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ENERGY SUPPLY PROBLEMS AND PROSPECTS

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The problems and long-term prospects of energy supply in the world and in Estonia have been discussed in the paper. The problems treated in this paper are: environmental impacts, economical using of energy sources, electricity supply, optimization of power and interconnected power systems and electricity supply prospects in Estonia. The vector optimization of energy supply with the objective to minimize the consumption of energy sources, environmental impacts, operational and investment costs in the long-term perspectives is recommended in the paper.

Introduction

Over the last 50–60 years the energy consumption has rapidly increased in the world mainly due to increasing population and economic development of countries. Great changes have been happening also in energy industry and in power engineering [1–3]. Power plants, electrical networks and electric power systems have been developing very rapidly. The new resource of primary energy – nuclear fission power has been taken into use, etc. During the last decades great attention has been paid to the environmental impacts and using of renewable energy resources. Many countries are dealing with the restructuring of energy industry and the opening of the energy markets.

Energy supply to the consumers is a vitally important service for every country and every human being. The supply of electricity is of course especially important, but also the supply of engine fuels and heat is very essential. The supply of electricity must be secured in sufficient quantity and quality at a competitive unit price [2, 3]. Because of that the electricity supply equipment and systems must satisfy the safety, reliability and many other requirements.

Energy supply is a very complicated systemic problem that must be analyzed from the long-term time point of view. Fossil fuels are the main

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resources of the primary energy. About 80-90% of the energy consumed in the world is obtained by combustion of fossil fuels such as oil, natural gas, coal and oil shale. There are two problems involved: 1) the reserves of fossil fuels are decreasing and some of these may be finished already during the current century; 2) the combustion of fossil fuels causes environmental problems.

The environmental policy has changed very actively. The participants of this movement presume that carbon dioxide going to the atmosphere during the combustion of fossil fuels causes the global climate change. The protectors of the environment recommend to finish using fossil fuels and to produce energy for consumers mainly on the basis of renewable energy sources (by wind and solar power). Such policy is not well-founded, possible and for many countries it is harmful.

In this paper we will discuss the following issues:

- Environmental impact
- Primary energy – sources and economical consumption
- Supply of electricity
- Optimization of power systems and interconnected power systems
- Electricity supply prospects in Estonia.

Environmental impacts

Energy conversation and transmission are bound with the environmental impact. A typical flue gas from the combustion of fossil fuels contains water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxides (NO_X) and very small amounts of other matters. The amounts of matters in flue gas are depending on the kind of fuel, on combustion technology and on boilers' loads. Today the pulverized firing (PF) technology is the most widely used combustion technology for solid fuels [4]. This combustion technology is not clean enough. But there are several new clean combustion technologies such as the atmospheric fluidized-bed combustion (AFBC), the pressurized fluidized-bed combustion (PFBC) and others. On the occasion of new combustion technologies the flue gas will consist mainly of water vapor and carbon dioxide [4].

The movement, fighting against the climate warming that many believe in, is based on the assumption that human-induced carbon dioxide emissions cause the dangerous climate change and that reducing these emissions will enable to stop the climate warming. Both assumptions have not yet been proved by scientific methods. These hypotheses are erroneous and the effect of human induced carbon dioxide emissions on climate is negligible [5].

The climate is a very complicated Markovian random process that is affected by hundreds of periodic and non-periodic processes on the sun, earthquakes, gushes of volcano, dynamics of winds, earth rotating and many other factors. Because of this the determination of warming trends for climate is a very complicated scientific problem. Many experts are of the opinion that now the climate is continuously cooling.

The methods used for "stopping" the climate warming – quotas and taxes of carbon dioxide emissions are not suitable for every country. These drastic means are very harmful for these countries who do not have remarkable hydroresources and who can generate electricity only by fossil fuels.

The hopes that wind power can substitute fossil fuels are also not well-founded. Nowadays even one power resource cannot substitute fossil fuels. The campaign against climate warming and against consumption of fossil fuels spends a lot of money and tries to deform the natural development of energy industry in the world. Instead of this we recommend to target the optimization of energy supply and energy consumption.

