Impact of High Photovoltaic Penetration on Distribution Systems

Group DEC1614

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Client: Alliant Energy

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Project Information and Background

Project Statement:

Solar Photovoltaic generation is gaining popularity across the nation, including Iowa. Because of its volatility nature, when generation exceeds certain limits, it introduces undesirable stability issues such as transients, high voltage levels, and reverse power flow. Our senior design project is to predict and analyze these new trends associated with high solar photovoltaic penetration in distribution feeders. Our team is collaborating with Alliant Energy to develop a preventive plan to tackle these instability issue as more photovoltaic generation is added to their Washington distribution feeder.

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Washington Area

- 35 miles South of Iowa City, IA
- 892 meters on the system
- Approximate Customers
  - PV Customers: 56
- Highest Concentration of Residential solar in the entire Alliant Energy Service area.

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Goals

- Develop a working model of a real world feeder with high PV penetration.
- Discover what locations are points of interest, then connect solar in multiple configurations (community and residential).
- Use findings to determine some guidelines that would benefit Alliant Energy to prevent future problems related to high solar PV penetration.

Milestones

Stage I: Learn Key Concepts and OpenDSS

- OpenDSS/IEEE/4 and 34 Bus Systems
- Solar Integration and Manipulation
- System Optimization and Lower Cost Concept Study

Stage II: Alliant Energy System Study

- Real World Load Shapes Analysis
- Research the topography of Washington Distribution System
- Match OpenDSS simulation solutions with Client's Data

Stage III: Manipulate Alliant Energy System for Research

- Create a Complete Test System Based on Current Alliant Energy System
- Add Solar PV System to Test System
- Evaluate the Test System under Different Scenarios
- Discuss different solution approaches with Alliant energy

