# Impacts of DERs on Rural Distribution Circuits

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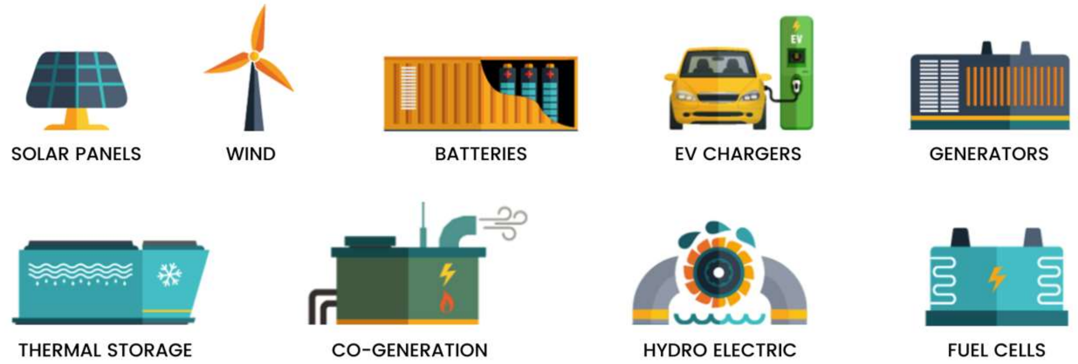
# Outline

- Background
- Electrification Analysis
- Digital Twins in Rural Distribution Circuits
- Digital Twin Model Construction
- Conclusion

# Background

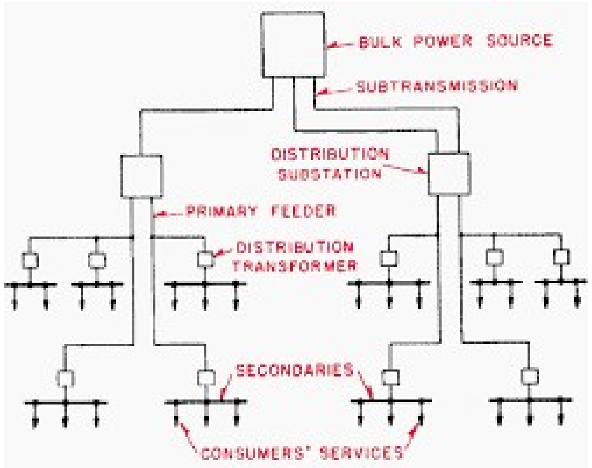
# Classify DERs and Rural Circuits

- Distributed Energy Resources
  - Smaller generation units
  - Typically, on the customer's side of the meter




https://www.fuergy.com/blog/der-and-microgrids

- Rural Circuits
  - Radial systems that are identified based on low density with customers further away from one another




https://electrical-engineering-portal.com/radial-distribution-systems-subtransmission-circuits

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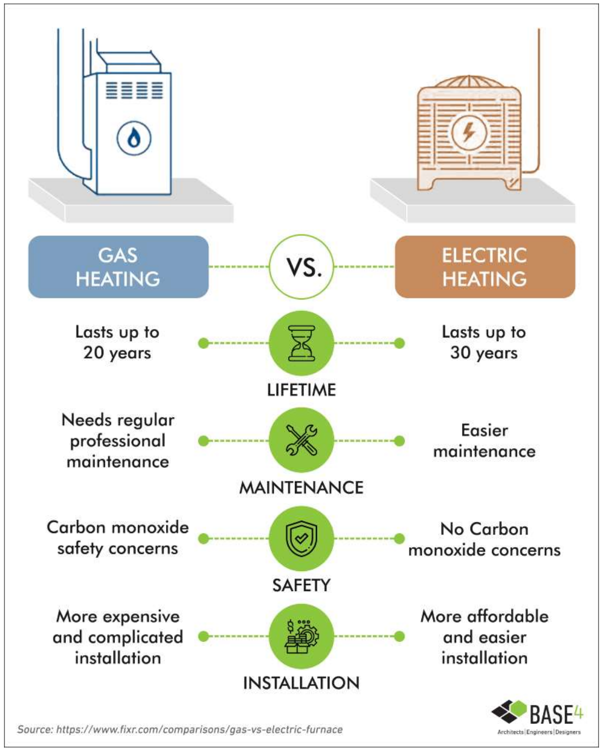
# Electrification Growth

- Newer developments are focusing on all electric homes
  - This includes changing to electric heating
- Significant benefits of using electric heating
- Want to estimate the impact of electrifying non- electrically heated homes
- Analyze the coolest and warmest months of 2020 (January and July)
- Goal: Determine load changes and evaluate grid impacts

VJ0




https://www.base-4.com/multifamily-development-gas-vs-electric-heat/

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**Slide 5**

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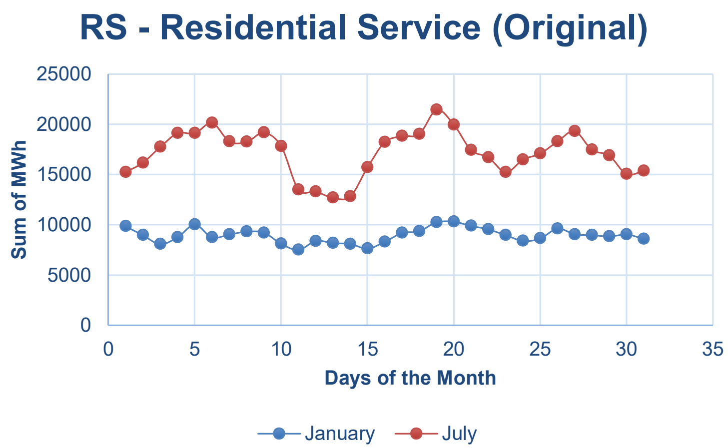
**VJ0** Grammar

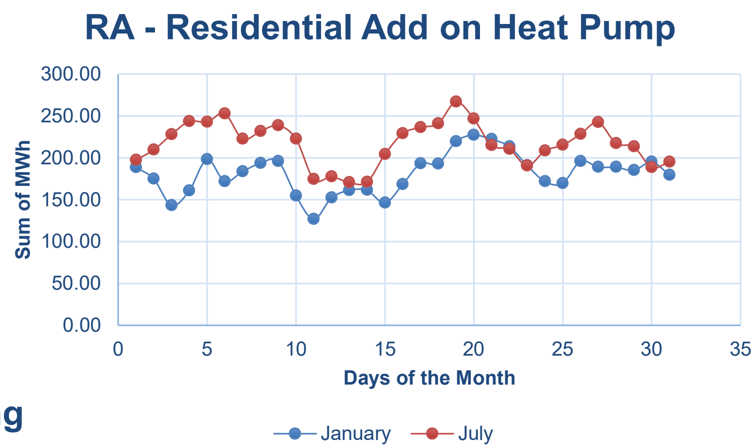
Determine load changes and evaluate grid impacts
Valentine, Jessica, 2023-04-21T16:08:58.519