Economical consumption of primary energy sources

In 2006 the structure of primary energy consumption in the world was the following [6]:

- Oil 36.6%
- Coal 27.2%
- Gas 23.0%
- Hydroelectric 6.3%
- Nuclear power 5.9%
- Wind, solar, wood, etc. 1.0%

Transport is the greatest oil consumer. Oil is also used for heating and for electricity generation. The coal is mainly used for electricity generation and for heating. Natural gas is used for generation of electricity and heating. The total part of fossil fuels in the world was 85%.

Renewable energy sources include hydro power, wind power, solar power and others. The hydro power is used for electricity generation and partly for doing mechanical work. Wind power, solar power and others are used for heating and also for electricity generation.

Nuclear power is used mainly for electricity generation.

The growth of energy consumption will continue. Energy consumption will increase especially rapidly in the developing countries. By 2050 the world energy consumption will be probably over two times more than presently and by 2100 3–4 times more than presently.

The main resources of primary energy are the fossil fuels. Wind power and solar power cannot substitute fossil fuels since their use for electricity and heat generation is not sufficiently controllable.

The reserves of fossil fuels in 2003 were as follows [6]:

- Oil – nearly 40 years
- Natural gas – nearly 60 years
- Nuclear fuels – nearly 70 years
- Coal – nearly 200 years
- Oil shale – approximately 200–400 years

The data about reserves of fossil fuels is of course very inexact since every year some new deposits of fuels are discovered. The data shows that the resources of natural oil, natural gas and nuclear fuels may become to an end already in the 21st century. Their prices may rise up more rapidly than the prices of coal and oil shale. The resources of coal and oil shale will continue to wet also in the 22nd century and further. Oil shale will be the future fuel since the oil shale resources are hundred times greater than coal resources. In the future the world will produce more electricity, oil and gas from the oil shale than presently. The production of bio-fuels will increase. The consumption of wind and solar power will also increase, but their rate in world energy balance will be not very high (<10%).

We do not know when a new technology that enables to produce energy from other sources such as the nuclear fusion power, hydrogen fuel or something else will be available for wide-spread practical use and when fossil fuels will be replaced. For that reason countries must consider fossil fuels as strategic resources and consume limited energy sources as economically as possible.

Objectives for economical consumption of energy resources

- To use the energy resources and mineral deposits as effectively as possible minimizing fuel losses and environmental impact.
- To organize fuel industry and fuel transport in a more optimal way.
- To intensify scientific research and innovation in the area of fuels and energy resources.
- To develop the possibilities for storing wind and solar power.

These objectives would be used in addition to the common economical criterions as to minimize the expectation of investments and operational costs, to maximize the profit, etc. The time horizon must be 50–70 years. If possible, it is desirable to use the methods of vector optimization and multi-stage optimization processes considering the real character of initial information.

The optimization of consumption of fuel and other energy sources enables to save energy sources and to decrease their environmental impact by at least 20–40%.

Supply of electricity

Supply of electricity is very specific as unlike coal, gas and water, the electricity cannot be stored and the supplier has small control over the load at any time. Energy resources and electric power systems are needed for supplying the electricity.

Power system (electric power system) is a technical system consisting of power plants located at a certain territory and of electric networks connecting the power plants themselves and with consumers’ appliances. Electricity generation, transmission, distribution and consumption proceed in a power system practically simultaneously. Because of that, power generation, demand and losses must be in equilibrium at any moment. As the load demand is continually changing in the power system, it is necessary to regulate the active and reactive power generation correspondingly [1–3].

The larger the power system, the greater its reliability, security and efficiency, and the simpler it is to guarantee the quality of frequency. For that reason power systems are often interconnected with neighboring power systems. Power systems and interconnected power systems are the most complicated artificial systems today.

The main components of the power system load are [7]:

1) extremely fast, irregular changes with the duration of few seconds and with very small amplitude (<0.5%)
2) fast, irregular changes with duration of a few minutes and with noticeable amplitude 0.5–1.5%
3) slow, nearly regular changes of load.

The slow load component in a day, week and year is the most changing one. A typical daily power system load curve is shown in Fig. 1.

As we can see from Fig. 1, at least 50–60% of generating capacity must be independently controllable in the isolated power system. Otherwise the electricity supply of consumers is not possible. This is a very important character of the power system. In the interconnected power systems a part of power systems may buy the service of generation control from other systems.

