Smart Energy and Smart Grids

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Annotation

This module deals with area of smart energy. Provides basic description of the electricity grid, electricity, electricity market and related processes as grid regulation. Introduces the area of metering, covers the basic mechanical meters as well as the most modern smart meters. Informs about European union plans and state of the implementation in smart metering deployment. Also describes accompanying system solutions such as Automated Meter Reading (AMR) and Advanced Metering Infrastructure (AMI). Introduces the concept of a smart grid and focuses in more detail on microgrids and the concept of energy hubs.

Objectives

By studying the module, students will gain an overview in the field of smart metering and smart grid. Besides technical aspects, there are also covered basic electricity market and process aspects. The student should understand the main direction and trends how the power grid is getting smart and which direction the evolution goes.

Keywords

power grid, power distribution, electricity market, smart meter, advanced metering infrastructure, smart grid, micro grid, energy hub

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CHAPTER 1

Electrical power grid

Electrical power grid is an interconnected network of power lines and related equipment for supply of electrical energy from producers to consumers.

Most electricity production is usually done in power plants (e.g. coal, nuclear or hydro) but they are often far away from consumers. The distance is caused by several factors such as economy, health, safety and environmental. Delivery usually takes place at two levels: **transmission** and **distribution**. **Transmission** part transmits energy over long distances (e.g. hundreds of kilometers) and uses higher voltages for more effective transmission. Distribution is focused on delivery for individual consumers and uses lower voltages for safer and easier distribution.

Interaktivní prvek

NOTE

In generally, the **energy chain** is production -> transmission -> distribution -> consumption.

Besides this traditional concept, there exist concept of **distributed energy resources** (**DER**).

NOTE

In DER concept, energy is generated near the point of consumption, e.g. in the same building.

DERs are usually small and environment friendly. They usually use solar energy, natural gas or wind. The location of all mentioned concepts is shown on the Fig. 1.
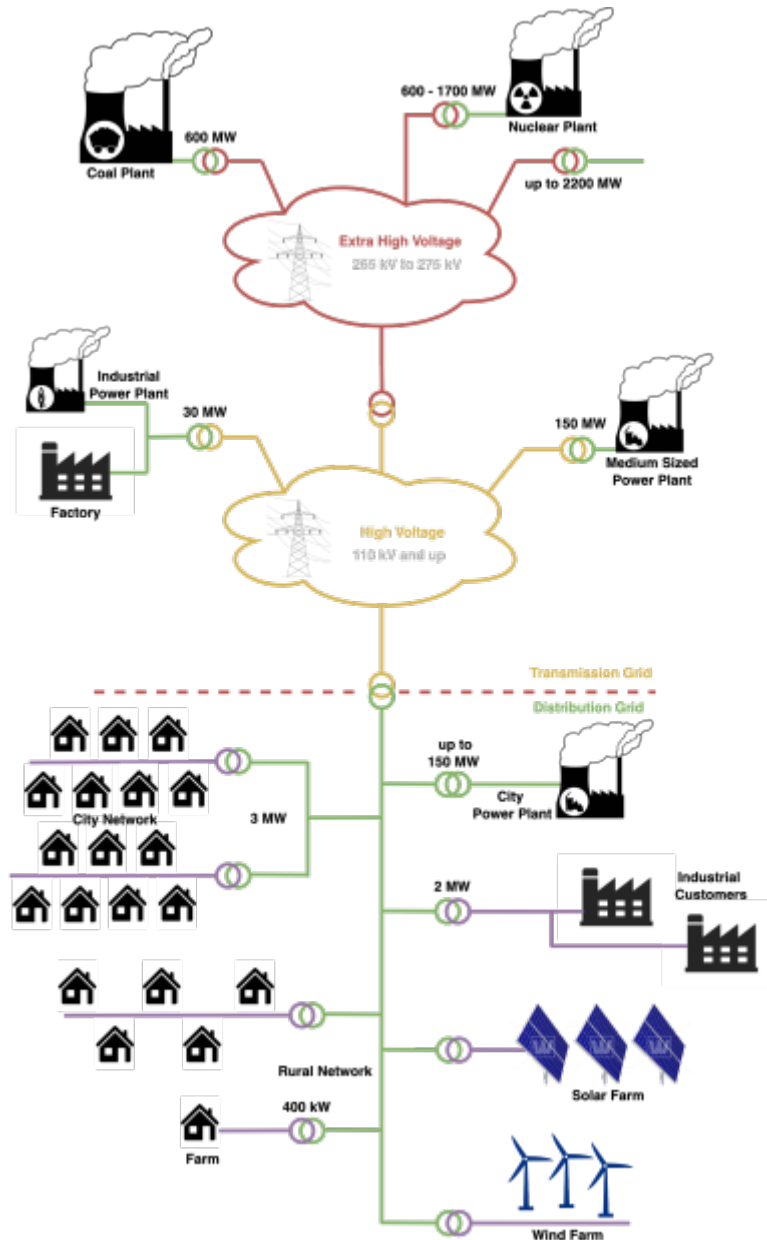
Fig. 1. Basic scheme of electric grid with energy generation, transmission, distribution, consumption

A clear separation of the transmission and distribution levels is also visible. This separation is also present in the operation of the power grid. The transmission part is operated by the **transmission system operators** (**TSO**) and distribution by the **distribution system operators** (**DSO**). Distribution operators can be regional or local.

Interaktivní prvek

INTERESTING

In Europe, there are above 3500 DSO companies. In some countries (e.g. as Czechia, Slovakia, Hungary), the three largest DSO deliver more than 60% of power.

Maps and schemes of transmission parts published by TSOs are publicly available, e.g. in [1] a scheme for whole Central Europe is available. Here we present here a partial view on Fig. 2.

Fig. 2. Power systems of central east Europe [1], zoomed to Slovak-Ukraine border, provided with permission SEPS a.s.

Explanation of active, reactive, apparent power, principle of power loss, power quality

In the following text we would like to explain in more detail what kind of power is present in the electric power grid and how it relates to energy loss in power grid.

> **EXAMPLE**
>
> Let's use a simple example on Fig. 3 to show what **reactive power is**. If the horse pulls the wagon in the direction of the rails, the wagon will go easily and with minimal friction. The whole effort of the horse represented by the force P (the so-called **active power**) is used to move the wagon.
>
> However, if the horse pulls perpendicular to the rails, the wagon must overcome friction during movement (our **reactive power Q**) and the horse must use more force, the so-called **apparent power S**, to get the wagon to the same place as in the first case. The cosine of the angle between forces, in our case powers, is the **power factor phi**.

Interaktivní prvek

In electricity power distribution, if the power factor is equal to 1, only the active component is transmitted, the apparent power is equal to the active one and the operation of the device is the most economical (minimal voltage drops and power losses).

> **DISADVANTAGE**
>
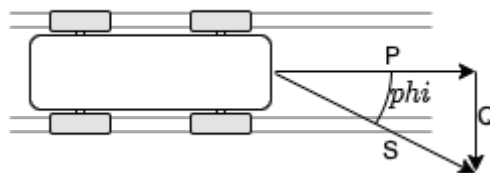> In real life, a minimum reactive energy is always present (the ideal power factor 1 is never reached).

Fig. 3. Schematic explanation of active and reactive energy

The major problem is the reactive power flow, which transmits no real power to the load. But the corresponding reactive currents are real and cause extra **heating losses** in the transmission circuit.

