SC D2 JWG D2/C6.47

Доклад по итогам работы CIGRE JWG D2/C6.47 "Перспективные системы управления энергоресурсами на стороне потребителей"

Алексей Небера, Федор Непша

23 ноября 2022

Москва, 2022

cigre

For power system expertise

JWG Scope and targets

SCOPE

ADVANCED CONSUMER-SIDE ENERGY RESOURCE MANAGEMENT SYSTEMS

- Mostly automatic, forecast, modeling and optimization based
- Focus is "behind the meter", in coordination with EPU control systems
- Combined resources, including power and heat

TARGET

- To identify and promote the evolutionary and conscious of "energy transition“ path

TASKS

- Analyze major DER types and their most frequent mixes for specified world regions
- Analyze risks of uncontrolled DER deployment and benefits of coordinated DER usage both for consumers and EPUs
- Evaluate a list of potential business cases for existing and new ICT solutions and their applicability for representative set of countries
- Analyze current state of new ICT applicable for coordinated or shared control of multiple DER and international experience in deployment of these technologies
- Define the most important interactions between control systems of EPU, generation or load aggregator and consumer, which need to be foreseen to keep reliability of supply and stability of a power system

cigre SC D2

Ch. 2 - Consumers classification by area of activity

1) INDUSTRIAL ENTERPRISES

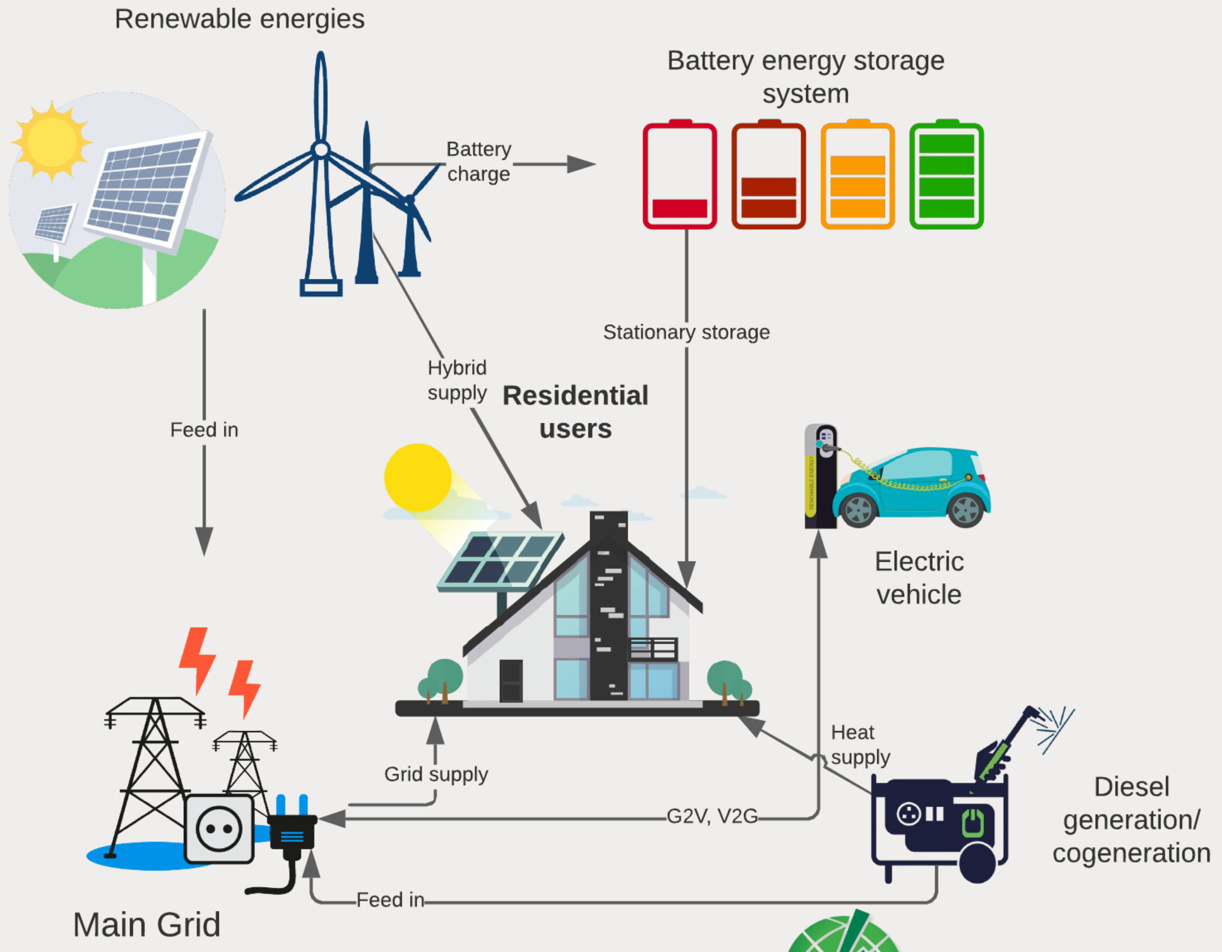
- ✓ Industrial enterprises: mineral excavation and processing; mechanical engineering and instrument making; chemical and metallurgical enterprises, energy engineering.
- ✓ Agricultural enterprises: greenhouses, livestock and forestry complexes, irrigation systems.
- ✓ Industrial parks.
- ✓ Cold stores
- ✓ etc.

2) COMMERCIAL & MUNICIPAL USERS

- ✓ Control centers for airports, railway traffic, gas and oil pipeline systems, urban transport control systems
- ✓ Data Shopping, sports and entertainment centers, theaters, shops
- ✓ Government buildings, office buildings
- ✓ Hospitals and hospital complexes
- ✓ Critical infrastructure enterprises: fire units, ambulance, police
- ✓ Special state institutions: prisons, military and police units

3) RESIDENTIAL USERS

- ✓ processing centers
- ✓ Multi-storey buildings with a complex set of different consumers;
- ✓ Apartment buildings
- ✓ Private households.



