Local False Data Injection Attacks Against Power Grid

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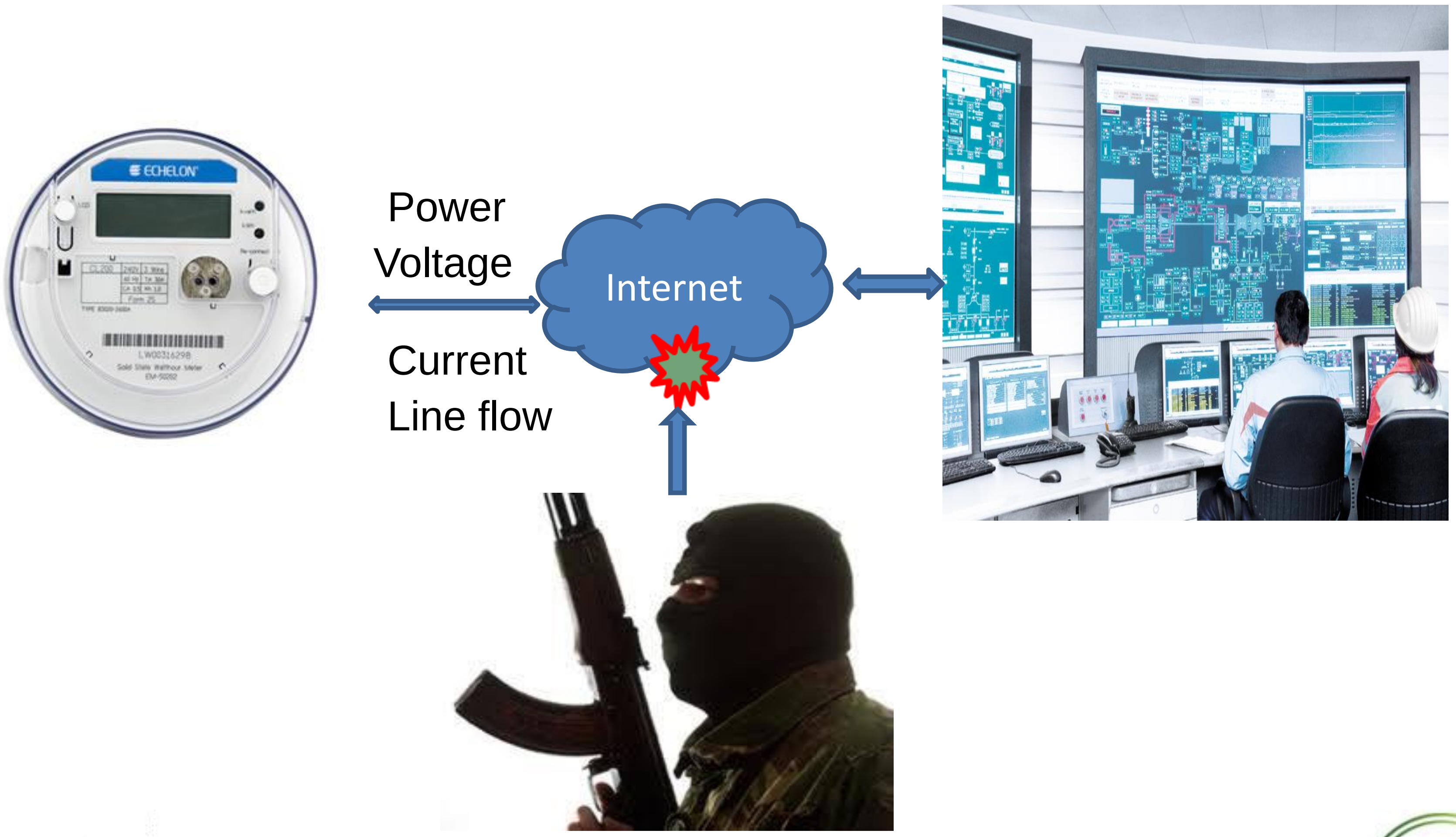
Outline

