Zonal Resource Adequacy for Voltage Control

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Intro

- Power system operators keep voltages regulated by maintaining sufficient reserves of reactive power. Insufficient reactive power causes blackouts
- Reactive power provides voltage support while active power provides the energy consumed
- The large scale of transmission systems along with reactive power's poor ability to travel long distances makes it hard to estimate sufficient reactive reserves
- By breaking the larger systems into smaller zones, the Voltage Control Areas framework helps identify reactive reserves

Methods

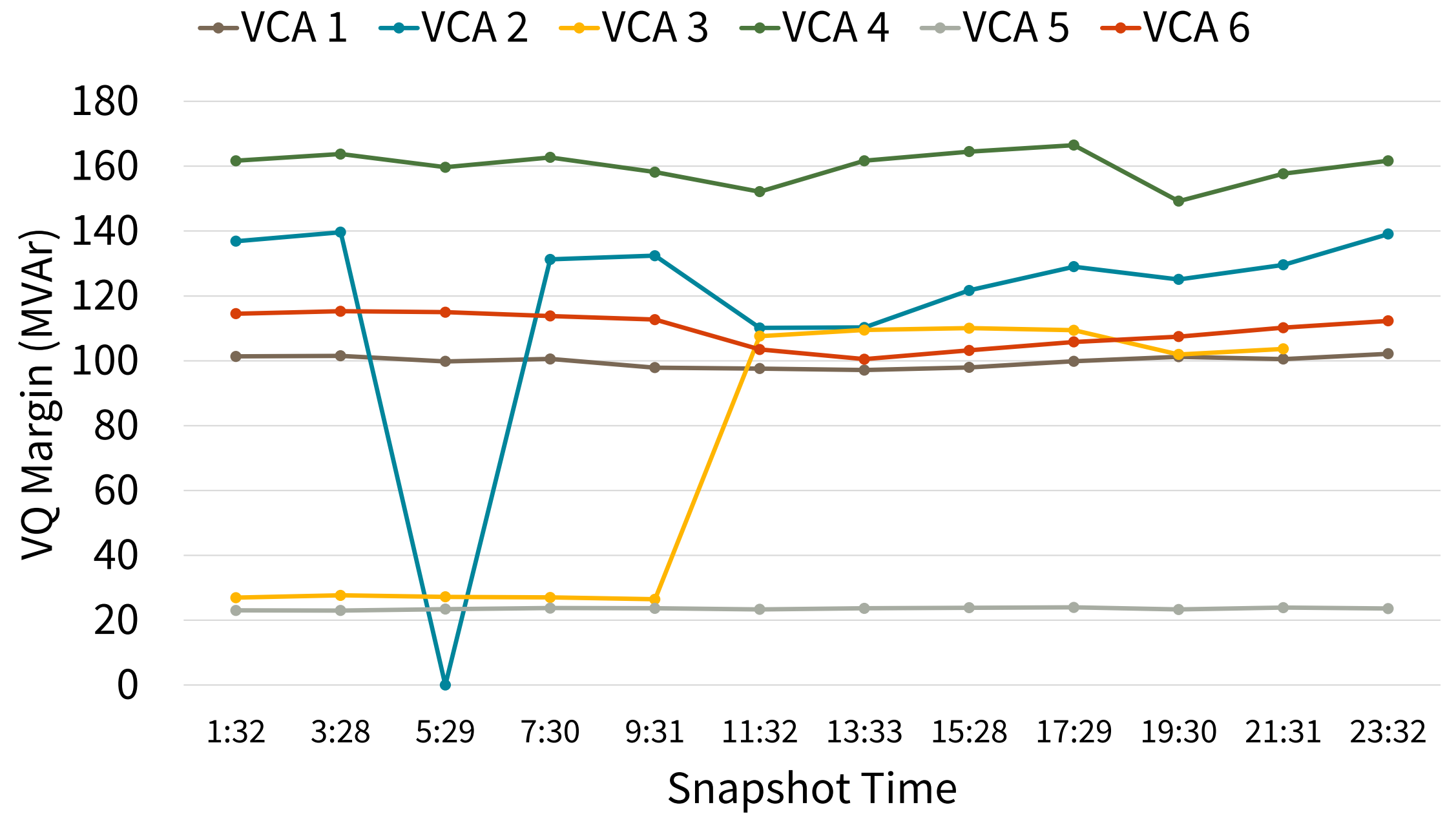
- Zones created by VCA clustering create boundaries for three reserve metrics:

