Voltage Stability Contingency Screening and Ranking for Voltage Control Areas

Tamer Ibrahim, K. Dowling, T. Tinoco De Rubira, Alberto Del Rosso, M. Patel, and A. Mohamd

Electric Power Research Institute (EPRI)
The City University of New York, City College
USA

Outline

- Overview
- QV analysis
- Voltage stability Indices .
- Methodology
- Results
- Conclusion

Overview

- Reactive power resources are important for maintaining adequate voltage levels and system voltage stability
- For technical and economical reasons, reactive power shouldn’t be transferred over long distances,
- Therefore, It is important to identify zones of the network within which reactive power resources are effective for voltage control and stability

- EPRI has developed and implemented a methodology and software to identify voltage control areas (VCA) in transmission networks

Overview Cont'd

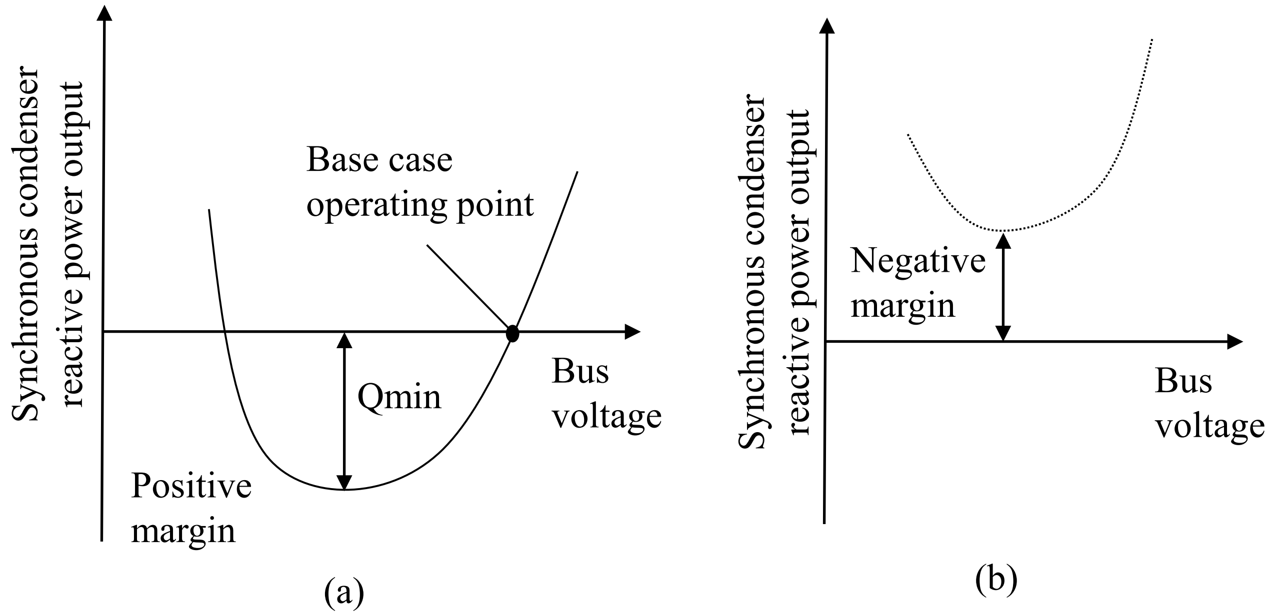
- The **main features** of EPRI's VCA tool are:
  - Identifying "voltage control areas" in the network based on electrical distance and clustering techniques
  - Assessing reactive power reserve adequacy throughout the system
  - Finding regions with deficient reactive power support or prone to voltage instability
  - Identifying effective mitigation or control actions to move the system back to secure operation conditions and increase reactive power margin
  - Evaluating reactive power adequacy to ensure voltage stability and security even during the most critical contingency

Overview Cont'd

- It is necessary to identify the most critical contingency from a list of given contingencies in order to properly evaluate voltage stability metrics
- Practically, the methodology to rank contingencies based on their severity and identify the most critical one needs to also be accurate and computationally efficient

- This paper investigates various voltage stability indices (VSI) that can be used to identify the most critical contingency for a VCA.

