

Detecting Circuit Breaker Status Errors in Substations

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Outline

- Introduction
- Motivation and Objectives
- Method 1: Two Stage State Estimation
- Method 2: Single Stage SE with Reduced Size Model
- Remarks and Conclusions

Introduction

- Substations are rapidly acquiring advanced computational and communication capabilities.
- EMS functions do not model substations in detail due to the complexity of the model.
- Certain measurements that are available at the substation can not be used by the central EMS functions.
- Such measurements can be readily processed at the substation to aid topology error detection.

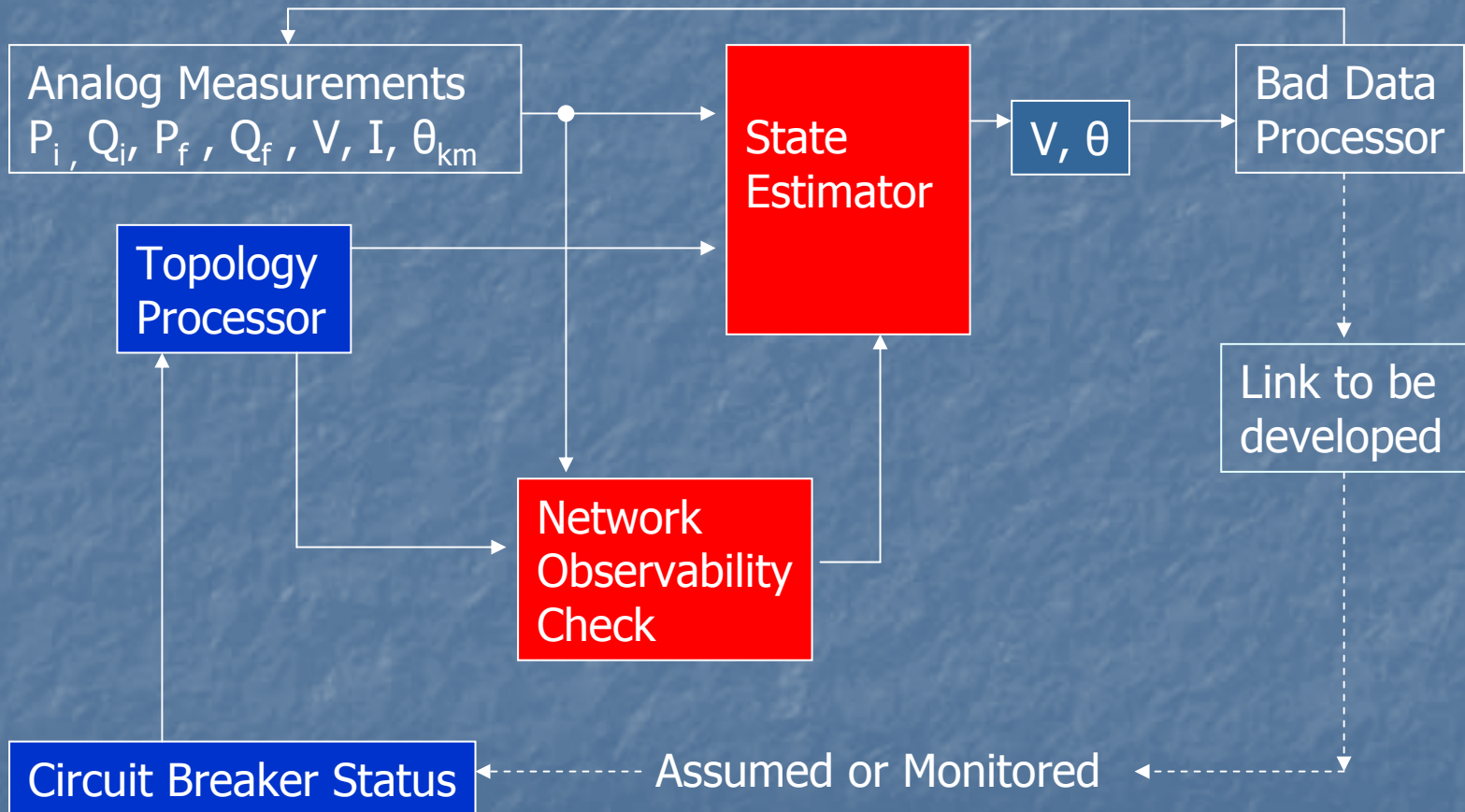
Motivation

- There are no well established and commonly implemented methods to detect, identify and eliminate topology errors.
- Computational and communication capabilities at the substation can be exploited for this purpose.
- Measurements which would otherwise be discarded, could be used if processing were done at the substation.