# Electrification Analysis

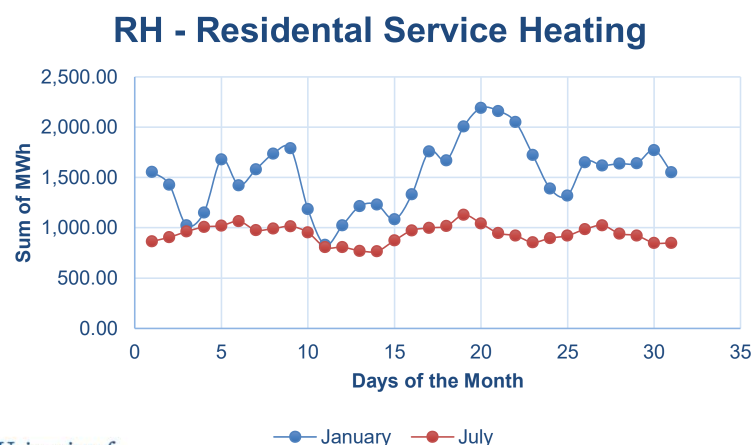
# Original Loads




~ 500,000 Customers




~ 6,000 Customers




~ 40,000 Customers

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# Altering Residential Load to Include Heat Pumps

- Assumptions:
  - Average Home Size: **1,489 sq. ft**
  - Electric heating system energy use: **7.5 Wh/sq. ft**
  - Average energy consumption per home due to electric heating system: **11,167.5 W per hour per home**
  - Number of residential customers that switch to electric heating systems: **382,850 customers**

VJ2

VJ0

- Based on these assumptions, the approximate increase in electric load due to 65% of residential customers electrifying heating loads is approximately **4,275.5MW per hour**
  - Realistically, there are 85% of customers using gas heating according to the rate classes

https://energyusecalculator.com/electricity_furnace.htm#:~:text=Electric%20furnaces%20range%20from%2010,the%20furnace%20is%20being%20used.
https://www.homes.com/pittsburgh-pa/what-is-my-home-worth/

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**VJ0** Is this an electric furnace/electric heating system? Should specify - it probably doesn't make sense to equate gas/electric as having the same energy usage.
Valentine, Jessica, 2023-04-21T16:14:38.200

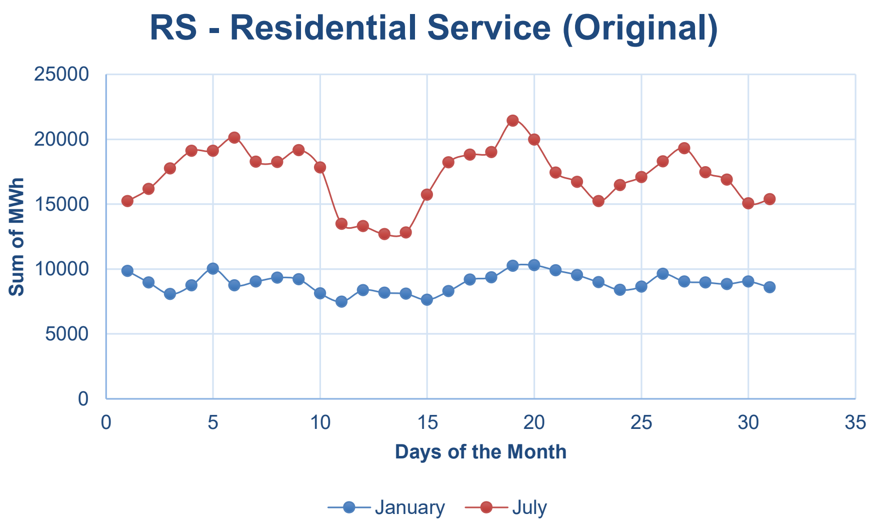
**VJ1** I might format this section differently.

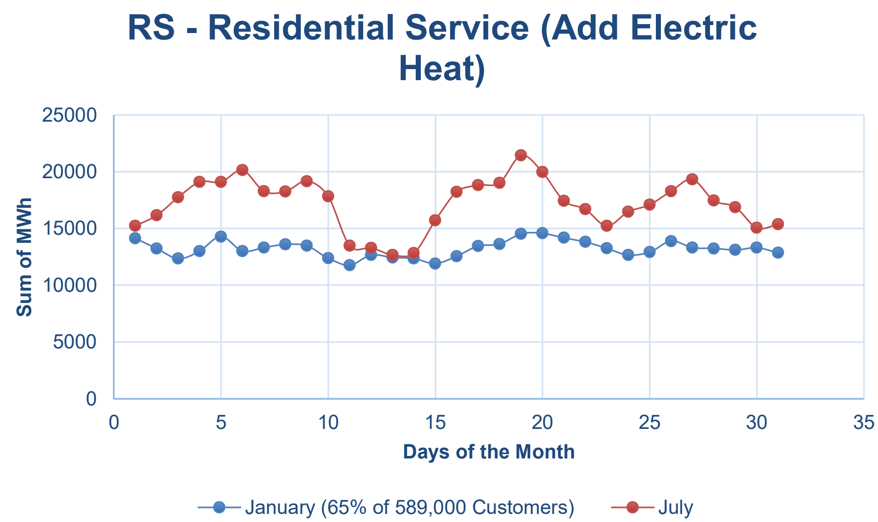
Assumptions:
Average home size: ___
Electric heating system energy use: __
Average energy consumption per home due to electric heating system: __
Number of residential customers that switch to electric heating systems: ___

Based on these assumptions, the approximate increase in electric load due to 65% of residential customers electrifying heating loads is approximately__
Valentine, Jessica, 2023-04-21T16:19:00.423

**VJ2** If you have citations/references for these values put them in as footnotes.
Valentine, Jessica, 2023-04-21T16:19:25.214

# Altering Residential Load to Include Heat Pumps




NOTE: This represents the maximum values and assuming that the heaters are running at full capacity, all day

This is addressed through the Interactive Excel

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# Comparing Original and Projected January

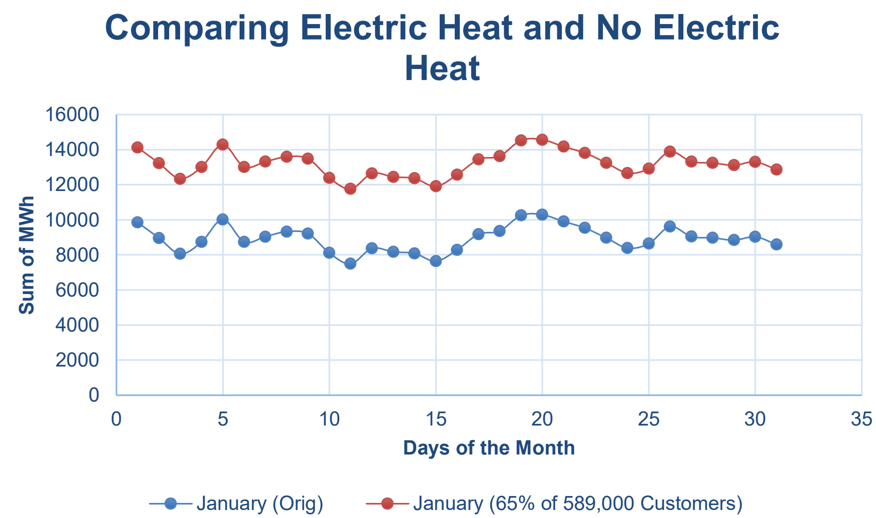
- The peak shift is an increase in electric usage of **4,275.5MWh**

Estimated Prof VJ2 ncrease:

| Rate Class | Rate ($/kWh) | Original January | Added Electric Heat January | Net Profit VJ0 |
|---|---|---|---|---|
| RS | $ 0.06 | $ 17 Million | $ 25 Million | $ 8 Million |

VJ1

VJ3

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## Slide 10

**VJ0** Phrasing is a little funky here.

I would delete this top box of the table.