cigre SC D2

Ch. 2 - DER classification

1) Electricity only

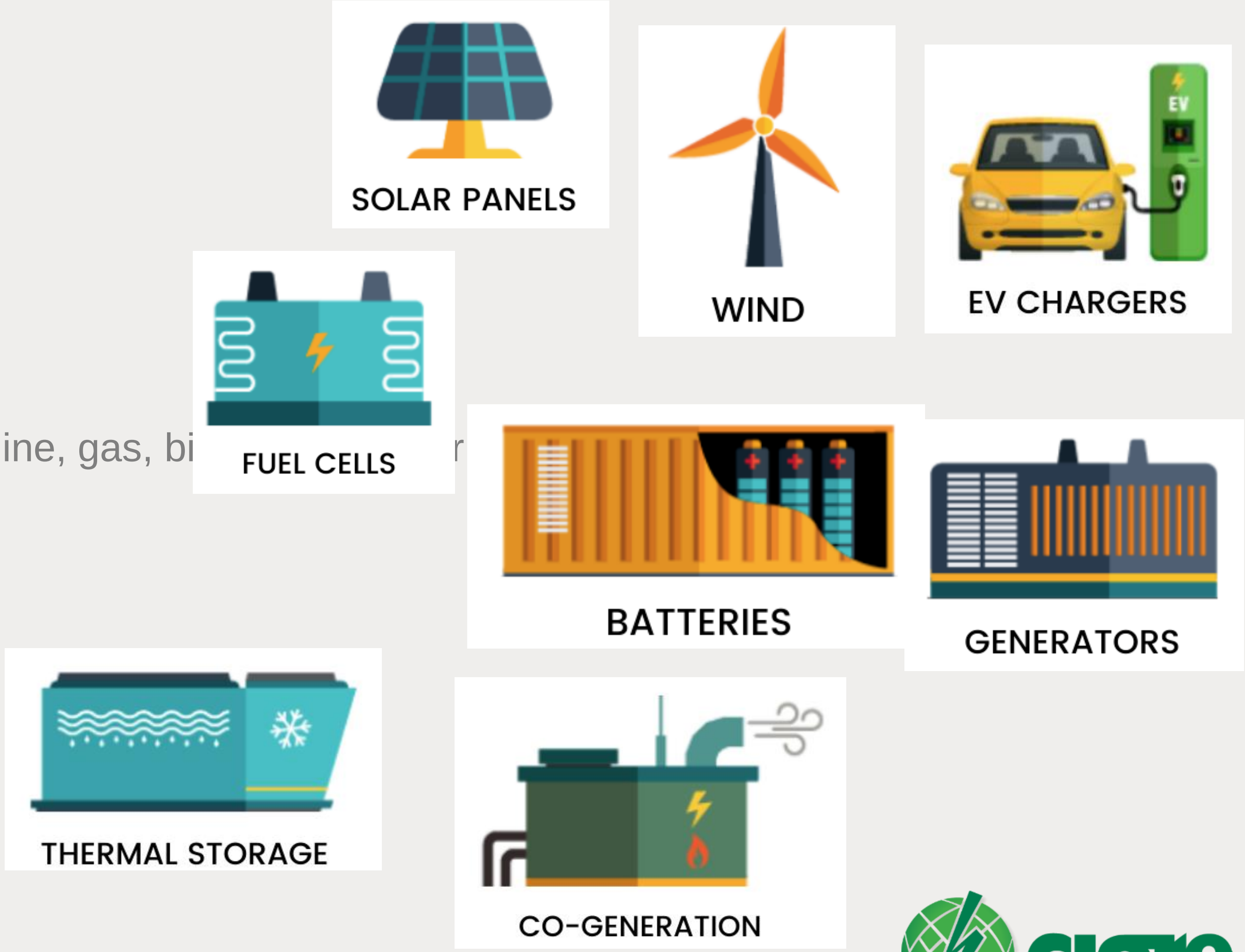
- Consumers with manageable load
- Electrical energy storages
- PV panels
- Wind turbines

2) Heat and Electricity

- Conventional generators: (oil, diesel, gasoline, gas, bi r
- Recycling generators
- Fuel cells
- Gas holder (storage), including H2

3) Heat only

- Solar thermal collector (heat)
- Heat pumps
- Heat energy storage



cigre
SC D2

Ch. 2 - DERs as flexibility resources

No	DERs	Quantiative													Economic	
		Direction	Power Capacity	Ramping Capacity	Energy Capacity	Ramp Duration	Service Duration	Reaction Duration	Rebound effect	Recovery Duration	Efficiency	Calendar lifetime	Usage number	CAPEX	OPEX
		Downward/ Upward/ Bidirectional	MW	MW/s	MWh	Seconds	Seconds	Seconds	MW	Seconds	%	years	#	$	$
1	Consumers with manageable load	D	Medium	Medium	Medium	High	High	Medium	High	Low	High	High	High	Low	Low
2	Supercapacitor energy storage	B	High	High	Low	Low	Low	Low	High	Medium	Medium	Medium	Medium	High	High
3	Battery and hybrid energy storages, including EV batteries	B	Medium	Medium	High	Medium	Medium	Medium	Low	Medium	Medium	Medium	Medium	Medium	Medium
4	Conventional generators: (oil, diesel, gasoline, gas, biofuel generator sets)	U	High	Medium	none	High	High	Medium	Medium	none	Medium	High	High	Medium	Medium
5	Recycling generators	U	High	Medium	none	High	High	Medium	Medium	none	Medium	High	High	Medium	Low
6	Solid state PV panels	U	Medium	Medium	none	Medium	High	High	High	none	Medium	Medium	High	Medium	Medium
7	Wind turbines	U	High	Medium	none	Medium	High	High	High	none	Medium	Medium	High	High	Medium
9	Solar thermal collector (heat)	none	None												
10	Gas holder (storage), including H_2	none													
11	Fuel cells	none													
12	Heat pumps	none													
13	Heat energy storage	none													

Ch. 2 - Flexibility services: initiators (operators) and providers (prosumers)

1) Position of ISOs, DSOs, Distribution grid and microgrid operators:

- **to reduce** the risks of uncontrolled development and undefined behavior of DERs.
- **to organize** local flexibility markets
- **to include** the requirements for flexibility provisioning in technical specifications for Power Grid connection

2) Position of prosumers:

- **to reduce** payback period of their DERs
- **to increase** power supply reliability
- **to provide** ancillary services and Demand Response accepted by aggregators/DSO/TSO/grid operators, as well as participation in a Peer-to-Peer Energy Market

