

# Decision Tree Assisted Online Security Assessment using PMU measurements



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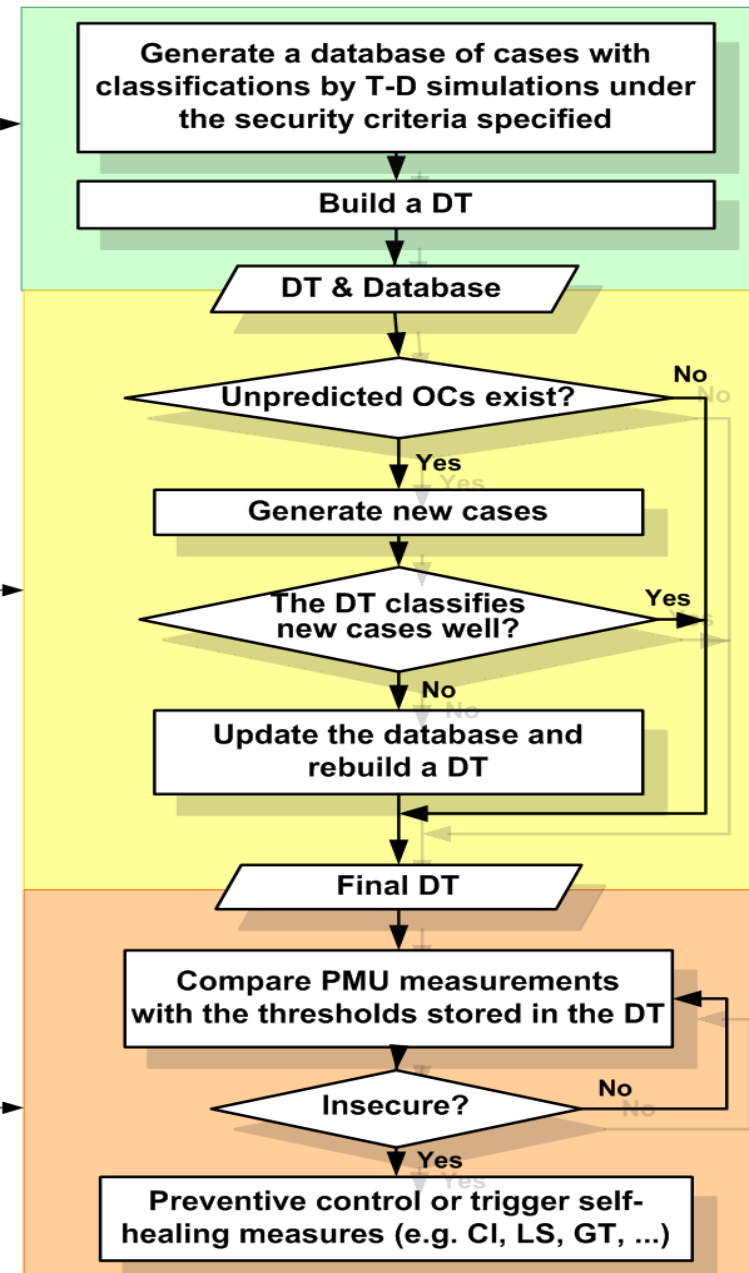
# Proposed scheme

- **Offline Decision Tree (DT) building (24 hours ahead)**
- **Periodic DT updating (every hour)**
- **Online security assessment & control**

