Investigating Solutions to Voltage Increase on Distributed Generation Power Systems

DESIGN DOCUMENT

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1 Introduction

1.1 PROJECT STATEMENT

Electric companies that have lightly loaded distribution feeders can experience high voltage as the amount of distributed generation (DG) being installed increases. When power is coming back onto the electric system from the end consumer, it can drive the voltage outside of ANSI limits (ANSI standard C84.1 Range A, 114V to 126V). Additional equipment, system upgrades, or special settings on existing equipment will be needed to bring the voltage on the feeder back within acceptable voltage limits.

1.2 PURPOSE

As distributed generation is becoming increasingly popular, distribution companies with low-loaded feeders are seeing increases in voltages on nearby lines and in some cases, all the way back to the substation. The results of this project should be very beneficial in providing a path forward for distribution companies with low-loaded feeders in ways to allow the amount of distributed generation installed to increase while having a minimal effect on the voltage of the grid in low-loaded systems.

1.3 GOALS

We would like to gain an understanding of distributed generation and its effects on low load distribution systems and determine a way to maximize the amount of DG a rural distribution system can contain using the latest technology. To accomplish this, we will:

- Quantify voltage rise issues in MVEC's feeders with different penetration levels of DG
- Model practical feeders using software such as WindMlil and OpenDSS.
- Explore new technologies such as the implementation of smart inverters and the proper settings.

2 Deliverables

The final deliverables for this project will be:

- A thorough report of our findings and a suggested path forward for Maquoketa Valley Rural Electric Cooperative (MVEC) on ways to allow for increased distributed generation on their system.
- We will also deliver a working system model implementing our solution.
- A cost comparison for the different solutions.

3 Design

Our process will be to model MVEC's system in WindMil and OpenDSS and understand the effects of distributed generation on their system. We will then research technologies that may help keep the voltage on the system within the ANSI system limits. We will then implement these researched technologies into our system models and determine the best way to maintain the system voltage. From the possible solutions, we will then perform a cost analysis to determine the most economically acceptable solution.

3.1 SYSTEM SPECIFICATIONS

The proposed solution must follow the IEEE 1547 standards (grid voltage must remain within +- 5% of 120V (ANSI Standard C84.1 Range A)) and the solution should prevent the DG from causing overvoltages on the distribution grid.

3.1.1 Non-functional

Learning to use modeling software WindMil and OpenDSS

Research into possible solutions to select the most universally applicable

Compiling our data and research to present to our client, MVEC

3.1.2 Functional

Keep all elements of the system within ANSI voltage limits under all conditions (114V to 126V).

Accurately model the system under differing load/DG conditions

Solving all instances where model departs from ANSI limits

3.2 PROPOSED DESIGN/METHOD

To determine the best method for controlling the effects of distributed generation on MVEC's distribution system, we will analyze SCADA data, AMI Data, solar data, and the system model provided by MVEC. We will use this data along with the WindMil software and OpenDSS to determine and analyze the worst-case scenarios (lightest loaded day with highest amount of solar generation) and the associated effects on the distribution system. Simultaneously, we will research technologies such as smart inverters, capacitor banks, storage, load tap changing transformers, and customer side voltage regulators and the beneficial effects they could have on MVEC's distribution systems, and how to implement them into the systems. We will then run several simulations with the various researched technologies in place and analyze the effects on the distribution systems. We will observe the effects not only on the voltage of the system, but we will need to also watch the power factor throughout the system as we add DG and also add devices to attempt to control the voltage rise. Once we have found a potential solution to MVEC's problem, we will inform them of our findings and provide them with a cost analysis performed by us and they will review and potentially implement the technology into the solar panels they have installed at their office building and we will be able to determine if the real-world effects are similar to the modeled results.

3.3 DESIGN ANALYSIS

We have received the AMI data and SCADA data for one of MVEC's most lightly loaded substations to begin out analysis on. We have also received rooftop solar data from MVEC's office solar panels. We have analyzed this data and found the days and times of highest solar generation, days and times of lowest load, and the cases where the kW difference between solar generation and load were minimized, which is our starting point for running simulations on. We have familiarized ourselves with basic WindMil usage and have begun testing the substation model, seen in Figure 1 below, with DG of various sizes in various locations and analyzing the effects on the system, such as voltage rise and power factor decreases. The real system currently only has one DG installation on it, a 25kW solar array that is not causing any grid problems. We have been told by MVEC to place DG installations throughout the model as we please, with the only guides being that currently, the individual solar installations on other substations range from 1.5 kW up to 75kW and that typically, clusters of neighbors will all put in solar panels on their houses. We are now in the process of creating voltage problems on the system by adding clusters of DG to various branches and observing the results, including power factor changes, increased voltage, and changes in the current. We are also beginning to learn how to model the possible solution technologies in WindMil and how to export our WindMil model to OpenDSS to run analyses over time.

