GENERALIZED STATE ESTIMATION & CIM

Nexant

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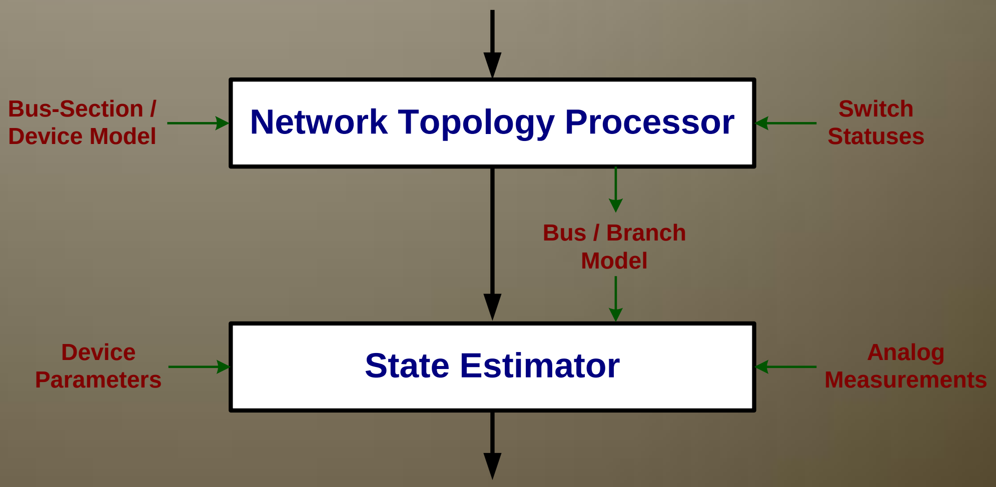
State Estimation – Typical (Conventional) Approach

- Bus/branch network model
- Redundant measurements (*z*), and state variables (*x*) as bus voltage magnitudes and phase angles
- Decoupled interactions between switch statuses, analog measurements & device parameters
- No topology or parameters errors
- Small errors (noise) in sensor data following a normal distribution

