Politecnico di Torino

A Crash introduction to Power Systems

Smart Electricity Systems

A.Y. 2025- 2026

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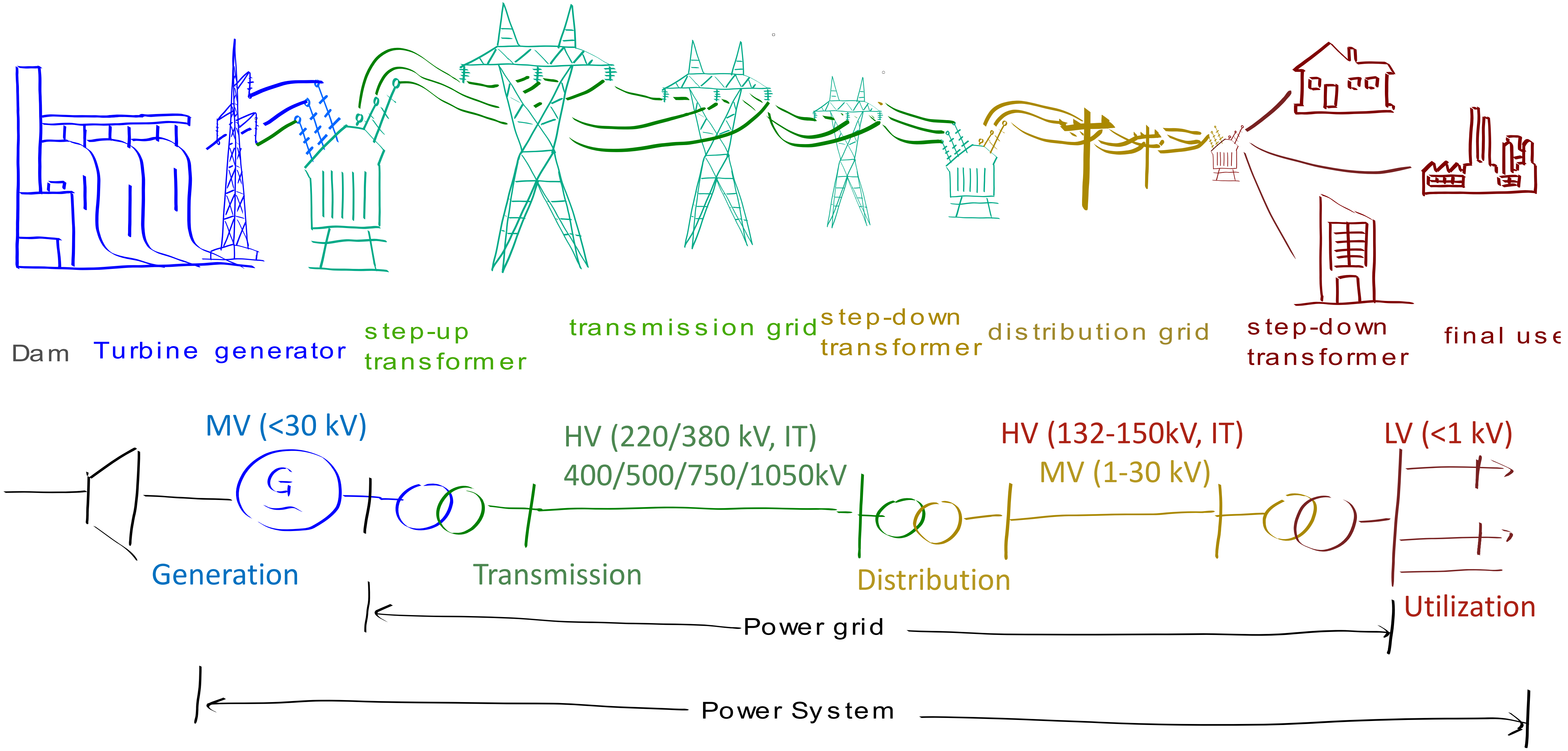
Outline

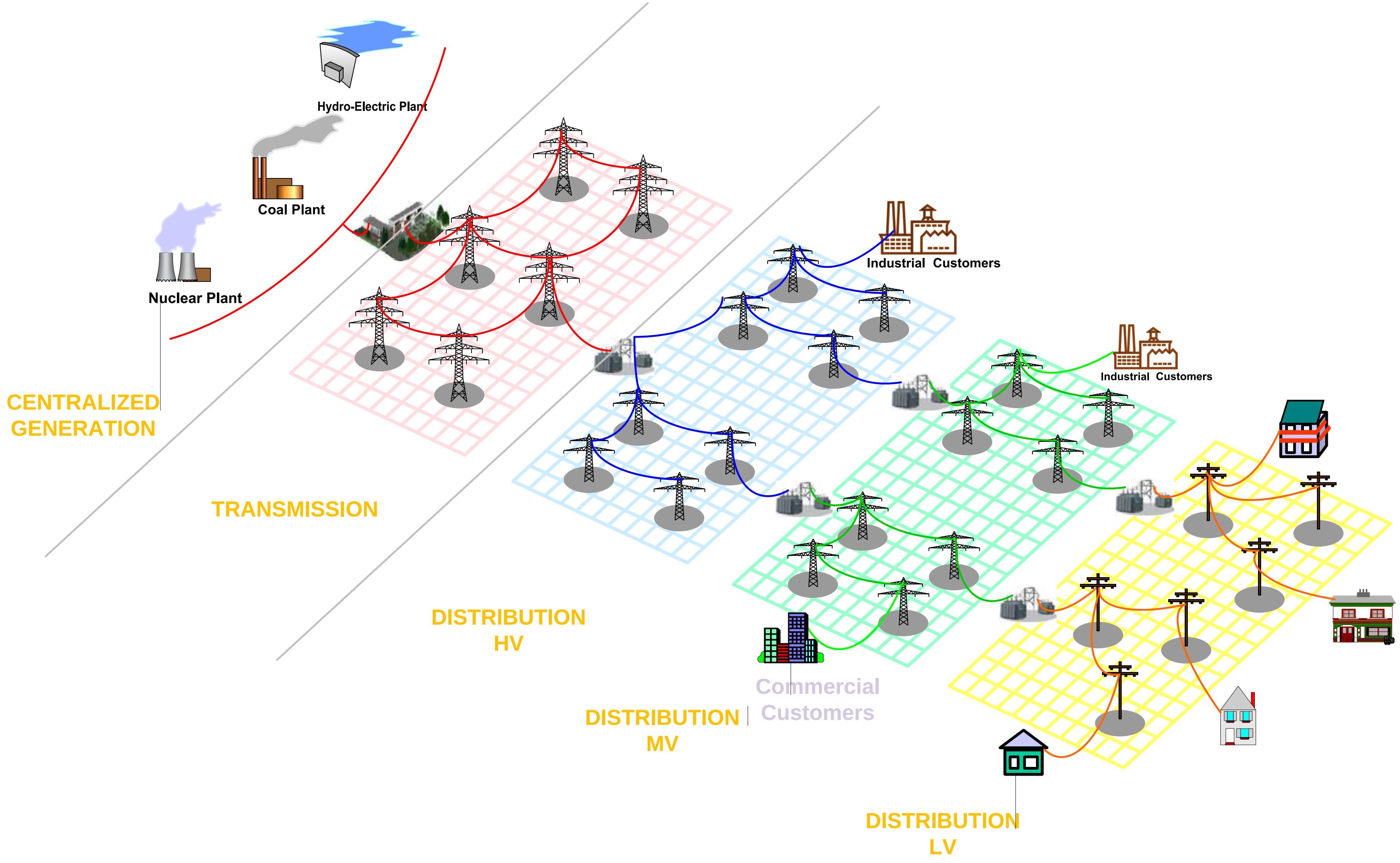
- Definition of (Traditional) Power Systems
- Evolution of power systems
- Peculiarity of power systems
- 3 phases and powers in power systems
- Smart electricity systems
- Examples of smart applications

Definition of (traditional) power systems

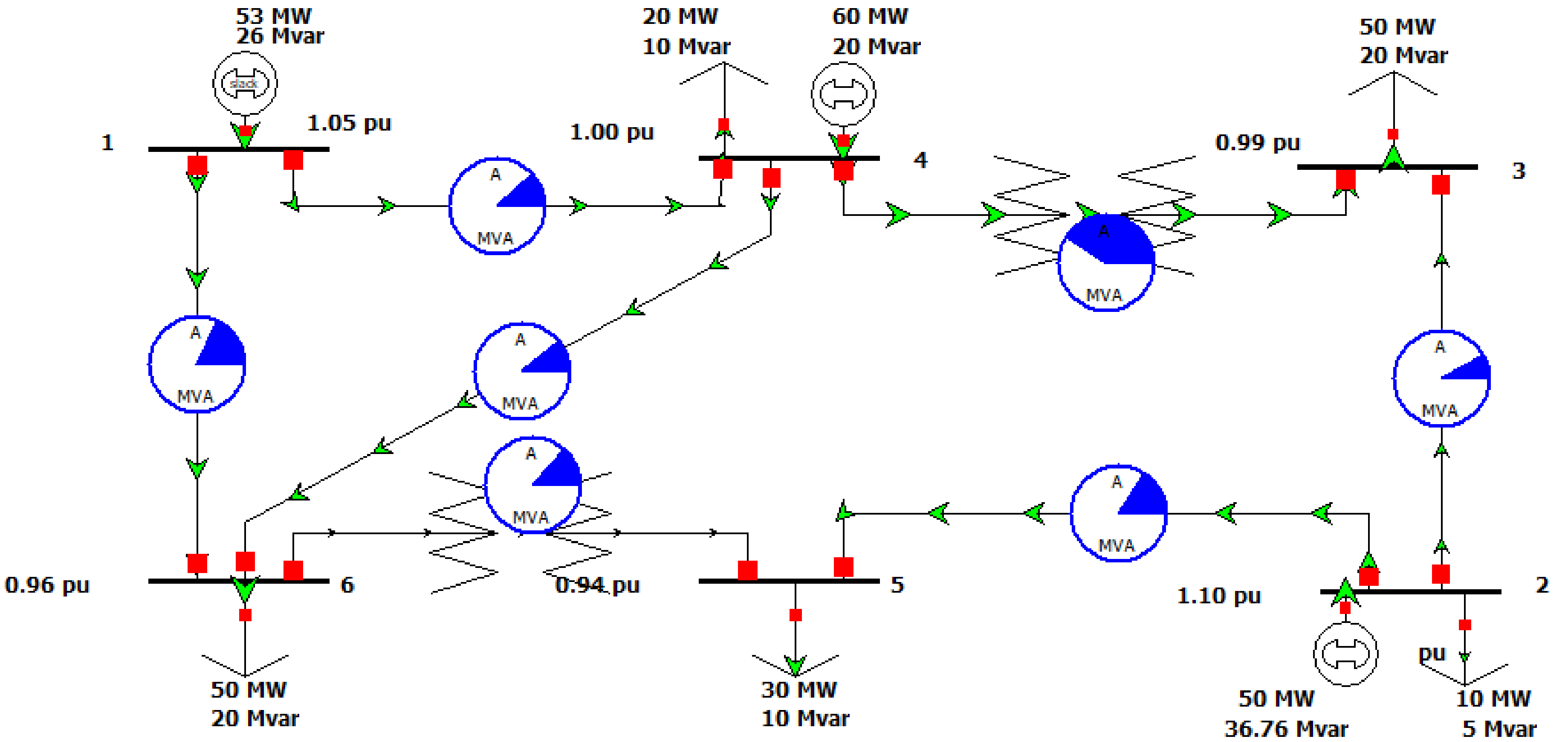
Power systems



Traditional centralized power systems

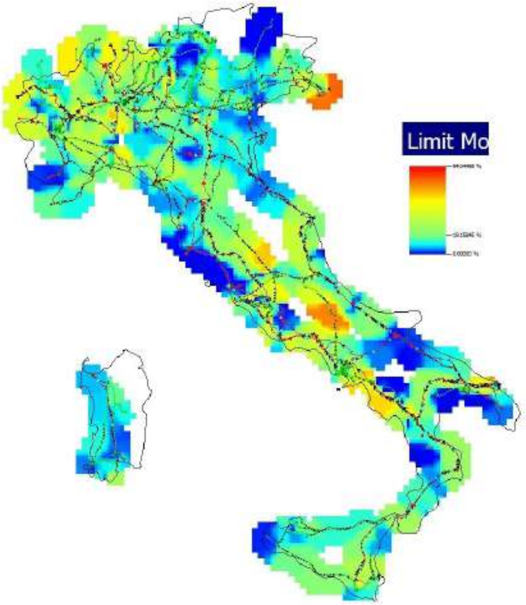


One-line representation of power systems

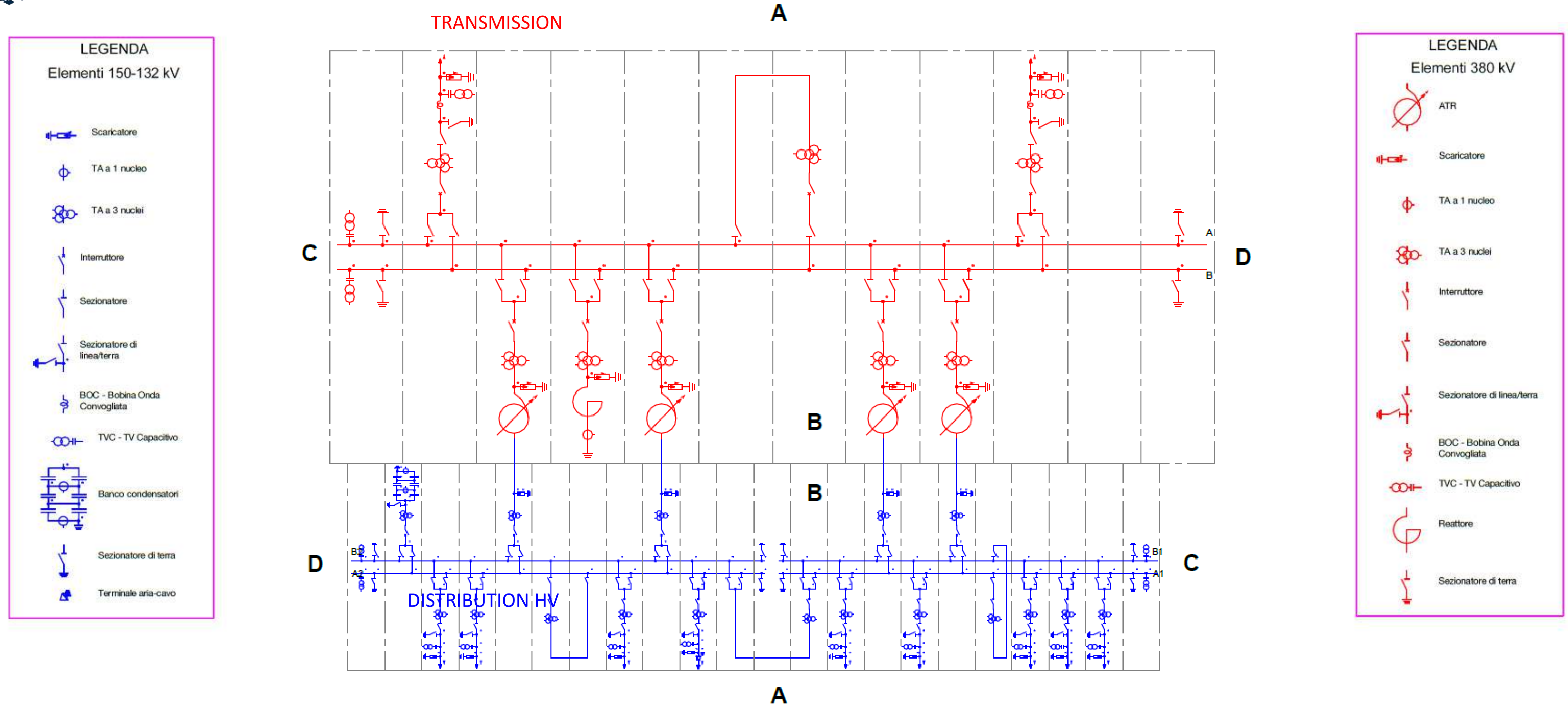


- Q: How many voltage levels do we have in the graph?
- Q: What is the voltage magnitude at each bus?

Italian transmission grid



Inside a substation



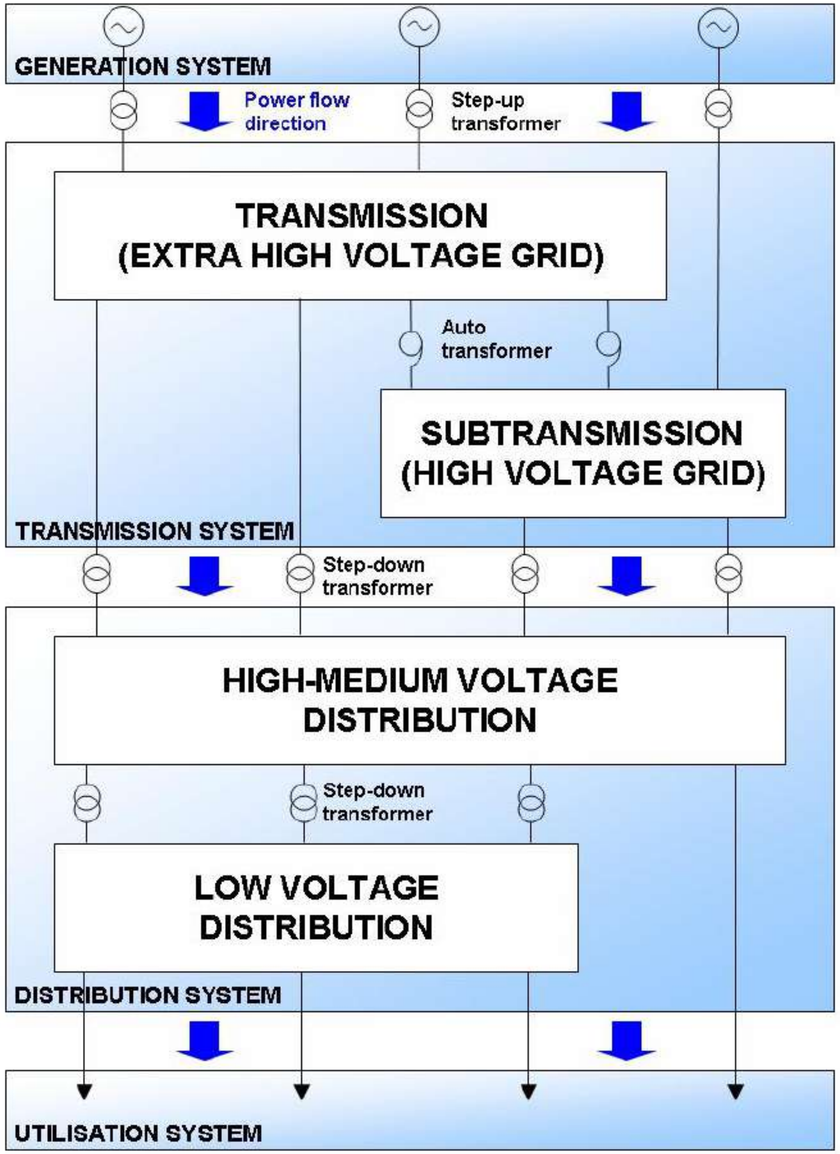
- Q: Can you recognize a bus in the graph?

Rondissone substation (example)

- Try by yourself:

https://www.openstreetmap.org/search?query=Rondissone#map=16/45.2337/7.9371
https://www.google.com/maps/@45.2334268,7.9356189,201m/data=!3m1!1e3

Power systems with subsystems



Evolution of power systems

The Grid's Evolution

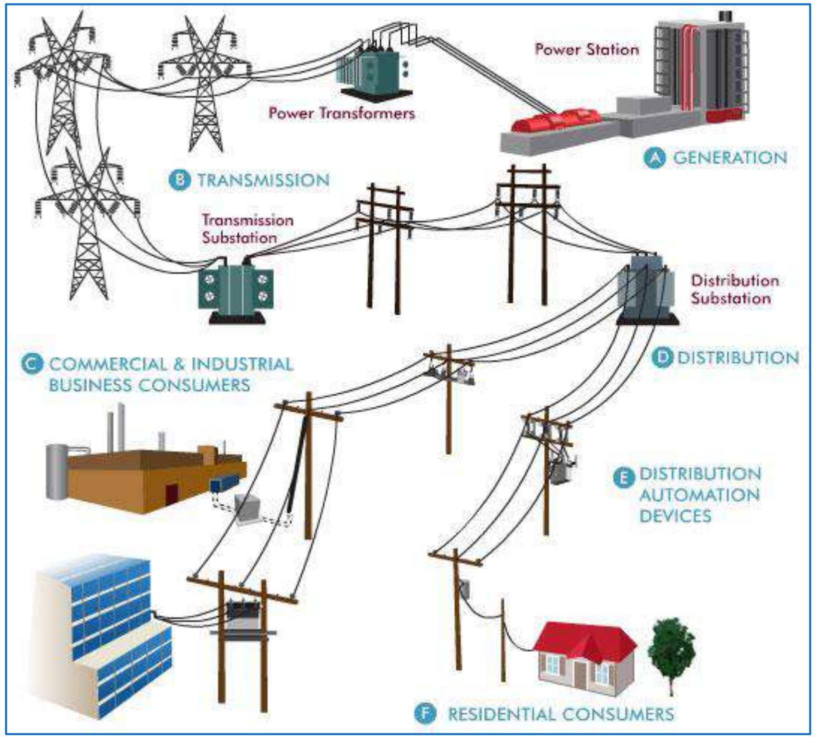


Image source: Smart grid in Europe is all about renewables

- Unidirectional flow
- Centralized control
- Passive consumers
- Limited data

•**Climate goals** (Net Zero → Need for renewables).
•**Digital revolution** (IoT, cloud computing, AI).
•**Rise of prosumers** (Rooftop solar, EVs, home batteries).