QV analysis

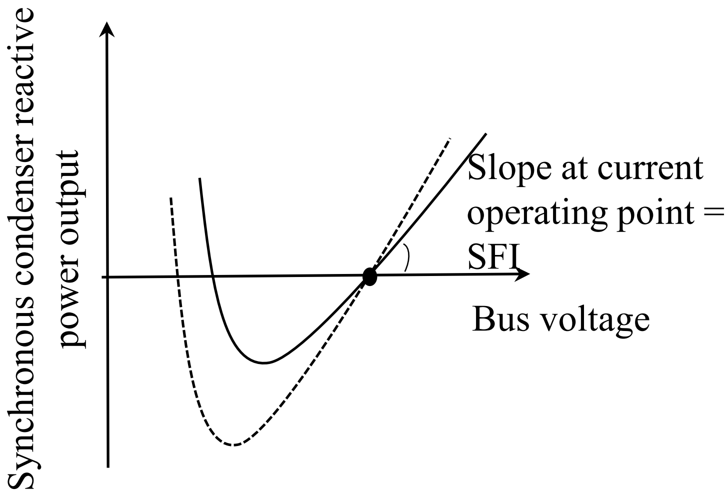


VQ curve, (a) stable case, (b) unstable case

Voltage Stability Indices – Voltage Sensitivity Factor

- $$SFI := \left(\left|\frac{dv_i}{dQ_i}\right|\right)^{-1},$$

where i denotes the critical bus of the VCA.



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Voltage Stability Indices – Fast Voltage stability Index

- The $FVSI$ depends on the reactive power flow in the branch and the sending end voltage

$$FVSI := max\left\{ \frac{4Z_{ij}^2 Q_j}{V_i^2 x_{ij}} \;\middle|\; (i,j) \in \mathcal{L} \right\},$$

where $\mathcal{L}$ is the set of lines connected to the critical bus of a VCA, Z_{ij} and x_{ij} are line impedance and reactance, respectively, Q_j is the reactive power at the receiving end, and V_i is the sending end voltage.

- For stable operation, the magnitude of the $FVSI$ should be less than 1 for each VCA.

Voltage Stability Indices – Voltage Collapse Proximity Index

- $VCPI$ can be defined as follows:

$$VCIP := \left| 1 - \frac{\sum_{k \neq i} V_k^{'}}{V_i} \right|$$

where i is the critical bus of a VCA,

$$V_k^{'} := \frac{Y_{ik}}{\sum_{j \neq i} Y_{ij}} V_k,$$

and Y denotes the admittance matrix of the network.

- $VCPI$ varies from zero during normal operation to one at voltage collapse.

Voltage Stability Indices – Voltage Reactive Power Index

- The VQI for a VCA is defined here as follows:

$$VQI \coloneqq max\left\{\frac{4Q_j}{|Y_{ij}|\sin(\theta_{ij})V_i^2}\,\middle|\,(i,j) \in \mathcal{L}\right\}$$

where $\mathcal{L}$ is the set of lines connected to the critical bus of the VCA.

- Once the VQI approaches unity, the voltage stability limit is reached.

Voltage Stability Indices - Tangent Vector Index

- The TVI for a VCA can be defined from the power flow equations as follows:

$$\begin{bmatrix} d\theta/d\lambda \\ dV/d\lambda \end{bmatrix} = [J]^{-1} \begin{bmatrix} P \\ Q \end{bmatrix}$$

where λ represents the load increase factor at all buses except the slack bus, J denotes the power flow Jacobean matrix, P and Q are bus power injections,

$$TVI := \left| \frac{dV_i}{d\lambda} \right|^{-1}$$

where i is the critical bus of the VCA.