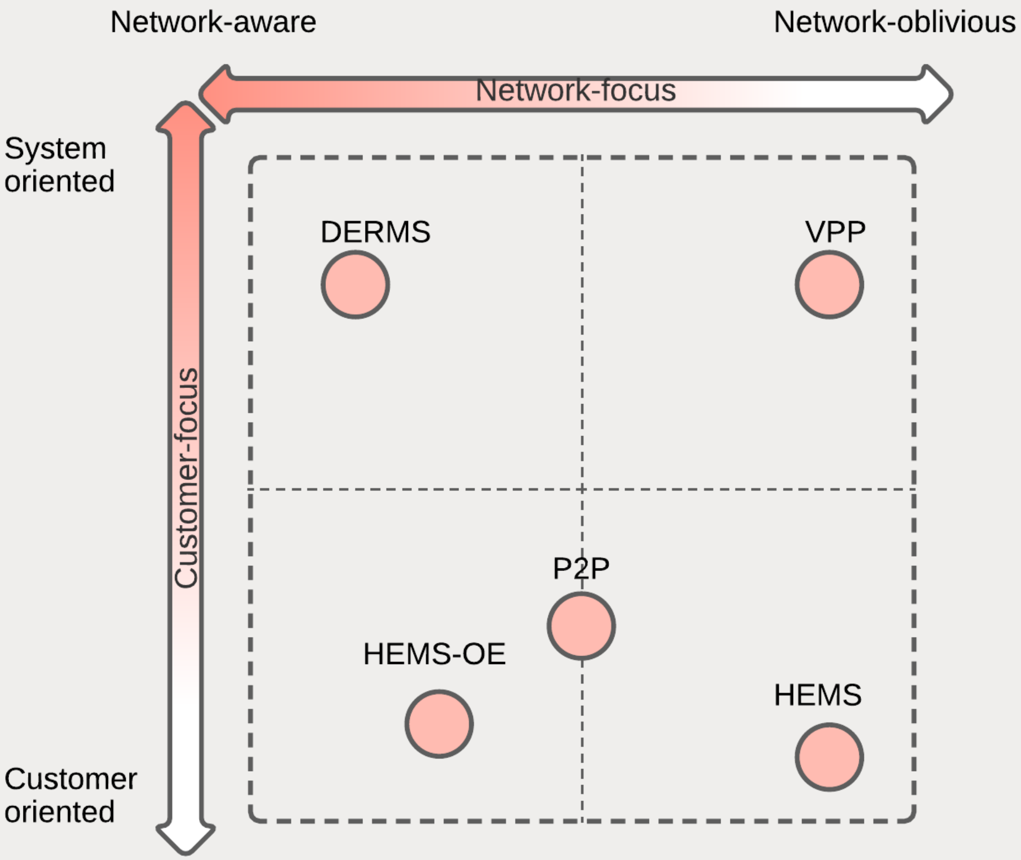
cigre
SC D2

Ch.3 - Uncontrolled deployment of consumer-side DER

No.		DER type	Electrical safety	Incorrect operation of relay protection	Stability	System inertia	Electric energy quality (U, f)	Power balances, network overload	Integral risk assessment
1	Electrical energy	Manageable load (ML)	none	none	none	none	low	trouble	trouble
2		Super-capacitor energy storages (SCAP)	low	low	low	medium	medium	medium	medium
3		Rechargeable Battery (RB) and hybrid (RB + SCAP) energy storages, including vehicle	low	low	low	medium	medium	medium	medium
4		Electrical solar panels (PV-panels)	low	low	low	trouble	trouble	trouble	trouble
5		Wind power farm (WPF)	low	low	low	trouble	trouble	trouble	trouble
6	Electrical energy and heat	Distributed conventional generators (DCGs): (crude oil, diesel, gasoline, gas, biofuel generator sets)	low	low	low	none	medium	trouble	trouble
7		Waste heat generators (WHG)	low	low	low	none	low	low	low
8		Fuel cells (FC)	low	low	low	medium	low	medium	medium
9		Gas storages (accumulators), including H2 (GS)	none	none	none	none	none	low	low
10	Heat	Solar collectors (heat)	none	none	none	none	none	low	low
11		Heat pumps	none	none	none	none	none	low	low
12		Thermal energy storages	none	none	none	none	none	low	low

SC D2

Ch.3 - DER integration approaches



J. Guerrero, D. Gebbran, S. Mhanna, A. C. Chapman, and G. Verbič, "Towards a transactive energy system for integration of distributed energy resources: Home energy management, distributed optimal power flow, and peer-to-peer energy trading," *Renewable and Sustainable Energy Reviews*, vol. 132, p. 110000, Oct. 2020, doi: 10.1016/j.rser.2020.110000.

UNCOORDINATED APPROACHES

- **HEMS (Home Energy Management System)**
  - ✓ Individual energy management
  - ✓ Suited to networks with low DER penetration
- **HEMS-OE (HEMS with Operating Envelopes) -** Short-term solution to DER penetration issues

COORDINATED APPROACHES

- **VPP (Virtual Power Plant)** - low and medium DER penetration
- **DERMS (DER management system) -** high level of DER penetration
- **P2P (Peer-to-Peer) - Suited to scenarios with high level of DER penetration (new business models)**

The implementation of the presented approaches **requires use of an energy management system**.

cigre SC D2

Ch.4 - Set of system demands and customer capabilities relating flexibility supply

	System demands for flexibility products	Manageable loads		Electrical energy storage systems RB		Electrical energy storage systems SCAP		PV		Concentrated solar power	Wind power farm		Distributed conventional generators		Waste head generators		Fuel cell		GS
		MV	LV	MV	LV	MV	LV	MV	LV	MV	MV	LV	MV	LV	MV	LV	MV	LV	
1.	Maintaining the inertia of electrical power systems by synthetic inertia (Inertial Response)	1	1	1	1	3	3	2*	1*	3	2	2	3	3	3	3	1	1	0
2.	Prevention of deep frequency drops in electrical power system with reduced inertia - Fast Frequency Response	1	1	1	1	3	3	2*	1*	3	2	1	0	0	0	0	1	1	0
3.	Prevention of deep frequency reduction through primary response (Primary Frequency Response)	0	0	2	2	3	3	2*	2*	3	2	1	3	3	1	1	1	1	0
4.	Frequency restoration, maintaining the area balance of power flows, removing network overloads - secondary regulation of frequency and power flows	1	1	3	3	1	0	2*	2*	1*	2	1	3	3	0	0	3	3	3
5.	Maintaining contingency power balances - tertiary reserves (Contingency Reserves: Spinning, Non-spinning, Replacement)	3	3	1	1	0	0	0	0	0	0	0	3	3	0	0	3	3	3
6.	Ensuring the balances of power consumption and generation in the conditions of ultra-fast changes of RES generation - ramping reserves	1	1	3	3	0	0	0	0	0	0	0	3	3	0	0	3	3	3

Ch.4 - Set of system demands and customer capabilities relating flexibility supply (continued)

	System demands for flexibility products	Manageable loads		Electrical energy storage systems RB		Electrical energy storage systems SCAP		PV		Concentrated solar power	Wind power farm		Distributed conventional generators		Waste head generators		Fuel cell		GS
		MV	LV	MV	LV	MV	LV	MV	LV	MV	MV	LV	MV	LV	MV	LV	MV	LV	
7.	Economic substitution of the involved operational power reserves - tertiary economic reserves (Economic dispatch)	1	1	3	3	0	0	0	0	0	0	0	3	3	0	0	3	3	3
8.	Voltage and reactive power support, harmonic mitigation of voltage and current components (Harmonic mitigation)	2	1	3	2	3	2	3	2	0	3	2	3	2	3	2	3	2	0
9.	Black start	0	0	3	3	2	2	1	0	0	1*	1*	3	3	1	0	3	3	0
10.	Reducing peaks in electricity market prices - demand response (Peak shifting/shaving)	3	3	3	3	0	0	0	0	0	1*	1*	3	3	0	0	3	3	3
11.	Refusal from building hydrocarbon peak generators	2	1	3	1	0	0	0	0	0	0	0	2	2	0	0	3	3	3
12.	Postponement in construction of electrical grids	2	1	3	1	0	0	1	1	1	1	1	1	1	1	1	3	3	3
13.	Fault Ride-Through capability, b	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0
14.	Administrative restrictions for the DER use mode (pre-curtailed)	0	0	3**	3**	3**	3**	3	3	1	3	3	1	1	0	0	3	3	0