- Background
- False Data Attacks
- Load Redistribution(LR) Attacks
- Local LR Attacks
- Feasibility Theorem
- Conclusion

Cyber Security Issue



State Estimation

$$\mathbf{z} = \mathbf{H}X + \mathbf{e}$$

$$\hat{\mathbf{x}}(\mathbf{z}) = (\mathbf{H}^T \mathbf{e}^{-1} \mathbf{H})^{-1} \mathbf{H}^T \mathbf{e}^{-1} \mathbf{z}$$

Z: Measurements

e: Measurement errors

H: Jacobian matrix

Bad Data Detection

- The residual r

$$\mathbf{r} = Z - H\hat{X}$$

- If

$$\|\mathbf{r}\| > \tau$$

Predetermined threshold

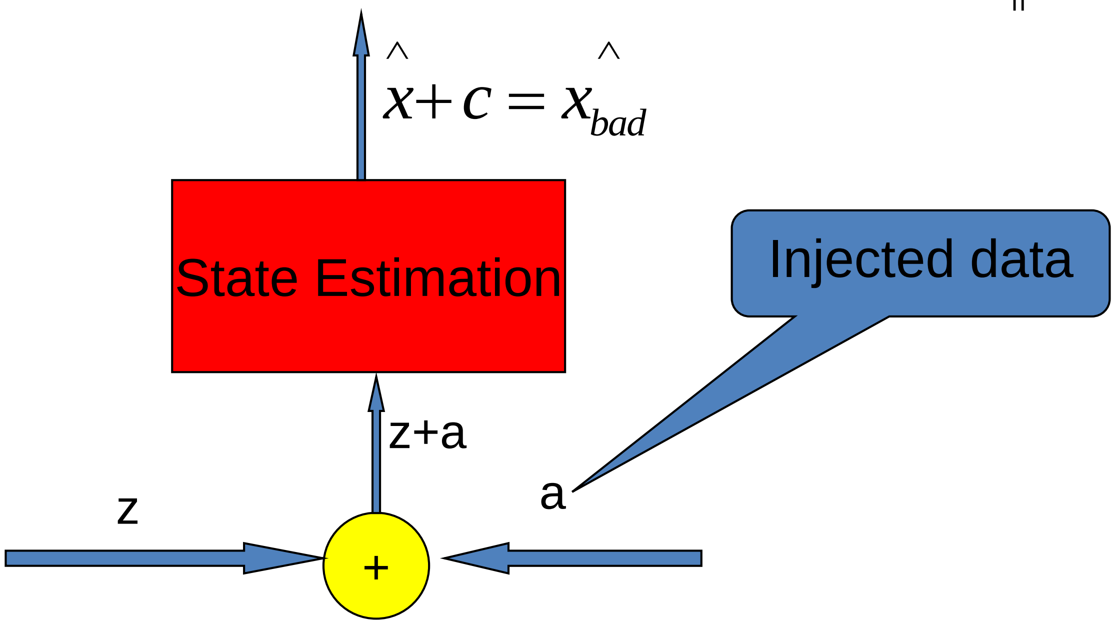
there is at least one faulty measurement.

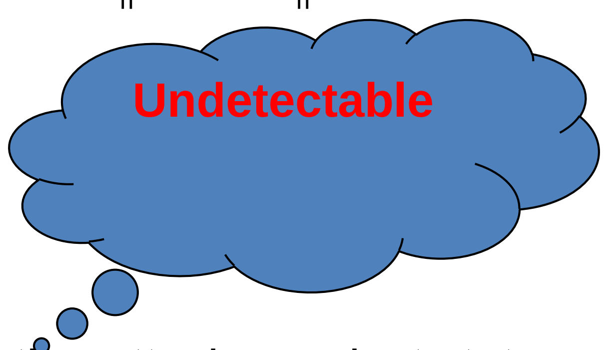
False Data Injection Attacks

$$a = Hc \Rightarrow \left\| z_a - H\hat{x}_{bad} \right\| = \left\| z + a - H(\hat{x} + c) \right\|$$

$$= \left\| z - H\hat{x} + (a - Hc) \right\|$$

$$= \left\| z - H\hat{x} \right\| \le \tau$$





Y. Liu, M. K. Reiter, and P. Ning,"False data injection attacks against state estimation in electric power grids," 2009.

Load Redistribution Attack

- Assumptions
  - Generator output measurements cannot be altered;
  - Bus injection measurements of zero-injection buses in the power grid cannot be altered;
  - Load measurements can be altered within certain ranges.