Let's take a simple example Fig.4. Here, the additional reactance causes an additional, phase-shifted current that is not consumed by the household, but causes additional energy loss as it passes through the power line (for the sake of simplicity depicted as real resistor). Since both households consume the same active power, they pay the same price per kWh.
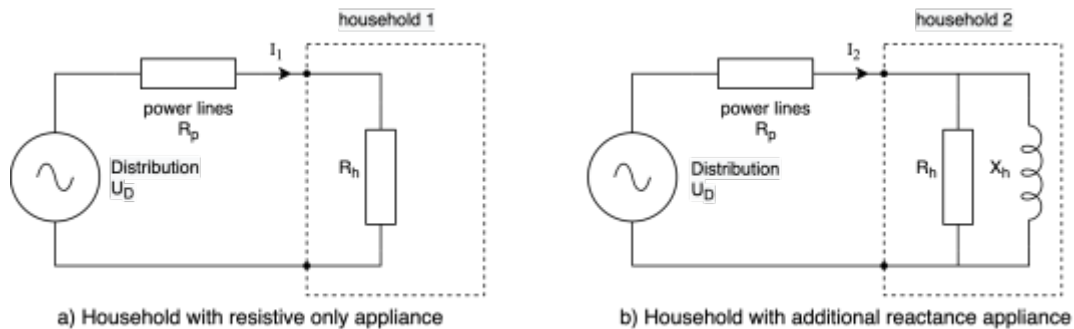

Fig. 4. Schematic comparison of power flows for households without and with additional reactance, it holds $|I\_h2| > |I\_h1|$

The distribution company usually adjusts its prices (tariffs) also to cover electricity losses in its network. So payments for losses are distributed among all households, not just those who primarily cause them. However, the situation is different in the case of small companies, where accurate measurement, including power factor, is carried out. Here, a bad power factor is usually already financially penalized.

Note, in EU is the AC voltage for the households specified by **EN 60038:2011** as **230/400V ±10%** .

First is the root-mean-square (**RMS**) voltage between a phase and the neutral connector, the second is the RMS voltage between two phases (the household connection to the power grid has typically 3 phases). The phases are denoted L1, L2, L3 and are mutually phase shifted by 120°.

Interaktivní prvek

For alternating electric current, RMS value is equal to that of a constant direct current that would produce the same heat loss in a resistive load.

When measurements are made with modern meters, there is common division between four quadrants (I, II, III, IV) that classifies which type of reactance (capacitive, inductive) predominates and in which direction energy flows (import = consumption = positive active power = A+, export = production = negative active power = A-).
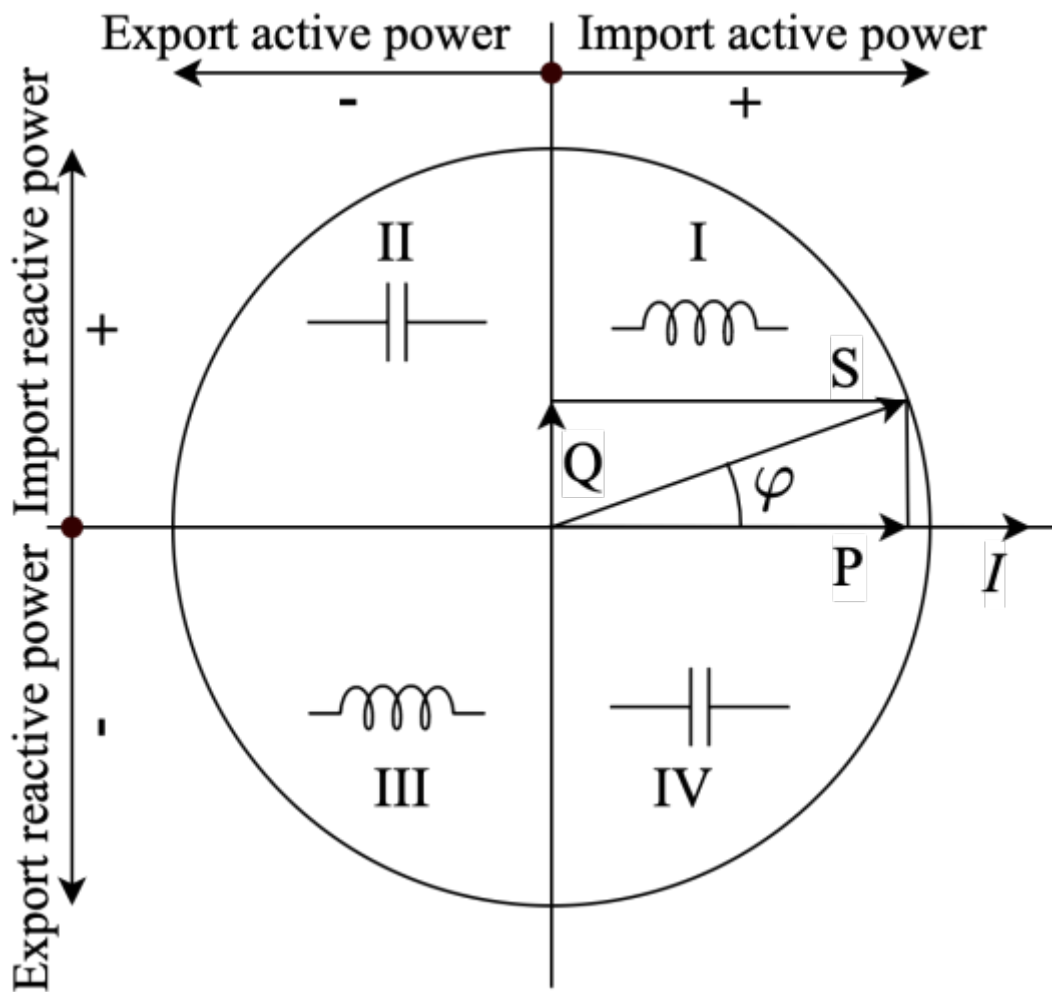
Fig. 5. The quadrant definition for active and reactive power according to IEC 62053-23

CHAPTER 3

Electricity market

All the electricity that flows through the electrical power grid was purchased on the electricity market. Basic market participants and their roles are depicted in diagram on Fig. 6.
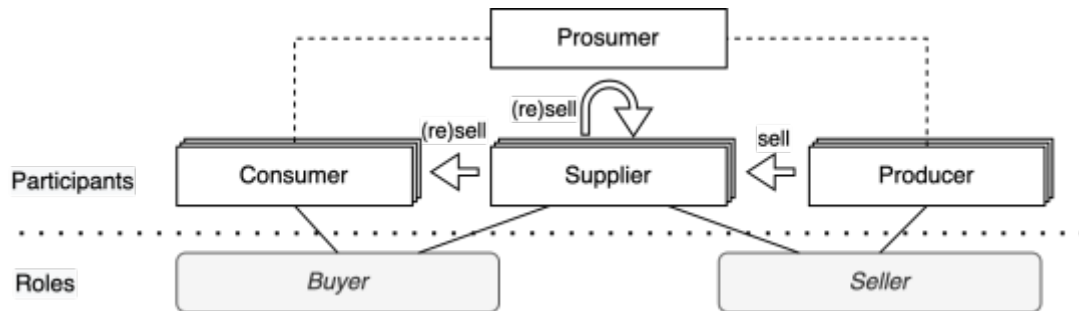

Fig. 6. Trading participants on the electricity market and their roles

The description of the roles is as follows:

- **Producer** – Producer of electric energy. It is most typically **seller**. It can sell energy to multiple suppliers.

- **Consumer** – Consumer of electric energy. It usually has one supplier, who is also responsible for consumer's imbalance. Most often it is the **buyer**.

- **Prosumer** - New role in EU legislation. A prosumer combines the roles of both producer and consumer because consumer can also become producer if he has some sort of energy source that can be monetized.

- **Supplier** - The role of the supplier is to concentrate the scattered demand of smaller consumers. Because each of them has a different consumption timeline, the supplier can combine sub-consumption diagrams, which are often very uneven, to obtain a much more even overall diagram for which it is more advantageous to buy electricity on the market. The supplier, besides the delivery, overtakes responsibility for the imbalance on behalf of the consumer and is himself registered as a subject of settlement (see the next chapter for details). The supplier can be both a buyer and a seller.

There are many different types and organizations of energy markets. All the different markets have its specifics. Basic division can be done as follows [2]:

The wholesale market can generally be divided according to the length and nature of the supply into three basic energy markets:

[Interaktivní prvek](#)

CHAPTER 4

Harmonization of financial and physical flow of energy, balancing, regulation

Since the network (grid) is generally a shared resource that needs to be kept in good condition, the process for aligning both flow levels is defined. Thus, the agreed and scheduled electricity flows in the financial level are checked against physical flows, whether they are physically produced and consumed according to schedule. This check is usually formulated for 15 min or 1 hour (**settlement period**). If the real consumption from some subject differs from the schedule, the subject exhibits **imbalance** and should be punished for this.

