Grid Resiliency Assessment using a Cross-Covariance Method for Electrical Load Classification

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Goal & Objective

Electric utility companies need to maintain a stable grid (minimum risk of outages) under high demand conditions (such as summertime air-conditioning): ***Voltage drops as electricity demand increases!***

Constant Impedance Loads: Electric water heaters, electric clothes dryer, stoves, ovens, portable room heaters, etc.

Constant Power Loads: Electronics, computers, LED lighting, air conditioning compressor motors, refrigerators, etc.

Constant power loads tend to destabilize the grid -> ***Blackout!***

Methods

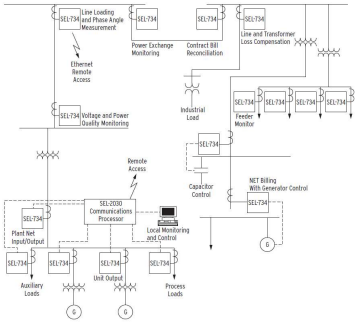

Fig. 1: Data collection block diagram.

Automated Data Collection System: Schweitzer Engineering Laboratories (SEL) provides equipment for automatically collecting and reporting electrical data. Analysis takes a moving average of the equivalent impedance.

Python Code

Matlab and Python code was developed to analyze the data obtained for the SEL instrumentation.

```
import os
import csv
filename = "C:\\Users\\ThisPC\\Downloads\\REU
FILES\\Railroad_Ia_Va_201904.csv"
fields = []
Ia=[]
Va=[]
with open(filename,'r') as csvfile:
    csvreader = csv.reader(csvfile)
    fields = next(csvreader)
    csvreader = csv.reader(csvfile, quoting=csv.QUOTE_NONNUMERIC)
    for row in csvreader:
        Ia.append(row[0])
        Va.append(row[1])
import statistics
window=6
IaMean=[]
VaMean=[]
meancounter=range (len(Ia)-(window-1))
for k in meancounter:
    IaMean.append(statistics.mean(Ia[k:k+6]))
    VaMean.append(statistics.mean(Va[k:k+6]))
IaVar=[0]*len(Ia)
VaVar=[0]*len(Va)
Zbuffer=[0]*len(Ia)
Z=[]
varcounter=range(len(Ia)-(window-1))
for k in varcounter:
VaVar[k]=Va[k]-VaMean[k]
IaVar[k]=Ia[k]-IaMean[k]
Zbuffer[k]=VaVar[k]*IaVar[k]
VaVar[k+1]=Va[k+1]-VaMean[k]
IaVar[k+1]=Ia[k+1]-IaMean[k]
Zbuffer[k+1]=VaVar[k+1]*IaVar[k+1]
VaVar[k+2]=Va[k+2]-VaMean[k]
IaVar[k+2]=Ia[k+2]-IaMean[k]
Zbuffer[k+2]=VaVar[k+2]*IaVar[k+2]
VaVar[k+3]=Va[k+3]-VaMean[k]
IaVar[k+3]=Ia[k+3]-IaMean[k]
Zbuffer[k+3]=VaVar[k+3]*IaVar[k+3]
Z.append(statistics.mean(Zbuffer[k:k+4]))
VaVar[k+1]=VaVar[k+2]=VaVar[k+3]=0
IaVar[k+1]=IaVar[k+2]=IaVar[k+3]=0
colum2 = []
with open('C:\\Users\\ThisPC\\
    Downloads\\REU FILES\\Results.csv', 'w', newline='') as
file:
writer = csv.writer(file)
for col in Z:
colum1 = [col]
writer.writerow(colum1)
csvfile.close()
exit()
```

Data Analysis

- Case study of Fayetteville Substation (Ozarks Electric Cooperative)
- Substation has automated data recording of voltage, current (electricity demand) and power.
- The following (Figs. 2 & 3) are GIS (geographical information system) images of the electric power system used in this study.

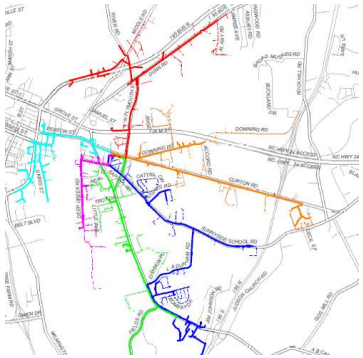

Fig. 2: GIS image of region.