OpenDSS Data Directory: C:\Users\Logan Heinen\Desktop\IEEETestCases\34Bus\

File Edit Do Set Make Export Show Visualize Plot Reset Help

Source/Fault | Vsource | SOURCE | Base Frequency = 60 Hz

C:\Users\Logan Heinen\Desktop\IEEETestCases\34Bus\ieee34Mod2_24hr_withSolar.dss

```
! Modified (Mod 2) version of IEEE 34-bus test case with buses added in the middle of line sections
! This gives a better match to the "distributed load" model used in the test case than Mod 1.
! The DSS Line model presently does not support the distributed load concept. Load objects may be attached
! only at buses.  Therefore, midpoint buses are created in this example.

Clear

New object=circuit.ieee34-2
~ basekv=69 pu=1.05 angle=30 mvasc3=200000  !stiffen up a bit over default

! Substation Transformer  -- Modification: Make source very stiff by using artificially low short circuit reactance
New Transformer.SubXF Phases=3 Windings=2 Xhl=0.001 ppm=0    ! Very low %Z and no shunt reactance added
~ wdg=1 bus=sourcebus conn=Delta kv=69    kva=25000   %r=0.0005  ! Set the %r very low
~ wdg=2 bus=800       conn=wye   kv=24.9  kva=25000   %r=0.0005

New loadshape.solar_24_hour 24 1
~ mult=(0 0 0 0 0 0 0.022261021 0.323657791 0.654735923 0.746180707 0.876909646 1 0.925360105 0.931034483 0.883457006 0.626582278 0.303579223 0 0 0 0 0 0 0)

New generator.solar bus1=840.1.2.3 kV= 24.900 kW=  27.0 kVAR=  21.0 pf=1 conn=wye duty=solar_24_hour Model=1

! import line codes with phase impedance matrices
Redirect        IEEELineCodes.dss   ! assumes original order is ABC rather than BAC

! Define Lines and mid-point buses
! NOTE: Since units are not specified for length, it is assumed to match the linecode units
New Line.L1      Phases=3 Bus1=800.1.2.3      Bus2=802.1.2.3      LineCode=300  Length=2.50
New Line.L2a     Phases=3 Bus1=802.1.2.3      Bus2=mid806.1.2.3  LineCode=300  Length=(1.73 2 /)  ! use in-line math to divide lenght by 2
New Line.L2b     Phases=3 Bus1=mid806.1.2.3  Bus2=806.1.2.3      LineCode=300  Length=(1.73 2 /)
New Line.L3      Phases=3 Bus1=806.1.2.3      Bus2=808.1.2.3      LineCode=300  Length=32.23
New Line.L4a     Phases=1 Bus1=808.2          Bus2=Mid810.2       LineCode=303  Length=(5.804 2 /)
New Line.L4b     Phases=1 Bus1=Mid810.2       Bus2=810.2          LineCode=303  Length=(5.804 2 /)
New Line.L5      Phases=3 Bus1=808.1.2.3      Bus2=812.1.2.3      LineCode=300  Length=37.5
New Line.L6      Phases=3 Bus1=812.1.2.3      Bus2=814.1.2.3      LineCode=300  Length=29.73
New Line.L7      Phases=3 Bus1=814r.1.2.3     Bus2=850.1.2.3      LineCode=301  Length=0.01
New Line.L24     Phases=3 Bus1=850.1.2.3      Bus2=816.1.2.3      LineCode=301  Length=0.31
New Line.L8      Phases=1 Bus1=816.1          Bus2=818.1          LineCode=302  Length=1.71
New Line.L9a     Phases=3 Bus1=816.1.2.3      Bus2=mid824.1.2.3  LineCode=301  Length=(10.21 2 /)
New Line.L9b     Phases=3 Bus1=mid824.1.2.3  Bus2=824.1.2.3      LineCode=301  Length=(10.21 2 /)
New Line.L10a    Phases=1 Bus1=818.1          Bus2=mid820.1       LineCode=302  Length=(48.15 2 /)
New Line.L10b    Phases=1 Bus1=mid820.1       Bus2=820.1          LineCode=302  Length=(48.15 2 /)
New Line.L11a    Phases=1 Bus1=820.1          Bus2=mid822.1       LineCode=302  Length=(13.74 2 /)
New Line.L11b    Phases=1 Bus1=mid822.1       Bus2=822.1          LineCode=302  Length=(13.74 2 /)
New Line.L12a    Phases=1 Bus1=824.2          Bus2=mid826.2       LineCode=303  Length=(3.03 2 /)
New Line.L12b    Phases=1 Bus1=mid826.2       Bus2=826.2          LineCode=303  Length=(3.03 2 /)
New Line.L13a    Phases=3 Bus1=824.1.2.3      Bus2=mid828.1.2.3  LineCode=301  Length=(0.84 2 /)
New Line.L13b    Phases=3 Bus1=mid828.1.2.3  Bus2=828.1.2.3      LineCode=301  Length=(0.84 2 /)
New Line.L14a    Phases=3 Bus1=828.1.2.3      Bus2=mid830.1.2.3  LineCode=301  Length=(20.44 2 /)
New Line.L14b    Phases=3 Bus1=mid830.1.2.3  Bus2=830.1.2.3      LineCode=301  Length=(20.44 2 /)
New Line.L15     Phases=3 Bus1=830.1.2.3      Bus2=854.1.2.3      LineCode=301  Length=0.52
New Line.L16a    Phases=3 Bus1=832.1.2.3      Bus2=mid858.1.2.3  LineCode=301  Length=(4.9 2 /)
New Line.L16b    Phases=3 Bus1=mid858.1.2.3  Bus2=858.1.2.3      LineCode=301  Length=(4.9 2 /)
New Line.L29a    Phases=3 Bus1=858.1.2.3      Bus2=mid834.1.2.3  LineCode=301  Length=(5.83 2 /)
New Line.L29b    Phases=3 Bus1=mid834.1.2.3  Bus2=834.1.2.3      LineCode=301  Length=(5.83 2 /)
New Line.L18     Phases=3 Bus1=834.1.2.3      Bus2=842.1.2.3      LineCode=301  Length=0.28
New Line.L19a    Phases=3 Bus1=836.1.2.3      Bus2=mid840.1.2.3  LineCode=301  Length=(0.86 2 /)
New Line.L19b    Phases=3 Bus1=mid840.1.2.3  Bus2=840.1.2.3      LineCode=301  Length=(0.86 2 /)
New Line.L21a    Phases=3 Bus1=842.1.2.3      Bus2=mid844.1.2.3  LineCode=301  Length=(1.35 2 /)
New Line.L21b    Phases=3 Bus1=mid844.1.2.3  Bus2=844.1.2.3      LineCode=301  Length=(1.35 2 /)
New Line.L22a    Phases=3 Bus1=844.1.2.3      Bus2=mid846.1.2.3  LineCode=301  Length=(3.64 2 /)
New Line.L22b    Phases=3 Bus1=mid846.1.2.3  Bus2=846.1.2.3      LineCode=301  Length=(3.64 2 /)
New Line.L23a    Phases=3 Bus1=846.1.2.3      Bus2=mid848.1.2.3  LineCode=301  Length=(0.53 2 /)
New Line.L23b    Phases=3 Bus1=mid848.1.2.3  Bus2=848.1.2.3      LineCode=301  Length=(0.53 2 /)
New Line.L26a    Phases=1 Bus1=854.2          Bus2=mid856.2       LineCode=303  Length=(23.33 2 /)
New Line.L26b    Phases=1 Bus1=mid856.2       Bus2=856.2          LineCode=303  Length=(23.33 2 /)
New Line.L27     Phases=3 Bus1=854.1.2.3      Bus2=852.1.2.3      LineCode=301  Length=36.83
! regulator in here
New Line.L25     Phases=3 Bus1=852r.1.2.3     Bus2=832.1.2.3      LineCode=301  Length=0.01

! Y-Y Stepdown transformer Transformer
New Transformer.XFM1  Phases=3 Windings=2 Xhl=4.08
~ wdg=1 bus=832  conn=wye kv=24.9  kva=500    %r=0.95
~ wdg=2 bus=888  conn=Wye kv=4.16  kva=500    %r=0.95
```

Main | ieee34Mod2_24hr_withSolar.dss | Run_IEEE34_24_hour_solar_violation.dss

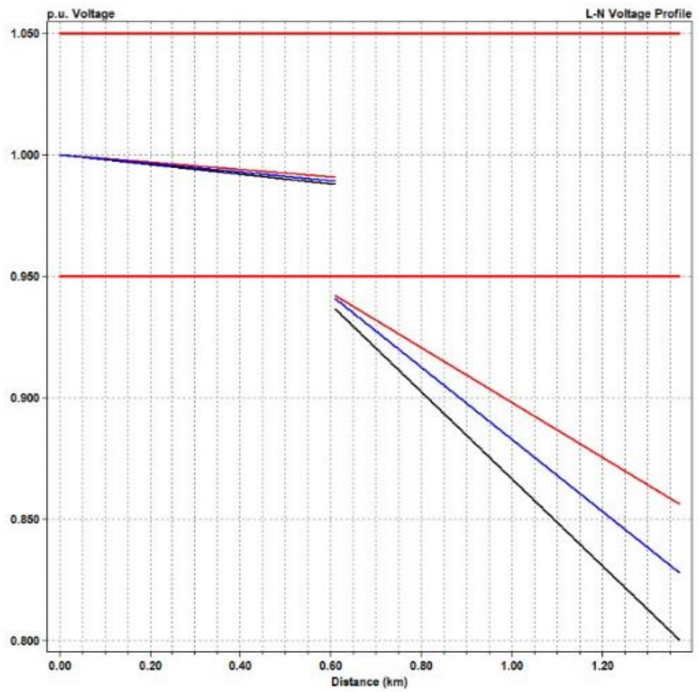
Messages: OpenDSS - C:\Users\Logan Heinen\Desktop\IEEETestCases\34Bus\ieee34Mod2_24hr_withSolar.dss

