Power System Monitoring Using Data Science

Charlas Virtuales 2021

Emilio Barocio Espejo

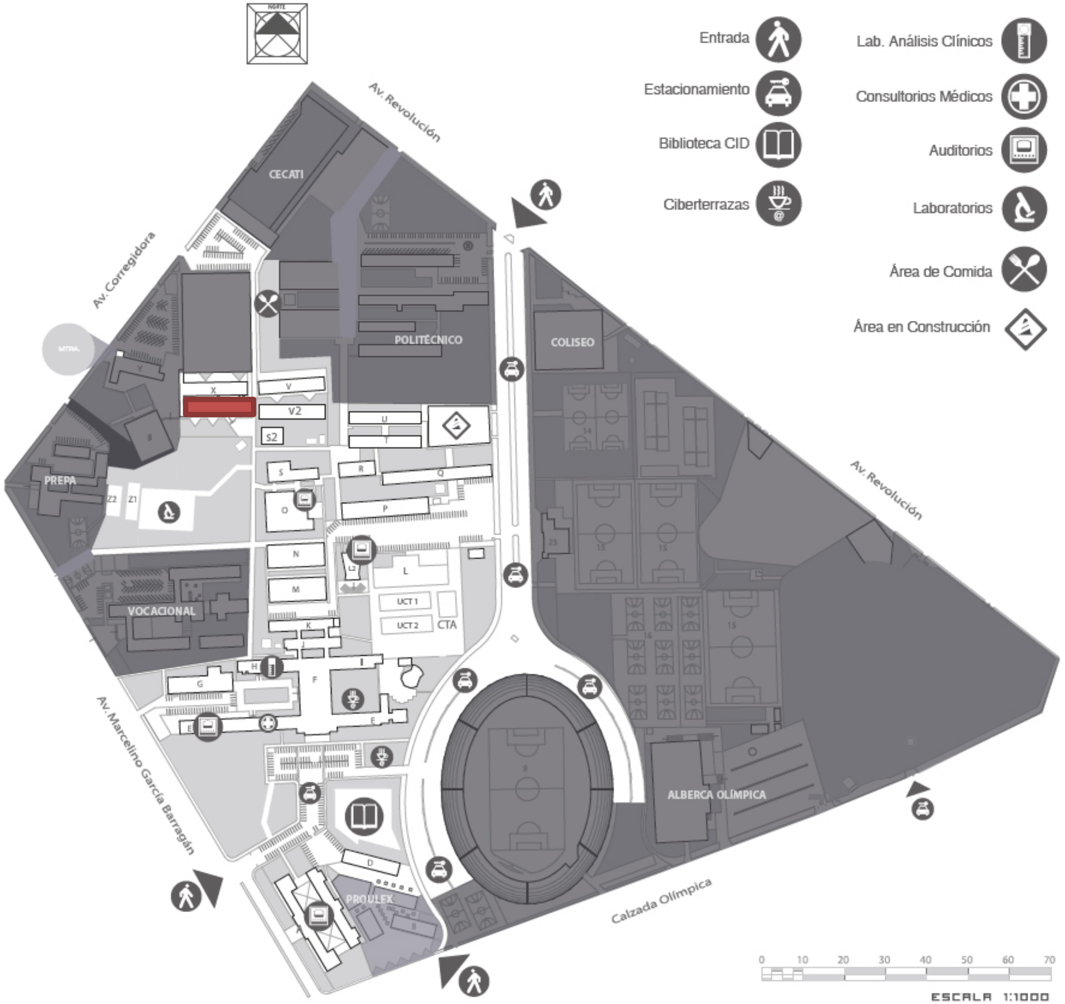
16-Abril-2021

TOOLS
DATA ANALYTIC GROUP

https://sites.google.com/view/grouptitan/home

Infraestructura CUCEI:

7.8 Hectares, 22 Edificios, 265 Aulas, 133Laboratorios, 10 talleres, 4 auditorios, bibliotecas, 12 mil estudiantes



Oferta academica:

- 18 Licenciaturas
- 15 Maestrias PNPC
- 9 Doctorados PNPC

Investigación:

- 290 SNI
- 490 Perfil PRODEP
- 35 areas de desarrollo
- 75 CA

Servicios:

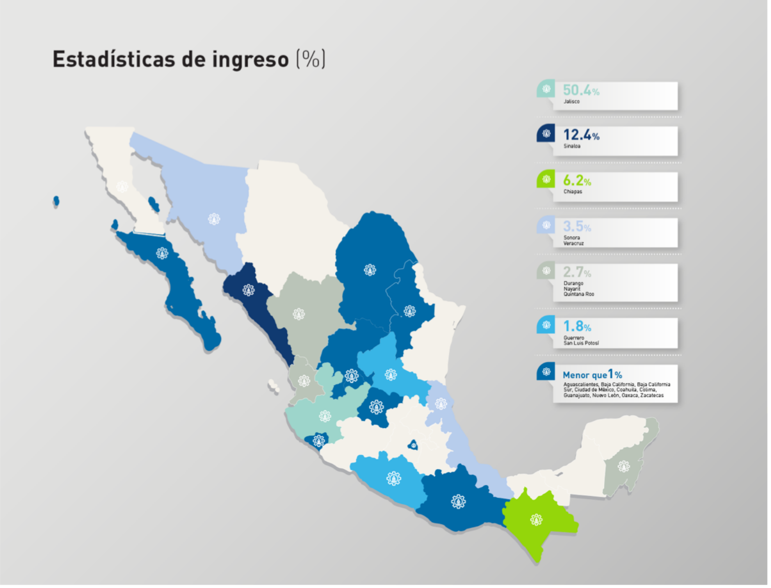
- Apoyo a idiomas
- Medico
- Bibliotecas
- Deportivos
- Internet
- Talleres

http://www.cucei.udg.mx/es

http://www.cucei.udg.mx/maestrias/electrica/

Areas de Investigación:

- Electronica de potencia en micro-redes.
- Análisis de transitorios electromagneticos y electromecanicos.
- Control lineal y no-lineal de sistemas electricos de potencia con fuentes intermitentes.
- Operación y control de sistemas industriales y redes de distribución.
- Aplicación de Ciencia de Datos al análisis de sistemas eléctricos de potencia.



- Posgrado **CONSOLIDADO**
- 150 graduados
- 75% de los profesores pertencen al SNI
- Laboratorio para simulación *Labvolt,* con una inversión de 5 millones.
- Software profesional en la enseñanza
- Experiencia en aplicaciones con la industria

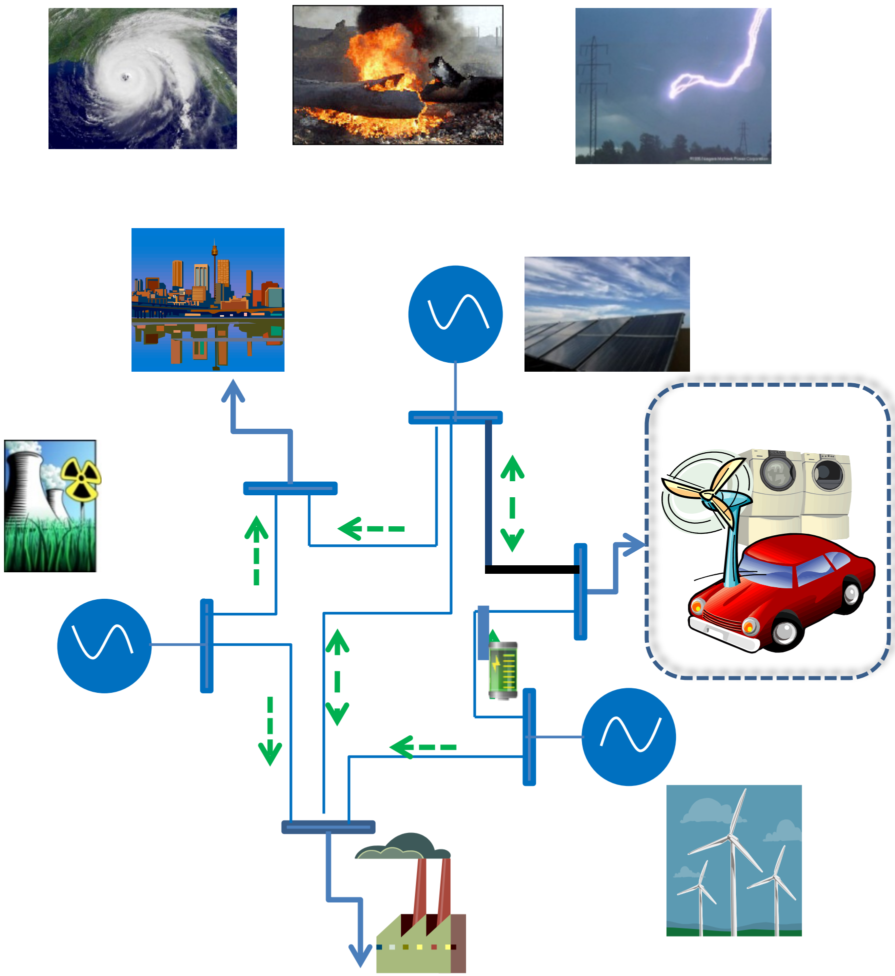
CONACYT
PNPC
Padrón Nacional de Posgrados de Calidad

Sesiones informativas: **meet.google.com/ogn-biyf-ofv**
Viernes 30 de abril del 2021, a las 12:00 horas
Viernes 21 de mayo del 2021, a las 12:00 horas

Agenda

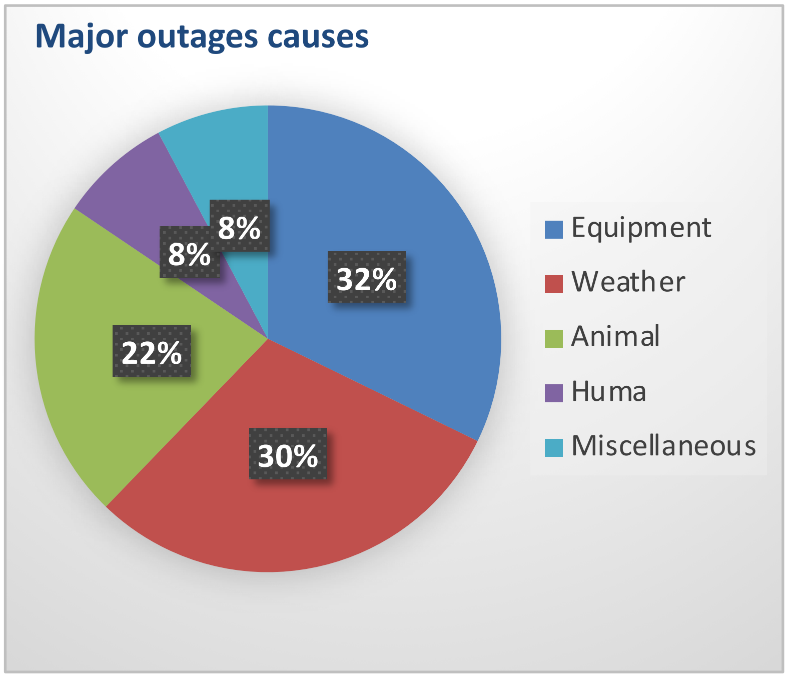
1. **Challenges on to power systems**
2. Data science in power systems
3. Tools based in data science algorithms.
4. Final remarks and future steps

Complex power system operation …



New challenges for the Power system:

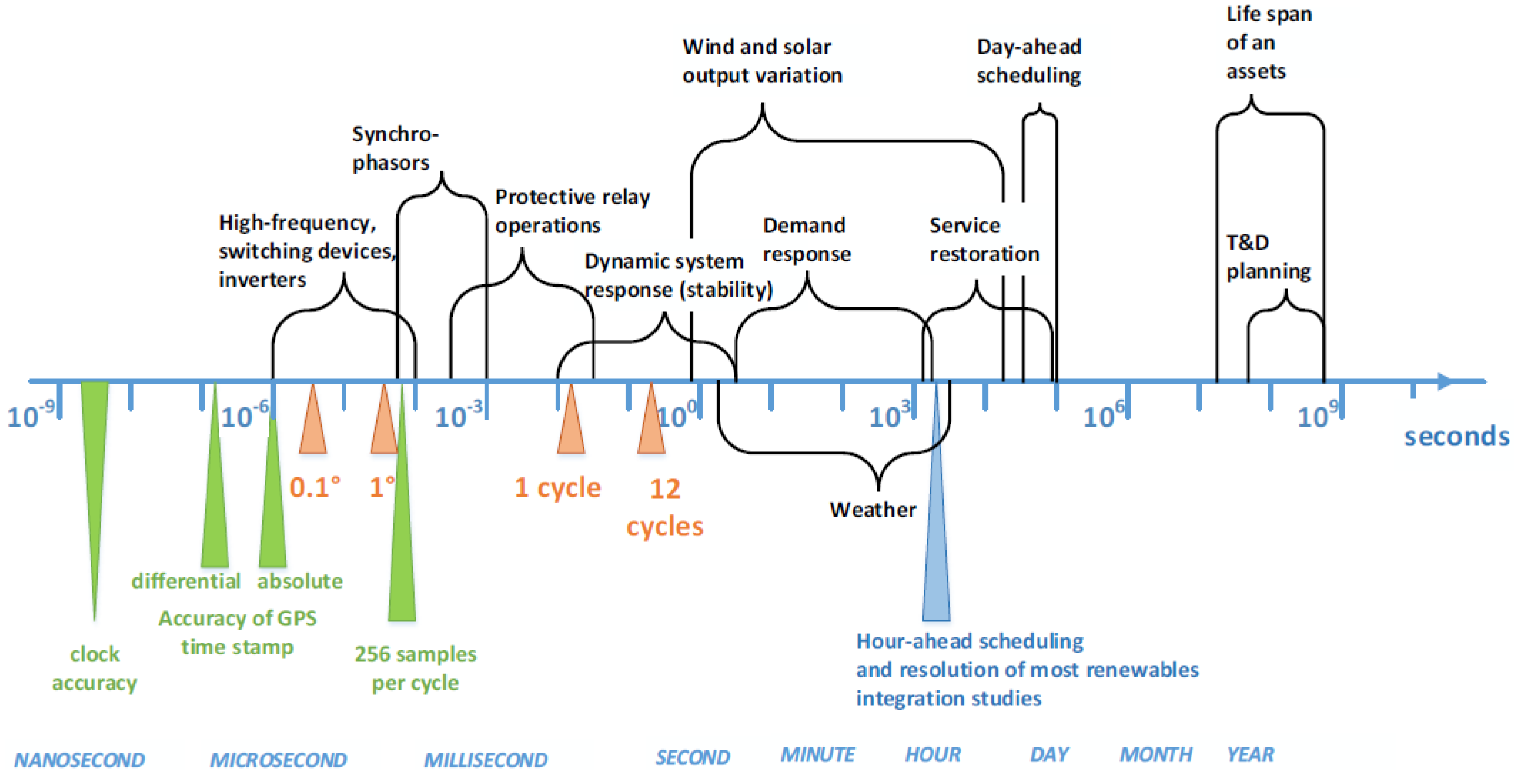
- Deregulated power systems.
- Intermittence on generation.
- New types of stochastic loads (Vehicles, house climate, ..)
- Multiple power flow direction.
- Climate change
- Multiple sources (battery storage, wind, solar, diesel,..)



Largest Blackouts …

2012 India blackouts	**620**	**India**	**July 30–31, 2012**
2001 India blackout	230	India	January 2, 2001
2014 Bangladesh blackout	150	Bangladesh	November 1, 2014
2015 Pakistan blackout	140	Pakistan	January 26, 2015
2019 Java blackout	120	Indonesia	August 4–5, 2019
2005 Java–Bali blackout	100	Indonesia	August 18, 2005
1999 Southern Brazil blackout	97	Brazil	March 11–June 22, 1999
2009 Brazil and Paraguay blackout	60	Brazil, Paraguay	November 10–20, 2009
2003 Italy blackout	56	Italy, Switzerland	September 28, 2003
Northeast blackout of 2003	**55**	**United States, Canada**	**August 14–28, 2003**
2019 Argentina, Paraguay and Uruguay blackout	48	Argentina, Paraguay, Uruguay	June 16, 2019
2002 Luzon blackout	40	Philippines	May 21, 2002
1978 Thailand blackout	40	Thailand	March 18, 1978
2001 Luzon blackout	35	Philippines	April 7, 2001
Northeast blackout of 1965	**30**	**United States, Canada**	**November 9, 1965**
2019 Venezuelan blackouts	30	Venezuela	March 7–September 23, 2019
2016 Sri Lanka blackout	21	Sri Lanka	March 13, 2016

Time scales on power system operation



TS: power system simulation

State-space

Parameters

$$\frac{dx}{dt} = f(x, t, \Theta, \Omega)$$

Dynamics

Stochastic effects

SSSA: power system simulation

$$\Delta\frac{dx}{dt} = f(\Delta x, \Delta t, \Delta\Theta, \Delta\Omega)$$

- Hidro-Gen
- Turbo-Gen
- DFIG-Gen
- Exciter
- PSS
- Turbine
- Governors
- SVC
- Loads
- Network

Measurement: WAMS, AMI, SCADA,MPMU

$$y(t_k) = h(t_k, x(t_k), \Psi)$$

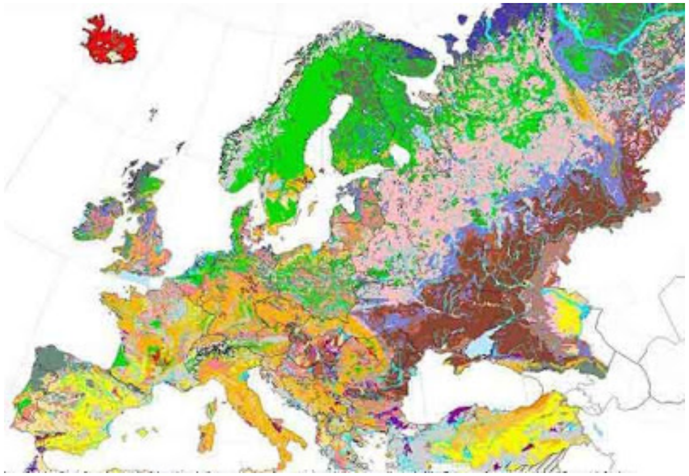
Measurement model

Measurement model

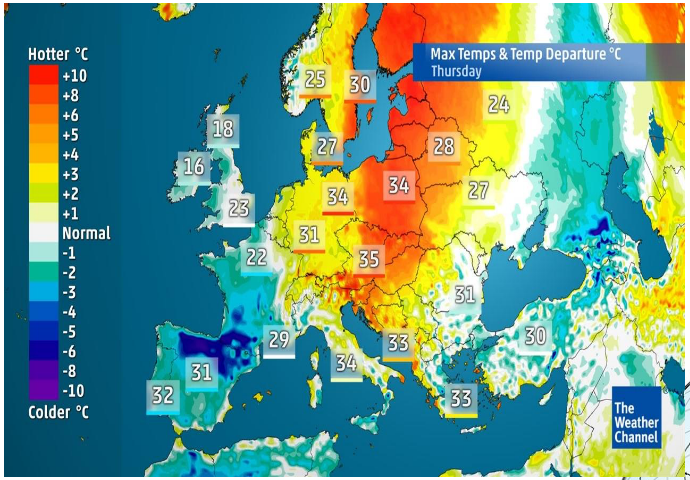
- Voltages
- Currents
- Power
- Frequency

Source of spatio-temporal “Big Data” in power systems

Vegetation indexes



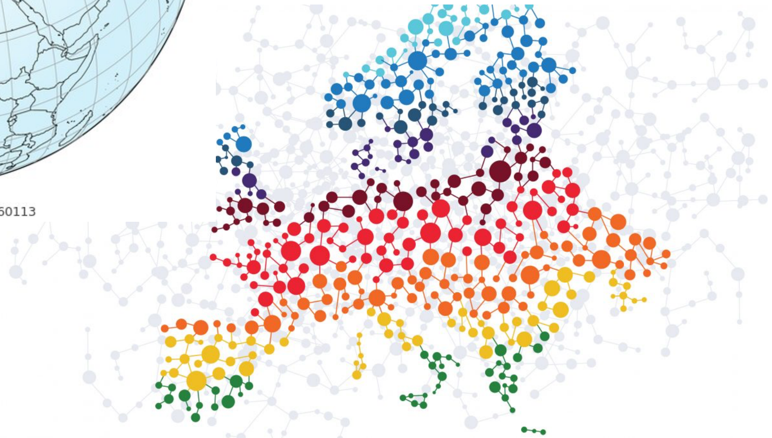
Whether forecast



GIS

WAMS and network assets data

Market data



Source of data properties …

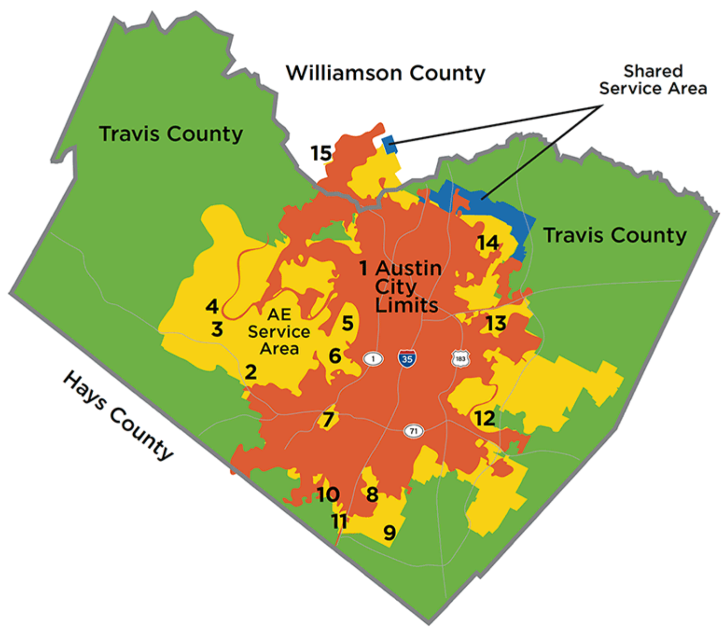
Utility measurements

Data source	Volume data file size	Velocity (Rate of use)	Veracity (Accuracy)
Smart meter	120 GB per day	Every 5-15 mints	Error <2.5%
Phasor measurement unit	30 GB per day	240 samples/sec	Error <1.0%
Digital fault recorder	10 MB per day	1600 samples/sec	Error <0.2%
Intelligent condition monitor	5 GB per day	250 samples/sec	Error <1.0%
µ-PMU	-		x
Simulations PSS, DSA-Tools	-	-	-

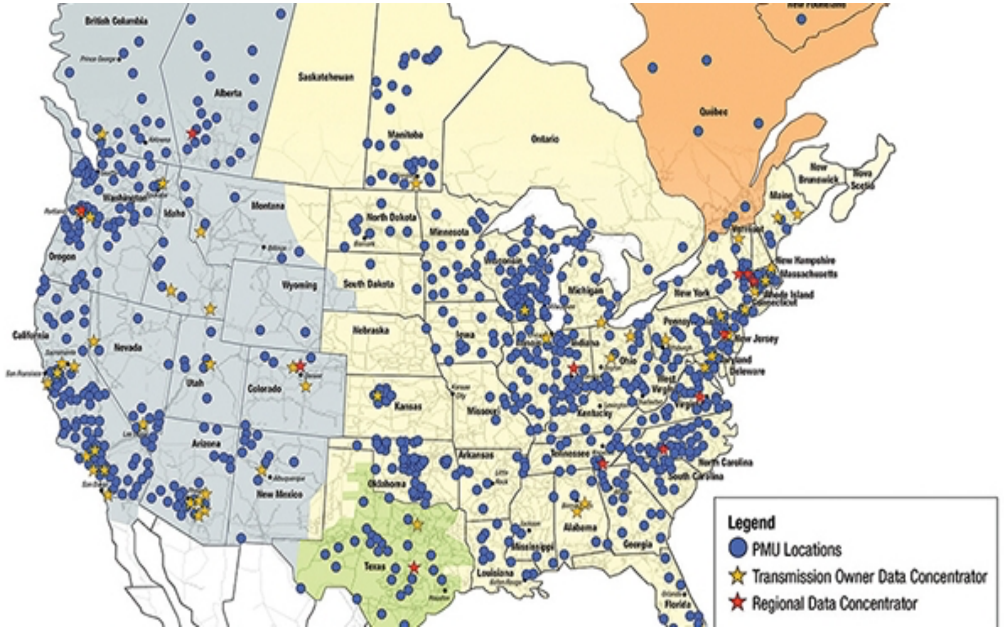
Weather data

Data source	Volume	Velocity	Veracity
Radar	612 MB day per radar scan	Every 4-10 min	1-2 dB; ms-1
Satellite	At least 10 GB per day	Every 1-15 min	x
Automated surface observing systems	10 MB7day per station	Every 1 min	x
National lightning detection network	40 MB7day	During lightning	
Weather forecast model	5-10 GB/day per model	15 min – 12 hours	Varies by parameter

Monitoreo de area amplia como una reto de “Big Data”.