World installed capacities of electricity generation by types of power plants were as follows (January 1, 2006 [8]):

• Conventional thermal power plants	2752,191 GW	68.59%
• Hydroelectric power plants	776,760 GW	19.36%
• Nuclear power plants	376,824 GW	9.39%
• Other generating capabilities	106,661 GW	2.66%
World total:	4012,435 GW	100%

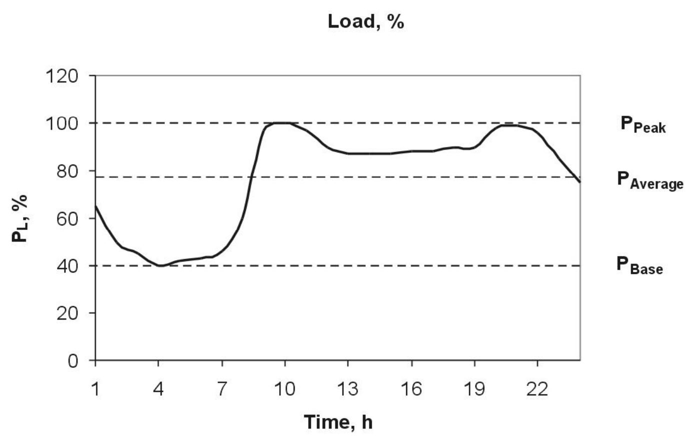


Fig. 1. A typical daily power system load curve: P_{Base} – daily basic load, P_{Peak}– peak load, $P_{Average}$ – average load.

The consumption of primary energy resources for electricity production is approximately the following [9]:

- Fossil fuel power plants 66.1%
  of which:
  - Coal fuel power plants 39.8%
  - Gas fuel power plants 19.6%
  - Oil fuel power plants 6.7%
- Hydropower plants 16.1%
- Nuclear power plants 15.7%
- Other power sources 2.1%.

Over two-thirds of electrical energy is produced by fossil fuel power plants. The main type of thermal power plant is the coal firing condensing power plant.

The capacity factor (CF) of a power plant is the ratio of the actual energy output of a power plant over a period time to its maximum energy output if it had operated at installed power at all times:

$$CF = \frac{W_A}{P^{Max} T}, \quad (1)$$

where W_A is the actual energy produced in the period T, P^{Max} – maximal capacity of power plant.

Capacity factor varies greatly depending on the type of power plant and load curves of the power system. Capacity factor of base load power plants is relatively high (0.7–0.9) and for peak load power plants – relatively small (0.1–0.2).

Hydroelectric power plants with water reservoirs

Hydroelectric power plants with water reservoirs are the most suitable power plants for electricity production and for controlling the active power balance. They can operate with both constant and changing power. Regulating cycle length (day, week, year or couple of years) of a hydro power plant depends on the size of its water reservoir [10]. Generating power of the hydro-electric power plant can be changed quickly in the interval of 0–100%. Hydroelectric power units can be started and stopped in a few minutes. The controlling losses are relatively small. Hydroelectric power plants can cover peak load, intermediate load, basic load or the entire load diagram. Average capacity factor of hydro power plants in the world was recently 0.44.

Condensing thermal power plants combusting organic fuels

Condensing thermal power plants combusting organic fuels are also power plants of controllable generation [7]. The interval of controllability depends on the fuel: between 50–100% for solid fuels (coal, oil shale), 30 to 100% for gas and oil fuels. The controlling losses are larger than in the hydroelectric power plants. The traditional condensing power plants can cover basic load or basic load + intermediate load or the entire load diagram.

Gas turbine power plants

Gas turbine power plants are intended for covering only peak load and acting as emergency reserves.

Cogeneration power plants

Cogeneration power plants operate according to thermal load diagram and produce electric energy as a side product. Only cogeneration power plant with heat accumulator or with a cogeneration turbine that has a condensing part can participate in the control of power balance.

Nuclear power plants

Nuclear power plants are designed for operating at maximum load in the basic part of the power system's load curve. They do not participate in the power balance regulation process. Because nuclear power plants suit only to power systems with hydroelectric power plants with water reservoirs or pumped-storage power plants for regulation of power balance, capacity factor of nuclear power plants is kept between 0.8–0.9. Nuclear power is not clean, it is dangerous. The dangers that would accompany the building of nuclear power units must be considered particularly in small countries.