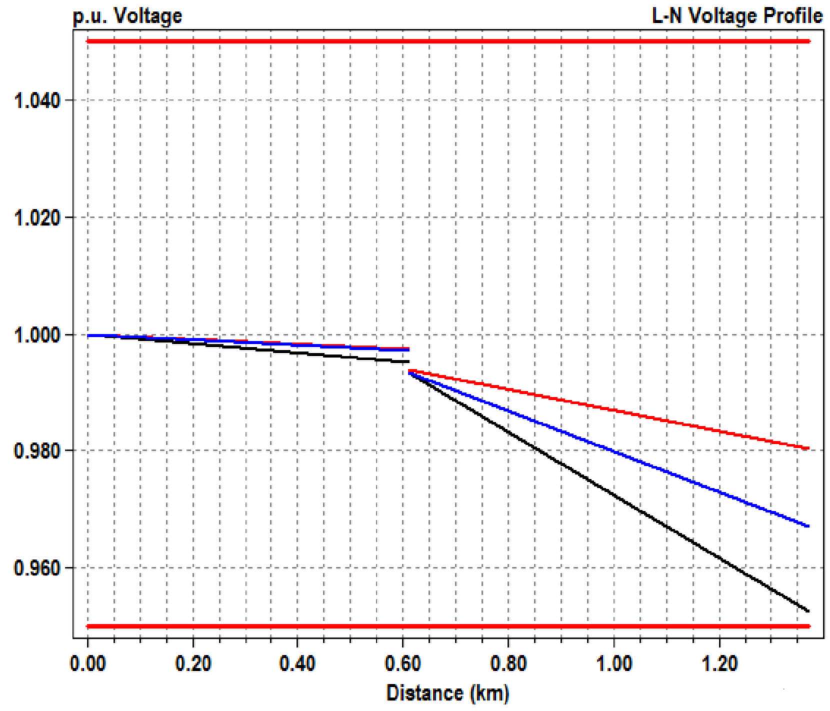
Summary | Results

Memory: 46148K | Circuit Status: SOLVED | Total Iterations = 12, Control Iterations = 3, Max Solution Iterations = 5

Ask me anything | 6:10 PM 11/8/2016

Stage I: Learn Key Concepts and OpenDSS (4-Bus System)





OpenDSS is an electric power Distribution System Simulator (DSS) for supporting distributed resource integration and grid modernization efforts.

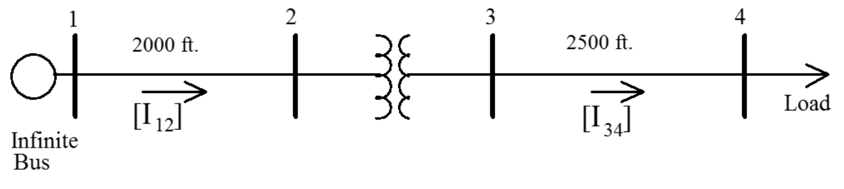


Figure 1 – IEEE 4 Node Test Feeder

Black line: Phase A
Red line: Phase B
Blue line: Phase C

Fix Voltage P.U. with Capacitors

- Node 4 Phase A = 4538 kVAR
- Node 4 Phase B = 4178 kVAR
- Node 4 Phase C = 4178 kVAR

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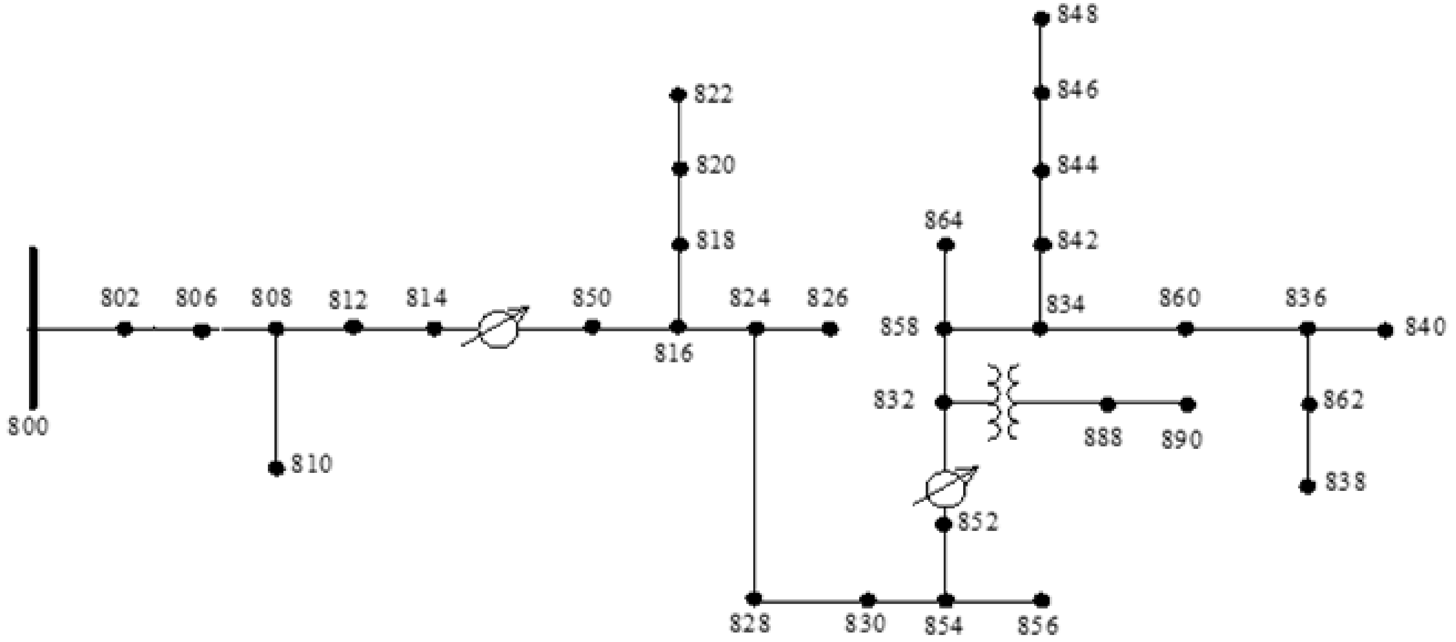
Stage I: Learn Key Concepts and OpenDSS (34-Bus System)