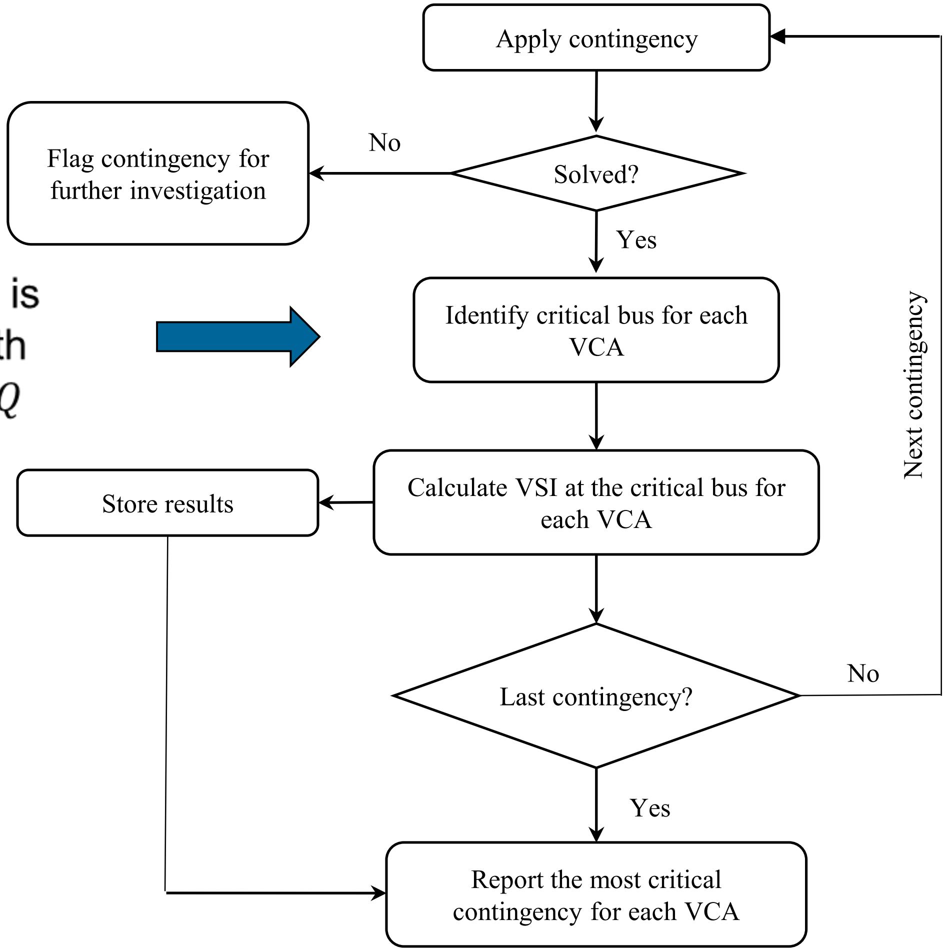
- As the collapse point is approached, $dV_i/d\lambda \rightarrow \infty$ and hence, $TVI \rightarrow 0$.

Voltage Stability Indices - Summary

Index	Calculation	Stability Threshold
Voltage Sensitivity Factor (SFI)	$SFI := \left(\left\| \frac{dv_i}{dQ_i} \right\| \right)^{-1}$	SFI > 0
Fast Voltage Stability Index (FVSI)	$FVSI := max \left\{ \frac{4Z_{ij}^2 Q_j}{V_i^2 x_{ij}} \middle\| (i,j) \in \mathcal{L} \right\}$	FVSI < 1
Voltage Collapse Prediction Index (VCIP)	$VCIP := \left\| 1 - \frac{\sum_{k \neq i} V_k'}{V_i} \right\|,$ $V_k' := \frac{Y_{ik}}{\sum_{j \neq i} Y_{ij}} V_k$	VCIP < 1
Voltage Reactive Power Index (VQI)	$VQI := max \left\{ \frac{4Q_j}{\|Y_{ij}\| \sin(\theta_{ij}) V_i^2} \middle\| (i,j) \in \mathcal{L} \right\}$	VQI < 1
Tangent Vector Index (TVI)	$TVI := \left\| \frac{dV_i}{d\lambda} \right\|^{-1}$	TVI > 0

Methodology

Critical bus is the bus with max $\partial V/\partial Q$



Methodology cont'd

- Three criteria are used to compare the performance of the different VSIs, in the following order:
  - Identification of the most critical contingency at each VCA
  - Profile of the VSI under stressed conditions
  - Computationally complexity

- VQ analysis is used as a benchmark for measuring the accuracy, in terms of contingency ranking and identification, of the other techniques

