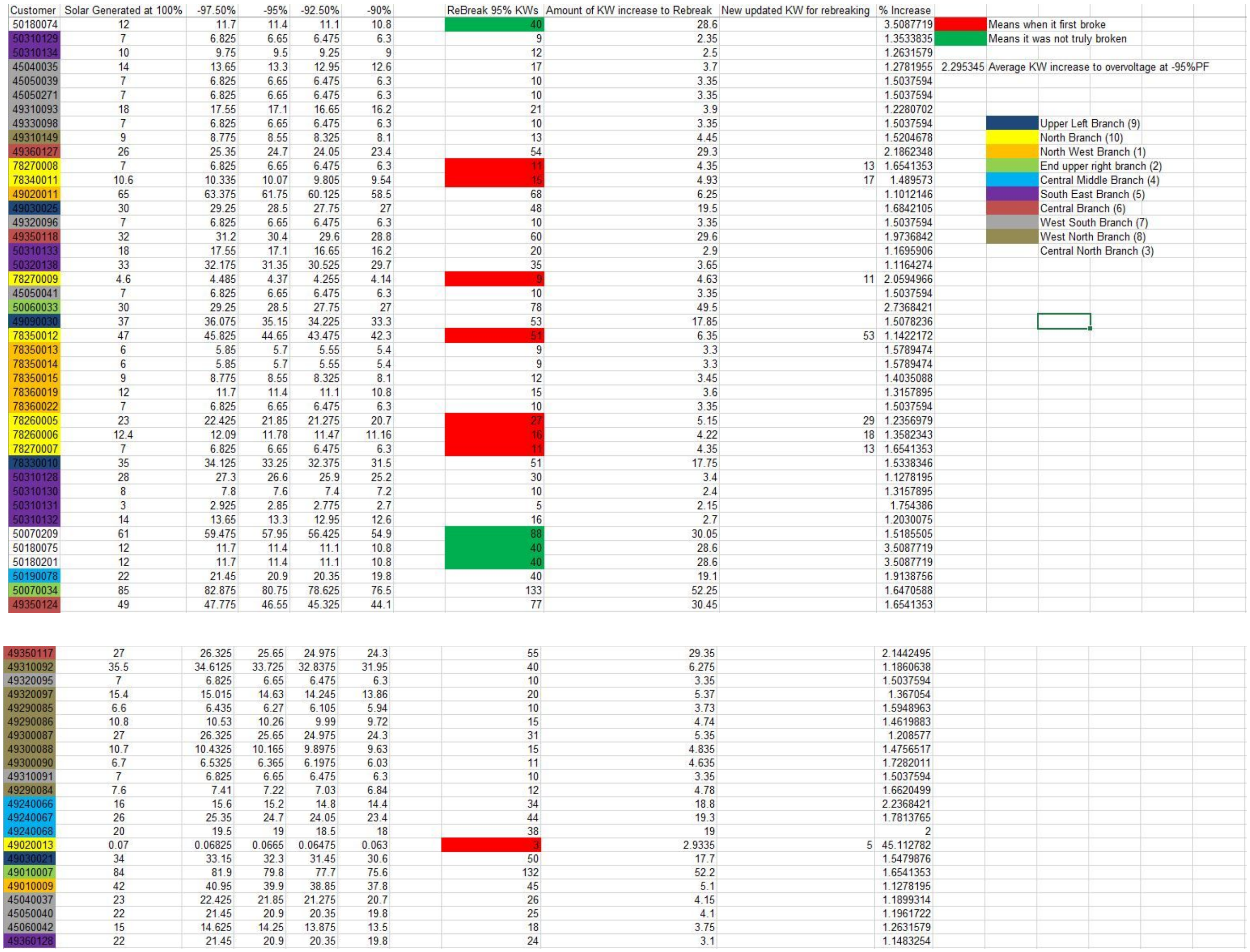
In our models, a large injection of DG on a particular single-phase line can actually decrease the voltage on another single-phase line even in a distant part of the system. This is likely due to the voltage out of the substation decreasing in response to the increased power generated on the system itself. Since the power leaving the substation is three-phase, the power on lines other than the phase with the high DG penetration may see a decrease in voltage. This was observed on all three substations, particularly on the Monmouth system between the North and Northeast branch and the Bernard system North-South running three phase line. For the Monmouth system, as the power on the North or Northeast branch was increased, the voltage on the other branch would decrease. More studies should be dedicated to this phenomenon to ensure that it does not cause unforeseen problems.

A2.6 Flicker

Inverters that do not have smart capabilities can create a flicker effect during short-lived, sudden variations to solar irradiance, such as a cloud passing over the sun. these spikes or dips in power output can create a flicker effect on the grid, which could be harmful to electronics. Smart inverters can serve to smooth these transition periods by storing and discharging small amounts of power, improving grid stability.