Project Objectives

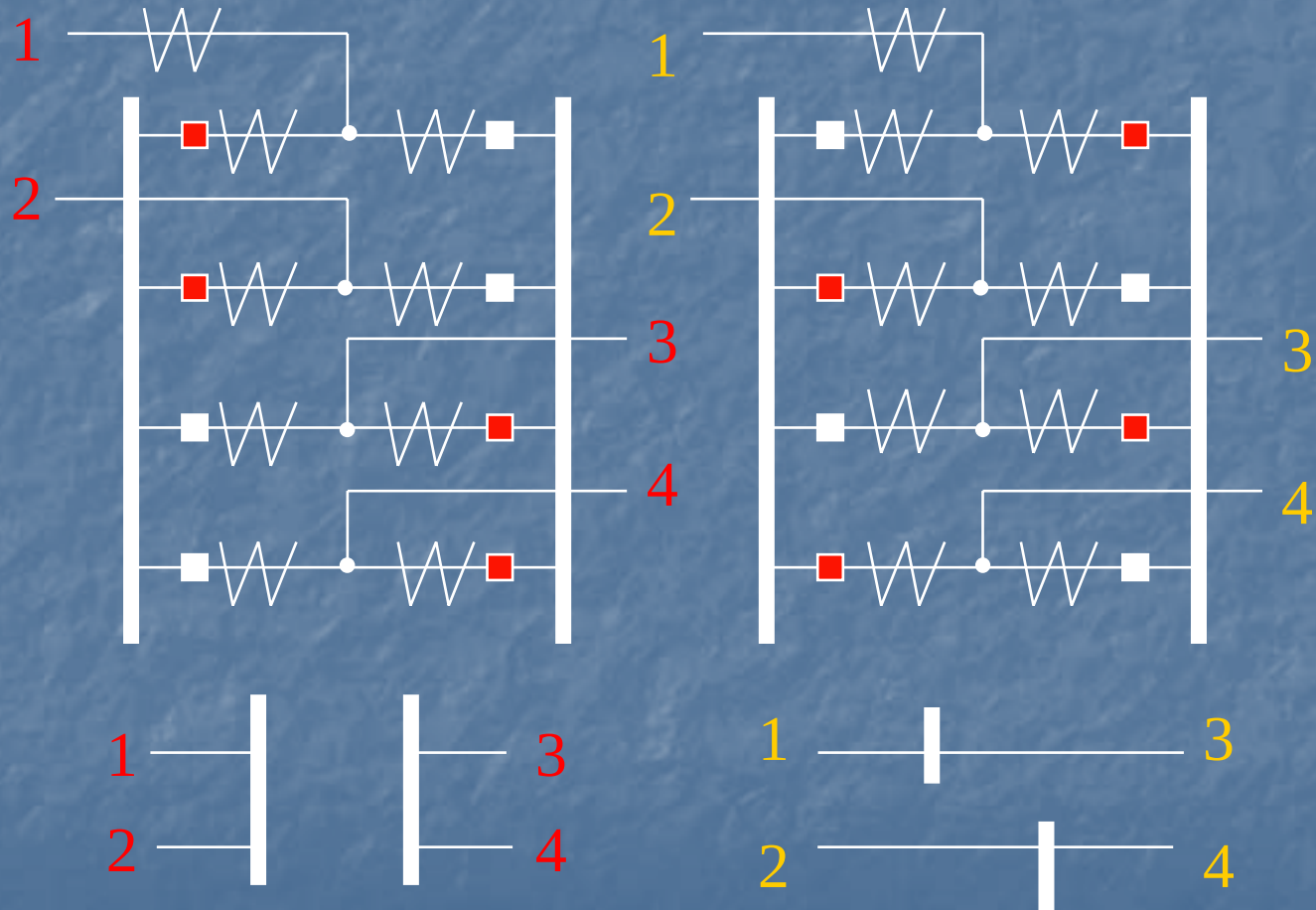
- Make use of all available measurements at the substation.
- Take advantage of CPU at the substation to improve EMS functions at the control center.
- Specifically, develop ways of detecting and identifying substation breaker status errors, so that State Estimation results will be more reliable and accurate.