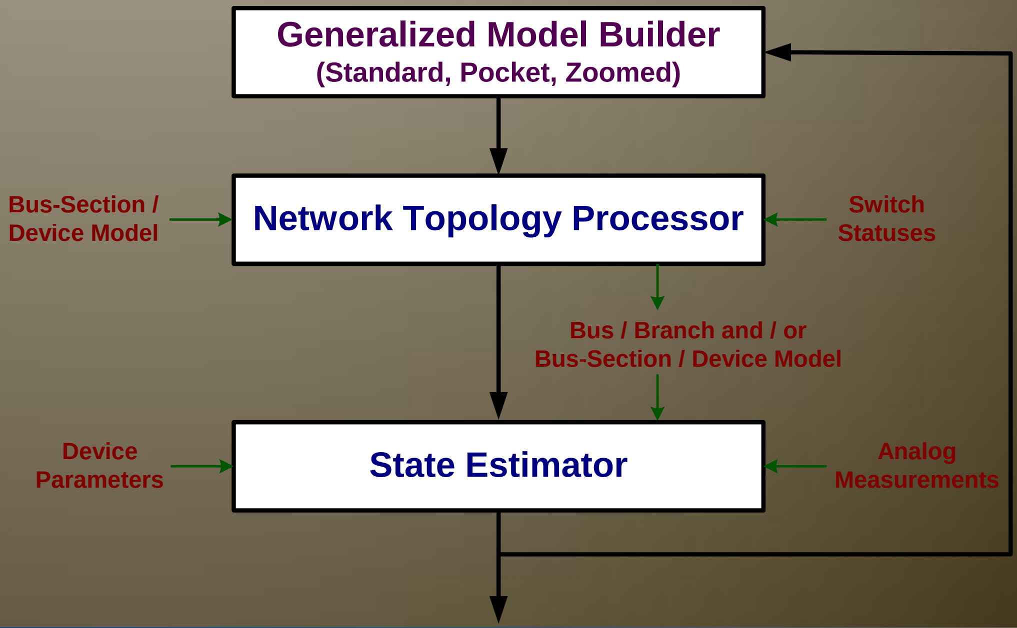
$$z_i = f(x_i) + e_i$$



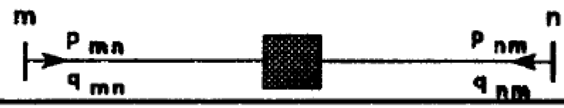
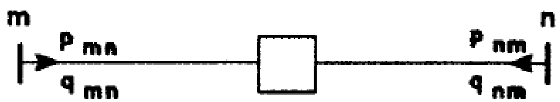
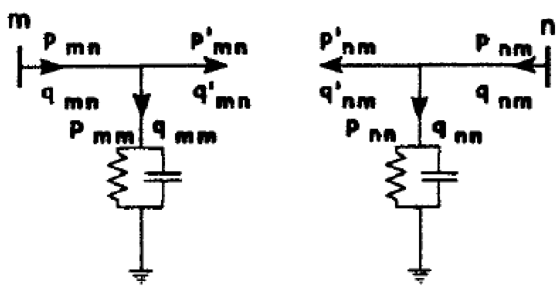
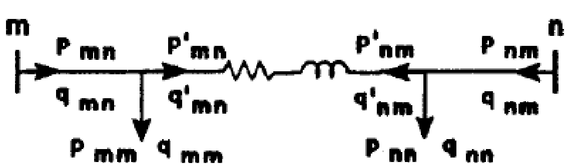
State Estimation – Generalized Approach

- Node/breaker network model
- Redundant measurements (*z*), and flows through switches (*s*) and network impedances (*p*) in addition to conventional state variables (*x*)
- A single interacting set of data of switch statuses, analog measurements & device parameters
- Small errors (noise) in sensor data following normal distribution
- Potential mistakes in switch statuses and device parameters

$$z_i = f(x_i, s_i, y_i) + e_i$$



Modeling of Switches & Uncertain Branch Parameters

Type	Diagram	Model	Pseudo-Measurement	State
Closed Switch		$p_{mn} = -p_{nm}$ $q_{mn} = -q_{nm}$	Zero Voltage Difference $0 = V_m - V_n$ $0 = \theta_m - \theta_n$	p_{mn} q_{mn}
Open Switch		$p_{mn} = -p_{nm}$ $q_{mn} = -q_{nm}$	Zero Flow $0 = p_{mn}$ $0 = q_{mn}$	p_{mn} q_{mn}
Series Branch		$p_{mn} = p_{mm} + p'_{mn}$ $q_{mn} = q_{mm} + q'_{mn}$ $p_{nm} = p_{nn} + p'_{nm}$ $q_{nm} = q_{nn} + q'_{nm}$	Zero Current Difference $0 = p'_{mn} \cdot V_n + (p'_{nm} \cdot \cos\theta_{mn} - q'_{nm} \cdot \sin\theta_{mn}) \cdot V_m$ $0 = q'_{mn} \cdot V_n + (p'_{nm} \cdot \sin\theta_{mn} + q'_{nm} \cdot \cos\theta_{mn}) \cdot V_m$	p'_{mn} q'_{mn} p'_{nm} q'_{nm}
Shunt Branch		$p_{mn} = p_{mm} + p'_{mn}$ $q_{mn} = q_{mm} + q'_{mn}$ $p_{nm} = p_{nn} + p'_{nm}$ $q_{nm} = q_{nn} + q'_{nm}$	Zero Admittance Difference $0 = p_{nn} \cdot V_m^2 - p_{mm} \cdot V_n^2$ $0 = q_{nn} \cdot V_m^2 - q_{mm} \cdot V_n^2$	p_{mm} q_{mm} p_{nn} q_{nn}