Appendix 3: Solar Sizing Data

A3.1 Backbone Substation



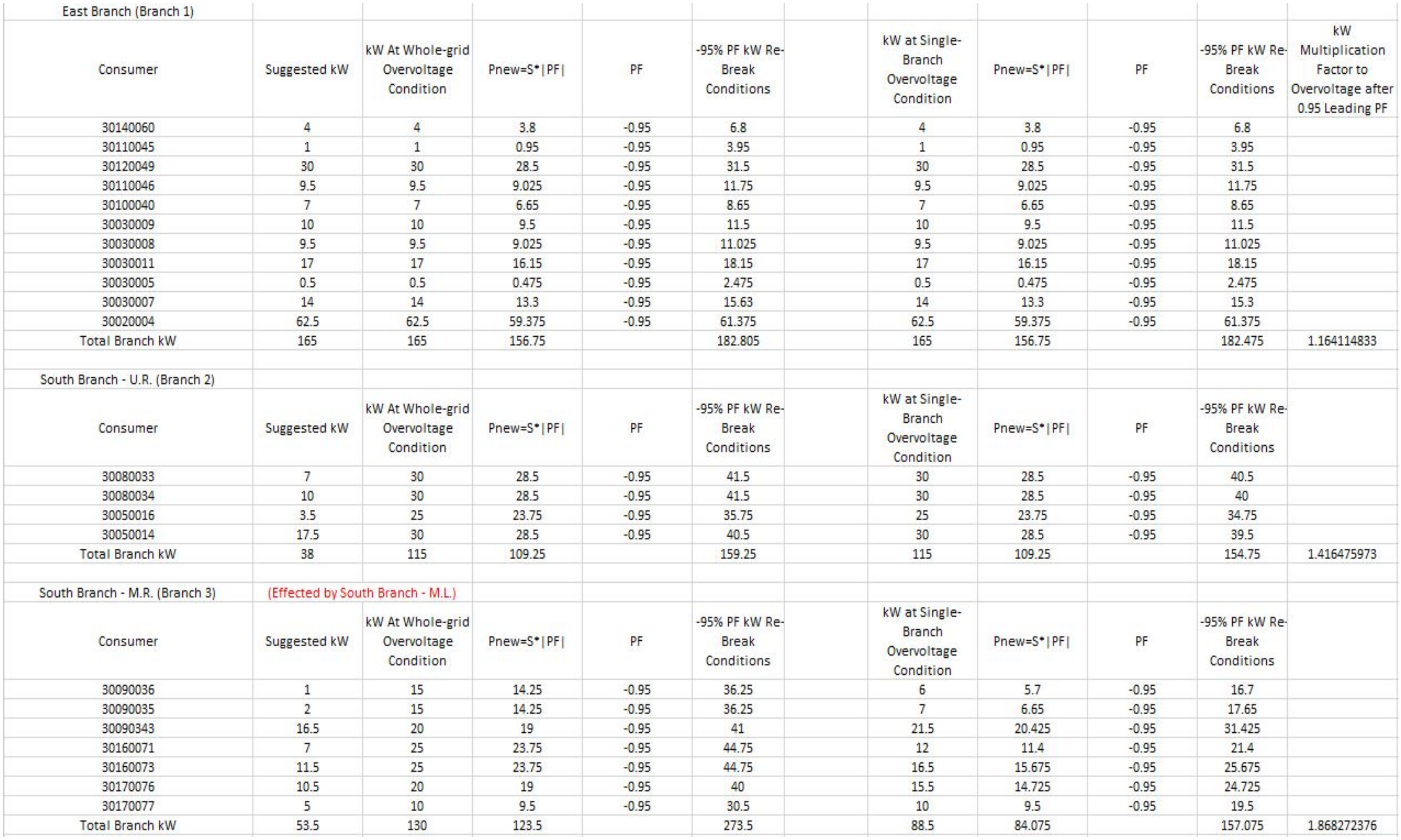
Customer	Solar Generated at 100%	-97.50%	-95%	-92.50%	-90%	ReBreak 95% KWs	Amount of KW increase to Rebreak	New updated KW for rebreaking	% Increase
50180074	12	11.7	11.4	11.1	10.8	40	28.6		3.5087719
50310129	7	6.825	6.65	6.475	6.3	9	2.35		1.3533835
50310134	10	9.75	9.5	9.25	9	12	2.5		1.2631579
45040035	14	13.65	13.3	12.95	12.6	17	3.7		1.2781955
45050039	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
45050271	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
49310093	18	17.55	17.1	16.65	16.2	21	3.9		1.2280702
49330098	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
49310149	9	8.775	8.55	8.325	8.1	13	4.45		1.5204678
49360127	26	25.35	24.7	24.05	23.4	54	29.3		2.1862348
78270008	7	6.825	6.65	6.475	6.3	11	4.35	13	1.6541353
78340011	10.6	10.335	10.07	9.805	9.54	15	4.93	17	1.489573
49020011	65	63.375	61.75	60.125	58.5	68	6.25		1.1012146
49030025	30	29.25	28.5	27.75	27	48	19.5		1.6842105
49320096	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
49350118	32	31.2	30.4	29.6	28.8	60	29.6		1.9736842
50310133	18	17.55	17.1	16.65	16.2	20	2.9		1.1695906
50320138	33	32.175	31.35	30.525	29.7	35	3.65		1.1164274
78270009	4.6	4.485	4.37	4.255	4.14	9	4.63	11	2.0594966
45050041	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
50060033	30	29.25	28.5	27.75	27	78	49.5		2.7368421
49090030	37	36.075	35.15	34.225	33.3	53	17.85		1.5078236
78350012	47	45.825	44.65	43.475	42.3	51	6.35	53	1.1422172
78350013	6	5.85	5.7	5.55	5.4	9	3.3		1.5789474
78350014	6	5.85	5.7	5.55	5.4	9	3.3		1.5789474
78350015	9	8.775	8.55	8.325	8.1	12	3.45		1.4035088
78360019	12	11.7	11.4	11.1	10.8	15	3.6		1.3157895
78360022	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
78260005	23	22.425	21.85	21.275	20.7	27	5.15	29	1.2356979
78260006	12.4	12.09	11.78	11.47	11.16	16	4.22	18	1.3582343
78270007	7	6.825	6.65	6.475	6.3	11	4.35	13	1.6541353
78330010	35	34.125	33.25	32.375	31.5	51	17.75		1.5338346
50310128	28	27.3	26.6	25.9	25.2	30	3.4		1.1278195
50310130	8	7.8	7.6	7.4	7.2	10	2.4		1.3157895
50310131	3	2.925	2.85	2.775	2.7	5	2.15		1.754386
50310132	14	13.65	13.3	12.95	12.6	16	2.7		1.2030075
50070209	61	59.475	57.95	56.425	54.9	88	30.05		1.5185505
50180075	12	11.7	11.4	11.1	10.8	40	28.6		3.5087719
50180201	12	11.7	11.4	11.1	10.8	40	28.6		3.5087719
50190078	22	21.45	20.9	20.35	19.8	40	19.1		1.9138756
50070034	85	82.875	80.75	78.625	76.5	133	52.25		1.6470588
49350124	49	47.775	46.55	45.325	44.1	77	30.45		1.6541353
49350117	27	26.325	25.65	24.975	24.3	55	29.35		2.1442495
49310092	35.5	34.6125	33.725	32.8375	31.95	40	6.275		1.1860638
49320095	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
49320097	15.4	15.015	14.63	14.245	13.86	20	5.37		1.367054
49290085	6.6	6.435	6.27	6.105	5.94	10	3.73		1.5948963
49290086	10.8	10.53	10.26	9.99	9.72	15	4.74		1.4619883
49300087	27	26.325	25.65	24.975	24.3	31	5.35		1.208577
49300088	10.7	10.4325	10.165	9.8975	9.63	15	4.835		1.4756517
49300090	6.7	6.5325	6.365	6.1975	6.03	11	4.635		1.7282011
49310091	7	6.825	6.65	6.475	6.3	10	3.35		1.5037594
49290084	7.6	7.41	7.22	7.03	6.84	12	4.78		1.6620499
49240066	16	15.6	15.2	14.8	14.4	34	18.8		2.2368421
49240067	26	25.35	24.7	24.05	23.4	44	19.3		1.7813765
49240068	20	19.5	19	18.5	18	38	19		2
49020013	0.07	0.06825	0.0665	0.06475	0.063	3	2.9335	5	45.112782
49030021	34	33.15	32.3	31.45	30.6	50	17.7		1.5479876
49010007	84	81.9	79.8	77.7	75.6	132	52.2		1.6541353
49010009	42	40.95	39.9	38.85	37.8	45	5.1		1.1278195
45040037	23	22.425	21.85	21.275	20.7	26	4.15		1.1899314
45050040	22	21.45	20.9	20.35	19.8	25	4.1		1.1961722
45060042	15	14.625	14.25	13.875	13.5	18	3.75		1.2631579
49360128	22	21.45	20.9	20.35	19.8	24	3.1		1.1483254

