C01 - Real time management and monitoring of power systems – an introduction (I)

1.1. Overview

In order to function as a modern society, today's civilisation needs energy. The primary energy provided by fuels or sun is raw energy, and can be used by cars, industrial furnaces, home cookers, light bulbs or cell phones only if it's converted by man into another, useful form of energy (for instance, burn coal to produce electricity or refine oil into gas).

An energy system can be defined as all equipments and infrastructure found on a geographical area, working together with the aim of producing, transmitting and using energy in different forms.

In an energy system (ES), energy is consumed in several forms. Fig. 1.1 depicts a comparison between the total world's primary energy consumption, by sources:

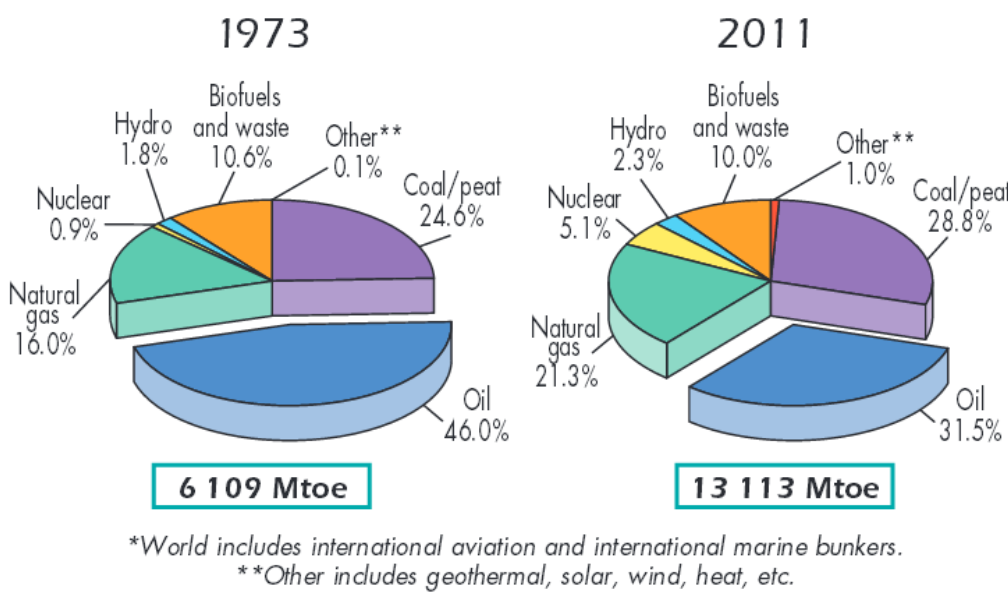

Fig. 1.1 - 1973 vs 2011 comparison of world's primary energy supply, image source [IEAStat 2013] (units are millions of tonnes of equivalent oil, converted as 71047 and 152504 TWh respectively)

The future growth trend predicted by U.S. Energy Information Administration estimates that world energy consumption will increase with 56% by 2040.

Electricity consumption represents an important fraction of consumption (14,5%), as deduced fronm Figs. 1.1. and. 1.3.

1.2. Electric Power Systems

An electric power system or EPS is a ES subsystem which includes all equipments and infrastructure needed for generation, transmission, distribution and use of electrical energy. Its function is to produce and deliver electricity to the consumers who need it in order to transform it into another form of energy (mechanical, light, heat) for their own use.

The main components of an EPS are (Fig. 1.2):

- the generators - producers of electricity from various primary sources (fossil fuels, nuclear, hydropower, wind, solar etc.)
- the electrical network or the grid - the infrastructure of poles, aerial and underground power lines, stations and substations needed to deliver the electricity to the consumers; it is divided into transmission (high voltage) and distribution (medium and low voltage);
- consumers - entities who need electricity