In 2007 there were 439 nuclear power reactors in operation in the world, operating in 31 countries.

Wind power plants

Power generated by wind power plant is changing together with changing of wind speed. If the wind speed is small (<5 m/s) or too high (>20 m/s), power generation will be zero. If the wind speed is changing from 5 m/s to 15 m/s, the generated power is changing from zero to maximum. The power generated by wind generator is not controllable in correspondence with the power system load changes. Due to the non-controllability of generation and changes in electricity generation with changing wind speed, the wind generator differs from a traditional power plant. The wind generator reminds rather the negative load of the power system. That is why the wind power plants or wind parks cannot secure the supply of electricity without the traditional power plants. Wind power plants are most suitable for the power systems with hydroelectric power plants with water reservoirs or pump-stored power plants, which will regulate the power balance in the power system. If the speed of wind is constant, the using of wind power plants may decrease also the load of thermal power plants to a certain extent. The capacity factor of wind power plants is usually 0.15–0.35. In order to use the production of the wind power plant at changing speed of wind it is necessary to compensate wind power changes by the traditional power plants. Controlling reserve for wind power plants must be very large (up to 100%).

Wind power is very expensive. The construction of wind power plants by campaigns and subsidies is not reasonable. The suitability of wind power plants for the power system needs a more specific analysis.

There are several types of power plants that can generate the electric power, but only two types of plants can regulate the power balance in the power systems. These are the hydroelectric power plants with water reservoirs and condensing thermal power plants combusting organic fuels. Because of that reason, the power system with unsufficient number of hydroelectric power plants with water reservoirs must have a sufficient number of condensing thermal power plants combusting fossil fuels. The other power plants have only a helping role in the supply of electricity.

Future trends

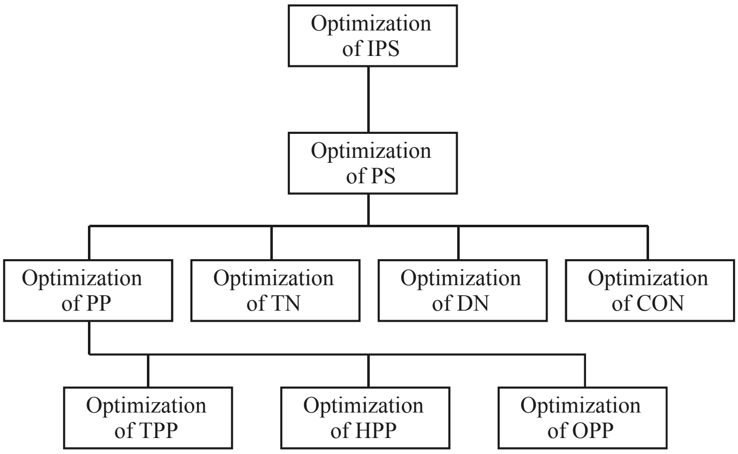
Coal remains the dominant fuel for electricity generation still for at least 50-100 years. The using of coal will grow 2–3% per year. Oil shale consumption will begin to increase, as oil shale resources in the world are very large. Also the gas, peat and wood consumption for electricity generation will grow. The consumption of renewable energy resources will also increase, but the part of wind power and solar power will be discreet. Perceptibly more attention should be paid to the optimization of electricity and thermal supply.

Objectives for optimization of power and interconnected power systems

The main objectives for optimization of power and interconnected power systems are:

1. Optimal operation and control of power plants, electrical networks and power systems and interconnected power systems:
   - Minimizing the total fuel cost and environmental pollutions (CO_2, SO_2, NO_X emissions). Time horizons [11]: minutes, hours, days, weeks, months, year.
   - Minimizing expected cost of operation. Time horizons: minutes, hours, days, weeks, months, year.
2. Optimal planning of structure and developing of power plants, electrical networks and power systems and interconnected power systems:
   - Minimizing expected investment and operation costs with reliability constraints. Time horizon: years (10–70 years).
3. Optimization of final consumption of electricity:
   - Consumers must minimize electricity consumption and participate in power system control under electricity market condition. Time horizons: day, months, years.