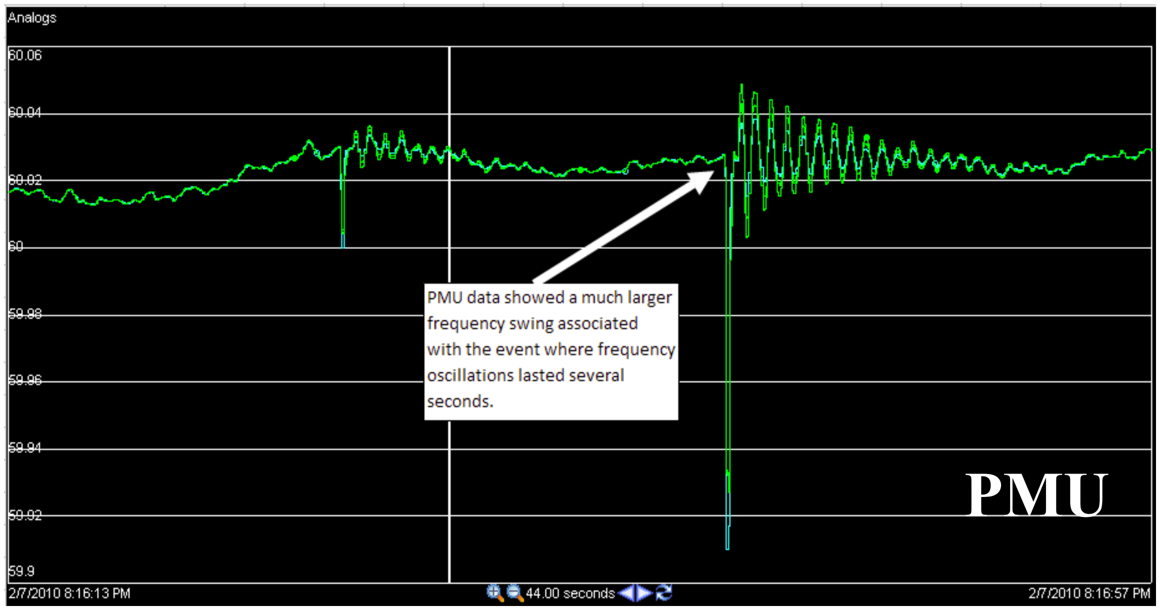
2,400 PMU estan generando 20 TB/Month



Austin Energy en Austin, Texas ha instalado 500,000 smart meters. El sistema de medición envia datos de cada SM cada 15-minutes, por tanto require de 200TB para almacenar la información.

- La India instalara 1700 PMUs
- Mexico tiene instalados 300 PMUs

Example of utility measurement with different time resolution …



Size of data …

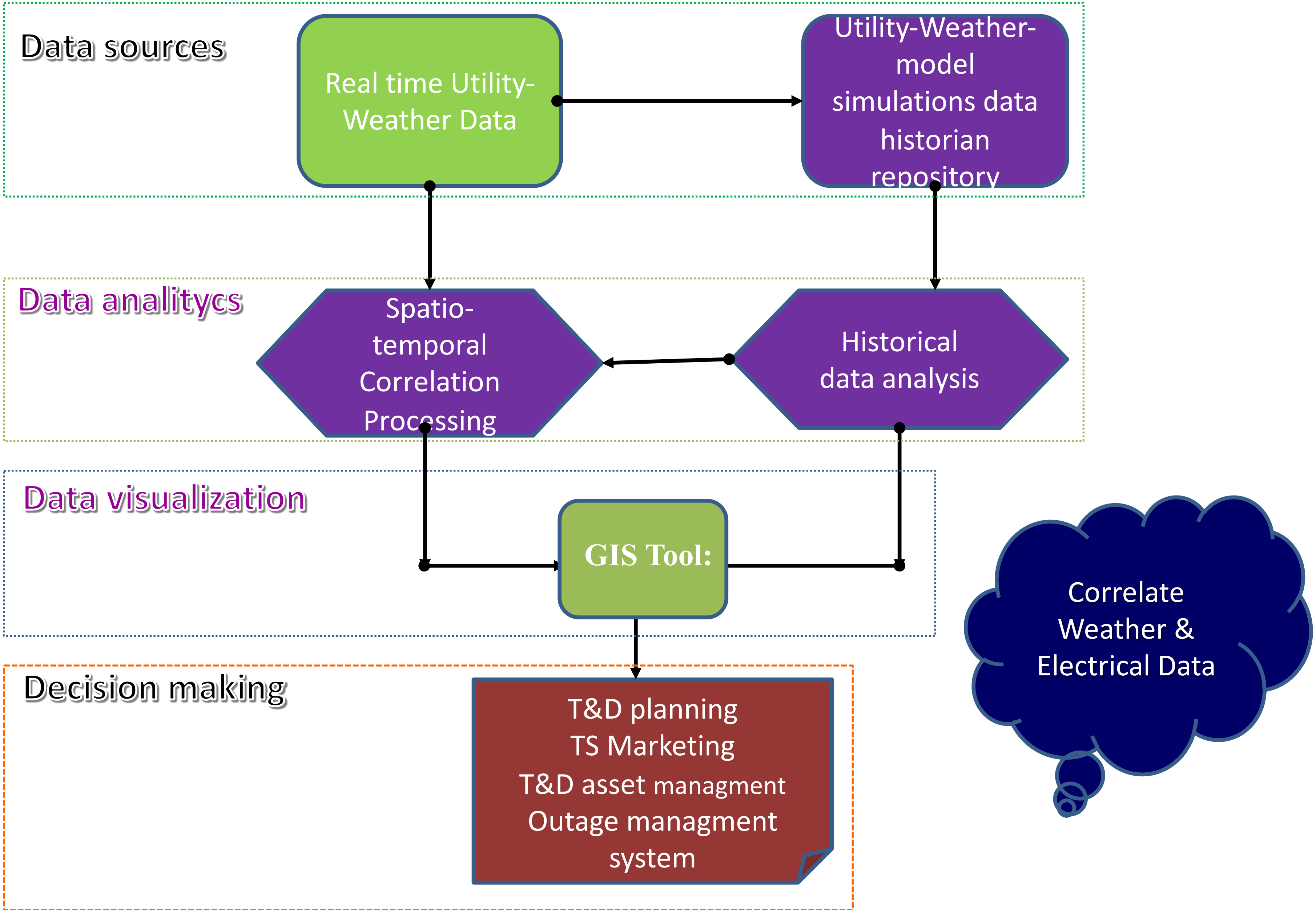
Métric	Value	Bytes
Byte (B)	1	1
Kilobyte (KB)	1.024^1	1.024
Megabyte (MB)	1.024^2	1.048.576
Gigabyte (GB)	1.024^3	1.073.741.824
Terabyte (TB)	1.024^4	1.099.511.627.776
Petabyte (PB)	1.024^5	1.125.899.906.842.624
Exabyte (EB)	1.024^6	1.152.921.504.606.846.976
Zettabyte (ZB)	1.024^7	1.180.591.620.717.411.303.424
Yottabyte (YB)	1.024^8	1.208.925.819.614.629.174.706.176

Walmart 2.5 PB per day

CERN 25 PB per day – 500 EB per day

The **sum total of data held** by all the big online storage and service companies like **Google, Amazon, Microsoft and Facebook** make up about 4,800 petabytes (**4.8 Exabytes**).

Challenges to integrate different source data



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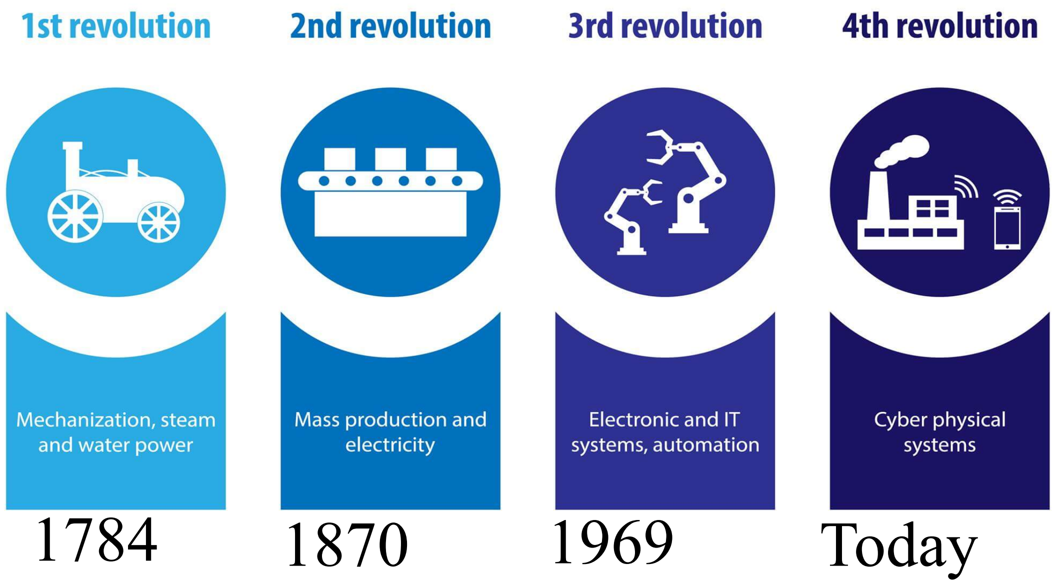
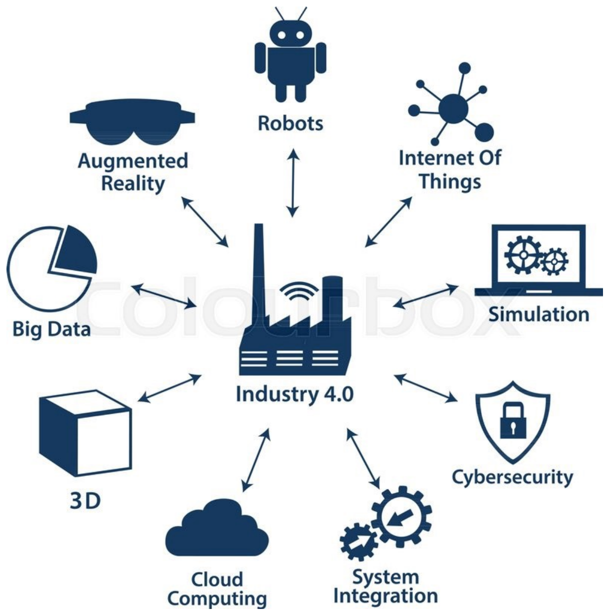
Industrial revolution



Industry 4.0



What about MX?

