LEAST COST ANALYSIS OF BELARUS ELECTRICITY GENERATION SYSTEM WITH FOCUS ON NUCLEAR OPTION

Alexander Mikhalevich, Anatoli Yakushau
Joint Institute of Power and Nuclear Research of National Academy of Sciences
220109 Minsk-Sosny, Krasin Str. 99, Belarus
mikhal@sosny.bas-net.by, iakoush@sosny.bas-net.by

ABSTRACT

A basic feature of the Belarus electricity system is that about 50% of the installed power capacity is used to produce heat for the central heating supply system. The Republic has one of the most developed districts heating system in Europe. The installation started in 1930, and developed very fast after 1945. Co-generation of electricity and thermal energy in central power plants has played a fundamental role in the local economy. Presently, Belarus electricity generation system includes:

- Total installed capacities of condensing turbines 3665 MW
- Total installed capacities of co-generation turbines 3889 MW.

It is expected that in 2020 in accordance with electricity demand forecast peak load demand will be equaled approximately 9500 MW. Taking into account that operation time of 60% existent co-generation turbine and 70% of condensing turbine can be extended up to 2020 during the period 2005 - 2020 it is necessity to install about 1500 MW of new co-generation units and about 2000 MW of condensing turbines.

To select the least cost scenario for electricity generation system expansion improved computer code WASP-IV for Windows had been used. As so far code WASP-IV do not allow finding out optimal solution for electricity generation system with high share of co-generation directly the methodology of application of this program for this case had been developed. Methodology is based on utilization of code WASP-IV for simulation condensing turbines and module BALANCE for modeling co-generation part of the system.

The scenarios for the electricity system expansion plan included only conventional technologies. Presently, the works connected with the preparedness for NPP construction in the Republic including site survey for NPP are being carried out. The first stage of siting process according to the IAEA classification has been completed. It was based on a set of criteria answered to A Safety Guide of the IAEA "Site Survey for Nuclear Power Plants" and requirements to be accepted in Russia for NPP placement sites. The result of the preliminary studies had shown that there are at least three suitable sites for construction of the NPP. It allows the nuclear power option to be included in the list of possible technologies for electricity generation.

The optimal expansion plan of the electricity generation system based on installation new combine cycle units, co-generation units and nuclear power plants has been developed. The optimal least cost expansion plan has been chosen as a result of comparative analysis of the three scenarios.

Using WASP III plus computer code optimal electricity generation system expansion plan for each scenario had been found. Calculations had been carried out for discount rate equaled 8%.

The results of calculation are shown that electricity system expansion plan based on utilization of coal as a fuel has the highest generation cost. Otherwise, implementation of the nuclear power will allow decreasing generation cost up to 3.26 cents/kWh. In accordance with the calculation optimal solution includes construction of the four nuclear units and the first unit is supposed to start up in 2014 year. For Scenario based on natural gas and nuclear fuel mix is expected to be least total electricity generation cost and it is the most economically attractive option.

1 BACKGROUND INFORMATION

The Republic of Belarus is situated on the West of Eastern-European. A compact shape of the territory of the Republic stipulates its similar length from north to south (560 km) and from west to east (650 km). The area of the Republic is 207600 km^2. Being situated close to the geographic center of Europe, the Republic of Belarus occupies an advantageous geographic position and an important place in the geopolitical European history. Here, the roads from the central regions of Russia pass to Western Europe, as well as from the Ukraine to Baltic countries and from the northwest part of Russia to the Ukraine. On the west it borders with Poland (the length of borders is 399 km), on the north-west with Lithuania (462 km), on the north with Latvia (143 km), on the north, north-east and east with Russia (990 km), and on the south with the Ukraine (975 km).

1.1 Depletable energy resources

The supply from home energy resources in 1990 constituted 13%. Thus, the development of the energy sector is mainly based of the imported fuel (natural gas, oil, and coal) and at a little extent on the domestic resources (oil, peat, woods, and wood waste). Crude oil resources, estimated as 363 mill tons, are most significant. About 45% of these resources had been explored and proven in Gomel region. Reserves being explored are of high quality (0.3% sulfur contents) and not over developed (with respect to the number of development wells drilled and the production rates). Crude oil production declined from 2.55 mill t in 1980 to about 2 mill t per year in 1985, and has remained steady at that level since. Associated with the crude oil, about 0.3 billion m^3 per year of gas is produced and fed into the gas transmission system.