Critical contingencies & 24-hour ahead OCs

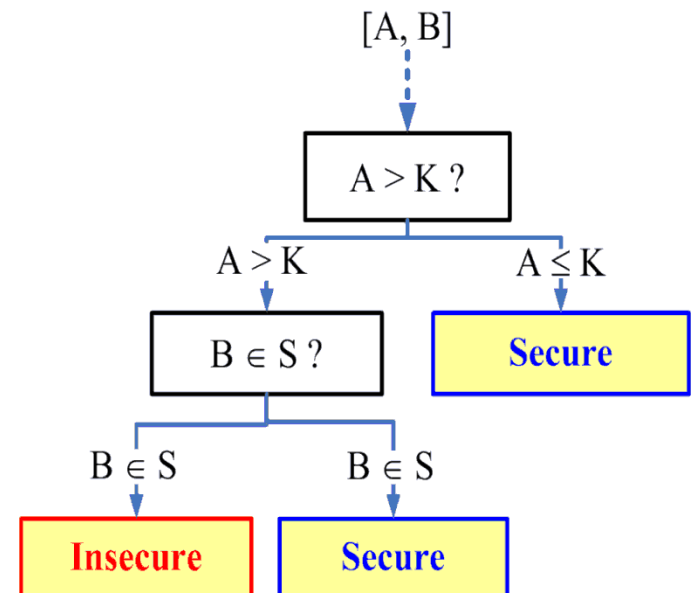
Prospective OCs of the next hour

Online PMU measurements of Critical Attributes



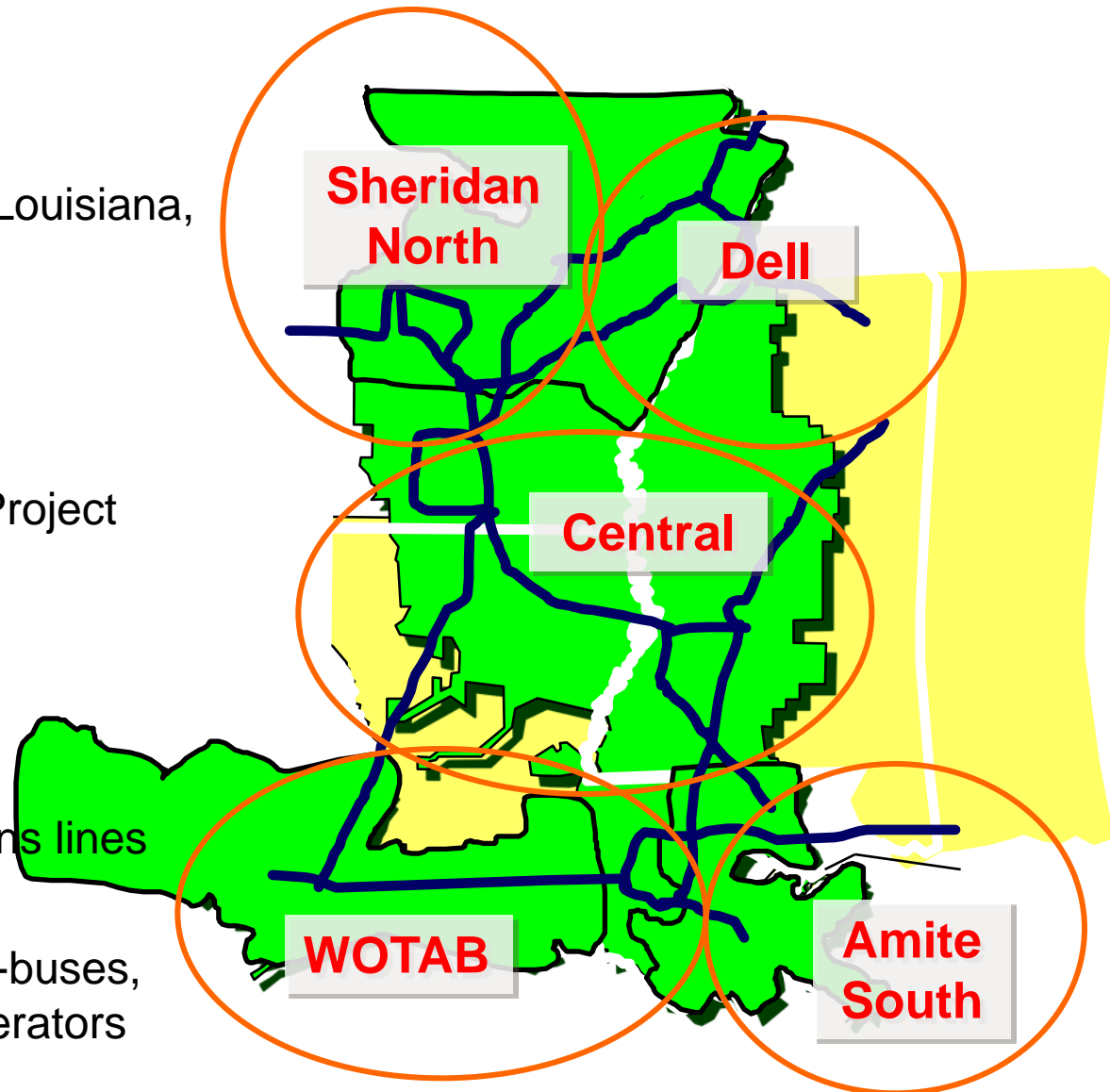
# Decision Tree (DT) Principle

- An effective supervised data mining tool to solve the classification problems
- Flowchart representing a classification system or predictive model for an object, e.g. secure or insecure
- Structured as a sequence of simple questions regarding critical attributes (CAs) and terminal node determines the final classification result
- Identify critical system attributes that contribute to power system security problems
- Assist system operators in online decision making



# Online Dynamic Security Assessment

- Entergy Corp.
  - Investor owned utility
  - Service area: Arkansas, Louisiana, Mississippi, and Texas.
  - Capacity: 30,000 MW
  - 2.6 million customers
  - Involved in the Eastern Interconnection Phasor Project (EIPP).
  - 9 PMUs were installed
- Power system
  - Five control areas
  - Over 15,000 miles of trans lines
  - 1450 substations
  - Operational model: 2100-buses, 2600-lines, and 240-generators



# Online Dynamic Security Assessment

- Database Creation
  - Generate 56 typical OCs for 7/19/2006
  - Select 280 “n-1” contingencies (3-phase faults on 230kV-500kV lines)
  - Security criteria settings:
    - *Transient stability*: stability margin > 5%
    - *Low damping*: damping ratios > 3% for 0.25~1.0Hz modes
  - Simulation Results:
    - 355/15680 (2.3%) cases violate the transient stability criterion
    - 2501/15680 (16.0%) cases violate the low-damping criterion
  - Predictor Selection: Faulted Bus (**FB**), Power Flow (**P<sub>i\_j</sub>**), Voltage Phase Angle Difference (**A<sub>i\_j</sub>**) from steady states
    - Group1: Existing PMUs
    - Group2: Existing PMUs + Candidate PMUs (all buses at 500 kV level)

For more details refer to - Sun, K., S. Likhate, V. Vittal, V. S. Kolluri, and S. Mandal, “An Online Dynamic Security Assessment Scheme using Phasor Measurements and Decision Trees,” *IEEE Transactions on Power Systems*, Vol. 22, No. 4, pp.1935-1943, November 2007.