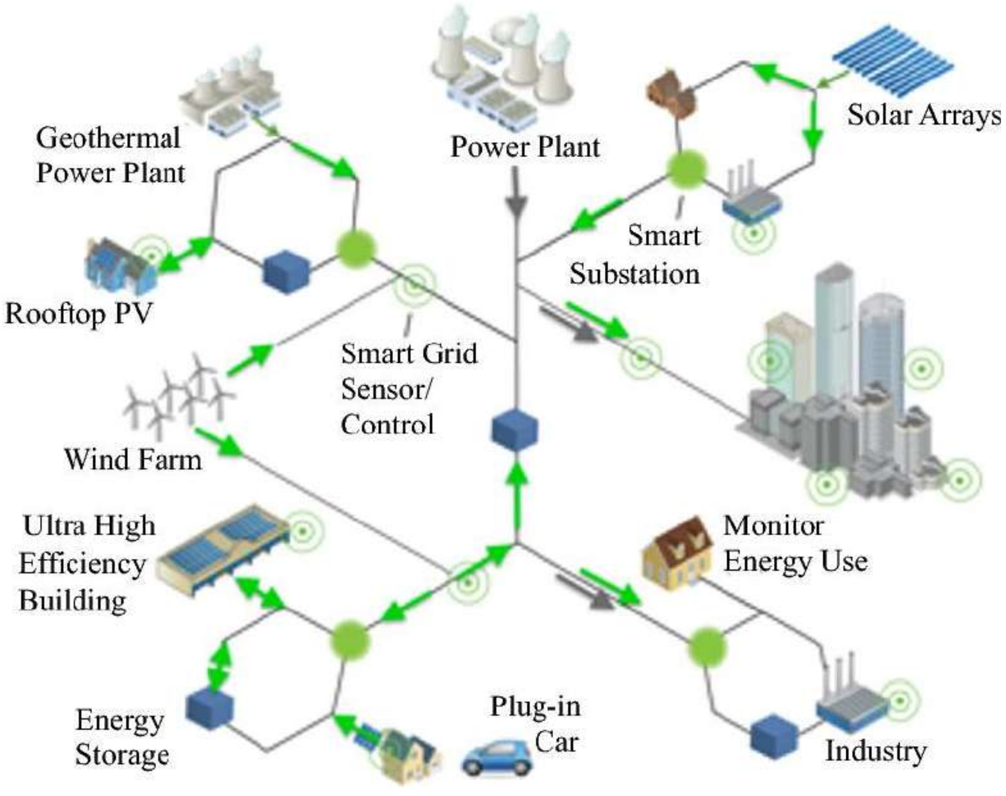
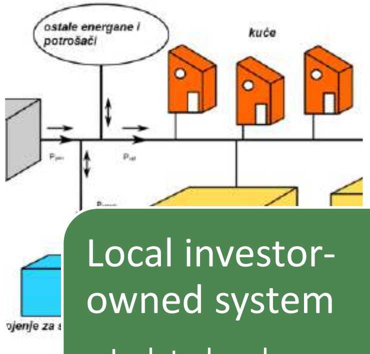


Image source: Integration of energy systems

- Bidirectional flows
- Distributed control
- Active prosumers
- Data-driven decisions

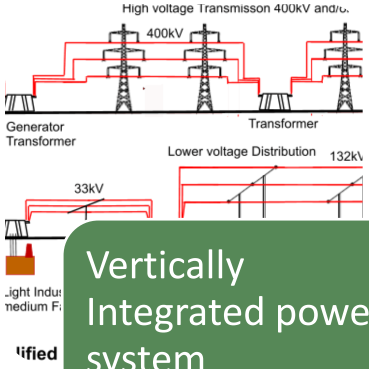
- Enhanced resilience
- Situational Awareness
- Deep integration of RES
- Energy digitalization

Evolution of the grids



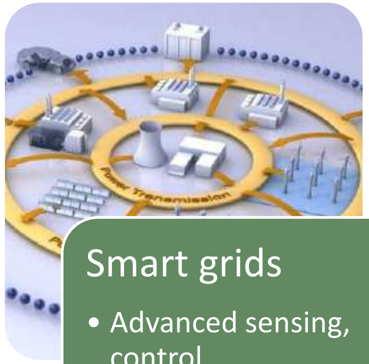
Local investor-owned system

- Isolated and independent



Vertically Integrated power system

- Connected to each other
- Highly centralized and regulated



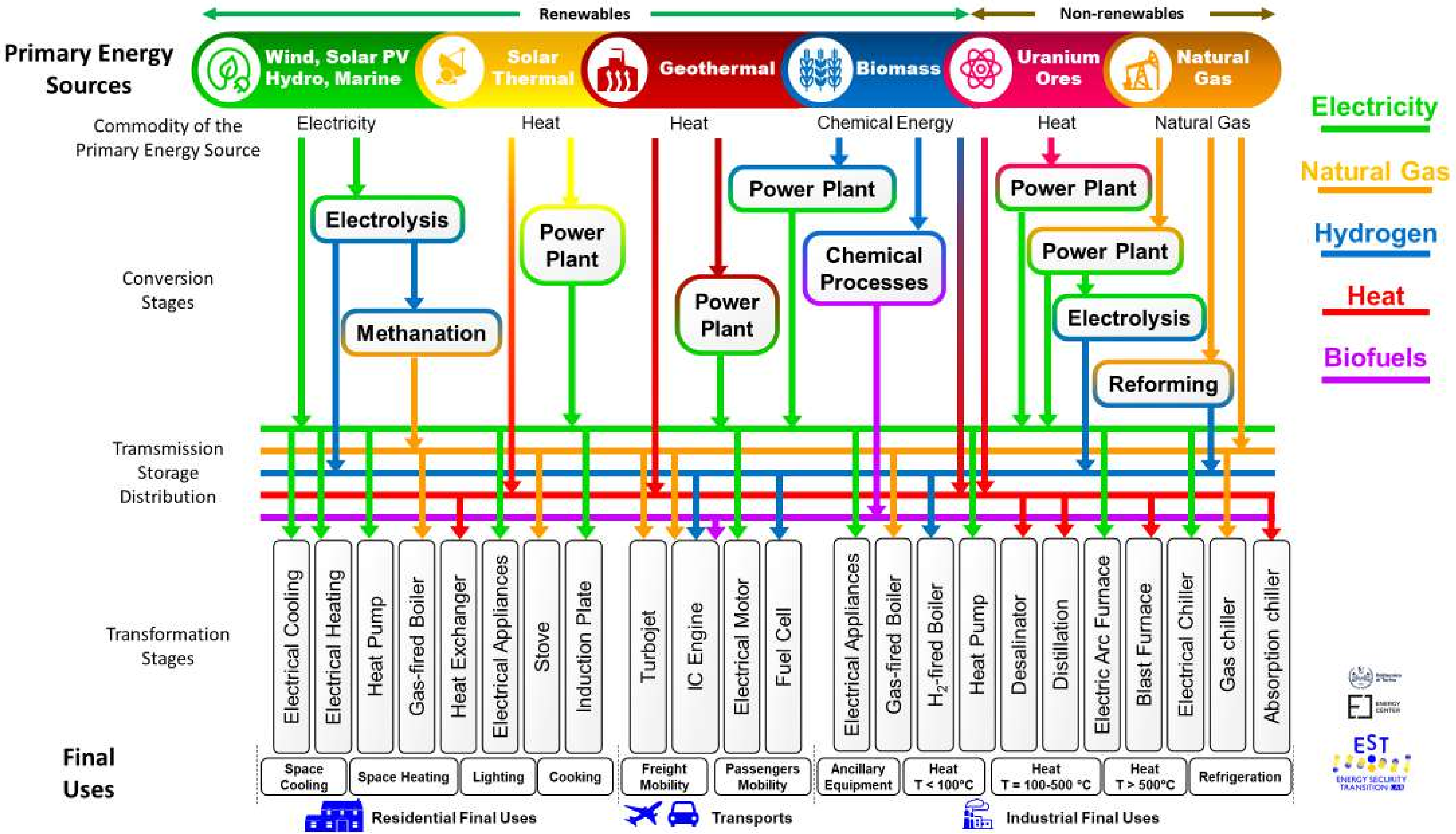
Smart grids

- Advanced sensing, control, communication
- Emerging new features

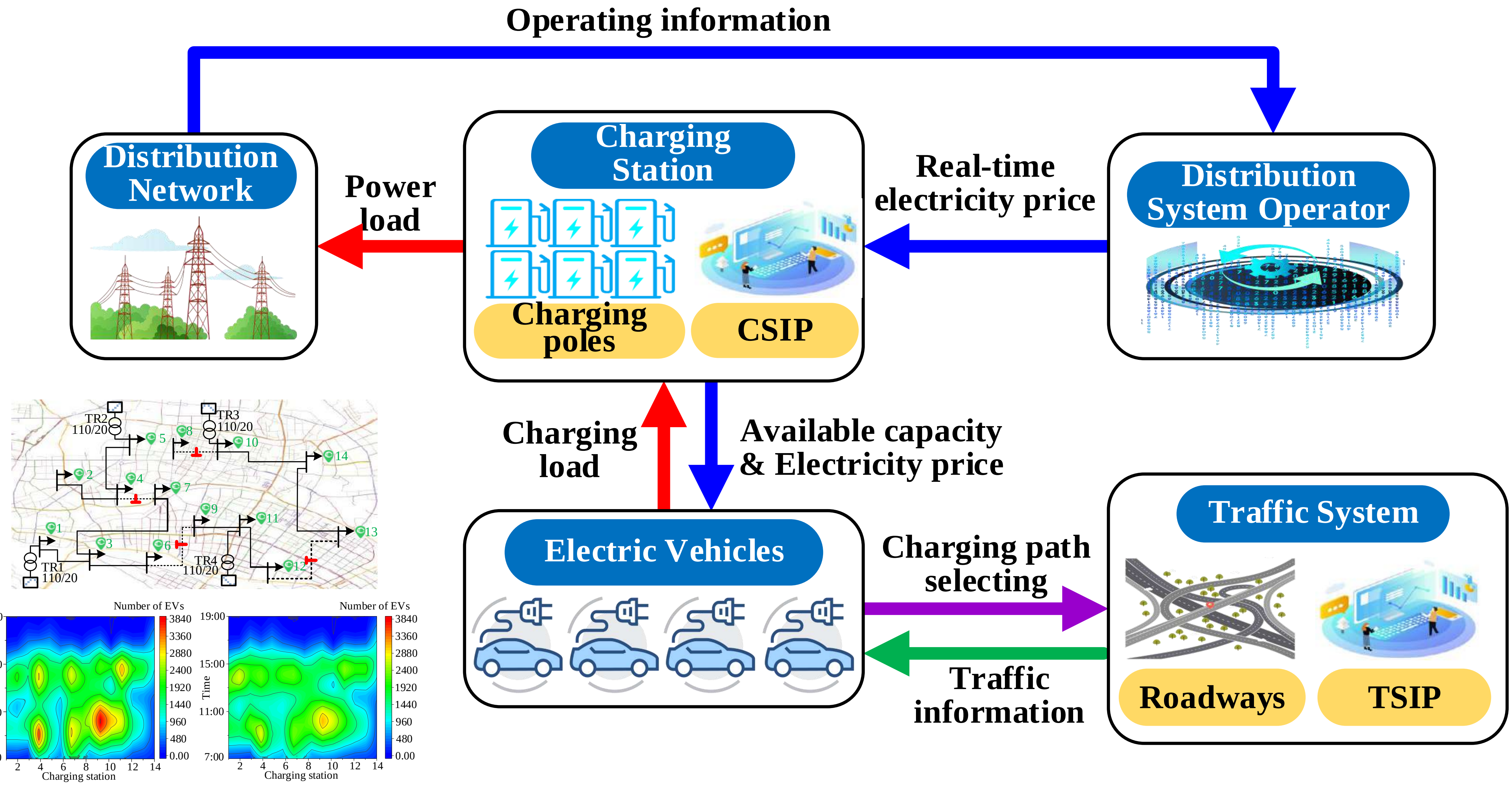
(Next generation smart grids) Energy internet

- Info-energy net
- Prosumer based
- P2P trades
- IoT
- Multiple energy systems

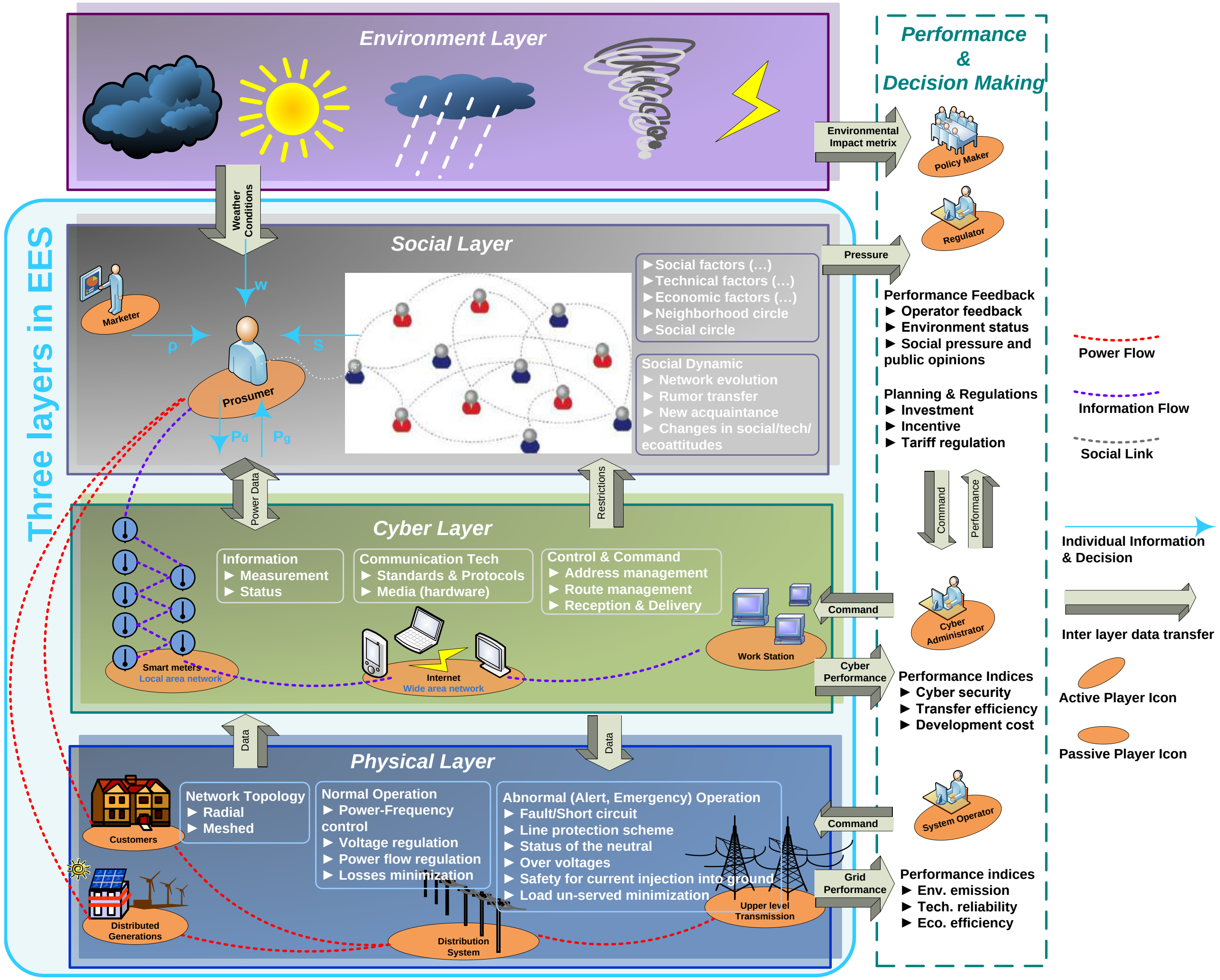
Multi-energy flow and products



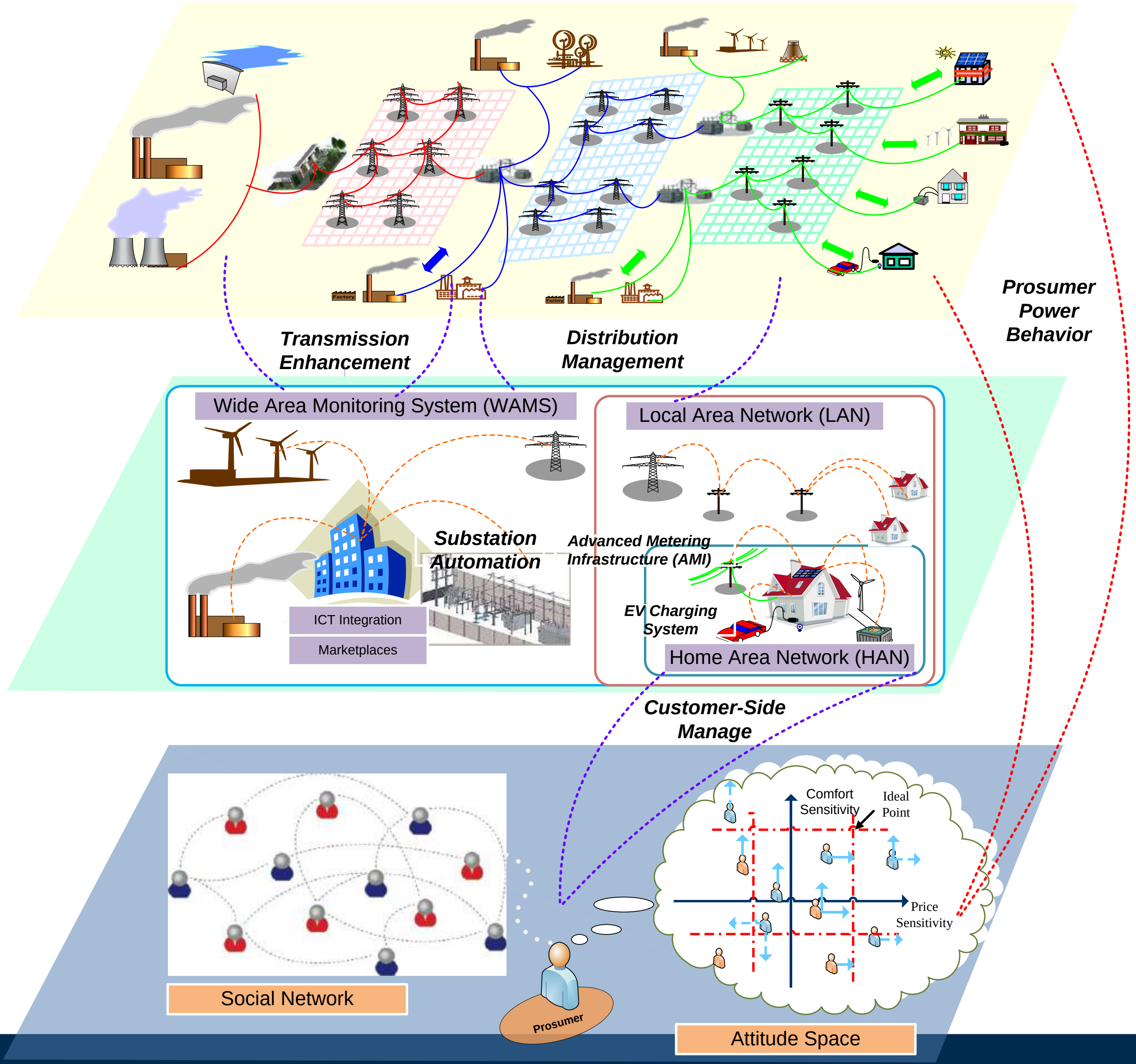
Interoperability with other infrastructures: Transport



Multilayer interactions in emerging distribution systems



Networked electricity society



- ***Power Network***

Network of energy (power) flows

WAMS LAN

- ***Cyber Network***

Network of Communications (information flows)

HAN

- ***Social Network***

Network of People (power consumers, prosumers) define and update power behaviors

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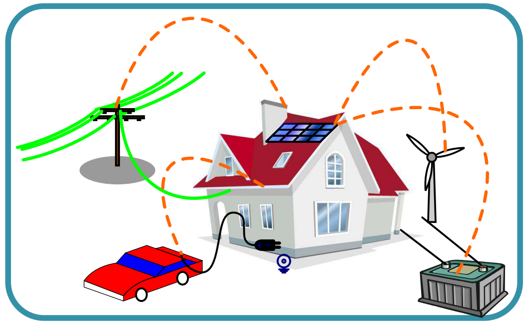
Interconnections of micro-grids/smart grids

By exploring all the bricks with physical/communication from prosumer side toward distribution, we list the components and highlight power/communication interface…