Global companies on industry 4.0

Global electrical companies on industry 4.0

SEL

Approved American National Standard ANSI

INSTITUTE OF INDUSTRIAL & SYSTEMS ENGINEERS

SIEMENS

IEEE

ABB

INEL INVENTARIO NACIONAL DE ENERGÍAS LIMPIAS

CENACE CENTRO NACIONAL DE CONTROL DE ENERGÍA

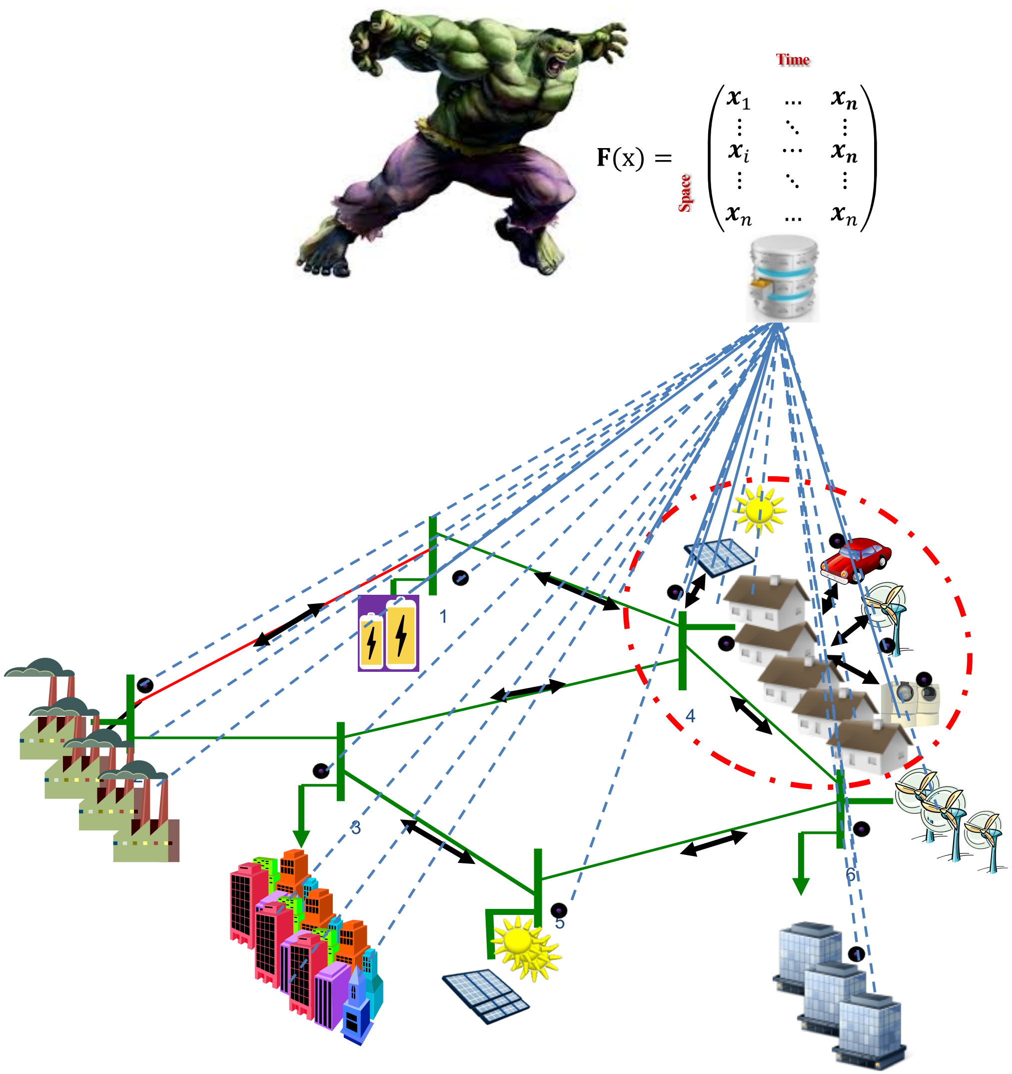
pjm

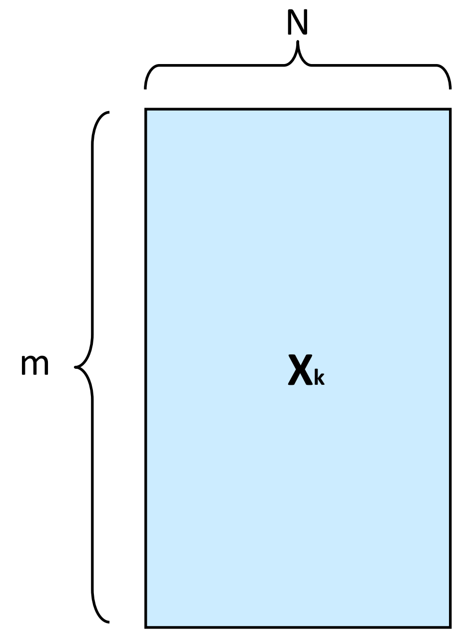
NERC NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

ercot

CFE Comisión Federal de Electricidad

Handling “big data” in PS …

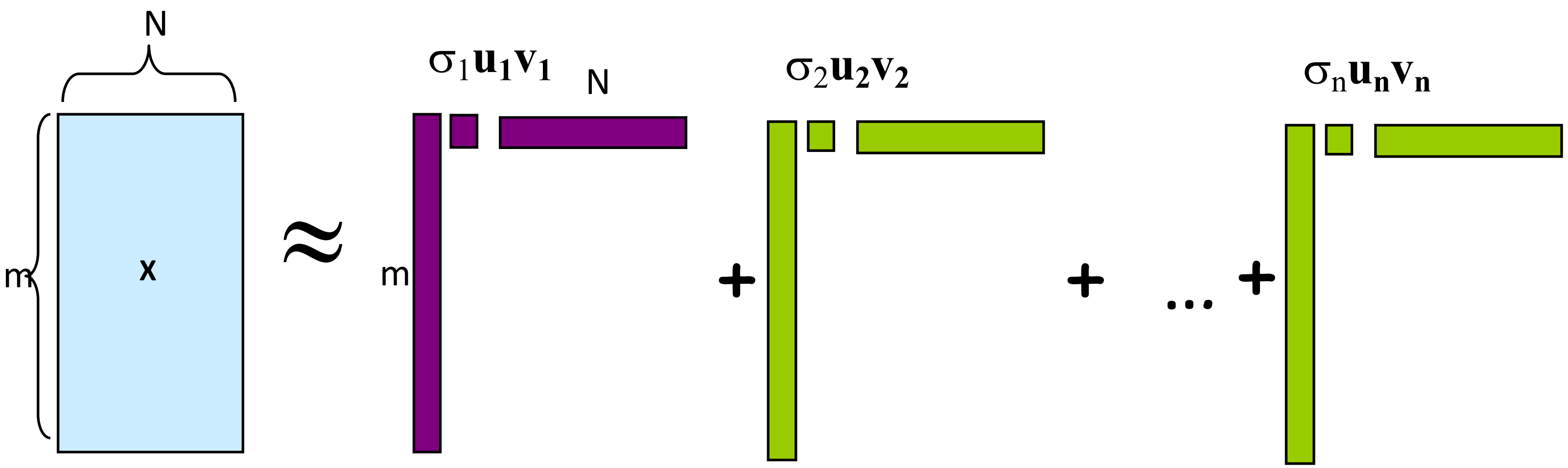




m: Preserve the **spatial information related at sensors**

N: Preserve the **temporal dynamic** behavior of each sensor

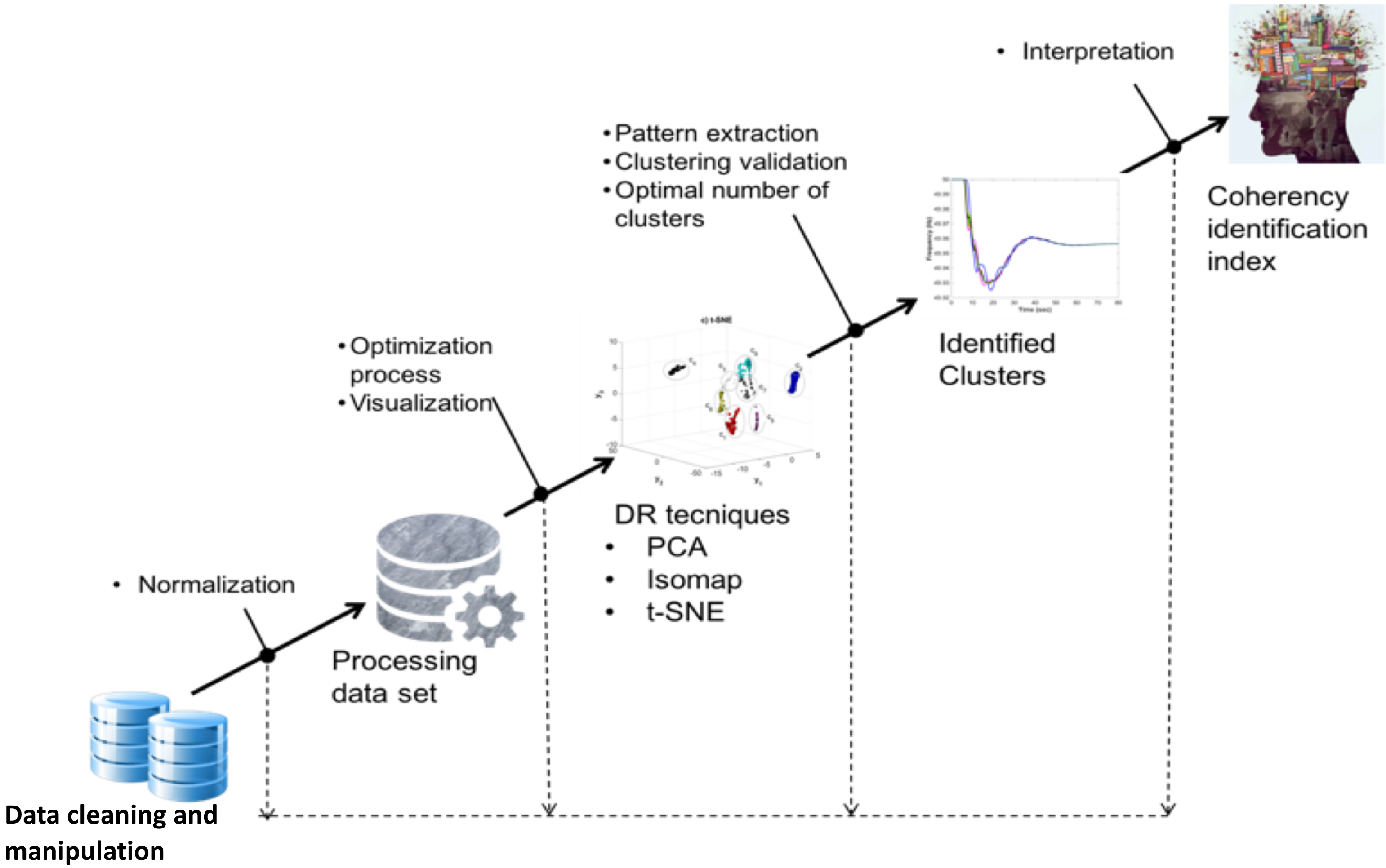
Powerful mathematical tools to analyze “big data” in PS …



Data-driving algorithm skills:

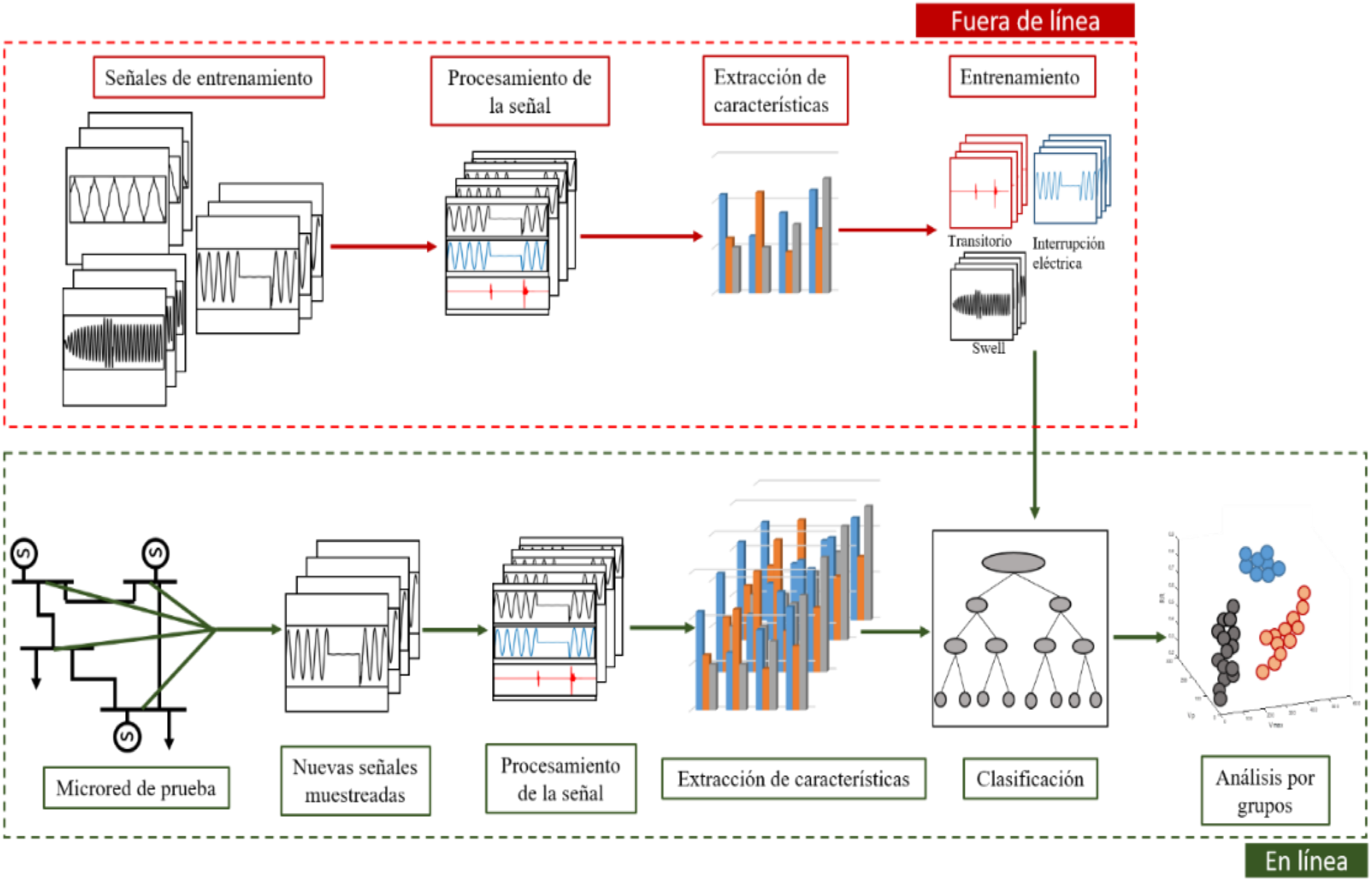
- Compression data
- Clustering data
- Prediction data
- Estimation data

Representation of the **architecture of LIS Analytics & Visualization**. This platform has been developed to optimize reliability and fast query retrieval.