The optimization tasks for different objects depend on one another, and these form a hierarchical system of optimization tasks (Fig. 2) [7].



IPS – interconnected power system, PS – power system, PP – power plants, TN – transmission network, DN – distribution network, CON – consumers, TPP – thermal power plants, HPP – hydroelectric power plants, OPP – other power plants

Fig. 2. Task hierarchy for optimization of interconnected power system operation.

The processes of power systems' optimization are multi-stage processes, where the needed information is changing with time more and more exactly. Considerably more attention must be paid to the vector optimization of power systems and to the consideration of probabilistic, uncertain and fuzzy information [12].

More perfect optimization of power systems enables to decrease the consumption of fossil and other fuels, to reduce pollution of environment and to improve other indices by about 10–30%. However, the effect may also be much greater. The exact estimation of available effect is impossible.

Electricity supply prospects in Estonia

As an example to the abovementioned, let us look at the electricity supply prospects in Estonia.

Estonia is a small country (45,227 km^2, 1.34 million inhabitants). The only local energy resource for producing electricity and oil is oil shale. Oil shale is a strategic mineral wealth of Estonia, the consumption of which must be economical for the long-term future.

Installed capacities of electricity generation in 2009 were the following [13]:

- Narva TPP 2000 MW
- Cogeneration PP 302 MW
- Wind PP 115 MW
- Hydroelectric PP 4 MW.

Over 90% of electric energy is produced from oil shale. Cogeneration power plants use also natural gas, oil shale and wood. The Narva power plants are the biggest oil shale power plants in the world. They consist of 200 MW and 215 MW power units. In 200 MW units PF combustion technology is used. Two 215 MW units are equipped with new boilers using AFBC combustion technology. Estonian power system is connected by indirect current lines (330 kV) with Latvian and Russian power systems and by direct current cable with Finland.

Consumption of electricity will increase by average 2–3% per year, which means that doubling time is 23–35 years. Daily load demand in Estonia changes approximately 2 times: at night time the power demand $P_D \approx 50\%$ and at peak load time $P_D = 100\%$ (Fig. 1) [13].

Estonian power system consists mainly of condensing thermal power plants and cogeneration power plants. The generation of condensing power unit is controllable within the range of 50–100% without shutdown or start-up of the unit. Therefore the oil shale condensing power units are suitable for the Estonian power system. Estonian power system is not suitable for wind power plants and nuclear power plants, as there lack the corresponding controllable generating capacities. The establishing of quotas and taxis for "fighting" against the climate warming is harmful for Estonian economy and energy development. Therefore we will look at the future of Estonian power system without carbon dioxide taxes.

The main ways to guarantee the energy supply of Estonia in the future are:

1. Continuing the development of oil shale mining and industry by the optimal way minimizing the oil shale losses and environmental impacts. The priorities of oil shale consumption must be as follows:
   1) Electricity production,
   2) Oil production and gas production,
   3) Chemical industry and other.
2. Optimizing the operation of the Estonian power system in the interconnecting power system under electricity market conditions minimizing the expected fuel cost, environmental impacts and operational costs.
3. Continuing the development of Estonian power system by the optimal way, minimizing the fuel cost, environmental impact and expected investment and operational costs with reliability constraints. The main options are the oil shale power units with clean combustion technology (AFBC or PFBC technology). For peak load covering and for emergency reserve is desirable to build some gas turbine power plants. It is desirable to develop the cogeneration of heat and electricity and using of renewable energy sources.
4. Optimizing of final consumption of electricity, heat and fuels.
5. Further developing the scientific research and innovation in Estonia.

Conclusions

1. The main problem of energy supply in the world is not the climate warming, because the effect of human-induced carbon dioxide emissions on climate is negligible, but the insufficiency of energy resources in the long-term perspective and waste of energy and energy resources.
2. For the future interests every country should pay more attention to the optimization of consumption of energy sources, power systems and interconnected power systems and final energy consumption by the vector objectives, minimizing the cost of energy resources, environmental impact, operating costs and investment costs. A complex optimization of energy resources consumption, energy supply processes and systems enables to save energy resources and to reduce the environmental impact by a considerable extent.
3. For the optimal solution of energy problems, further development of the energy research and innovation is needed.

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