Networked Prosumer



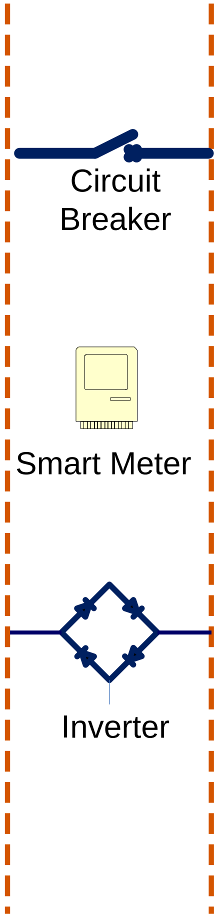
- Networked Prosumer in LV or MV distribution system

- Bus for communication and control among devices, separated from power flows

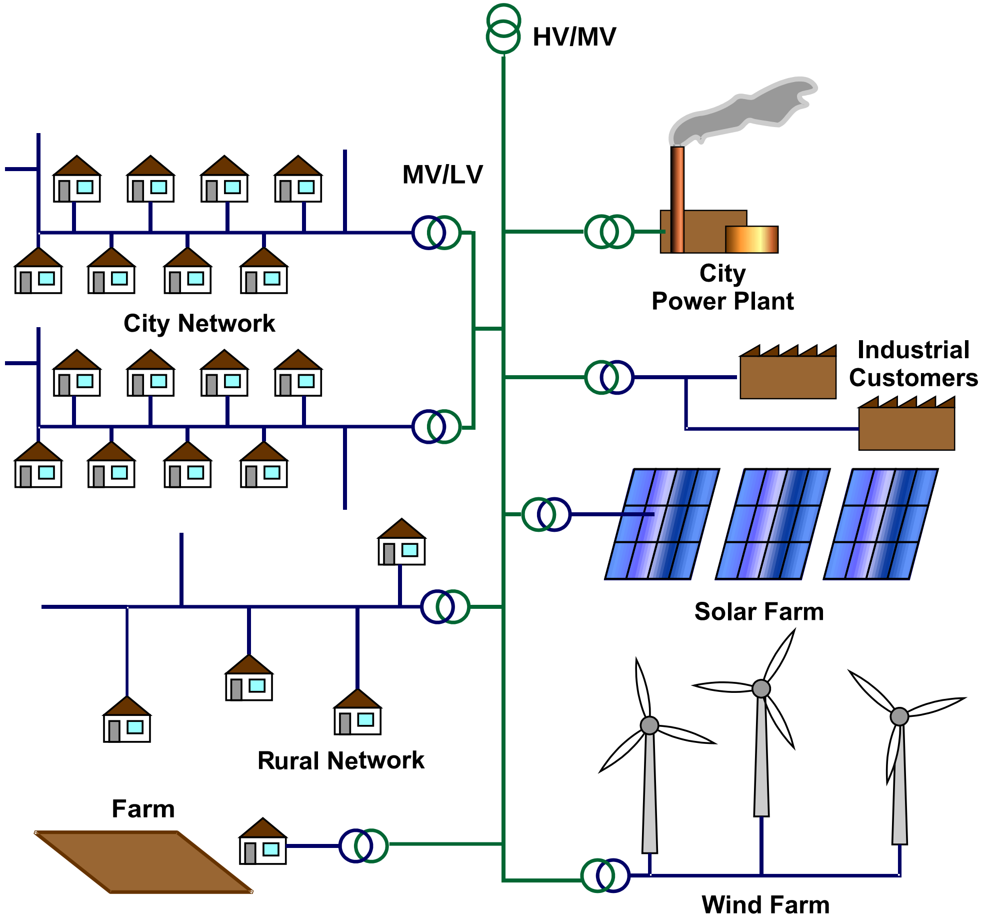
- Hardware:
Devices and appliances, such as distributed generation and storage

- Software:
Home area network
Home device control Interface
Building (neighborhood) system management

Interface

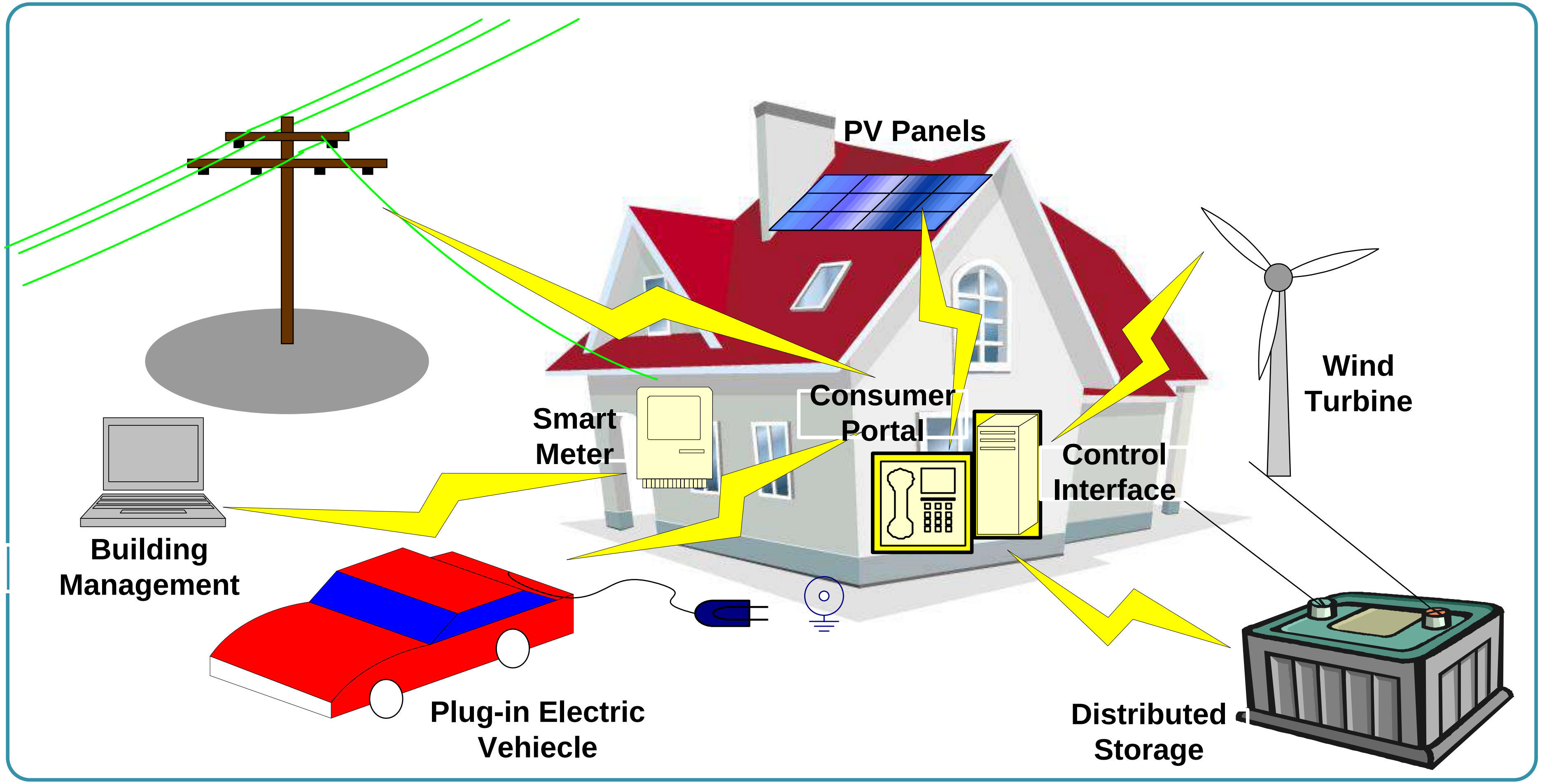


Distribution Grid



Networked prosumers

With both power and information flows in a prosumer house/building, the components would be monitored and controlled through wired / wireless networks



Peculiarity of power systems

Peculiarity of power system operation

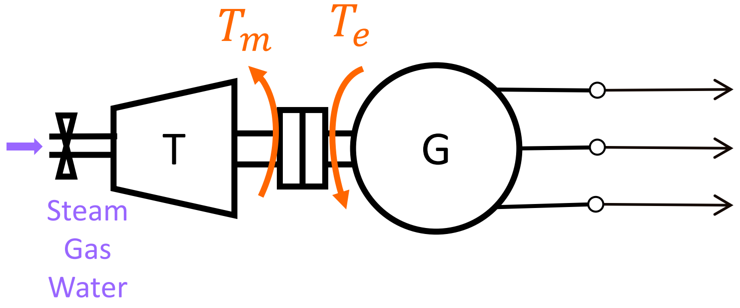
- Need for an instantaneous balance between power production and power consumption plus losses;
- Non storability of electricity (very large scale);
- Power flow path depending on the system physical parameters;
- Transmission losses;
- Limits on the flows feasibility when transferring power from/to different locations;
- Various operational limits that define the feasible region of the system and must be enforced;

The need of instantaneous power balance

- The dynamic behavior of generators can be described by swing equation of generator:

$$J\frac{d\omega_m}{dt} = T_m - T_e$$

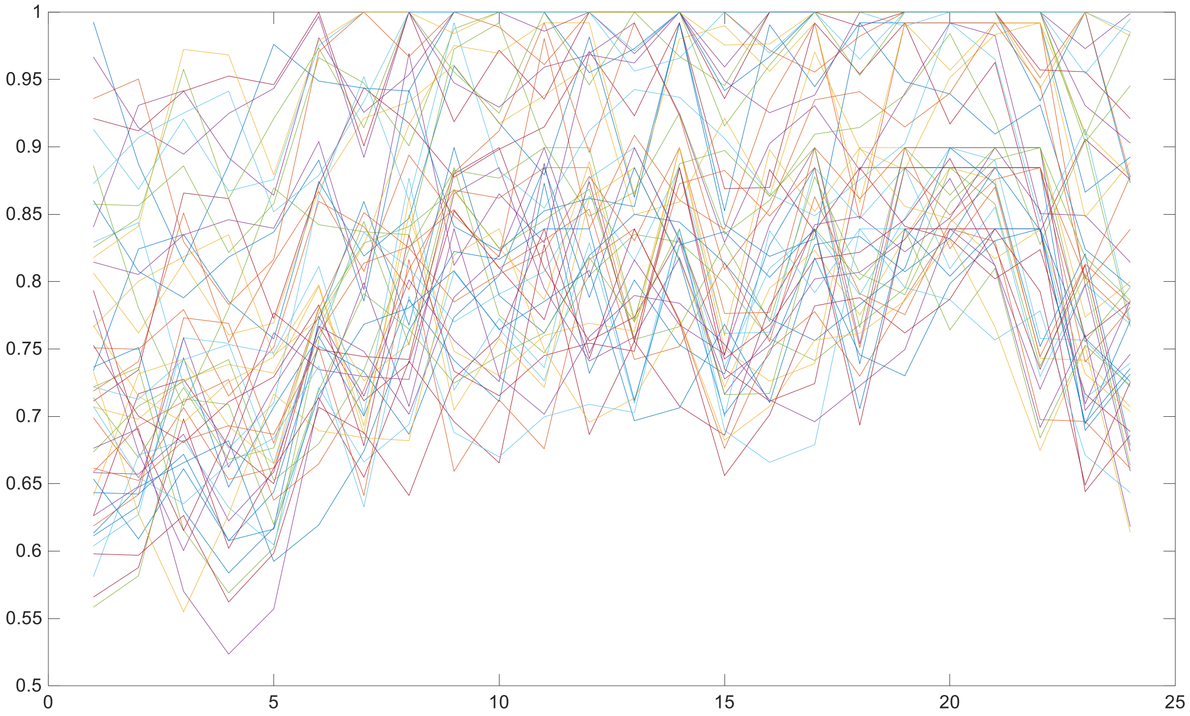
  - J: combined moment of inertia of generator and turbine $[kg \cdot m^2]$
  - ω_m : mechanical rotational speed $[rad/s]$
  - T_m: mechanical torque provided by the primer mover [Nm]
  - T_e electromechanical resistant torque of the generator [Nm]
  - p: the number of pairs of poles



- $\omega_m = \frac{2\pi f}{p} \Rightarrow \frac{d\,\omega_m}{dt} = \frac{2\pi}{p}\frac{df}{dt}$ ➡ $J\frac{d\,\omega_m}{dt} = J\frac{2\pi}{p}\frac{df}{dt} = T_m - T_e$ ➡ 49.98 Hz< f <50.02 Hz

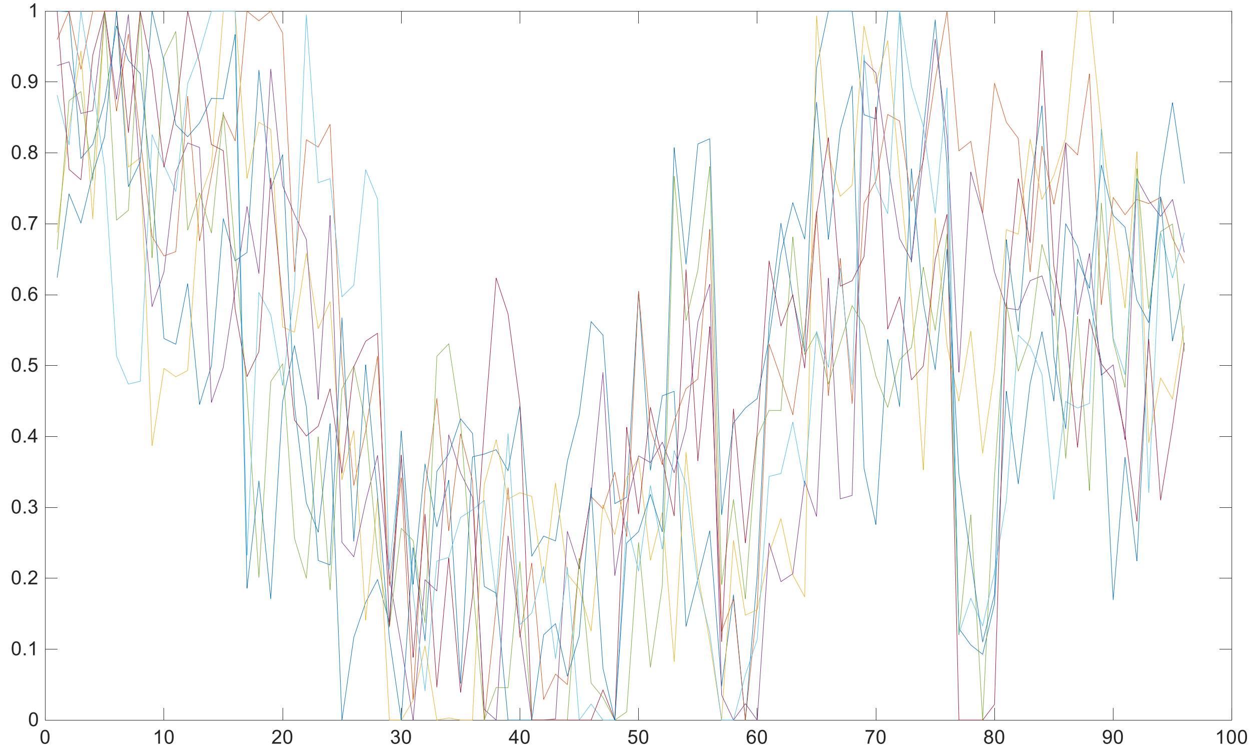
- *Q:* What are the following corresponding situations, how can we correct it if necessary?
  - $T_m - T_e = 0$
  - $T_m - T_e > 0$
  - $T_m - T_e < 0$

Volatility of the demand and (RES) generation



Electricity demand (50 days)

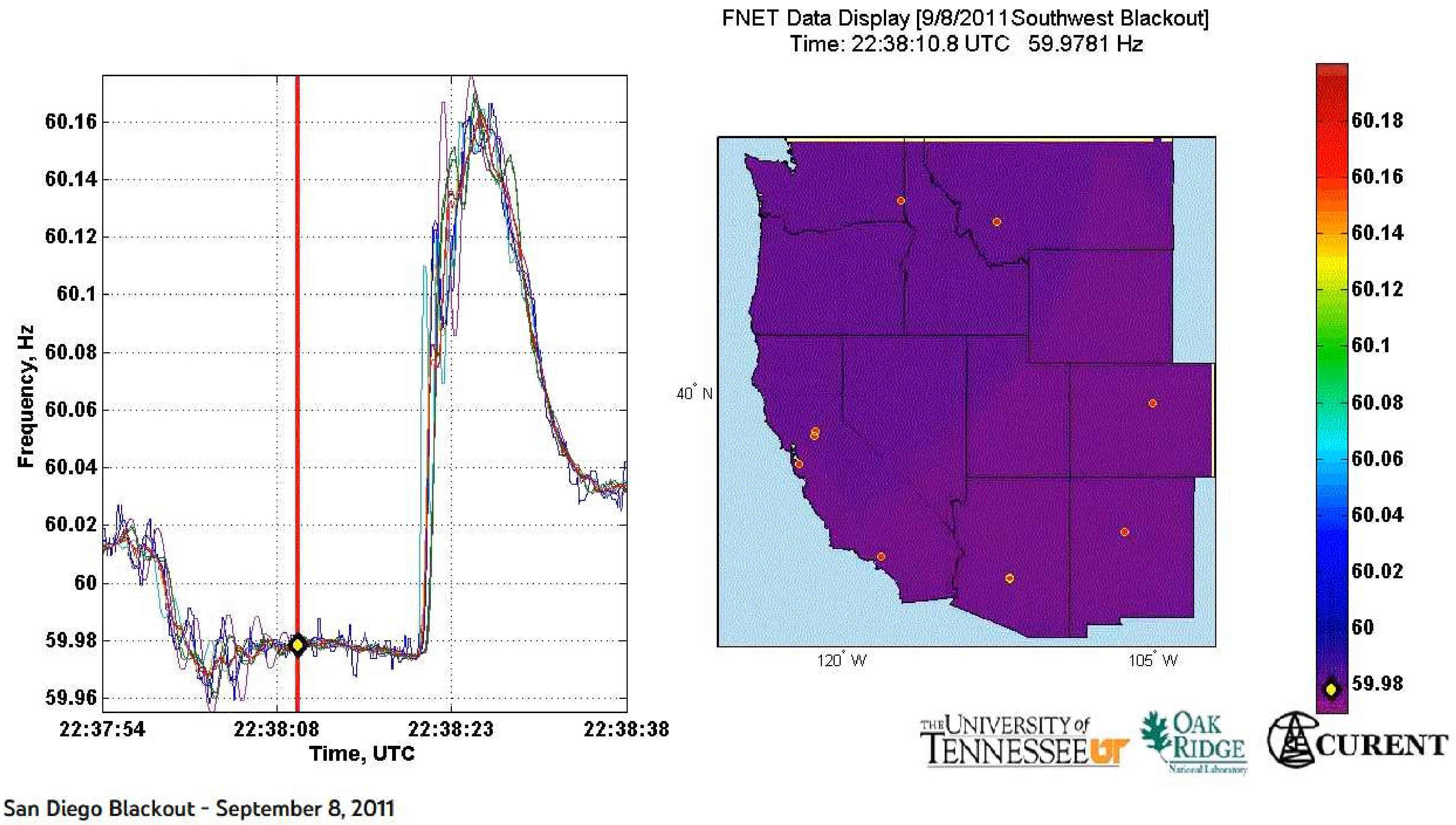
Wind generation ([1,7,12,17,20,35,44,50] days)



37.3◦ N, 106.7◦ E, Ningxia Province, China

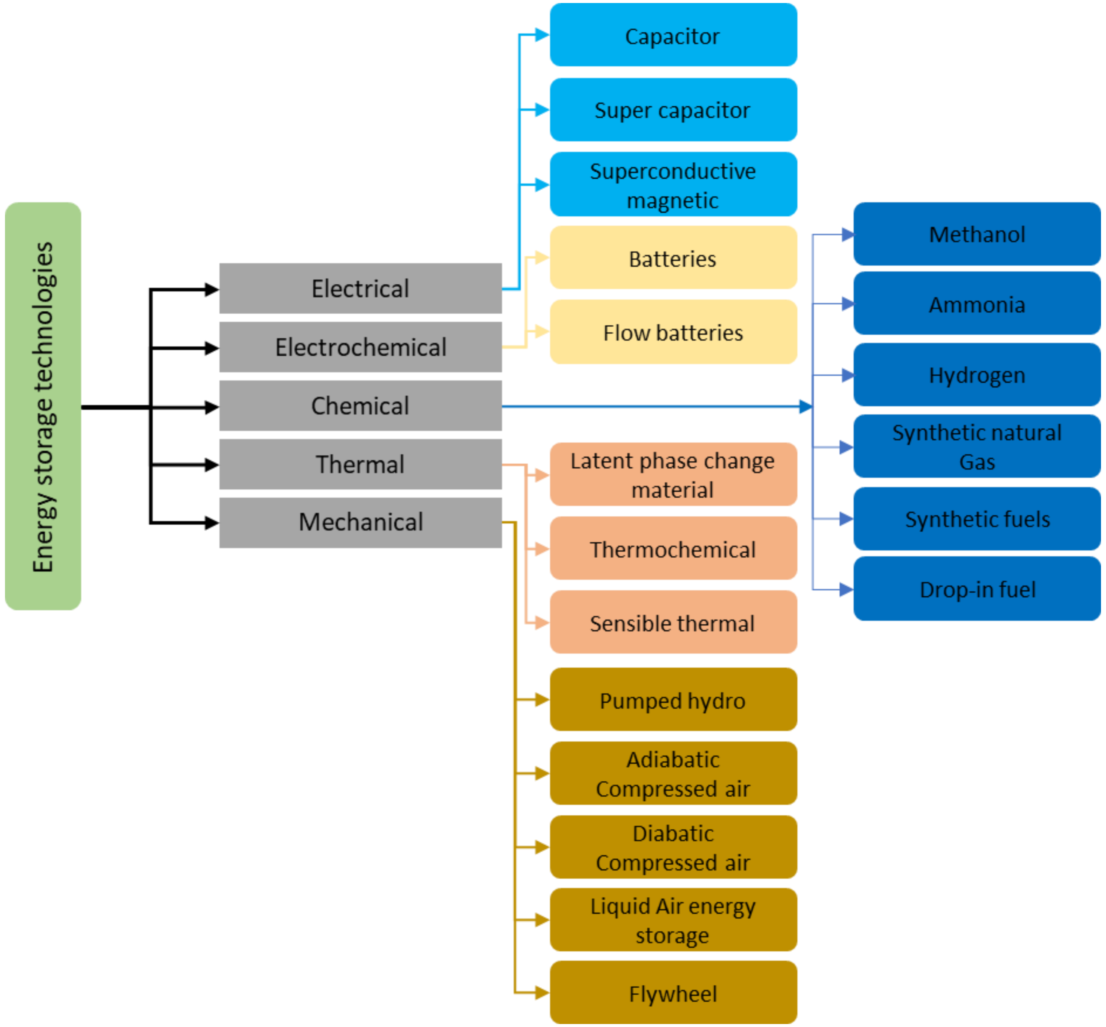
Data: Guo, Zhongjie & Wei, Wei & Shahidehpour, M. & Laijun, Chen & Mei, Shengwei. (2022). Two-Timescale Dynamic Energy and Reserve Dispatch With Wind Power and Energy Storage. IEEE Transactions on Sustainable Energy. PP. 10.1109/TSTE.2022.3217173.