Test Plan

1. Fix Voltage p.u. With Capacitors
2. Manipulate Setting in Voltage Regulators
3. 24 hour Load Profile
4. 24 hour Solar PV Penetration
5. Observe Tap Changes, Losses, and Violations with different Solar PV locations and penetration

IEEE 34 Node Test Feeder



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Stage I: Learn Key Concepts and OpenDSS (34-Bus System)

Results

1. PV Penetration 0%-100%
2. 6 different locations for Solar
3. Losses
4. Number of tap changes
5. Number of Violations

PV	Location of PV	Peak Losses	# of Tap Changes	Violations
0%	808	273.5kW (15.42%)	30	814 Phase A, 4 hours (14-17) below 0.95
0%	814	273.5kW (15.42%)	30	814 Phase A, 4 hours (14-17) below 0.95
0%	830	273.5kW (15.42%)	30	814 Phase A, 4 hours (14-17) below 0.95
0%	852	273.5kW (15.42%)	30	814 Phase A, 4 hours (14-17) below 0.95
0%	848	273.5kW (15.42%)	30	814 Phase A, 4 hours (14-17) below 0.95
0%	840	273.5kW (15.42%)	30	814 Phase A, 4 hours (14-17) below 0.95
20%	808	257.1kW (14.51%)	27	0
20%	814	225.9kW (12.75%)	33	0
20%	830	207.2kW (11.69%)	27	0
20%	852	184.2kW (10.39%)	30	0
20%	848	181.0kW (10.19%)	32	0
20%	840	181.0kW (10.19%)	31	0
40%	808	243.6kW (13.76%)	29	0
40%	814	190.0kW (10.73%)	31	0
40%	830	158.2kW (8.91%)	28	0
40%	852	121.9kW (6.86%)	33	0
40%	848	115.9kW (6.55%)	34	0
40%	840	116.1kW (6.56%)	33	0
60%	808	234.0kW (13.21%)	33	808 Phase C, 6 hours (1-5,24) above 1.05
60%	814	165.0kW (9.30%)	32	808 Phase C, 8 hours (1-6,23-24) above 1.05
				814 Phase B, 6 hours (1-5, 24) above 1.05
				814 Phase C, 8 hours (1-6, 23-24) above 1.05
60%	830	124.5kW (7.01%)	27	808 Phase B, 3 hours (2-4) above 1.05
				808 Phase C, 8 hours (1-6, 23-24) above 1.05
				814 Phase B, 7 hours (1-5, 23-24) above 1.05
				814 Phase C, 8 hours (1-6, 23-24) above 1.05
60%	852	81.3kW (4.58%)	29	808 Phase B, 5 hours (1-4, 24) above 1.05
				808 Phase C, 8 hours (1-6, 23-24) above 1.05
				814 Phase B, 8 hours (1-6, 23-24) above 1.05
				814 Phase C, 8 hours (1-6, 23-24) above 1.05
60%	848	77.5kW (4.37%)	31	808 Phase B, 5 hours (1-4, 24) above 1.05
				808 Phase C, 8 hours (1-6, 23-24) above 1.05
				814 Phase B, 8 hours (1-6, 23-24) above 1.05
				814 Phase C, 8 hours (1-6, 23-24) above 1.05
60%	840	77.7kW (4.38%)	31	808 Phase B, 5 hours (1-4, 24) above 1.05
				808 Phase C, 8 hours (1-6, 23-24) above 1.05
				814 Phase B, 8 hours (1-6, 23-24) above 1.05
				814 Phase C, 8 hours (1-6, 23-24) above 1.05