🟥 Means when it first broke
🟩 Means it was not truly broken

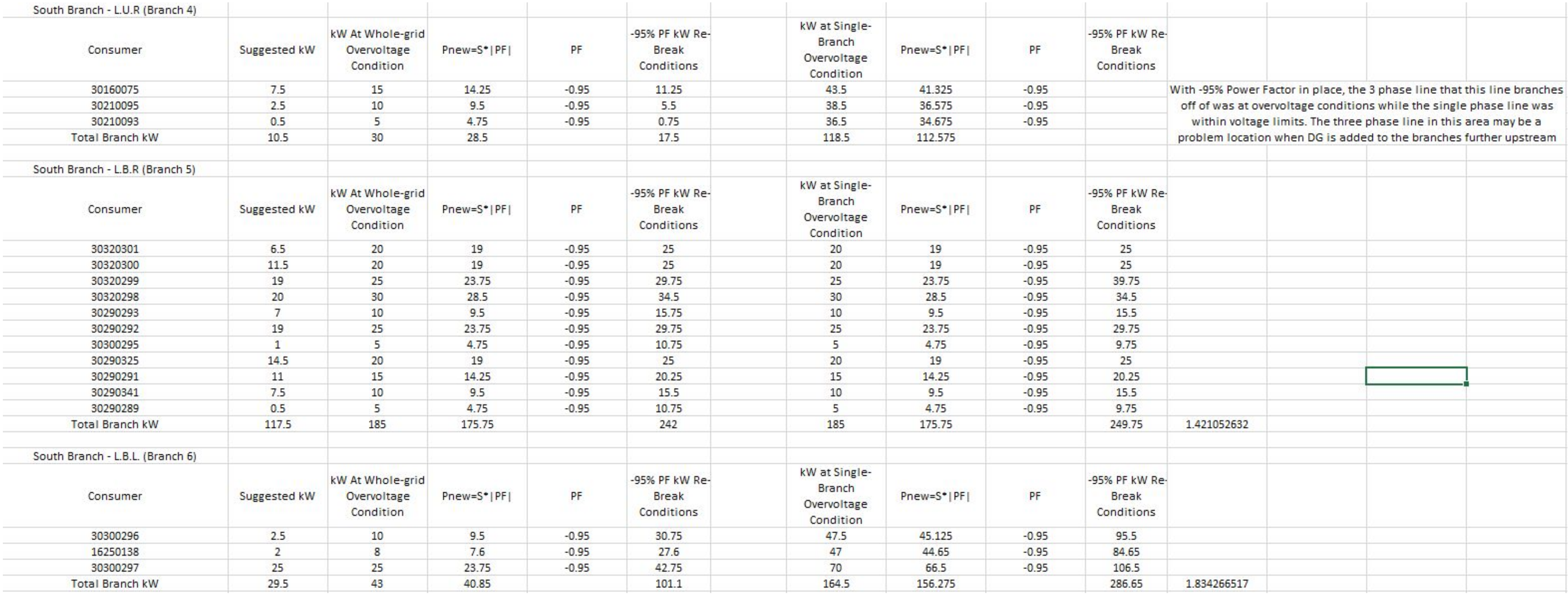
2.295345 Average KW increase to overvoltage at -95%PF