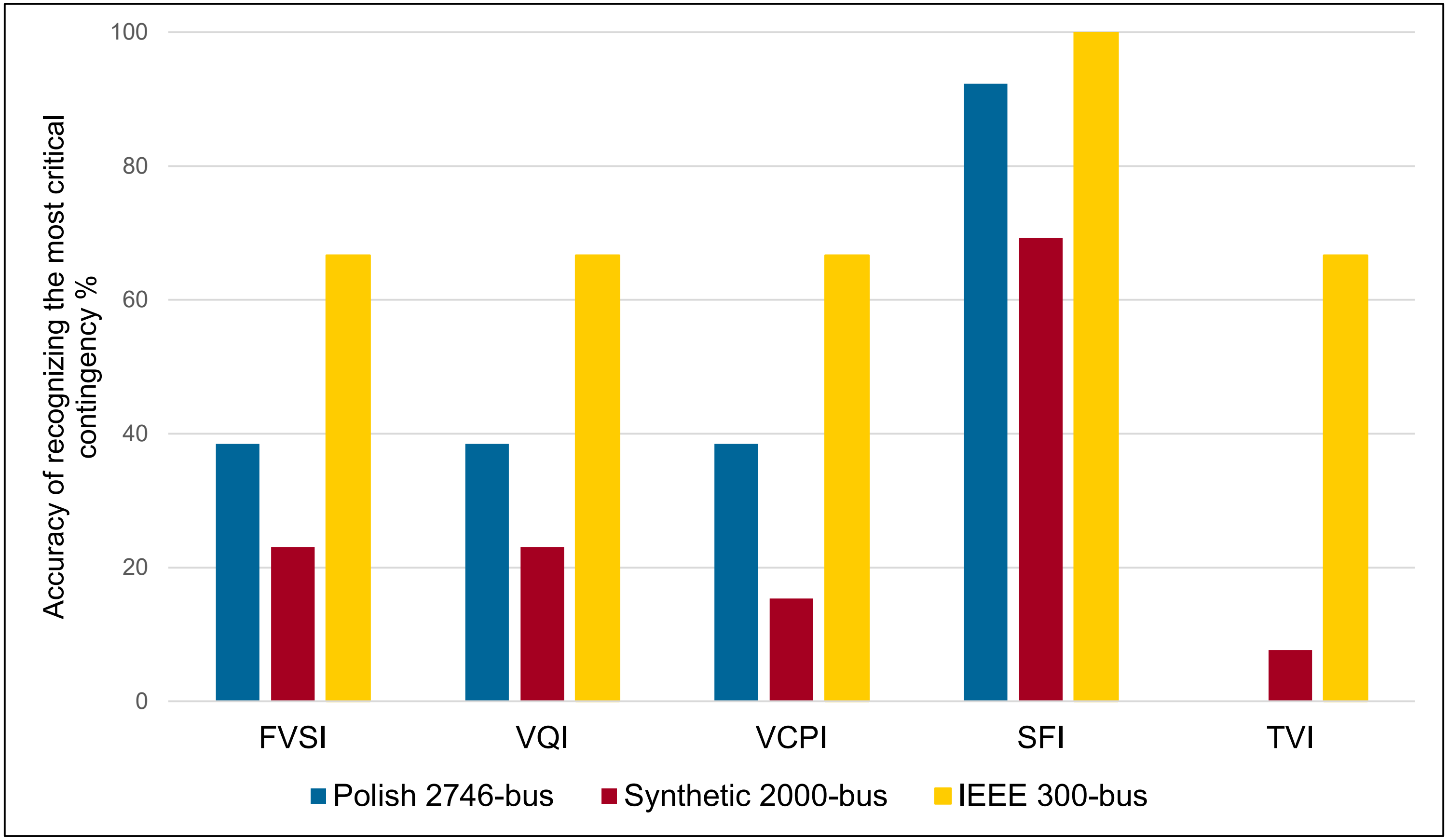
Results

- The performance of the VSIs is evaluated using different test networks and under different loading conditions.