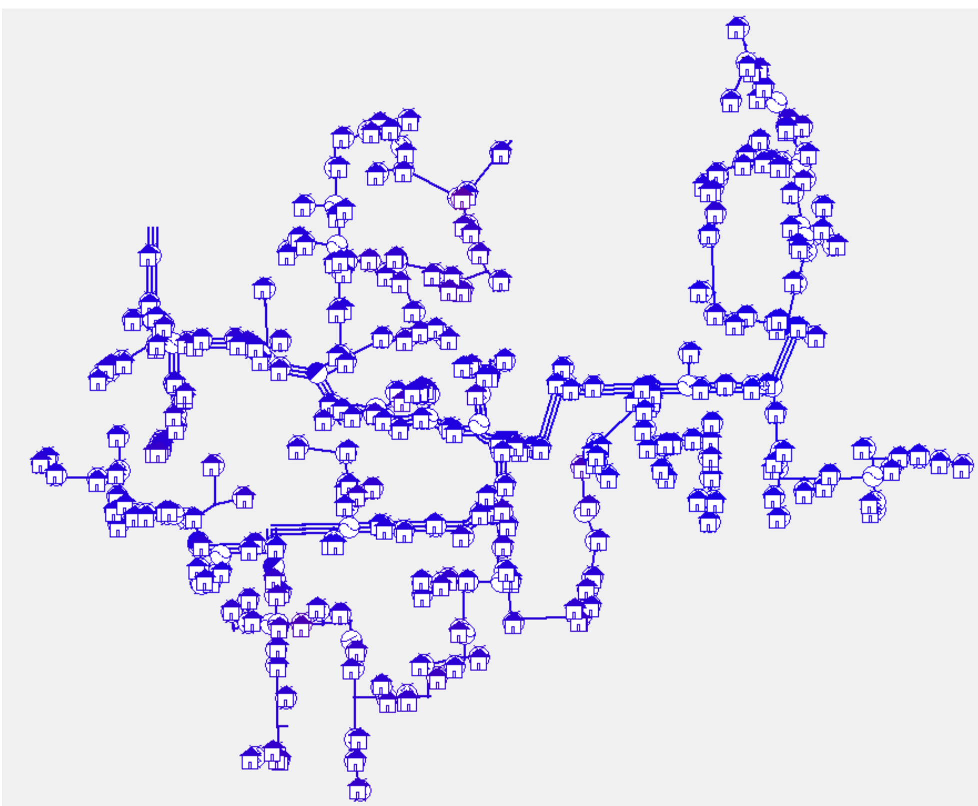

Figure 1 Base model of lightly-loaded feeders provided by MVEC. No DG was included in the model.

4 Testing/Development

4.1 INTERFACE SPECIFICATIONS

There is no hardware/software interfacing required for this project.

4.2 HARDWARE/SOFTWARE

WindMil - WindMil is used to graphically model the system provided by MVEC. WindMil will be used to create a snapshot analysis of the distribution system under specific conditions. The results from WindMil will be used as a check to verify that our OpenDSS model is working correctly.

OpenDSS - OpenDSS will be used to create an analysis over time of the MVEC system. As the output of solar panels is always changing based on the weather, OpenDSS will be able to provide a much more accurate model of the system and the effects of the DG on the system over time and what the effects are of the technology being tested.

4.2 PROCESS

To perform our testing, we will analyze one substation's feeders' model provided by MVEC at a time. We will use the determined methods for controlling the voltage on the grid (storage, smart inverters, capacitor banks, load tap changing transformers, and customer side voltage regulation) and test each method independently on the same model. We will first implement the technology being tested into the WindMil software and analyze the effects under several solar production and load scenarios to develop a baseline. We will then transfer the model to OpenDSS and analyze the effects over time and under varying conditions. We will then repeat the process for the next technologies.

Once a technology is found that adequately limits the effects of DG on the distribution grid (the voltage is maintained between 114V and 126V throughout the system, the power factor is maintained at a level acceptable to MVEC, and MVEC's power losses are minimized), that technology will be implemented into several other substation system models provided by MVEC. We will then analyze this technology on each of those substation systems using WindMil first and then OpenDSS. If the results fit the specifications, we present the results to MVEC to implement on the rooftop solar panels that they have on their office building for real-world testing. If the results do not fit the specifications, we will search for another technology.