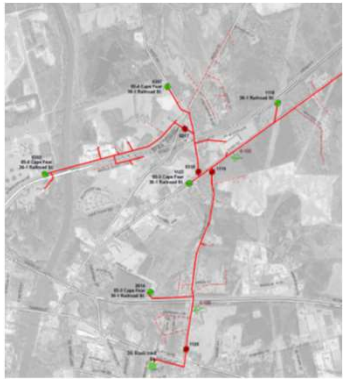

Fig. 3: GIS image of substation feeder.

- Data collected for May, June, July and August of 2019. Example from May 2019 collected data is shown below in Fig. 4.
- Daily peaks are evident. In addition, electrical variations in peak demand are visible indicating changes in electrical loads throughout the month due to variations in weather conditions.

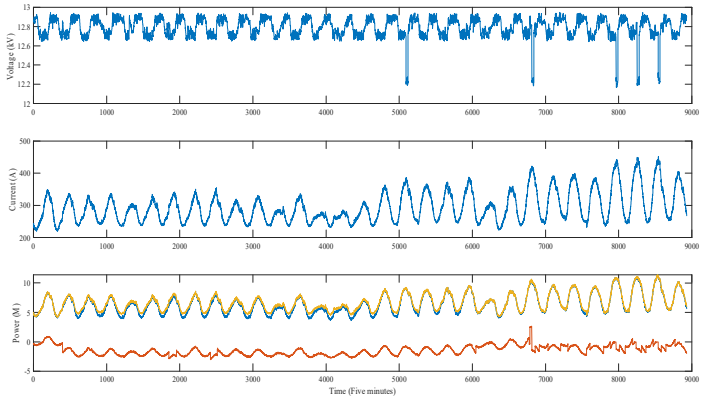

Fig. 4: Example of one month (30 days) of 5 minute interval data collection.

Results

- Determination of load type is determined by analyzing the data:
- Data collected at 5 minute intervals [1].
- Measurements of voltage and current are logged.
- If a gaussian probability distribution is assumed in the load variability, the impedance can be expressed as the cross covariance of voltage and current [2].
- Numerical methods are available to estimate the cross covariance of time-series data [3], [4].
- The interactions of power system voltage and current fluctuations has been previously documented [5].
- Figures show estimated impedances (Z) as cross covariance of voltage and current.
- ***Positive Z is impedance load***
- ***Negative is constant power load***
- ***Figure 7 indicates loss of load stability!***

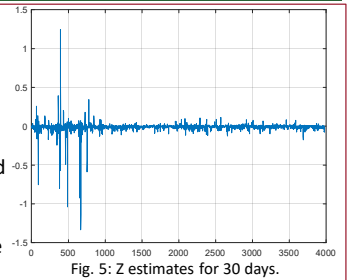

Fig. 5: Z estimates for 30 days.

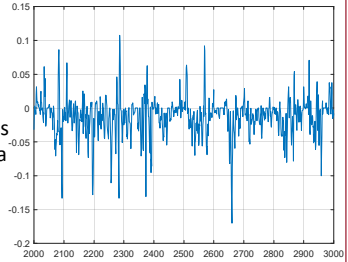

Fig. 6: Z estimates for 7 days.

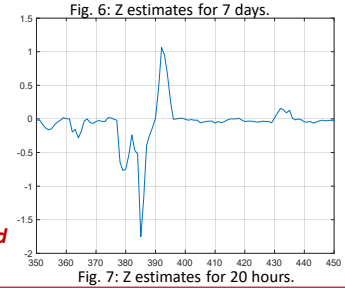

Fig. 7: Z estimates for 20 hours.

References

[1] SEL-734 Advanced Metering System, SEL-734 Data Sheet , Schweitzer Engineering Laboratories, Inc. Retrieved from https://cdn.selinc.com/assets/Literature/

[2] Donald W. Boyd, CHAPTER 8 - Stochastic Analysis, Editor(s): Donald W. Boyd, Systems Analysis and Modeling, Academic Press, 2001, pp. 211-227.

[3] Sample cross-correlation, Mathworks, Retrieved from https://www.mathworks.com/

[4] M. Diaz-Aguiló *et al.*, "Field-Validated Load Model for the Analysis of CVR in Distribution Secondary Networks: Energy Conservation," in *IEEE Transactions on Power Delivery*, vol. 28, no. 4, pp. 2428-2436, Oct. 2013, doi: 10.1109/TPWRD.2013.2271095.

[5] Shim, K.-S.; Go, S.-I.; Yun, S.-Y.; Choi, J.-H.; Nam-Koong, W.; Shin, C.-H.; Ahn, S.-J. Estimation of Conservation Voltage Reduction Factors Using Measurement Data of KEPCO System. *Energies* 2017, *10*, 2148.

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