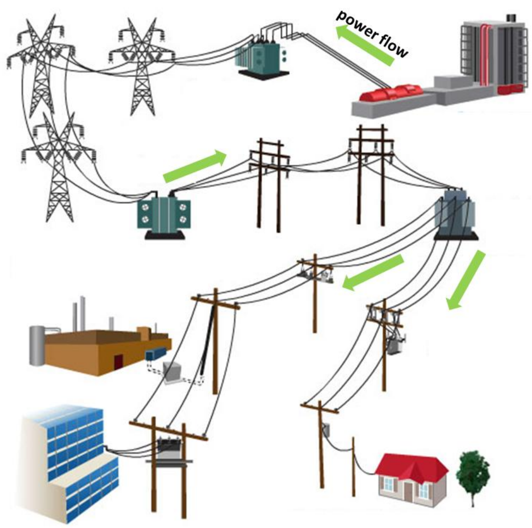

Fig. 1.2 – The typical architecture of a power system, image source [wwwVenture]

1.2.1. Electricity production

The main primary sources of electricity production are given in Fig. 1.2, as found by the 2013 International Agency report. It can be seen that fossil fuels are dominant as primary source, with an almost 70% share. A quick description of each resource is given in Table 1.1

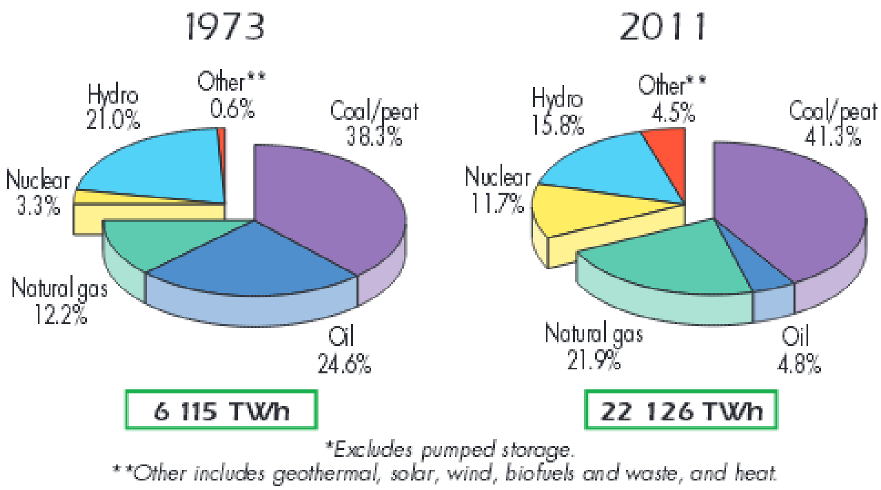

Fig. 1.3 - 1973 vs. 2011 comparison of world's electricity source by type of fuel used to produce it, image source [IEAStat 2013]

Table 1.1 - Overview of the main generation resources for electricity

Resource	Technical view	Economical view	Environmental view
fossil	High capacity units. built in remote areas; biggest plant: 5600 MW, Shoaiba, Saudi Arabia; RO - Turceni, 1920 MW, Rovinari - 1320 MW Low efficiency (37% coal, 46% natural gas)	Low cost for coal, variable prices for oil and natural gas High startup times (60-72 hours)	polluting
hydropower	High and small capacity units; the biggest: Yangtze – Three Gorges, China, 22500 MW; RO - Portile de Fier I, 1050 MW	Smallest running costs because do not use fuel, but high initial investment cost Fast startup times: 5 minutes	Non-polluting, but dams may endanger animal habitats and larger ecosystems
nuclear	High capacity units; the highest: Kashiwazaki-Kariwa, Japan, 8212 MW; RO - Cernavoda - 1400 MW	High startup times: 1-2 days Low and constant production cost	Non-polluting in normal operation; accidents and waste can have disastrous effects
wind	Farms of small capacity units (2-5 MW); highest: Gansu, China, 6000 MW; RO - Fantanele, 240x2,5 MW	High investment cost, subsidized Highly dependent on weather conditions	Non-poluting, renewable

1.2.2. The grid

The classic power systems are built around the paradigm of using large power plants, placed usually near their primary fuel source or in remote areas. High voltage AC lines are used over long distances to bring electricity near the consumption places, where the voltage is reduced in two steps, medium and low AC voltage, to supply the consumers.

The high voltage lines are called **transmission lines**. They are built usually in the 3-phase AC technology and stretch over long distances, from the power plants to the immediate vicinity of cities or industrial consumers. Their construction is usually aerial, with overhead lines and steel poles (Fig. 1.4). They carry high powers (hundreds, tens of megawatts) and ensure redundancy, a consumption place being supplied from at least two sources.