Example of San Diego Blackout – 8th Sept. 2011



Source: https://www.youtube.com/watch?v=YsksUyeLu2Y

Non-storable vs. storage techniques



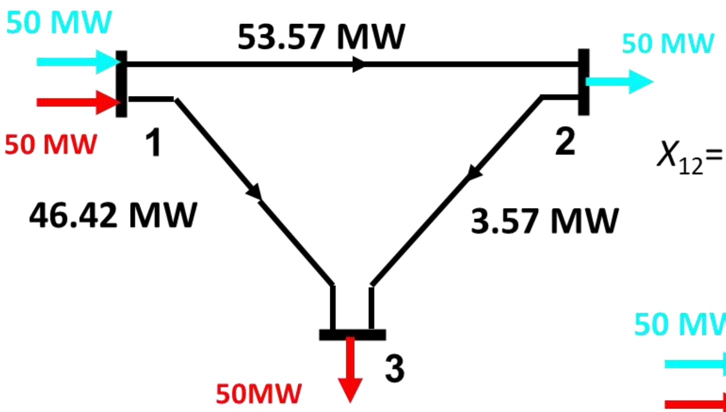
- Currently, electricity cannot be stored economically in large amounts.
- Charge and discharge will incur losses.
- A form of storage for electricity are pumping hydro plants that pump water into an upper reservoir during off-peak hours to produce power during peak hours.
- Other storage forms of electrical energy (capacitor, battery, superconductor) allow for storing a very small amount of energy.
- Emerging scenario is happening with interactions among different energy commodities.

"European Association for Storage of Energy (EASE)." https://ease-storage.eu/energy-storage/applications/ (accessed Jul. 08, 2022).

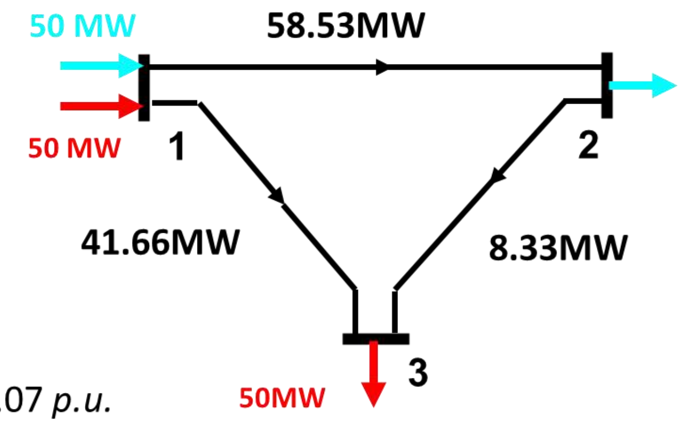
- Q: What is missing from the above list?

Network provide physical paths and constraints

- The power flow path in the transmission network is dependent on the physical parameters of the network (line resistance and reactance) and its configuration (line connections) (admittance matrix)



X_{12}= 0.04 $p.u.$ X_{13} = X_{23}=0.05 $p.u$



X_{12}= 0.04 $p.u.$ X_{13} =X_{23}=0.07 $p.u.$

Q: What is the maximum transfer capability of the following circuit?

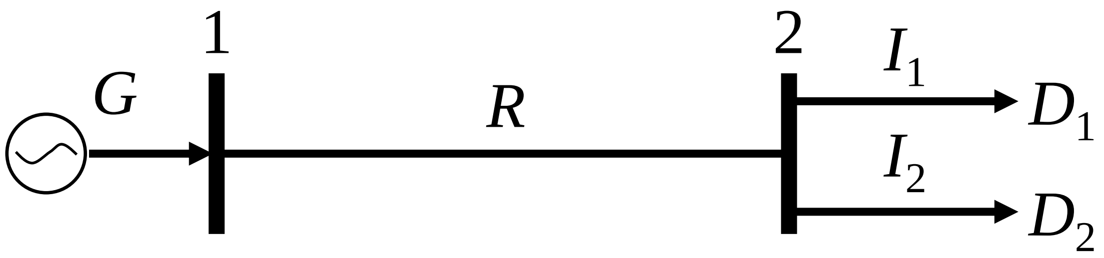
x2 = 0.1 pu, Lim = 50 MW

x2 = 0.2 pu, Lim = 50 MW

a. 50 MW b. 100 MW
c. 75 MW d. other

Try it: 3bus-impedance.pwb

Losses presented during the delivery of the electricity



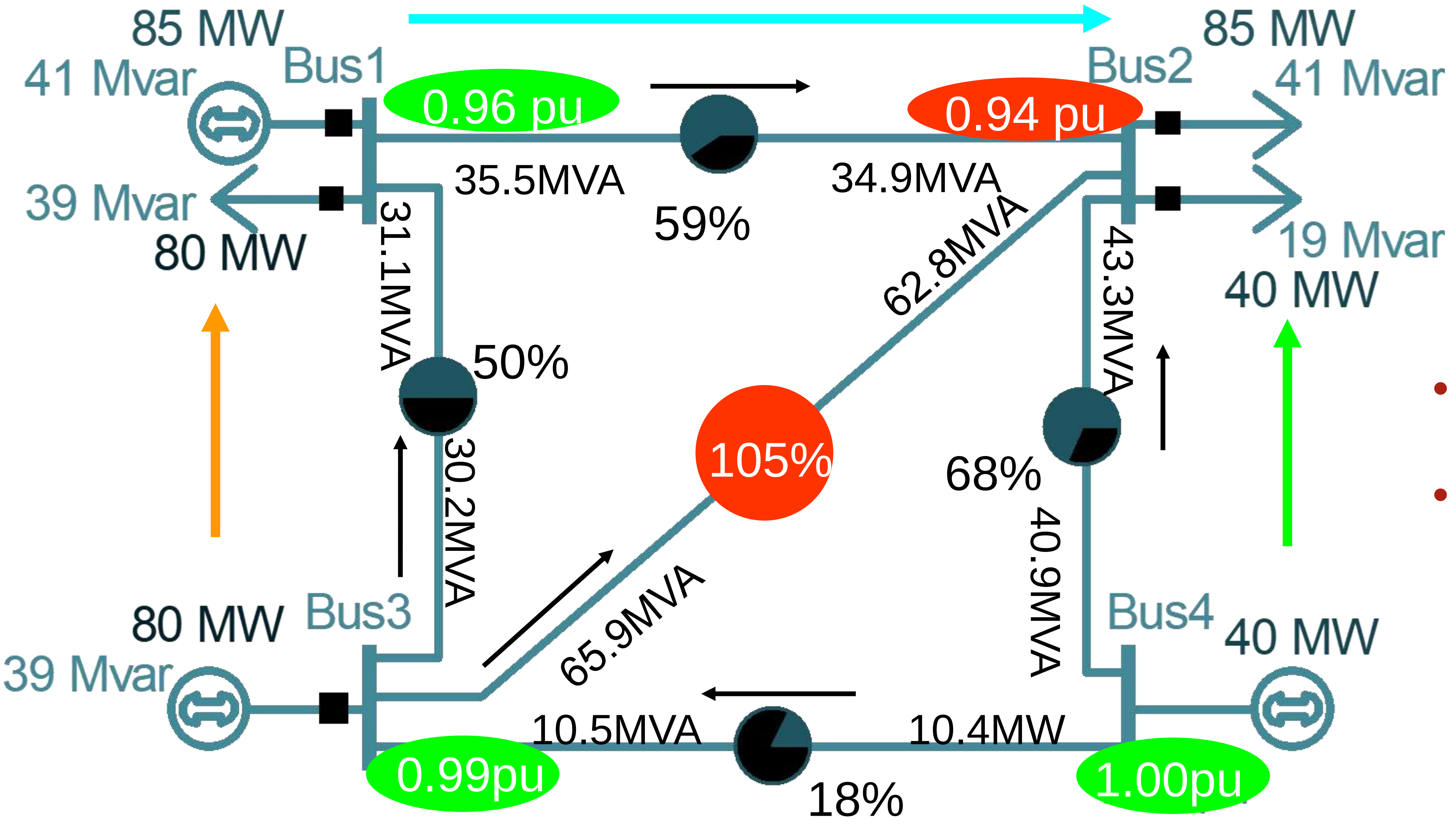
$$\Delta L = R\,(I_1 + I_2)^2$$

$$\Delta L = R\,I_1^{\,2} + RI_2^{\,2} + 2RI_1I_2$$

D_1 D_2 ?

- Loss allocation problem does not have a rigorous solution due to the cross term

Other static physical and operational constraints



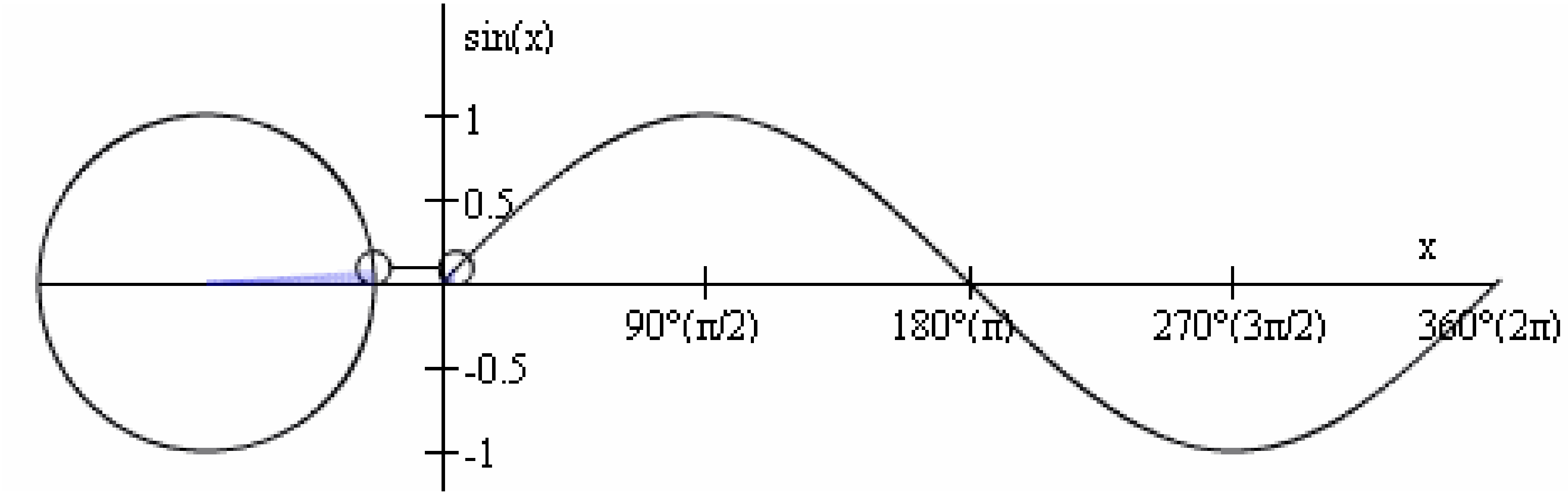
- 0.95<V<1.05 [pu]
- |flow| < F^{max}

- Q: What should we do?
- Can you propose some solutions?

Power limit for each line (MVA)	Voltage limit for each bus	Power factor for each bus
60	0.95~1.05 pu	cosθ =0.9; tgθ =0.483

3 phases and powers in power systems

[Math background] 3 ways of representing sinusoidal alternating quantities



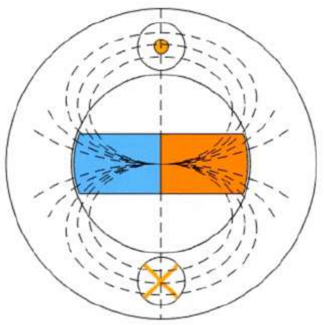
$$\sin(\omega t + \varphi) = \cos(\omega t + \varphi + \pi / 2) \qquad \cos(\omega t + \varphi) = \sin(\omega t + \varphi + \pi / 2)$$

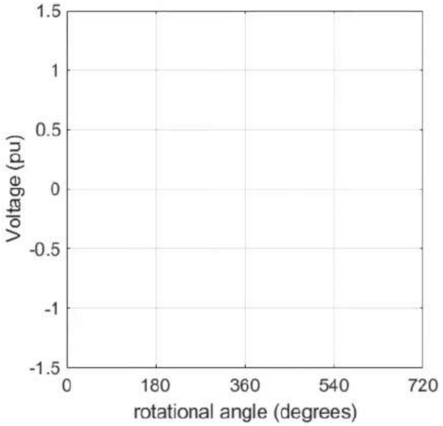
The representation of the sinusoidal alternating quantities can be expressed in forms of algebraic, trigonometric and exponential of complex numbers:

$$\dot{U} = a + jb \qquad \dot{U} = U(cos\varphi + jsin\varphi) \qquad \dot{U} = Ue^{j\varphi} \Rightarrow \dot{U} = U\angle\varphi$$

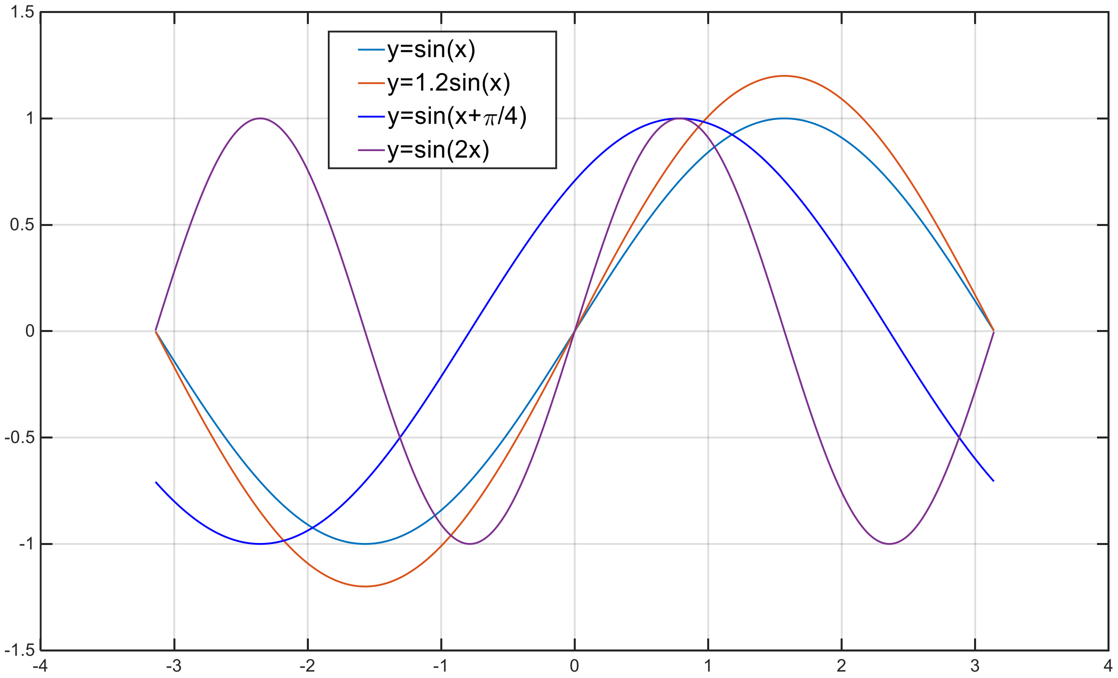
- Q: under which condition, the 3 representing ways are equivalent?

Time variant value of sinusoidal quantities for electric circuit





- u=$u(t)$, i = $i(t)$ are two fundamental time variant values.
- A sinusoid is determined by 3 parameters: amplitude/magnitude, frqeuency, initial phase
- Q: can you describe the influence of each of the parameters?



$$u(t) = \hat{U}\sin(\omega t + \varphi) = \sqrt{2}U\sin(\omega t + \varphi)$$

$\omega = 2\pi/T$ [rad/s] pulsation

$T = 2\pi/\omega$ [s] period

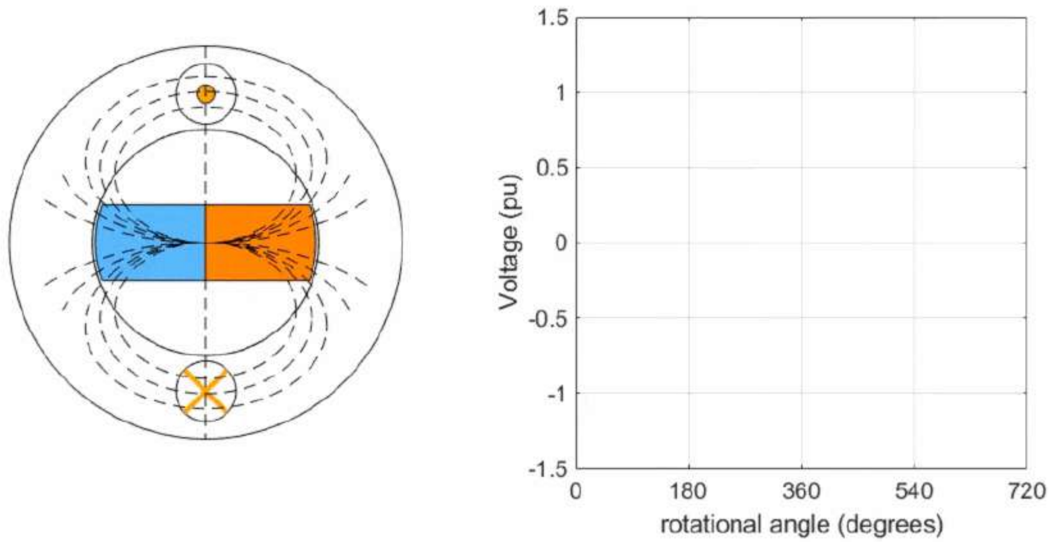
$f = 1/T$ [Hz] frequency

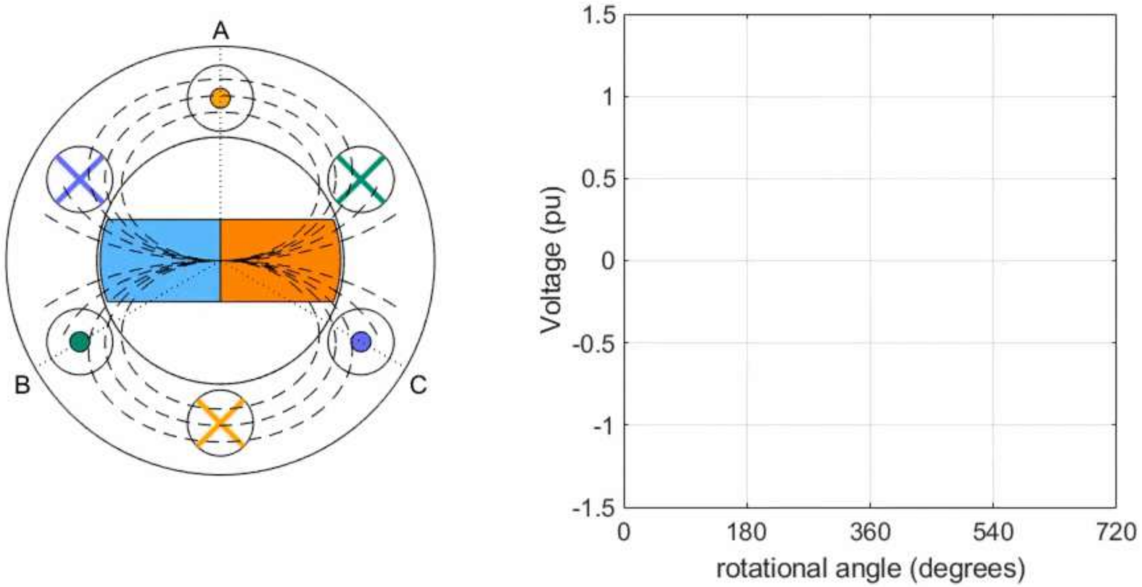
Q: Do you know what does it mean?

