” Using Machine Learning for Detection and Classification of PQ phenomenon”

by

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European Pattern Recognition project

PART OF:
Smart Grids Plus ERA-Net

WITH FUNDING FROM:
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TÜBİTAK
The Research Council of Norway
Swedish Energy Agency

Power Quality monitoring from past until today

1990 | 2000 | 2015

1st generation

- Very basic instruments like voltmeters etc were used.
- First portable power quality analyzers were introduced

2nd generation

- Permanent installed power quality analyzers were introduced.
- Power quality analyzers based on IEC 61000-4-30 class A were introduced

3rd generation

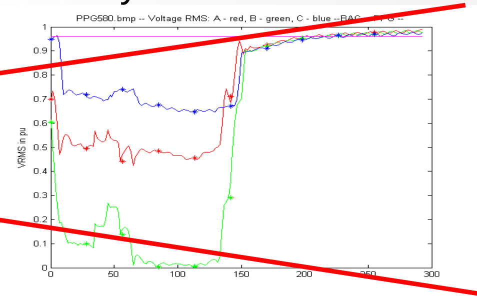
- Sophisticated signal processing methods are ued for automatic and accurate analysis of measurement data
- Integration

3rd generation measurement system - objectives

~~"Classical"~~

~~Manual Analysis of recorded data~~

~~Only characteristics~~



Something happen in the grid

" Preferred"

3rd generation

Tell what really happened

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Power Quality Monitoring – 3rd generation

- In the past: Evaluation of data was made by manual inspection
  - Time consuming (and tedious)
  - Quality of the result depends on the knowledge level and skills of the person doing the analysis

- 3rd generation: Take use of information (data) from previous measurements to automate the evaluation process

  - Automatic detection and classification of power quality phenomenon
  - Less time consuming evaluation process
  - Higher quality and more reliable results
  - Important information contained in the data - hidden for a manual inspection – can be detected – Trend analysis
  - Adaptive process – by continuously adding new data from previous measurements into the machine learning algorithm the PQ system will continuously learn and increase the precision and accuracy
  - Opens up to use the PQ system in new valuable applications like fault detection and preventive maintenance etc

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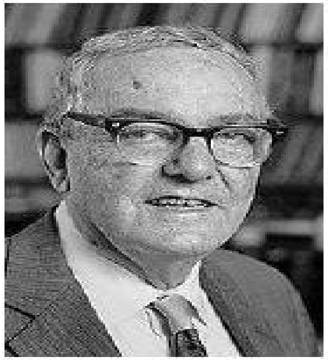
Machine learning (ML)

- Herbert Simon:
  ”Learning is any process by which a system (computer,robot etc) improves performance from experience”.

- Machine Learning is concerned with computer programs that automatically improve their performance through experience



Herbert Simon
Turing Award 1975
Nobel Prize in Economics 1978

Pattern recognition

Pattern recognition:
A machine learning algorithm that is trained to recognize a particular pattern in a large data stream

Pattern recognition –
a general technique used in many applications

- Text analysis:	Search engines
- Image analysis:	Face recognition
- Financial analysis:	Stock price forecasts
- *Power system analysis:*	*Detection and lassification of voltage disturbances*
	fault detection and classifications
	preventive maintenance
	trend analysis, forecasting