* From O. Alsac, N. Vempati, B. Stott & A. Monticelli IEEE Paper

Conventional vs. Generalized State Estimation

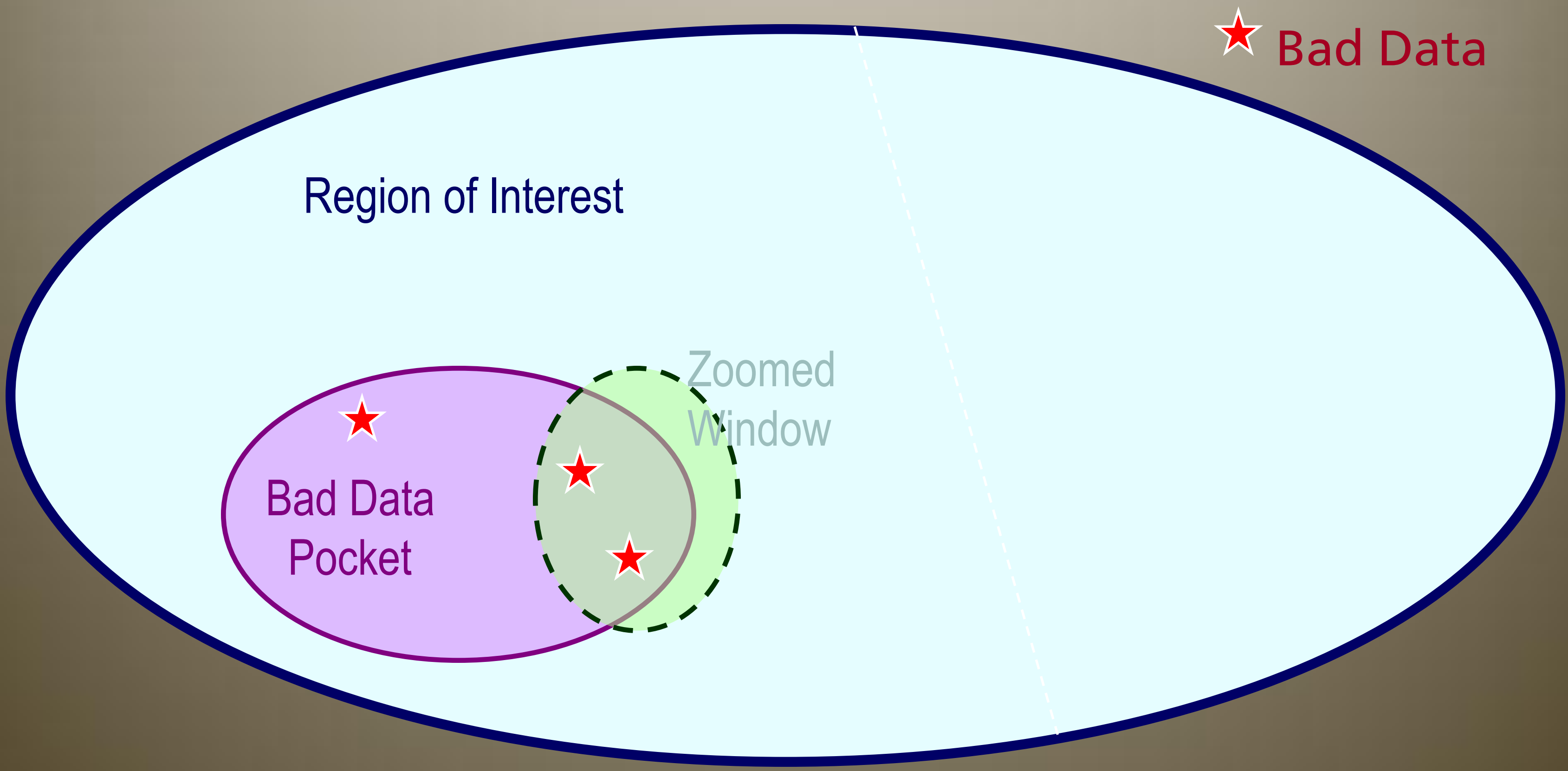
Conventional

- Read in node/breaker data
- Run measurement plausibility
- Do network topology processing
- Run SE on bus/branch model
- Run bad data (BD) analysis
  - If none, stop
  - Delete measurements with the largest normalized residuals & run SE again