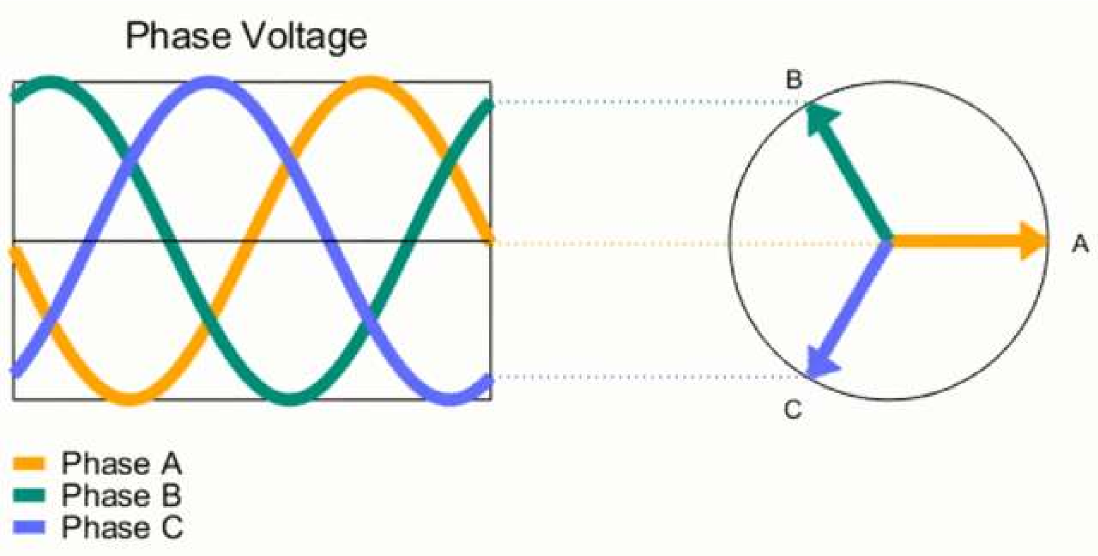
$$\hat{U} = \sqrt{2}U$$

- For power systems, we have f=50 Hz, ω =314.159 rad/s, T=20 ms

Single phase vs 3 phase: Generation







Single phase: $V = V_m \cos(\omega t + 0^\circ)$

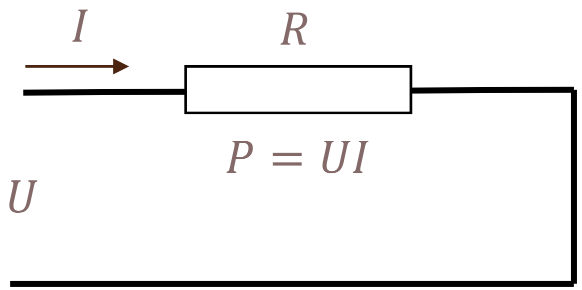
3 phase:

$$V_a = V_m \cos(\omega t + 0^\circ)$$
$$V_b = V_m \cos(\omega t - 120^\circ)$$
$$V_c = V_m \cos(\omega t - 240^\circ)$$

Gif sources: What is 3-phase power? G. Dudgeon Mathworks

Power in sinusoidal regime: single phase

- [Recall] DC circuit in high school.



$$p(t) = u(t)i(t)$$
$$u(t) = \sqrt{2}U\sin(\omega t + \varphi_U)$$
$$i(t) = \sqrt{2}I\sin(\omega t + \varphi_I)$$

$$p(t) = u(t)i(t) = UI\cos\left(\varphi_U - \varphi_I\right)\left[1 - \cos\left(2(\omega t + \varphi_I)\right)\right] + UI\sin(\varphi_U - \varphi_I)\sin\left(2\left(\omega t + \varphi_I\right)\right) = p_a + p_r$$

- The phase angle between voltage and current $\varphi = \varphi_U - \varphi_I$ defines the relationship between the two vectors.
- Conventionally, $\varphi = \varphi_U - \varphi_I > 0$ means current lags voltage; and $\varphi = \varphi_U - \varphi_I < 0$ means current leads voltage.
- Conventionally, we define the positive sign of an angle in the counterclockwise direction.

Active vs. reactive power

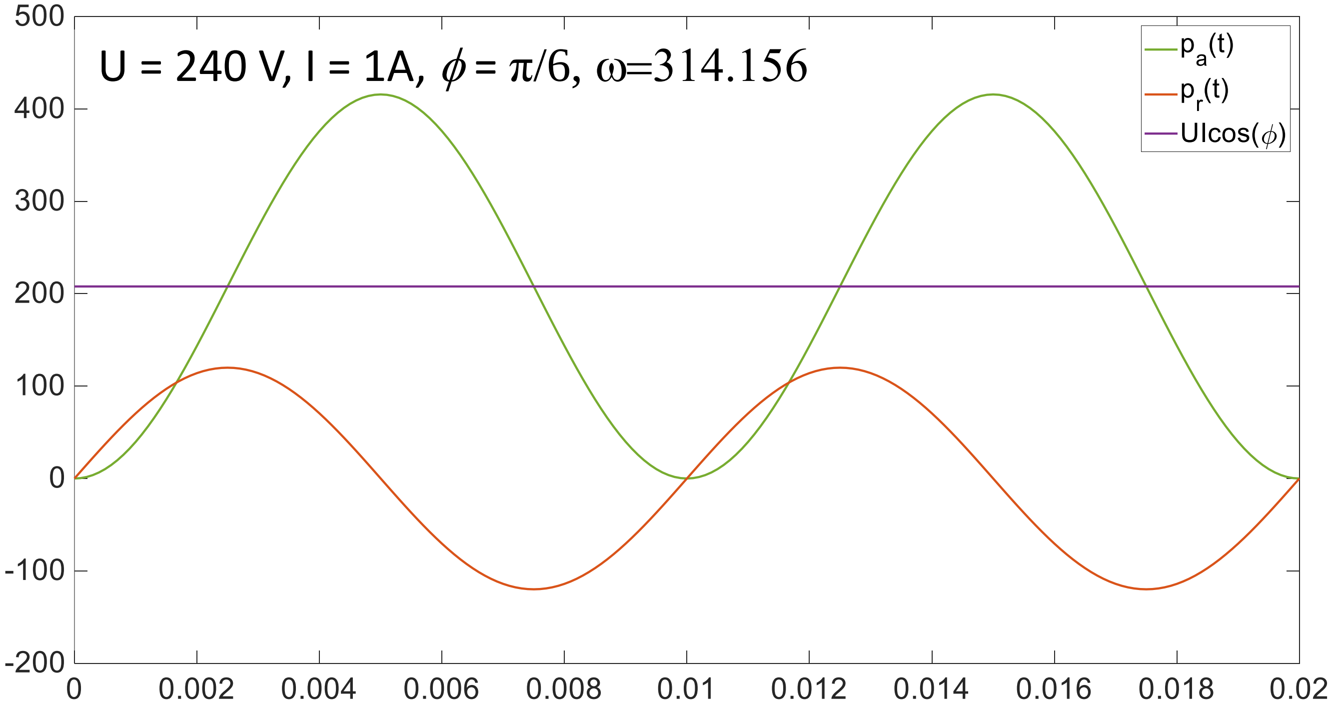
- $p_a(t)$ → constant term $UIcos\varphi$ plus cosinusoidal term, of amplitude $UIcos\varphi$ and double pulsation with respect to voltage and current → *active power* (*W*)
- $p_r(t)$ → sinusoidal term of amplitude $UIcos\varphi$ *and* double pulsation with respect to voltage and current → *reactive power* (*var*)

$$p_a(t) = UI\cos\varphi[1 - \cos(2(\omega t + \varphi_I))]$$

- → P = UIcosϕ

$$p_r(t) = UI\sin\varphi\sin(2(\omega t + \varphi_I))$$

- → Q = UIsinϕ



Complex power and power triangle

- We define the complex power as:

$$\dot{S} = P + jQ = UI\cos\varphi + jUI\sin\varphi = UIe^{j(\varphi_U - \varphi_I)} = \dot{U}\dot{I}^*$$

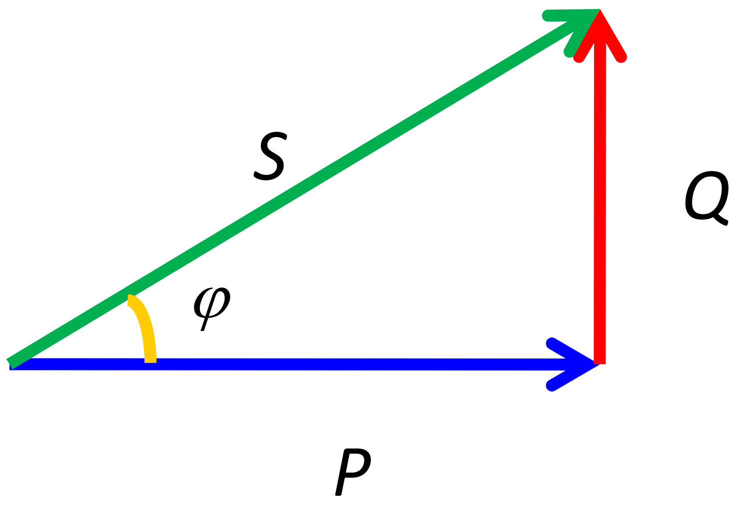
- The magnitude of the complex power is defined as apparent power:

$$\left|\dot{S}\right| = S$$

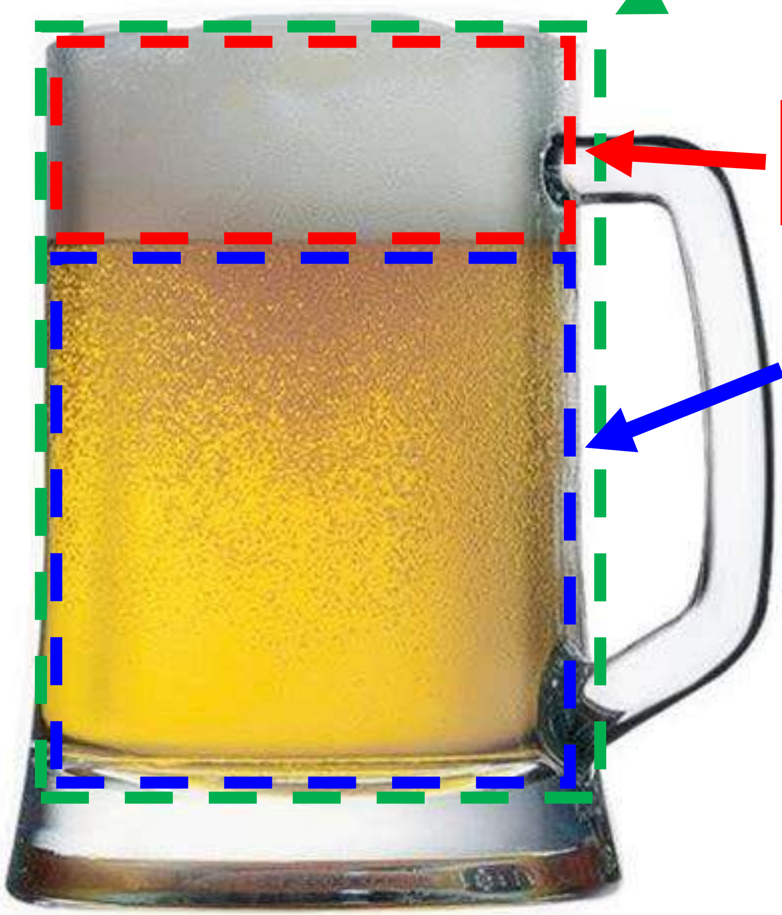
- Thus, we have:

$$S = \sqrt{P^2 + Q^2}$$

$$Q = P\tan\varphi$$



Power(s) vs. beer



Mug volume → apparent power [S, VA]

Foam volume → reactive power [Q, var]

Beer volume → active power [P, W]

$$PF = \cos\varphi = \frac{beer \ (\rightarrow P)}{cup \ \ volume \ (\rightarrow S)}$$

Smart electricity systems

Key innovations and advantages of Smart Electricity Systems/Smart Grids

- **Key Innovations:**
  - **1990s–2000s:** Digital Supervisory Control and Data Acquisition (SCADA) systems, smart meters.
  - **2010s:** Internet of Thing (IoT) sensors, distributed Energy Resource (DER) integration, demand response.
  - **2020s:** AI-driven grid optimization, blockchain for peer-to-peer (P2P) trading.
- **Core Advantages:**
  - Bidirectional energy flows (prosumers feed power back).
  - Real-time data for predictive maintenance and load balancing.
  - Resilience (self-healing) via microgrids and decentralized control.
  - Renewable integration increase from limited (<20%) to scalable (50%+)

"Advanced grid technologies, including smart grids, could reduce global CO_2 emissions by 2.6 gigatonnes annually by 2050."

IEA (2020), Energy Technology Perspectives 2020

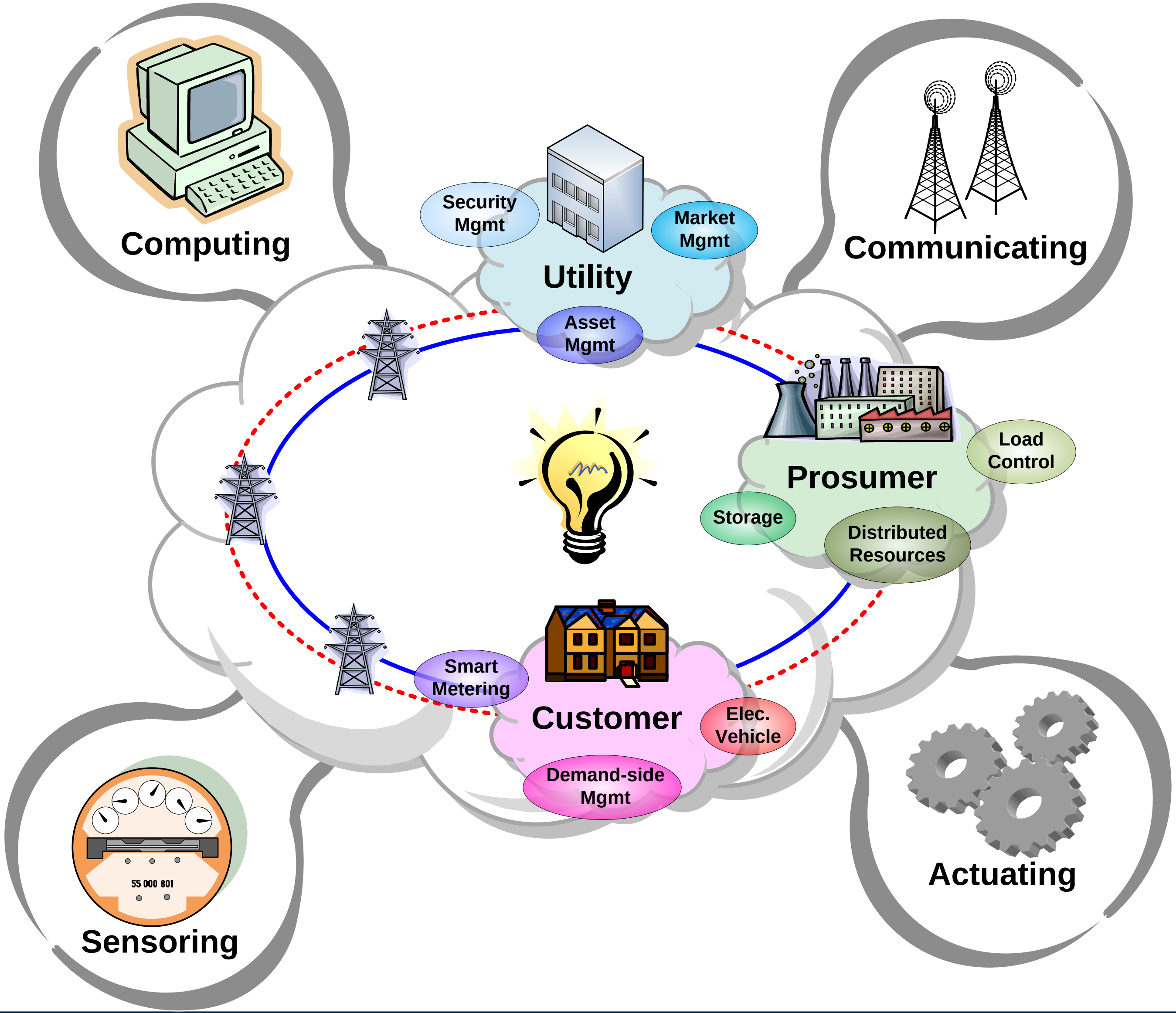
1970s
Oil crises → Focus on energy efficiency

2003
Northeast Blackout (U.S./Canada) → Push for grid automation

2015
Paris Agreement → Accelerated renewable adoption

2020s
AI/ML → integration for grid orchestration

What does it mean for a grid to be smart?



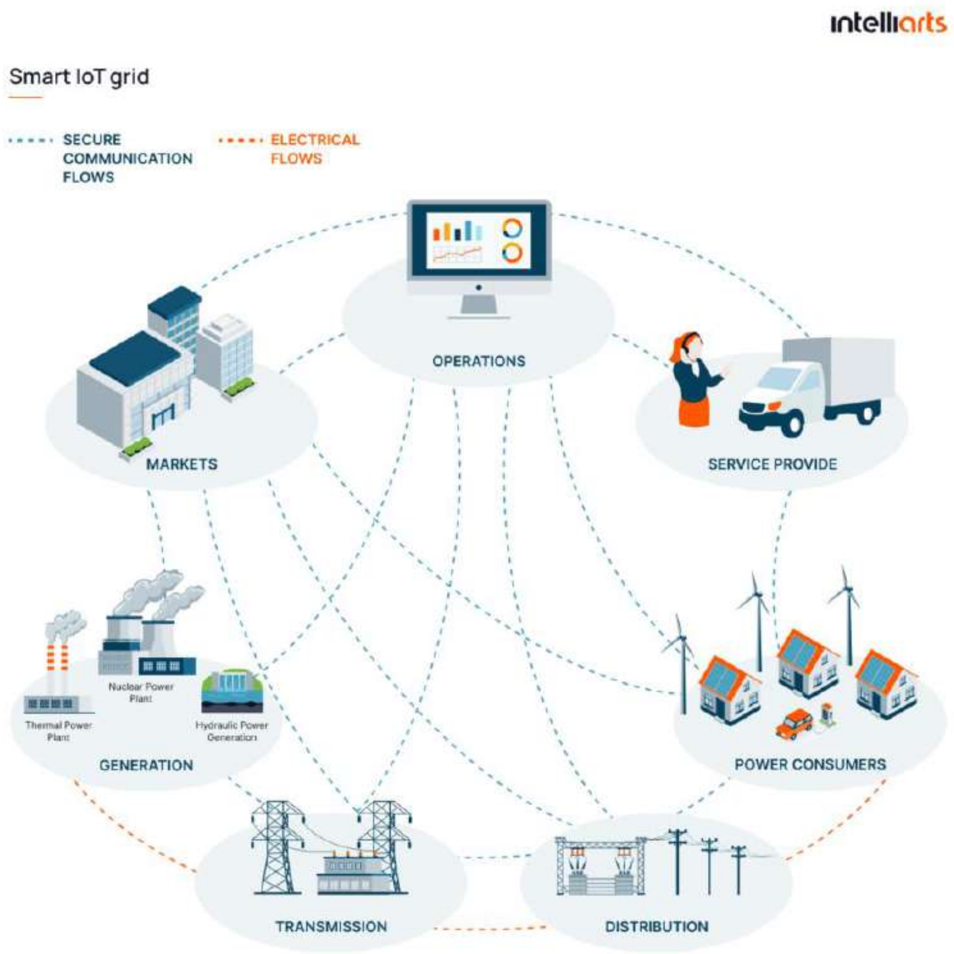
- *No longer distribution networks but micro-grids* (able to match locally supply and demand) interconnected with the transmission system.
- Smart grid for electricity only? *Multiple energetic vectors* are possible (Energy Hubs)
- *(Distributed) storage* from the "just in time" production provides new opportunities for efficiency
- Accommodating *intermittence of supply*
- *Interoperability* of devices and actors: standardization as a key for *"open access"* to the internet of energy
- Loads from *supply follower* to *active participator*
- *Regulation* (incentives & market signals for technological and economic efficiency)
- Managing *technical and economic complexity* of a system with a multitude of devices and actors with hectic behaviors

Hardware, Software, and Connectivity – The Triad of Modern Grids

- **Hardware**
  - IoT Sensors: Monitor grid conditions (voltage, temperature, faults).
  - DERs: Solar panels, wind turbines, EV batteries generating/storing power.
  - Advanced Inverters: Convert and stabilize renewable energy for grid compatibility.
- **Software**
  - AI/ML Analytics: Predict demand, optimize routing, and prevent outages (e.g., Google's DeepMind for wind forecasting).
  - Blockchain: Enable P2P energy trading (e.g., Brooklyn Microgrid's LO3 Energy).
  - Grid Management Systems: SCADA, ADMS (Advanced Distribution Management Systems).
- **Connectivity**
  - 5G/IoT Networks: High-speed data transmission between devices and control centers.
  - Interoperability Standards: IEEE 2030.5 (smart grid communication), OpenADR (demand response).
  - Cybersecurity Protocols: Encryption, zero-trust architectures to protect grid data.

Smart Grids = **Hardware** (generation/storage/sensing) + **Software** (analytics/automation) + **Connectivity** (secure, real-time data exchange).