🟦 Upper Left Branch (9)
🟨 North Branch (10)
🟧 North West Branch (1)
🟩 End upper right branch (2)
🟦 Central Middle Branch (4)
🟪 South East Branch (5)
🟥 Central Branch (6)
⬜ West South Branch (7)
🟫 West North Branch (8)
Central North Branch (3)

A3.2 Bernard Substation Solar Array Data



East Branch (Branch 1)											
Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	kW Multiplication Factor to Overvoltage after 0.95 Leading PF
30140060	4	4	3.8	-0.95	6.8		4	3.8	-0.95	6.8	
30110045	1	1	0.95	-0.95	3.95		1	0.95	-0.95	3.95	
30120049	30	30	28.5	-0.95	31.5		30	28.5	-0.95	31.5	
30110046	9.5	9.5	9.025	-0.95	11.75		9.5	9.025	-0.95	11.75	
30100040	7	7	6.65	-0.95	8.65		7	6.65	-0.95	8.65	
30030009	10	10	9.5	-0.95	11.5		10	9.5	-0.95	11.5	
30030008	9.5	9.5	9.025	-0.95	11.025		9.5	9.025	-0.95	11.025	
30030011	17	17	16.15	-0.95	18.15		17	16.15	-0.95	18.15	
30030005	0.5	0.5	0.475	-0.95	2.475		0.5	0.475	-0.95	2.475	
30030007	14	14	13.3	-0.95	15.63		14	13.3	-0.95	15.3	
30020004	62.5	62.5	59.375	-0.95	61.375		62.5	59.375	-0.95	61.375	
Total Branch kW	165	165	156.75		182.805		165	156.75		182.475	1.164114833
South Branch - U.R. (Branch 2)											
Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
30080033	7	30	28.5	-0.95	41.5		30	28.5	-0.95	40.5	
30080034	10	30	28.5	-0.95	41.5		30	28.5	-0.95	40	
30050016	3.5	25	23.75	-0.95	35.75		25	23.75	-0.95	34.75	
30050014	17.5	30	28.5	-0.95	40.5		30	28.5	-0.95	39.5	
Total Branch kW	38	115	109.25		159.25		115	109.25		154.75	1.416475973
South Branch - M.R. (Branch 3)	(Effected by South Branch - M.L.)										
Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
30090036	1	15	14.25	-0.95	36.25		6	5.7	-0.95	16.7	
30090035	2	15	14.25	-0.95	36.25		7	6.65	-0.95	17.65	
30090343	16.5	20	19	-0.95	41		21.5	20.425	-0.95	31.425	
30160071	7	25	23.75	-0.95	44.75		12	11.4	-0.95	21.4	
30160073	11.5	25	23.75	-0.95	44.75		16.5	15.675	-0.95	25.675	
30170076	10.5	20	19	-0.95	40		15.5	14.725	-0.95	24.725	
30170077	5	10	9.5	-0.95	30.5		10	9.5	-0.95	19.5	
Total Branch kW	53.5	130	123.5		273.5		88.5	84.075		157.075	1.868272376



South Branch - L.U.R (Branch 4)

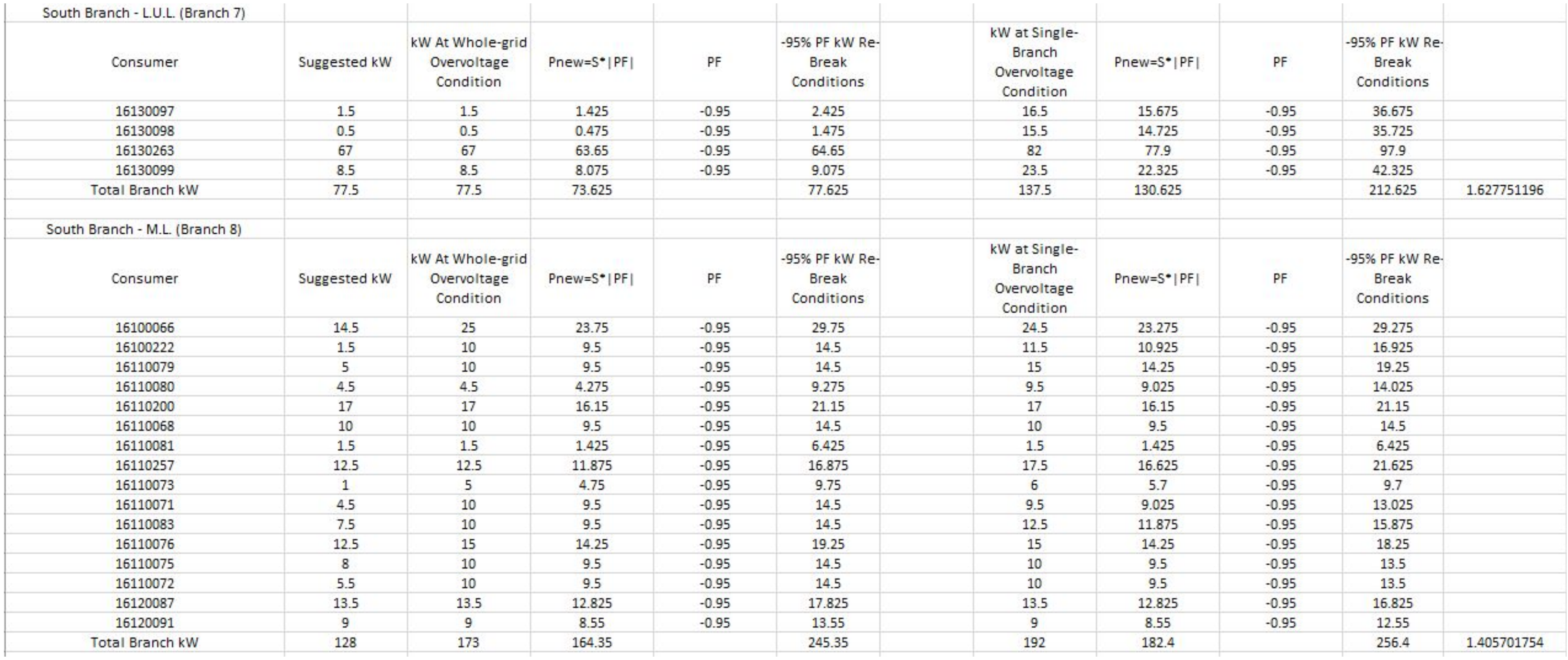
Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
30160075	7.5	15	14.25	-0.95	11.25		43.5	41.325	-0.95		With -95% Power Factor in place, the 3 phase line that this line branches off of was at overvoltage conditions while the single phase line was within voltage limits. The three phase line in this area may be a problem location when DG is added to the branches further upstream
30210095	2.5	10	9.5	-0.95	5.5		38.5	36.575	-0.95		
30210093	0.5	5	4.75	-0.95	0.75		36.5	34.675	-0.95		
Total Branch kW	10.5	30	28.5		17.5		118.5	112.575			