Valentine, Jessica, 2023-04-21T16:21:52.628

**VJ1** Rate Class not Case

Valentine, Jessica, 2023-04-21T16:22:05.836

**VJ2** "Estimated Profit Increase" may be better.

Valentine, Jessica, 2023-04-21T16:22:30.835

**VJ3** Take off some of the sig figs here - I doubt we know this to this level of accuracy based on high-level assumptions

Valentine, Jessica, 2023-04-21T16:22:58.821

# Verifying Conductor Capacity

- For the purposes of rating the current on the line in a 23kV circuit, it is assumed that **10 homes are being evaluated for heat electrification** VJ2
- If electric heat were added to those 10 homes, the current would **increase by 4.86 amps** on the same circuit
  - The typical current draw would be 10.14 amps, based on a 23kV circuit and 382,850 customers consume an average of 8,929,794 Watts in an hour VJ3
  - Current carrying capacity is 500A on average, so **100 homes is already 10%** VJ0

VJ1

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## Slide 11

**VJ0** Isn't this the exact same thing that is stated in the second bullet?
Valentine, Jessica, 2023-04-21T16:24:45.182

**VJ1** May want to define this acronym if it isn't defined already
Valentine, Jessica, 2023-04-21T16:25:46.249

**VJ2** 10 homes being evaluated or 10 homes assumed to electrify?
Valentine, Jessica, 2023-04-21T16:26:18.932

**VJ3** The two parts of this sentence don't seem connected to me. What does the 10.14 amps have to do with the customers consuming an average W/hr
Valentine, Jessica, 2023-04-21T16:27:13.882

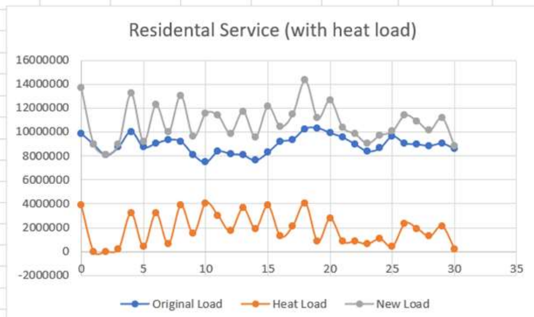
**NS3 0** That's how you solve for the current since only the voltage and power are known, so I wanted to state the assumptions used for calculations
Nguyen, Sabrina, 2023-04-21T17:03:44.957

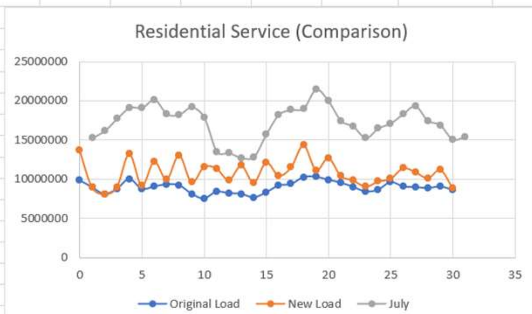
# Integrating Diversification - Code

Excel File: Heating Load Python Supplemental
Python Code: Curve Generator

| Diversification | |
|---|---|
| Diversification was randomized from the Python Code, average value was used for some of the analyses | |
| Average amount of diversification based on code: | 43.7097% |

Graphs below show the typical behavior of the system WITH this added electrified heat at the percent diversification




VJ0

| Power Per Circuit | | | | |
|---|---|---|---|---|
| What is the change in power per circuit (MAX) (assuming there are 164 23kV circuits) | | | | |
| 26069.98399 | kW per circuit | or | 26.06998399 | MW per circuit |
| With the average diversification, what is the change in power the circuit will actually see? | | | | |
| 11395.10591 | kW per circuit | or | 11.39510591 | MW per circuit |

| Ampacity | | |
|---|---|---|
| To reflect the changes that are going to be seen on the system, the ampacity is also evaluated | | |
| Number of homes: 10 | | |
| With electric heat, the max power per home is | 11167.5 | W per home |
| With the average diversification, power per home: | 4881.278226 | W per home |
| Given the number of homes, this has a power of | 48812.78226 | W |
| On a 23kV circuit, this would increase current by | 2.122294881 | A |

**Profit (in a month for entire system)**

In order to quantify the profit based on the assumed diversification, assume the following rate cases

| Case | Rate ($/kWh) | Original Jan | Added Heat Jan | Profit |
|---|---|---|---|---|
| RS | $ 0.06 | $ 16,609,416.84 | $ 20,085,379.95 | $ 3,475,963.11 |
| RH | $ 0.04 | $ 11,072,944.56 | $ 13,390,253.30 | $ 2,317,308.74 |
| RA | $ 0.02 | $ 4,429,177.83 | $ 5,356,101.32 | $ 926,923.49 |

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## Slide 12

**VJ0** Can't read the last part of this clearly because white on white

Valentine, Jessica, 2023-04-21T16:27:37.669

# Digital Twins in Rural Distribution Circuits

# Background – Digital Twins

- **Digital twins** create a **virtual model of a physical system** that updates in real time to take advantage of high volumes of data
  - Used to run simulations to test theories before applying to the real system
- Digital twins help expose and mitigate potential vulnerabilities in the grid
- Various applications in power systems
  - Utilities
  - Battery systems, EVs, Renewable Energy Generators

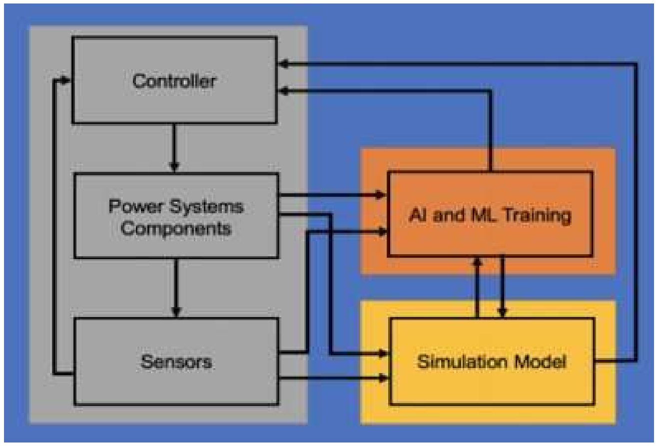
Adil Rasheed, Omer San, and Trond Kvamsdal. Digital twin: Values, challenges and enablers from a modeling perspective. IEEE Access, 8:21980–22012, 2020

# How Do Digital Twins Work?

- Digital twins use an approximated, virtual model alongside a physical system to perform analyses and utilize machine learning and other analyses to better understand the system and perform experimentations

| Level 1: Pre- Digital Twin | Level 2: Digital Twin |
|---|---|
| *Physics – Based Simulation* | *Physics – Based Simulation* |
| Physical System | *Physical System* |
| Adaptive GUI | Adaptive GUI |
| Machine Learning | Machine Learning |
| **Level 3: Adaptive Digital Twin** | **Level 4: Intelligent Digital Twin** |
| *Physics – Based Simulation* | *Physics – Based Simulation* |
| *Physical System* | *Physical System* |
| *Adaptive GUI* | *Adaptive GUI* |
| Machine Learning | *Machine Learning* |

William Danilczyk, Yan Sun, and Haibo He. Angel: An intelligent digital twin framework for microgrid security. IEEE, 2019.




Ahmed Saad, Samy Faddel, Tarek Youssef, and Osama A. Mohammed. On the implementation of iot-based digital twin for networked microgrids resiliency against cyber attacks. IEEE Transactions on Smart Grid, 11:5138–5150, 11 2020.

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# How to Use Digital Twins in Power Systems?