DEFINITION

Imbalance summed for all subject connected to power grid represents **system imbalance**.

NOTE

Significant system imbalance may lead to technical problems, even **blackout**.

DEFINITION

To make the grid stable, the system imbalance shall be neutralized. The main tool for this is the **regulation energy**.

A grid operator monitors the grid and in case of system imbalances adds positive or negative regulation energy into grid, just to neutralize the system imbalance.

[Interaktivní prvek](#)

DEFINITION

Negative regulation energy means, that the energy is consumed by the negative regulation energy provider.

Lack of energy in grid causes frequency decrease (below 50 Hz) and surplus of energy causes frequency increase (above 50Hz).

NOTE

Lack of energy is worse and has stricter management. Lack of energy occurs if producers produce less energy as scheduled and/or consumers consume more as scheduled. Excess energy occurs if producers produce more energy as scheduled and/or consumers consume less as scheduled.

After the settlement period, the situation is evaluated. Since all schedules are centrally collected by grid operator (financial level) and all producers and consumers have electricity meter (physical level) it is easy to compare these two levels to find out who the sinners are. Schematically the situation is depicted on Fig. 7. The sinner shall pay for the regulation energy that was necessary to keep the grid stable in the corresponding evaluation period.

DEFINITION

However, the evaluation is performed against entity called **balancing responsible party** (**BRP**). This entity owns balancing group, which is group of consumers/producers for whose **forecasts and sends the schedules** for the grid operator and **takes the responsibility for their imbalance and their settlement**.

NOTE

The bigger the balancing group is, the better statistical chances have the BPR that the scheduled production/consumption will be aligned with real production/consumption.

For the end-users, i.e. consumers like households, all the energy purchasing and responsibility for the imbalance usually cover the energy companies, based on the contract with consumer. The consumer just simply pays his monthly bill based on parameters agreed in contract, such as max. consumption, tariffs, daily schedule, etc. and on consumption registered on electricity meter installed at connection point.

DEFINITION

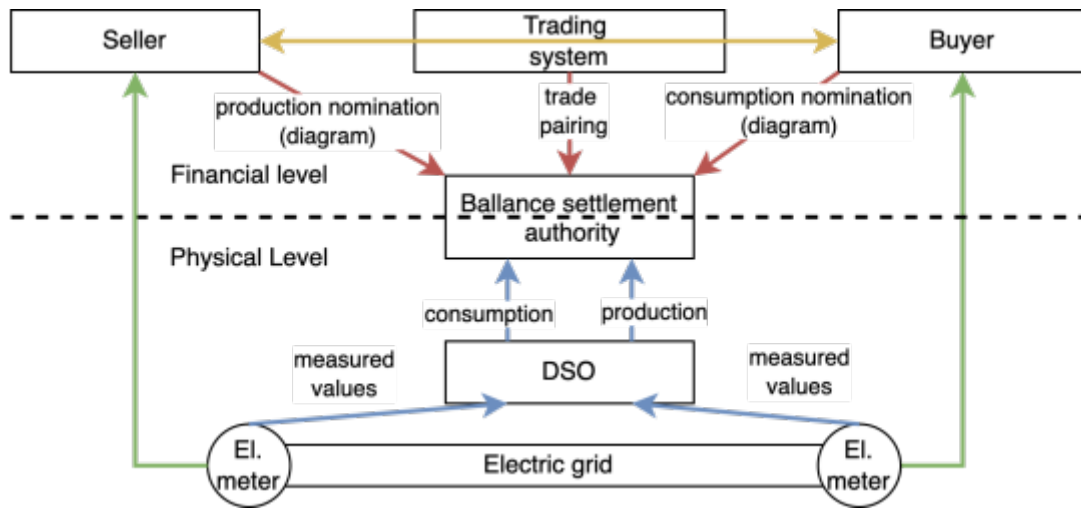**Connection point** is the place, where the subject is connected to the power grid.

Fig. 7. Principle of financial level and physical level pairing and imbalance computation

CHAPTER 5

Smart metering

The task of power measurements in electrical grid is very important. It is very important not only for billing the customers but also for control and optimization of the whole grid. The more frequent the measurements, the better overview we can have.

INTERESTING

The basic device for such measurements is the electricity meter which measures electricity consumption and further parameters in specified point in the electrical grid. Typically, such point is the connection point of the consumer. Here the meter provides data necessary for billing, basically the electricity consumption in kWh.

DEFINITION

Concept of **Smart metering** defines the minimal set of capabilities of electricity meters to be considered as "smart", such as certain level of autonomy, communication capabilities, upgradeability, etc.

NOTE

The concept of smart metering requires certain architecture of the whole metering system to operate efficiently. In the following text the technical solution preceding the smart metering are described as well.

Interaktivní prvek

CHAPTER 6

Electromechanical power meters

The classic type of electricity meter is the alternating current (**AC**) electromechanical induction kilowatt-hour meter.

DEFINITION

This meter works through electromagnetic induction by counting the revolutions of a non-magnetic, but electrically conductive metal (usually aluminum) disc.

INTERESTING

The disc rotates at a speed proportional to the power passing through the meter. The principle is shown on Fig. 8. An aluminum disc rotates in the air gap driven by eddy currents. The measured current flows via current coil under the disc on the two-arm core. Thanks to the closed iron core, the pressure coil has a large inductance compared to the current coil therefore there is phase shift almost 90° between the magnetic fluxes of both coils while active load is present. These magnetic fluxes create a rotating magnetic field that rotates disc. The rotating disk drives a mechanical counter via the shaft.
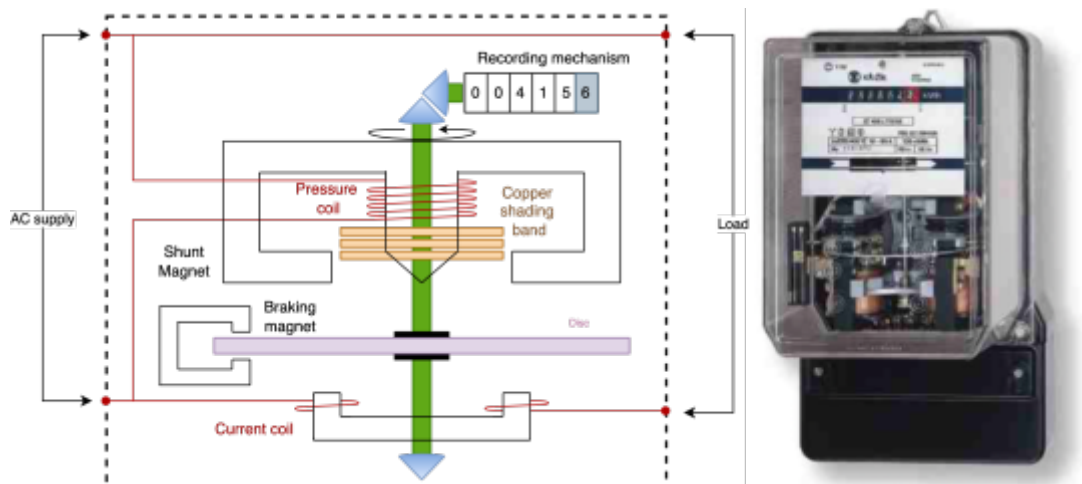

Fig. 8. Principle of electromechanical meter (left), example of realization (right)

CHAPTER 7

Solid state power meters

More modern approach does not use any moving parts. Such meters are called **solid state electricity meters**.

INTERESTING

They also measure current and voltage but instead a rotating disk, coils, gears they use electronic components and circuits, such as analog-to-digital converters (**ADC**), microprocessors, LCD displays, etc. They are capable to measure multiple values such as voltage, active power, reactive power, power factor, etc.

