Fault detection and faulted line identification in power systems using synchrophasor-based real-time state estimation

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The problem

Existing protection schemes are ***specific*** according to:

- Voltage level;
- Type of network;
- Possible fault types;
- Presence of renewables, etc…

The idea

- State estimation output is not affected by these issues;
- Synchronized phasor measurements have high reporting rates and low latency.

The solution

Unique protection scheme based on parallel synchrophasor-based state estimators.

Method

Assumptions:

- Knowledge of network admittance matrix (**H** exact);
- Measurement noise covariance **R** known;
- PMUs installed in every bus;
- Bad data removed a-priori.

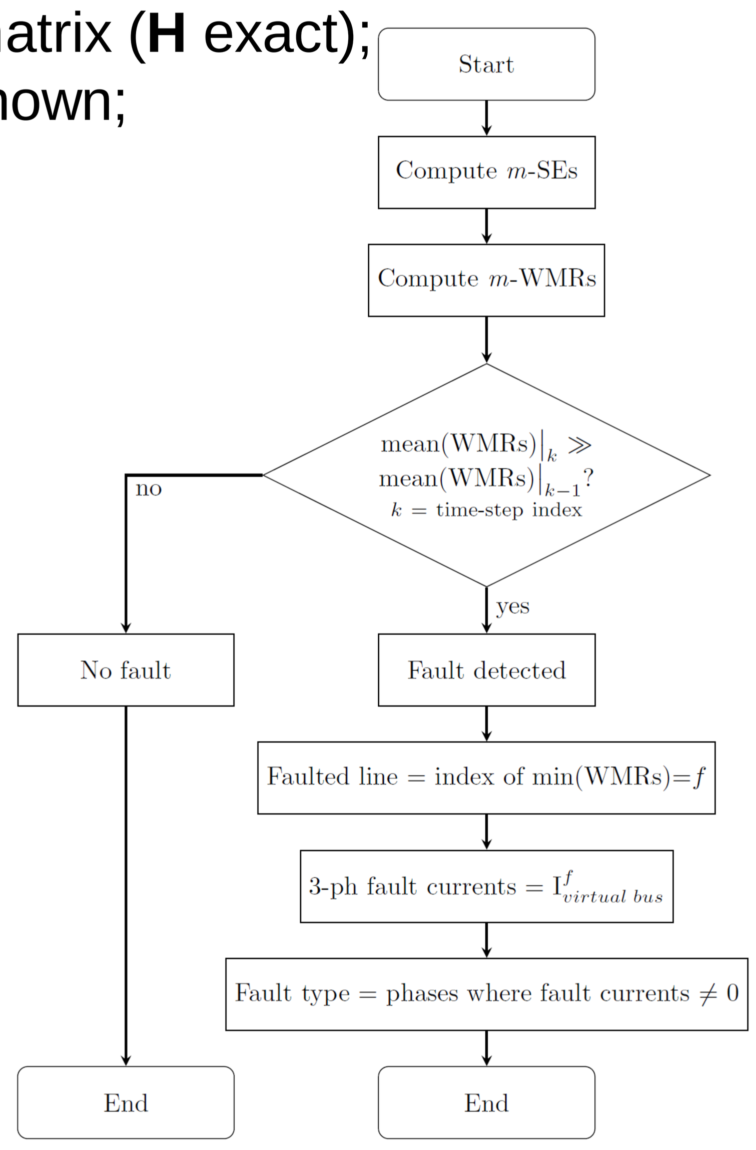
Procedure:

For every new set of measurements and for every *j*-SE, with j ∈ [1, …, m]