Pattern recognition methods

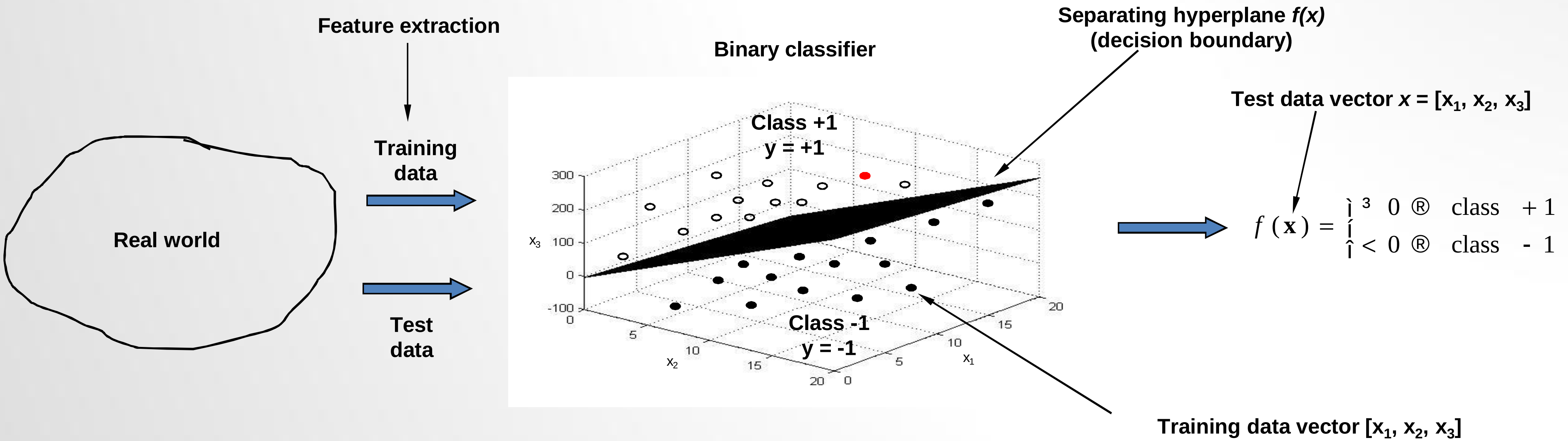
Many pattern recognition methods are available (different techniques with the same goal – to identify a particular pattern in a data stream)

- k Nearest Neighbor (kNN)
- Neural Networks
- AdaBoost
- *Support Vector machines*

A premium method: The Support Vector Machine (SVM)

- Uses large number of pre-classified training data.
- Features are extracted from the training data and placed in an n-dimentional data space.
- The classifier decides type of disturbance (class) by using an optimal separating hyperplane.

A premium method:
The Support Vector Machine (SVM)