Problem Formulation for Load Redistribution Attack

Load redistribution attacking model is formulated as:

$$\sum_{d=1}^{ND} \Delta D_d = 0 \qquad (1)$$

$$-\tau D_d \le \Delta D_d \le \tau D_d \qquad (2)$$

S: shift factor matrix

$$\mathbf{\Delta F} = -\mathbf{S}.\mathbf{V}.\mathbf{\Delta D} \qquad (3)$$

V: Bus-load incidence matrix

Y. Yuan, Z. Li, and K. Ren, “Modeling load redistribution attacks in power systems,” *IEEE Transaction on Smart Grid*, vol. 2, no. 2, pp. 382–390, Jun. 2011.

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Issues for General False Data Injection Attack

$$a = Hc$$

To construct a, an attacker must know the topology and parameter information of the entire network;

It is impossible for an attacker to do so;

Does it mean that power systems are immune to false data injection attacks?

----------------No!!!!!!

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Local Load Redistribution Attack

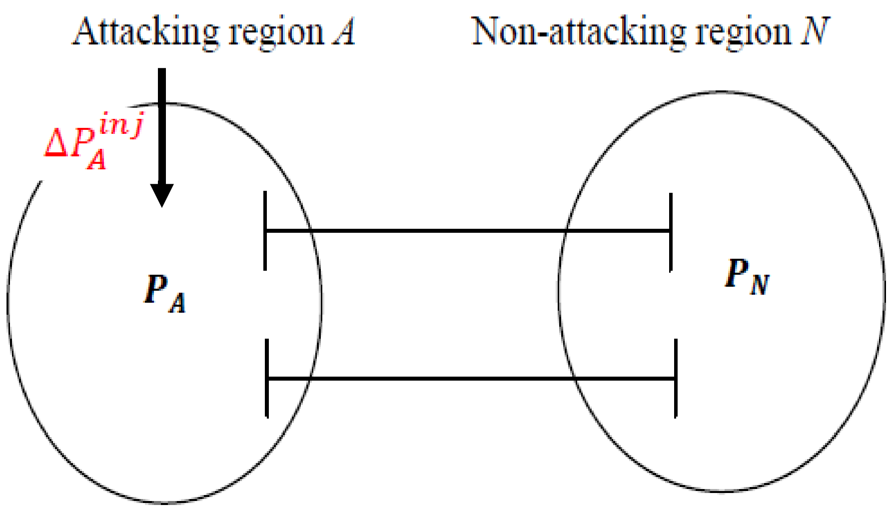


Fig. 1 Illustrative diagram for attacking region and non-attacking region

Theorem 1 indicates that $\Delta \mathbf{P}_{\mathbf{A}}^{\mathbf{inj}}$ can be constructed by an attacker who has only the information of the attacking region ($\boldsymbol{B}_{A'}$) and who does not have any information of the rest of the power grid.