Fig. 1.4 - Overhead 400 kV transmission lines

AC is used because it can be transformed. High voltage is preferred because, at the same transferred power, the current is lower, and thus line isolation stress is lower and losses diminish. Transmission systems are managed at country or state level, being considered objectives of strategic importance, and dispatched at national level. In Romania, the national transmission system operator is the state-owned company Transelectrica. Its transmission network operates 400 kV and 220 kV lines, in a meshed configuration. The latest map of the Romanian transmission system is given in Fig. 1.5, and its main equipment list is given in Table 1.2. The 750 kV line is only a transit line between Ukraine and Bulgaria.

Table 1.2 - The structure of the Romanian transmission system [monogTE]

Electrical lines	750 kV - 155 km 400 kV – 4701 km 220 kV - 4035 km 110 kV - 38 km	
Stations (78)	750 kV – 1 (works at 400 kV) 400 kV - 35 220 kV - 42	215 transformers, with a total rated power of 36.815 MVA.

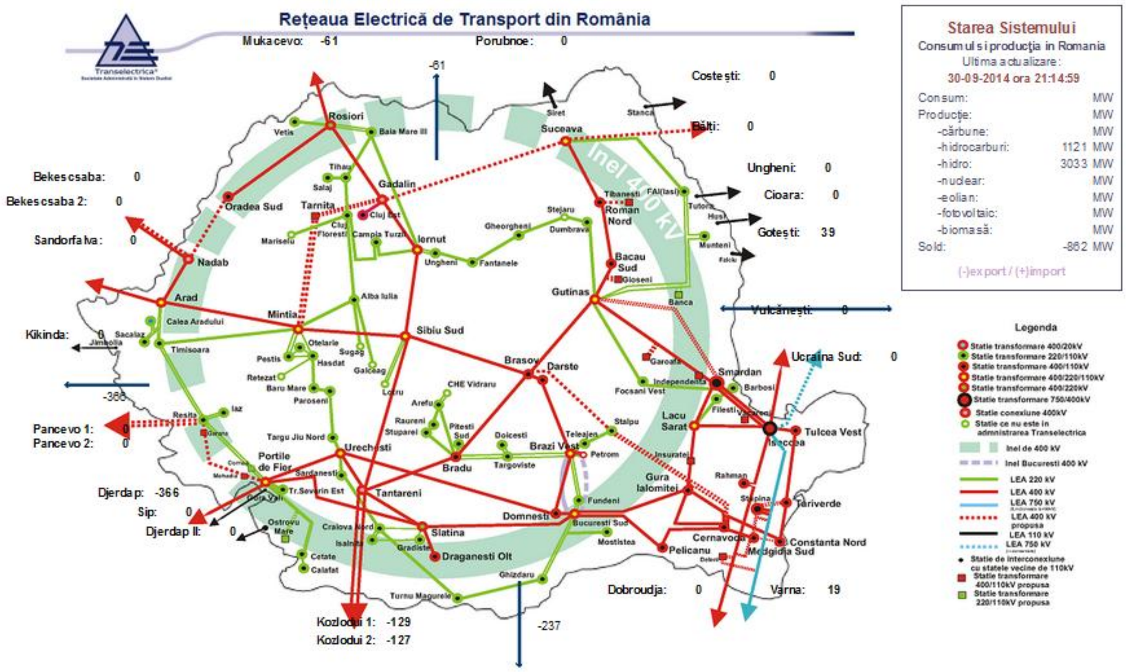

Fig. 1.5 - The Romanian HV transmission system owned by Transelectrica, with 400 kV (red) and 220 kV (green) lines

The interfaces between the transmission system and the distribution system are called substations (Fig. 1.6). Substations have the role of reducing the voltage to a lower level (in Romania, 110 kV) and inject power in the distribution system.

Fig. 1.6 - The 400/110 kV Medgidia Sud station, Romania

The distribution lines are

- high voltage lines (110 kV), in aerial construction, on steel poles, with one or more circuits (Fig. 1.7). The 110 kV voltage is then transformed in substations at medium voltage (in Romania, 20 and 6 kV). MV Distribution systems carry powers of megawatts and tens of megawatts.