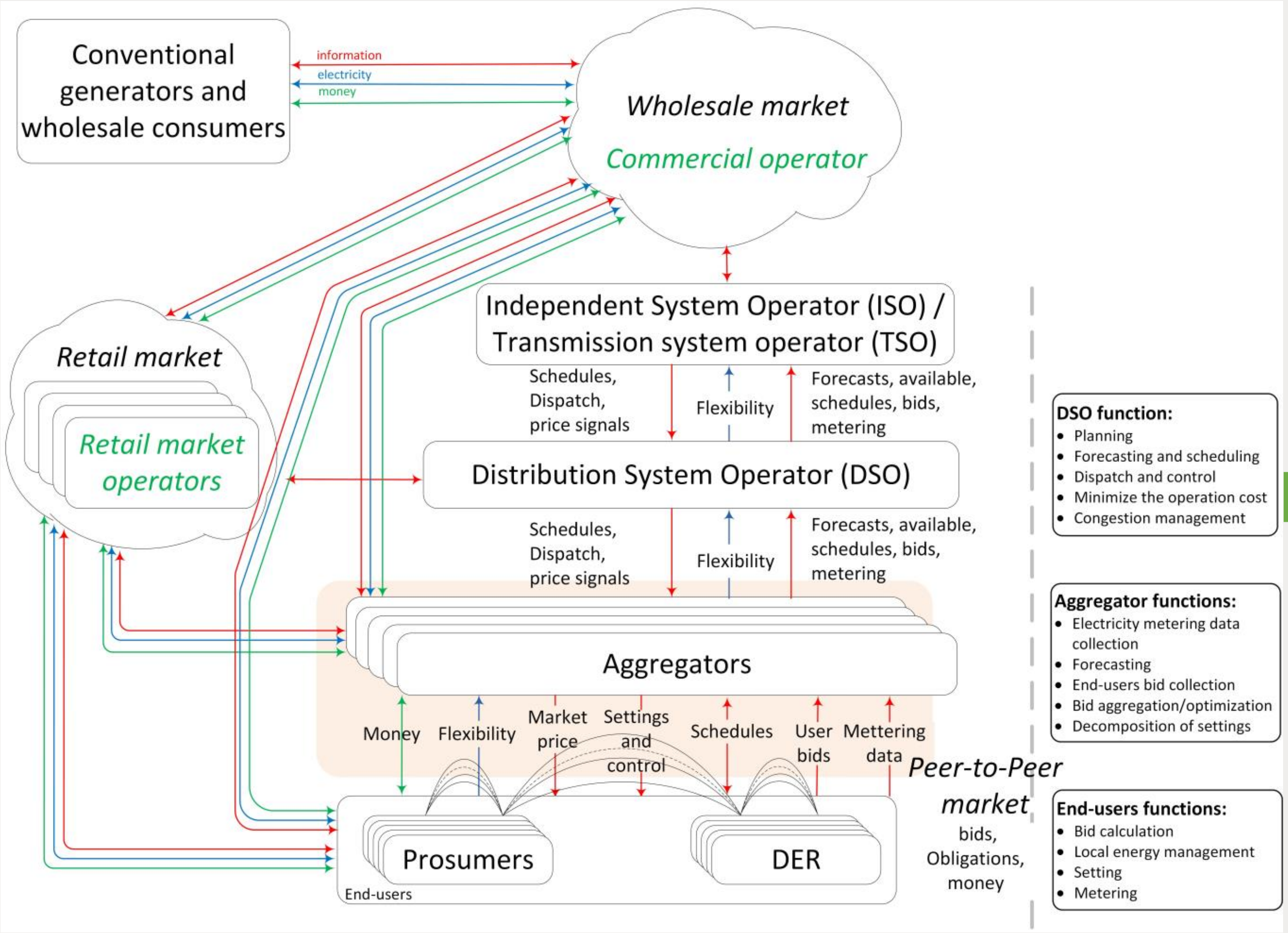
Ch.4 - Requirements for measurement of electrical network parameters

		System needs	Required flexibility characteristic				Requirements for electrical parameters measurement: frequency, voltage, currents and power flows				
			As far as in advance	How fast	How much	How long	Frequency of measurements		regularity	duration	synchronization
							Monitoring	accounting	Monitoring accounting	Monitoring accounting	Monitoring accounting
1.	Ancillary services	Synthetic inertia (Inertial Response)	–	≤10 ms	contract	up to 30 s	≥ 50 kHz	≥ 50 kHz	continuously	–	required
2.		Fast Frequency Response	–	≤50 ms	contract	up to 30 m	≥ 50 Hz	≥ 50 Hz	continuously	–	required
3.		Primary Frequency Response	–	≤500 ms	% Pnomgen	up to 60 m	≥ 10 Hz	≥ 10 Hz	continuously	–	not required
4.		Secondary regulation of frequency and power flows (Frequency Restoration Reserves, Regulating Reserves)	–	≤1 s	contract	up to 60 m	≥ 1 Hz	≥ 1 Hz	continuously	–	not required
5.		Extended tertiary reserves (Ramping reserves)	–	≤60 s	contract	up to 90 m	≥ 0.1 Hz	≥ 0.1 Hz	continuously	–	not required
6.		Voltage support, damping of low-frequency fluctuations of voltage and power flows	–	≤20 ms	%Pnomgen	up to 60 m	≥ 10 Hz	≥ 10 Hz	continuously	–	not required
		filtering/compensation of harmonic components of currents and voltages	–	≤3 ms	%Pnomgen	up to 60 m	≥ 10 Hz	≥ 10 Hz	continuously	–	not required
7.		Black start	contract	≤1 s	Pnomgen	hours	≥ 1 Hz	≥ 1 Hz	continuously	–	not required
8.		Fault Ride-Through capability	–	t_{off}=f(U)		–	≥ 10 Hz	≥ 10 Hz	continuously	–	not required
9.	Energy market	Contingency Reserves: Spinning, Non-spinning, Replacement)	contract	≤60 s	contract	up to 90 m	≥ 0.1 Hz	≥ 0.1 Hz	continuously	–	not required
10.		Tertiary economic reserves (Economic dispatch)	5 min	≤60 s	contract	up to 90 m	≥ 0.1 Hz	≥ 0.1 Hz	continuously	–	not required
11.	Demand management	Reducing peaks in electricity market prices - demand response (Peak shifting/shaving)		≤1 s	contract	contract	≥ 1 Hz	≥ 1 Hz	during execution periods in accordance with the demand management program		not required
12.	Power market	Refusal from building hydrocarbon peak generators	years	–	–	–	≥ 0.1 Hz	–	–	–	not required
13.	Construction of electrical power grids	Construction postponement of electrical grids	years	–	–	–	≥ 0.1 Hz	–	–	–	not required
14.	Limitations according to National Grid Codes	Limitations of DER use mode	–	≤1 s	contract	contract	≥ 1 Hz	≥ 1 Hz	continuously	–	not required