1. Conventional Reactive Reserves (CQR): Finds reserve power based on the difference between generator max limit and operating point
2. Effective Reactive Reserves (EQR): Adds a sensitivity factor to CQR to account for generator location and reactive line losses
3. Voltage-Collapse Reactive Reserves (VQR): Uses generator outputs under voltage collapse as upper limit

- Also finds VQ Margin which is a measure of system stability

Results

- Finds critical contingencies and buses for each zone
- Able to analyze reactive power distribution and identify zones needing additional reactive resources with VQ Margin



The VQ Margin for each VCA zone of an actual utility system over a period of 24 hours.

Discussion

- VQ Margin works very well with the VCA framework
- As expected, CQR is a poor indicator of system stability
- VQR and EQR predict reserves closer to VQ Margin stability, but additional work needs to be done to verify their results
- Future work includes expanding to other types of reactive reserves and estimating necessary reserves to restore stability

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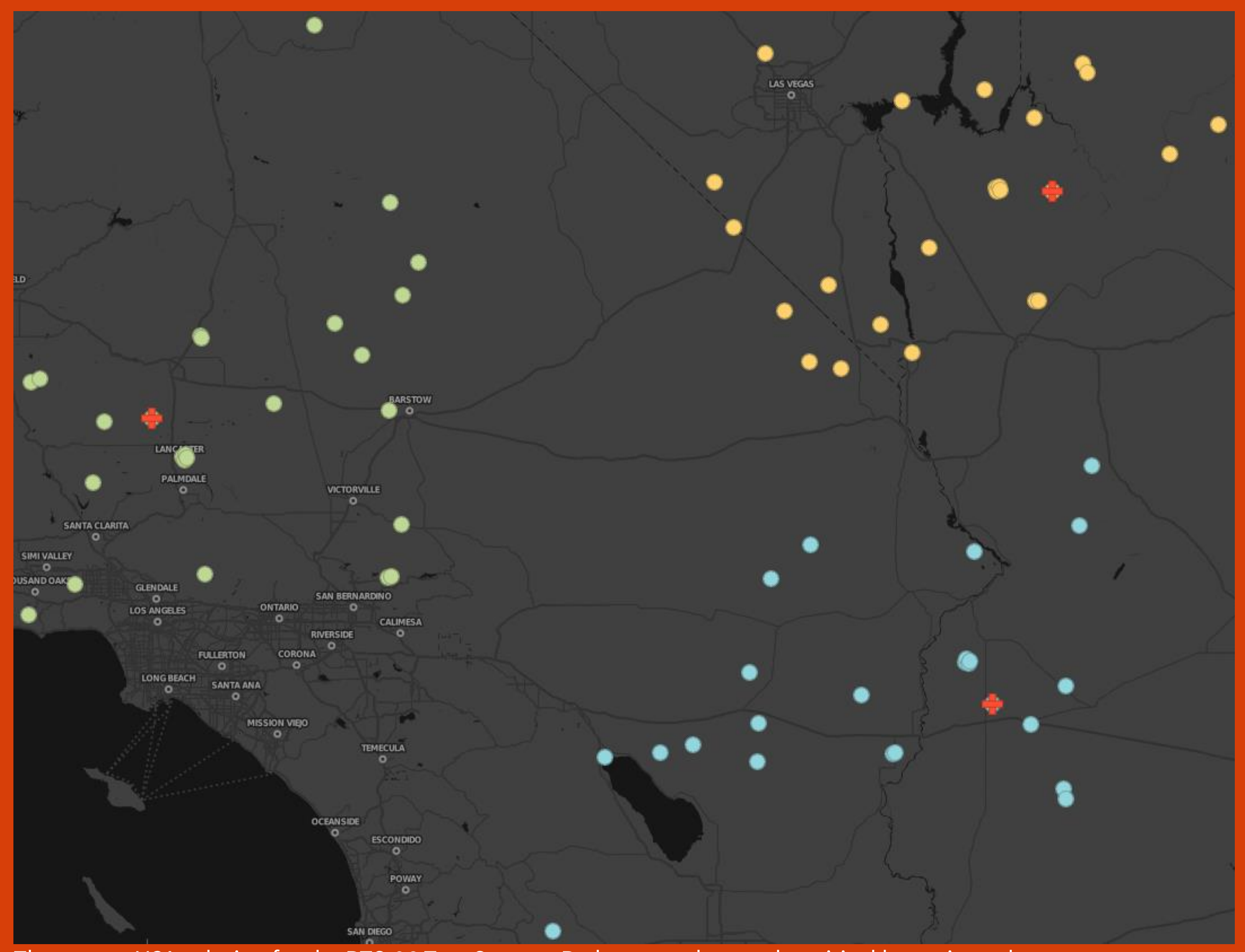
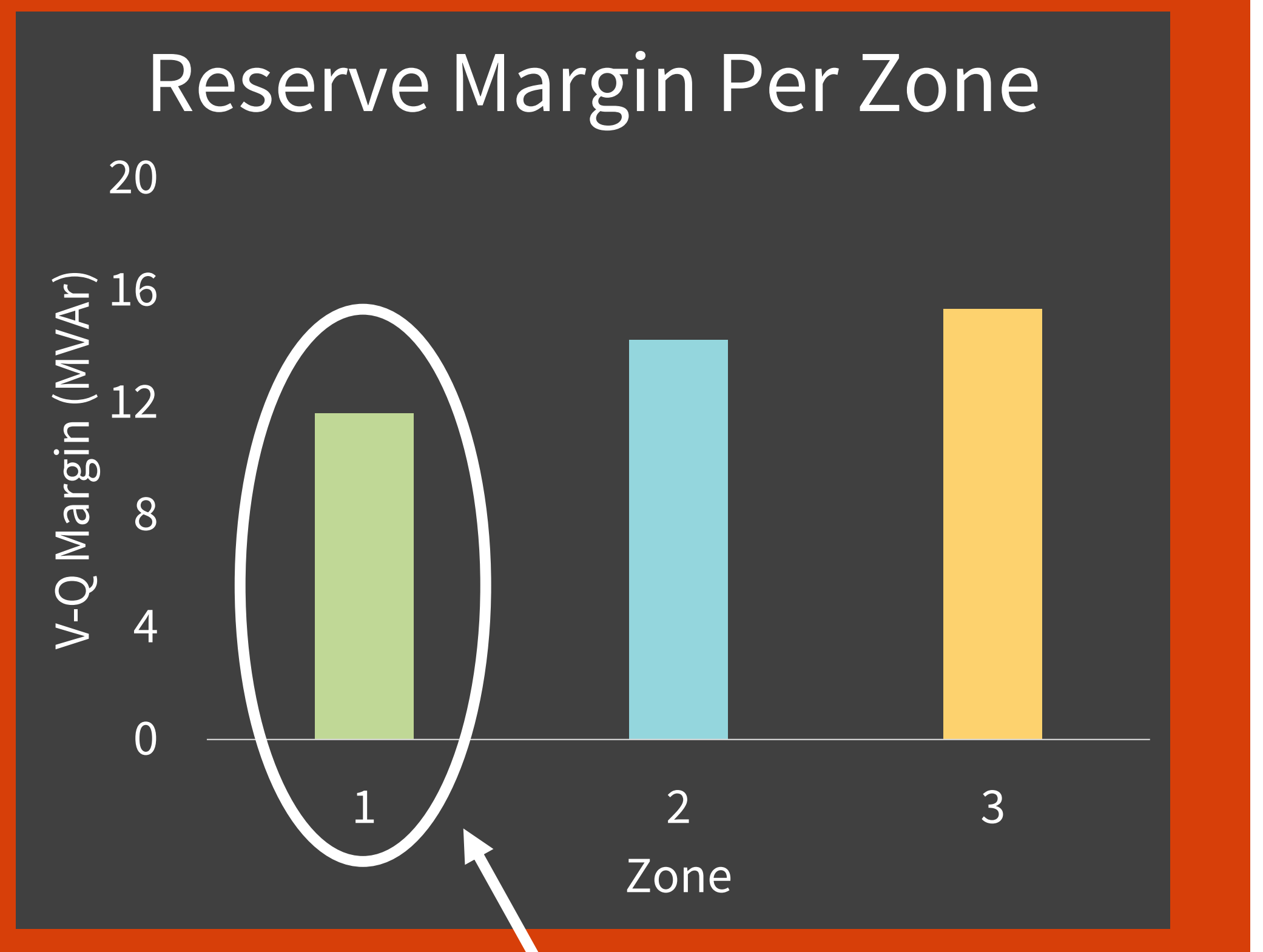
Voltage Control Areas identify zones needing **reactive support.**