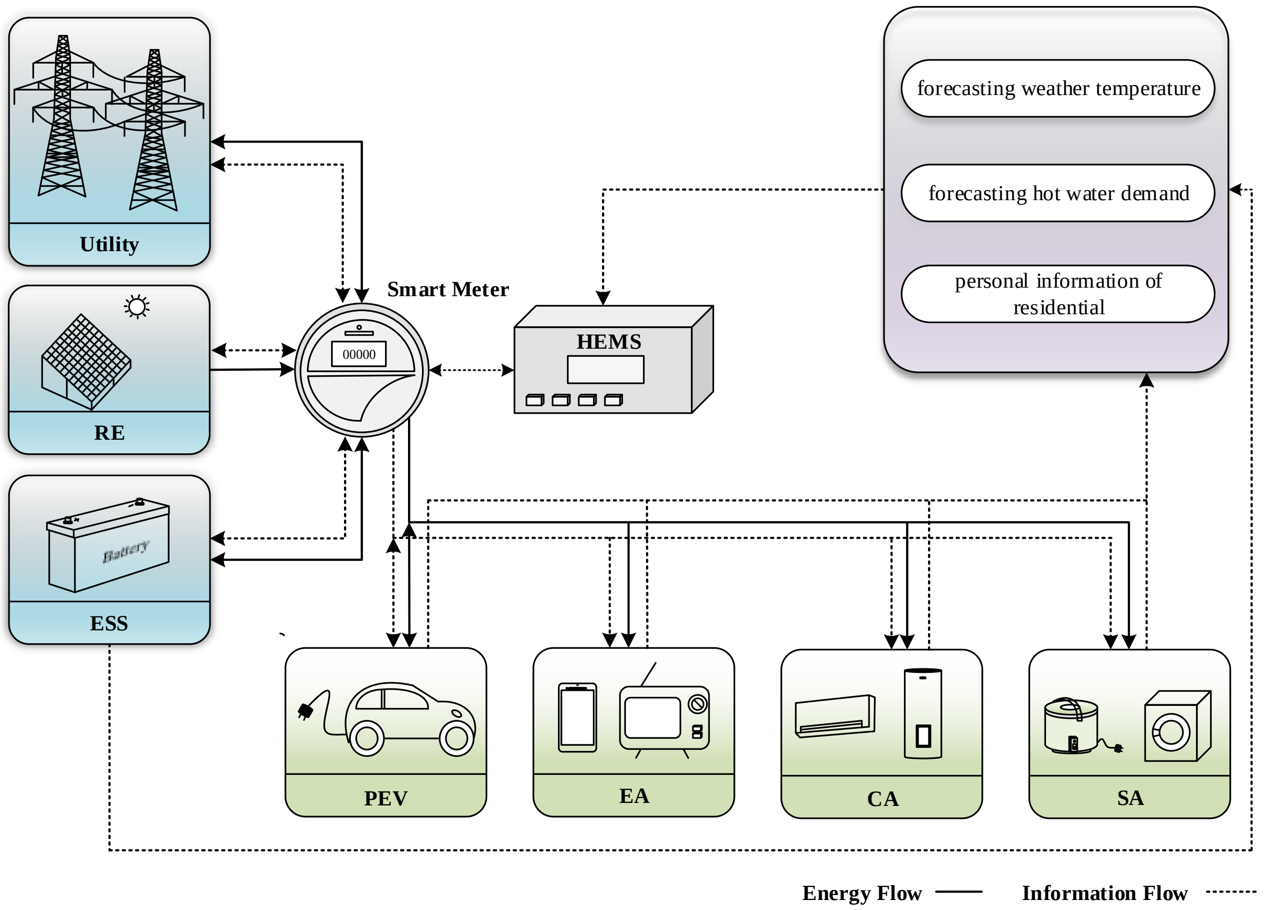
IoT for Smart Grids: *Multifunctional Enablers of Grid Intelligence*



- Grid Monitoring & Stability
  - Real-Time Fault Detection and Localization
  - Dynamic Line Rating (DLR)
  - Power Quality Monitoring
- Market & Operation
  - Electricity markets
  - Grid flexibility
  - Self-healing
- Asset Management
  - Predictive Maintenance
  - Corrosion and Wear Monitoring
- Environmental & Safety
  - Wildfire Risk Mitigation
  - Vegetation Management
- Renewable Integration
  - Solar/Wind Forecasting
  - Grid Synchronization
- Cybersecurity & Compliance
  - Anomaly Detection
  - Regulatory Compliance
- Consumer Engagement
  - Smart home energy management
- …

Image source: The Role of IoT in Smart Grid Technology

Smart Meters: Enabling Active Participation in Grid Modernization



- Core functionalities of smart meter:
  - Real-Time Data Acquisition (voltage, current, power quality monitoring) .
  - Demand Response Integration (time-of-use pricing support).
  - Cybersecurity Protocols (encrypted data transmission)

- Interoperability: Integration with home energy management systems (HEMS) and payment gateways
  - Dynamic Pricing: Supports time-of-use tariffs, enabling consumers to shift usage to off-peak hours.
  - Outage Management: Automatic fault detection reduces restoration time via real-time alerts.
  - Renewable Integration: Facilitates bidirectional energy flow for prosumers with solar/wind systems.
  - Gateway of self-organized bilateral trading within community

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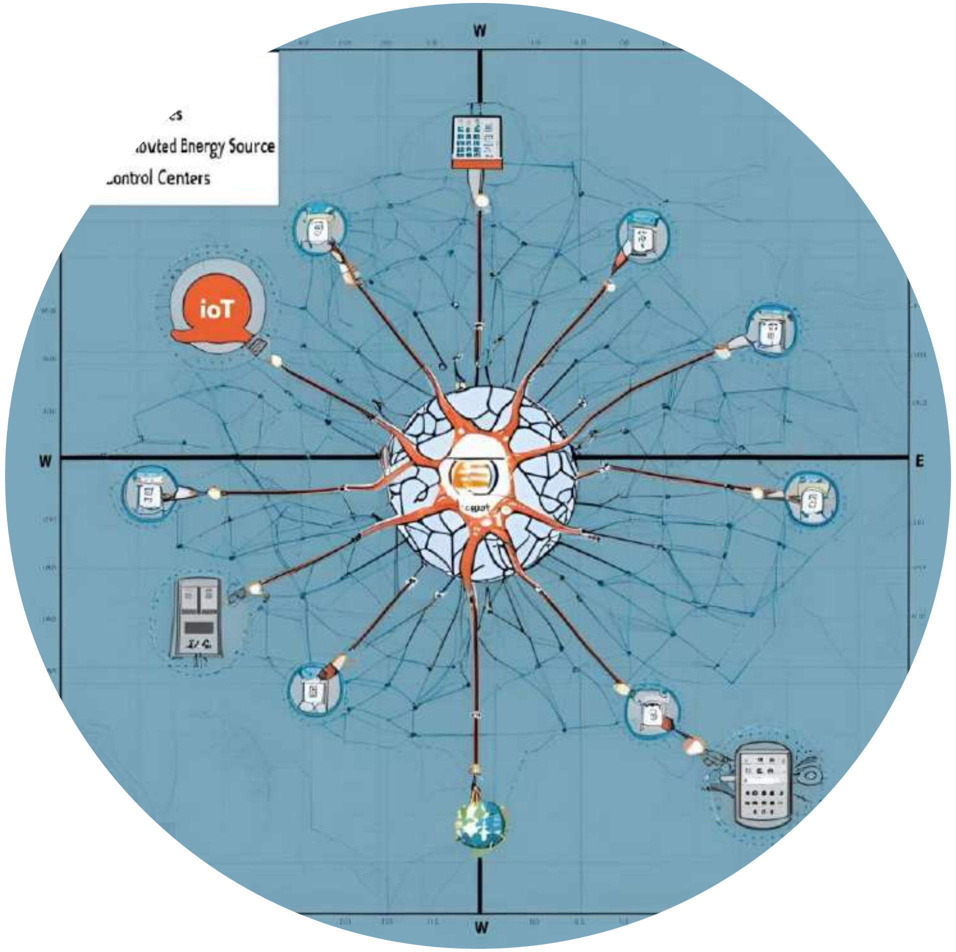
Distributed Energy Resources (DERs): Decentralized Power Generation and Grid Integration

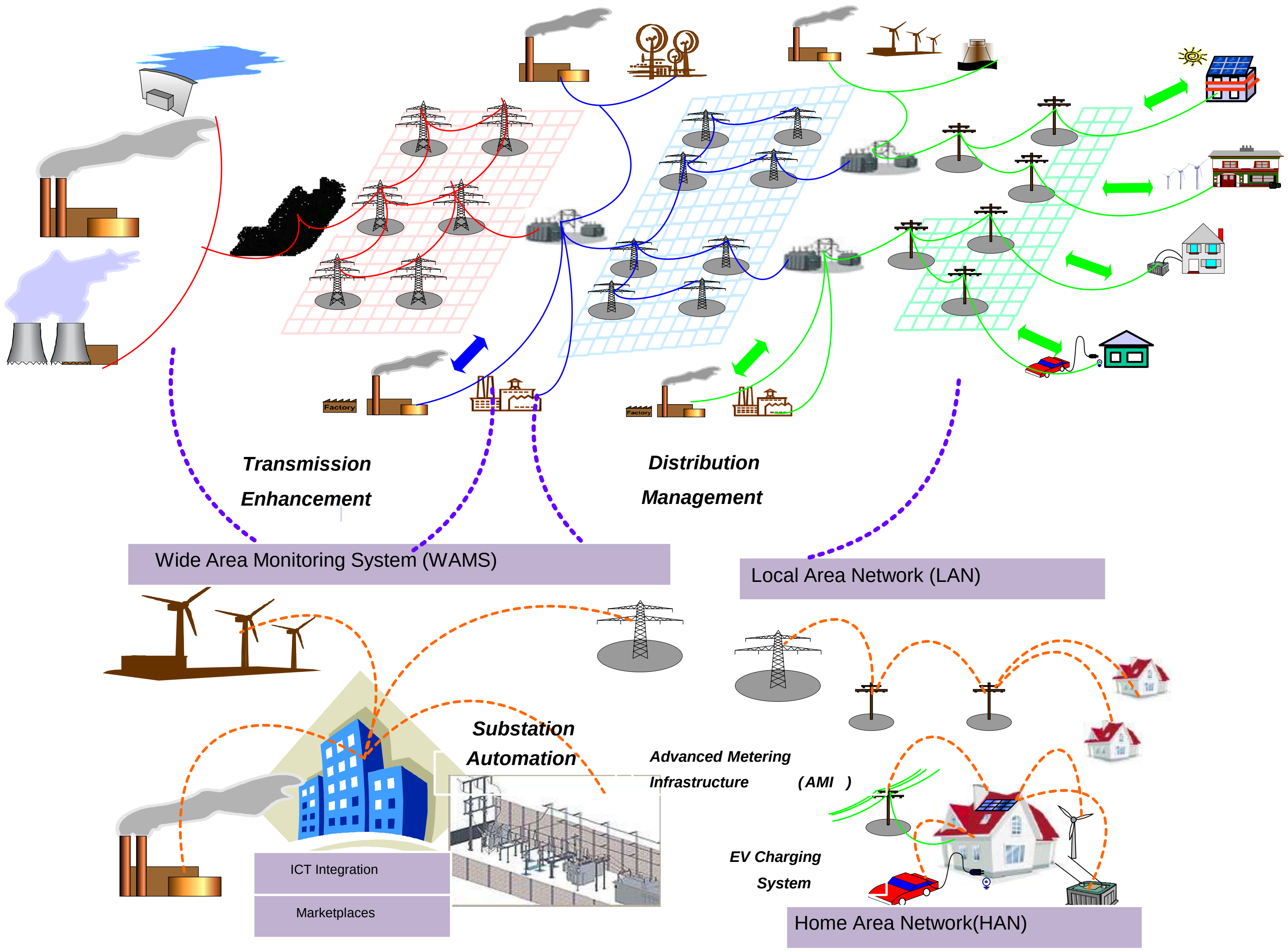
- DER Architecture
  - Grid-Forming vs. Grid-Following Inverters:
  - Grid-forming: Provide voltage/frequency stability (critical for islanded microgrids).
  - Grid-following: Synchronize with the main grid (standard for rooftop solar).
  - Communication Protocols: IEEE 2030.5 (SEP 2.0) for DER-to-grid interoperability.
- Technical Challenges
  - Grid Stability: Voltage fluctuations due to intermittent renewables.
  - Cybersecurity: Vulnerabilities in DER control systems (e.g., inverter firmware).
  - Interoperability: Harmonizing diverse DERs with legacy grid infrastructure.
- Solutions & Standards
  - IEEE 1547-2018: Specifies DER grid interconnection requirements (voltage ride-through, anti-islanding).
  - Virtual Power Plants (VPPs): Aggregating DERs via cloud platforms for grid services (e.g., peak shaving).

Software: Orchestrating Intelligence, Adaptability, and Resilience

- Software as the Central Nervous System
  - Integration: Aggregates data from millions of IoT devices (smart meters, PMUs) into a unified operational view.
  - Decision-Making: Executes pre-programmed rules (e.g., IEEE 1547-2018 compliance) and adaptive protocols (e.g., voltage regulation during solar intermittency).
- Foundational Software Functions
  - Real-Time Optimization: Balances load and generation dynamically (e.g., during cloud cover reducing solar output).
  - Predictive Protocols: Rule-based systems preemptively shed non-critical loads during congestion.
  - Cybersecurity "Immune System": Embedded firewalls, intrusion detection systems (IDS), and protocol validation (e.g., IEC 62351).
- Architectural Components
  - Edge Computing: Local decision-making at substations to reduce latency (e.g., fault isolation in <10ms).
  - Cloud Platforms: Centralized analytics for long-term grid planning (e.g., load growth forecasting).
  - APIs for Interoperability: Enables DERs, legacy systems, and third-party apps to communicate seamlessly.



Communication networks in Smart Grids



- *A layered architecture* for supporting all identified smart grid functionalities.
- Support a huge number of devices located over large geographical areas.
- Support bilateral communication of multi-point-to-point and point-to-multiple-point traffic.
- Enhance the management of all segments of power systems.
- Provide communication media for measurements and control commands, either local or remote, automatic or manual.
- Enable non-technical information exchange, e.g. price, weather information, etc.

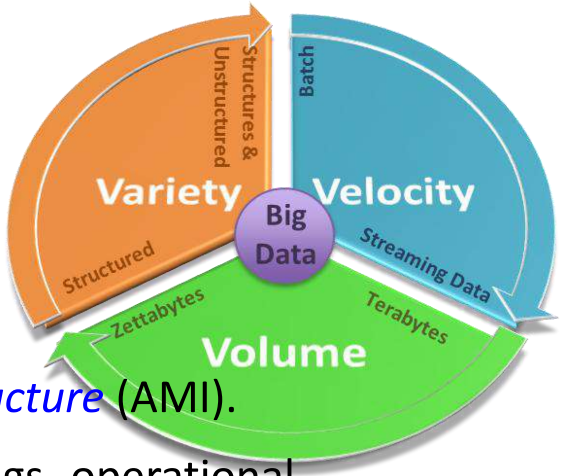
Cybersecurity Challenges in Smart Grids

- Risks
  - Data Breaches: Exploitation of vulnerabilities in AMI (Advanced Metering Infrastructure) to access consumer usage patterns.
  - Ransomware: Encryption of critical OT systems (e.g., Siemens SIPROTEC relays) demanding payment for decryption.
  - Grid Destabilization: FDI attacks manipulating PMU (Phasor Measurement Unit) data to trigger false load shedding.
- Solutions
  - Encryption:
  - AES-256: Used in smart meters for secure data storage (IEEE 2030.2-2015 recommendation).
  - TLS 1.3: Secures communication between DERs and grid operators (IETF RFC 8446).
  - Zero-Trust Architecture:
  - Continuous Verification: Multi-factor authentication (MFA) for SCADA operators.
  - Micro-Segmentation: Isolate DER control systems from enterprise IT networks.
- Standards & Frameworks
  - NIST IR 7628: Guidelines for cryptographic key management and intrusion detection.
  - MITRE ATT&CK for ICS: Framework for modeling industrial control system (ICS) threats.

Challenges in electricity sectors

- High penetration of RES
  - *Less controllable*, *low forecastable precision*, *low flexibility* for voltage and frequency regulation, *complex control* schemes, *difficulties for coordination and protection*
- Supergrid vs. smart grid
  - Super grid: *transcontinental* / international interconnection, *large scale* centralized generation, intelligent, *peak-shifting*, *centralized* control
  - Smart grid: *local, distributed* generation, *renewable* energy, *bottom-up* structure, *prosumers*, high automation, *ICT* technology, distributed decision
- Drastic changes in the distribution systems
  - Large number of *prosumers*, *bidirectional* power flows, increasing amount of communication data and commands, connections of *Electric Vehicles*, *output based regulation*, *new business models* for large number of players.
- Security
  - *Aged infrastructure* facing fast changing new energy mix and final use
  - *Decreasing resources* for normal and emergency operation of the network, e.g. *frequency and voltage control*
  - Large amount of access point for the ICT layer, vulnerable for *cyber-attacks*
  - Large scale interconnection, easy to *propagate fault* and *large blackout*.

Big data in electricity systems



- *Massive amount* of available data in the electricity systems from *Advanced Metering Infrastructure* (AMI).
- Different groups of data: *structured* (e.g. AMI collected data, weather data, maintenance logs, operational orders, etc.) and *unstructured* (e.g. social media data, free text data, voice data, surveys, risk logs, failure histories, customer preferences, customer movements etc.)
- Heterogeneity of data makes *fusing* and *analyzing* energy-related data *challenging*.
- Example of data:
  - Turin's distribution network: 8 HV/MV + 3800 MV/LV substations, 2100 km MV + 3000 km LV cables, 561,000 households (around 80k population).
  - Supposing voltage and current sampling frequency 1 kHz, distributed temperature sensing data in the cables every 2 meters
  - The collected data is *5 million* for each sampling time and the generated structured data is of the order of *tens to hundreds Gbps*.
- Too many available data equal *no information unless analyze them efficiently and effectively* to discover the insights

Big data application in power systems

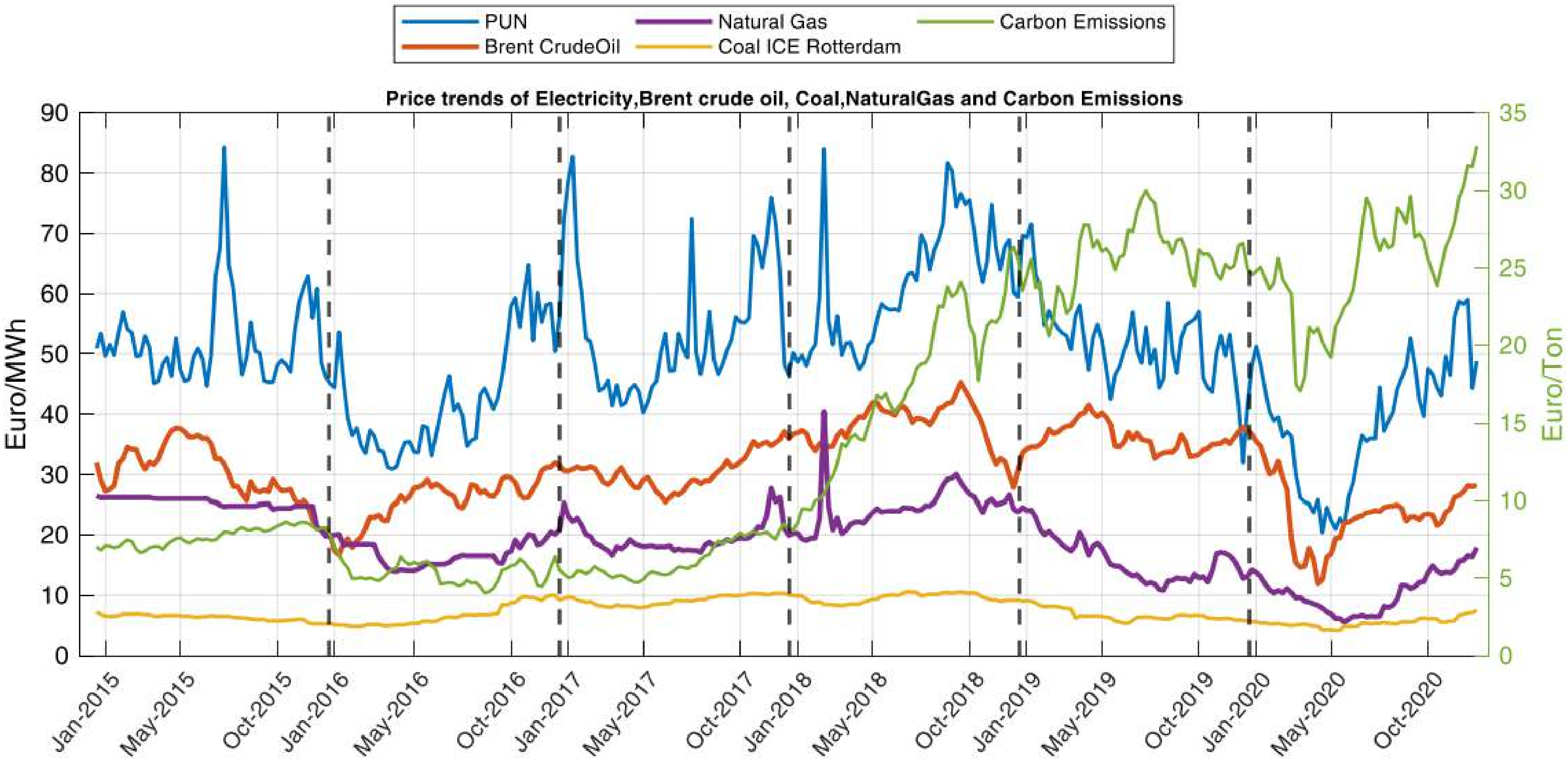
- Improve network resilience
- Better maintenance schemes
- Customer centered network design and upgrading
- Optimal network operation driven by big data
- Better contingency plans considering multiple relevant factors rather than network data only
- Understanding customers' behaviors for better business plans
- Correlation of spatial-temporal load with customers' activities and mobilization for better flexibility control
- Optimal utilization of EV changing and storage resource
- ….