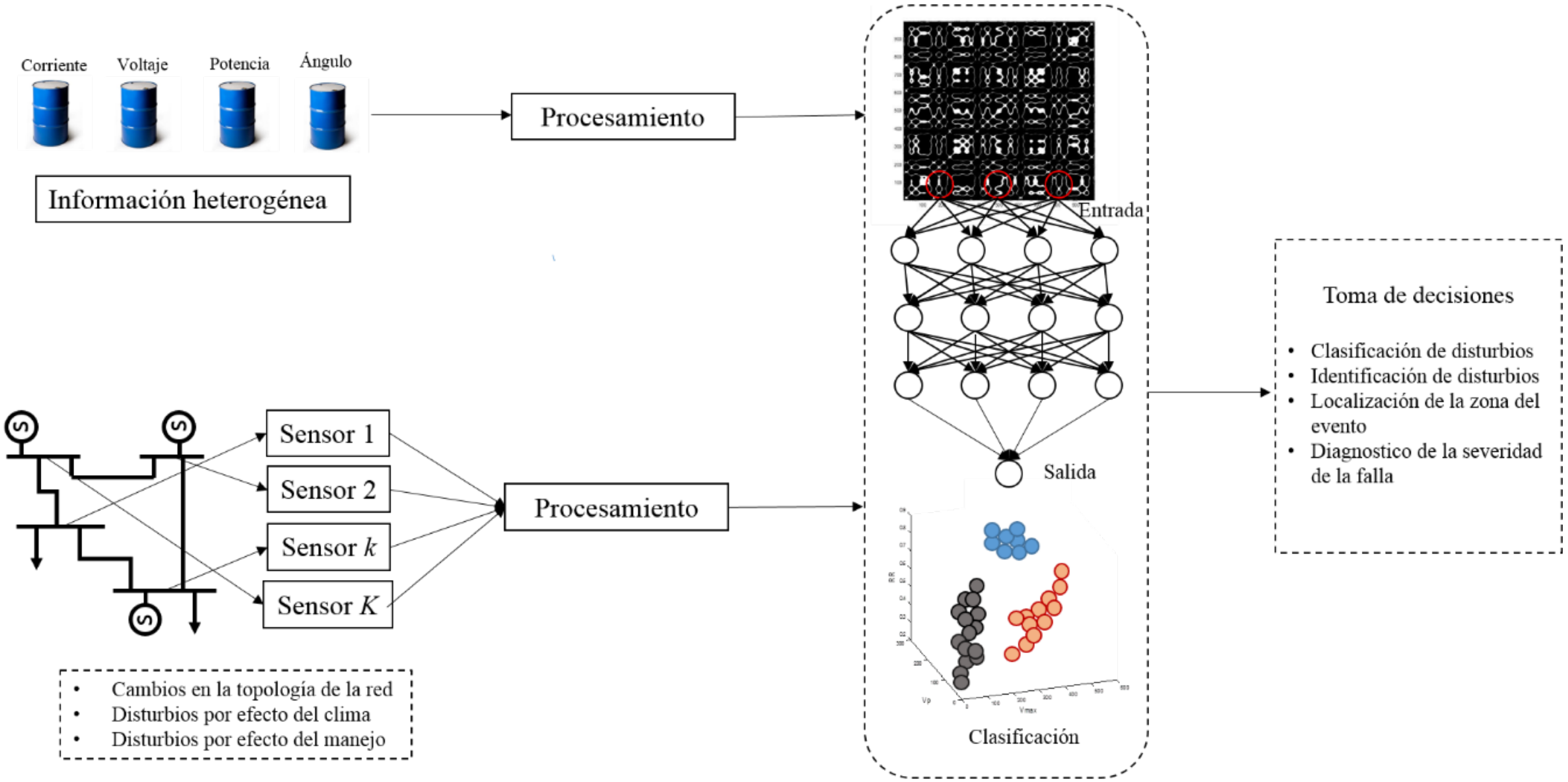
[*] Felix Rafael Segundo Sevilla, Petr Korba, Emilio Barocio, Walter Sattinger, "Data Analytic Tool for Clustering Identification based on Dimensionality Reduction of Frequency Measurements", IEEE International Conference on Smart Grid Synchronized Measurements and Analytics, Texas at Texas A&M University, ***2019.***

Unsupervised ML …

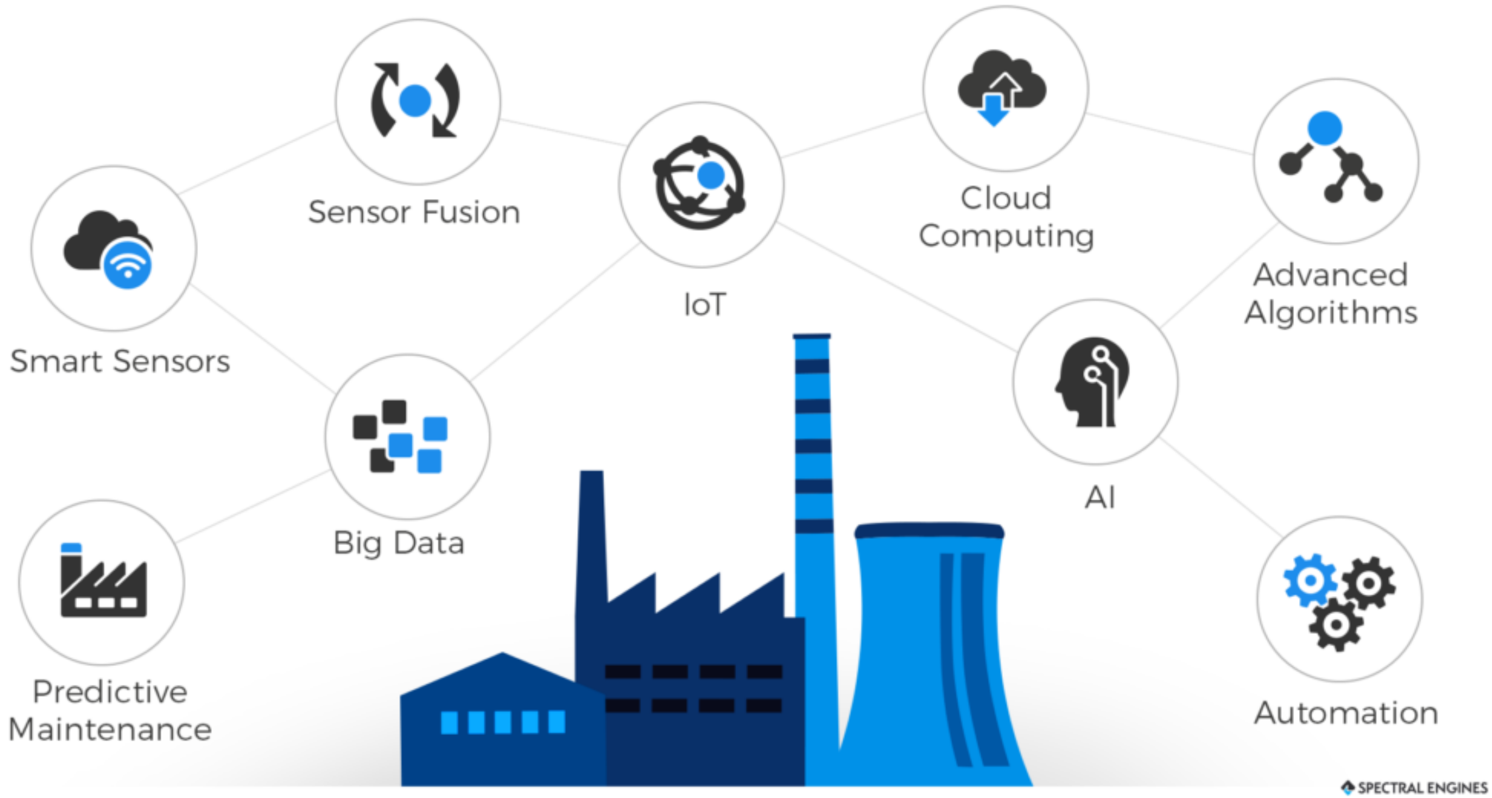


O. Cortes-Robles, Emilio Barocio, J. Segundo, D. Guillen, J.C. Olivares-Galvan, “A qualitative-quantitative hybrid approach for power quality disturbance monitoring on microgrid systems”, Measurement 2020.

Unsupervised Deep Learning …

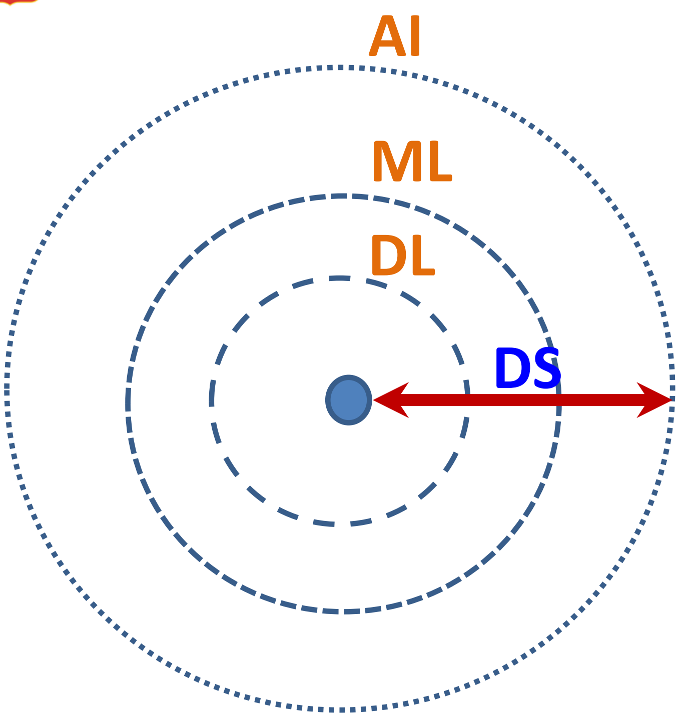


Background of the DS applied to power systems…



- Mathematics
- IoT
- Coding
- Data base handling
- **Expertise area of application**

AI vs ML vs DL vs DS



AI: Enable the machine to think

- Generalized-strong-superintelligence
- Particular-weak

ML: Statistical tools to explore and analyze the data:

- Supervised (Past leabed data)
- Unsupervised (Clustering)
- Reinforment (semi-supervised: some part of data are labeled and other part not)

DL: Multi neural network arquitecture:

- ANN
- CNN
- RNN

DS: Transversal knowledge of AI, ML, DL:

- Probabilidad
- Statistics
- Optimization
- Algebra
- ….