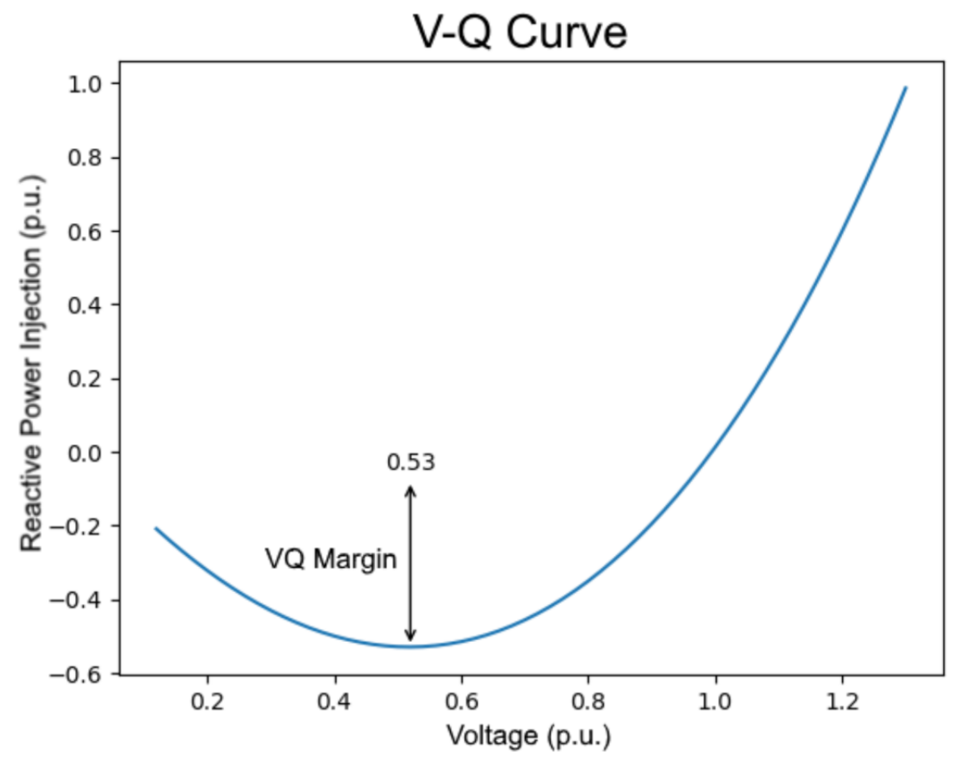


Three-zone VCA solution for the RTS-96 Test System. Red crosses denote the critical buses in each zone.