Typical construction is depicted on Fig. 9.
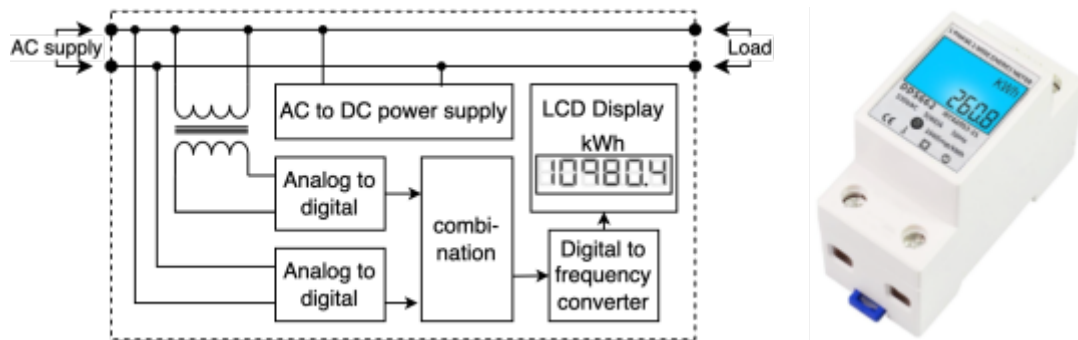
Fig. 9. Principle of a solid state electricity meter (left), example of realization (right)

Naturally, there arises the question how to convey the data from the meter to the information system that process the data. Early architectures such as **automatic meter reading** (**AMR**) set the goal to automate the process of meter readings.

NOTE

Before the introduction of AMR, utilities company had to do everything manually by staff directly reading the digits from the devices. A huge amount of time was wasted in the service areas with this process.

DEFINITION

According to the Demand Response and Advanced Metering Coalition, AMR is defined as a "system where aggregated kWh / water / gas usage, and in some cases demand, is retrieved via an automatic means such as a **drive-by vehicle** or **walk-by handheld system**." [3].

The reading process is usually radio-frequency (**RF**) based, where various RF technologies can be used such as ZigBee, Bluetooth, WiFi, etc. The **fixed network** connection can be used as well.

INTERESTING

Regardless of how the meter is read, **communication is one-way**. The meter is communicating with the meter-reading device, but the device cannot send a command back to the meter. The AMR system delivers data to the **company's databases**. Data in AMR systems are typically gathered only **monthly or, at most, daily**.

Interaktivní prvek

CHAPTER 8

From AMR systems to AMI systems

Adding more automation and bidirectional communication to the AMR systems we get **AMI** (**Advanced Meter Integration** or **Advanced Meter Infrastructure**) systems.

NOTE

Such systems start to appear around 2005. AMI allows real-time; **on-demand** integration with metering endpoints. Metering system **records consumption hourly or more frequently** (e.g. each 15min) and ensures **daily or more frequent transmission** of measurements via a communication network to a central collection point.

INTERESTING

The ultimate target of an AMI is [4] to have real-time energy data for utilities, consumers, and producers, to support their decision while considering the energy price as well.

DEFINITION

AMI systems are part of the **Smart metering systems**.

Interaktivní prvek

AMI is perceived as an infrastructure that includes smart meters, communication networks, and meter data management Systems (MDMS) for data analysis and storage.

DEFINITION

The smart metering systems are in EU specified by the Commission Recommendation 2012/148/EU, which defines 10 common minimum functionalities for smart metering systems:

For the customer:

1. Provide data readings directly to consumer and/or any 3rd party

2. Upgrade data readings frequently enough to use energy saving schemes

For the metering operator:

3. Allow remote data reading by the operator

4. Provide 2-way communication for maintenance and control

5. Allow frequent enough data readings for network planning

For commercial aspects of energy supply:

6. Support advanced tariff systems

7. Remote ON/OFF control of the supply AND/OR flow or power limitation

For security and data protection:

8. Provide secure data communications

9. Fraud prevention and detection

For distributed generation:

10. Provide import/export and reactive metering

Interaktivní prvek

CHAPTER 9

What makes smart meter smart

Basic scheme and example picture of a smart meter is on Fig. 10. Visually there is not much to see except for display. When comparing to classical solid state / AMR meter, the core changes are inside.

Good example of smart features are events. There are four basic categories of events:

- **Meter status events**, such as "last gasp" (information about power failure), "first breath" (information about power restore). These notifications should be sent at a random interval to prevent communication congestion in case of mass events (or the meter has intelligence to distinguish between a mass blackout and individual loss of power.

- **Power quality events**, such as voltage sag / surge (shorter duration of higher/lower voltage) and high/low voltage alarms (longer duration of higher/lower voltage). Here shorter means < 500ms , lower/higher means outside of the ±10% interval around the nominal value.

- **Meter tamper flags**, such as reverse energy flow.

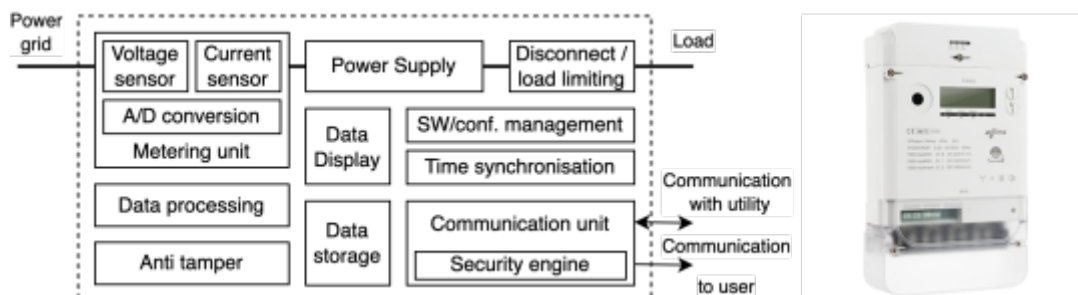- **Meter hardware information**, such as battery alarms.

Fig. 10. Block scheme of a smart meter (left), example of realization (right)

Interaktivní prvek

CHAPTER 10

DLMS/COSEM/OBIS/IDIS

The events are logged in the event log usually as objects.

99=Abstract data profiles (if A=0), or Electricity data profile (if A=1)

- D – identifies the type of data processing result, e.g. 3=minimum, 6=maximum, 8=time integral

- E – identifies further processing, if A=1 then e.g. 0=total, 1=rate (tariff) 1, 2=rate (tariff) 2, but e.g. if C= 11 or 12 the meaning of E changes ot 0=total, 1=1st harmonics, 120=120th harmonics, 124=**Total Harmonic Distortion** (**THD**)

- F - identifies historical data

EXAMPLE

Table 1. Example explanations of selected OBIS codes are presented in the table.

OBIS code	Explanation
1.8.0	Positive active energy (A+) total [kWh]
1.8.1	Positive active energy (A+) in tariff T1 [kWh]
2.8.0	Negative active energy (A+) total [kWh]
2.8.1	Negative active energy (A+) in tariff T1 [kWh]
99.98.x	Event log
99.1.x	Load profile with recording period 1
99.2.x	Load profile with recording period 2

Note: "x" means any value within the valid range 0-255

In the table we see more examples of profiles, that are objects that are used to hold series of measurements (objects) of one or similar quantities and/or to group various data. **For basic measurements the recording period is usually set to 15 min and DSO company fetches it once a day.**

NOTE

In addition to mentioned standards describing DLMS/COSEM and OBIS, there is a great help of **IDIS** (**Interoperable Device Interface Specification**) Association, which aims to reach pan-European interoperability. Supports various use cases such as automatic meter registration, remote tariff programming, disconnection and reconnection of electricity supply, system wide clock synchronization, demand/load management, remote firmware update.

EXAMPLE

For example, IDIS specifies in more detail event code classification such as:

- event code 7: Replace battery - Battery has reached expected end of lifetime and must be replaced

- event code 40: Meter cover removed – Indicates, that meter cover has been removed.

[Interaktivní prvek](#)

CHAPTER 11

Interfaces of smart meter

As stated in the Fig. 10, there are two types of communication – with DSO and to user.