5 Results

Results of our research are pointing us towards the use of smart inverters for reactive power control as the best solution to MVEC's problem (Collins and Ward, 2015), however, further research into Load Tap Changing Transformers (Kabiri, et al, 2014) also shows a potential solution in lowering the magnitude of voltage supplied to the grid during peak DG generation times from the substation and allowing the DG installations to bring the voltage back up to a normal level (within ANSI standards) . We have placed DG in various locations on the provided model and caused several overvoltage scenarios which include a significantly decreased power factor on various lines near the DG installations. Moving forward, we will need to consider both the voltage effects and the power factor effects of the DG on the system and we will have to find ways to successfully maintain voltage levels while maintaining power factor levels. We will fill table 1 with our findings from next semesters work.

Table 1: Analysis criteria of our given technologies.

Technology	Voltage Regulation	Power Factor Regulation	Costs per Unit	Additional Comments
Solar Inverters				
Battery Storage				
LTC transformers				
Customer Side Regulation				
Capacitor Banks				

6 Conclusions

To this point, we are a little behind schedule due to problems with getting a signed NDA form from Iowa State University and we have also been delayed by getting a sufficient WindMil license to successfully model the MVEC system. We now have a working WindMil model and have begun to implement DG into the model and analyze the results. The power factor changes to the system along with the voltage rise due to the added DG will require more research and deeper analysis as we were not anticipating such a significant power factor change due to inexperience with this sort of work. Future work will focus on maintaining voltage levels within ANSI standards and also maintaining power factor levels throughout the system. With a little more research and practice with properly implementing the technologies we are going to test into the model, we will be fully prepared to begin testing with WindMil and OpenDSS in the fall semester.

7 References

Real and reactive power control of distributed PV inverters for overvoltage prevention and increased renewable generation hosting capacity
Collins, L.; Ward, J.K. : Renewable Energy, September 2015, Vol.81, pp.464-471 [Peer Reviewed Journal]

The Influence of Pv Inverter Reactive Power Injection on Grid Voltage Regulation
Kabiri, R ; Holmes, D.G. ; McGrath, B.P. : IEEE Xplore, IEEE, June 2014

IEEE 1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems)

ANSI Standard C84.1 Range A

8 Appendices

Software Manuals Used:

OpenDSS Manual from EPRI

Table 2: Analysis criteria of our given technologies.

Technology	Voltage Regulation	Power Factor Regulation	Costs per Unit	Additional Comments
Solar Inverters				
Battery Storage				
LTC transformers				
Customer Side Regulation				
Capacitor Banks				

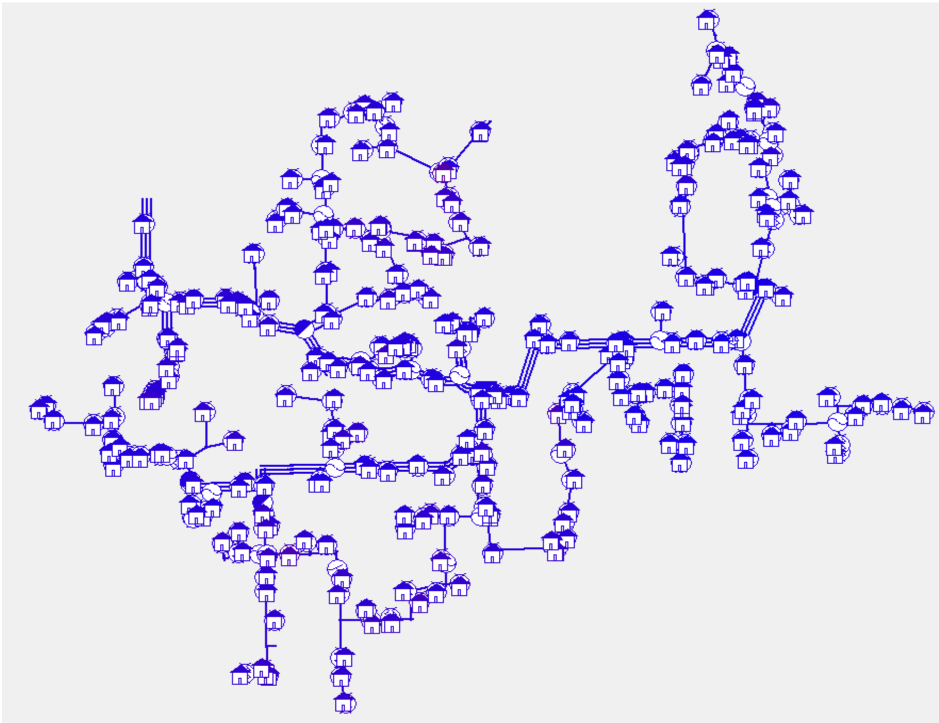

Figure 2 Base model of lightly-loaded feeders provided by MVEC. No DG was included in the model.