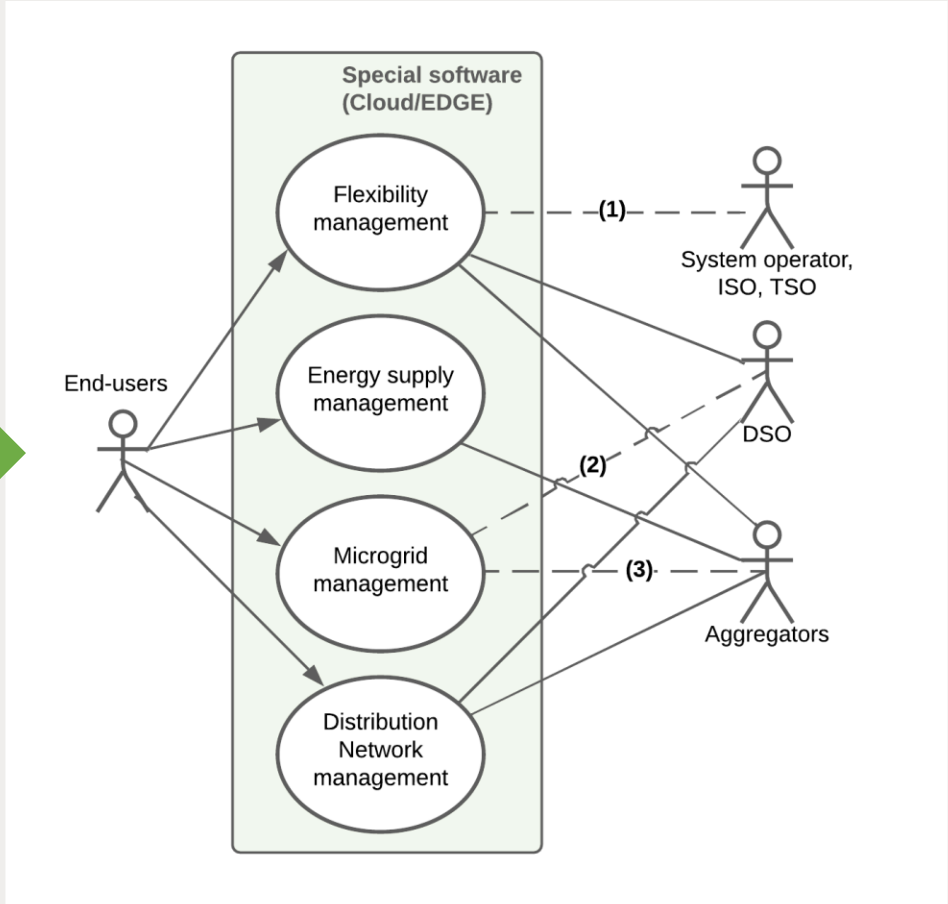
Ch.4 - Distribution of the main functions supporting flexibility services by control level

	Software and hardware functions	Aggregators	Consumers - owners of DER
1	Forecast	Creation of: • aggregated load profiles • RES generation profiles • electricity price profiles at the points of connection of end users - suppliers of flexibility products to the grid	Creation of: • load profiles, including electric vehicle charging and heat pumps • RES generation profiles (based on meteorological forecasts) • thermal load profiles (based on temperature forecasts, solar radiation, wind strength and direction forecasts) • cloud cover and photovoltaic panel shading (10 minutes ahead)
2	Aggregation and disaggregation	Summation of consumer offers (if there are no network constraints) and decomposition by consumers of obligations received from SO or distribution grid operators	no
3	Optimization	Economic or competitive selection of end-user offers to form an aggregate offer (if there are network constraints) and decomposition by consumers of obligations received from SO or distribution grid operators	Formation of the optimal offer or the limits of the end user's offer range
4	Calculations of parameters of set-points and settings	no (only ensure that setpoints and settings are sent to users' equipment, calculated by system and network operators)	no
5	Control of end-user power equipment	no	Realization of control based on profiles obtained from an aggregator