# Online Dynamic Security Assessment

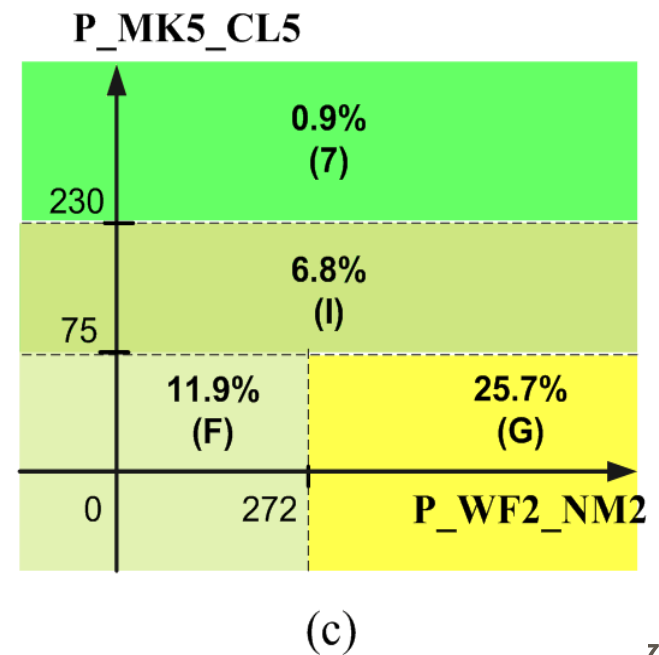
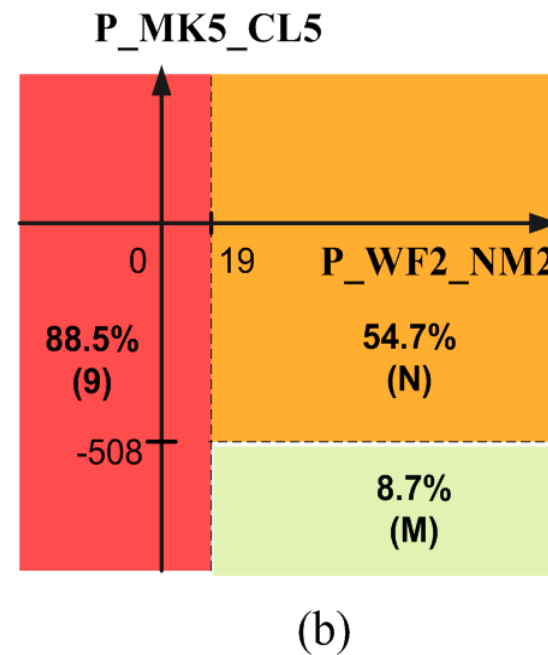
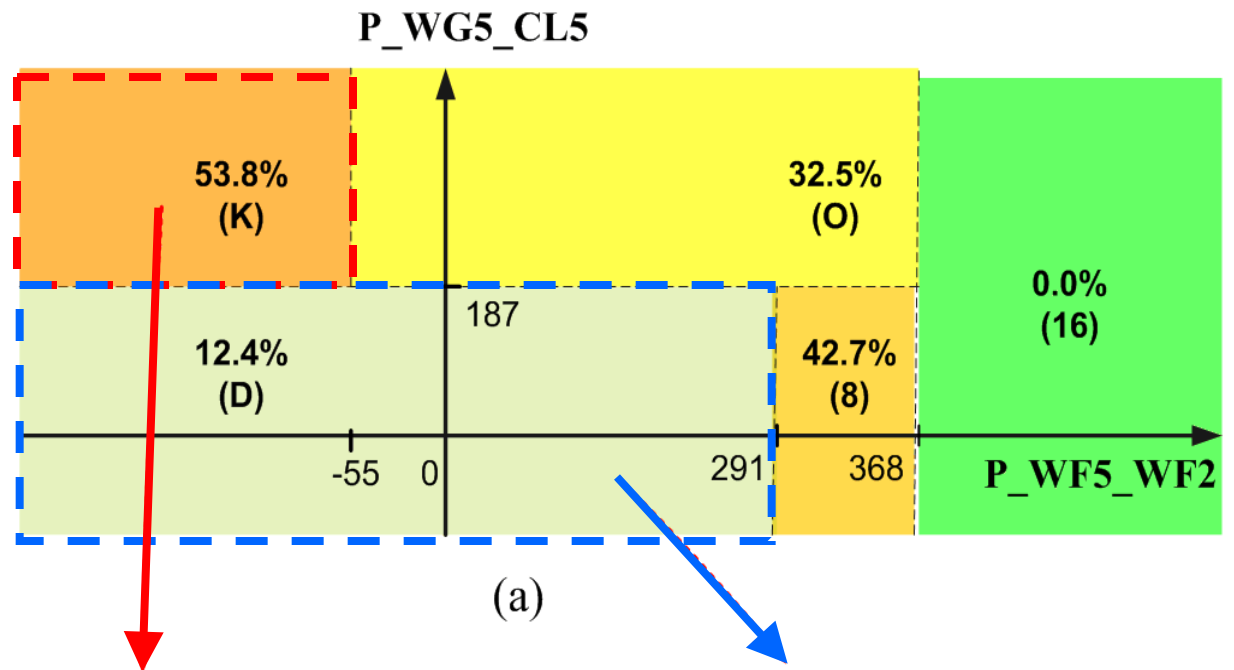
- DT Training
  - Learning set: 20% randomly
  - Test set: the other 80% cases
  - Costs of misclassifying an insecure case as a secure case are reasonably increased
  - DT trained:
    - For damping problem:  $DT^{SS1}$  based on Group1 and  $DT^{SS2}$  based on Group2
    - For transient stability problem:  $DT^{TS1}$  based on Group1 and  $DT^{TS2}$  based on Group2