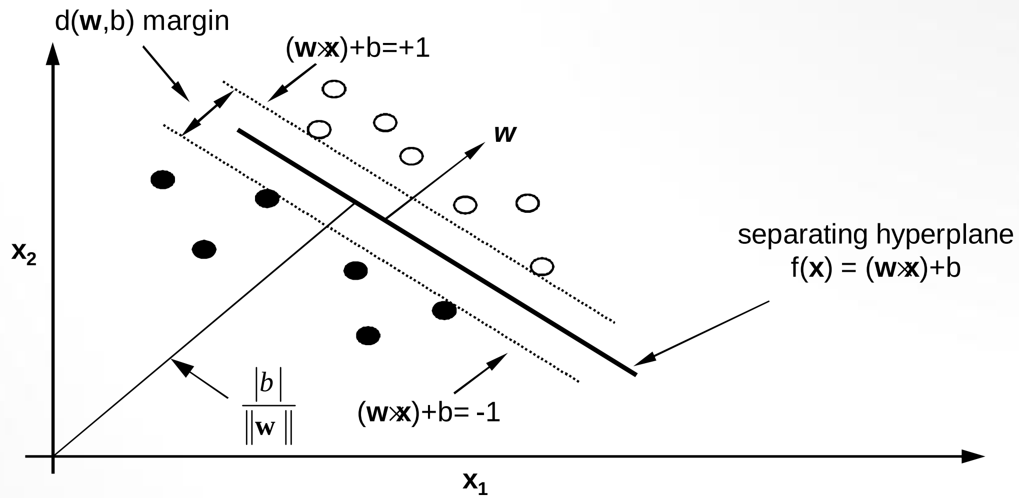
Calculating the separating hyperplane

$$f(\mathbf{x}) = (\mathbf{w} \cdot \mathbf{x}) + b$$

$$(\mathbf{w} \cdot \mathbf{x}_i) + b \geq 1 \quad for \quad y_i = +1$$

$$(\mathbf{w} \cdot \mathbf{x}_i) + b \leq -1 \quad for \quad y_i = -1$$

$$y_i \cdot ((\mathbf{w} \cdot \mathbf{x}_i) + b) \geq 1 \quad i = 1,\ldots, n$$



The margin

$$d(\mathbf{w}, b) = \frac{|(\mathbf{w} \cdot \mathbf{x}_1) + b|}{\|\mathbf{w}\|} + \frac{|(\mathbf{w} \cdot \mathbf{x}_2) + b|}{\|\mathbf{w}\|} = \frac{2}{\|\mathbf{w}\|}$$

Maximum margin is achieved for

$$\min_{\mathbf{w}} \frac{1}{2} \|\mathbf{w}\|^2$$

$$y_i \cdot ((\mathbf{w} \cdot \mathbf{x}_i) + b) \geq 1 \quad i = 1,\ldots, n$$

Quadratic Optimization **problem (QP-problem)**

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Calculating the separating hyperplane

$$\min_{\mathbf{w}} \frac{1}{2}\|\mathbf{w}\|^2$$

$$y_i \cdot ((\mathbf{w} \cdot \mathbf{x}_i) + b) \geq 1 \quad i = 1,\ldots, n$$

Introduce the Lagrangian functional and re-formulate the QP-problem:

$$L(\mathbf{w}, b, \alpha) = \frac{1}{2}\|\mathbf{w}\|^2 - \sum_{i=1}^{n} \alpha_i [y_i \cdot ((\mathbf{w} \cdot \mathbf{x}_i) + b) - 1] = \frac{1}{2}\|\mathbf{w}\|^2 - \sum_{i=1}^{n} \alpha_i \cdot y_i \cdot (\mathbf{w} \cdot \mathbf{x}_i) - b \sum_{i=1}^{n} \alpha_i y_i + \sum_{i=1}^{n} \alpha_i$$

Optimal solution is given by the saddle point of the Lagrangian functional

$$\max_{\alpha} \left(\min_{\mathbf{w}, b} L(\mathbf{w}, b, \alpha) \right) \longrightarrow$$

$$\frac{dL(\mathbf{w}, b, \alpha)}{db} = -\sum_{i=1}^{n} \alpha_i y_i = 0 \Rightarrow \underline{\sum_{i=1}^{n} \alpha_i y_i = 0}$$

$$\frac{dL(\mathbf{w}, b, \alpha)}{d\mathbf{w}} = \mathbf{w} - \sum_{i=1}^{n} \alpha_i y_i \mathbf{x}_i = 0 \Rightarrow \underline{\mathbf{w} = \sum_{i=1}^{n} \alpha_i y_i \mathbf{x}_i}$$

$$\longrightarrow \max_{\alpha} L(\mathbf{w}, b, \alpha) = \max_{\alpha} \left(\sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i,j=1}^{n} \alpha_i \alpha_j y_i y_j (\mathbf{x}_i \cdot \mathbf{x}_j) \right)$$

subject to the constraints

$$\sum_{i=1}^{n} \alpha_i y_i = 0 \quad \text{and} \quad \alpha_i \geq 0 \quad i = 1, \ldots, n$$