Ch. 5 - Scenarios of effective interaction between DER and EPU control systems

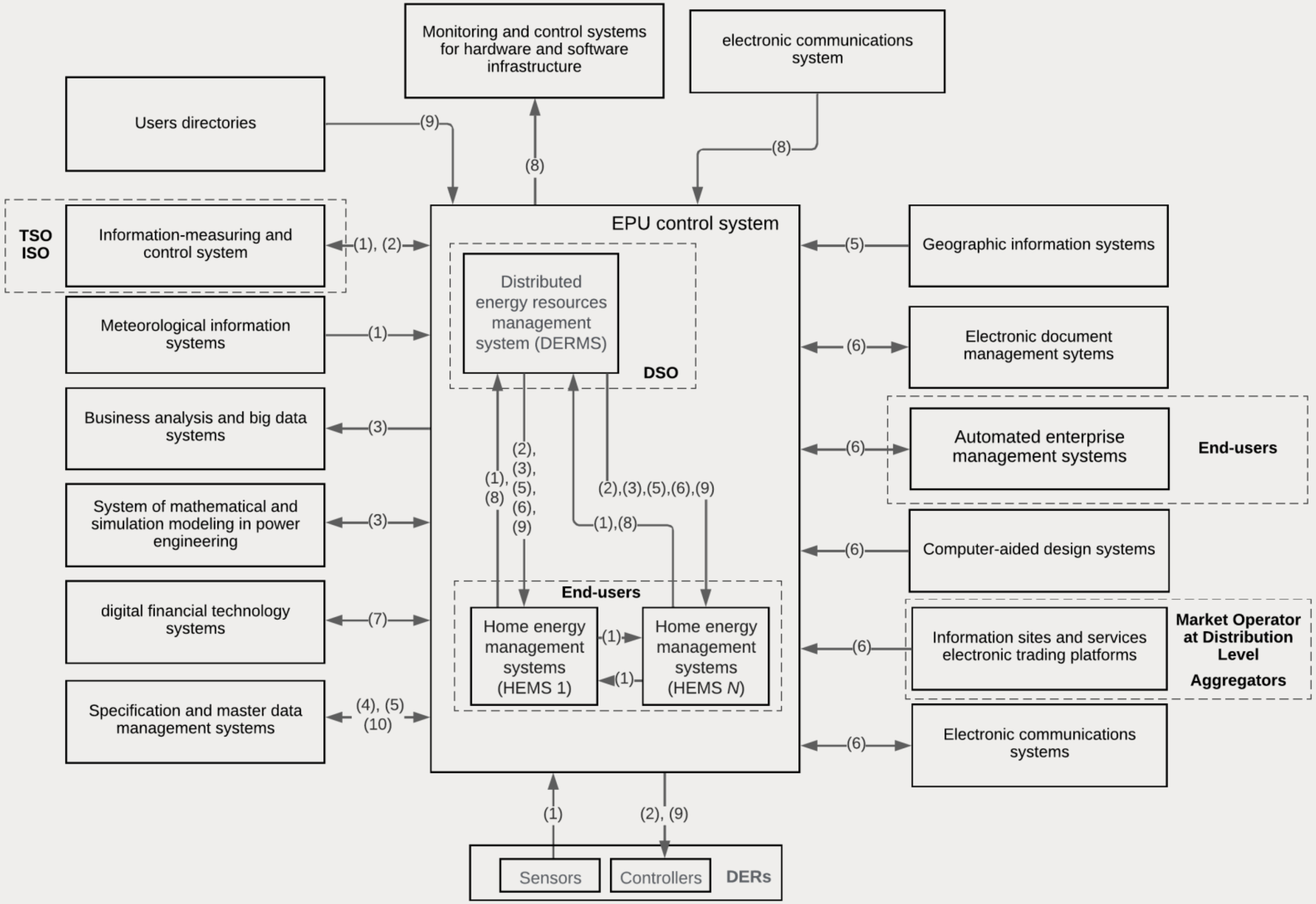


Stakeholders' interaction diagram



4 scenarios of interaction between DER and stakeholders

Ch. 6 - Interaction scheme between active consumers and DERs



Typical information links - data flows between Digital control system and the external environment:

(1) telemetry data

(2) equipment control settings and commands

(3) data on profiles, equipment modes, prices

(4) data sheets and specifications

(5) master data

(6) electronic documents

(7) data of energy transactions and smart contracts

(8) platform and application health monitoring logs

(9) data for identification, authorization and authentication

(10) ontological model

Ch. 6 - Interaction protocols for transferring different types of data

#	Data flow type	Communication protocols	Comments
1	Telemetry data	IEC 60870-5-104, IEC 60870-5-101, IEC 61850, OPC UA, Modbus TCP, CoAP, MQTT, AMQP, SNMP, proprietary protocols, file formats	EPU control systems should provide work with different protocols, while data should be stored inside the system in accordance with a single interoperable data structure
2	Equipment control settings and commands		
3	Data on profiles, equipment modes, prices	REST API, electronic documents (*.xls, *.pdf, *.doc, *.odt)	In the near future, all marketplaces might have a REST API (e.g. Thomson Reuters APIs)
4	Data sheets and specifications	IEC 61970, 61698, 62325, electronic documents (*.xls, *.pdf, *.doc), proprietary protocols, file formats (e.g. gbXML, *ies form in DIAlux program)	It is assumed that large equipment vendors will have to systematize information about their equipment and present it in a machine-readable format similar to the format used by Dialux or for Buidling Energy Modeling (Green Building XML, gbXML)
5	Master data	IEC 61970, 61698, 62325, proprietary protocols, file formats	

Ch. 6 - Interaction protocols for transferring different types of data

#	Data flow type	Communication protocols	Comments
6	Electronic documents	*.pdf, *.doc, *.docx, *.xls, *.xlsx, *.odt	
7	Data of energy transactions and smart contracts	REST API, OCF, Matter	
8	Application health monitoring logs	REST API, Syslog UDP/TCP	
9	Data for identification, authorization and authentication	REST API, OAuth 2.0, OIDC	
10	Ontological model	RDF/XML, Turtle, OWL/XML, JSON-LD	

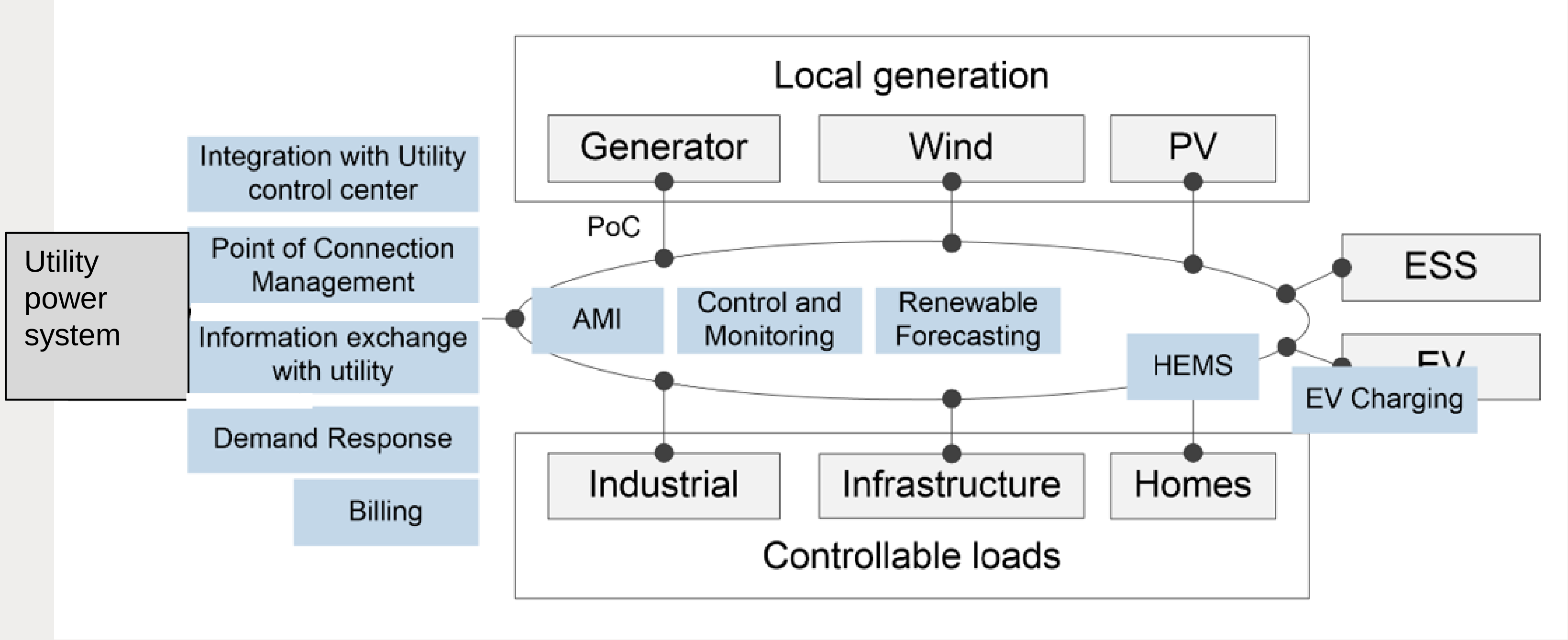
•External services will sooner or later switch to interaction through API, in this regard, EPU control systems should be able to interact through REST API (using HTTP or WebSocket)