Theorem 1: If an additional injected power into region A makes the phase angles of all its boundary buses increase or decrease the same

Then:

(1) All buses in region N have the same incremental phase angle

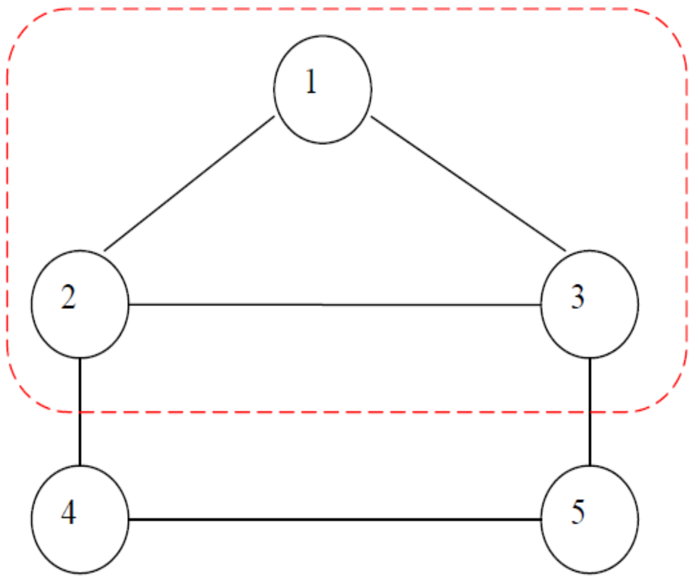
(2) The power flows in region N remain the same.

(3) The incremental bus power injection vector and the incremental phase angle vector in region A satisfy

$$\Delta \mathbf{P}_{\mathbf{A}}^{\mathbf{inj}} = \boldsymbol{B}_{A'} \Delta \boldsymbol{\theta}_{A}$$

$\boldsymbol{B}_{A'}$ is the bus susceptance matrix in region A excluding tie lines;

Example



- According to KCL, for the attacking region:

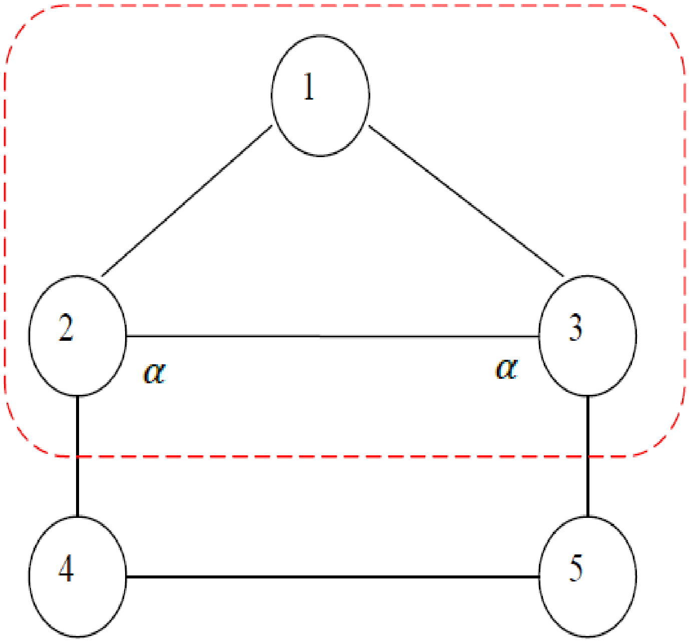
Line	Admittance
1-2	0.1
1-3	0.2
2-3	0.1
2-4	0.1
3-5	0.2
4-5	0.1

$$\Delta D_1 = -15\Delta\theta_1 + 10\Delta\theta_2 + 5\Delta\theta_3$$

$$\Delta D_2 = 10\Delta\theta_1 - 20\Delta\theta_2 + 10\Delta\theta_3$$

$$\Delta D_3 = 5\Delta\theta_1 + 10\Delta\theta_2 - 15\Delta\theta_3$$

Example



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$$\Delta D_3 = 5\Delta\theta_1 + 10\Delta\theta_2 - 15\Delta\theta_3$$