$$\hat{\mathbf{x}}_j = \mathbf{G}^{-1}\mathbf{H}_j^T\mathbf{R}^{-1}\mathbf{z}$$

$$\hat{\mathbf{z}}_j = \mathbf{H}_j\hat{\mathbf{x}}_j$$

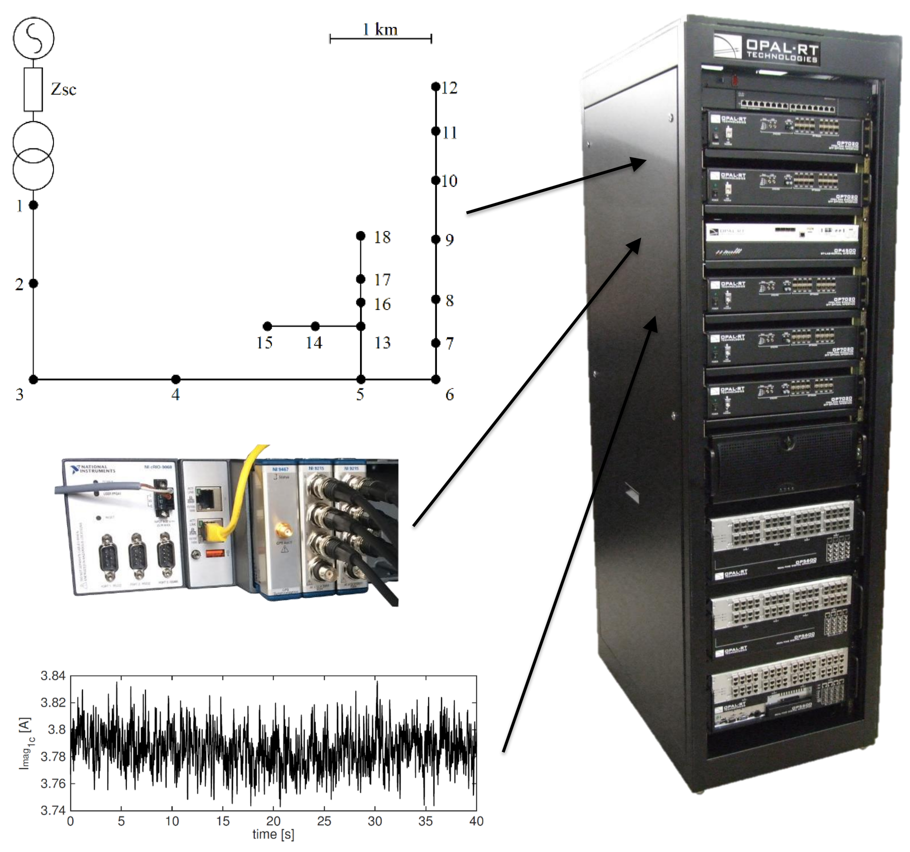
$$\mathrm{WMR}_j = \sum_{i=1}^{D} \frac{|\mathbf{z}^i - \hat{\mathbf{z}}_j^i|}{\boldsymbol{\sigma}_{\mathbf{z}^i}}$$

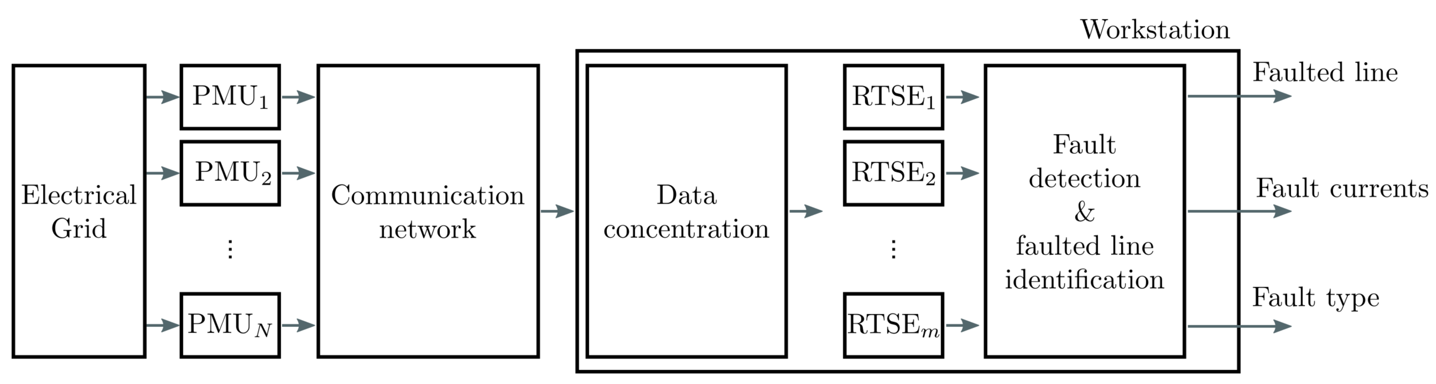


Real-time validation

Implementation:

- **Real-time simulator** to reproduce real-network behavior in real-time;
- Real **PMU algorithm** (used in EPFL) to generate the measurements;
- Real measurement **noise model** (obtained in EPFL).