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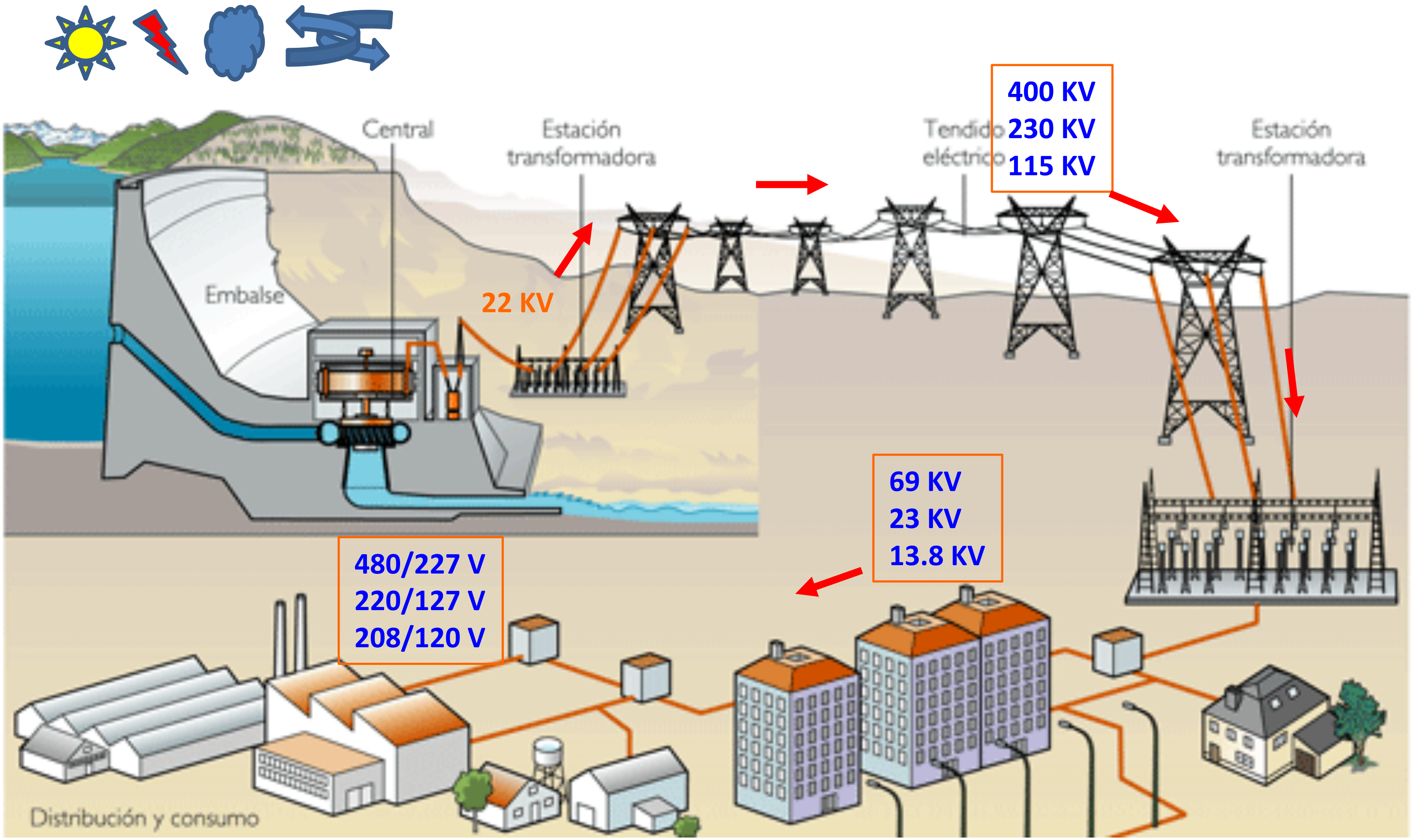
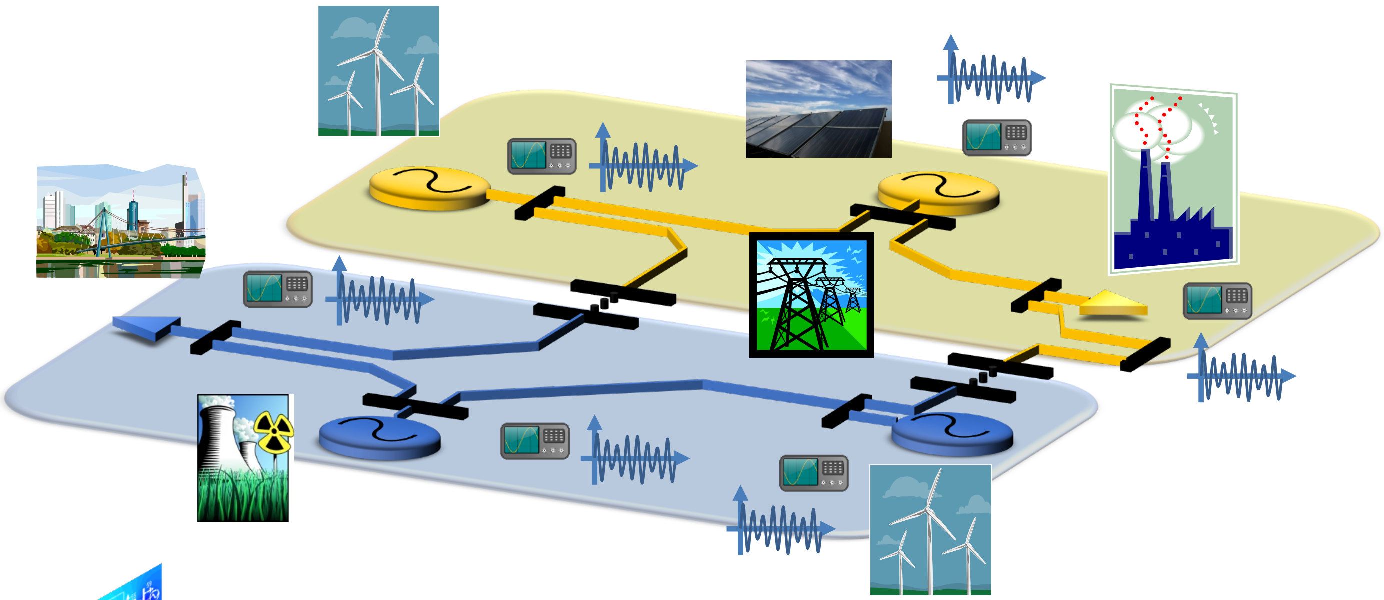
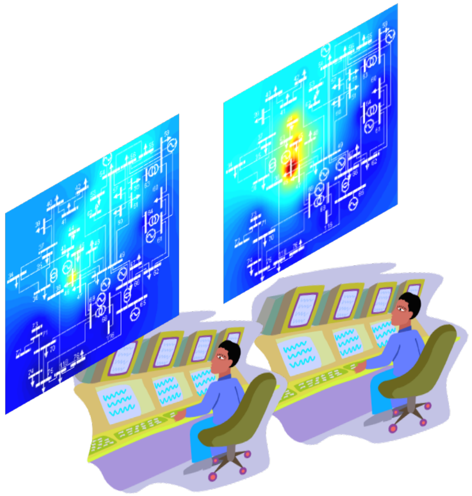
Electric power system



Tools for Electric power system





Power system monitoring:

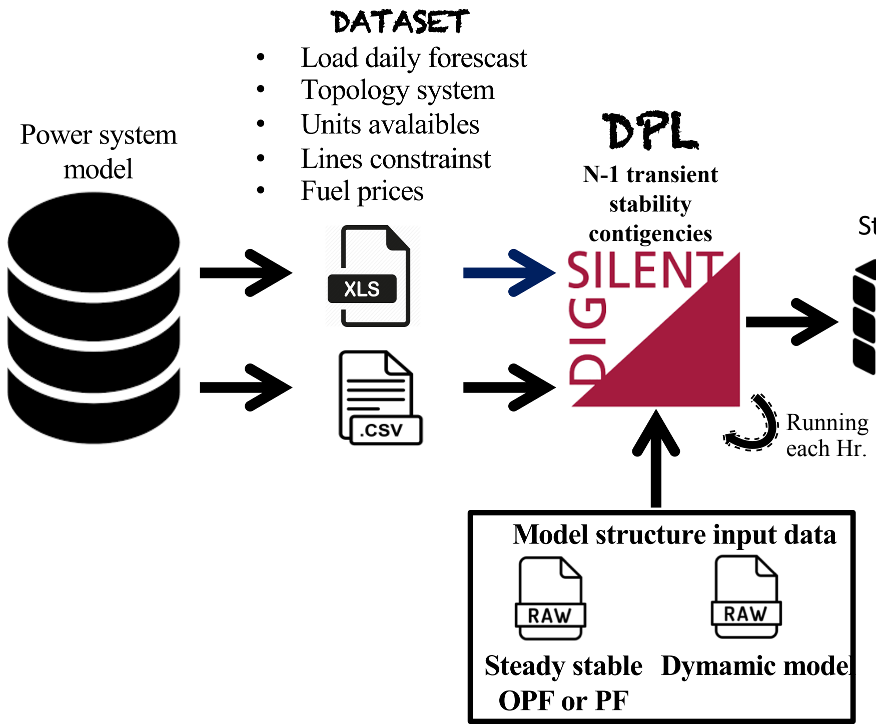
E1: Plug in tool for DSA (400-115 KV)

E2: Online coherency identification (400-115 KV)

E3: Power quality monitoring (69-13.8 KV)

E4: Smart building monitoring (120-220 V)

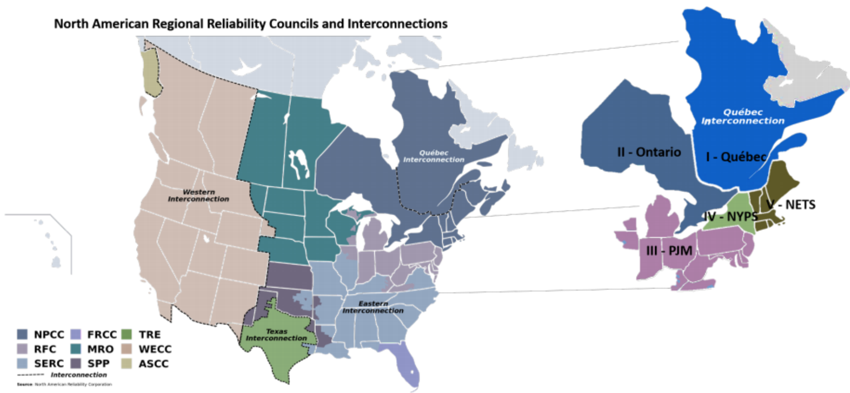
E1: Plug in tool for Dynamic Security Assessment

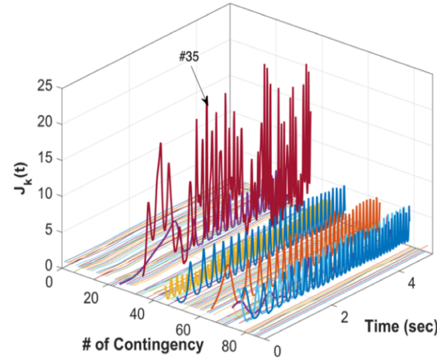


DSA Tool:

- Open source codig
- Plug in with professional software
- Intuitive global index
- Easy interpretation

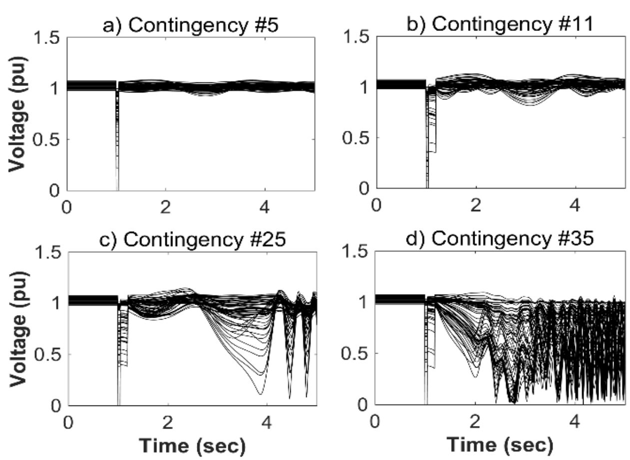
CENACE CENTRO NACIONAL DE CONTROL DE ENERGÍA **CEMIE**

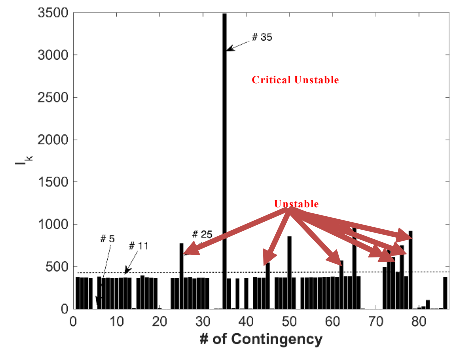


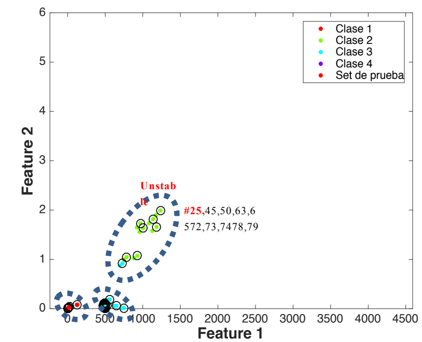


- The global index captures the average of time-varying dynamic behavior produced by each contingency.
- Identify the contingency that excite the electromecanical modes.

- 68 three faults are carry out at 50% of each transmission line. The datasets measurements from step-by-step simulations were simultaneously recorded over 5 seconds at a rate of 100 Hz.







- A global index can judge the severity of contingency events, because the entire energy is concentrated in this measure.
- Four stability statues are identify: Stable, critical stable, **unstable**, critical unstable power system operation conditions.