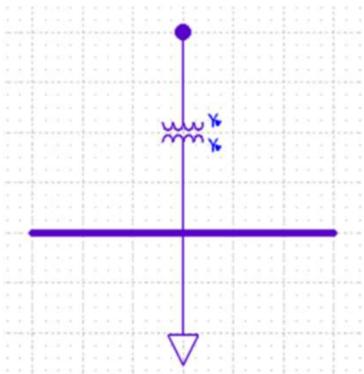
- Create a way to have a singular digital representation of an existing system
- Having a digital twin of a power system will allow for machine learning to provide utility information on how to better modify and upgrade the system
  - Can be used to increase reliability and predictability
  - Help to make more informed decisions and increase visibility of the power system

# Digital Twin Model Construction

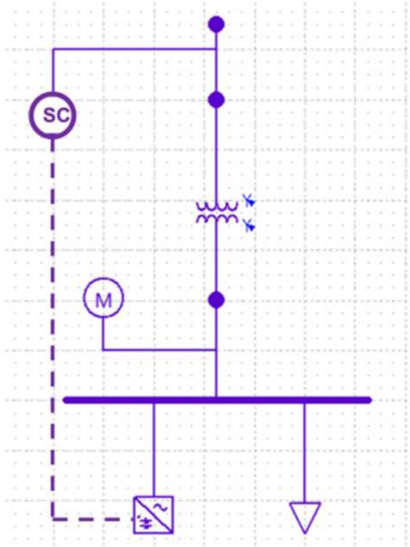
# Model Construction – Circuit Map

- Chose an arbitrary poor performing circuit
- Modeled in OpenDSS
- Use of Python to interface with OpenDSS

Manipulated Circuit



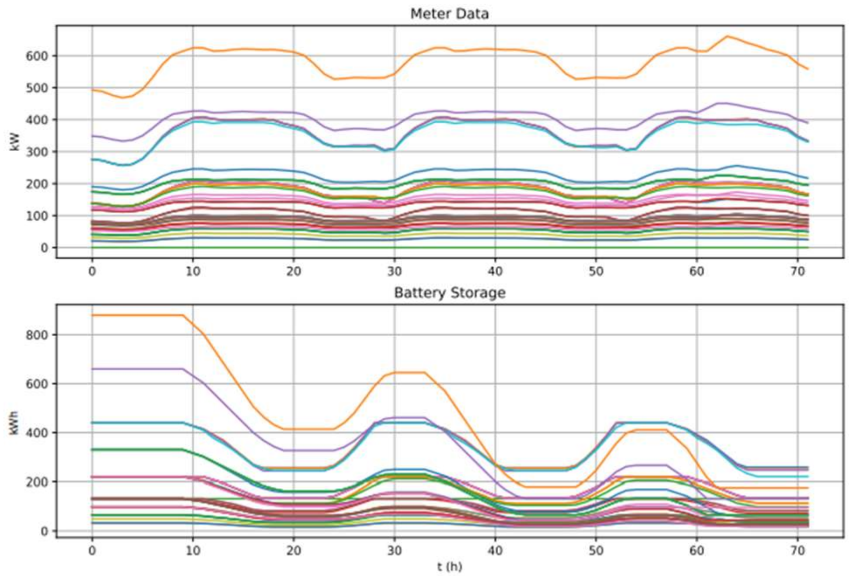
Original Configuration



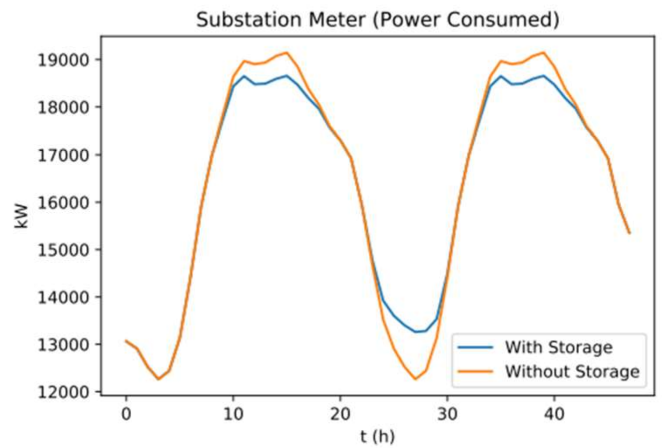

Modified Configuration

# Results – Impact of Storage (Real Circuit, No Solar)

Skip = 15, 30% Peak Shaving, Storage = Load




- Left Graph
  - Each line is a meter storage pair (47)
  - Can visualize peak shaving
- Bottom Graph
  - Evaluates substation meter for entire system
  - Has a peak decrease of ~2.5%

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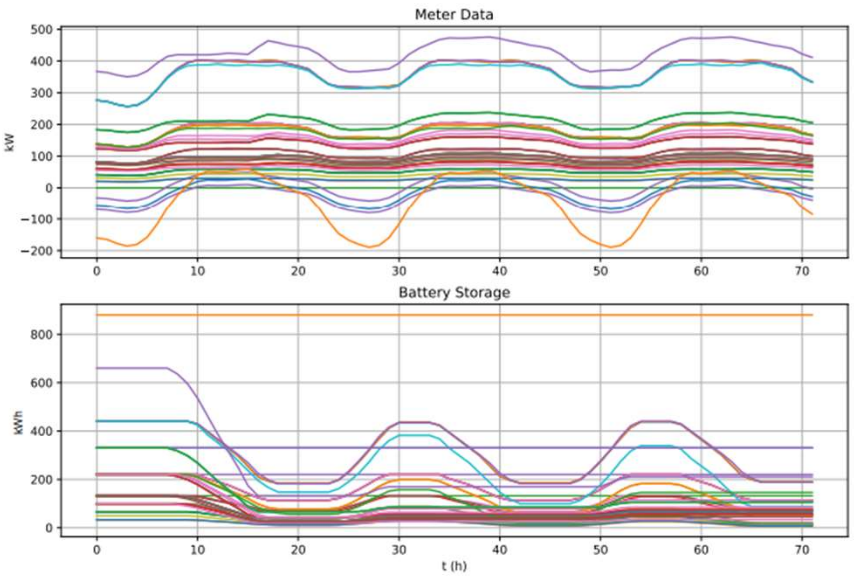
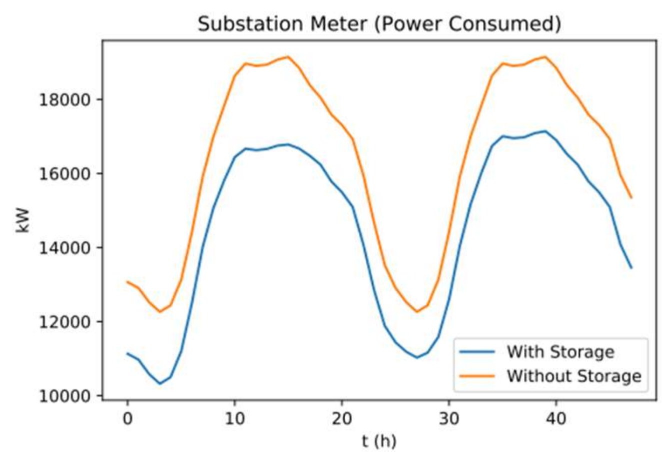
# Results – Impact of Storage (Real Circuit, 2000kW Solar)

Skip = 15, 30% Peak Shaving, Storage = Load




- Left Graph
  - Each line is a meter storage pair
  - Only some of the feeders add the solar (Orange)
- Bottom Graph
  - Has a peak decrease of ~12.5%