Support Vector Machine

For the binary classifier

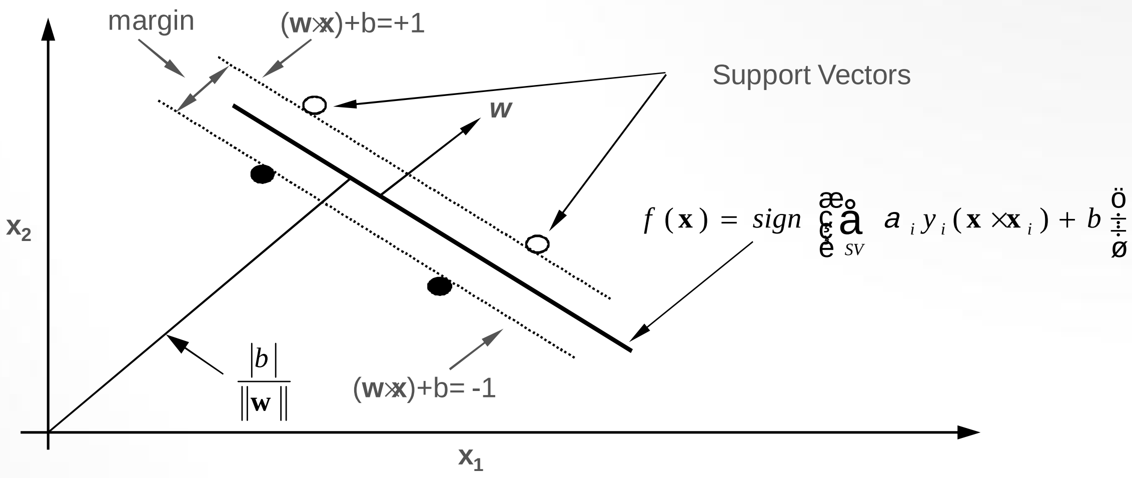
$$f(\mathbf{x}) = sign\left(f(\mathbf{w} \cdot \mathbf{x}) + b\right) = sign\left(\sum_{i=1}^{n} a_i y_i (\mathbf{x}_i \cdot \mathbf{x}) + b\right)$$

Karush-Kuhn-Tucker conditions states

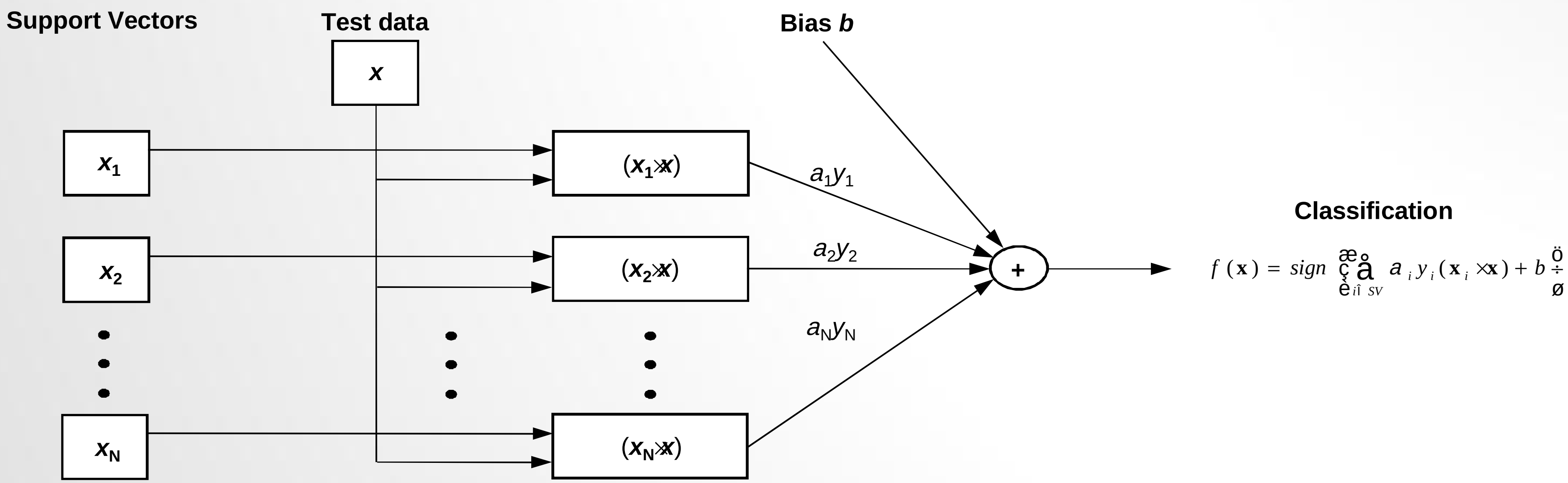
$$a_i\left(y_i\left((\mathbf{w} \cdot \mathbf{x}_i) + b\right) - 1\right) = 0 \quad for \quad i = 1,\dots, n$$