- **To verify** time-domains simulations for specific contingencies are display swissgrid

E2: Online coherency identification and stability condition

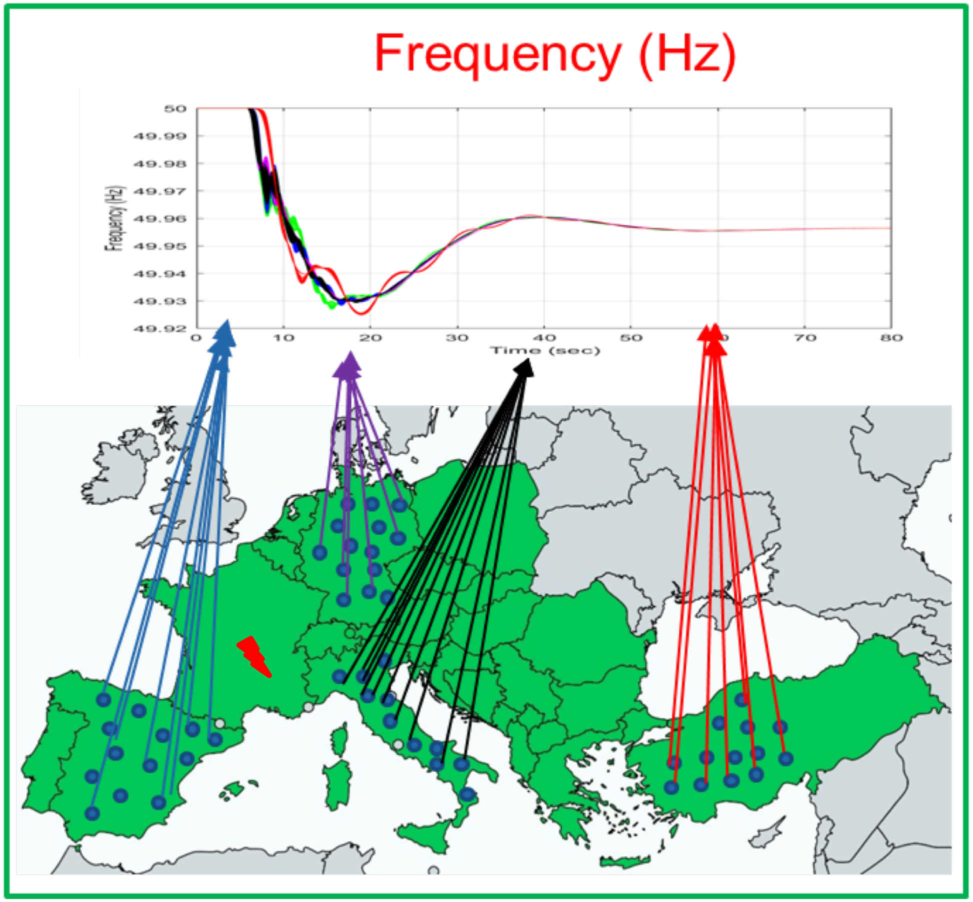
- To assess the severity of the system, 184 simulations are performed

- DigSilent PowerFactory version 15.2.1 developed by ZHAW and Swissgrid

- Comprehensive representation of the interconnected Continental Europe power system
- France, Germany, Italy, Greece and Spain are described in more detailed

Model Quick Facts:

23’000 Buses	**18’000 Loads**	**1’000 Syn Gen**



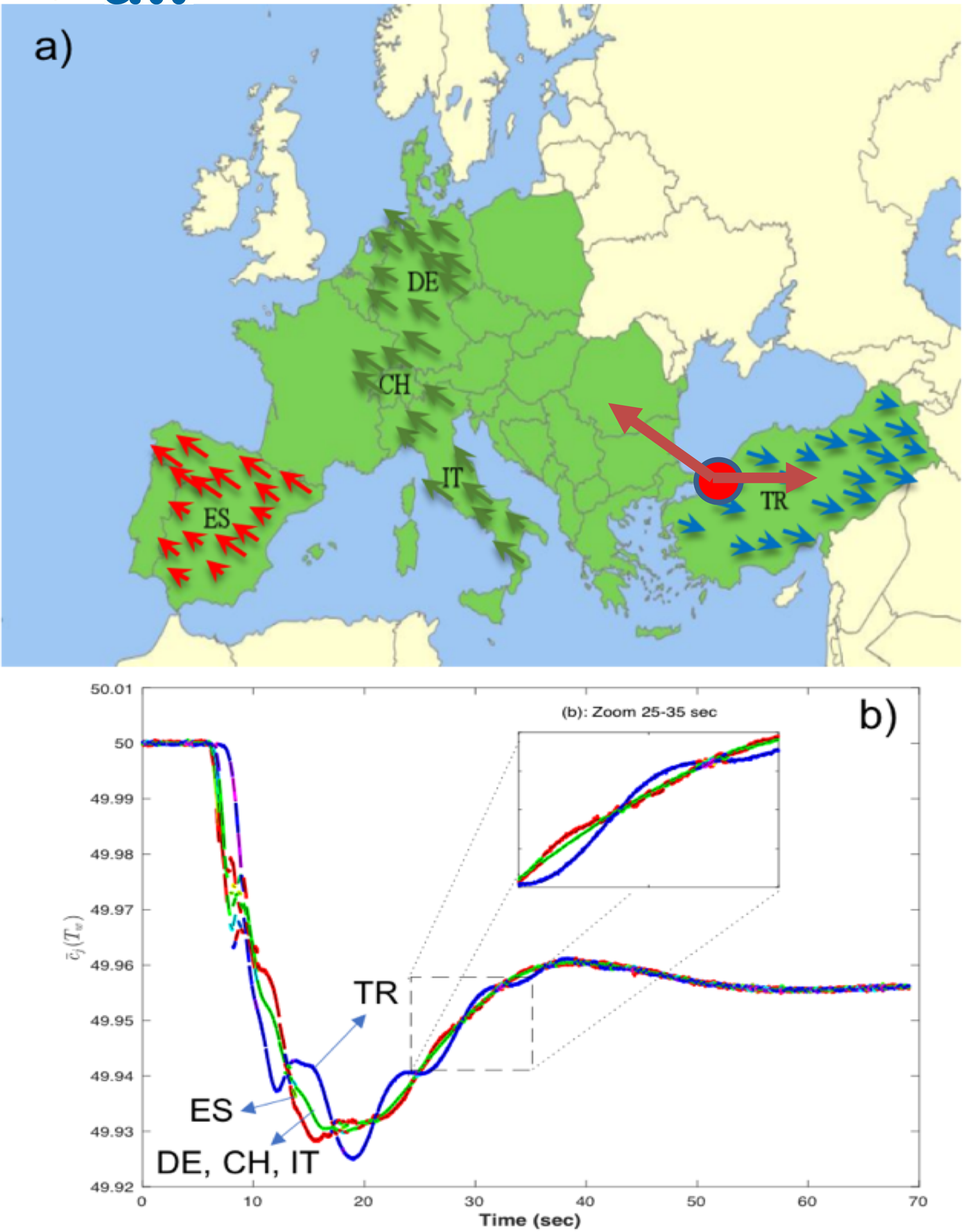
- Emphasis on following countries:
  - Spain (ES),
  - Germany (DE),
  - Italy (IT)
  - Turkey (TR)
- + **600 synchronous machines**
- Following outage of large gen unit
  - France (1.4 GW)

Emilio Barocio, Petr Korb, Walter Sattinge, Felix Rafael Segundo Sevilla, "Online coherency identification and stabilitycondition for large interconnected powersystems using an unsupervised data mining technique", IET Generation, Transmission & Distribution, **2019**

Table 1 Number of synchronous generators per country and their total active power generation in GW

	Germany (DE)	Italy (IT)	Spain (ES)	Turkey (TR)
Num. Gen	292	144	70	127
Total GW	53.014	20.241	26.195	36.403

Geographical location of evolving clusters …

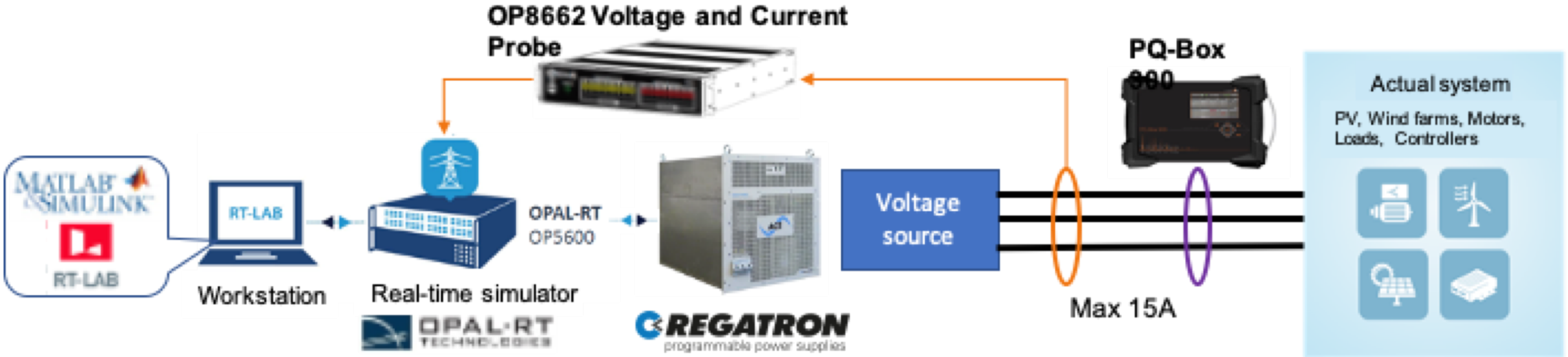


- Online (**1/4sec**) visual dynamic information to awareness the power system stability status and evolving oscillatory coherency phenomenon mechanism is provided.
- A security index based on clustering can be used for online islanding detection.

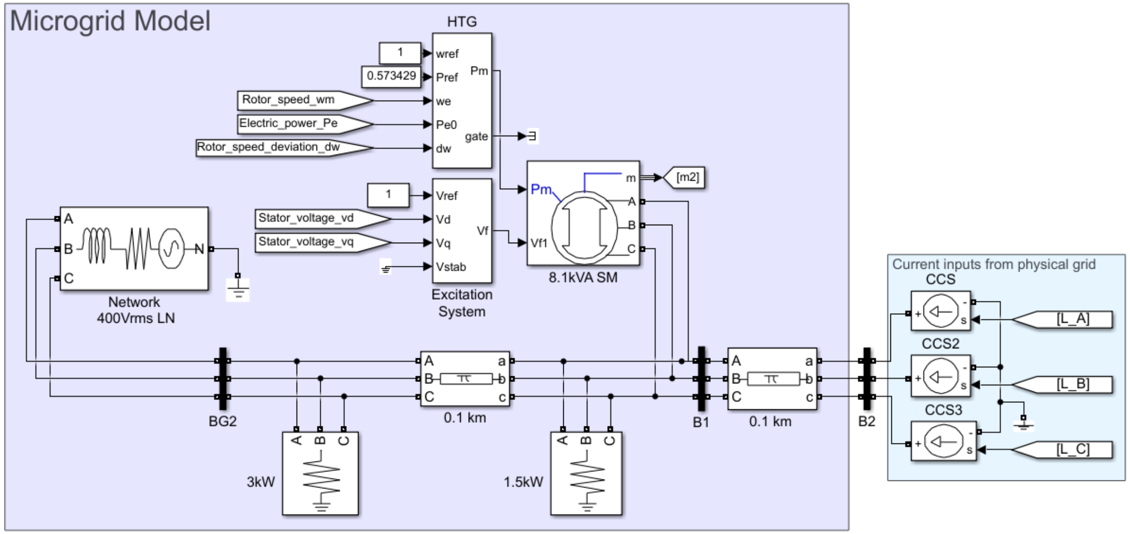
(a) Geographical location of clusters

(b) Online slope clustering.

E3: Power quality monitoring by unsupervised ML…

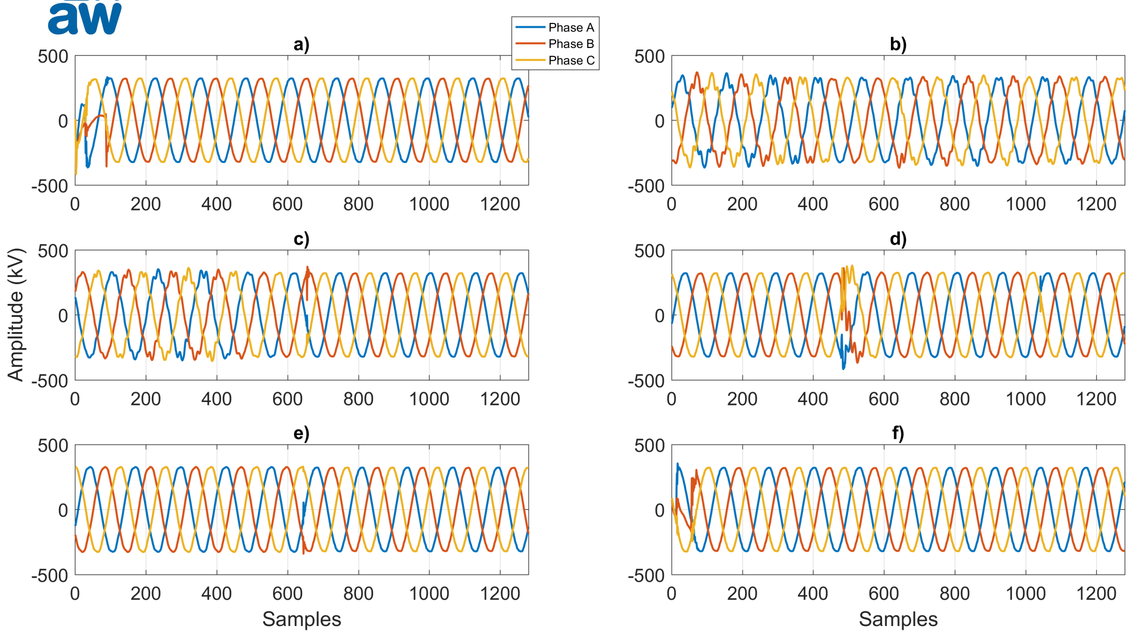


The synchronous machine is from Simulink library with 50Hz 400V 8.1kVA 1500RPM the corresponding parameters.