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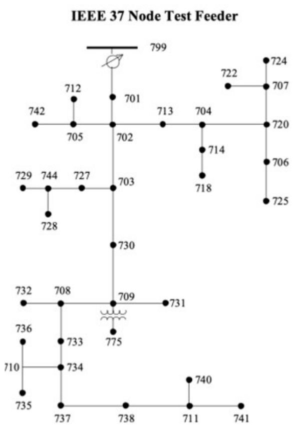
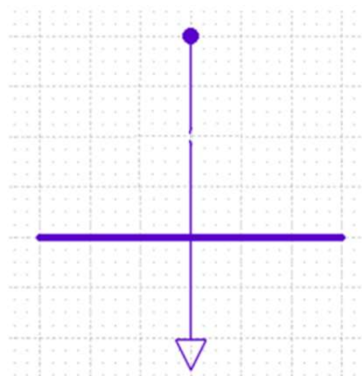
# Model Construction – Circuit Map

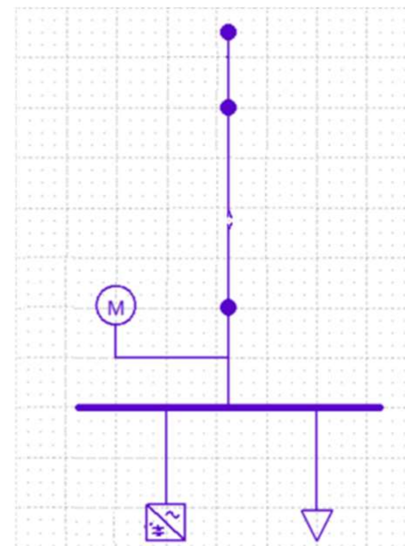
- Use of IEEE 37 Node System
- Constructed our own controller
- Manually scale and place batteries




Manipulated Circuit



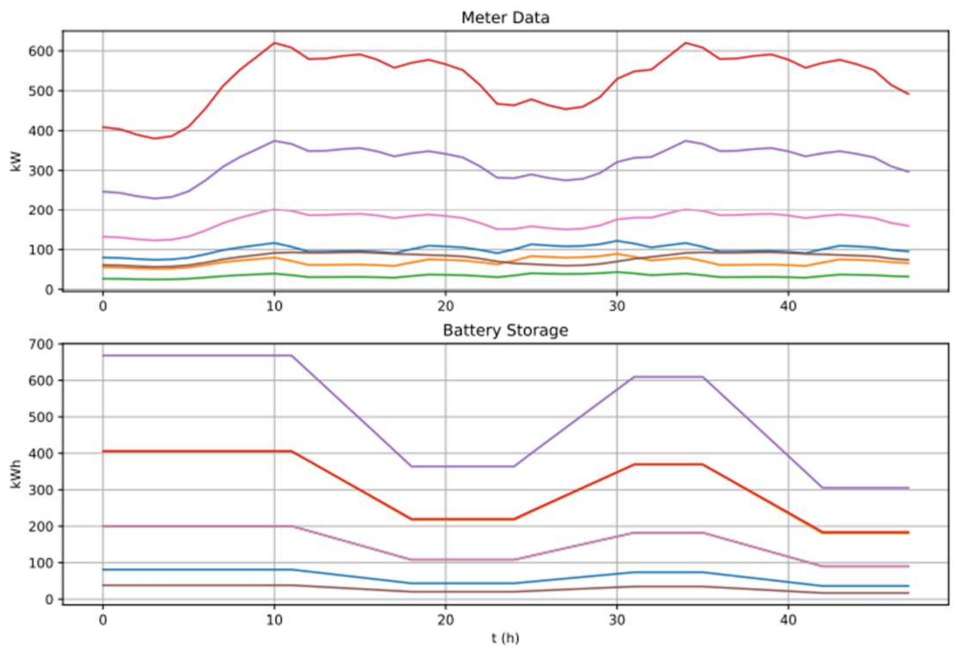
Original Configuration



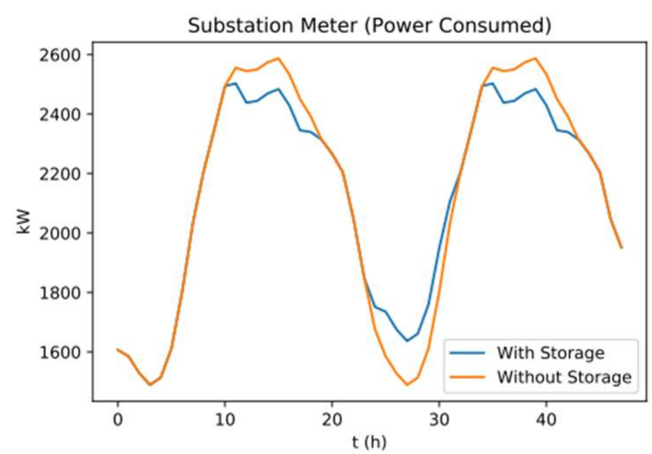

Modified Configuration

# Results – Impact of Storage (IEEE Circuit, No Solar)

Skip = 2, Storage = 2000kW

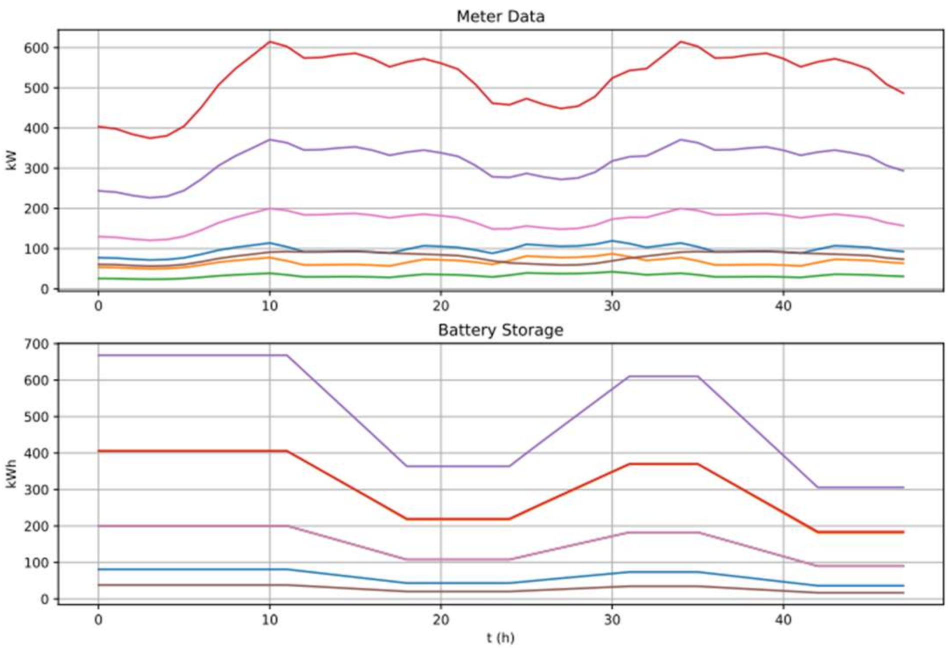



- Left Graph
  - 7 Storage Unit Meter Pairs
  - Peak Shave 30%
- Bottom Graph
  - Has a peak decrease of ~3.8%