Classifications of artificial intelligence algorithms

- **Based on Capability:**
- Narrow AI (Weak AI): Designed for specific tasks (e.g., Siri, Alexa).
- General AI (Strong AI): Human-like intelligence (theoretical).
- Superintelligent AI: Surpasses human intelligence (hypothetical).
- **Based on Functionality:**
- Reactive Machines: No memory, task-specific (e.g., IBM Deep Blue).
- Limited Memory: Uses past data for decisions (e.g., self-driving cars).
- Theory of Mind: Understands emotions and thoughts (in development).
- Self-Aware AI: Conscious and self-aware (hypothetical).
- **Based on Learning Approach:**
- Supervised Learning: Labeled data (e.g., image recognition).
- Unsupervised Learning: Unlabeled data (e.g., clustering).
- Reinforcement Learning: Learns through rewards/punishments (e.g., game-playing AI).

Examples of smart applications

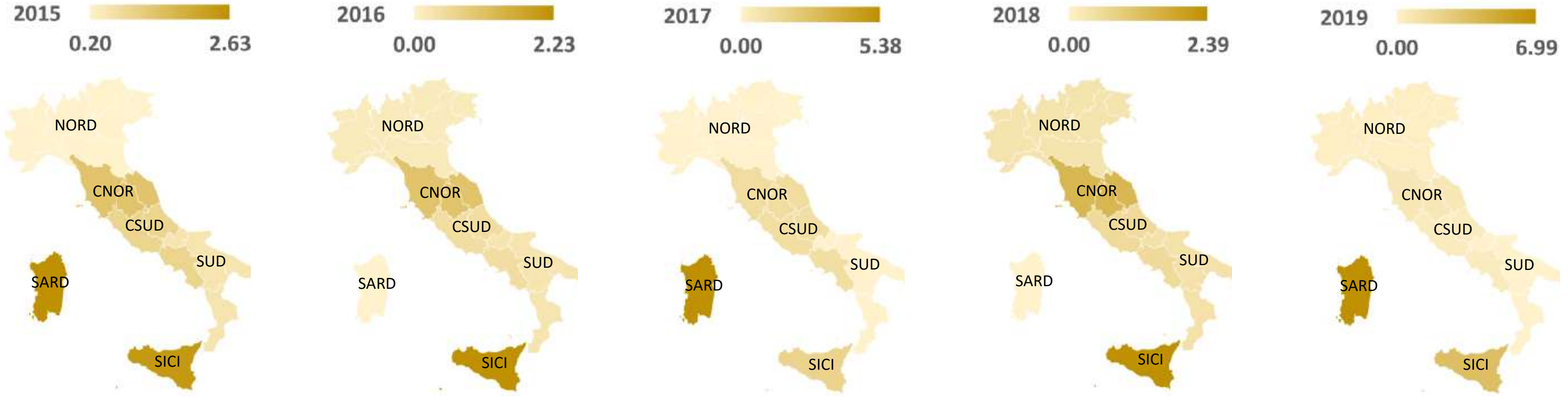
Example application: price relevance analysis



- PUN prices have higher volatility than other prices
- Correlation between PUN-Oil has two-months lags except 2020

Example applications: best renewable generation location based on market data

Increase of 100 MW wind generation



Increase of 100 MW PV generation

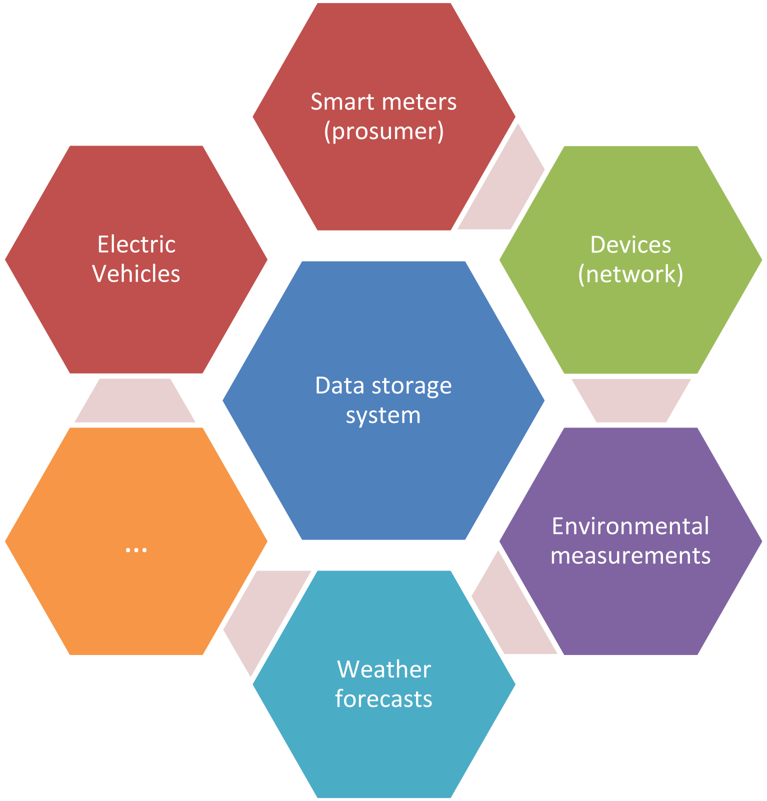
Example application: Improving grid resilience

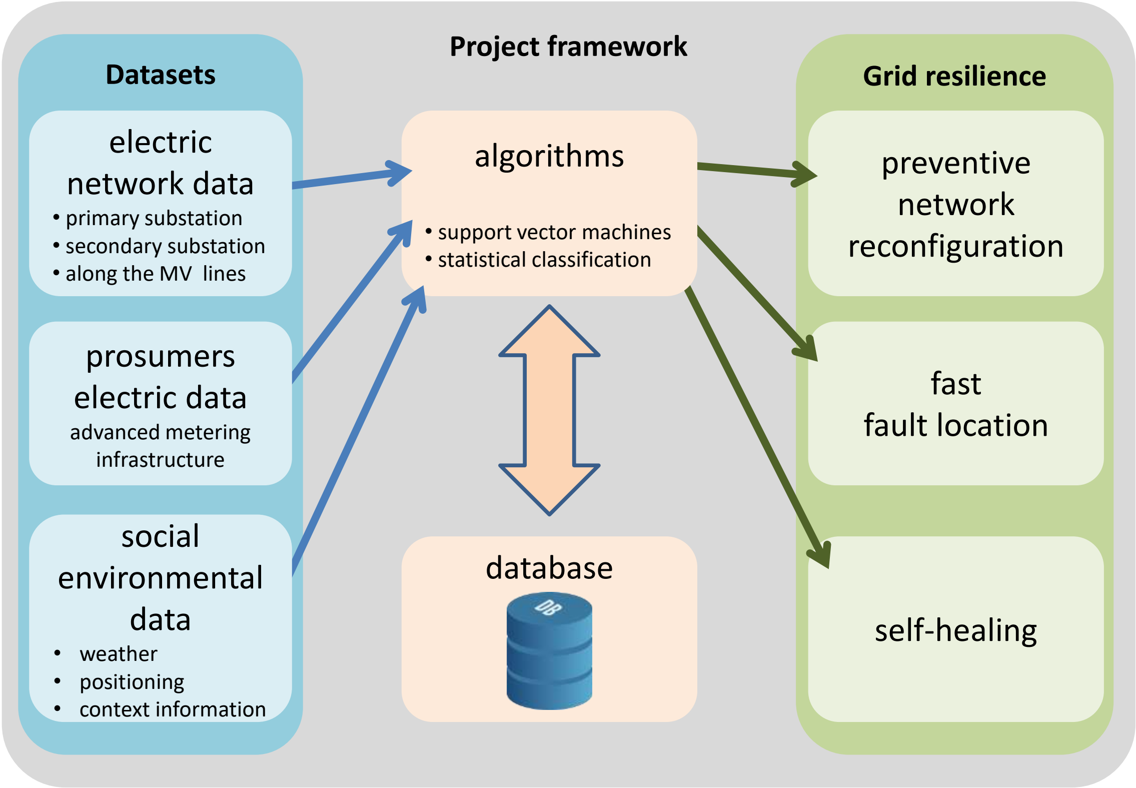
Grid Resilience:

Resilience is the *preparedness* and ability to adapt to *external operational changing* situations, to assure the *continuity* and *quality* of the electricity supply to the end-users.

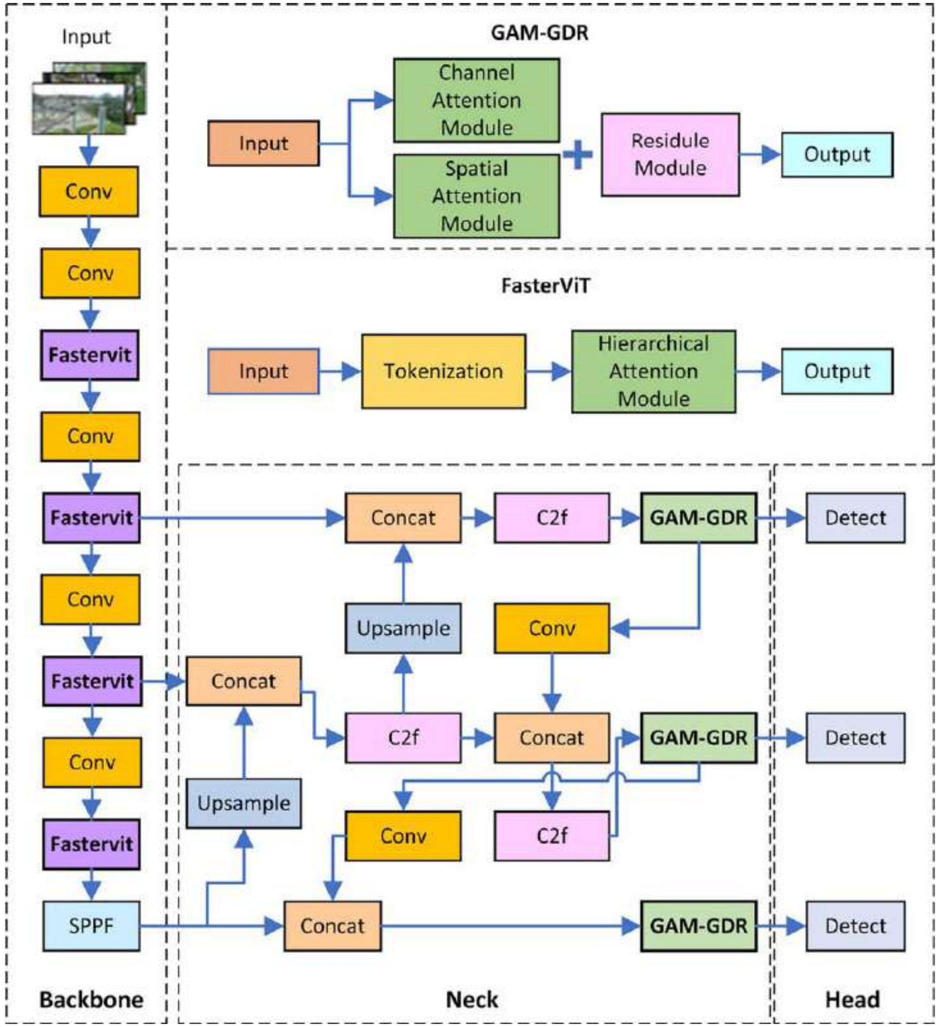
Components:

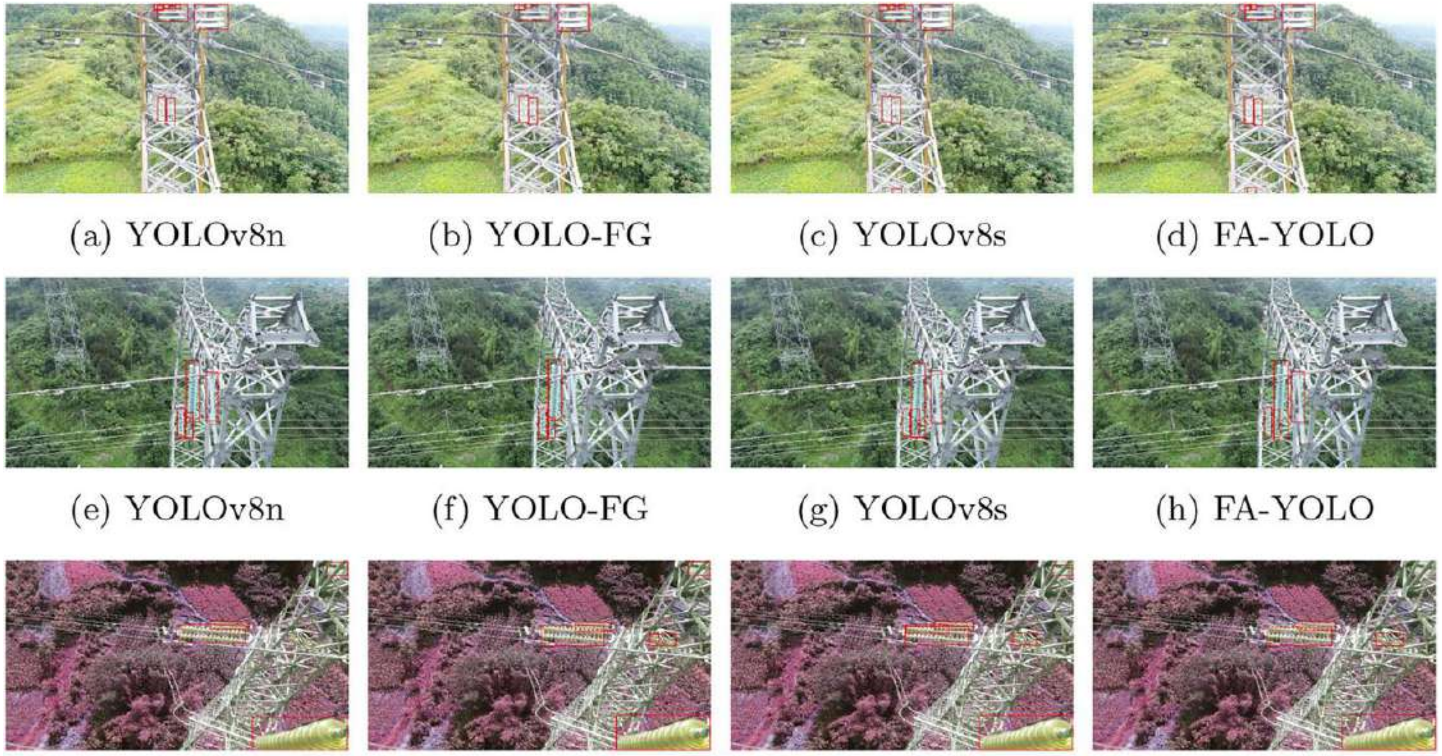
data gathering (from existing monitoring systems and through an enhancement of the system itself), *development of big data methods and algorithms* and *grid performance analysis for resilience.*





Example application: Insulator identification





(a) YOLOv8n (b) YOLO-FG (c) YOLOv8s (d) FA-YOLO

(e) YOLOv8n (f) YOLO-FG (g) YOLOv8s (h) FA-YOLO

(i) YOLOv8n (j) YOLO-FG (k) YOLOv8s (l) FA-YOLO

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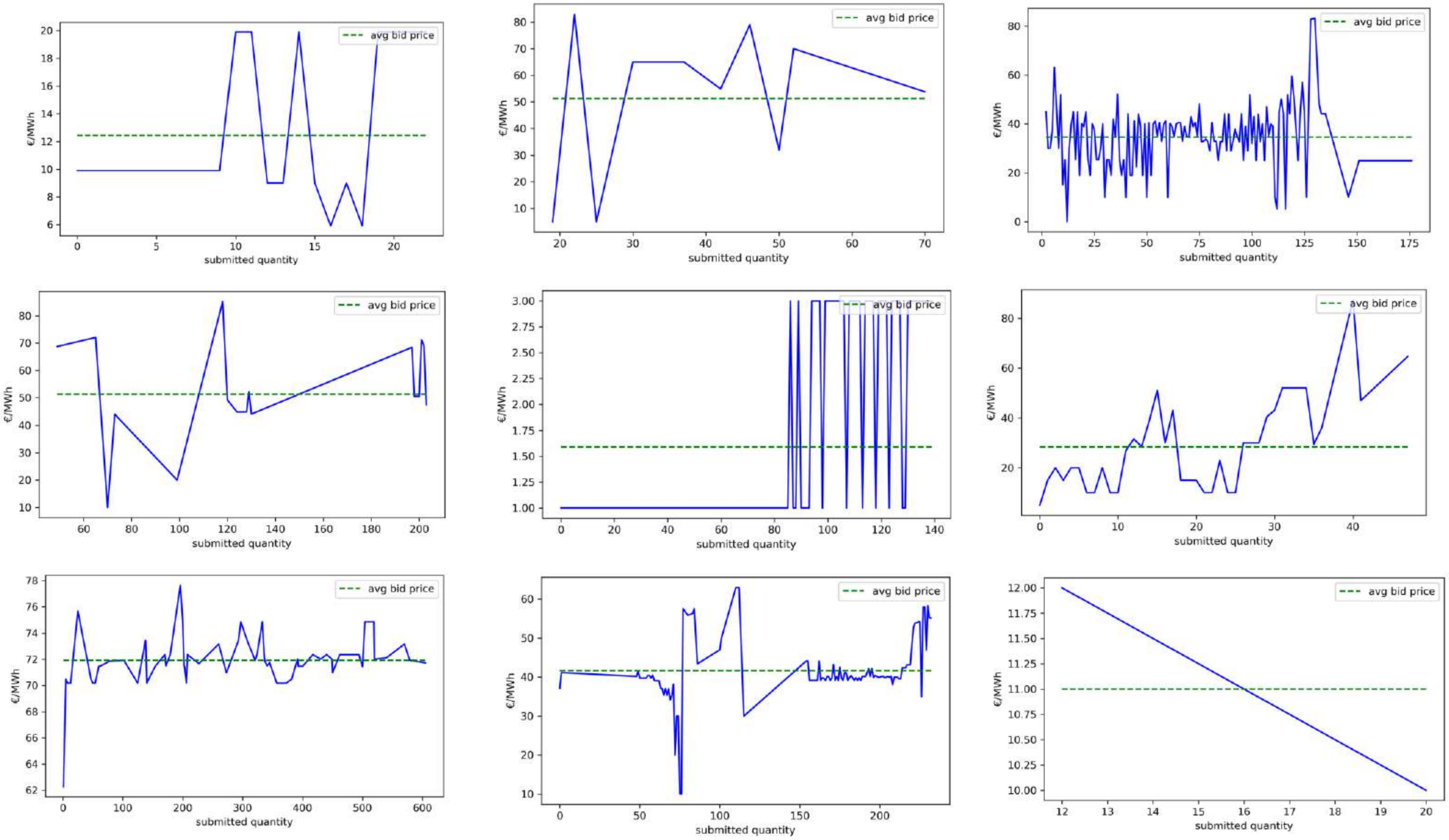
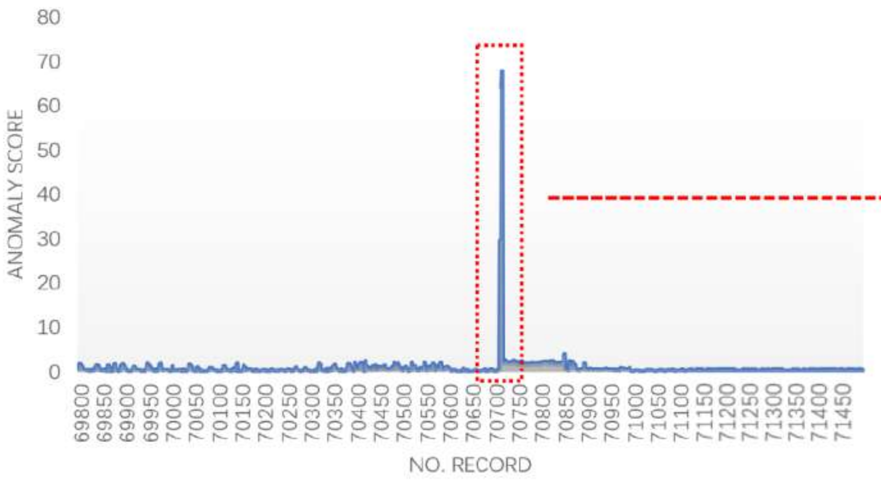
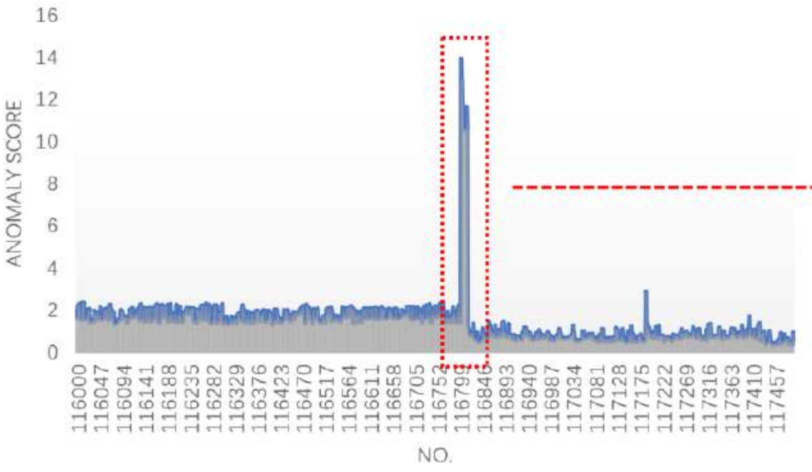
Bidding/offering curves of market participants