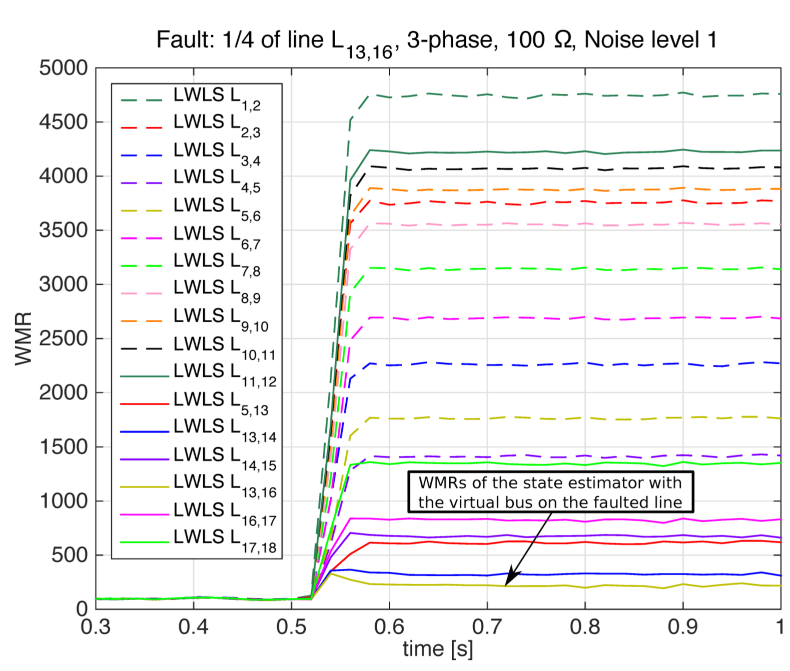


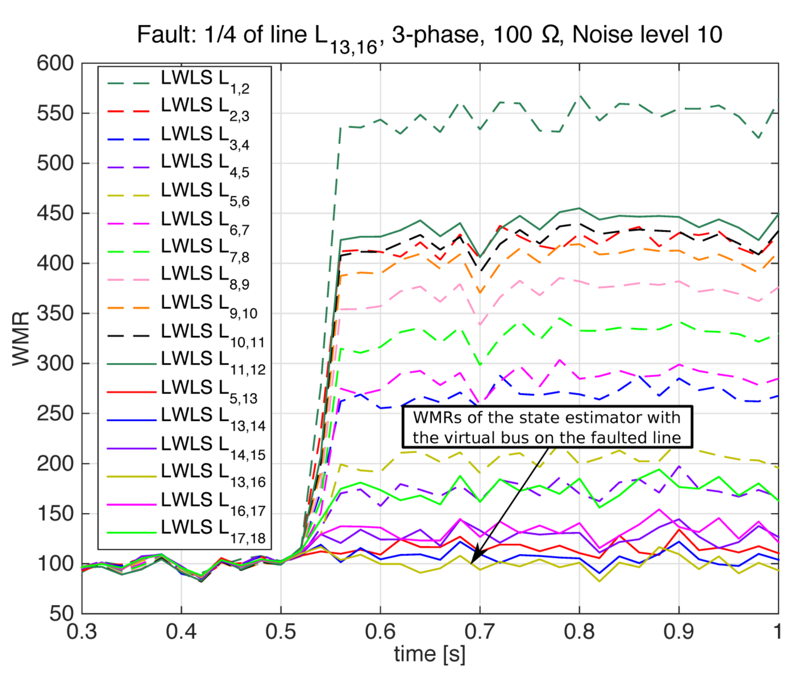


Results

Extensively tested for:

- Real **distribution** or **transmission** test network;
- Low, high or very high **impedance** faults (1 Ω, 10 Ω, 1000 Ω);
- Several fault **types** and fault **locations**;
- Earthed or unearthed **neutral**;
- Large presence of **distributed generation** and different **operating conditions**.