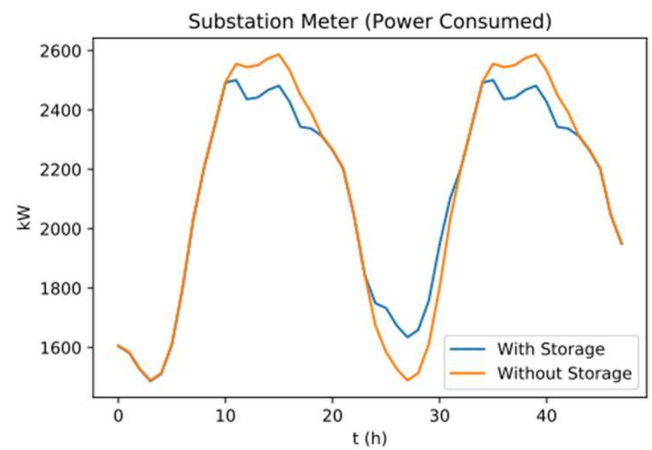


# Results – Impact of Storage (IEEE Circuit, 10kW Solar)

Skip = 2, 30% Peak Shaving, Storage = 2000kW




- 10kW = ~ 5 Homes with 2kW panels (Average)
- Left Graph
  - Peak power shift from ~600kW to ~550kW
- Bottom Graph
  - Has a peak decrease of ~4.5%

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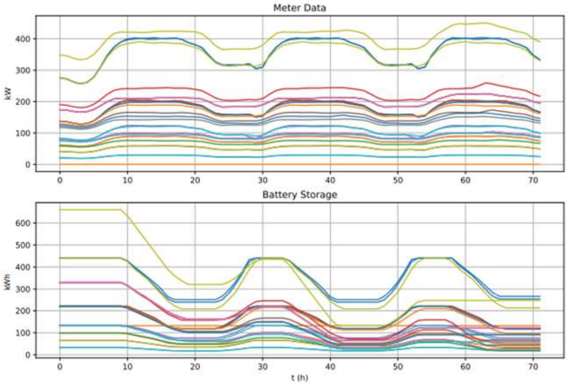
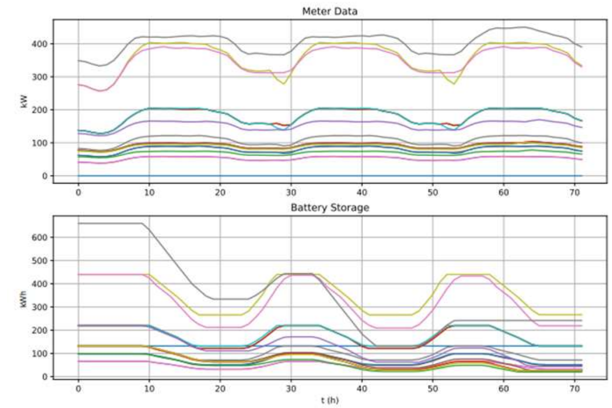
# Varying Penetration Levels – Real Circuit

75% - 31 devices

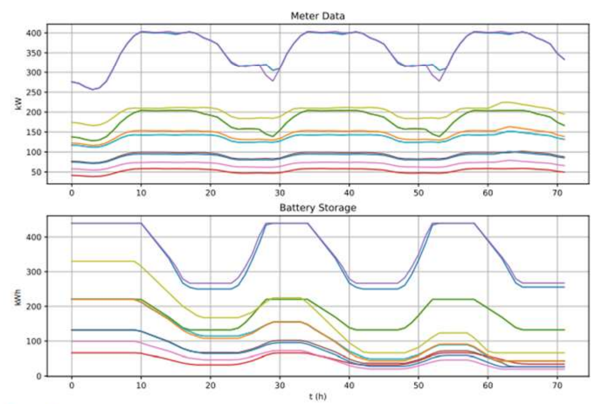



All graphs still follow the same trend no matter the number of devices

50% - 19 devices




25% - 12 devices

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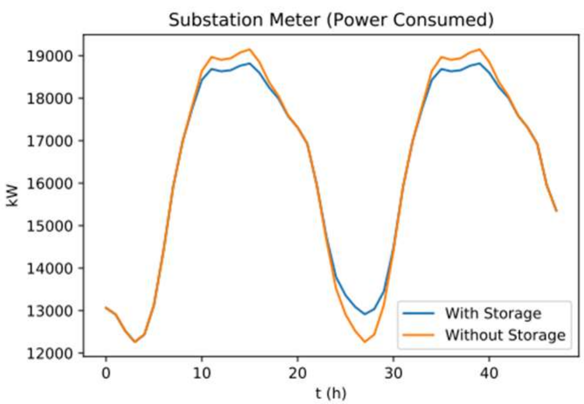
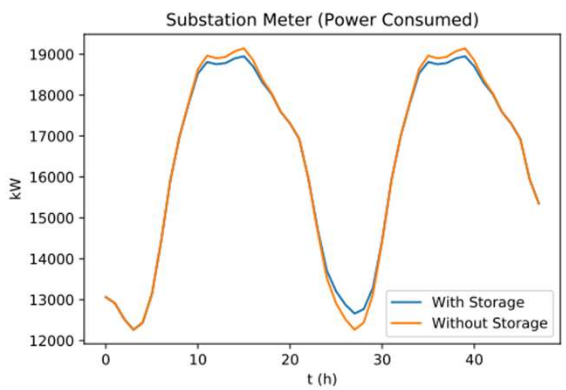
# Varying Penetration Levels – Real Circuit

| Penetration % | # of Storage Units | % Decrease |
|---|---|---|
| 100% | 47 | 2.56% |
| 75% | 31 | 1.73% |
| 50% | 19 | 1.01% |
| 25% | 12 | 0.70% |