Example application: Abnormal bidding behaviors analysis based on variational autoencoder

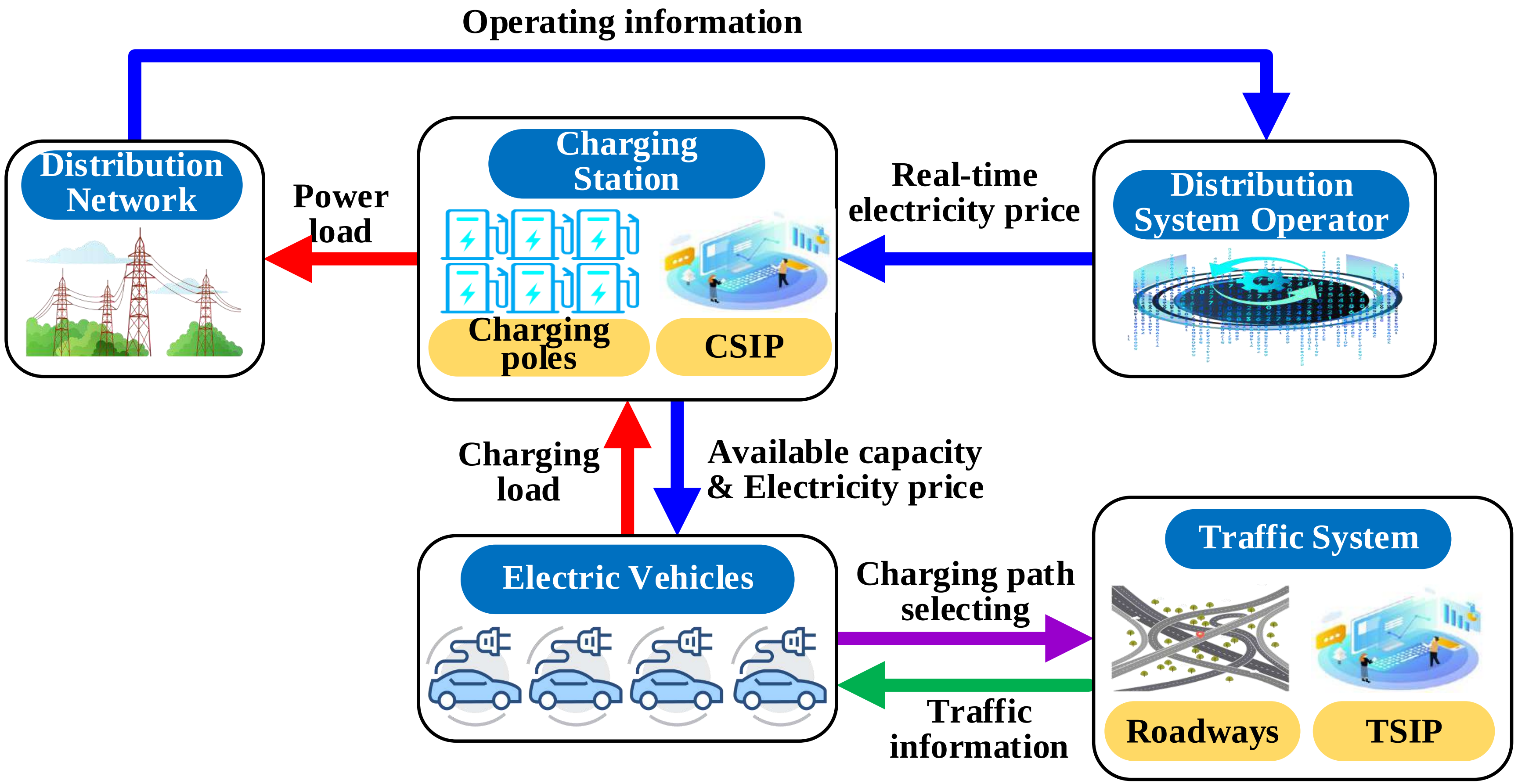


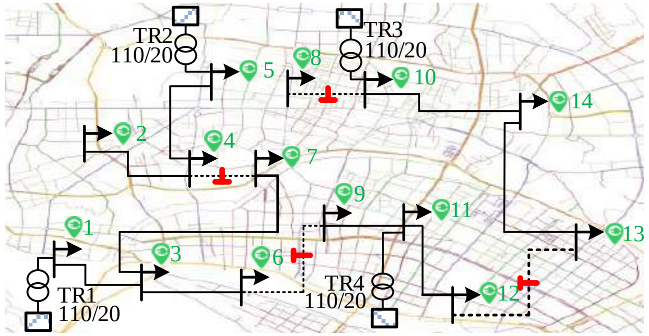
No.	score
70711	0.523286
70712	0.486725
70713	0.391323
70714	29.60618
70715	29.68574
70716	29.79828
70717	63.99295
70718	67.68642
70719	1.968713
70720	2.083777

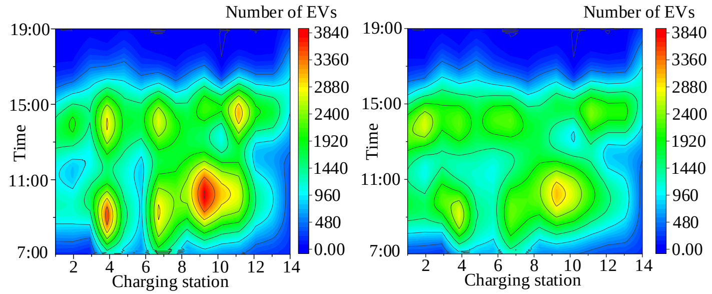


No.	score
116804	13.92828
116805	12.93763
116806	12.91044
116807	11.88643
116808	11.74893
116809	10.58913
116810	10.60317
116811	10.57932
116812	10.53762
116813	10.58585
116814	10.5448
116815	10.57998
116816	11.62158
116817	10.78996
116818	10.62343

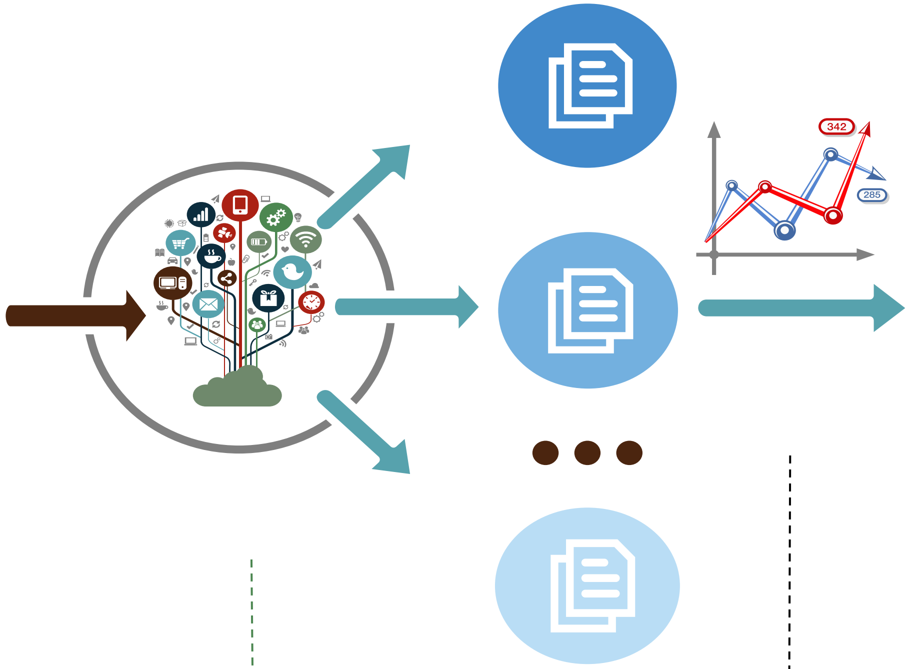
Example application: Interoperability with Transport infrastructures-Changing navigation

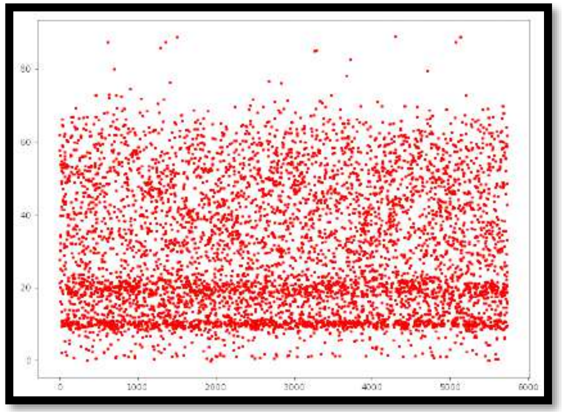




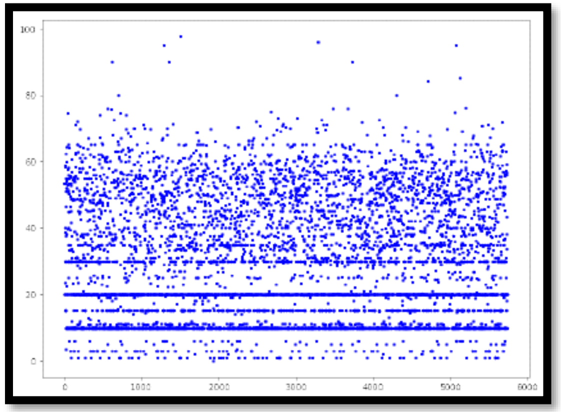


Example application: Price forecast for electricity markets





MSE = 27



KMEANS Clustering

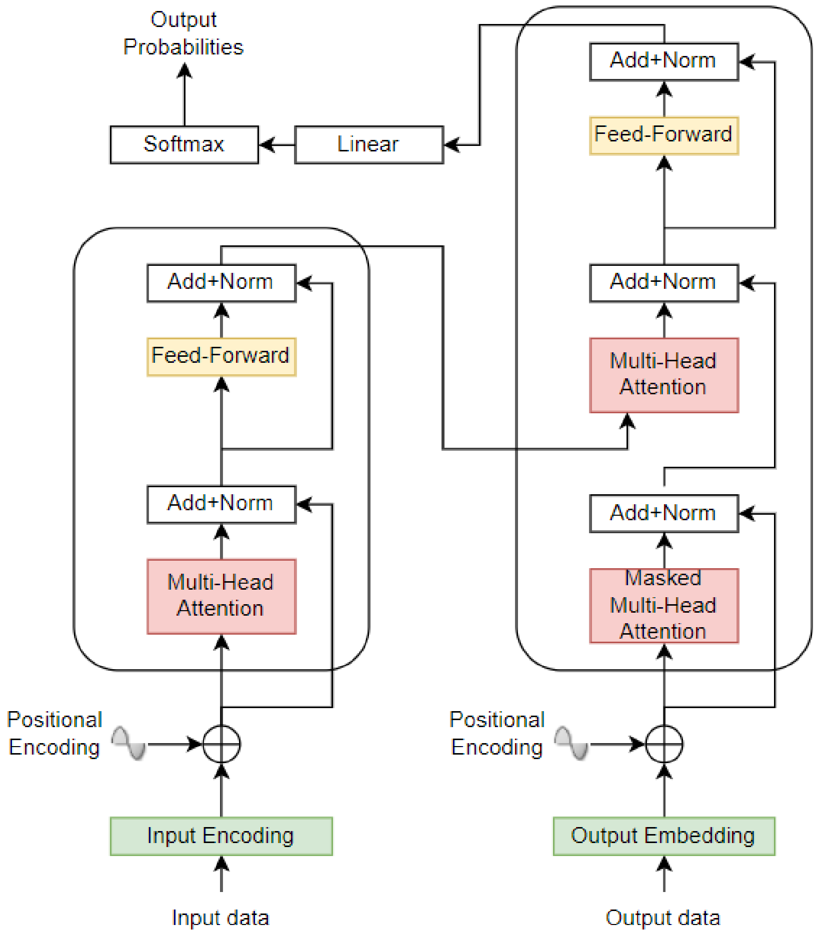
Divide dataset into 15 classes

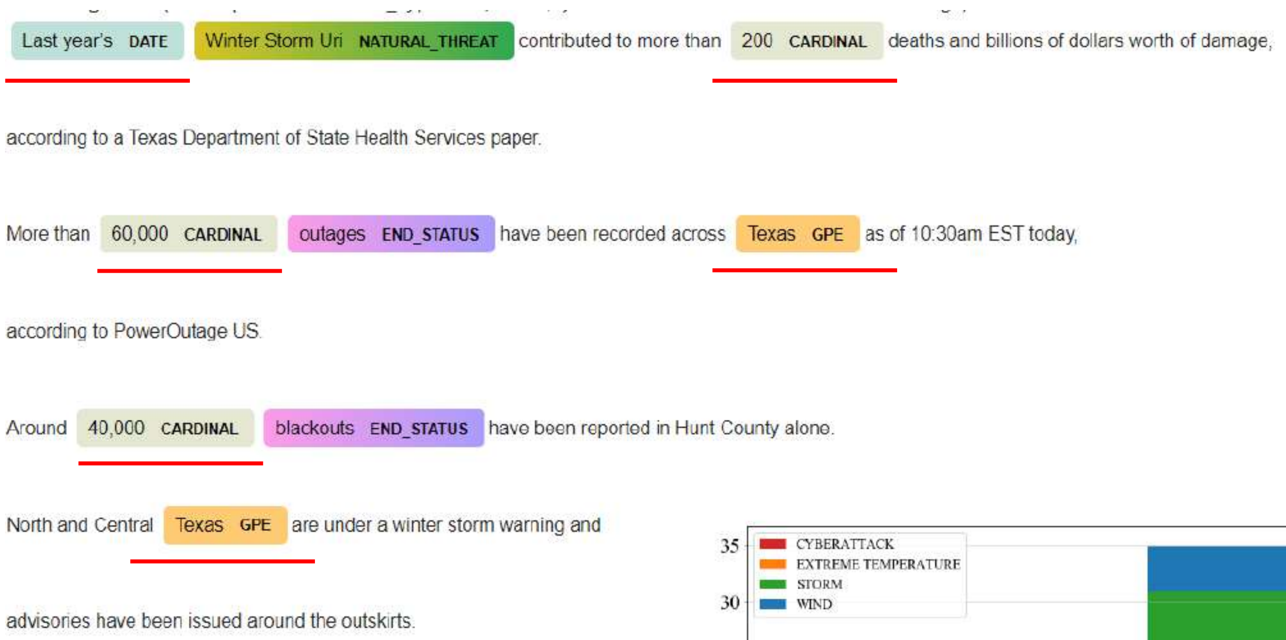
Neural network

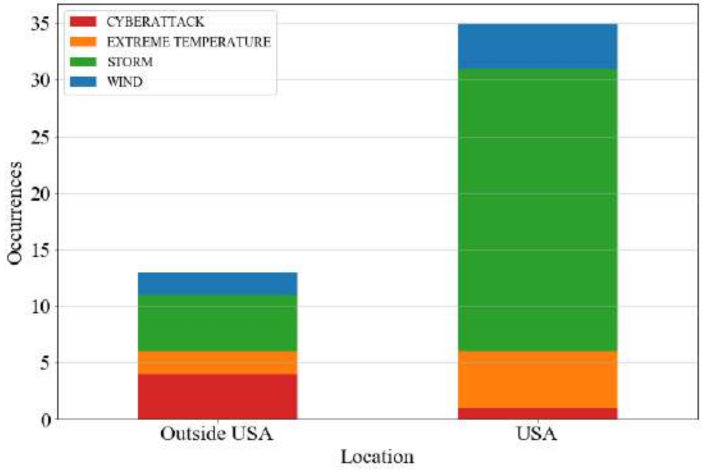
Predicted price vs Real price

(1 class with 157462 records)

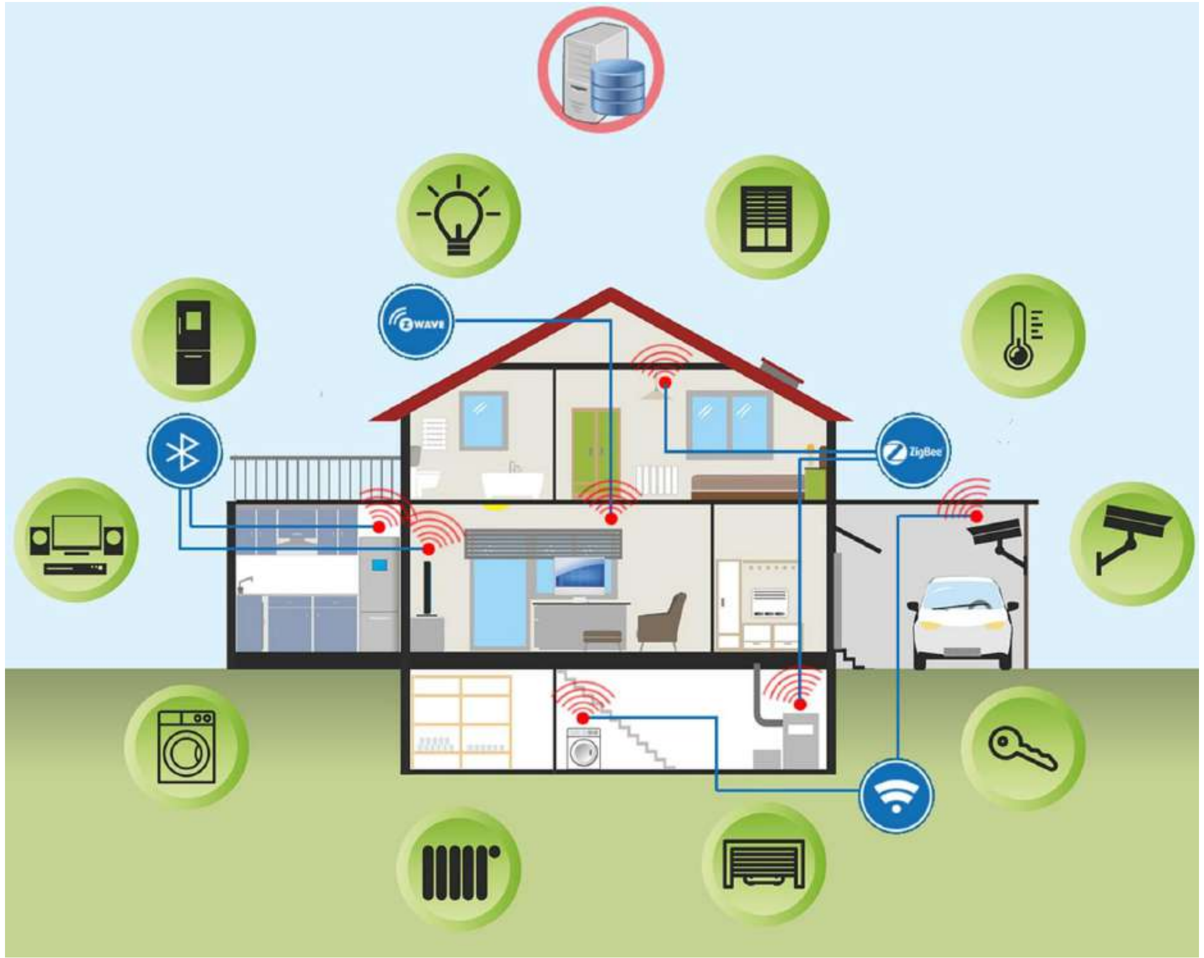
Example application: An ontological approach for automatic tracking causes of blackouts

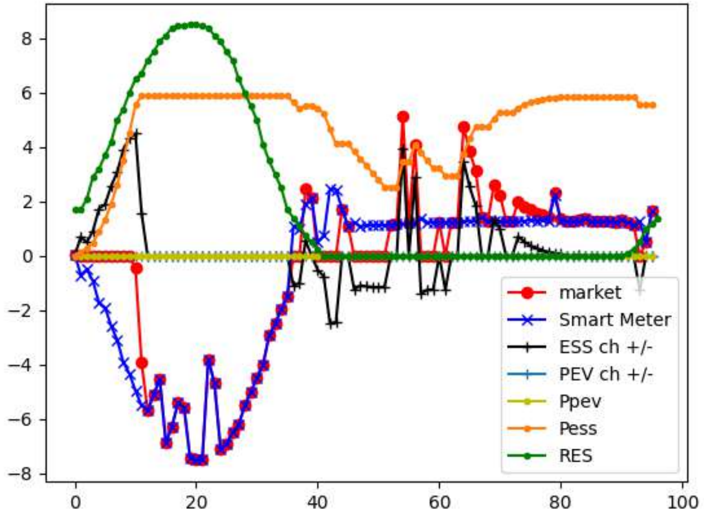






Example application: cross-protocol smart home energy management system





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Info-Energy flows in a smart home