Stage I: Learn Key Concepts and OpenDSS

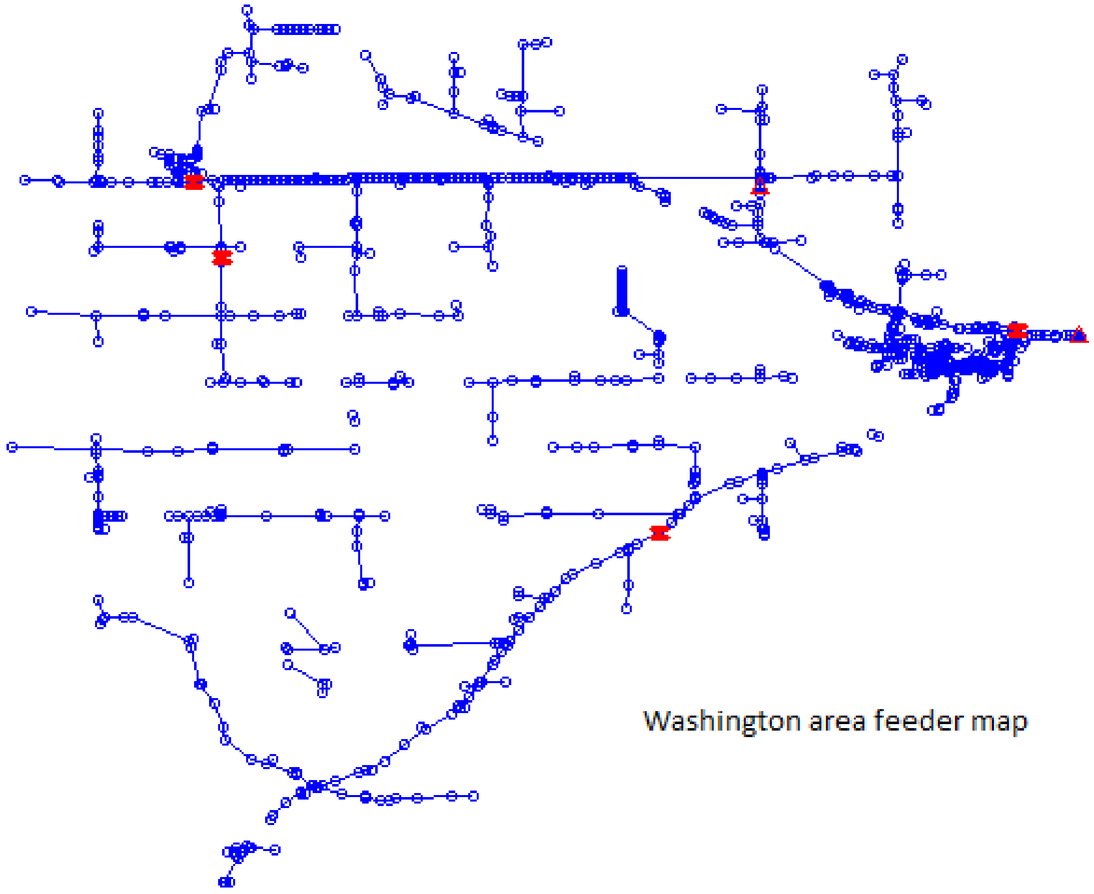
Challenge

OpenDSS is not user friendly which creates coding errors along with collecting data and searching for information.

Stage II: Alliant Energy System Study (Washington 1329-bus system)

Analysis plan

- Understand the real world system and locate points of interest.
- Match the output data in OpenDSS with the data provided by Darin.
- Add solar at points of interest with varying penetration levels.
- Develop a guideline to the amount of penetration possible on the feeder.



Washington area feeder map

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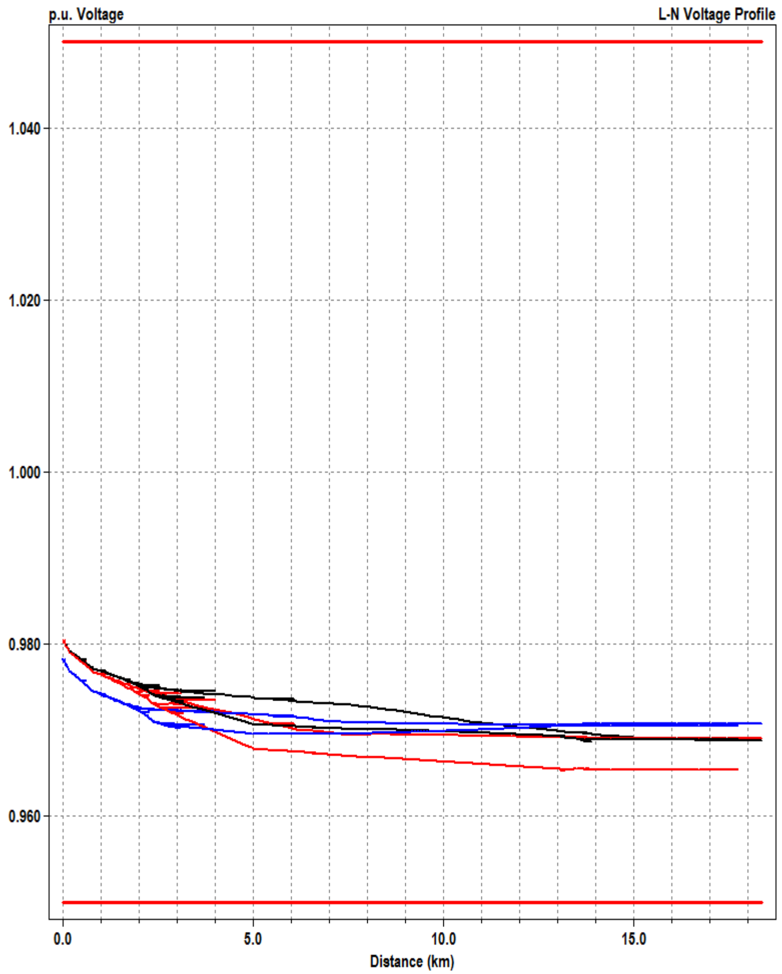
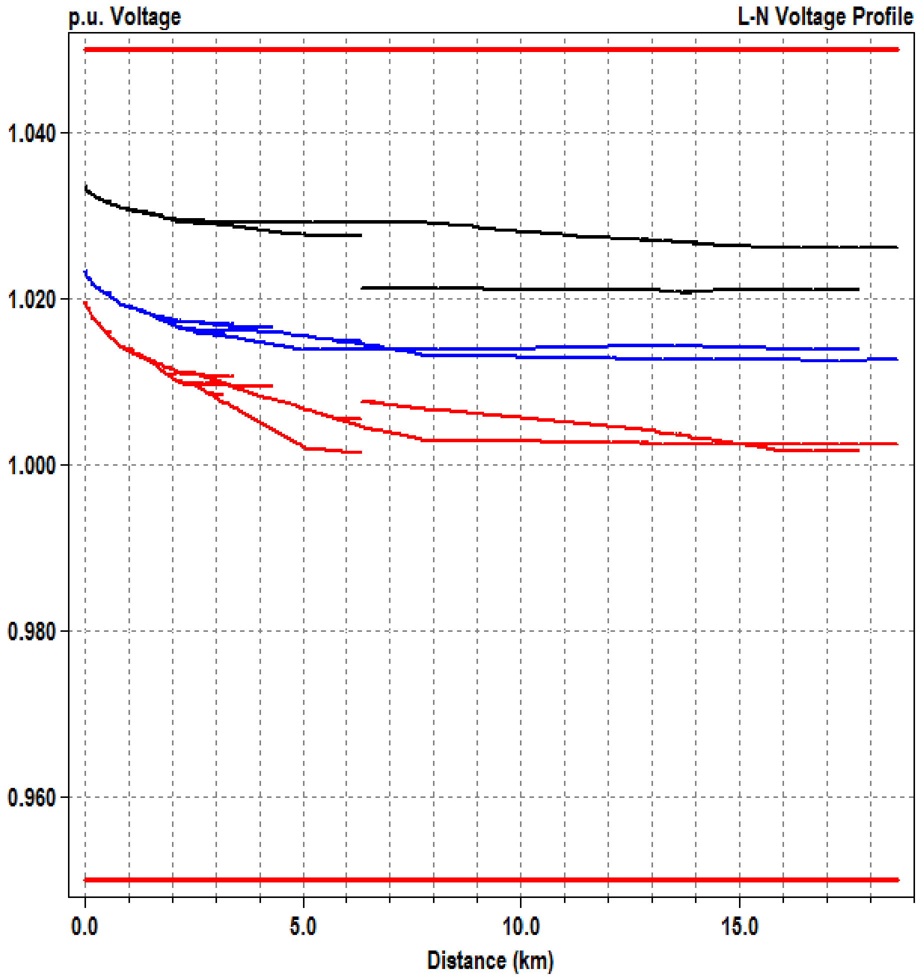
Stage II: Alliant Energy System Study

