ESF II project of the University of West Bohemia in Pilsen

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EMEE - Lecture n. 07

Balance of Power Systems

„Those who do not know or do not balance can hardly control something, let alone manage something, because they do not have real information on the basis of which it is possible to judge what could be done with it in order to achieve the desired goal.“

e.d.

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Lecture content

1) **What is a function (what is it used for) Energy (Electric) System.**
2) **What we mean by the production system in the ES.**
3) **How to define the energy content of a tradable commodity.**
4) **How to make an ES balance.**

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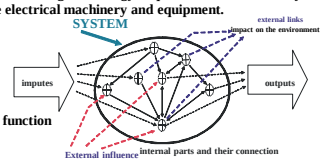
System Definition

Any system is a purposefully defined set of elements and connections between them (influencing the properties of this system), which as a whole has certain properties. It is a certain complex of elements located in a certain (defined) interaction and has defined inputs and outputs. The system is affected by the external environment and also acts on it. To define a system, it is necessary to define an object, its:

- **structure,**
- **properties,**
- **behavior.**

Electric Power (Energy) system (Electrification System - EES) - It is a generic term for a system that ensures meeting the energy requirements of electricity consumers represented by the electrical machinery and equipment.

In general, the system serves the specified (defined) goal (purpose) and the fulfillment of goals is performed using the purpose (objective) function of the system.



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System Concepts - Parameters

System:	purpose-defined set of elements and relationships between them, which as a whole has a certain property
System Element:	smallest elementary part of the system at the selected level of resolution
Bonds in the System:	way of connecting elements
Bond Content:	tangible, intangible, information
Bond Parameters:	ties depends on the nature and purpose of examining (information → type of information medium, frequency)
Direction of Links:	unidirectional, bidirectional, vertical, horizontal, diagonal
System Structure:	relatively static, functionally ordered set of elements and relations system
System Surroundings:	that part of the neighbourhood, which is running in the interaction → *open, closed systems, border elements*

System Target = state whose system has achieved
System functions = characteristic that reflects its finality (mission, competence, skill)

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System Properties - Parameters

System operation: system behavior - system responses to stimuli → ES function as transformation systems - transformation of energy inputs is their way of achieving goals.

Transformation: conversion of inputs into outputs, which can take place:
- **deterministically** - stimuli evoke a clear reaction, (ES - respects conservation law),
- **stochastically** - reaction with a certain probability.

System hardness: the extent to which the system can be objectively recognized and described by exact formalized means:
- **hard system** - usually simple technical systems,
- **soft system** - social and economic (can be described differently, although the target function can be defined in the same way).

System regulation: active, purposeful influencing of the course of processes in the system, so that the system is in equilibrium at the required (in the ES it is the power of appliances) value, which changes / does not change:
- **programmatically** - target is a function of time,
- **adaptable** - the goal depends on previous states, experience,
- **optimal** - the goal is max. min. value of the controlled function (in the ES, for example, at the maximum value of transformation of PES to FES, minimum delivery costs
  - the value of the target function changes with time or may be constant.

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Objective (purpose) Function of ES – Production System

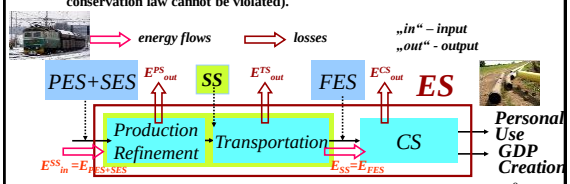
- The energy system is a hard deterministic transformation production system, operating on the basis of the law of conservation of energy whose target function is:
  coverage of necessary work (W - work) from the Supply Subsystem requirements of connected appliances in the Consumer Subsystem:
  $W^{SS}_{out} = W^{CS}_{in}$
- The ES production system transforms original energy forms (natural resources), ("raw materials"), Primary Energy Source (PES) and secondary energy sources (SES) which go into ES from others production systems, which have another target of objective function (agriculture, civil engineering, ...) or as the waste from consumption systems - into final (utility) energy forms (FES) that require consumption appliances.
- For system power balance there is necessary to now energy volume of inputting energy sources, that is possible to calculate or measure. For some energy sources it is a little complicated, therefore is better (more easy) to put to the power balance of ES output from production transformation system of natural sources – nuclear fusion = heat, solar radiation = electricity or heat.
- These energy forms inputting to ES (balance perception) are called Primary Energy or Primary Energy Sources – PES.
- In the production process of ES , the input energy forms can go through the transformation into another energy form or through refining, where only the energy content ("energy density") of the input energy form increases to secondary energy.
- The amount of the work (energy) delivered to appliances is equal to the work consumed over a period of time represents the power delivered to the appliances.

$$P=W/t\ [J/s=Watt]$$

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Objective function of ES Supply System

- Work is delivered to appliances through transport systems, which consume part of work (losses) between production and consumption to fulfil their purpose. The necessary work for transport systems is covered by production and is usually considered as necessary additional production needed for the realization of consumption. Therefore, the production system together with transport are collectively referred to as the Supply System (SS) and consumption as the Consumer System (CS) – *see picture*.
- The system is controlled programmatically, while the target value can be achieved, for example, at the optimal value of PES transformation to FES, minimum FES delivery costs, minimum environmental impact, profit maximization (financial), etc. - in any case the target value is the same (energy conservation law cannot be violated).