Effect of Breaker Status Errors on State Estimation



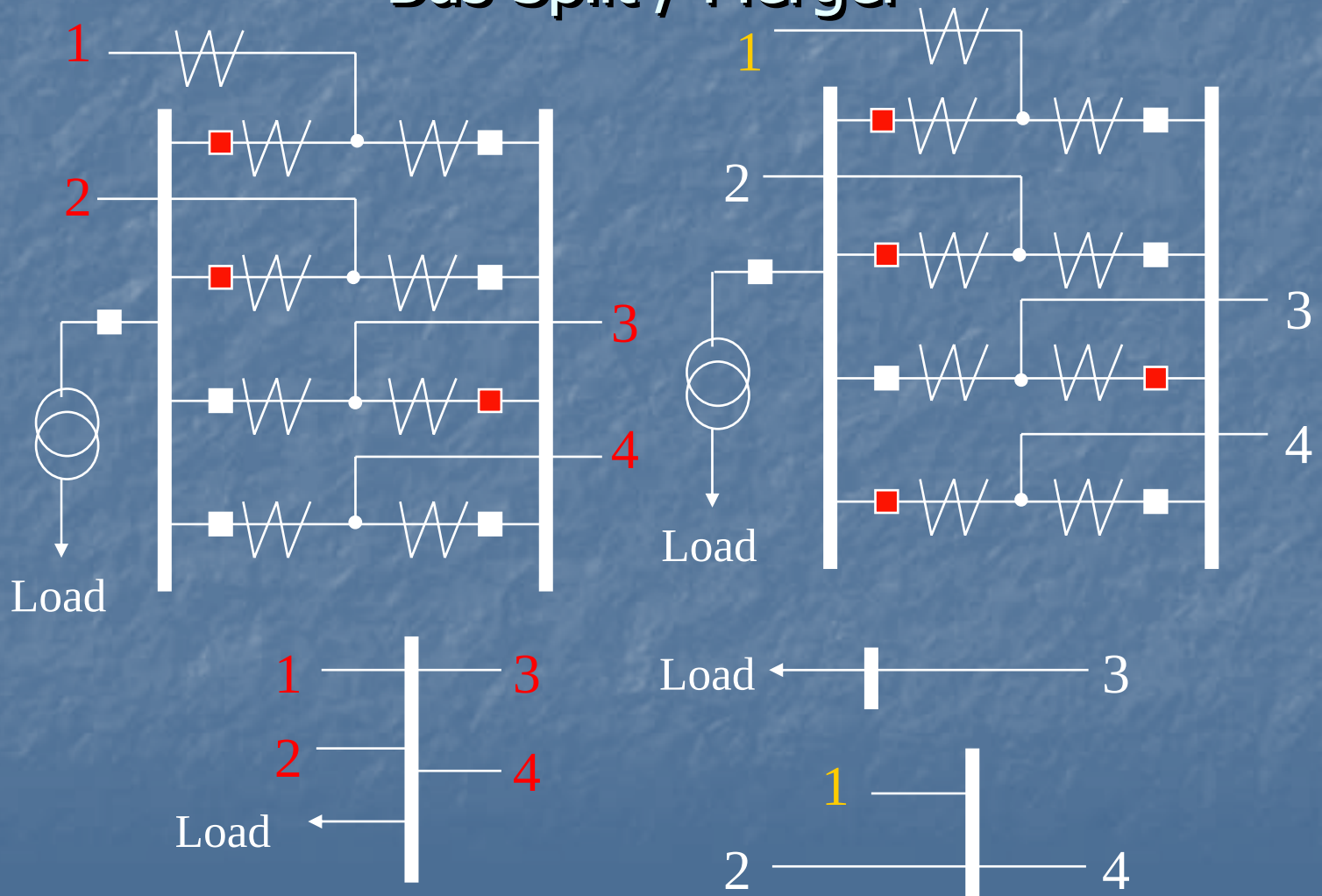
Types of Topology Errors

Bus Reconfiguration



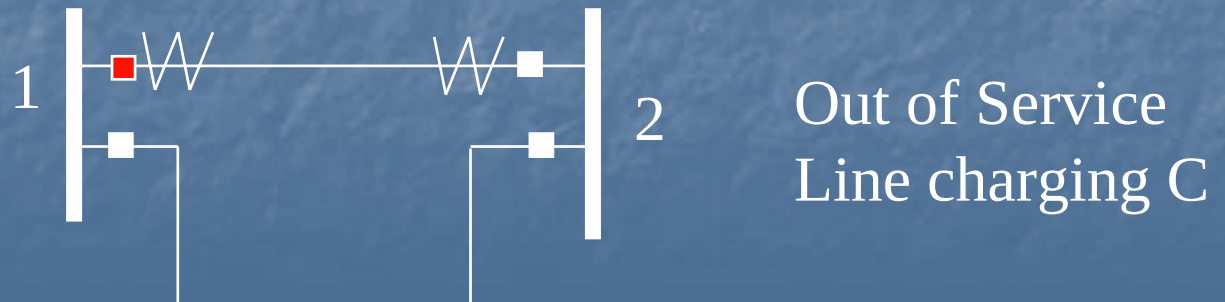
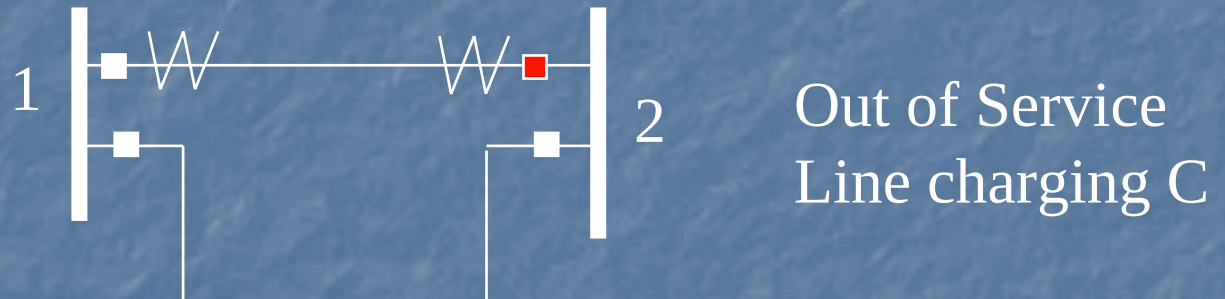
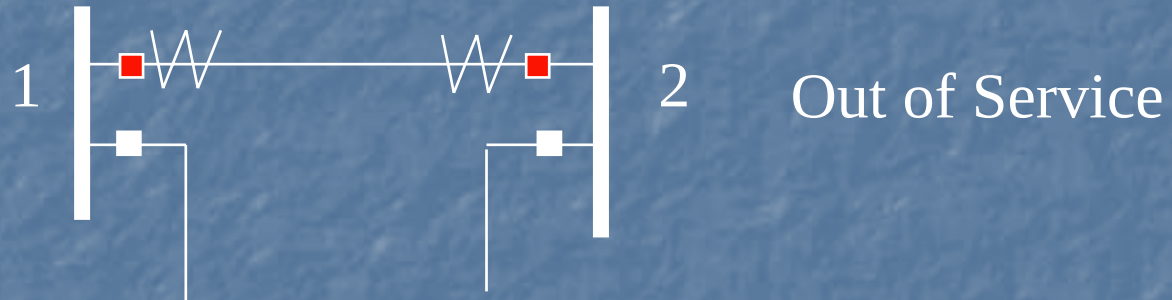
Types of Topology Errors