- DT Performance

DTs	Size	$R^{ts} \pm \Delta R^{ts}$	$CR_i^{ts}(\%)$	$CR_S^{ts}(\%)$
$DT^{SS}_1$	31	0.113±0.006	96.7	91.1
$DT^{SS}_2$	31	0.100±0.005	97.9	91.0
$DT^{TS}_1$	17	0.072±0.005	97.3	95.3
$DT^{TS}_2$	17	0.070±0.005	97.3	95.5

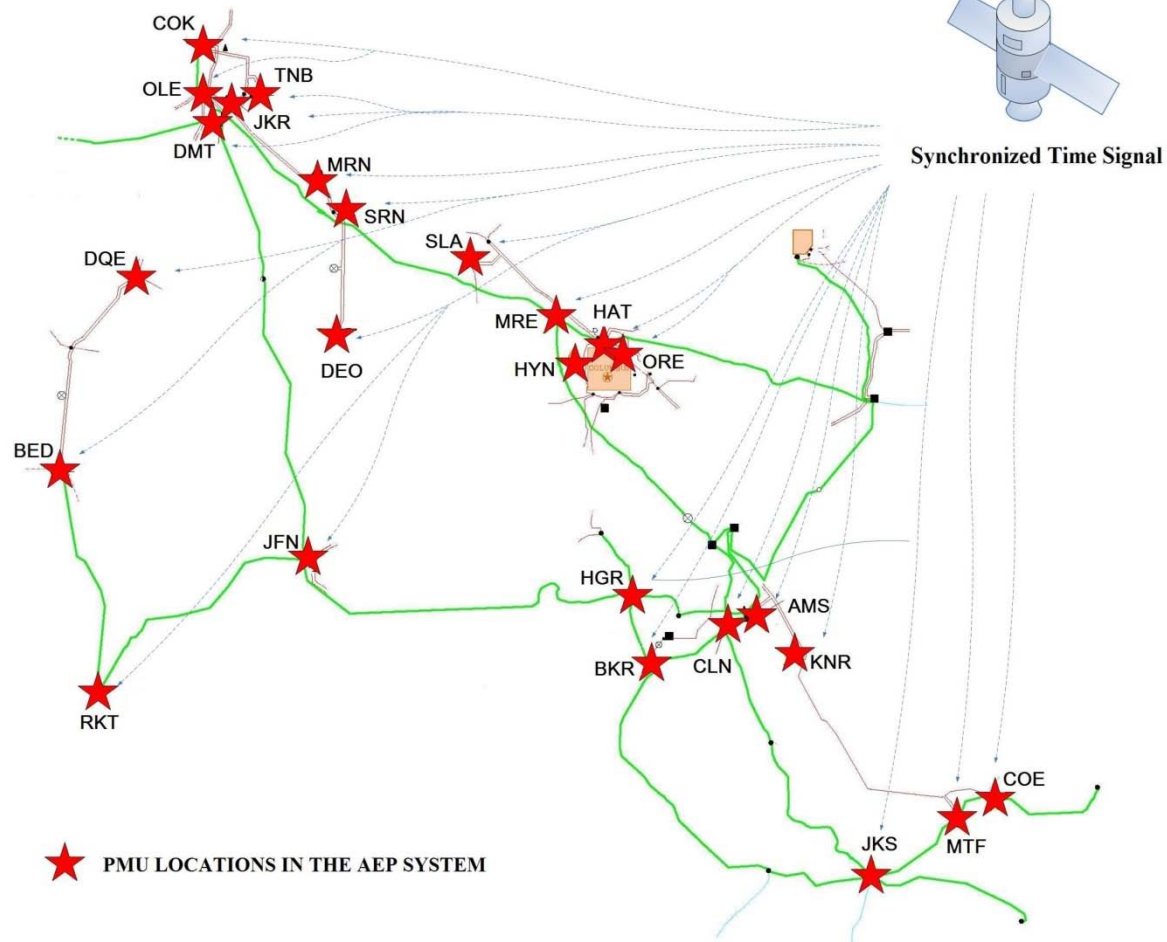
- A path based DT method is developed to improve DT performance when the system conditions are perturbed.