Generalized

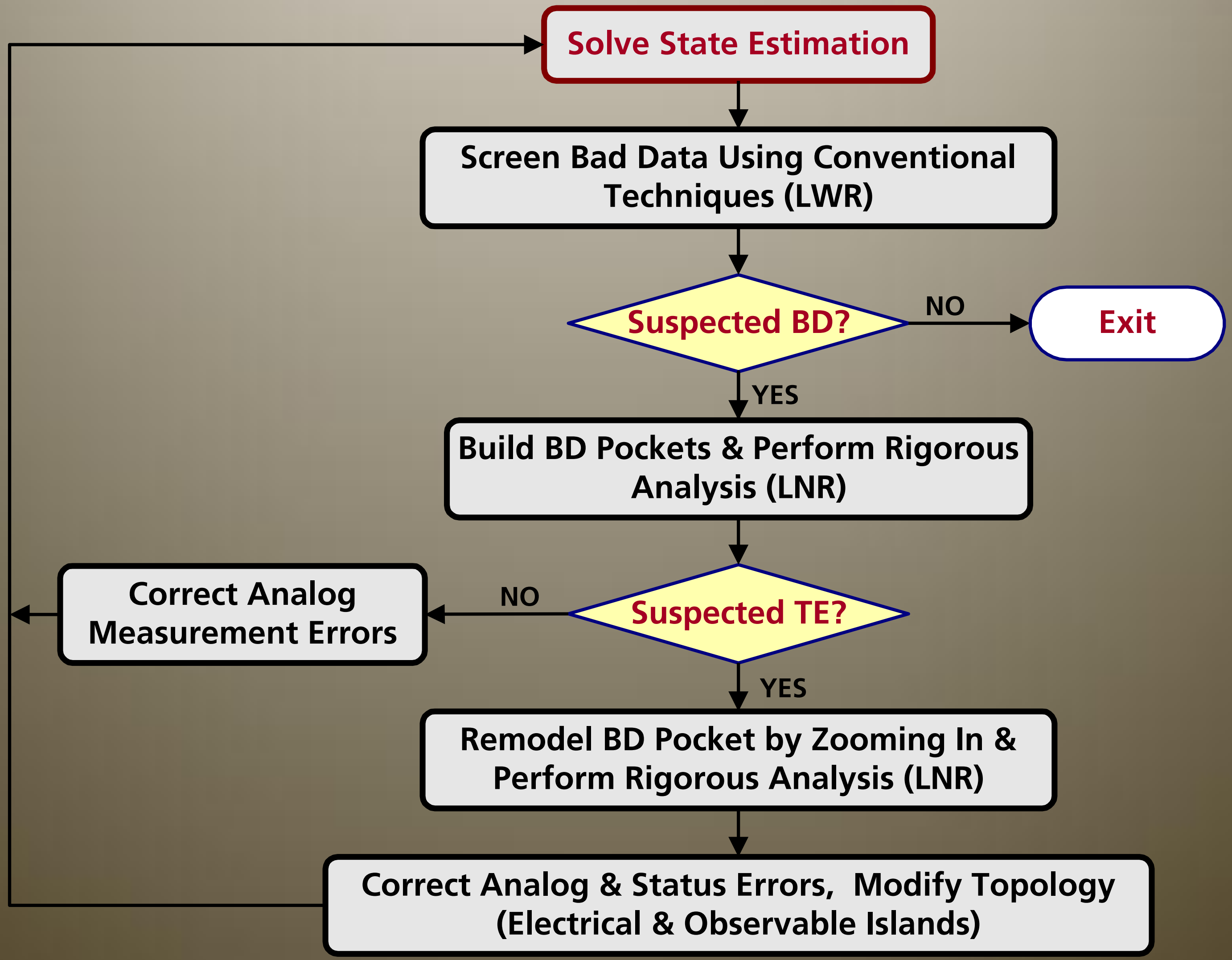
- Read in node/breaker data
- Run measurement plausibility
- Do network topology processing
- Run SE on bus/branch model
- Run bad data (BD) analysis
  - If none, stop
  - If BD are detected, go to next SE run
- Read in node/breaker data
- Build bad data pockets
- Use a hybrid model & model bad data pockets in detail
- Zoom around BD in pockets & perform combinatorial analysis
  - Correct TE & eliminate BD

Bad Data Pockets & Zooming In



Pockets & windows do not grow in size with total number of buses, thus their solutions are system size independent

Generalized SE Flow in the Presence of BD



Modular CIM Profiles*

- Equipment
- Connectivity
- Geographical
- Measurement
- Topology
- State
- Graphics
- Boundary**