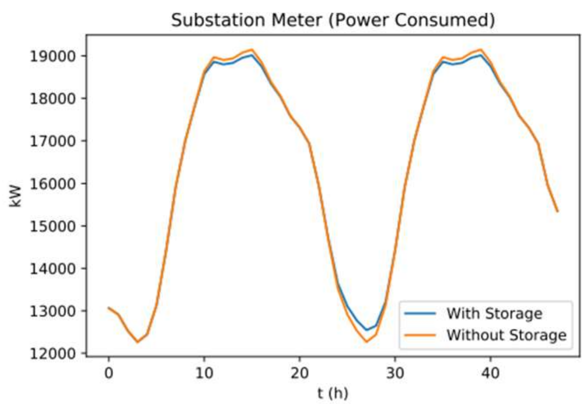
75% - 31 devices




50% - 19 devices




25% - 12 devices

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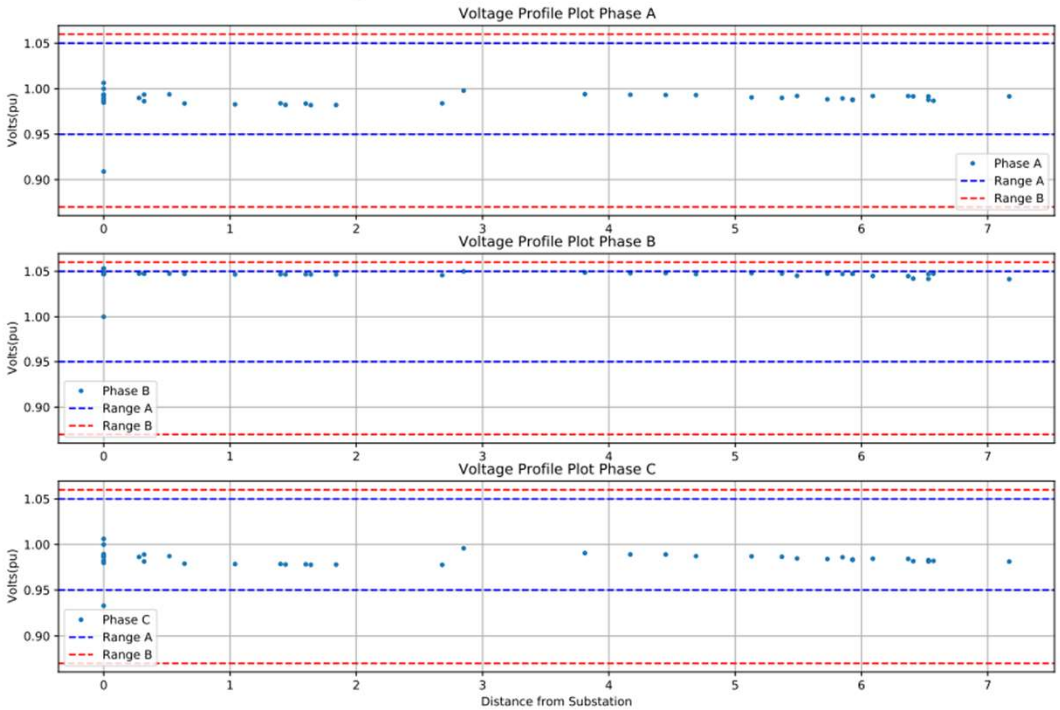
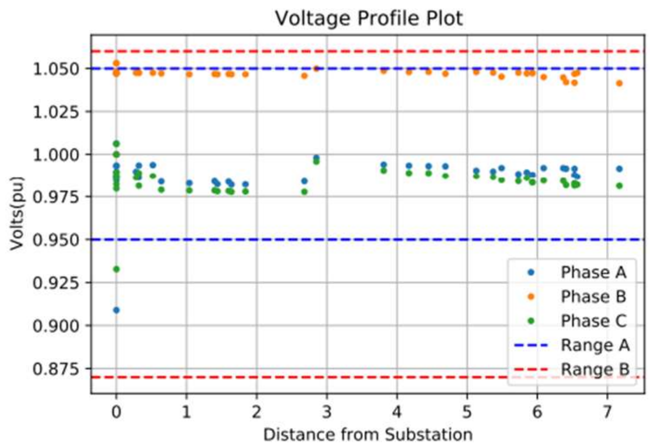
# Optimization of Uniform Placement – IEEE Circuit

Voltage Regulation Per Phase




ANSI Standard C84
Range A: +5%/-5%
Range B: +6%/-13%

Voltage Regulation Combined

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# Conclusion

- There is an inevitable increase in load in residential areas
- Use of non-wires alternatives as a method for providing support the rural system
- Creation of a digital model to see the impact of the addition of distributed solar and storage
- Evaluate:
  - Use of distributed generation for peak shaving to
  - Enhanced grid reliability through a non wires alternative
  - Decreased outage times due to alternative generation source
  - Impacts even with small levels of penetration

Questions?

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# Appendix

# Electrification Analysis

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# Integrating Diversification - Excel

Excel File: *Heating Load Interactive*

- In order to make the shift in heat more realistic, it is important to realize that the heaters will not be running at full capacity, in every home, for the entire day.
- To take this into account, an Excel file was generated so the user can choose the percent of diversification and the corresponding values shown in this presentation will be generated.
  - The shift in the graph will be displayed
  - Ampacity will be provided for a user selected number of homes
  - The profit over the entire month in the system is calculated
  - NEW: the power per circuit will also be shown for the 164, 23kV circuits
- This spreadsheet also provides pregenerated analyses for 25, 50, 75, and 100% diversification for comparisons

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# Integrating Diversification - Excel

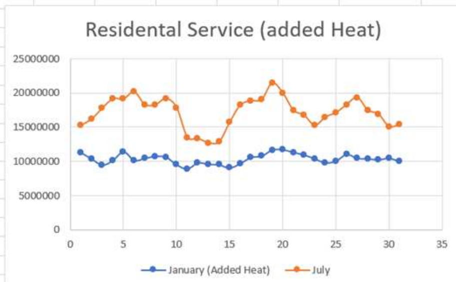
Excel File: *Heating Load Interactive*

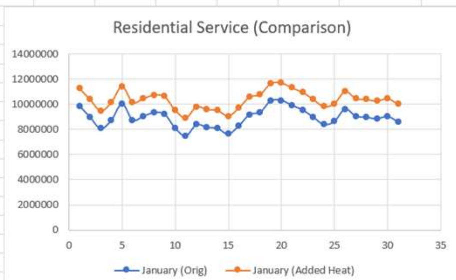
**Diversification**

Based on this baseline, the amount of diversification can be chosen to see how the system will be affected

Please type the chosen amount of diversification: 33%

Graphs below show the typical behavior of the system WITH this added electrified heat at the percent diversification




**Power Per Circuit**

What is the change in power per circuit (MAX) (assuming there are 164 23kV circuits)

26069.984 kW per circuit or 26.06998399 MW per circuit

With the previous amount of diversification, what is the change in power the circuit will actually see?

8603.09472 kW per circuit or 8.603094718 MW per circuit

**Ampacity**

To reflect the changes that are going to be seen on the system, the ampacity is also evaluated

Number of homes: 10

| | | |
|---|---|---|
| With electric heat, the max power per home is | 11167.5 | W per home |
| Given the diversification, power per home is | 3685.275 | W per home |
| Given the number of homes, this has a power of | 36852.75 | W |
| On a 23kV circuit, this would increase current by | 1.602293478 | A |

**Profit (in a month for entire system)**

In order to quantify the profit based on the assumed diversification, assume the following rate cases

| Case | Rate ($/kWh) | Original Jan | Added Heat Jan | Profit |
|---|---|---|---|---|
| RS | $ 0.06 | $ 16,609,416.84 | $ 19,233,704.86 | $ 2,624,288.01 |
| RH | $ 0.04 | $ 11,072,944.56 | $ 12,822,469.90 | $ 1,749,525.34 |
| RA | $ 0.02 | $ 4,429,177.83 | $ 5,128,987.96 | $ 699,810.14 |

Interactive Sheet | Interactive Sheet (25%) | Interactive Sheet (50%) | Interactive Sheet (75%) | Interactive Sheet (100%) | Data for Plotting | Heating Assumptions ...

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# Integrating Diversification - Code

Excel File: Heating Load Python Supplemental Python Code: Curve Generator

- To try and create an even more accurate representation of how the load might change, a Python code was created which will choose random percent of diversification values for each day in the month that will be added to the original load to have fluctuation within the heating load
  - Code Input – Update the Excel sheet “Input for Python”
    - Max Diversification (max range value)
    - Min Diversification (min range value)
    - Step Diversification (intermediate value steps)
- This code will export four columns of data in Excel (*Added Heat*) which the user can then use and convert into one plot for a visualization
  - Days of the Month
  - Original Load
  - Heating Load
  - New Load
- Values from *Added Heat* are to be copied and pasted in the indicated boxes on the “Data for Plotting” sheet in *Heating Load Python Supplemental*
- “Analysis” sheet provides similar deliverables as *Heating Load Interactive*

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# Power Flow Challenges in Rural Circuits