Network	Number of VCAs
Polish 2746-bus	13
Synthetic 2000-bus	13
IEEE 300-bus	3

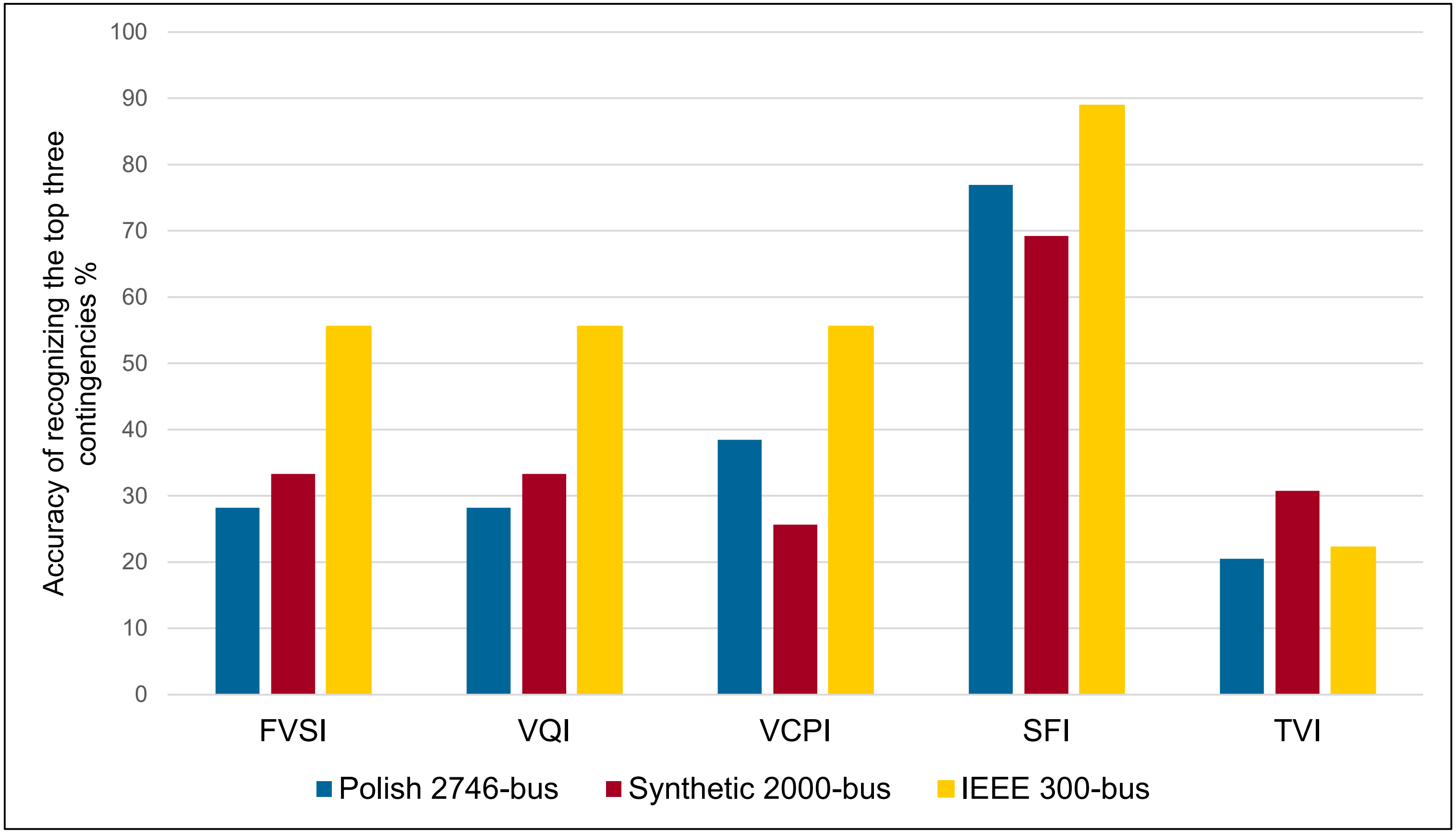
Results - Critical Contingency Identification

- Accuracy of VSIs for identifying the most critical contingency for each VCA



Results - Critical Contingency Identification

- Accuracy of VSIs for identifying the top three critical contingencies for each VCA