Bus Split / Merger



Types of Topology Errors

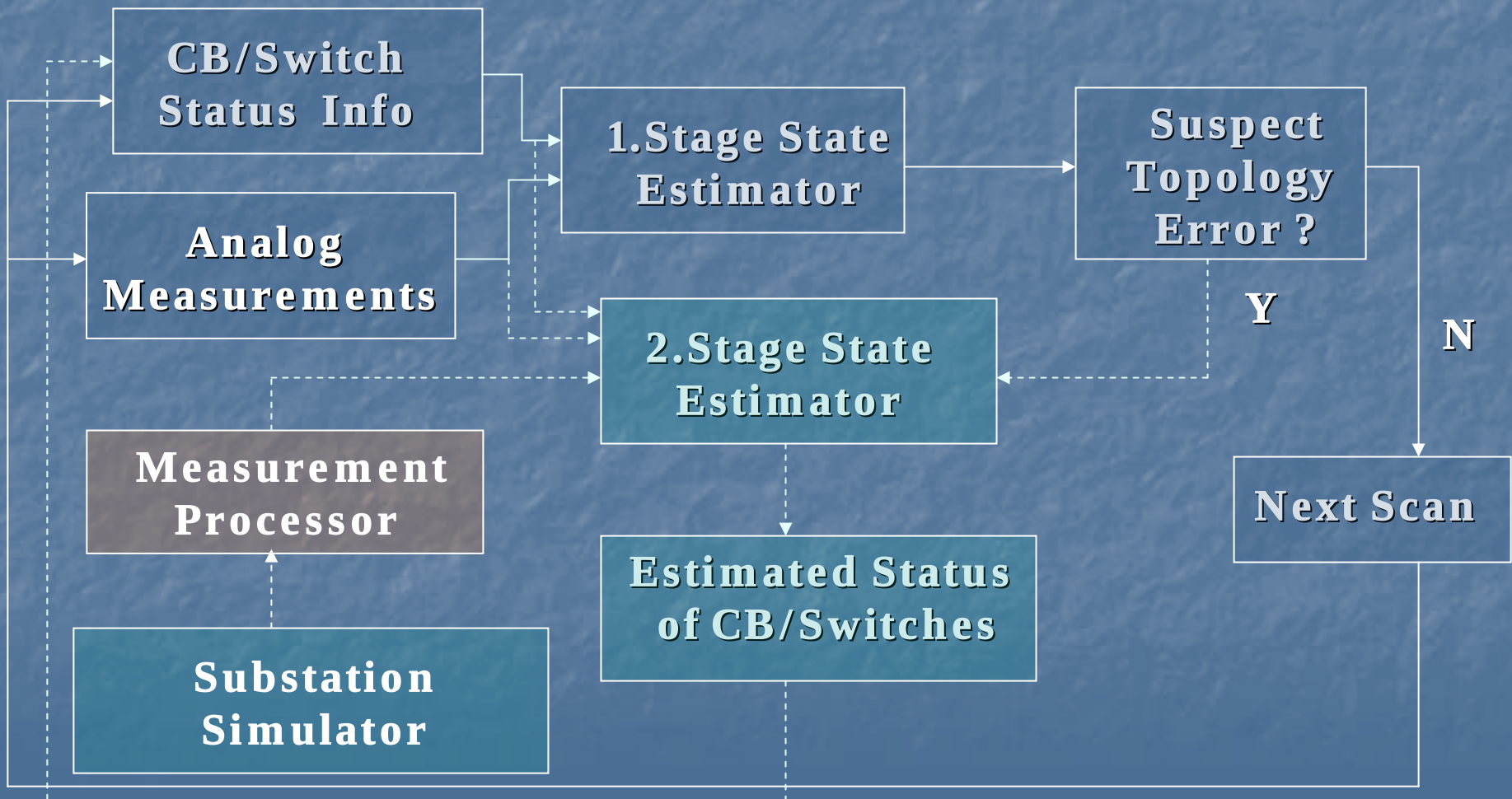
Branch In/(Out of) Service



Proposed Two-Stage Approach

- Stage1: Identify the suspected buses by normalized residuals of measurements
- Stage2: Introduce detailed models of suspected substations. Repeat the SE process using the expanded system model.

Two-stage State Estimator



Estimation of Breaker Status

- Estimation procedure:
 - ① Identification of error location (substation).
Use of measurement residuals
 - ② Insert detailed substation model into SE.
Model the substation using breaker / tie switch models and all internal measurements
 - ③ Estimate the status for all breakers.
Concur the most likely substation configuration based on the estimated status of breakers and report it to the control center.

Measurement Equations

$$z = h(x, f) + e$$

Where:

z is the measurement vector;

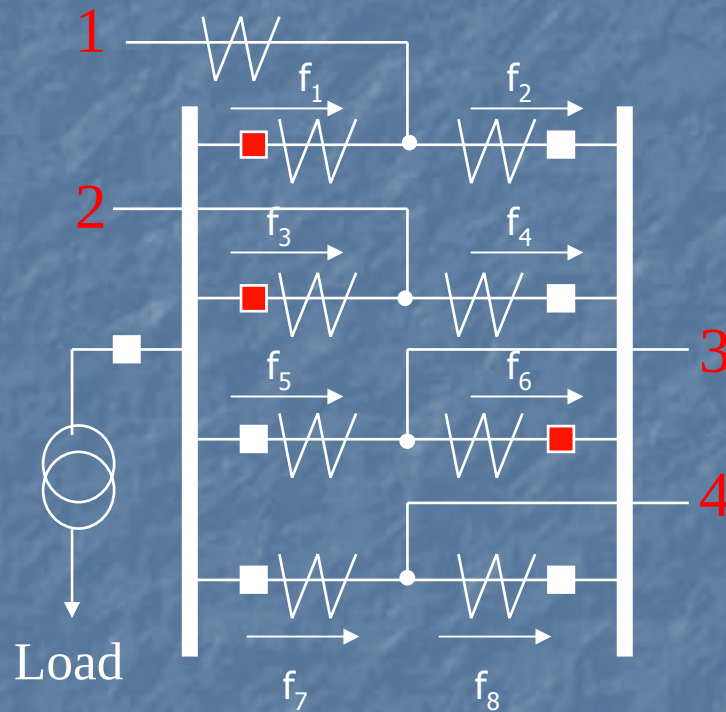
$h(.)$ is the measurement function;

x is the state vector;

f is the vector of breaker flows;

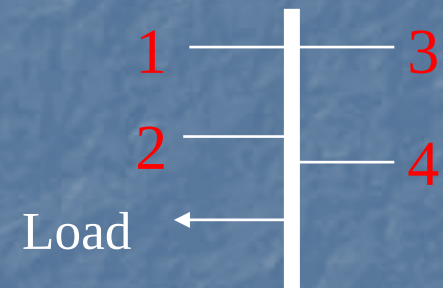
e is the measurement noise vector.

Model Used in Stage II:



$\longrightarrow$: breaker flow
 $f_1=0$
 $f_3=0$
 $f_6=0$

Model Used in Stage I:



$$f = [f_1, \dots, f_3, \dots, f_8]$$

Integrating Breakers into the Measurement Equations

$$\Delta z = H \cdot \Delta x + M \cdot f + e$$

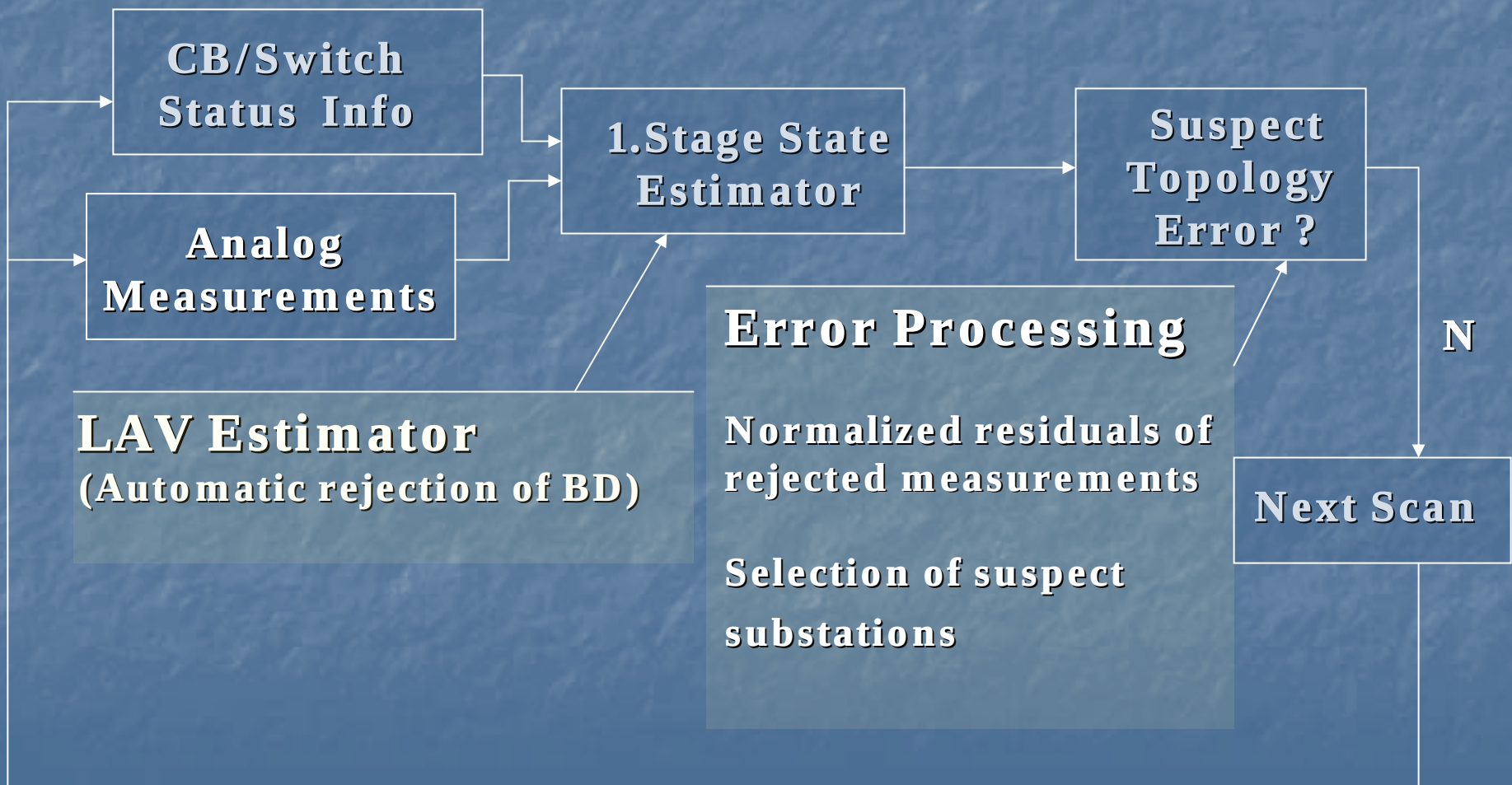
if the measurement i is an injection:

$$M_{ij} = \begin{cases} 1 & \text{if the injection is at the to - end of the breaker } j \\ -1 & \text{if the injection is at the from - end of the breaker } j \\ 0 & \text{otherwise} \end{cases}$$

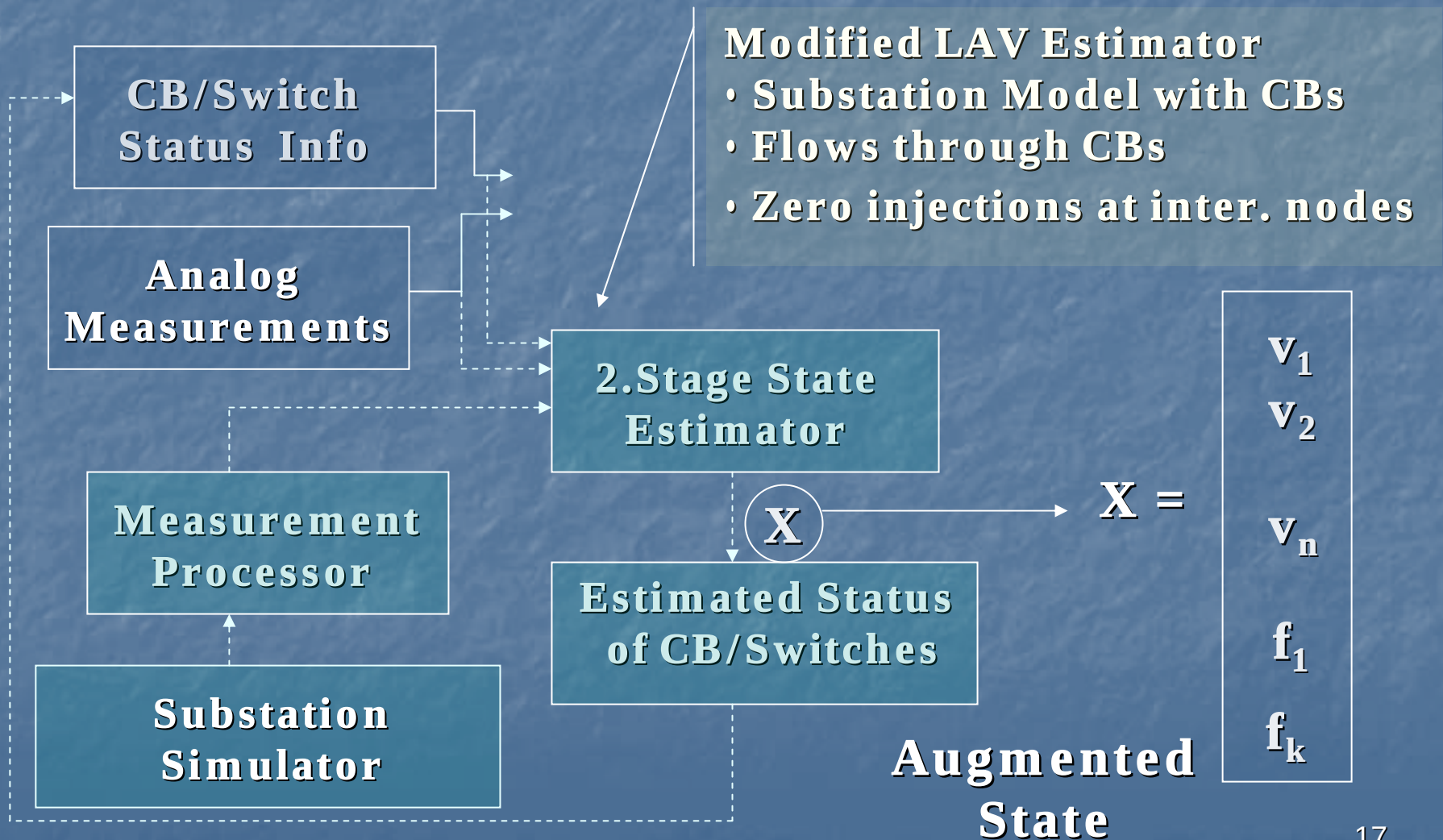
if the measurement i is a power flow:

$$M_{ij} = \begin{cases} -1 & \text{if the flow is at the to - end of the breaker } j \\ 1 & \text{if the flow is at the from - end of the breaker } j \\ 0 & \text{otherwise} \end{cases}$$

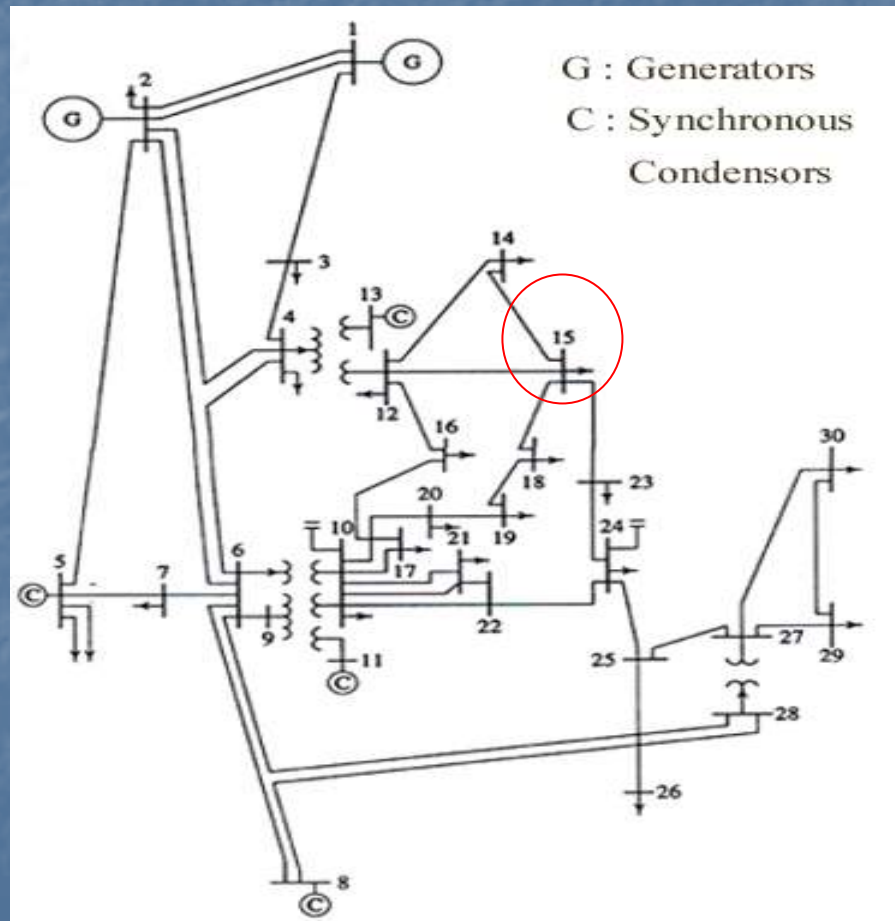
State Estimator



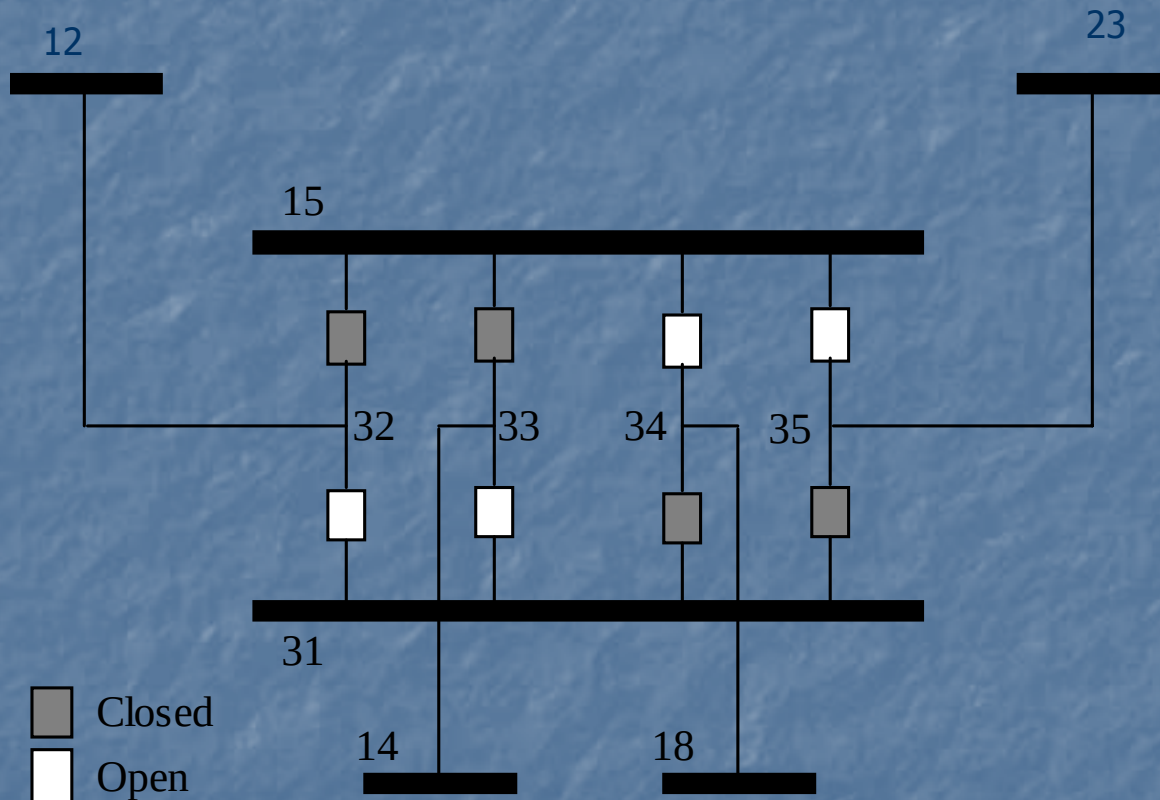
CB Status Estimator



Example: IEEE 30 Bus System



Substation Configuration of Bus 15



Estimated State of Circuit Breaker

Circuit Breaker	Normalized P Flow	Normalized Q Flow	Estimated Status
15-32	-85.51	-23.39	Closed
15-33	7.63	-0.36	Closed
15-34	0.00	0.00	Open
15-35	0.00	0.00	Open
31-32	0.00	0.00	Open
31-33	0.00	0.02	Open
31-34	4.36	-7.38	Closed
31-35	-4.36	7.39	Closed

Weakness of the method: How to identify the suspect substations?

- Use of Normalized residuals:
 - Suspect substation measurements may not have the largest normalized residuals.
 - Including too many substations in the suspect list may degrade the second stage state estimator performance due to increased complexity of the system model.

Alternative Method: Use of Reduced Model

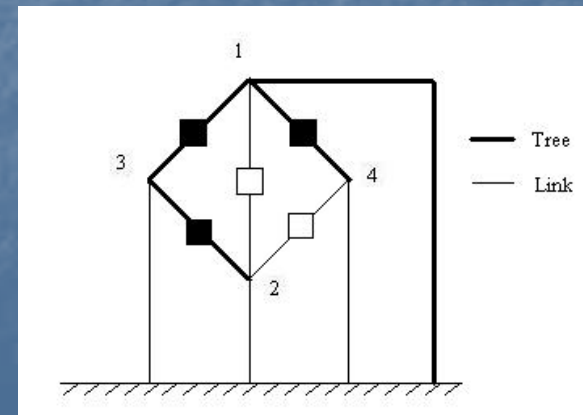
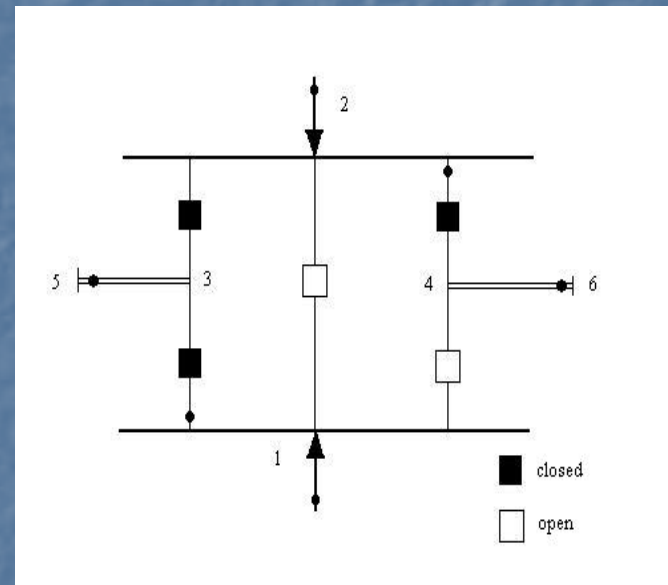
$$z = h(x_I, x_{CB}) + e$$

$$c(x_I, x_{CB}) = 0$$

$$x_{CB} = 0$$

$$x_I = [\theta_1, p_2]^t$$

$$x_{CB} = [\theta_{13}, \theta_{23}, \theta_{14}, p_{12}, p_{24}]^t$$