South Branch - L.B.R (Branch 5)

Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
30320301	6.5	20	19	-0.95	25		20	19	-0.95	25	
30320300	11.5	20	19	-0.95	25		20	19	-0.95	25	
30320299	19	25	23.75	-0.95	29.75		25	23.75	-0.95	39.75	
30320298	20	30	28.5	-0.95	34.5		30	28.5	-0.95	34.5	
30290293	7	10	9.5	-0.95	15.75		10	9.5	-0.95	15.5	
30290292	19	25	23.75	-0.95	29.75		25	23.75	-0.95	29.75	
30300295	1	5	4.75	-0.95	10.75		5	4.75	-0.95	9.75	
30290325	14.5	20	19	-0.95	25		20	19	-0.95	25	
30290291	11	15	14.25	-0.95	20.25		15	14.25	-0.95	20.25	
30290341	7.5	10	9.5	-0.95	15.5		10	9.5	-0.95	15.5	
30290289	0.5	5	4.75	-0.95	10.75		5	4.75	-0.95	9.75	
Total Branch kW	117.5	185	175.75		242		185	175.75		249.75	1.421052632

South Branch - L.B.L. (Branch 6)

Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
30300296	2.5	10	9.5	-0.95	30.75		47.5	45.125	-0.95	95.5	
16250138	2	8	7.6	-0.95	27.6		47	44.65	-0.95	84.65	
30300297	25	25	23.75	-0.95	42.75		70	66.5	-0.95	106.5	
Total Branch kW	29.5	43	40.85		101.1		164.5	156.275		286.65	1.834266517



South Branch - L.U.L. (Branch 7)

Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
16130097	1.5	1.5	1.425	-0.95	2.425		16.5	15.675	-0.95	36.675	
16130098	0.5	0.5	0.475	-0.95	1.475		15.5	14.725	-0.95	35.725	
16130263	67	67	63.65	-0.95	64.65		82	77.9	-0.95	97.9	
16130099	8.5	8.5	8.075	-0.95	9.075		23.5	22.325	-0.95	42.325	
Total Branch kW	77.5	77.5	73.625		77.625		137.5	130.625		212.625	1.627751196

South Branch - M.L. (Branch 8)

Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
16100066	14.5	25	23.75	-0.95	29.75		24.5	23.275	-0.95	29.275	
16100222	1.5	10	9.5	-0.95	14.5		11.5	10.925	-0.95	16.925	
16110079	5	10	9.5	-0.95	14.5		15	14.25	-0.95	19.25	
16110080	4.5	4.5	4.275	-0.95	9.275		9.5	9.025	-0.95	14.025	
16110200	17	17	16.15	-0.95	21.15		17	16.15	-0.95	21.15	
16110068	10	10	9.5	-0.95	14.5		10	9.5	-0.95	14.5	
16110081	1.5	1.5	1.425	-0.95	6.425		1.5	1.425	-0.95	6.425	
16110257	12.5	12.5	11.875	-0.95	16.875		17.5	16.625	-0.95	21.625	
16110073	1	5	4.75	-0.95	9.75		6	5.7	-0.95	9.7	
16110071	4.5	10	9.5	-0.95	14.5		9.5	9.025	-0.95	13.025	
16110083	7.5	10	9.5	-0.95	14.5		12.5	11.875	-0.95	15.875	
16110076	12.5	15	14.25	-0.95	19.25		15	14.25	-0.95	18.25	
16110075	8	10	9.5	-0.95	14.5		10	9.5	-0.95	13.5	
16110072	5.5	10	9.5	-0.95	14.5		10	9.5	-0.95	13.5	
16120087	13.5	13.5	12.825	-0.95	17.825		13.5	12.825	-0.95	16.825	
16120091	9	9	8.55	-0.95	13.55		9	8.55	-0.95	12.55	
Total Branch kW	128	173	164.35		245.35		192	182.4		256.4	1.405701754

Southwest Branch (Branch 9)

Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
54320194	2	4	3.8	-0.95	13.8		5	4.75	-0.95	16.75	
54320225	7.5	9.5	9.025	-0.95	19.025		10.5	9.975	-0.95	21.975	
54320335	13.5	15.5	14.725	-0.95	24.725		16.5	15.675	-0.95	26.675	
16050027	4	6	5.7	-0.95	15.7		7	6.65	-0.95	17.65	
16040229	17.5	19.5	18.525	-0.95	28.525		20.5	19.475	-0.95	30.475	
54330245	30.5	32.5	30.875	-0.95	40.875		33.5	31.825	-0.95	42.825	
54330228	14	16	15.2	-0.95	25.2		17	16.15	-0.95	27.15	
16040014	14	16	15.2	-0.95	25.2		17	16.15	-0.95	27.15	
54330274	3.5	5.5	5.225	-0.95	15.225		6.5	6.175	-0.95	17.175	
54330230	9	11	10.45	-0.95	20.45		12	11.4	-0.95	22.4	
54330229	11	12	11.4	-0.95	21.4		14	13.3	-0.95	24.3	
16040243	8.5	9.5	9.025	-0.95	19.025		10.5	9.975	-0.95	20.975	
16040016	16	17	16.15	-0.95	25.15		18	17.1	-0.95	28.1	
16040254	9.5	10	9.5	-0.95	18.5		11.5	10.925	-0.95	21.925	
16040202	14.5	15	14.25	-0.95	23.25		16.5	15.675	-0.95	26.675	
16040215	18	20	19	-0.95	28		20	19	-0.95	31	
16040010	4	6	5.7	-0.95	14.7		6	5.7	-0.95	17.7	
16030008	2	4	3.8	-0.95	12.8		4	3.8	-0.95	15.8	
16030009	10	12	11.4	-0.95	20.4		12	11.4	-0.95	23.4	
16020004	6	10	9.5	-0.95	18.5		10	9.5	-0.95	21.5	
16020005	10	15	14.25	-0.95	23.25		15	14.25	-0.95	26.25	
16020006	9	14	13.3	-0.95	22.3		14	13.3	-0.95	25.3	
Total Branch kW	234	280	266		476		297	282.15		533.15	1.889597732

Northwest Branches 3 Phase (Branch 10)

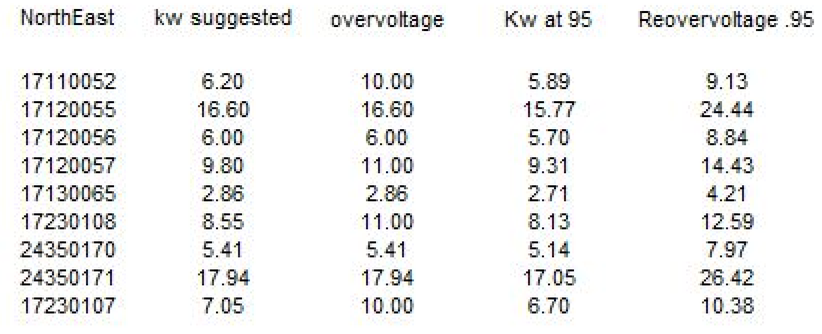
Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
54290179	38	38	36.1	-0.95	56.1		53	50.35	-0.95	65.35	
54290272	42	42	39.9	-0.95	59.9		57	54.15	-0.95	69.15	
54280166	34	34	32.3	-0.95	52.3		49	46.55	-0.95	61.55	
54280168	28.5	28.5	27.075	-0.95	47.075		43.5	41.325	-0.95	56.325	
54270155	9.5	9.5	9.025	-0.95	29.025		24.5	23.275	-0.95	38.275	
54270154	13	13	12.35	-0.95	32.35		28	26.6	-0.95	41.6	
54270153	8	8	7.6	-0.95	27.6		23	21.85	-0.95	36.85	
Total Branch kW	173	173	164.35		304.35		278	264.1		369.1	1.397576676

Northwest Branches 1 Phase (Branch 11)	(Effected by Northwest Branch 3										
Consumer	Suggested kW	kW At Whole-grid Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions		kW at Single-Branch Overvoltage Condition	Pnew=S*|PF|	PF	-95% PF kW Re-Break Conditions	
54220276	7.5	7.5	7.125	-0.95	12.125		9.5	9.025	-0.95	14.025	
54230109	12	12	11.4	-0.95	16.4		14	13.3	-0.95	18.3	
54230108	5	5	4.75	-0.95	9.75		7	6.65	-0.95	11.65	
54230111	11.5	11.5	10.925	-0.95	15.925		13.5	12.825	-0.95	17.825	
55180095	18	18	17.1	-0.95	22.1		19	18.05	-0.95	23.05	
55180189	9.5	9.5	9.025	-0.95	14.025		10.5	9.975	-0.95	14.975	
54130058	9	9	8.55	-0.95	13.55		10	9.5	-0.95	14.5	
54240114	4.5	4.5	4.275	-0.95	9.275		5.5	5.225	-0.95	10.225	
54240113	22	22	20.9	-0.95	25.9		23	21.85	-0.95	26.85	
55190364	0.5	0.5	0.475	-0.95	5.475		3.5	3.325	-0.95	8.325	
55190099	1.5	1.5	1.425	-0.95	6.425		4.5	4.275	-0.95	9.275	
55190100	15	15	14.25	-0.95	19.25		18	17.1	-0.95	22.1	
55190098	11	11	10.45	-0.95	15.45		14	13.3	-0.95	18.3	
54240117	18	18	17.1	-0.95	22.1		21	19.95	-0.95	24.95	
54240116	8	8	7.6	-0.95	12.6		11	10.45	-0.95	15.45	
54250126	5	5	4.75	-0.95	9.75		8	7.6	-0.95	12.6	
54250133	22	22	20.9	-0.95	25.9		25	23.75	-0.95	28.75	
54250120	4.5	4.5	4.275	-0.95	9.275		7.5	7.125	-0.95	12.125	
54250127	8	8	7.6	-0.95	12.6		11	10.45	-0.95	15.45	
54250121	5	5	4.75	-0.95	9.75		8	7.6	-0.95	12.6	
54250135	16	16	15.2	-0.95	20.2		16	15.2	-0.95	20.2	
54250122	30	30	28.5	-0.95	33.5		30	28.5	-0.95	33.5	
Total Branch kW	243.5	243.5	231.325		341.325		289.5	275.025		385.025	1.39996364