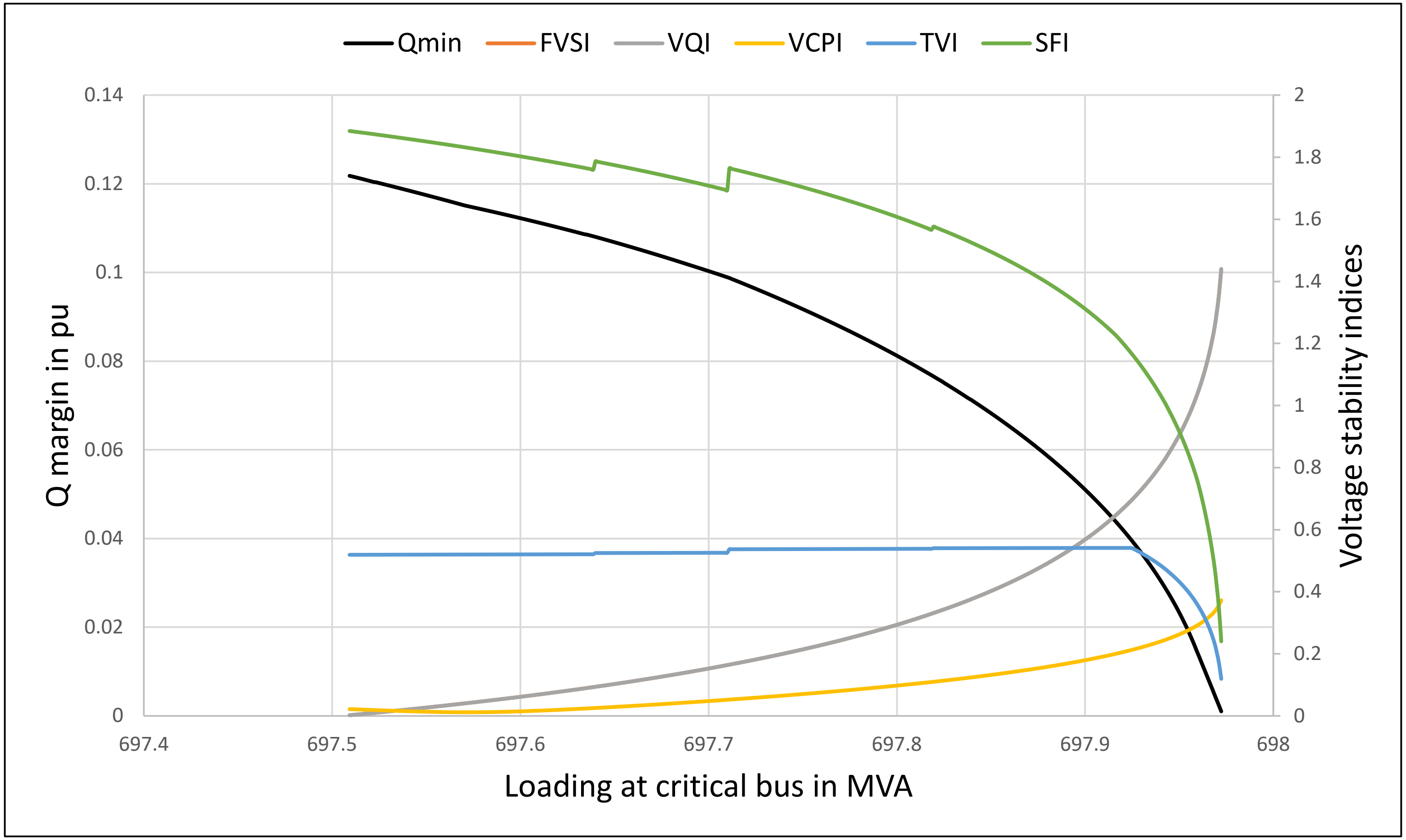
Results – Execution Time

- The execution time (in minutes) of calculating the VSIs:

Network	VQ	FVSI	VQI	VCPI	SFI	TVI
Polish 2746-bus	113.2	12.10	12.15	12.9	12.0	33.6
Synthetic 2000-bus	1826.1	19.18	19.34	21.5	18.5	42.4
IEEE 300-bus	3.95	0.277	0.286	0.290	0.257	0.34