INTERESTING

This important feature is also present in reference architecture for smart metering communications [5] developed by the **Smart Metering Coordination Group**, whose simplified version is depicted on Fig. 11. Here, the H1 interface connects the smart meter system to an external display. The H2, H3 interfaces connects the smart meter system with the Home Energy management / Home automation and provide a two-way communication. The connection is either using Local or neighboring Access point. Smart meter data from is directly shared externally via the AMI headend with the Meter Data Management System (MDMS) via G1 interface. Or indirectly through C and G2 interface.

NOTE

In [5] there is an overview of the preferred communication technologies for the different interfaces H1-H3, G1-G2 and C per country. For the G1, G2 prevails GSM based technology (sometimes closer specified as GPRS, 3G, 4G, LTE, NB-IoT). With the C interface **Power Line Communication** (**PLC**) prevails (the NNAP device servers as data concentrator in this case). The most varying are the preferences for the H interfaces.

INTERESTING

Standardization as requested in directive 2019/944 is still far from EU-wide unity. The obligation imposed in Directive 2009/72/EC is an 80 % roll-out of smart metering by 2020. Details of the official deployment strategy per country is on Fig. 12.
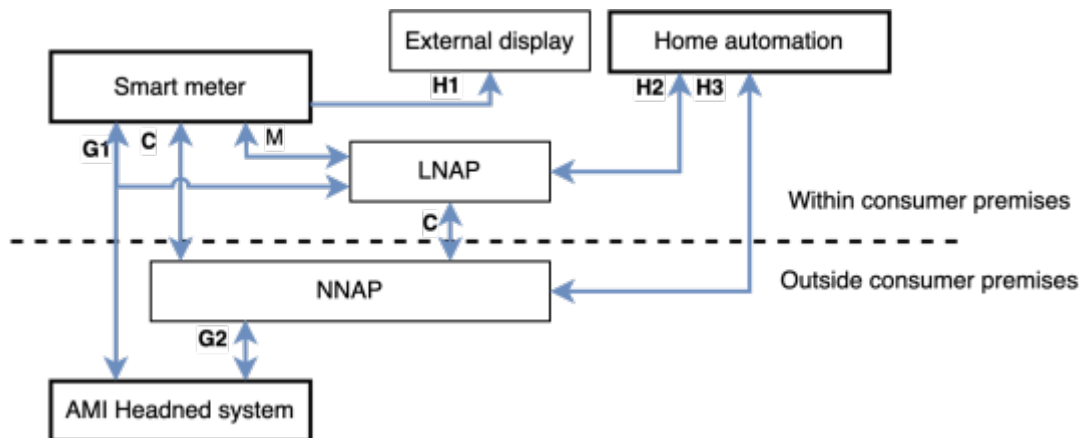
Fig. 11. Simplified and partial reference architecture for smart metering communications
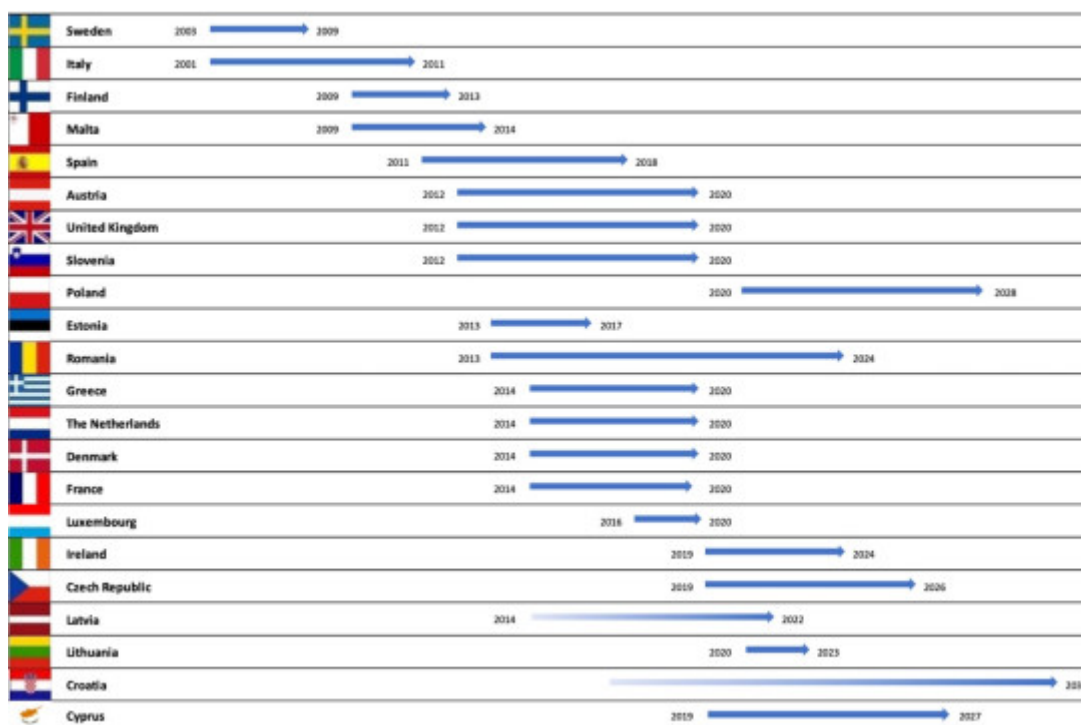
Fig. 12. Official smart metering deployment plan per country on the large-scale roll-out (80 % or higher coverage) of smart electricity meters [6]

Interaktivní prvek

CHAPTER 12

Smart metering backend systems (HES, MDMS), interface and roles

INTERESTING

As mentioned on Fig. 11, the AMI ends on DSO side with the **AMI Head End System** (**HES**). The role of the HES in the Smart Metering system architecture is to acquire meter data automatically, manage the connectivity and data acquisition, enable secure access to meters, configuration, software updates and ad-hoc requests. This area can be seen as **Meter Data Collection** (**MDC**). After collection, the data are stored in the **Meter Data Management** (**MDM**) systems.

NOTE

The scope of MDC / MDM systems is:

- **meter data collection** – from HES systems, legacy systems, manual data input, …

- **data Validation, Estimation, and Editing** (VEE) – includes various data checks, provide estimation of missing data, enables manual data editing, assigns data quality evaluation, …

- **data aggregation** – provide the required data aggregation, create and report statistics, …

NOTE

Optionally, MDM can serve as infrastructure mapping and asset management system especially for smaller DSO. The competencies of both, MDM and HES/MDC systems partially overlap, however MDM is more oriented to **metering data lifecycle** and HES focuses more on **infrastructure, devices, and communication**. However, cases as event management and functionality configuration of the smart meters are bound with both systems and must be coordinated by both. Moreover, specific events such as "last gasp" are an important input for DSO 's **operational technology (OT) systems** such as Supervisory control and data acquisition (**SCADA**) system, Outage Management System (**OMS**) or a Distribution Management System (**DMS**) which control the power grid.

INTERESTING

On the HES-MDMS interface, the IEC 61698 is considered as the standard. IEC 61698-9 specifies the information content of a set of message types that can be used to support meter reading and control, events, customer data synchronization and customer switching. IEC 61968-11 specifies **common information model** (**CIM**) which supports messages and extends the base CIM (IEC 61970) to the needs of distribution networks.