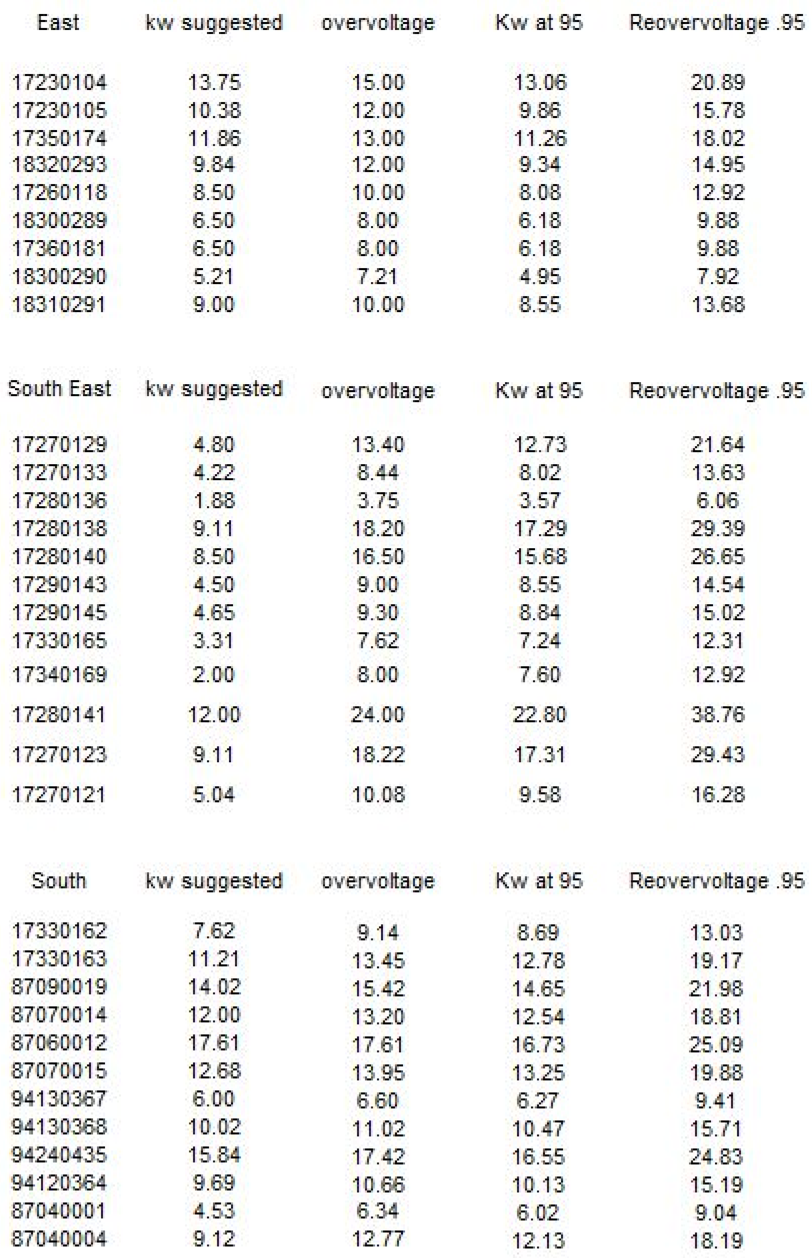
A3.3 Monmouth Solar Array Data

northwest	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
17050025	14.20	14.20	13.49	18.89
98010119	5.38	5.38	5.11	7.16
98010122	5.86	5.86	5.57	7.79
98010123	9.62	9.62	9.14	12.79
98010126	7.02	7.02	6.67	9.34
98010127	2.85	2.85	2.71	3.79
98110181	30.00	30.00	28.50	39.90
98120185	3.02	3.02	2.87	4.02
98130163	10.30	10.30	9.79	13.70

North	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
17070033	3.40	3.40	3.23	4.68
17170075	5.00	5.00	4.75	6.89
17180076	10.00	10.00	9.50	13.78
17180078	7.69	7.69	7.30	10.59
17180079	9.70	9.70	9.22	13.36
17180080	5.00	5.00	4.75	6.89
17180187	15.00	15.00	14.25	20.66
17190082	5.00	5.00	4.75	6.89
17190084	2.98	2.98	2.83	4.10
17190086	14.05	14.05	13.34	19.35
17190088	8.00	8.00	7.60	11.02
98130189	9.12	9.12	8.67	12.57
98130191	6.18	6.18	5.87	8.51
98130192	11.37	11.37	10.80	15.66
98240237	7.67	7.67	7.29	10.57