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Originaly vs. Secondary Materials inputing to ES

Raw materials - natural substances of inorganic or organic origin, intended for further processing - in the ES are called fuel-energy raw materials - Originally Energy Sources - OES. OES enters / exits (delivery to other) ES :

- mining in the territory (domestic) EES, -file Surovinová základna ČR a perspektivy její těžby
- import/export,
- from reservoirs in the territory EES.

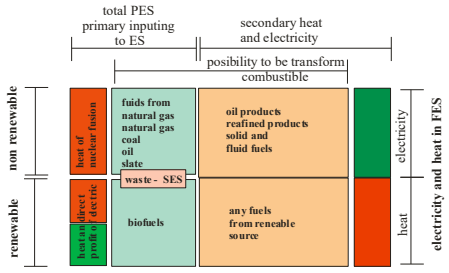
Dividing of OES:

- renewable – they naturally regenerate:
  - carbon neutral – solar radiation, wind, rain, tide, waves and geothermal heat, biomass ???,
- non renewable – fosil fuels, nuclear fuels (nuclear fission).

Secondary materials - raw materials or materials obtained from waste (from others production systems or consumer systems) that are suitable for further economic or other uses. In the ES, they can be transformed back into FES .

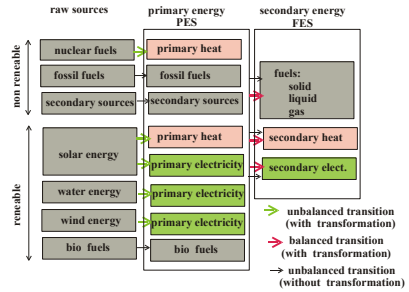
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Transformation to electricity and heat in ES



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Block diagram of ES balance



Transformation processes via production systems

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Balancce PES of Czech Republic

Sorce Type	Raw Sources	transf.	PES	2001		2002		2003		2004		2005	
				[PJ]	[%]	[PJ]	[%]	[PJ]	[%]	[PJ]	[%]	[PJ]	[%]
Non renewable	fossil fuels		solid fuels	914,4	53,8	882,8	51,8	906,3	50,0	900,4	48,9	882,7	46,5
	nuclear fuels		liquid fuels	316,0	18,1	338,5	18,6	343,0	18,9	371,4	20,2	395,7	20,8
Renewable	solfar		gasseous fuels	338,8	19,5	331,9	19,5	336,3	18,6	335,4	18,2	323,9	17,0
	Wind		primary heat	148,3	9,2	204,1	12,0	260,2	15,5	284,4	15,4	268,9	14,1
	Water		primary electricity	-26,9	-1,5	-32,0	-1,5	-53,4	-2,8	-49,3	-2,7	-36,8	-1,9
	Biofuelis		OZE (bez vody)									67,0	3,5
			total	1693,2	100,0	1703,3	100,4	1814,0	100,1	1842,3	100,0	1901,9	100,0

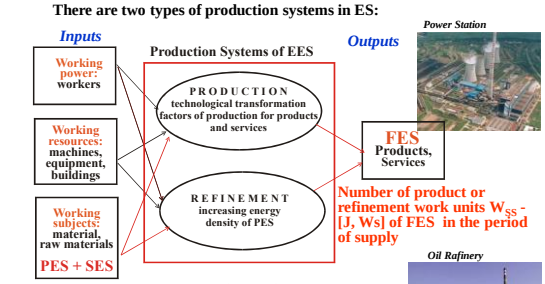
Primary Energy Sources of the any territorial ES are the sum of domestic or imported energy sources expressed in energy units. Primary heat here means heat produced in nuclear reactors, primary electricity is electricity produced in hydroelectric power plants (excluding PVE) plus the balance of electricity imports and exports.

Data sources:
Energetické bilance České republiky 2001, 2002, 2003 (publikace ČSÚ únor 2005)
Energetické bilance České republiky 2002, 2003, 2004 (publikace ČSÚ březen 2006):

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Types of Production Systems of ES

There are two types of production systems in ES:



Power Station

Number of product or refinement work units W_{SS} - [J, Ws] of FES in the period of supply

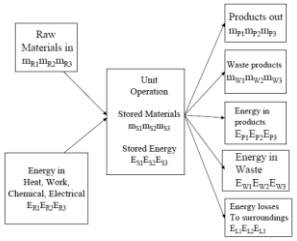
Oil Rafinery



Energy Density = Energy value of unit of measurey PES - ρ_{PES} [J/kg, J/m^3, J/m^2]

The law of mass conservation in ES

Mass or a material balance*: Mass In = Mass Out + Mass Stored*



Raw Materials = Products + Wastes + Stored Materials.

$$\Sigma m_R = \Sigma m_P + \Sigma m_W + \Sigma m_S$$

If there are no chemical changes occurring in the system, the law of conservation of mass will apply also to each component

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The law of energy conservation in ES

The energy coming into a unit operation can be balanced with the energy coming out and the energy stored.