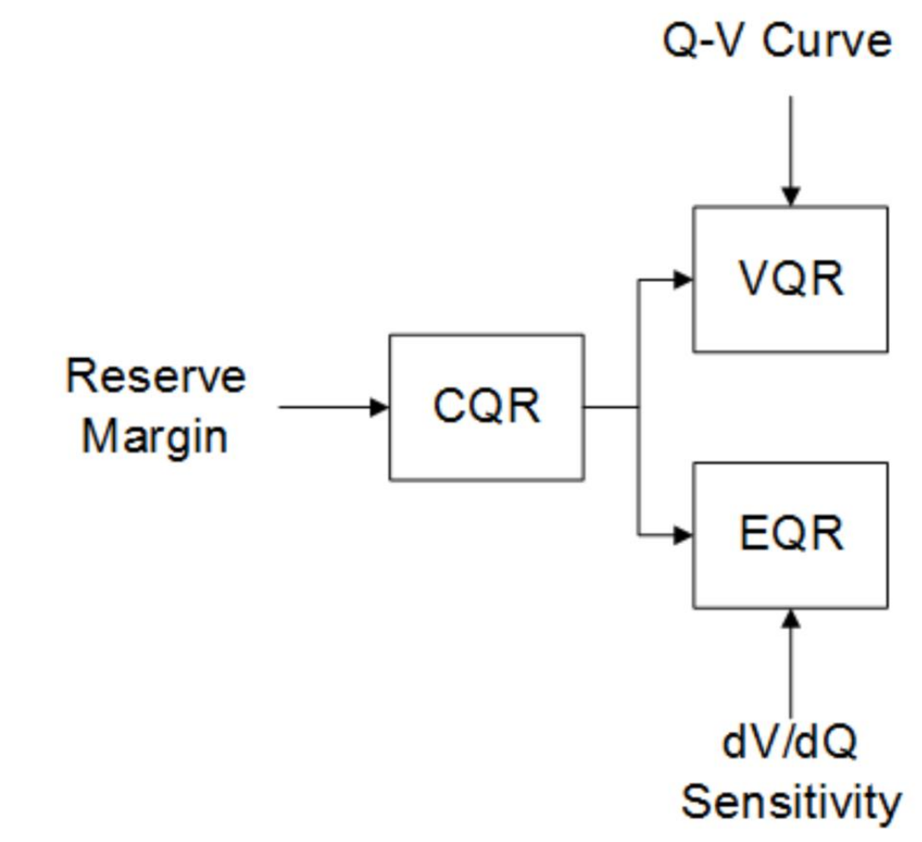


Zone 1 has the lowest voltage stability

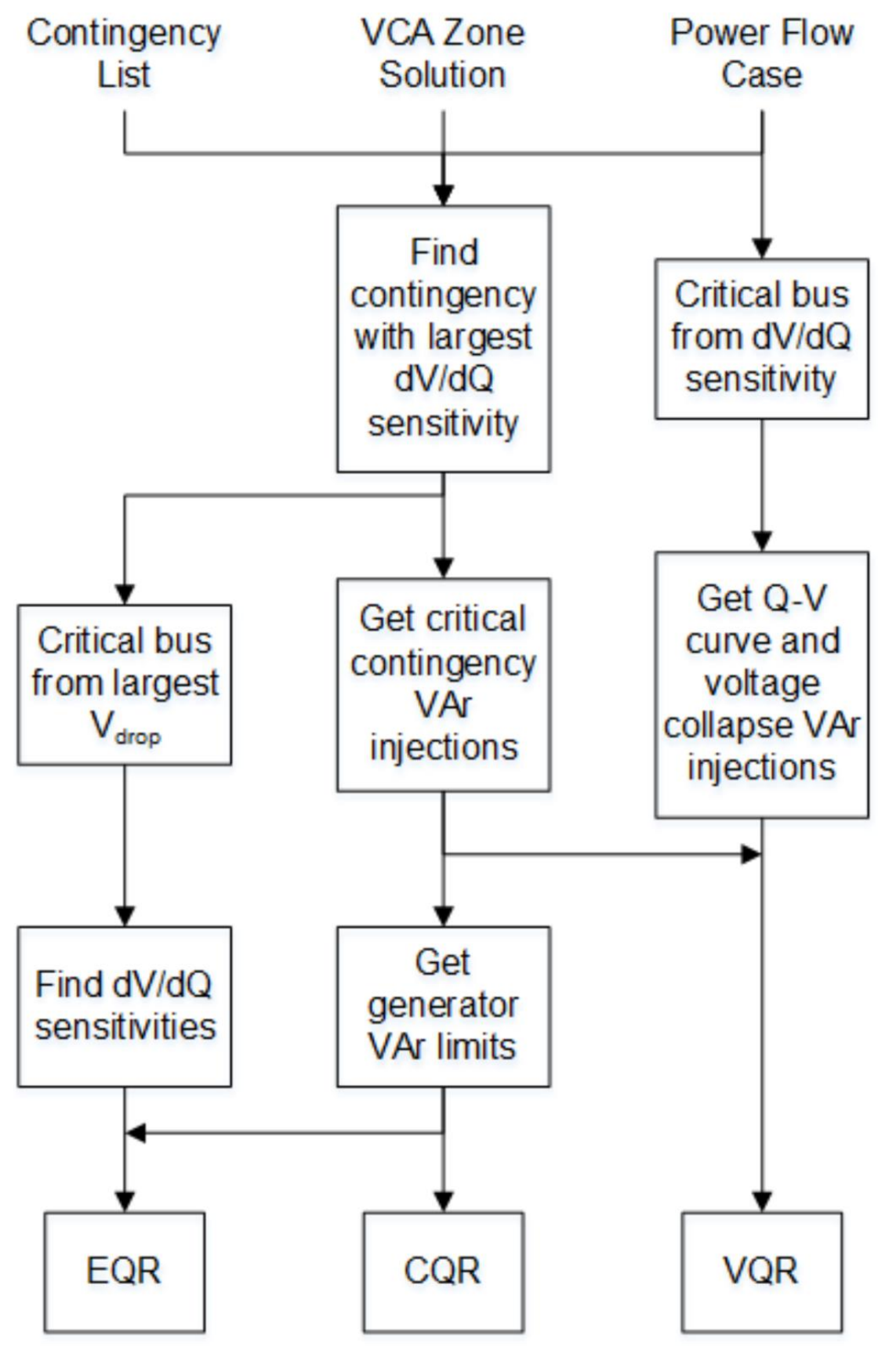
Additional Tables, Figures & Equations



A sample V-Q Curve which shows the relationship between reactive power and voltage. The bottom of the curve signifies voltage collapse. The VQ Margin is the difference in reactive power between voltage collapse and operating points.



A flowchart of the reactive reserve metrics and the additional information required for each metric