Only those training samples corresponding to non-zero Lagrange multipliers are needed!
These are placed on the margins and called Support Vectors

$$f(\mathbf{x}) = sign\left(\sum_{SV} a_i y_i (\mathbf{x}_i \cdot \mathbf{x}) + b\right)$$



Blockdiagram of the Support Vector Machine

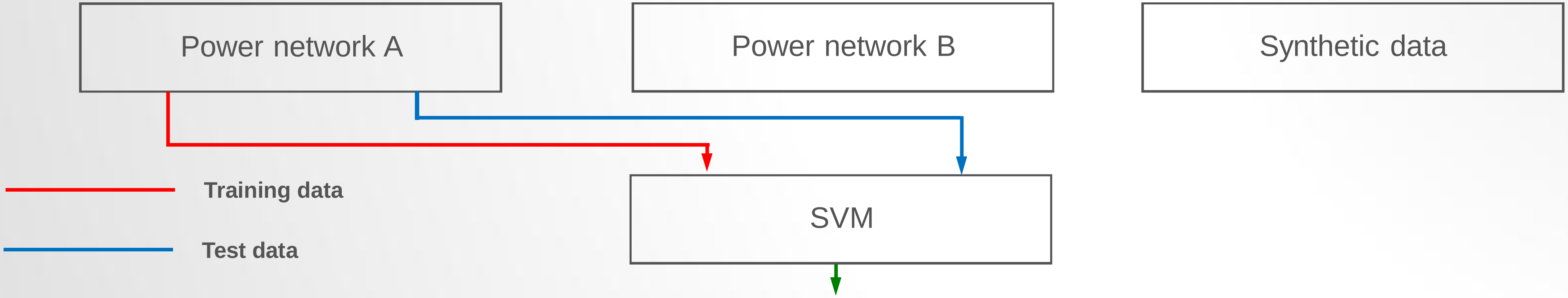


Conducted experiments

Types of voltage disturbances

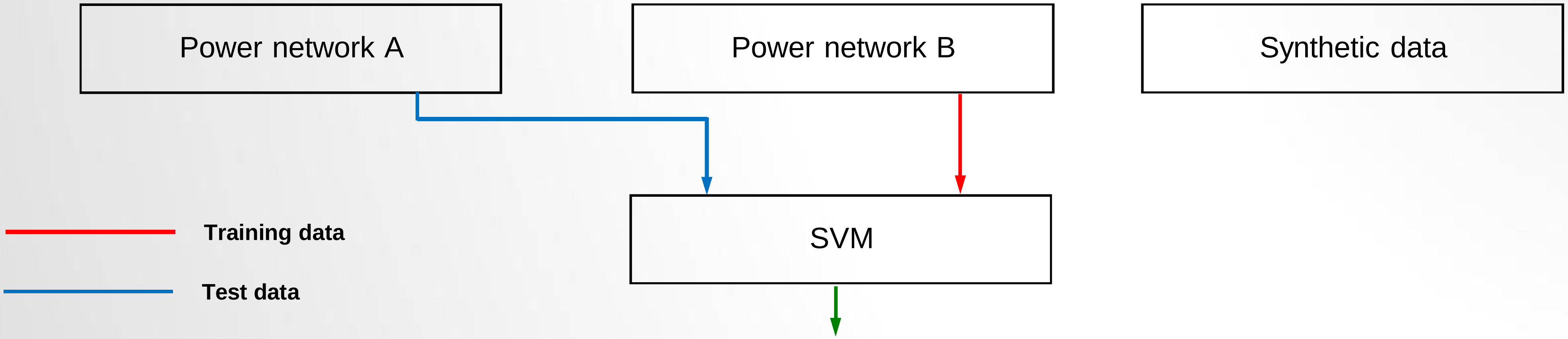
Type	Fault types	# of disturbances originated from Power network A	# of disturbances Originated from Power network B	# of disturbances originated from synthetic generated data
D1	Single phase-to-ground fault	141	475	225
D2	Phase-to-phase fault	181	125	225
D3	Three-phase fault	251	196	223
D4	Double phase fault with one phase more affected	127	67	250
D5	Transformer energizing	214	0	250