Steps of Topology Error Identification Procedure

- Step 1. Topology Processing

First a proper tree is selected for each substation. Based on the tree, the state variables are categorized into two groups:

$$X_I \text{ and } X_{CB}$$

- Step 2. State Estimation

Essentially identical to traditional state estimation carried out by existing methods.

Obtain both:

- the measurement residual vector r
- and the Lagrange multiplier vector of zero injections

Steps of Topology Error Identification Procedure

- Step 3. Compute the normalized residuals for the measurements and the normalized Lagrange multipliers for the circuit breaker variables.
- Step 4. Bad Data and Topology Error Identification

Check the largest normalized residual or Lagrange multiplier.

If it is larger than the threshold, suspect the corresponding measurement or the breaker to be the source of error in estimation.

Reduced Model Formulation

Form the Lagrangian:

$$L = \frac{1}{2} r^t W r - \mu^t c(x_I, x_{CB}) - \lambda^t x_{CB}$$

Optimality conditions:

$$\begin{bmatrix} I & 0 & H_I \\ 0 & 0 & C_I \\ H_I^t W & C_I^t & 0 \end{bmatrix} \begin{bmatrix} r \\ \mu \\ x_I \end{bmatrix} = \begin{bmatrix} z \\ c_I \\ 0 \end{bmatrix}$$

Note that x_{CB} is zero !