ENTSO-E
- Equipment
- Topology
- State

CPSM
- Equipment
- Connectivity
- Measurement

CDPSM
- Equipment
- Connectivity
- Measurement
- Geographical

* From A. McMorran, A.d. Vos, J. Britton & G. Ault presentation

** Additional proposed profile group

CIM Requirements for Conventional & Generalized State Estimation

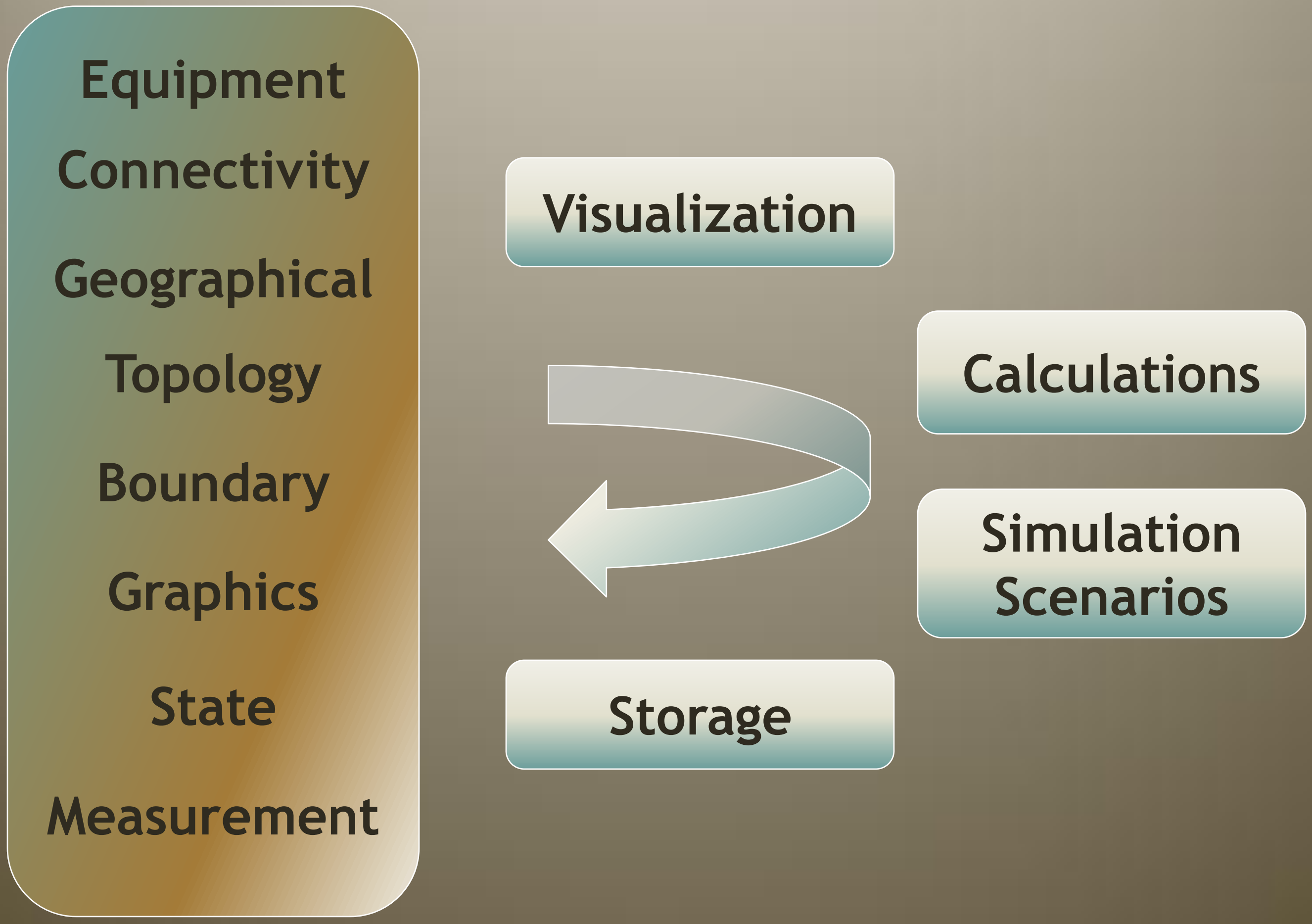
Conventional

- Read in CIM data (node/breaker data)
  - EQ
  - GEO
  - CN
- Run topology processing & produce TP
  - Use CN & TP for visualization
- Run conventional SE
  - Feedback SV
  - Show BD (if any)
  - Run SE again with same TP (if necessary)

Generalized

- Read in CIM data (node/breaker data)
  - EQ
  - GEO
  - CN
- Run topology processing & produce TP
  - Use CN & TP for visualization
  - Keep CN& TP mapping
- Run generalized SE
  - If BD detected
    - Run G-SE with pockets
    - Zoom into bad data with hybrid modeling (interacting with CN&TP mapping)

Modular CIM Profile for Generalized SE



Complications & Challenges

- Network topology processing
  - Needs to be consistent at different layers/functions
- Boundary profile group
  - As multiple network models used in the simulations/calculations increase, so do the complications for retaining data in both node/breaker & bus/branch formats
- Multiple sequential SE runs require mapping between node/breaker & bus/branch formats to persist accurately
- Visualization
  - Needs both node/breaker & bus/branch to be consistently available

Conclusions

- Generalized SE is much more powerful and robust than the conventional state estimation
- It will get more focus and become a regular EMS component as network modeling accuracy requirements become more rigorous
- CIM is a powerful data interface for generalized SE
  - Meets the requirements for tailoring to both node/breaker & bus/branch models
  - Similar to the problems/challenges that have been traditionally a big problem for transmission network operators vs. planners
  - Further complications due to its ever-evolving nature and not necessarily a user friendly format
  - Still the best choice for hybrid data requirements