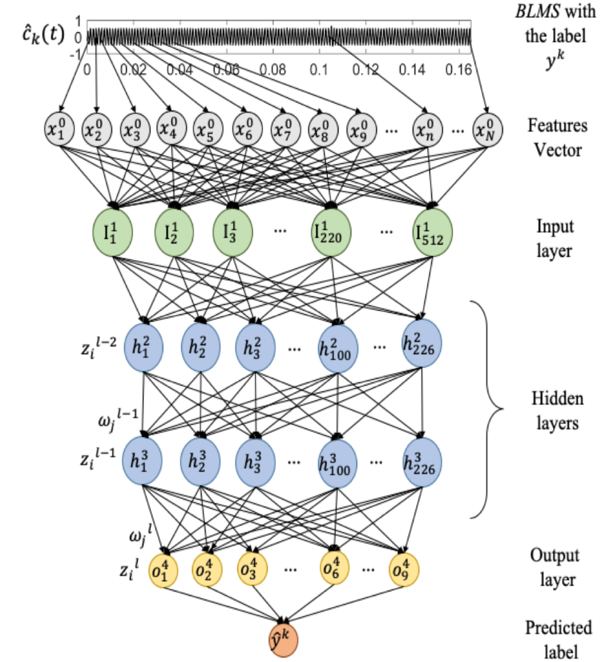


- The system under investigation works with a frequency of 50 Hz with a sampling frequency of 40.962 kHz.
- The recorded signals are first re-sampled to 6.4 kHz to match the number of samples as in the training process.
- Then, 10 cycles of the recorded signals are analyzed using the proposed approach.PCC

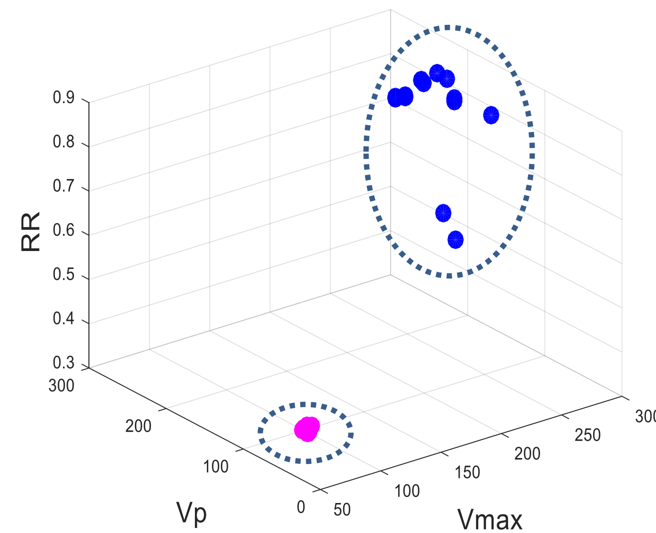
O. Cortes-Robles, Emilio Barocio, Artjoms Obushevs, Petr Korba, and Felix Rafael Segundo Sevilla, "Fast-training feedforward neural network for multi-scale power quality monitoring in power systems with distributed generation sources", *Measurement*, **2021**



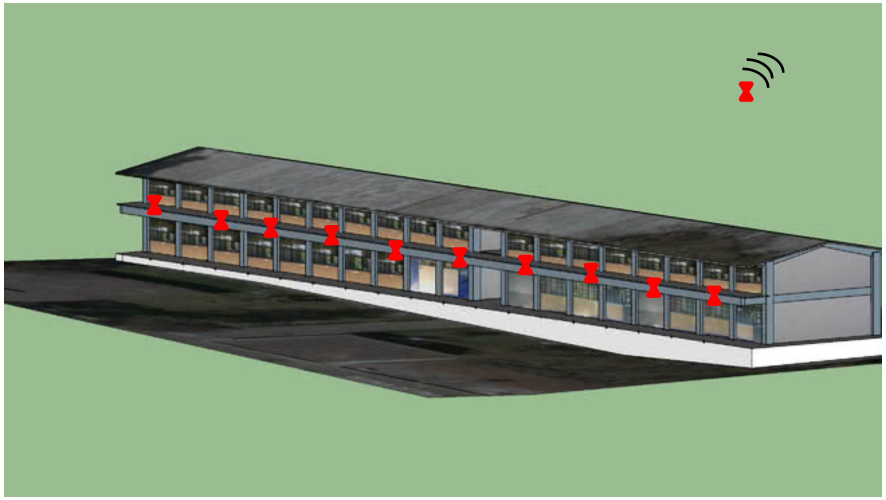
a) PV connection to the grid, b) PV synchronisation to the grid, c) PV tripping from the grid, d) Capacitor switch on e) Capacitor switch off, f) Load connection to the grid

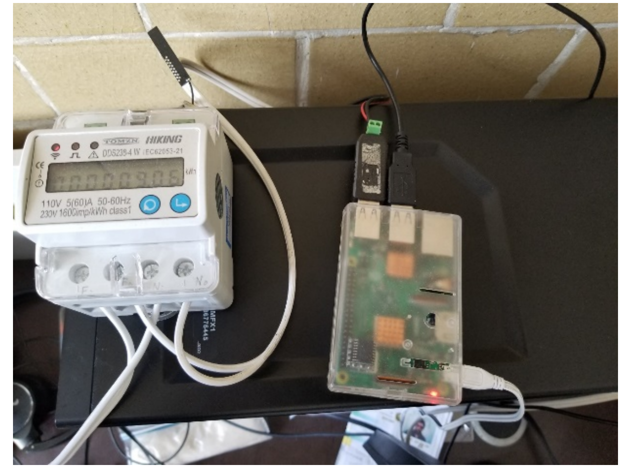


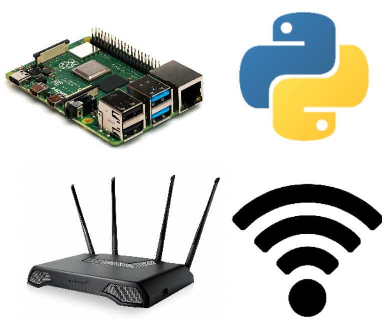
Parámetros para generar los disturbios que forman la librería		
Disturbio	Duración	Magnitud de voltaje
Sag	1 ciclo - 6 ciclos	1.1 pu – 1.4 pu
Swell	1 ciclo - 6 ciclos	0.9 pu – 0.6 pu
Impulso	< 1 ms	1.2 pu – 1.5 pu
Transitorio	< 50 ms	< 4 pu
Interrupción eléctrica	3 ciclos - 6 ciclos	< 0.1 pu
Armónicos		< 0.3 pu
Notch		< 0.1 pu
Estado estable		1 pu



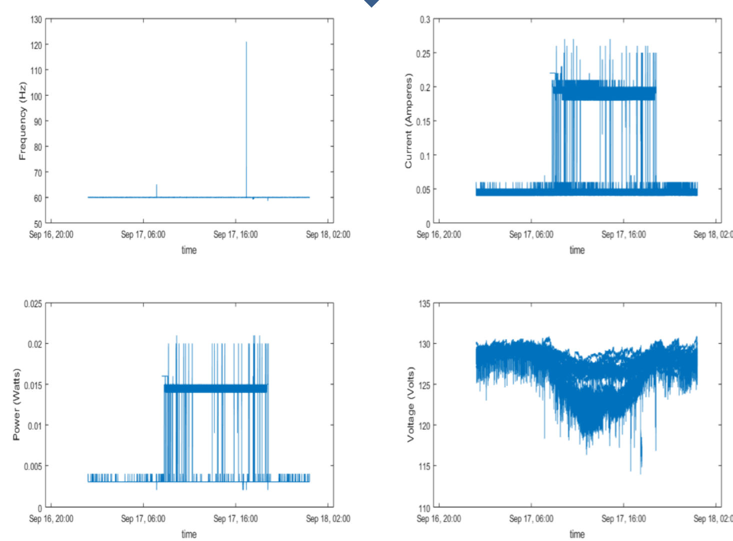
E4: Smart building monitoring low cost and data free analysis platform…







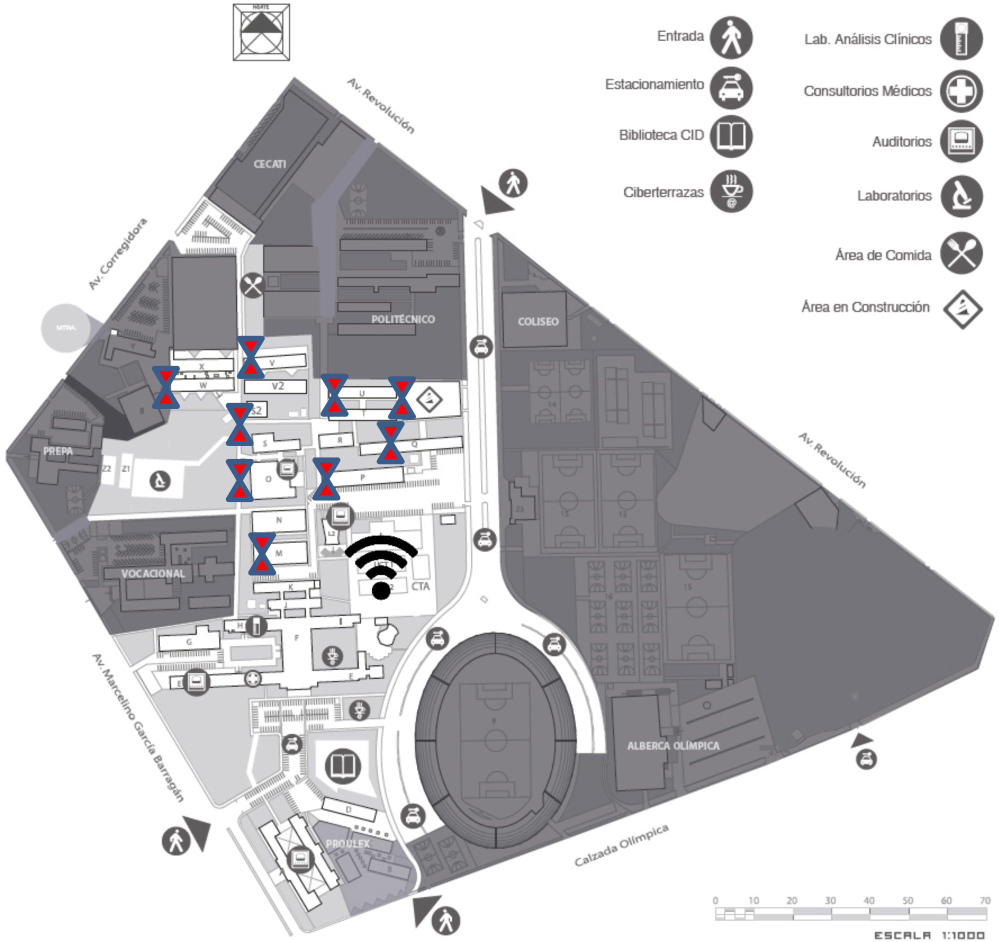
$50,000



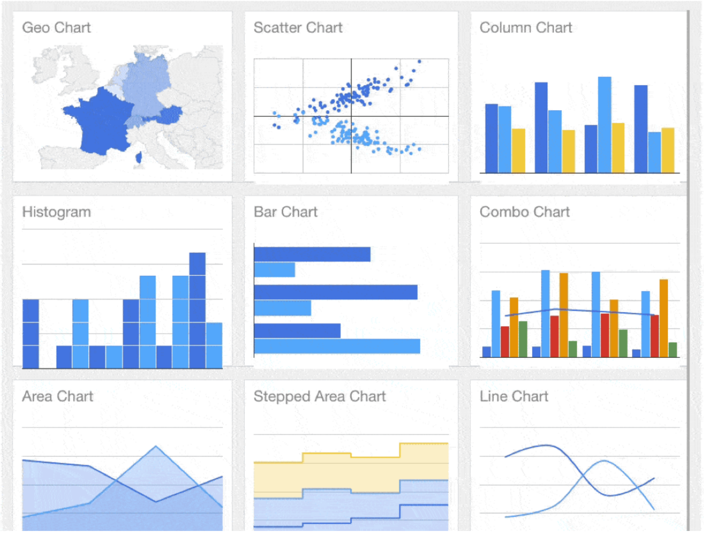
Ernesto Beltran, J. Guadalupe Fuentes, Emilio Barocio, Cesar Angeles b., “Unsupervised machine learning method to detect and classify anomaly voltage dips in distribution Systems”, in process 2021.

Data analytic platform:

- Data Compression
- Data clustering
- Data prediction
- Data Estimation



Visualization data: Representation of data inform of charts, diagram etc…



Agenda

1. Challenges on to power systems
2. Data science in power systems
3. Tools based in data science algorithm.
4. **Final remarks and future steps**

1. Develop of DA tools that allows correlate weather & electrical data.

2. Incorporation of novel and innovative algorithms in the control room of transmission system operators to facilitate the decision making, find the stability margins.

3. The open-free software such that: Python and R open an important opportunity to develop more advance tools due to flexibility to interact with professional software.

4. DA engineers with background in power systems & data analytic are begin demand by the electrical industry