Four to five millions tons of peat as a fuel were produced annually during the last ten years, most of which was harvested at locations near 37 peat pellets plants. The Government, in order to protect agricultural land wetlands, has decided to restrict peat production to already harvested deposits. Therefore, only about 11% percent of total peat resources can be considered as energy reserves.

The total standing stock of wood is about 1 billion (solid) m^3 covering about 8 million hectares. The total annual harvest of wood, 10 - 12 million m^3 in the 1993, has recently declined to 9 million m^3. In 1990, energy application amounted to 2.2 mill m^3 (approximately 1.5 mill t of wood or about 4.1 mill Gcal). Approximately 0.3 mill m^3 of fuel wood used to be sold to household by wood processing plants. The rural population harvests same additional wood under a (case by case) permit system. Of the 6.7 mill m^3 industrial round wood harvested in 1990, 40% represented waste, out of which 1 - 1.5 mill m^3 was burned in boiler.

The annual increase in wood biomass is estimated at 23 - 25 mill m^3. Given the need to build up standing stock (due to a very unbalanced distribution in age classes) and taking into account that only about 80% of the forested area is exploitable (due to forests contamination from the Chernobyl accident and environmental protection of certain forested area), the annual allowable cut is estimated at 15 mill m^3 On this basis, about 6 million m3 (4.2 mill metric tons) per year of additional wood can be considered available. In additionally, there is about 1 mill m^3 of unutilized wood waste in industry.

2 ELECTRICITY GENERATION SYSTEM

A basic feature of the Belarus electricity system is that about 50% of the installed power capacity is used to produce heat for the central heating supply system. The Republic has one of the most developed districts heating system in Europe. The installation started in 1930, and developed very fast after 1945. Co-generation of electricity and thermal energy in central power plants has played a fundamental role in the local economy. Presently, Belarus electricity generation system includes:

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It is expected that in 2020 in accordance with electricity demand forecast peak load demand will be equal approximately 9500 MW. Taking into account that operation time of 60% existent co-generation turbine and 70% of condensing turbine can be extended up to 2020 during the period 2005 - 2020 it is necessary to install about 1500 MW of new co-generation units and about 2000 MW of condensing turbines.

Up to 1997 electricity and heat generation system of Belarus was under supervision of Ministry of Power and Fuel of the Republic of Belarus. Ministry was responsible on generation, transmission and distribution of electricity. It also contained a number of specialized associations providing construction, design, and research institutes. In August 1997 Ministry of Power and Fuel was liquidated and State Electricity Generation Concern BELENERGO had been found. The Concern is carrying out the same type of activity like Ministry did.

2.1 Transmission and Distribution System

The transmission system of Belarus is an interconnected network. With a decline of consumption it is now an oversized network. Table 1 shows line lengths and cable voltages.

Table 1 Cable Voltages and Lines

Voltage, kV	Overhead line, km	Conductor size, mm^2	Underground cable, km
750	761	5×300	NA
330	3529	2×300	NA
110	15528	1×95 to 240	14
35	11890	1×50 to 95	17
10	104189	1×16 to 50	9025
6	NA	NA	1391
0.4	95286	NA	8144

The 750 kV lines are on steel poles; and the 330, 220, 110, 35 and 10 kV lines are on concrete poles. About 60% of 0.4 kV lines are carried on wooden poles many of which need replacing, the rest are on concrete poles. The 750 kV lines have five conductors per phase and are carried on steel poles with earth wires, which are isolated at towers and used for communications. All 330 kV lines are carried on concrete poles with two conductors per phase. These lines have single circuit construction.