Experiment #1



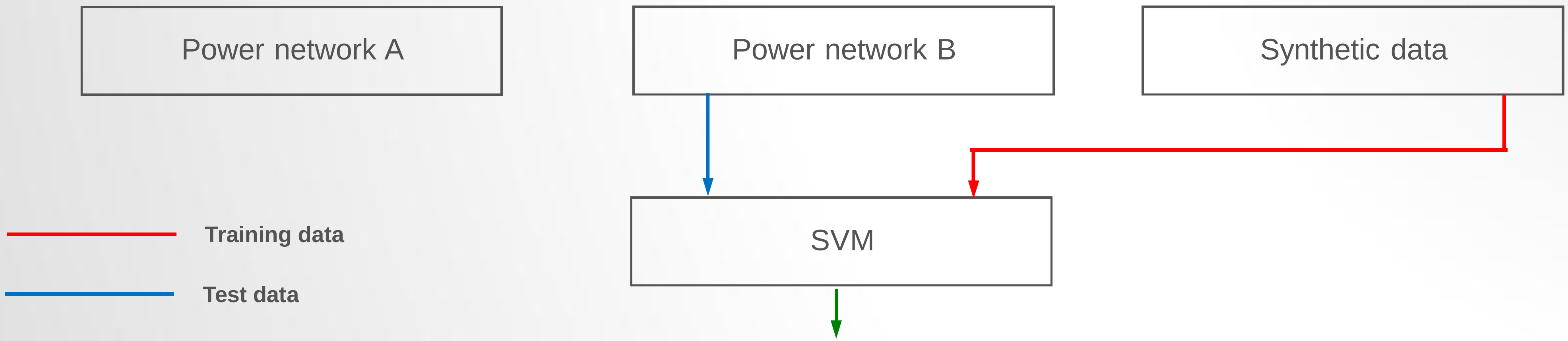
	D1	D2	D3	D4	D5	NC	Detection rate
Single phase-to-ground fault (D1)	**63**	0	1	3	0	4	**88.7 %**
Phase-to-phase fault (D2)	0	**84**	4	0	0	3	**92.3 %**
Three-Phase Fault (D3)	5	3	**113**	0	0	5	**89.7 %**
Double phase fault with one phase more affected (D4)	0	0	0	**63**	1	0	**98.4 %**
Transformer energizing (D5)	0	0	0	0	**103**	4	**96.3 %**
Overall detection rate: **93.1 %**							

Experiment #2



	D1	D2	D3	D4	D5	NC	Detection rate
Single phase-to-ground fault (D1)	**137**	0	2	1	0	1	**97.2 %**
Phase-to-phase fault (D2)	0	**154**	16	0	0	11	**85.1 %**
Three-Phase Fault (D3)	10	1	**232**	0	0	8	**92.4 %**
Double phase fault with one phase more affected (D4)	4	1	1	**121**	1	0	**95.2 %**
Overall detection rate: **92.5 %**							

