636 – Optimal Placement of Power Quality Monitors for Enhanced Observability with Fewer Devices

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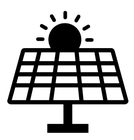
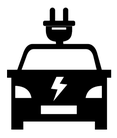
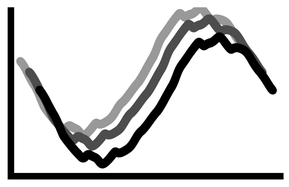
1. Motivation

Integration of more PV & EV → **... causes power quality issues** → **... requires more monitoring** → **... which is expensive.**


Inverters


Non-linear loads


Power Quality (PQ) Disturbances


Distribution System Operator (DSO)

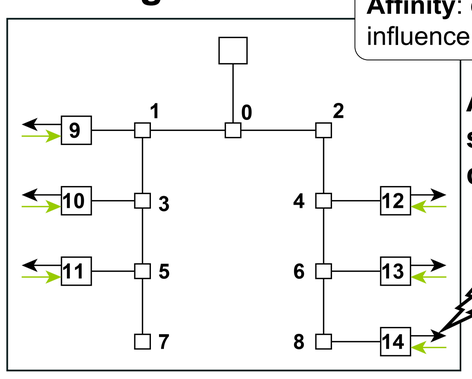
Monitoring everything is too expensive!

What if fewer monitors could do the job — if placed just right?

2. Methodology

I. Simulate

Digital Twin



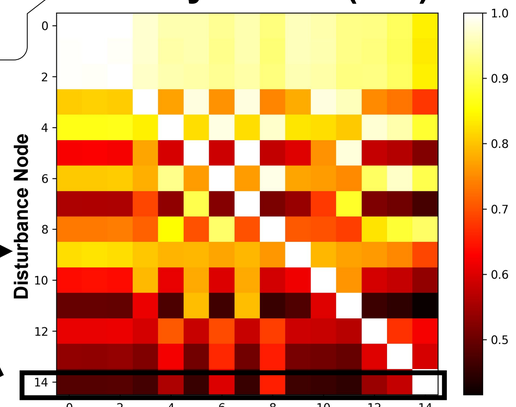
Affinity: degree of influence between nodes

At each node: simulate disturbance

At each other node: measure propagation

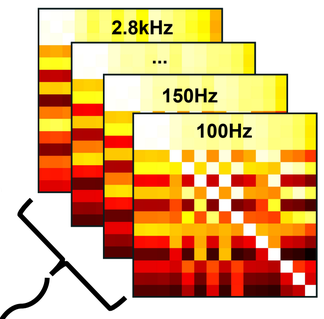
II. Build affinity matrix

Affinity Matrix (AM)



III. Aggregate affinity matrices

Voltage

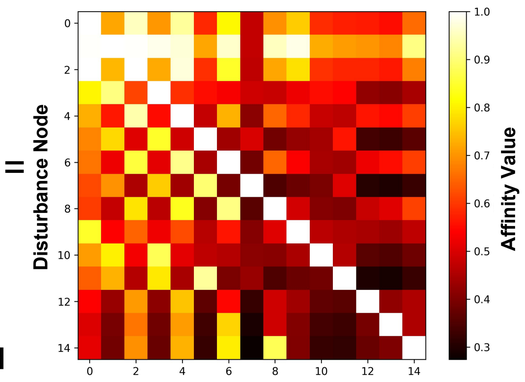


... repeat for each frequency

Current

... for both voltage and current measurements

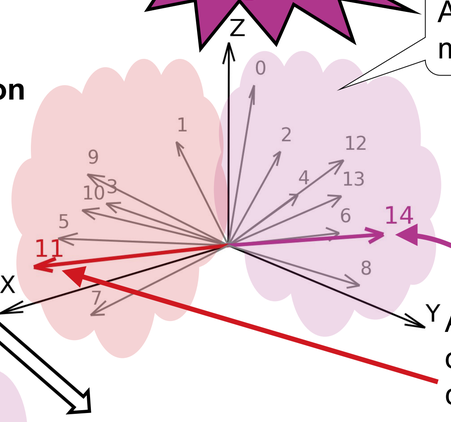
Aggregated AM



IV. Graph theory

Aggregated AM[1]

Eigen-Decomposition

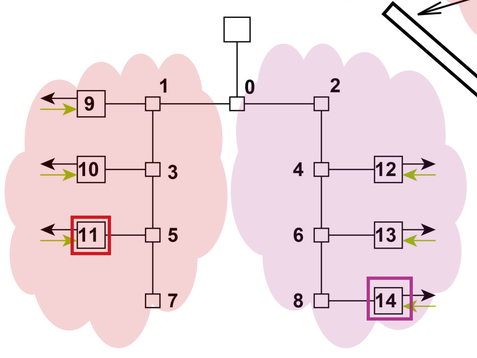


Arrows represent measurement nodes[2]

Arrows close to each other capture similar patterns

Arrows pointing in opposite directions capture highest variance

***k*-means clustering**



Within each cluster, find node that captures highest variance

Optimal placements!

magic!