Then, λ can be solved as: $\lambda = T \begin{bmatrix} r \\ \mu \end{bmatrix}$

where: $T = - \begin{bmatrix} W H_{CB} \\ C_{CB} \end{bmatrix}^t$

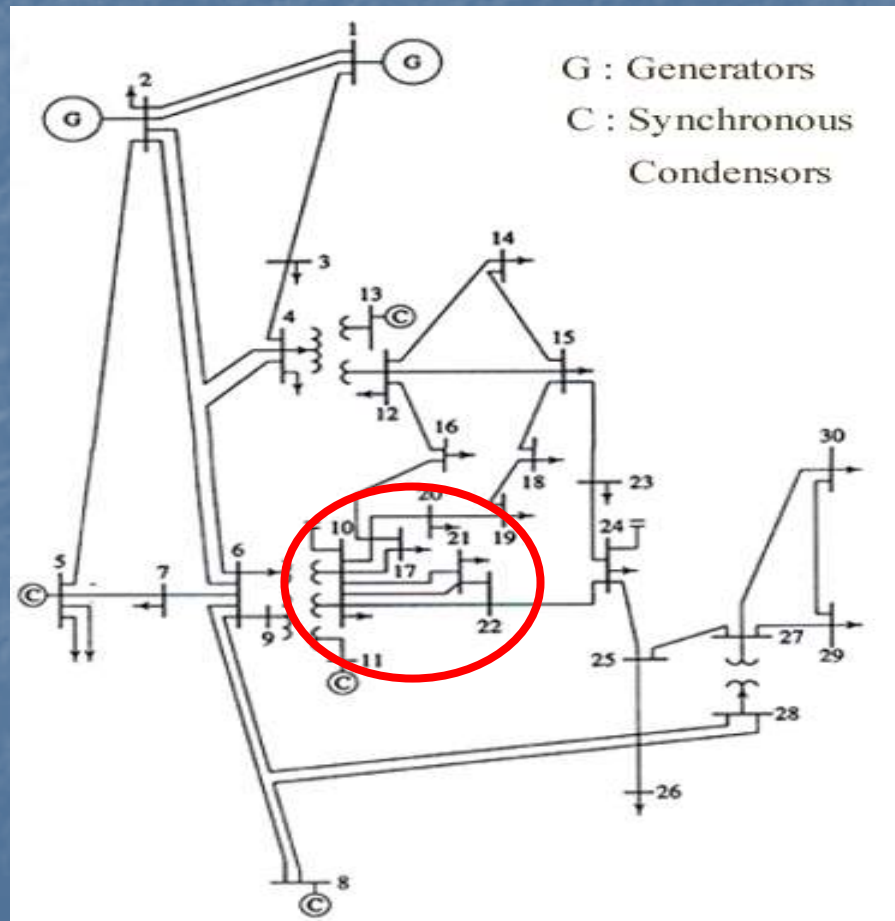
State Variables Used

Model	State Variables
Full	$\theta_1, \theta_2, \theta_3, \theta_4,$ $p_{13}, p_{14}, p_{23},$ p_{24}, p_{12}
Implicit	θ_1, p_2

Simulated Topology and Measurement Errors

Test System	Wrong status CB & Outaged Line/ Meas.		
	Test A		Test B
14-bus	CB_{34-32}	Line 5-6	p_{34-32}
30-bus	CB_{74-68}	Line 10-22	p_{74-68}
57-bus	CB_{80-78}	Line 4-6	p_{80-78}

Example: IEEE 30 Bus System

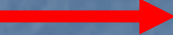
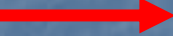


Results of Error Identification

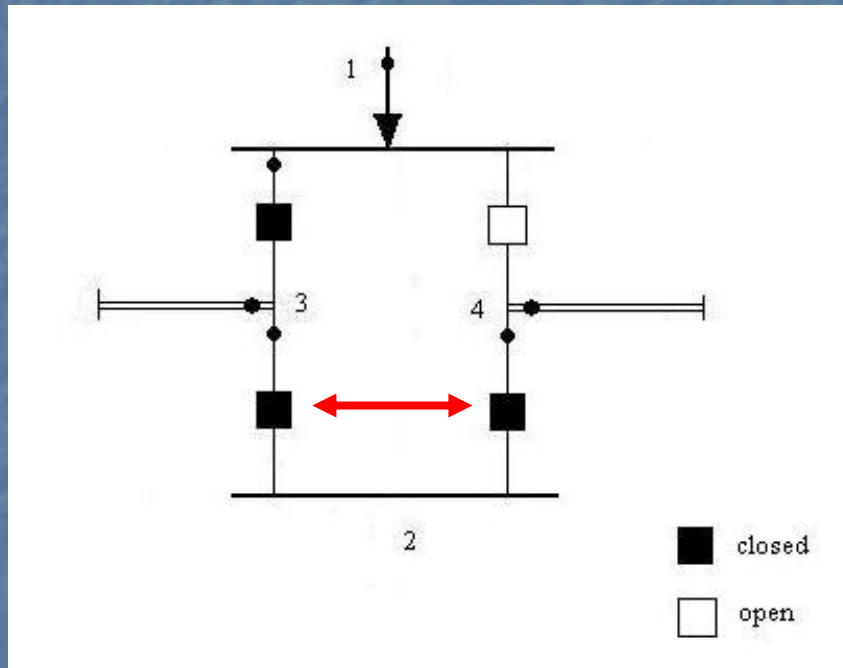
30-Bus System

Test A		Test B	
<i>Measurement/ Topology</i>	<i>Normalized residual / λ^N</i>	<i>Measurement/ Topology</i>	<i>Normalized residual / λ^N</i>
CB_{74-68}	212.30	p_{74-68}	97.18
CB_{70-68}	199.09	CB_{74-68}	38.37
CB_{10-71}	160.95	CB_{73-74}	38.12
$CB_{105-104}$	157.04	CB_{36-34}	28.00
$CB_{106-104}$	157.04	CB_{33-31}	22.59

Results of Error Identification 57-Bus System

Test A		Test B	
<i>Measurement/ Topology</i>	<i>Normalized residual / λ^N</i>	<i>Measurement/ Topology</i>	<i>Normalized residual / λ^N</i>
 CB_{80-78}	371.63	p_{80-78}	96.40
 CB_{82-78}	371.63	$p_{1228-124}$	39.08
CB_{81-82}	282.65	CB_{80-78}	37.87
CB_{76-75}	212.03	CB_{82-78}	37.87
CB_{77-75}	212.03	CB_{79-80}	36.93

Critical Breaker Pairs



Either one of breakers 2-3 and 2-4 can disconnect the line incident to bus 4.

Hence, status errors in these Breakers can be DETECTED but can NOT be IDENTIFIED.

CONCLUSIONS

- Measurements can be processed at the substation in order to assist breaker error detection and identification.
- State estimation results can be improved by proper identification of topology errors.
- Two-stage approach works well as long as the suspect substation is properly identified.
- Reduced order SE allows topology error identification without the need to identify suspect substations. Implementation may be more involved.