There are over 20,000 substations and the oldest one of them is more than 25 years old. The 110 kV lines are supported on reinforced concrete poles and only 2% of them are over 40 years old. The 110 and 35 kV lines have single-phase conductors with steel earth wires, 80% of the insulators are glass. There are 600 substations at 110 and 35 kV with about 1000 transformers sized 7-630 KVA. Eighty percent of 110 and 35 KV lines have glass insulators. Plastic insulators are also used on 110 kV lines. This type of insulator is developed and manufactured in Belarus.

There is only one 750/330 kV substation with 3 phase transformers, each 330 MVA, and approximately 26 substations 330/220 kV, 330/110 kV, normally equipped with two transformers of 200 or 185 MVA. There are 15 substations for 220 kV lines interconnected by 2000 km of line.

The 750 kV line from Lithuania (operating at 330 kV) was commissioned in 1990. The 750 kV line from Smolensk, which terminates on a single-phase 330 MVA (1000 MVA total) transformer with tap changes was commissioned at the beginning of 1994. The later line (417 km length) has two banks of 3 single-phase 100 MVA reactors at the Smolensk end and the same reactors with a provision for a second bank at the Belarus end. The natural loading of the line is 1200 MW but it is only carrying 700 MW leading to excessive MVA generation. Proposals for a tertiary 160 MVA synchronous compensator at the Belarus end are being considered. Russia does not make a large static dynamic compensator.

2.2 Dispatch Center

The National Dispatch Center in Minsk is responsible for the overall security of the system, instructing loading at power plants total capacity greater than 500 kW, switching at substations of 330 and 750 kV and foreign trading.

There are six regional dispatch centers, Minsk, Grodno, Brest, Mogilev, Gomel, Vitebsk responsible for transmission circuits at 220, 110 and 35 kV including switching, instructing loading order for power plants less than 500 kW capacities and for managing local heat supply distribution. The electricity dispatch centers (3-5 per region) are responsible for managing 110 and 35 kV distribution circuits and are responsible for controlling 10, 6 and 0.4 kV distribution networks.

2.3 Installed Capacity

Electricity generation facilities in Belarus include very old units. The oldest of them had been built in 1927. If this equipment is operated in accordance with the existing rules of operation, 2005 will retire about 60% of it. Most of the electric power units either have exhausted their operating life (300,000 hours operating life for a turbine) or will reach it by 2005. Changes in the installed capacity of the Belarus electricity generating system including retired are shown in Figure 1. Here the forecast of peak demand is from the World Bank Report. The retirement schedule assumes that units are taken out of operation 300 000 hours after their startup.

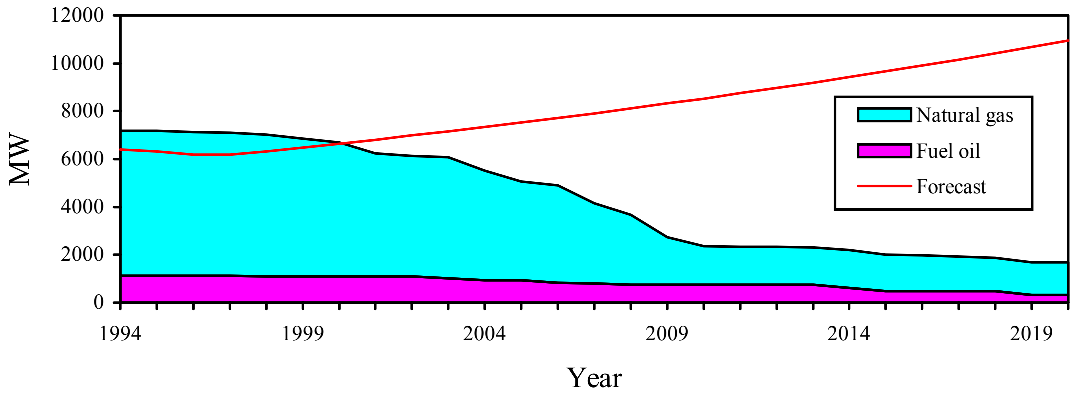

Figure 1 Evaluation of the Installed Capacity by Fuel Type

The primary fuel for electric power stations in Belarus is gas and fuel oil. For the last two years the share of natural gas has increased from 40% to 60%. Fuel oil needed for electric power generation has been produced at Belarus oil refineries, with additional supplies from Russia. Last time oil supplies were cut, the country was forced to buy fuel oil as well as natural gas from abroad, in order to run the power plants.