A flowchart of the complete reactive reserve metrics

$$\mathrm{CQR}_k = \sum_{i=\varepsilon} Q_{i,\max} - Q_{i,\mathrm{cc}}$$

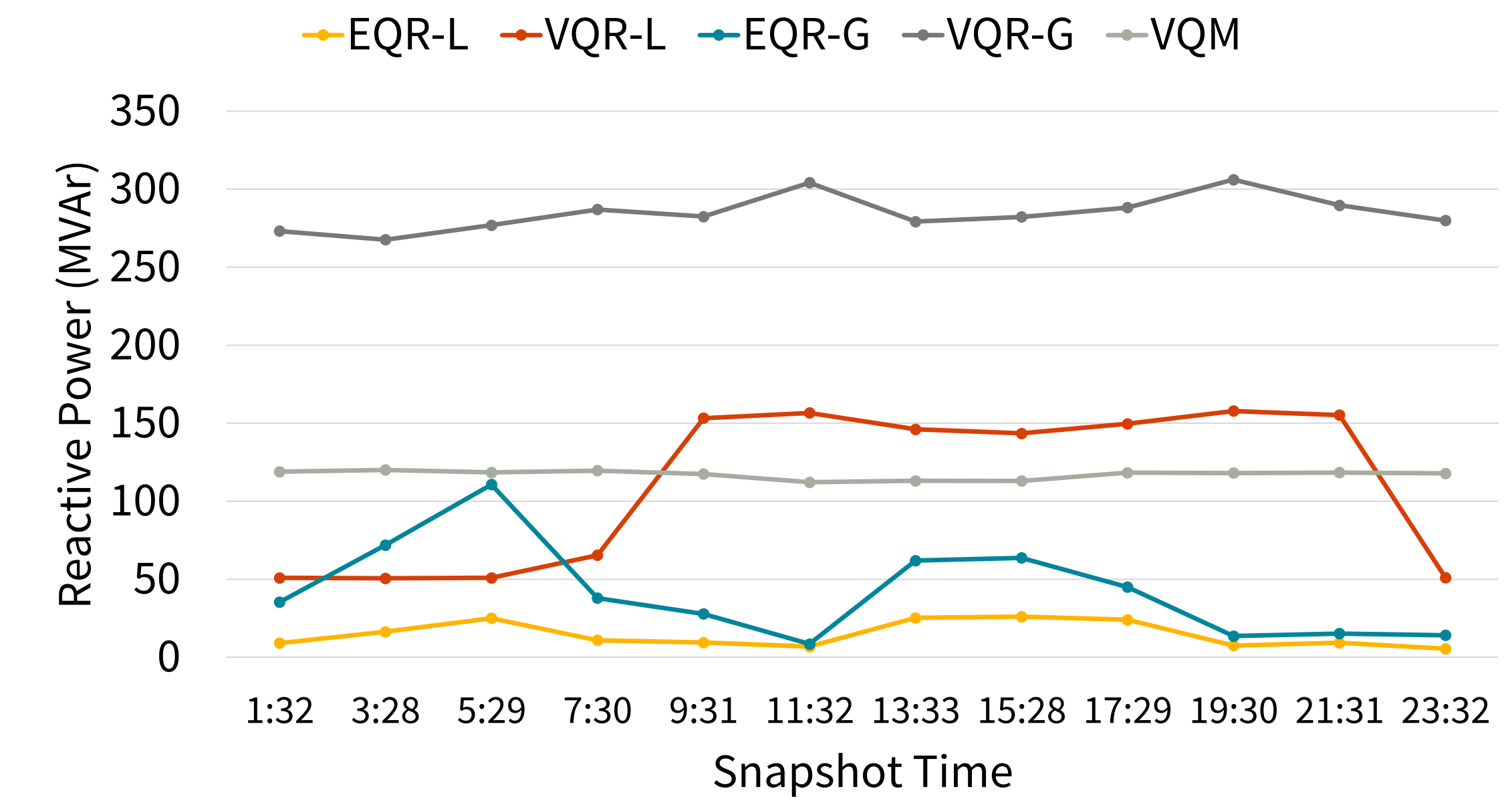
$$\mathrm{EQR}_k = \sum_{i=\varepsilon} \alpha_{i,k,p}\left(Q_{i,\max} - Q_{i,\mathrm{cc}}\right)$$

$$\mathrm{VQR}_k = \sum_{i=\varepsilon} Q_{i,\mathrm{vcol}} - Q_{i,\mathrm{cc}}$$