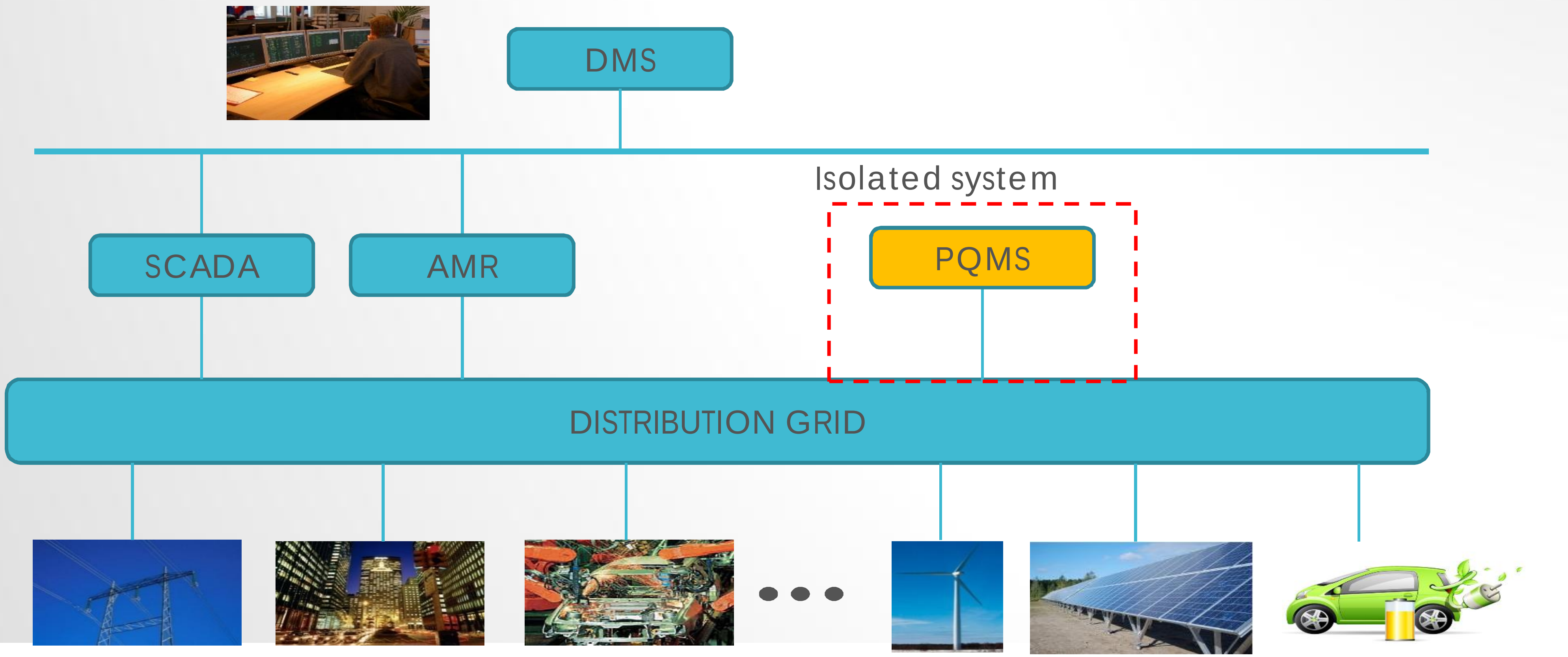
Experiment #3



	D1	D2	D3	NC	Detection rate (%)
Single phase-to-ground fault (D1)	**393**	0	2	23	**94.0%**
Phase-to-phase fault (D2)	3	**80**	0	9	**87.0%**
Three-Phase Fault (D3)	2	0	**126**	14	**88.7%**
Overall detection rate: **91.9%**					