TRANSMISSION: 1-PH-TO GROUND FAULT, 1 Ω

Fault Position		Noise Level 1	Noise Level 10
$L_{1,3}$	1/4	100%	100%
	1/2	100%	100%
$L_{3,4}$	1/4	100%	100%
	1/2	100%	100%
$L_{1,5}$	1/4	100%	100%
	1/2	100%	100%

TRANSMISSION: 1-PH-TO GROUND FAULT, 100 Ω

Fault Position		Noise Level 1	Noise Level 10
$L_{1,3}$	1/4	100%	99.67%
	1/2	100%	100%
$L_{3,4}$	1/4	100%	99.99%
	1/2	100%	100%
$L_{1,5}$	1/4	100%	91.35%
	1/2	100%	100%

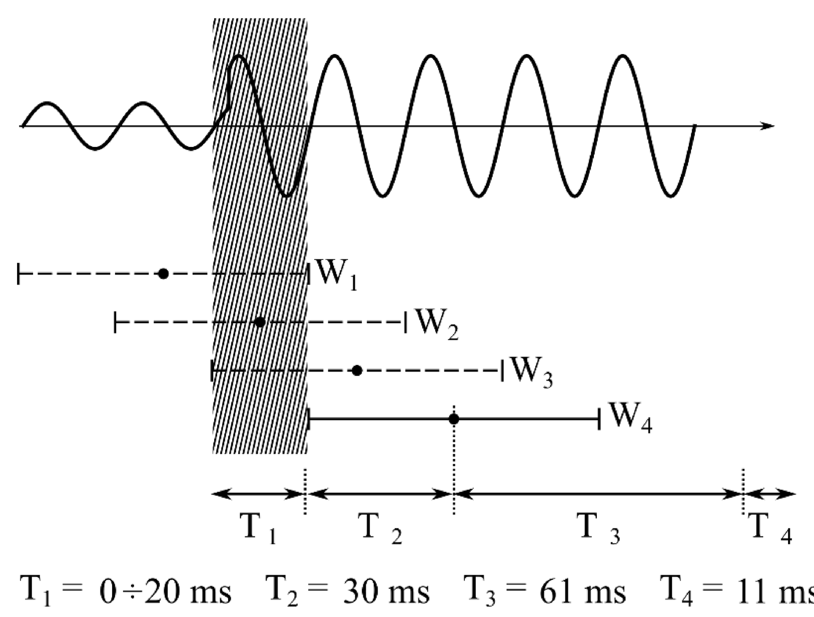
DISTRIBUTION: 3-PH FAULT, 1 Ω

Fault Position		Noise Level 1	Noise Level 10
$L_{4,5}$	1/4	100%	100%
	1/2	100%	100%
$L_{9,10}$	1/4	100%	100%
	1/2	100%	100%
$L_{13,16}$	1/4	100%	100%
	1/2	100%	100%

DISTRIBUTION: 3-PH FAULT, 100 Ω

Fault Position		Noise Level 1	Noise Level 10
$L_{4,5}$	1/4	100%	99.27%
	1/2	100%	99.85%
$L_{9,10}$	1/4	100%	98.54%
	1/2	100%	99.90%
$L_{13,16}$	1/4	100%	84.65%
	1/2	100%	99.74%

Latency assessment**:**



$T_1 = 0 \div 20$ ms $T_2 = 30$ ms $T_3 = 61$ ms $T_4 = 11$ ms

T_{tot} = 102 ÷ 122 ms

Future steps

- Validation in the **real field**;
- Localization of the fault along the line with an offline procedure;
- Study of the robustness of the method with respect to errors in the input parameters.

[1] M. Pignati; L. Zanni; P. Romano; R. Cherkaoui; M. Paolone, "Fault Detection and Faulted Line Identification in Active Distribution Networks using Synchrophasors-based Real-Time State Estimation," in IEEE Transactions on Power Delivery

[2] P. Romano, M. Pignati and M. Paolone, "Integration of an IEEE Std. C37.118 compliant PMU into a real-time simulator," PowerTech, 2015 IEEE Eindhoven, Eindhoven, 2015.