The overall architecture of Smart metering system including AMI and DSO metering-related back office systems is depicted on Fig. 13.
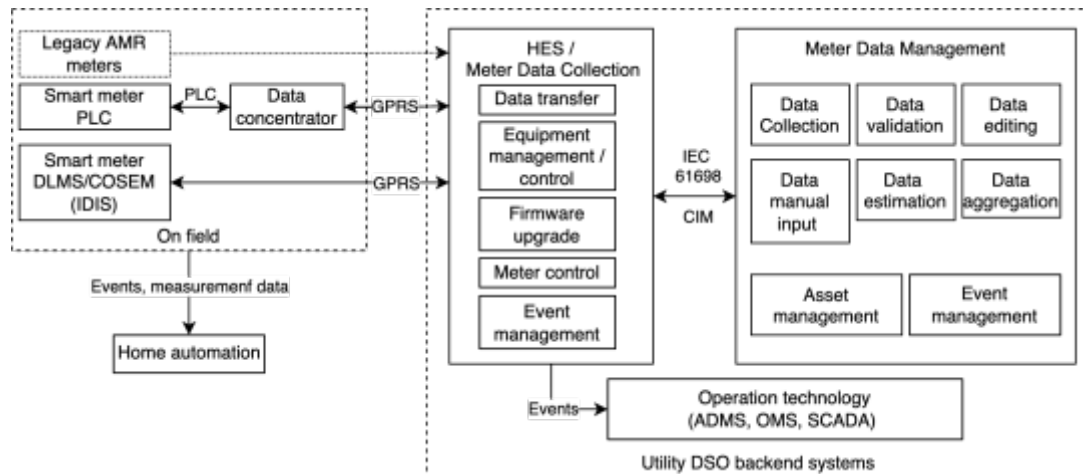
Fig. 13. Smart metering system - overview picture with AMI (left side) and DSO metering-related back office systems (right side)

Interaktivní prvek

Interaktivní prvek

CHAPTER 13

Smart grids

Smart grid is a significantly broader term than smart metering. Smart metering is only a basic function within a smart grid, which aims to provide all participants with information about the actual conditions and "health" of the grid and to provide basic data for their decisions.

DEFINITION

As a true smart grid can be viewed a power grid, that can automatically reuse gathered information and provides services, that increase **reliability**, **survivability**, and **responsiveness** of the power grid.

NOTE

Specifically, it can e.g., deal with locally produced energy, predict power outages before they occur, rapidly restore service. Such a grid can be called "self-healing" and "making decisions".

Interaktivní prvek

INTERESTING

An aim is total automation of the electricity distribution network – including local production and consumption.

EXAMPLE

Some examples of automation are

Ability to automatically re-route electricity when a transmission line is downed

Reduce other flows when someone's rooftop solar panels suddenly send a burst of energy onto the grid.

INTERESTING

Technically, the building blocks for a smart grid are already available. Deployment of smart grids is one of the priority thematic areas under the **Trans-European Networks for Energy** (**TEN-E**) policy (policy that is focused on linking the energy infrastructure of EU countries) aiming to help integrate renewable energy, complete the European energy market, and allow consumers to better regulate their energy consumption [7].

Table 2. Smart grid – list of the essential systems, note the Smart metering systems in the list

Domain or Function	Systems
Generation	Generation management system
Transmission management system	Substation automation system
	Blackout Prevention System - Wide Area Measurement Protection and Control System (WAMPAC)
	EMS SCADA system
	Flexible AC Transmission Systems
Distribution management systems	FACTS Substation automation system
	Feeder automation system
	Advanced Distribution Management System (ADMS)
	FACTS system
DER operation systems	DER operation system
Smart Metering systems	AMI system
	Metering-related back office system
Demand and production (generation) flexibility systems	Aggregated prosumers management system
Micro-grid	Micro-grid systems
Marketplace system	Marketplace system
	Trading system
E-mobility (connection to grid) Administration systems	E-mobility systems
Administration systems	Asset and Maintenance Management system
	Communication network management system
	Clock reference system
	Authentication, Authorization, Accounting system
	Device remote Management system

Weather forecast and observation system

CHAPTER 14

Smart grid architecture model (SGAM)

The important reference regarding smart grid systems and architecture of the smart grid as whole provides the **Smart Grid Architecture Model** (**SGAM**).

The original scope of the SGAM was created in the M/490 mandate of the **European Commission** (**EC**) to the European standardization bodies **CEN** (**ComitéEuropéen de Normalisation**), **CENELEC** (**European Committee for Electrotechnical Standardization**), and **ETSI** (**European Telecommunications Standards Institute**).

The SGAM acts as a reference designation system providing three main axis for the dimensions: **Domains**, **Zones**, and **Interoperability Layers** as depicted on Fig. 14.

Interaktivní prvek
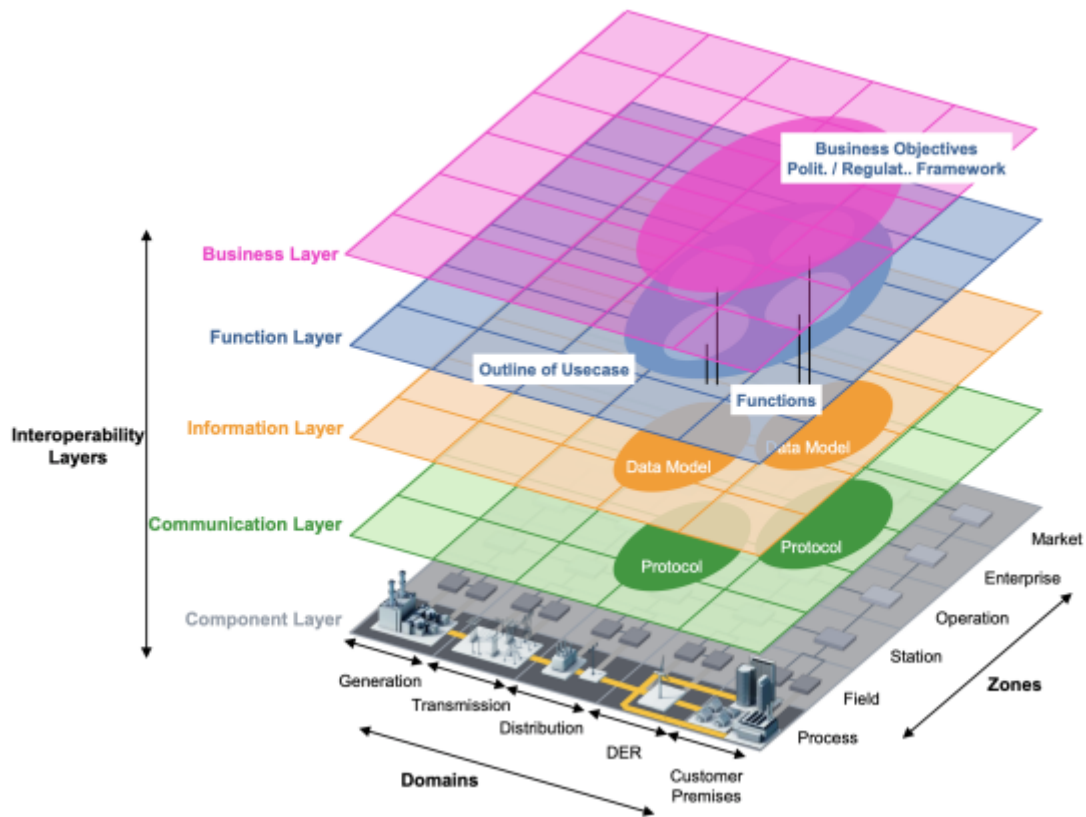
Fig. 14. Smart Grid Architecture Model framework [8]

As the key enabler of smart grid is seen the interoperability. The systems are considered as interoperable, if they are able to perform cooperatively a specific function by using information which is exchanged.

There are 5 layers of interoperability defined in SGAM:

- **Business Layer** - Represents the business view on the information exchange related to smart grids. Can be used to map regulatory and economic (market) structures and policies, business models, processes, products and services.

- **Function Layer** - Describes functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components.

- **Information Layer** - Describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying data models.

- **Communication Layer** - Describes protocols and mechanisms for exchanging information between components

- **Component Layer** – Describes physical distribution of all participating components in the smart grid context.

Domains basically represent the energy conversion chain similarly to the basic scheme of the electric grid as provided on Fig. 1, they can be described as follows:

- **Mass production** - Represents generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plants, typically connected to the transmission system.

- **Transmission** - Represents the infrastructure and organization which transports electricity over long distances.

- **Distribution** - Represents the infrastructure and organization which distributes electricity to customers.

- **DER** - Represents distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10.000 kW). These distributed electrical resources may be directly controlled by DSO.

- **Customer premises** – Represents both - end users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbors, shopping centers, homes). Also represents the generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines...