•EPU control systems should use CIM model as the basis for storing master data and reference information, but it should fulfill the requirements taking into account the specifics of the subject area of the 0.4 - 35 kV power grid

Ch. 7 - Application specific communication protocols

Advanced Metering Infrastructure (AMI): IEC 62056-21:2002
Billing: DLMS/COSEM
Control and monitoring: DNP3, IEC 60870-5-101, 104, Modbus

Demand response: OpenADR - IEC 62746-10-1:2018
Electricity market: DPWS
Energy Management System: DDS



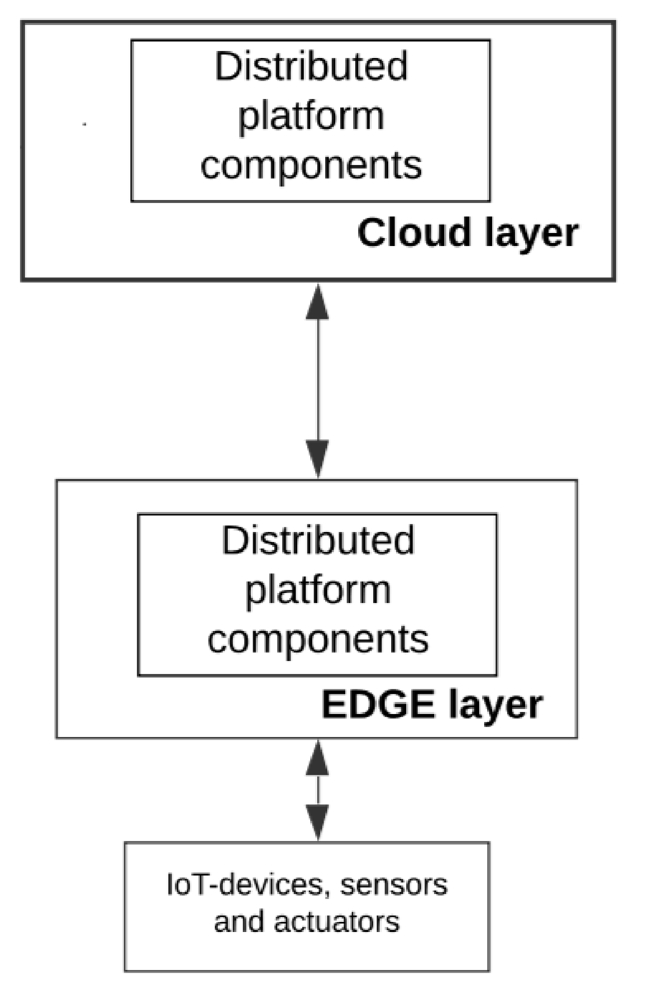
HEMS: ZeroMQ, ISO/IEC 10192-3:2017, ZigBee
Integration of IoT: XMPP
Substation Automation Systems: OPC UA, CORBA, 61850
Wind power station: IEC 61400-25
Point of Connection management: IEEE 1547-2018

EV Charging: OCCP - Open Charge Point Protocol 2.0.1, Road vehicles — Vehicle to grid communication interface — Part 1: General information and use-case definition
Integration with utility control center: ICCP
Market information: IEC 61970, 62325, REST API,
Smart Home: CoAP, MQTT, AMQP

cigre SC D2

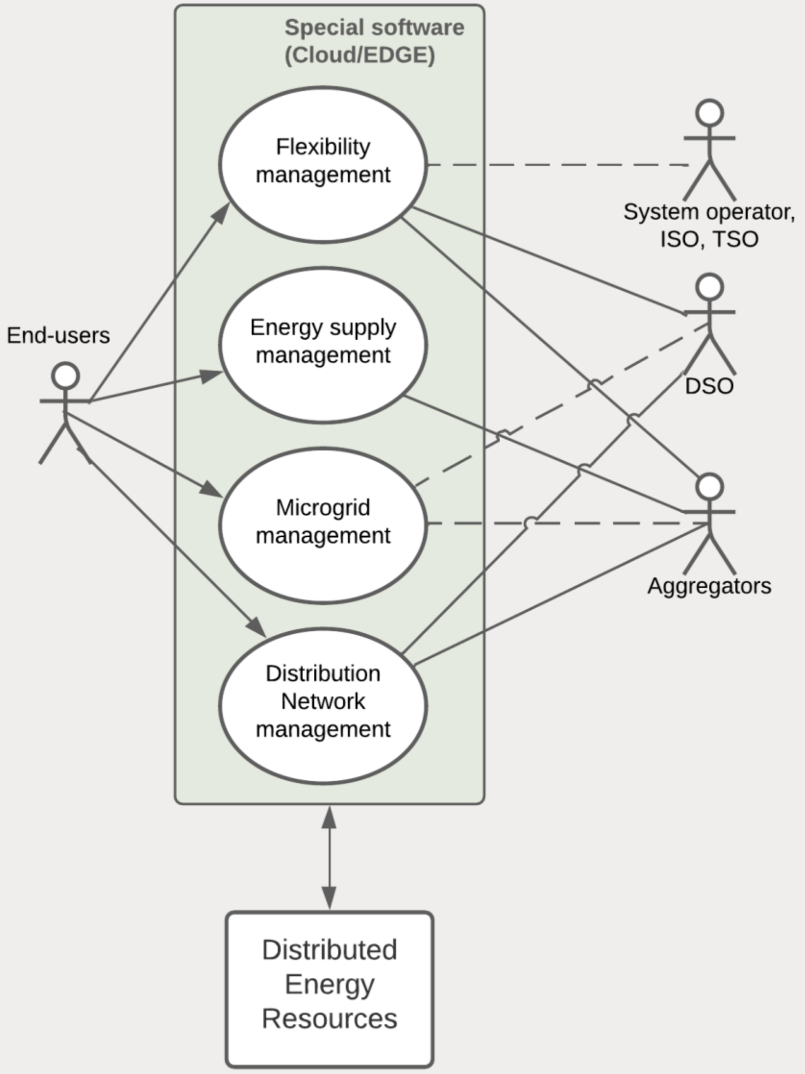
Ch. 7 - ICT challenges for DER management

- **Performance** → network traffic, huge amount of data, heavy reliance on the cloud
- **Reliability** → adaptability to changing environmental conditions, resistance to long-term usability and security problems
- **Security and privacy** → a large number of malware entry points, which increases vulnerability
- **Scalability** → enabling unified addition of new devices
- **Precision** → necessary to control and shape voltage and frequency
- **Interoperability** → IoT should facilitate services to all DER devices regardless of the type
- **Configuration management** → automated tools for remote device configuration, software updates etc.