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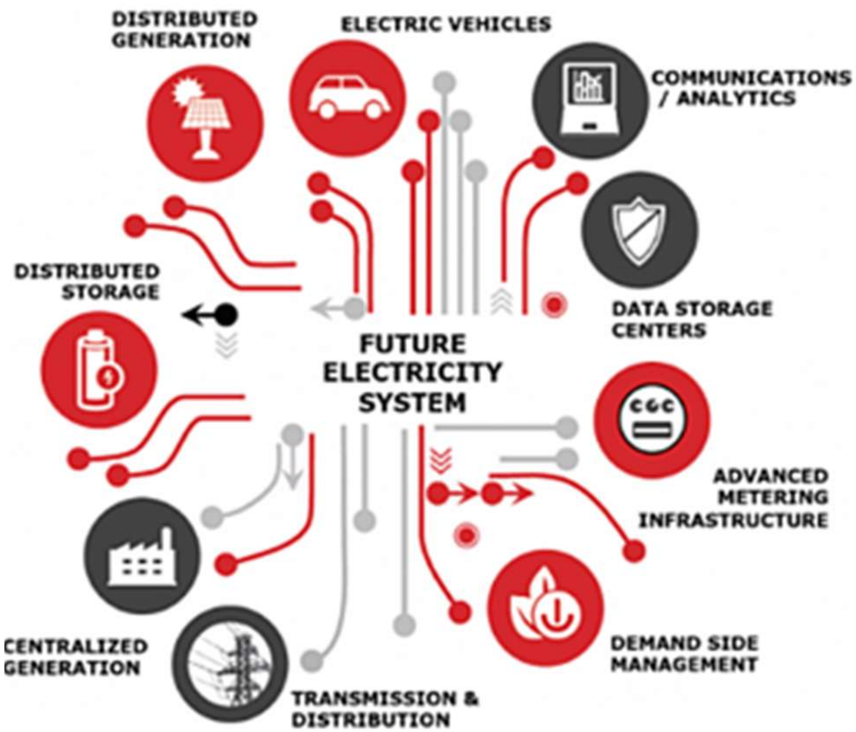
# Power Flow Challenges in Rural Circuits

- Rural Circuits
- Adding Edge of Grid  Devices
- Voltage and Power Flow

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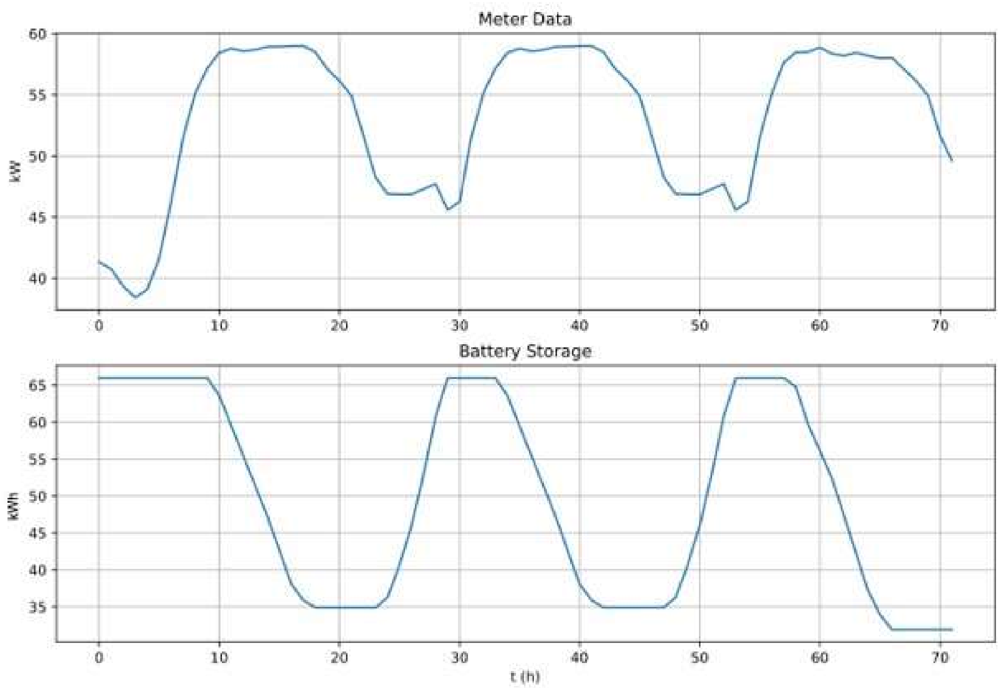
# Impact on Reliability – Real Circuit




Peak battery Capacity is ~65kWh
Peak demand is ~60kW
Expect a little over 1 hour of support

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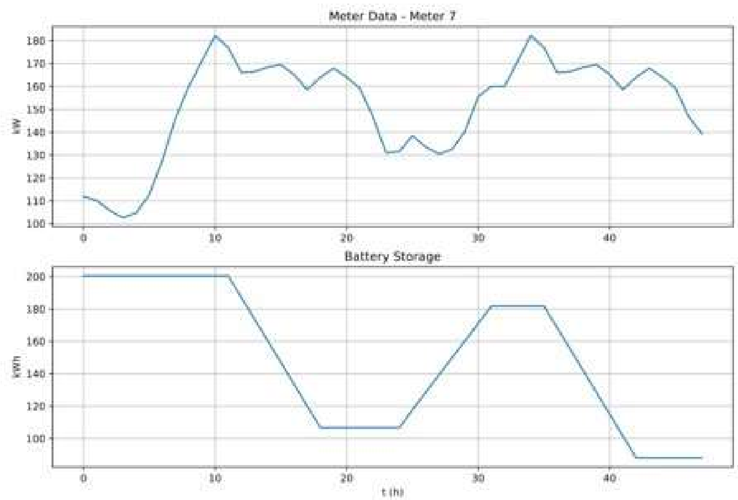
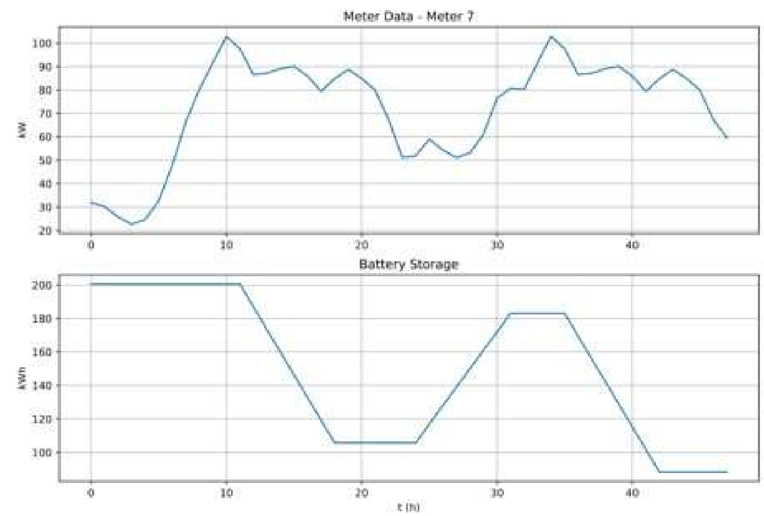
# Impact on Reliability – IEEE Circuit

One Location of Storage Data 100kW Solar




Peak battery Capacity is ~200kWh
Peak demand is ~180kW
Expect a little over 1 hour of support

One Location of Storage Data 500kW Solar




Peak battery Capacity is ~200kWh
Peak demand is ~100kW
Expect a little over 2 hour of support

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# Distributed Device Vulnerabilities

- Battery Storage Concerns
  - Cybersecurity Threats
  - Battery Degradation
  - Weather
- Solar Panels Concerns
  - Intermittency
  - Weather
  - Deterioration

# Future Work

- Continue developing optimization in placement of energy storage
- Build upon the battery controller's behavior – Machine Learning integration
- Use of battery storage coming from electric vehicles and monitoring their charge and discharge curves – V2G or V2X
- Create a complete digital twin for Picolab

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