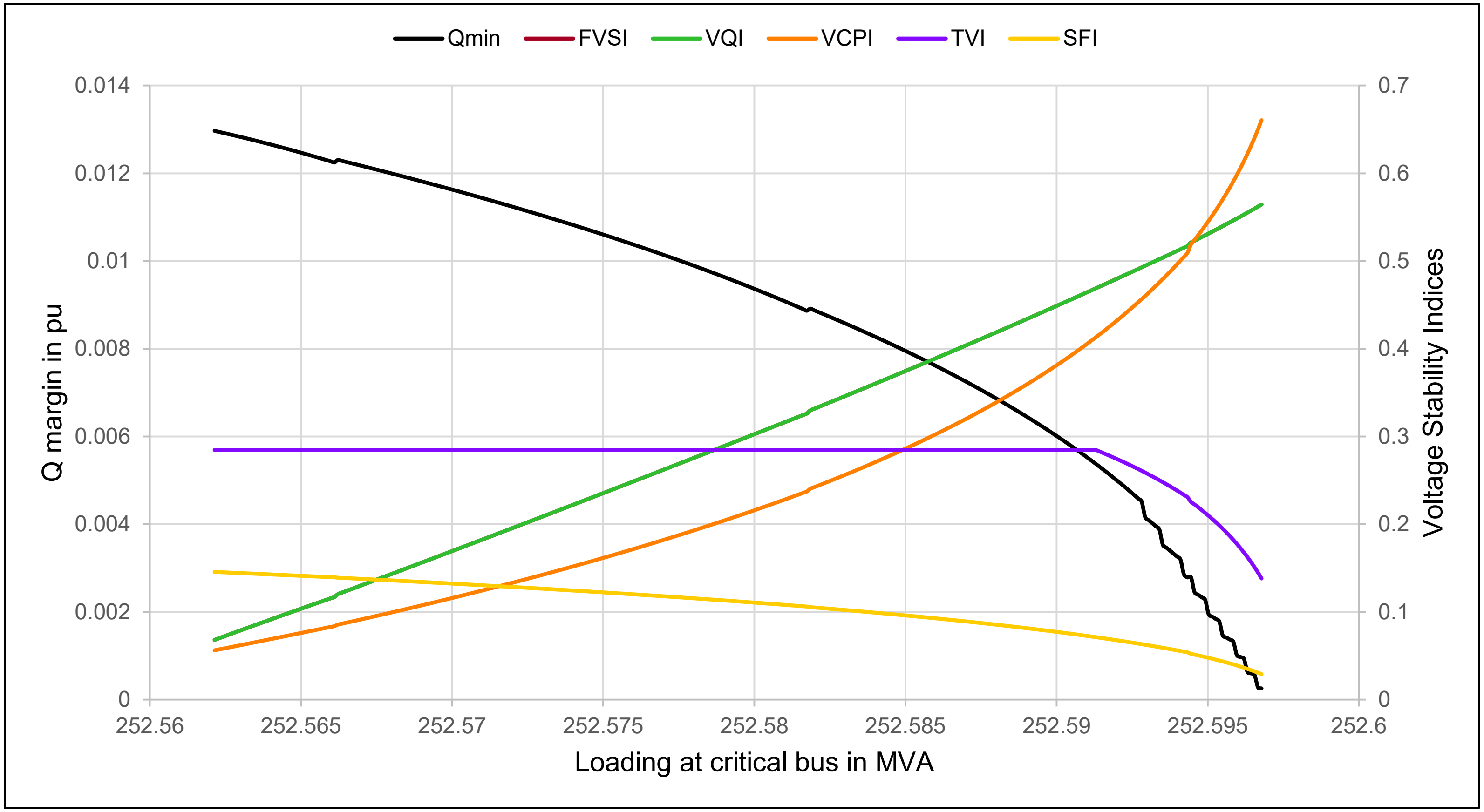
Results - Profile of the VSI under Stressed Conditions

- VSIs at bus number 1011, Synthetic 2000-bus network



Results - Profile of the VSI under Stressed Conditions

- VSIs at bus number 9042, IEEE 300-bus network



Conclusion

- This paper presents a comparative study of the performance of some voltage stability indices for identifying critical contingencies of VCAs
- The results and application of these indices on IEEE 300-bus, synthetic 2000-bus, and the Polish 2746-bus networks are reported
- The results obtained indicate that the sensitivity factor index performs better under different stress conditions and networks compared to other indices
- your feedback is appreciated!!

For any inquiries regarding VCA tool, Please contact

Dr. Alberto Del Rosso

Principal Project Manager at Electric Power Research Institute (EPRI)

adelrosso@epri.com

ELECTRIC POWER RESEARCH INSTITUTE

Together…Shaping the Future of Electricity

ELECTRIC POWER RESEARCH INSTITUTE