V. Determine number of monitors

a) Determine application-specific thresholds

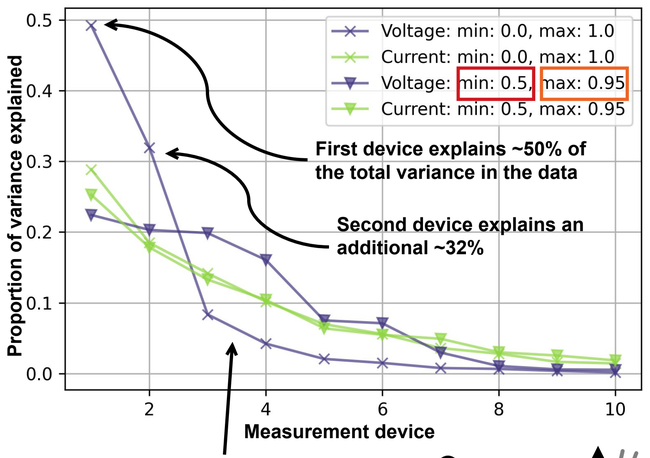
b) Repeat *k*-means clustering with different *k*

c) Find proportion of variance explained by *k* amount of measurements

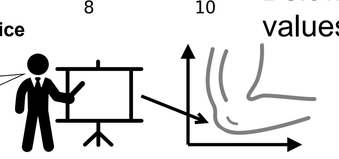
- **Accuracy requirements vary by application or use case**
- **State estimation requires higher precision than basic fault recognition**

What is the right amount of monitors for my application?

Scree plot of the explained variance
for the CIGRE LV grid



A good choice is at the *„knee“* of the plot

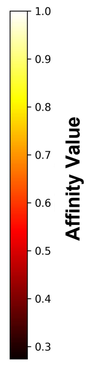


Max. threshold

„Sufficiently recognized“: Above the max. threshold all values are set to 1

Min. threshold

„Insufficient for the use case or noise“: Below the min. threshold all values are set to 0



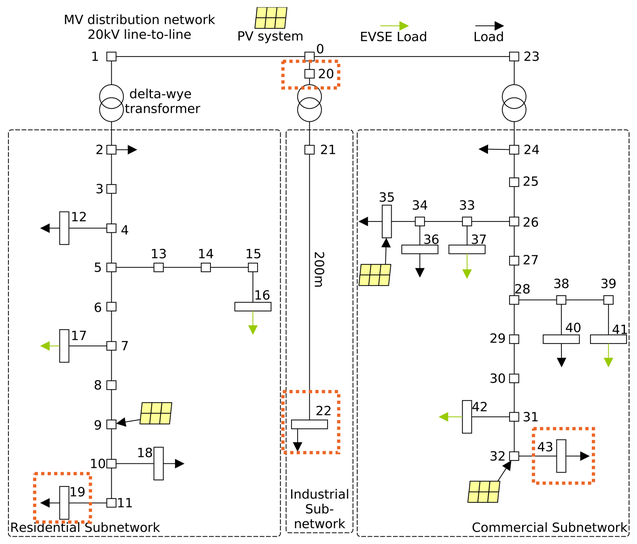
3. Results

When monitoring voltage only:

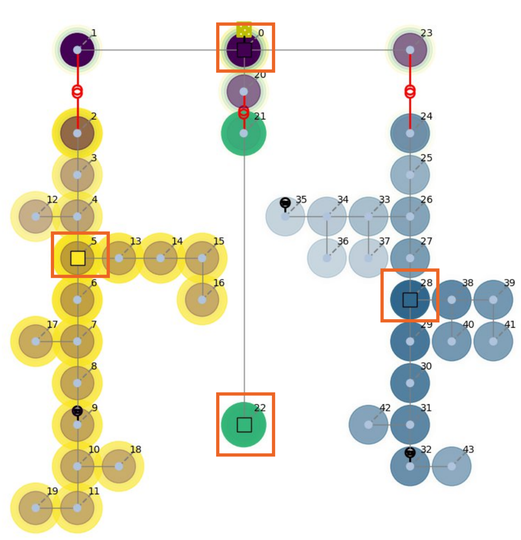
Place monitors away from strong sources!

For voltage and current measurements:

Place monitors at central junctions!



CIGRE LV distribution grid



Meter reach for combined measurements

Opacity shows percentage of error recognized

[1]For voltage-only measurements, [2]Conceptual illustration, not literal encoding

4. Conclusion

- ✓ **Data-driven PQM placement: scalable and efficient**
- ✓ **Placement considers use cases through application-specific thresholds**
- ✓ **Finds amount of required measurements**
- ✓ **Few PQ monitors needed (3-4 in typical grids)**

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