Choose bus 1 as the reference bus, and set :

$$\Delta\theta_2 = \Delta\theta_3 = \alpha \qquad (3)$$

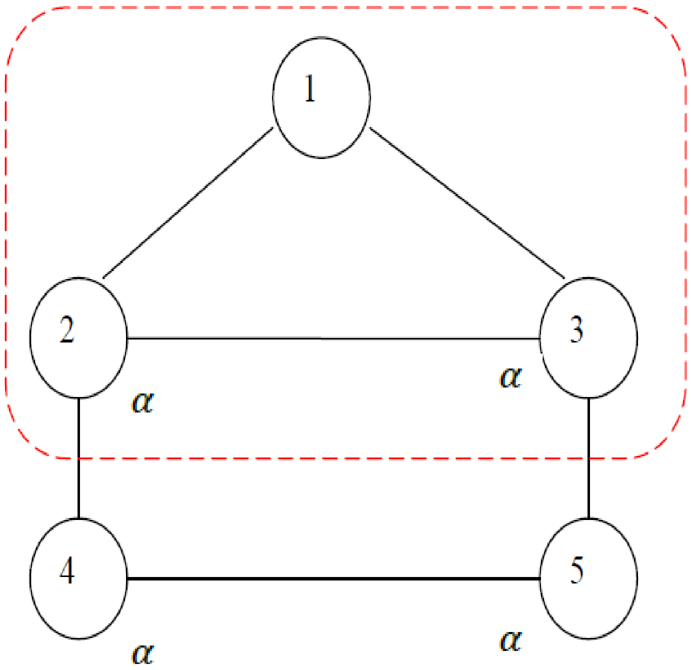
Substituting (3) into the KCL equations, we have the vector of false data injection of powers as follows:

$$\Delta D_1 = 15\alpha$$

$$\Delta D_2 = -10\alpha$$

$$\Delta D_3 = -5\alpha$$

Example



Since bus 4 and bus 5 is in the non-attacking region,

$$\Delta D_4 = 10\Delta\theta_2 - 20\Delta\theta_4 + 10\Delta\theta_5 = 0$$

$$\Delta D_5 = 5\Delta\theta_3 + 10\Delta\theta_4 - 15\Delta\theta_5 = 0$$

Substituting $\Delta\theta_2 = \Delta\theta_3 = \alpha$,

$$10\alpha - 20\Delta\theta_4 + 10\Delta\theta_5 = 0 \quad (4)$$

$$5\alpha + 10\Delta\theta_4 - 15\Delta\theta_5 = 0 \quad (5)$$

Solving (4) and (5), we have

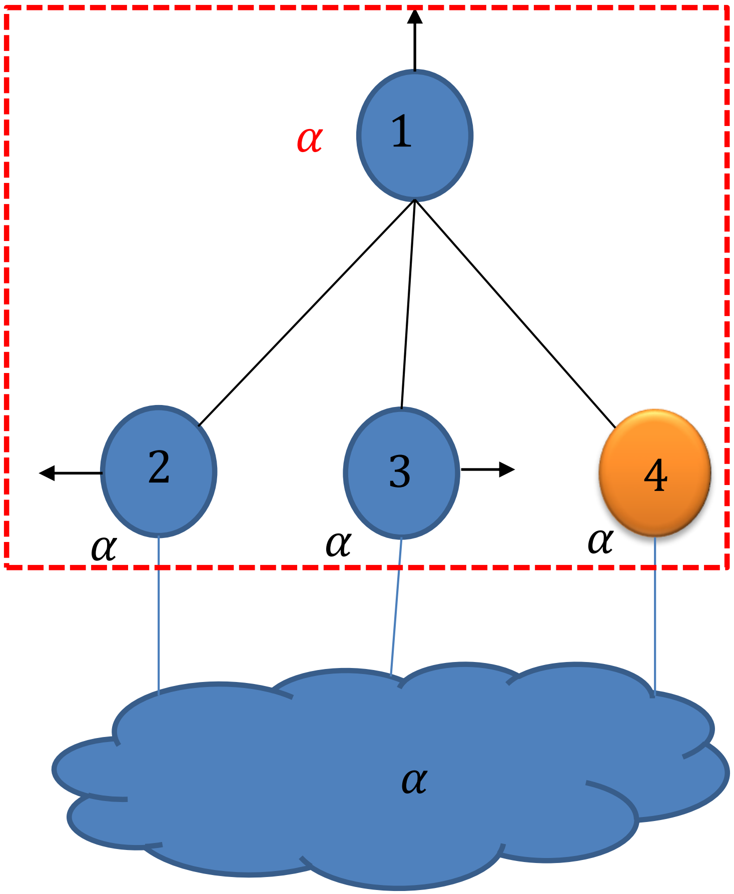
$$\Delta\theta_4 = \Delta\theta_5 = \alpha$$

Feasibility Theorem for Local Load Redistribution Attack

- How to guarantee the feasibility of the attacking vector?