- Added a voltage regulator to the system
- Match data provided by Darin
- Rerun SynerGEE export with peak load conditions





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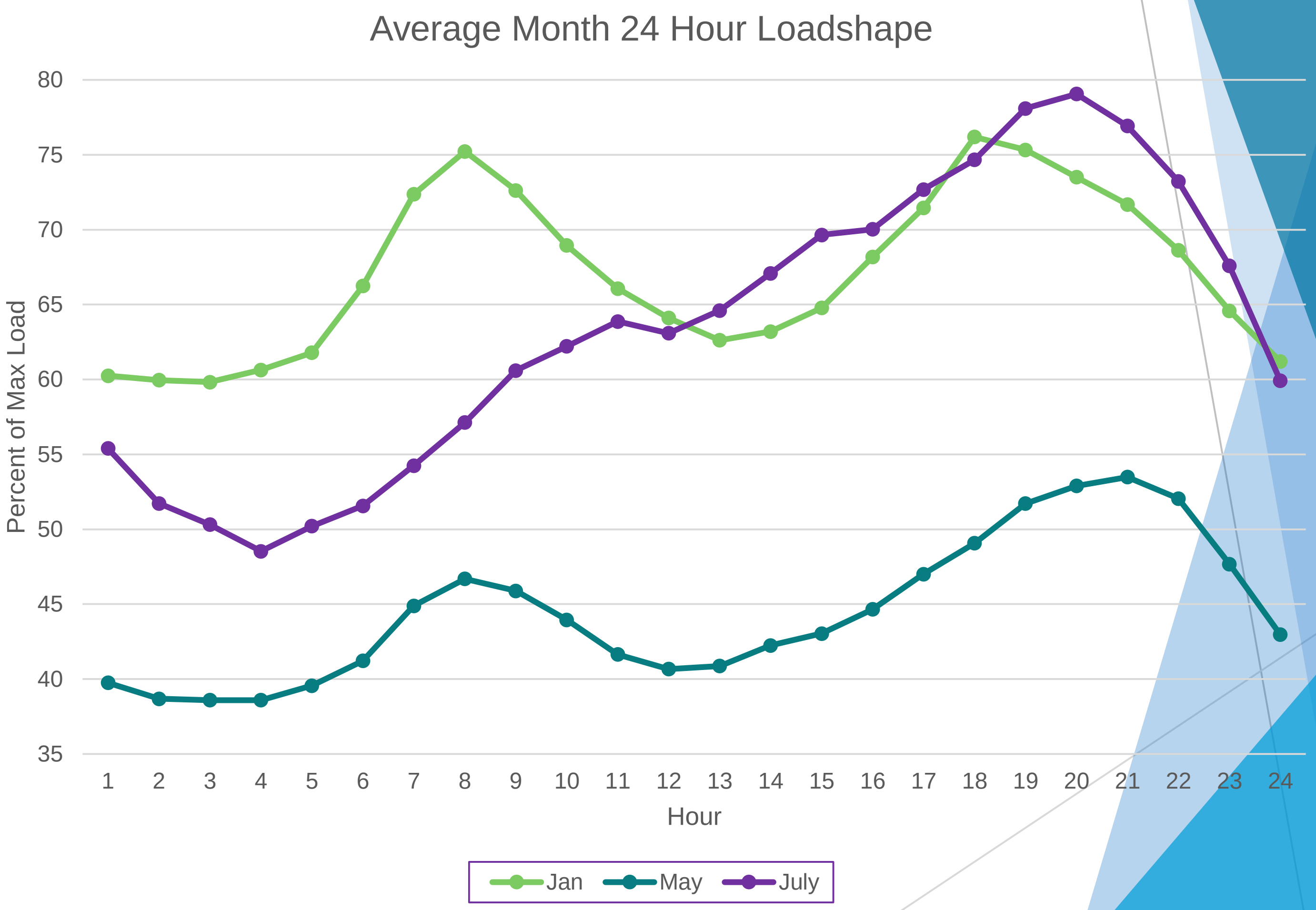
Stage II: Alliant Energy System Study

Loadshape for months of interest

- July is Alliant Energy's peak values
- May is Alliant Energy's low load values
- January is highest duck curve loadshape



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Stage II: Alliant Energy System Study

Challenge

OpenDSS has a limit to the amount memory in a .dss file. Therefore, Alliant Energy could not transfer over all of the system, through SynerGEE.