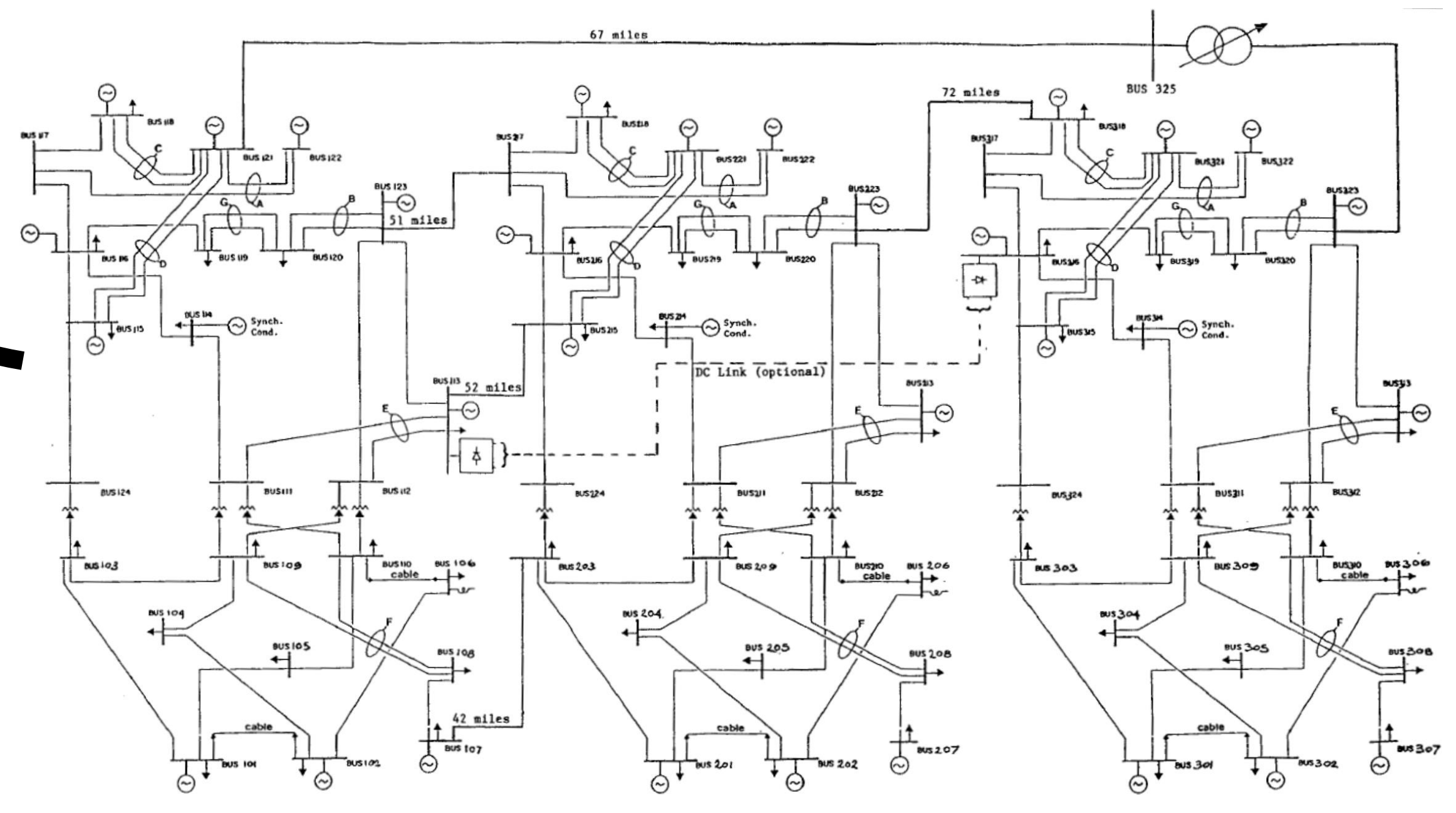
Equations for the three reserve metrics

VCA Zone	Buses	Gens
1	251	1-4
2	73	2-8
3	1262	63-116
4	34	0-4
5	407	9-24
6	8	0

Case data for the utility system shown in the VQ Margin results, Notice the wide variation in VCA size, caused by closely meshed areas in urban centers.



A plot of the two network-influenced reserve metrics showing both in zone and out of zone reserves.



A one-line diagram of the RTS-96 test system. Note the three natural zones, which correspond to the three zones found by the VCA clustering. Despite the extensive information provided on this diagram, it would still be impossible to determine critical buses or reactive reserves.