The Zones are orthogonal to the domains and basically represent the Information and Communication Technology (ICT) based power system management, controlling the energy conversion chain. There are two main concepts of aggregation:

- **Data aggregation** – Data from the field zone is usually aggregated or concentrated in the station zone to reduce the amount of data to be communicated and processed in the operation zone.

- **Spatial aggregation** – Aggregation from distinct locations to wider area (e.g. power system equipment is usually arranged in bays, several bays form a substation; multiple DER form a plant station, DER meters in customer premises are aggregated by concentrators for a neighborhood).

Based on this aggregation concepts an additional functional separation concept, the individual zones are described as follows [8]:

- **Process** - Includes the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind ...) and the physical equipment directly involved. (e.g. generators,

transformers, circuit breakers, cables).

- **Field** - Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices which acquire and use process data from the power system.

- **Station** - Represents the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local SCADA systems, equipment supervision...

- **Operation** – Includes the operation of the energy system control in the relevant area, e.g. distribution management systems (**DMS**), energy management systems (**EMS**) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (**EV**) fleet charging management systems.

- **Enterprise** - Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders ...), e.g. asset management, logistics, work force management, customer relation management, billing.

- **Market** - Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market..

INTERESTING

It is possible to map all systems that are used in the smart grid to SGAM (e.g. the essential systems provided in Tab. 2).

Interaktivní prvek

CHAPTER 15

Micro-grid as a system in a smart grid, main roles of smart grid

Among the smart grid systems (see Tab. 2) the **micro-grid systems** are a specialty.

From a "domain" dimension prospective, micro-grids are "Smart Grids in small" and cover 3 main domains: Distribution, DER and Customer premises as it is shown on conceptual diagram Fig. 15.

Micro grids essentially contain the same systems from these domains as smart grids. The rest of the smart grid is sometimes called as **macro-grid**.

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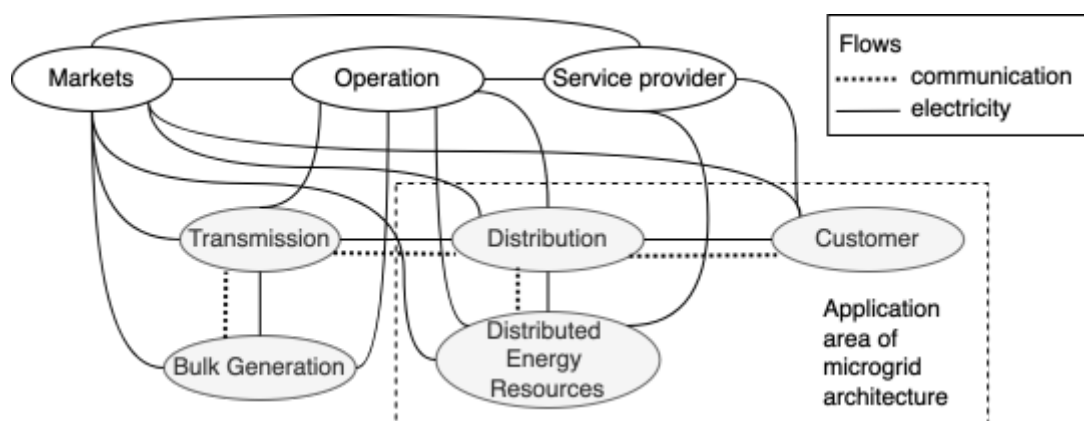
Fig. 15. Conceptual model of smart grid domains and corresponding flows [8]. Note that Markets, operations are zones, service provider represents a group of actors which has universal role (the role is defined by the particular use case) in the context of smart grid

A schematic view of micro-grid, its components and relations is provided on Fig. 16. A micro-grid system provides following major functions:

- **Monitoring and control** of the micro-grid in real time (SCADA)

- **Distribute** electricity to any micro-grid users

- **Protect and maintain** the related micro-grid assets

- **Ensure balance** of demand and supply

- **Handle islanding**, connection and disconnection

Based on distribution and DER domains and process zone which includes the micro-grid primary devices, a micro-grid system needs to maintain its stability, voltage, frequency and reliability.

NOTE

Micro-grid can operate in two basic modes:

- **Grid connected mode** – Micro-grid is interconnected with macro grid, offers various support functions such as Peak Management, Responsive Reserves, Grid Voltage Support (**VARS**), Backup Emergency Power, Islanding on requests/emergency.

- **Island mode** – Micro-grid operates as disconnected disconnected/isolated from macro grid, a micro-grid system may be called on to perform the following functions: Grid Synchronizing & (re-) Connection, Balancing Supply & Demand, Active/Reactive Power Compensation/Voltage Control Economic Dispatch, Load Control.

NOTE

Architectures for micro-grids as thy need to manage the energy flows from different types of sources, can be classified into three topologies:

- **AC micro-grid**– Uses AC bus. Power sources with AC output use AC/AC converter to transform the voltage (and eventually frequency) and DC power sources use DC/AC converters to connect to the bus.

- **DC micro-grids** – Uses DC bus. Power sources connect to bus using DC/DC or AC/DC converters.

- **Hybrid micro-grids** – Has both buses, which are connected to each other through a bidirectional converter.
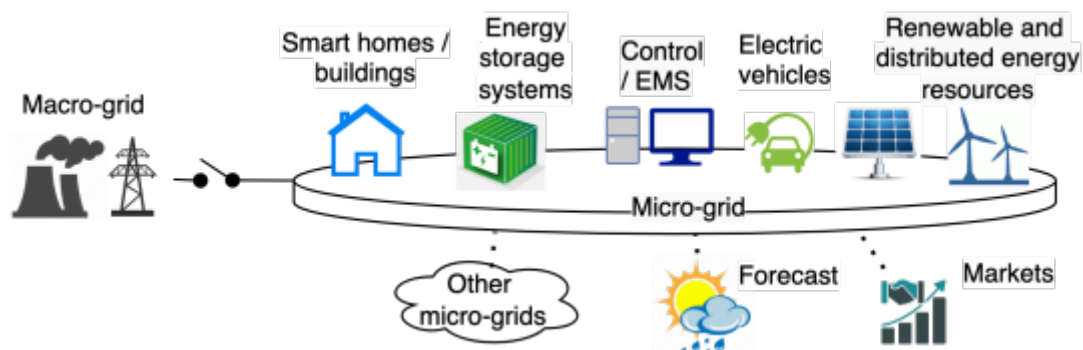
Fig. 16. Schematic view of micro-grid, its components and relations

So far, we have explicitly spoken about electricity, but smart grid is not limited to electricity and enables optimizations that interconnect all the energy forms, its transformation, and synergies.

INTERESTING

Considering this, the basic components categories in micro-grid are:

- **Power sources** – A micro-grid represents different types of production sources that supply the user with electricity, heating, and cooling. These sources are divided into two major groups – thermal energy sources (e.g, natural gas or biogas generators) and renewable generation sources (e.g., wind turbines and solar). There can be also combination e.g. combined heat and power produced using cogeneration units.

- **Power consumption** - Simply refers to elements that consume electricity, heat, and cooling. This can be single devices, lighting and heating systems of buildings, commercial centers, etc.

- **Energy storage** - Includes all types of storage technologies, such as chemical, electrical, pressure, gravitational, flywheel, heat. Energy storage performs multiple functions, e.g.:

  - Ensures power quality, including frequency and voltage regulation.

  - Smoothes the output of renewable energy sources.

  - Provides backup power for the system.

  - Plays a key role in cost optimization.

CHAPTER 16

Microgrid and EMS systems

Microgrid is a place, where much can be gained and lost. A lot of effort has been and will be spent on optimizing the structure and management of micro-grid.

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INTERESTING

Power sources and loads can be controllable so the consumption/generation can reflect demands of the network. Moreover, storages offer additional degrees of freedom for control strategies.

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EXAMPLE

When multiple energy storages with various capacities, technologies and resulting properties are available in a micro-grid, it is advantageous to coordinate their charging and discharging to achieve original parameters of the system.

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INTERESTING

Systems designed to such optimizations are called energy management systems (**EMS**) or home energy management systems (**HEMS**), building energy management systems (**BEMS**) according to used deployment. Often such systems have hierarchical control. Generally, there are two main control strategies – **centralized** and **decentralized**.