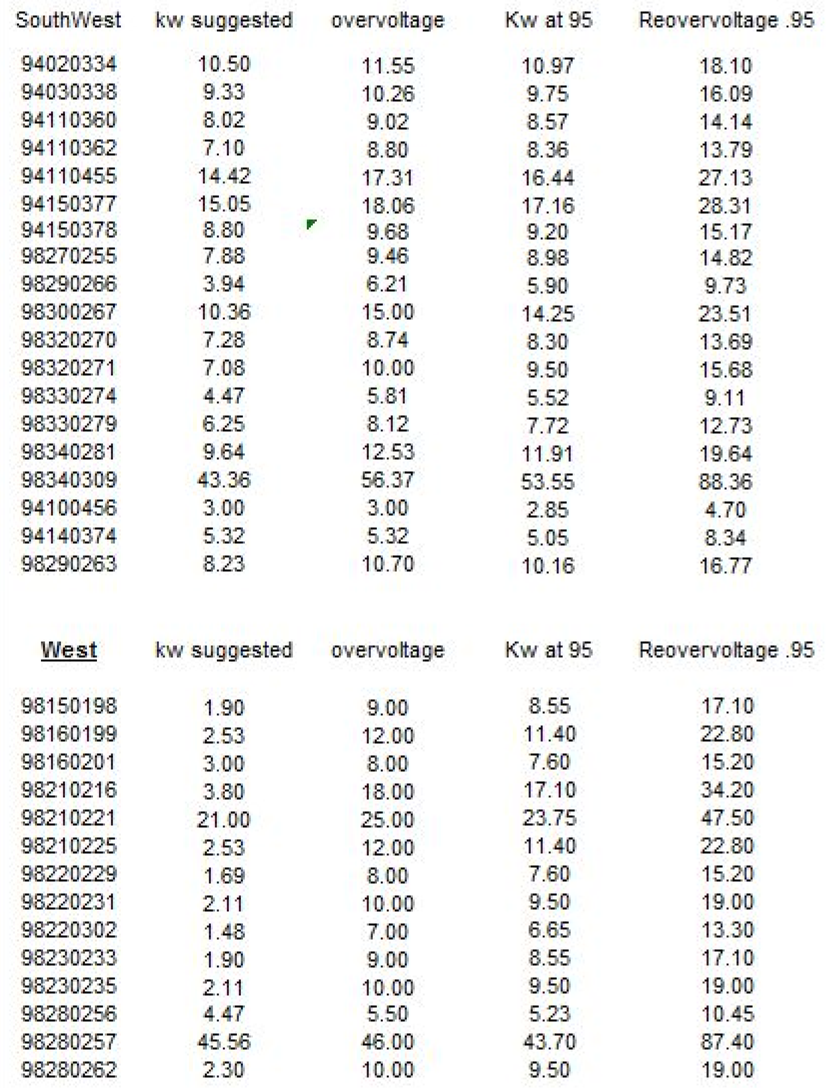
NorthEast	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
17110052	6.20	10.00	5.89	9.13
17120055	16.60	16.60	15.77	24.44
17120056	6.00	6.00	5.70	8.84
17120057	9.80	11.00	9.31	14.43
17130065	2.86	2.86	2.71	4.21
17230108	8.55	11.00	8.13	12.59
24350170	5.41	5.41	5.14	7.97
24350171	17.94	17.94	17.05	26.42
17230107	7.05	10.00	6.70	10.38



East	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
17230104	13.75	15.00	13.06	20.89
17230105	10.38	12.00	9.86	15.78
17350174	11.86	13.00	11.26	18.02
18320293	9.84	12.00	9.34	14.95
17260118	8.50	10.00	8.08	12.92
18300289	6.50	8.00	6.18	9.88
17360181	6.50	8.00	6.18	9.88
18300290	5.21	7.21	4.95	7.92
18310291	9.00	10.00	8.55	13.68

South East	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
17270129	4.80	13.40	12.73	21.64
17270133	4.22	8.44	8.02	13.63
17280136	1.88	3.75	3.57	6.06
17280138	9.11	18.20	17.29	29.39
17280140	8.50	16.50	15.68	26.65
17290143	4.50	9.00	8.55	14.54
17290145	4.65	9.30	8.84	15.02
17330165	3.31	7.62	7.24	12.31
17340169	2.00	8.00	7.60	12.92
17280141	12.00	24.00	22.80	38.76
17270123	9.11	18.22	17.31	29.43
17270121	5.04	10.08	9.58	16.28

South	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
17330162	7.62	9.14	8.69	13.03
17330163	11.21	13.45	12.78	19.17
87090019	14.02	15.42	14.65	21.98
87070014	12.00	13.20	12.54	18.81
87060012	17.61	17.61	16.73	25.09
87070015	12.68	13.95	13.25	19.88
94130367	6.00	6.60	6.27	9.41
94130368	10.02	11.02	10.47	15.71
94240435	15.84	17.42	16.55	24.83
94120364	9.69	10.66	10.13	15.19
87040001	4.53	6.34	6.02	9.04
87040004	9.12	12.77	12.13	18.19



SouthWest	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
94020334	10.50	11.55	10.97	18.10
94030338	9.33	10.26	9.75	16.09
94110360	8.02	9.02	8.57	14.14
94110362	7.10	8.80	8.36	13.79
94110455	14.42	17.31	16.44	27.13
94150377	15.05	18.06	17.16	28.31
94150378	8.80	9.68	9.20	15.17
98270255	7.88	9.46	8.98	14.82
98290266	3.94	6.21	5.90	9.73
98300267	10.36	15.00	14.25	23.51
98320270	7.28	8.74	8.30	13.69
98320271	7.08	10.00	9.50	15.68
98330274	4.47	5.81	5.52	9.11
98330279	6.25	8.12	7.72	12.73
98340281	9.64	12.53	11.91	19.64
98340309	43.36	56.37	53.55	88.36
94100456	3.00	3.00	2.85	4.70
94140374	5.32	5.32	5.05	8.34
98290263	8.23	10.70	10.16	16.77

West	kw suggested	overvoltage	Kw at 95	Reovervoltage .95
98150198	1.90	9.00	8.55	17.10
98160199	2.53	12.00	11.40	22.80
98160201	3.00	8.00	7.60	15.20
98210216	3.80	18.00	17.10	34.20
98210221	21.00	25.00	23.75	47.50
98210225	2.53	12.00	11.40	22.80
98220229	1.69	8.00	7.60	15.20
98220231	2.11	10.00	9.50	19.00
98220302	1.48	7.00	6.65	13.30
98230233	1.90	9.00	8.55	17.10
98230235	2.11	10.00	9.50	19.00
98280256	4.47	5.50	5.23	10.45
98280257	45.56	46.00	43.70	87.40
98280262	2.30	10.00	9.50	19.00