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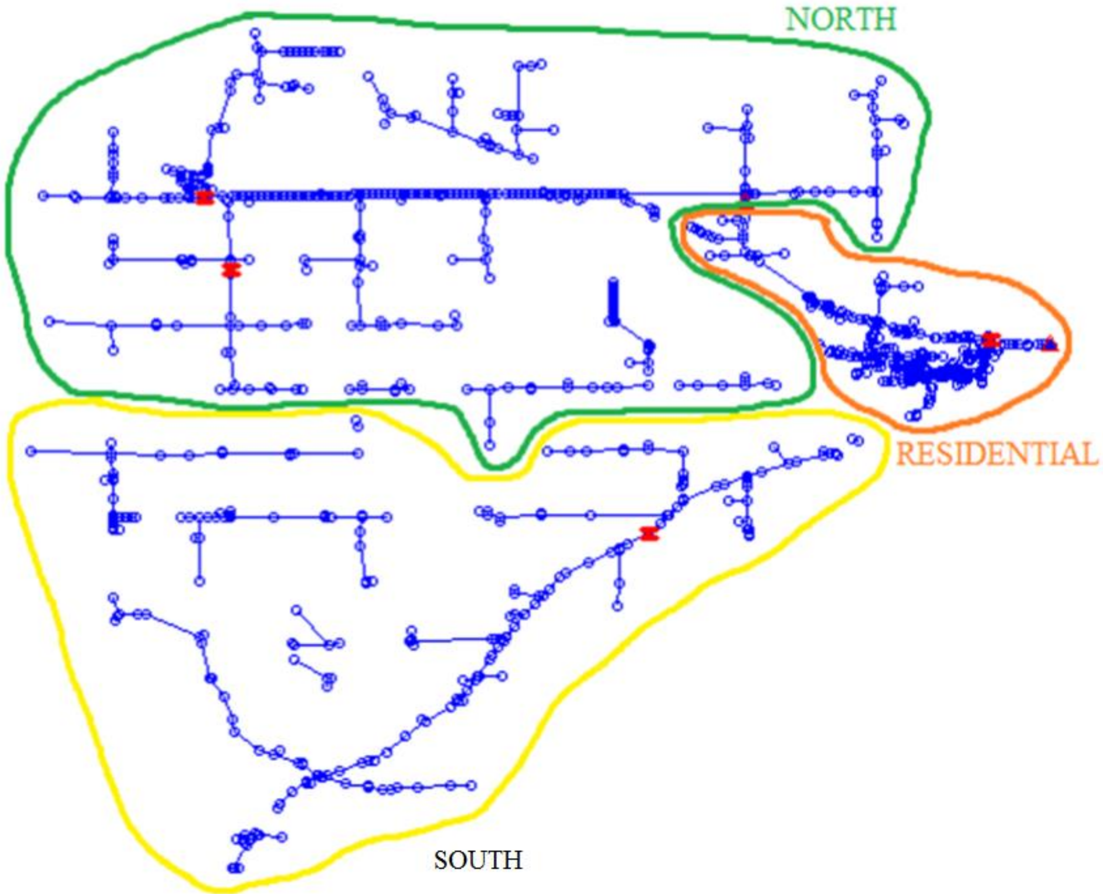
Stage III: Manipulating Alliant Energy System for Research

- North, South, Residential Regions
- Single solar site and distributed solar
- Power ranges from 10-100% of maximum load



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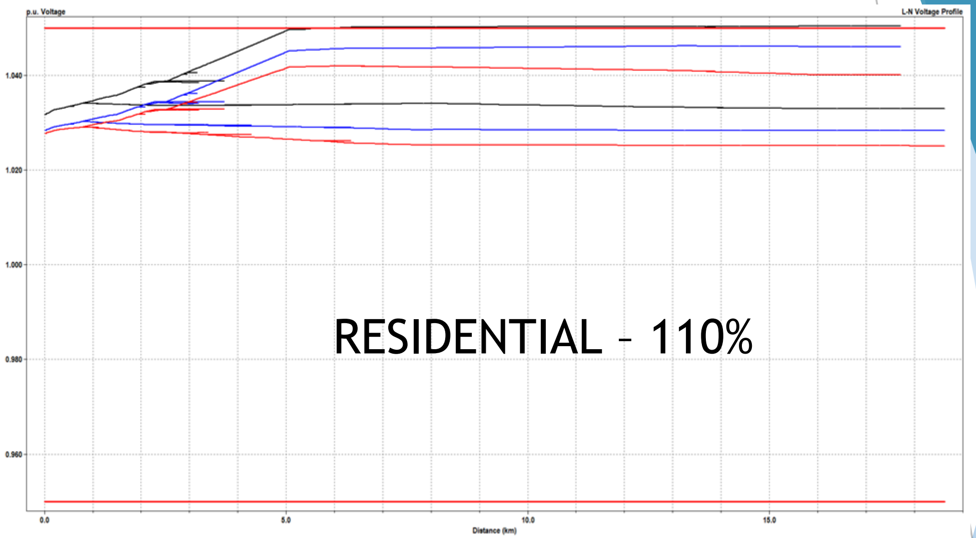
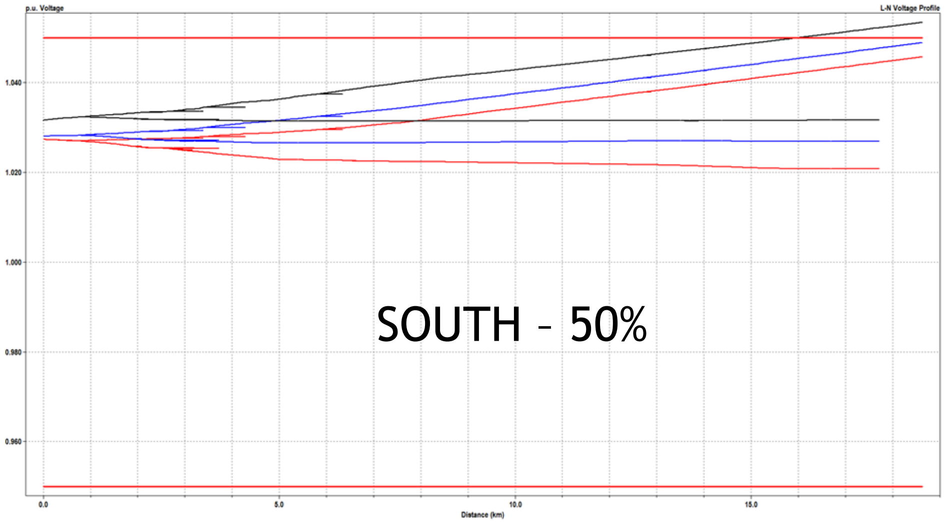
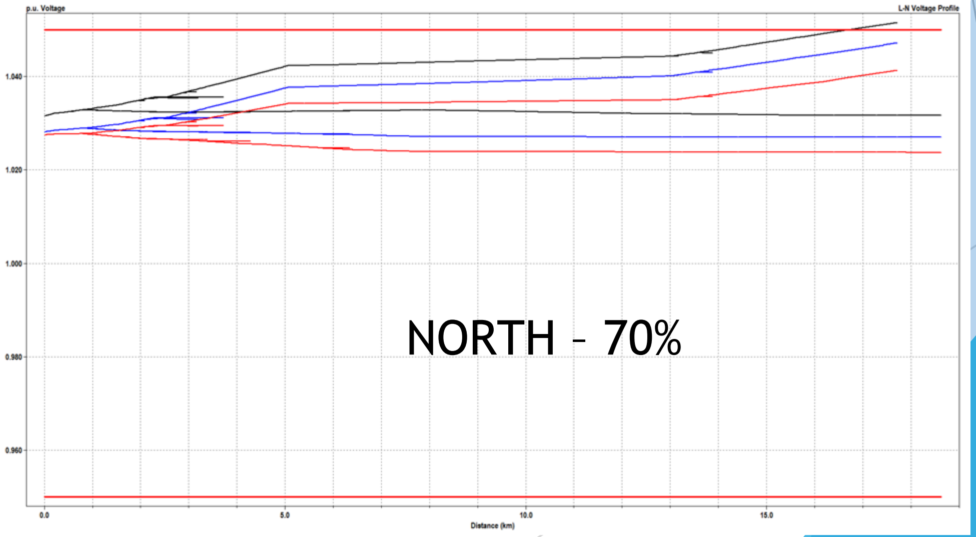
Stage III: Manipulating Alliant Energy System for Research