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They both have advantages and disadvantages, see Tab. 3 for sample details.

Table 3. Main advantages and disadvantages of centralized and decentralized micro-grid control

System	Centralized control	Decentralized controls
Advantage	Proper coordination and leadership, global information	Local measurement and regulation, easy implementation
Disadvantage	Single Point of failure (SPOF)	Lack of global information

For micro-grid a **hierarchical** control is often adopted because it introduces a certain degree of independence between different control levels. It is more reliable as it continues to be operational even in the case of failure of the centralized control.

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NOTE

Hierarchical control introduces 3 levels of control [9]:

- **Primary control** copes with instant power sharing control and current/voltage regulations.

</div>

- **Secondary control** has a slower reaction time (seconds to minutes), deals with the voltage compensation and balancing, power quality requirements.

- **Tertiary control** has the slowest reaction time (minutes to hours), performs power/energy management, system optimization, considers pricing factors. Often involves prediction of weather, tariffs, loads and aims to achieve economic savings. Here, techniques such as deep neural networks are taken into account.

As the reaction time grows in the control levels, the necessary communication bandwidth decreases. This allows appropriate hierarchical solutions and services which can use modern concepts on ICT as virtualization, cloud-based services and communication platforms.

Interaktivní prvek

Interaktivní prvek

CHAPTER 17

Energy Hubs

One interesting approach for future energy systems are the **energy hubs** [10]. It reflects movement towards **multi-energy systems** (**MES**), where different energy carriers and systems interact together in a synergic way.

This concept requires a suitable tool for integrated management of the system components.

Key element form here **Energy hub** (**EH**) that can be defined as the place where the production, conversion, storage, and consumption of different energy carriers takes place.

As inputs, energy hubs consume power (e.g., electricity, natural gas) and provide certain required energy services such as electricity, heating, cooling, etc. Figure 17 shows an example of an energy hub.
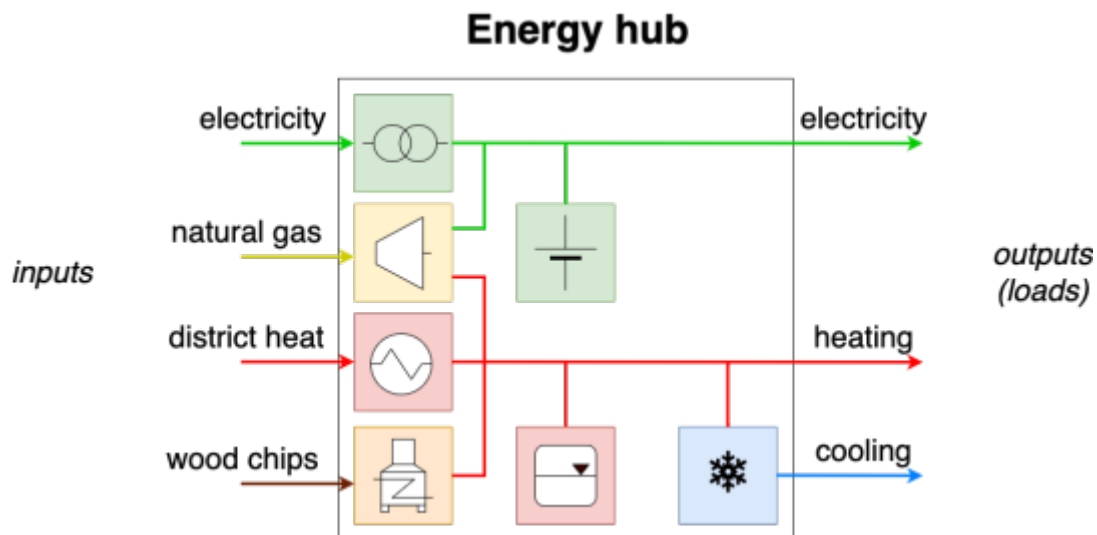

Fig. 17. Example of an energy hub and its components, containing a transformer, a micro turbine, a heat exchanger, a furnace, absorption cooler, a battery, and hot water storage.

Interaktivní prvek

Interaktivní prvek

Energy hub

CHAPTER 18

Test

What is the main purpose of Transmission in Electic grid

- ○ It deliveres energy to end customer.

- ○ it provides transmission of energy data to Utility providers

- ○ It carries the power for long distances using higher voltages

- ○ It transforms voltage of energy from producers.

What are advantages of centralized control of Micro Grid?

- ☐ Proper coordination and leadership

- ☐ global information

- ☐ Local measurement and regulation

- ☐ easy implementation

What does lack of energy in grid cause?

What are advantages of decentralized control of Micro Grid?

- ☐ Proper coordination and leadership

- ☐ global information

- ☐ Local measurement and regulation

- ☐ easy implementation

What is system imbalance?

○ It is summed up difference between scheduled and consumed energy of all participants of the marked

○ It is estimated difference between scheduled and consumed energy of all participants of the marked

○ It is difference of energy consumed in whole country compared to its neighbours

○ It is technical specificity of Slovak National Grid.

Why is reactive energy undesired in grid?

☐ It transmits no real power to the load

☐ It returns back to power plant and damages it.

☐ It causes energy to flow in incorrect direction.

☐ It causes extra heating losses

The market participant that produces and consumes energy is the so-called?

○ Supplier

○ Producer

○ Consumer

○ Prosumer

Which axis are part of reference SGAM Architecture?

☐ Domains

☐ Stratums

☐ Zones

☐ Levels

How do electromechanical power meters operate?

○ It operates through electromagnetic induction by counting the revolutions of a aluminum disc

○ It uses electronic components and circuits such as Analog-Digital Convertors to measure multiple values

○ it counts electrons using very sensible cameras

○ It operates using voltage convertors.

Which of these statements about Smart meter intefaces are correct?

☐ The H2, H3 interfaces connects the smart meter with the Home Energy management.

☐ H1 interface connects the smart meter system to customer smart phone

☐ The H2, H3 interfaces provide a two-way communication

☐ For the G1, G2 prevails GSM based technology.

What is the scope of MDC/MDM systems?

○ Meter Data Collection

○ Manage Communication Process

○ Meter Delivery Controll

○ Data Delivery Process

Which are the standards used in smart metering systems?

☐ CIM

☐ DLMS/COSEM

☐ AMR

☐ OBIS

What are the main features of smart grid?

☐ It is more robust than traditional grid

☐ it can automatically reuse gathered information

☐ It requires 5G data connectivity.

☐ It can operate fully automatically.

What is OBIS code

○ Serial number of the smart meter

○ Codes that identify data using a hierarchical structure

○ Identification of Delivery point.

○ Unique communication address of smart meter

What is a Energy hub concept?

○ Concept of central ellectricity battery center.

○ Concept where electricity is used to produce multiple other energy carriers

○ Concept where the production, conversion, storage, and consumption of different energy carriers takes place.

○ Place where energy returns back to nature.

How do Solid-State power meters operate?

○ It operates through electromagnetic induction by counting the revolutions of a aluminum disc

○ It uses electronic components and circuits such as Analog-Digital Convertors to measure multiple values

○ it counts electrons using very sensible cameras

○ It operates using voltage convertors.

What are the main features of smart meters?

○ They require very stable energy source

○ They cannot operate without fast internet connection

○ It can be read only by utility operator.

○ Capability of event management

What defines the SGAM model?

○ It defines communication between multiple Smart grid systems.

○ It acts as an economical model for a smart grid implementation.

○ It acts as a reference designation system of Smart grid system

○ It defines transition process from traditional grids to smart grids.

How are smart metering systems specified in EU Recommendation?

○ They are defined by exact meter architecture.

○ They are defined by SGAM model.

○ They are defined by DLMS/COSEM standard.

○ They are defined by 10 common minimum functionalities.

What has to be part of every customer that consumes or produces energy?

○ He has to be part of any Spot market.

○ He has to be part of one Balance Responsibility Party at a time.

○ He has to be part of multiple Balance Responsibility Party.

○ He has to be participant on the Long-Term energy market.