SC D2

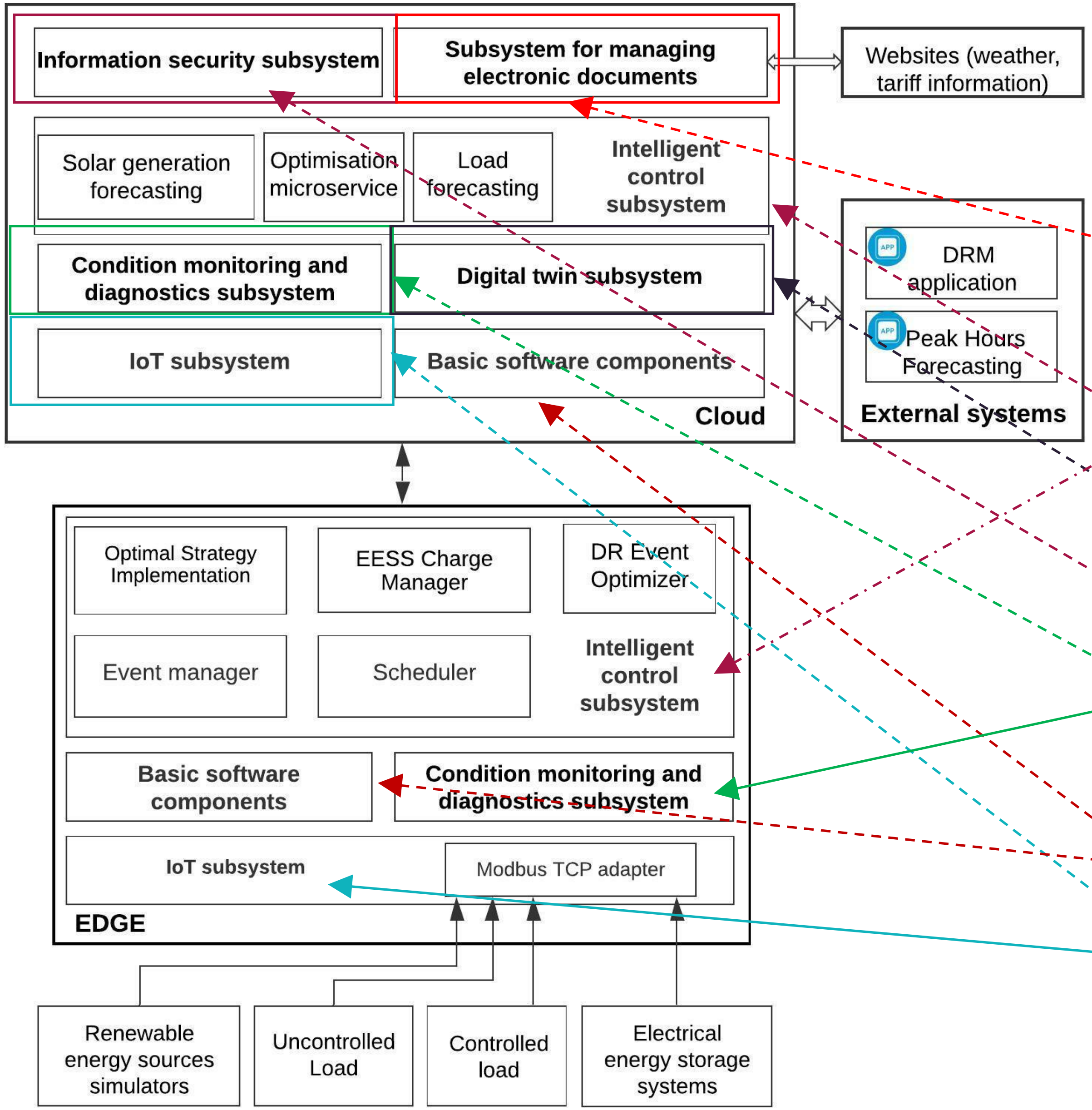
Ch. 8 - Challenges of the interaction of Consumer DER and Utilities control systems



1. A good example for large scale DER management is a DER Management System (DERMS) usually deployed by DSOs.
2. But DERMS is a “one provider – many users” type of system which might not fulfill all needs for flexibility market management
3. End-users of flexibility markets should be able to choose other service providers than DSO and freely change them
4. Unlike traditional EPU control system, the flexibility market tasks are more diverse in terms of relationship types and more dynamic in development
5. For these tasks a system type of “many providers - many users is appropriate.
6. Therefore, digital platform approach, as a more promising, and new in Energy industry, is further considered in tutorial

SC D2

Ch. 8 - Digital platform subsystems



The following subsystems can be represented at Edge and Cloud layers:

- Subsystem for Managing Electronic Documents
- Intelligent Control Subsystem
- Digital Twin Subsystem
- Information Security Subsystem
- Condition Monitoring and Diagnostics Subsystem
- Basic Software Components
- IoT Subsystem

cigre SC D2

Ch. 8 - Drivers for involving prosumers in the use of platform solutions

- **Implementation of flexible control algorithms** developed with the experience of platform ecosystem stakeholders
- **Effective provision of flexibility services** through integration with centralized management systems
- **Reducing the cost of transforming the control system** while switching from uncoordinated to coordinated approach
- **Increasing the power supply reliability** through the efficient use of DERs
- **Access to the platform ecosystem**, where it is possible to find answers to questions on the operation of DERs, information and communication systems, as well as formulate tasks for stakeholders (research institutions), the solution of which will increase the DERs efficiency
- **Gaining access to ecosystem services** that allow determining the optimal configuration of the power supply system, choosing the range of provided ancillary services
- **Formation of a unified knowledge base** to improve the training quality of prosumers and specialists

SC D2

Conclusions

- This technical brochure is intended for a wide range of specialists in the field of creating control systems for DER active consumers. It provides an overview and recommendations on how to use a particular type of ICT to improve the integration of DERs by actively engaging them in energy flexibility markets.
- The presented materials can be useful as guidelines for choosing ICTs that provide integration of control systems, active consumers and DERs, and also open up further horizons for the development of a platform approach for the technical and economic rationalization of solutions aimed at efficient and cost-effective DER integration.

SC D2


Вопросы?