- **Theorem 2**: Suppose the attacking region consists of ρ non-boundary buses. If there are at most $\rho - 1$ non-attackable buses, then a feasible attacking vector can be constructed.

Examples



There are $\rho = 1$ non-boundary buses, so

$$zm \leq \rho - 1 = 0$$

Assuming bus 4 is non-attackable, we can obtain

$$\Delta\theta_1 = \Delta\theta_2 = \Delta\theta_3 = \Delta\theta_4 = 0$$

So,

$$\Delta D_1 = \Delta D_2 = \Delta D_3 = \Delta D_4 = 0$$

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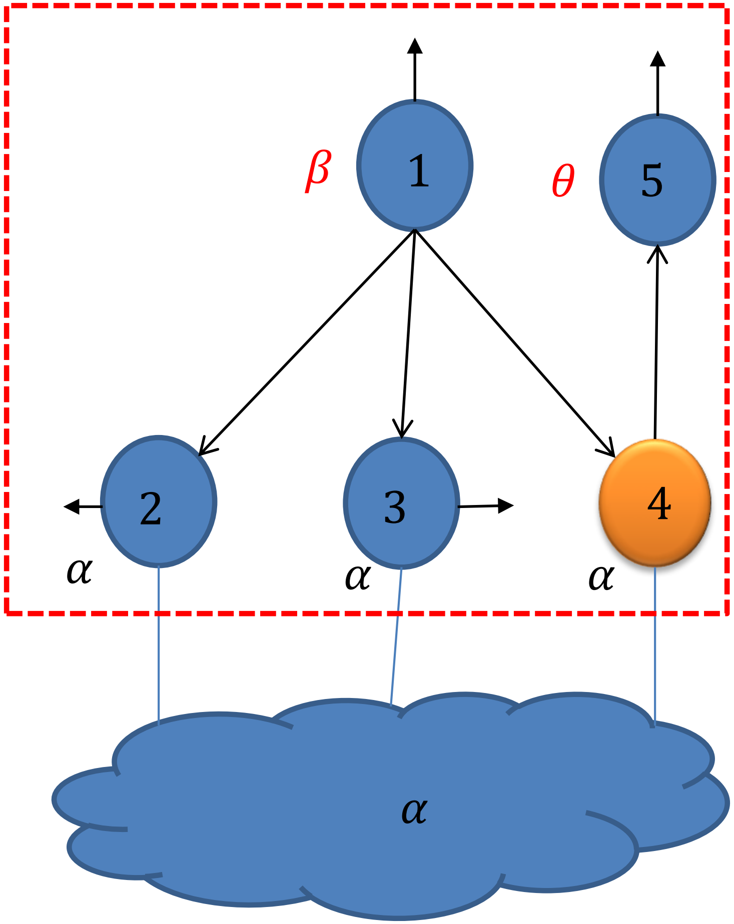
Examples



There are $\rho = 2$ non-boundary buses, so

$$zm \leq 2 - 1 = 1$$

The attacking vector is:

$$\Delta D_1 = 3(\alpha - \beta)$$

$$\Delta D_2 = \beta - \alpha$$

$$\Delta D_3 = \beta - \alpha$$

$$\Delta D_5 = \alpha - \theta$$

Conclusion

- An attacker can launch a successful false data attacks with local network information;
- Developing effective detecting methods becomes very important;
- Defending power grids against local false data attacks.

Thanks!