System Integration

System Integration – situation until today



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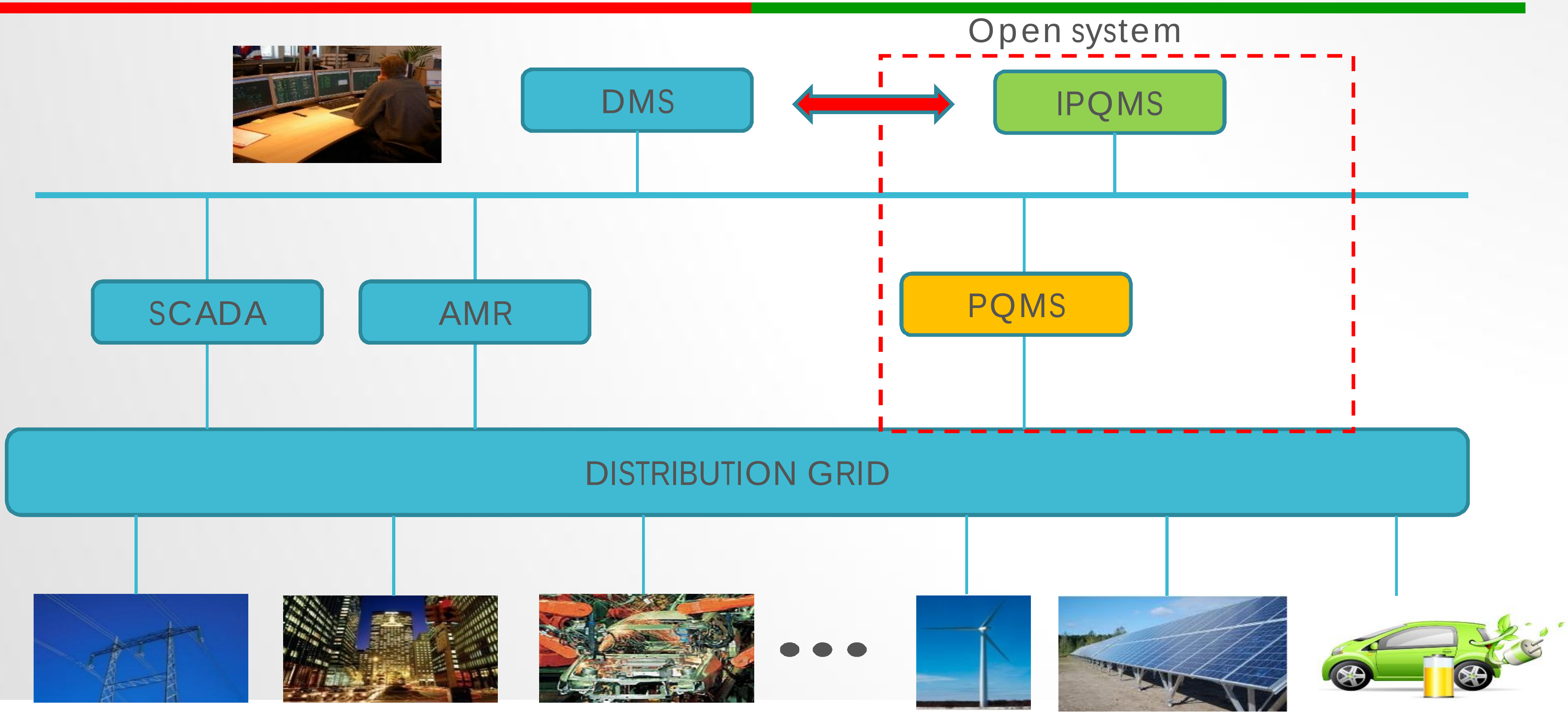
Integration – situation tomorrow



IPQMS = Integrated Power Quality Monitoring System

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Conclusions

- The 3rd generation system will be based on powerful pattern recognition techniques to perform traditional PQ analysis in a more efficient way
  - from manual toward automatic analysis of PQ data
  - trend analysis used for preventive maintenance
  - automatic detection and classification of faults
  - forecasting
- The 3rd generation system will be an open system ready to interchange data with other systems