# Nomograms from $DT^{SS}_2$



# Online Voltage Security Assessment

- AEP Services Corp.
  - Service area: 11 states
  - Capacity: 38,000 MW
  - 5 million customers
  - 27 PMUs are installed
- Power system
  - Over 39,000 miles of transmission lines
  - 1450 substations
  - Operational model: 2414 buses, 2416 lines, and 116 generators
  - Voltage level: up to 765 kV



# Online Voltage Security Assessment

- 29 stressed OCs are generated
- 163 severe N-1 contingencies are selected
- Voltage security criteria
  - Whether loss of a branch diverges the power flow
- Predictor Selection (8 groups):
- Contingency-dependent information
  - An unordered bus pair FB and OB, representing the faulted branch
- Contingency-independent information
  - voltage phase angle differences ( $A_{x_y}$ )
  - current magnitude on branch ( $I_{x_y}$ )
  - reactive power magnitude ( $Q_{x_y}$ )
  - square of voltage magnitude on PMU buses ( $V^2_x$ )
  - current magnitude multiplied by branch impedance ( $IZ_{x_y}$ )

# Online Voltage Security Assessment

- Voltage security predictor groups

Group No.	Predictors
Group 1	FB, OB
Group 2	A_x_y
Group 3	A_x_y, FB, OB
Group 4	I_x_y, FB, OB
Group 5	Q_x_y, FB, OB
Group 6	V <sup>2</sup> _x , FB, OB
Group 7	IZ_x_y, FB, OB
Group 8	A_x_y, Q_x_y, I_x_y, V <sup>2</sup> _x, IZ_x_y, FB, OB

- DT performance

- 20% of the 9454 cases are randomly selected as a test set
- 8 DTs are trained and the best accuracy occurs in DT4

Opt. DTs	Size	Leaning Set Accuracy (%)			Test Set Accuracy (%)		
		I	S	Overall	I	S	Overall
DT4	50	99.50	95.66	96.97	92.95	94.93	94.24

# Online Voltage Security Assessment

- Several methods are developed to improve DT performance

- Multiple optimal DTs:

Each case is examined by various DTs to obtain a comprehensive result. The accuracy for the test set is improved to 94.66%.

- Corrective DTs

Replace the paths with poor performance in a single DT with corrective DTs by including more predictors. The accuracy for the test set is improved to 95.45%.

- Maximum DTs

Accuracy for the whole database is above 99%.

# Conclusions

- An online security assessment scheme using PMUs and DTs is proposed for both dynamic security and voltage security
- Several new methods are developed to improve DT performance.
- Case studies demonstrate:
  - The proposed scheme can identify key security indicators and give accurate online security predictions
  - Can reliably predict unseen operating conditions