- Worst case scenario day was in May (38.6%)
- Single site experiences problems quicker than distributed sites







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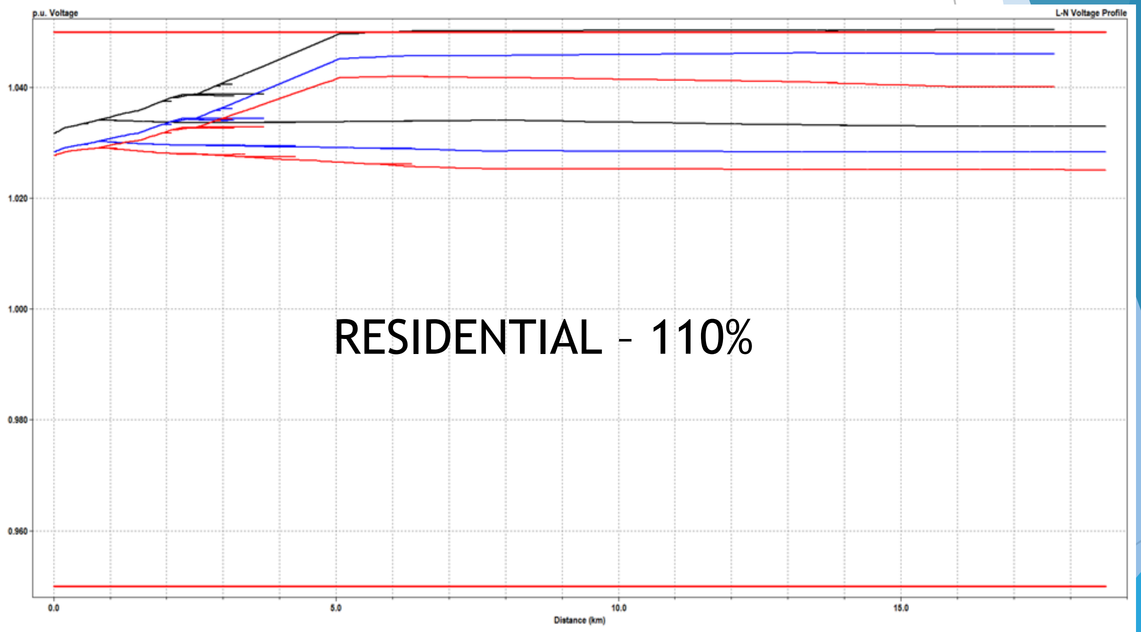
Stage III: Manipulating Alliant Energy System for Research

- Guideline
  - Distributed configuration
  - Residential Region



Stage III: Manipulating Alliant Energy System for Research

Challenge

Recording the number of buses experiencing reverse power flow.

Group Members Take Away

- **Zhengyu Wang:**

A deeper and better understanding of Solar PV and real world distribution system from designer and utility viewpoint.

- **Redouane Zaou:**

Hands on experience on how utility companies simulate distribution systems to prevent possible problems in the future. Such analysis is crucial for the future of solar as a source of renewable energy.

- **Difeng Liu:**

Searching for the best point of interest of adding solar PV and balancing the cost and functionality is essential to the project.

- **Logan Heinen:**

Strong understanding of how to operate OpenDSS and working with Solar PV.

Conclusion

- With the growing desire and interconnection of PV at the distribution level.
- Over-voltage, Reverse power flow, etc.
- Utilities are performing studies and taking action.

Special Thanks

- Prof. V. Ajjarapu
- Darin Lamos
- Ankit Singhal

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Questions?

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