- medium voltage lines, which in cities use underground cables, running from the substations down to the immediate vicinity of the consumer (Fig. 1.8). In rural areas, often concrete or wood poles and aerial conductors are used (Fig. 1.9). Some big consumers can be supplied directly from the MV network. The medium voltage is further transformed in smaller substations (Fig. 1.9 - outdoor pole MV/LV substation; Fig. 1.11 - enclosed MV/LV substation), with transformers rated at 10 kVA - 1.2 MVA)

The high and medium voltage lines are 3-phase lines.

- low voltage lines, which supply small consumers. In Romania, the supply is usually at 380V 3-phase and 230 V 1-phase, underground in cities and aerial in rural areas (Fig. 1.10).

Fig. 1.7 - 110 kV pole with 4 circuits

Fig. 1.8 - Underground 20

kV cable line, Iasi, Romania

Fig. 1.9 - MV concrete pole and outdoor MV/LV substation

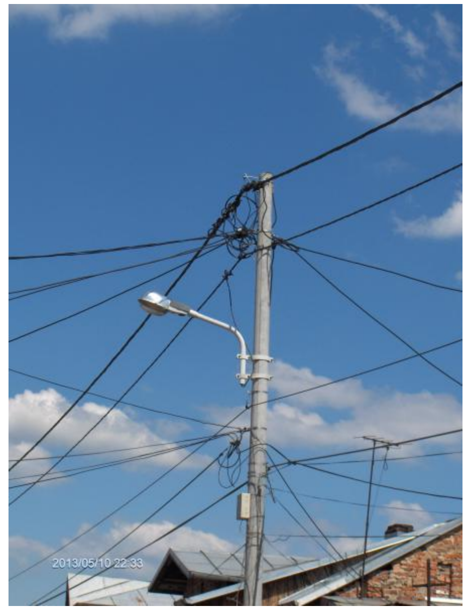

Fig. 1.10 - Concrete LV pole

Fig. 1.11 - Enclosed 1.2 MVA MV/LV substation [webSUP]

In Romania, distribution systems are operated and dispatched by 8 local monopolies, all privatized in some degree. (Fig. 1.12).

Fig. 1.12 - The Romanian regional distribution monopolies

1.3. The Consumer

The consumer is the sole reason for which power systems exist. Power systems have as main role the delivery of the electricity required by consumers, who have consumption devices connected to the grid, which need electricity in order to convert it in other useful forms of energy.

According to its daily needs, each consumer, regardless of type and size, is characterized by a load profile or curve, whose shape and magnitude vary according to the consumer type (residential, commercial, public service, industrial etc.) . The aggregated load curves of all consumers make the system load curve (Fig. 1.13), which is never a flat line at system level. Producers have to adapt their output in order to match the varying demand, because electricity cannot be economically stored in large quantities and the entity in charge of maintaining this balance is usually the system operator.

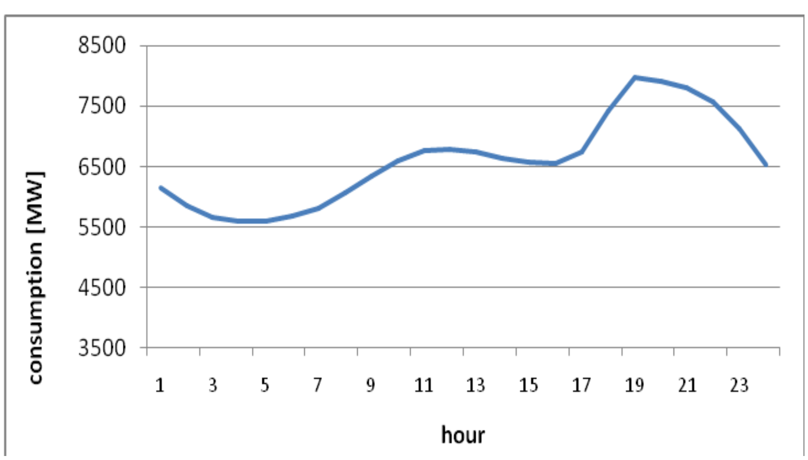

Fig. 1.13 - The system consumption curve in Romania, on 29.12.2012 [webTE]

References:

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[webTE] www.transelectrica.ro