Energy In = Energy Out + Energy Stored

$$\Sigma E_R = \Sigma E_P + \Sigma E_W + \Sigma E_L + \Sigma E_S$$

where:

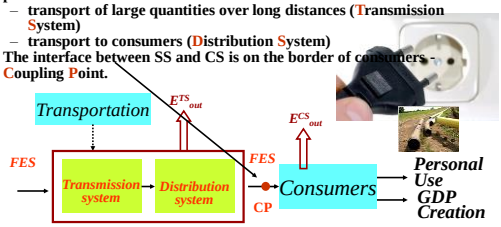
$\Sigma E_R = E_{R1} + E_{R2} + E_{R3} + \ldots$ = Total Energy (Raw) Entering
$\Sigma E_p = E_{P1} + E_{P2} + E_{P3} + \ldots$ = Total Energy Leaving with Products
$\Sigma E_W = E_{W1} + E_{W2} + E_{W3} + \ldots$= Total Energy Leaving with Waste
$\Sigma E_L = E_{L1} + E_{L2} + E_{L3} + \ldots$= Total Energy Lost to Surroundings
$\Sigma E_S = E_{S1} + E_{S2} + E_{S3} + \ldots$= Total Energy Stored

Energy balances are often complicated because forms of energy can be interconverted, for example mechanical energy to heat energy, but overall the quantities must balance.

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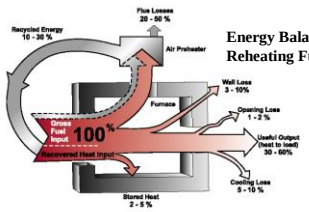
ES - Conection SS and CS

- Each goods item should be delivered to the customer - thus fulfilling the purpose of the production system.
- The transport of energy goods can be carried out:
  - continuously - using product pipelines (electricity, gas, heat)
  - in pieces - fuels (liquid, solid) .
- For continuous transport, the transport system is divided into two parts:
  - transport of large quantities over long distances (Transmission System)
  - transport to consumers (Distribution System)
- The interface between SS and CS is on the border of consumers - Coupling Point.



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Sankey Diagram of any Energy Balance

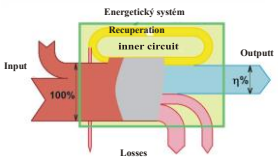


Energy Balance for a Reheating Furnace

- The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler generation, fired heaters, furnaces after carrying out energy balance calculation. This diagram represents visually various outputs and losses so that energy managers can focus on finding improvements in a prioritized manner.

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Energy Balances of Production ES without accumulation possibility





By EB we mean the expression of partial energy inputs, outputs and system losses:
Input: all energy sources go in:

PES:
Renewable –
- energy of the wind
- energy of solar radiation
- tide energy
- water waves
- geothermal heat
- biomass

Unrenewable –
- fossil fuels
- nuclear fuels

SES : energy sources go from other production systems:
Personal use:
- municipal waste

Power Systems:
- coke and flue gas at coall

Agriculture:
- straw, barn manure

Metallurgy:
- blast furnace gas

Paper industry
- black liquor

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Type Energy Balances

- **Immediate (efficiency) - at a given point in time = power balance.**
- **The resulting - for a certain period (usually a year).**
- **Prospective - for the future time horizon**

Objective of the final balance:

- **Find out the state of the current (efficiency) energy system.**
- **Identify shortcomings in energy management (losses).**
- **Provide opportunities to increase efficiency and ensure process inputs.**

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Balance Units - 1

Energy Balances can be work out tabular in:
per mass units [m.u.]

To:	kg	t	lt	st	lb
From:	*multiply by:*				
kilogram (kg)	1	0.001	9.84×10^{-4}	1.102×10^{-3}	2.2046
tonne (t)	1000	1	0.984	1.1023	2204.6
long ton (lt)	1016	1.016	1	1.120	2240.0
short ton (st)	907.2	0.9072	0.893	1	2000.0
pound (lb)	0.454	4.54×10^{-4}	4.46×10^{-4}	5.0×10^{-4}	1

per volume units [v.u.]:

To:	gal U.S.	gal U.K.	bbl	ft^3	l	m^3
From:	*multiply by:*					
U.S. Gallon (gal)	1	0.8327	0.02381	0.1337	3.785	0.0038
U.K. Gallon (gal)	1.201	1	0.02859	0.1605	4.546	0.0045
Barrel (bbl)	42.0	34.97	1	5.615	159.0	0.159
Cubic foot (ft^3)	7.48	6.229	0.1781	1	28.3	0.0283
Litre (l)	0.2642	0.220	0.0063	0.0353	1	0.001
Cubic metre (m^3)	264.2	220.0	6.289	35.3147	1000.0	1

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Balance Units - 2

The best expresions power balances is in per energy units [e.u.]:

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	*multiply by:*				
TJ	1	238.8	2.388×10^{-4}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

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