For the majority of units in the Belarus energy system, natural gas or fuel oil can be used as fuel. With the exception of Lukomol Power Plant, where pure condensed turbines were installed, all the plants of the Belarus energy system can generate electric energy and heat. Co-generation units include steam bleeding and back pressure turbine.

Since the construction of Minsk nuclear power plant (NPP) was stopped in 1986, the Government of Belarus approved the construction of the Minsk-5 Plant on the site chosen for the NPP. The first unit of 330 MW of the Minsk-5 had been put into operation in 1999. In 1996-1997 the decision about construction of a combined cycle unit with the capacity of 62 MW had been approved. GEC ALSTHON had won an international tender on the right to realize this project in Orsha PP. The project had been completed in 1999 and now Belarus electricity generation system includes combine cycle units.

Presently the main problem of the Belarus electricity generating system is to determine an optimum plan for the system's expansion because a number of units are to be retired in the near term. A principal question is whether the old units should be reconstructed with their operating life prolonged, or if new units should be put into operation. And if new units are put into operation, then what power technologies are preferable for the conditions of the structure of electric energy consumption in Belarus. One of the possible ways for solving this problem can be the construction of a NPP with low fuel cost for supplying base load energy, and combined cycle plants which could be used for peak loads.

2.4 Annual Load Description

Electricity consumption increased in Belarus during the late 1970's and 1980's (5.3-6.0% per year). After 1991 consumption dropped from 49.2 TWh in 1991 to 39.4 TWh in 1993 and to 32 TWh in 1995. Two peaks characterize the hourly load curve. Figure 2-2 and Figure 2-3 summarize typical hourly loads for a working day and Sunday for winter, spring, summer and fall. The morning peak is at 10 am and the afternoon peak is at 6 p.m. Both peaks are close to each other, the morning peak is slightly higher.

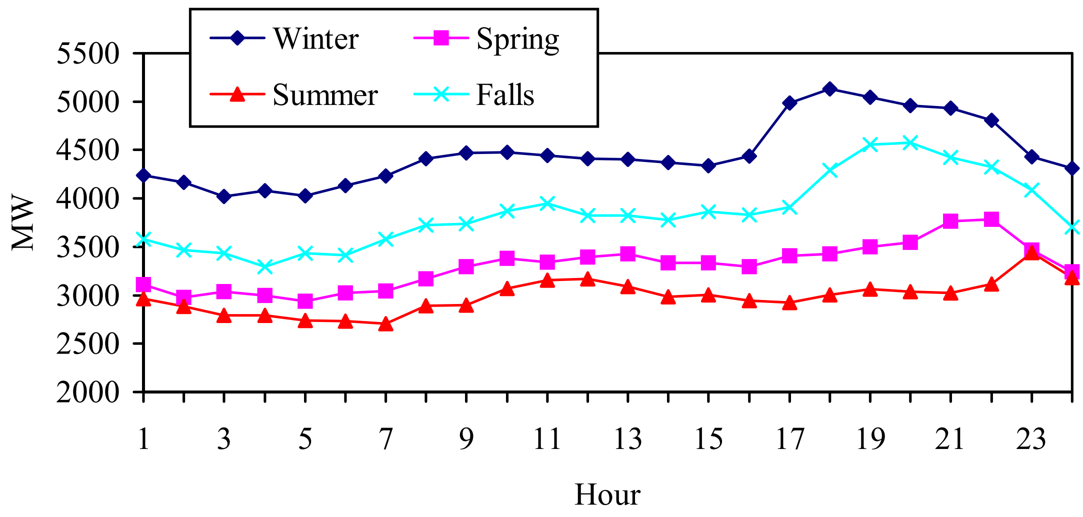

Figure 2 Typical Hourly Load Data for Sunday, MW (1998)

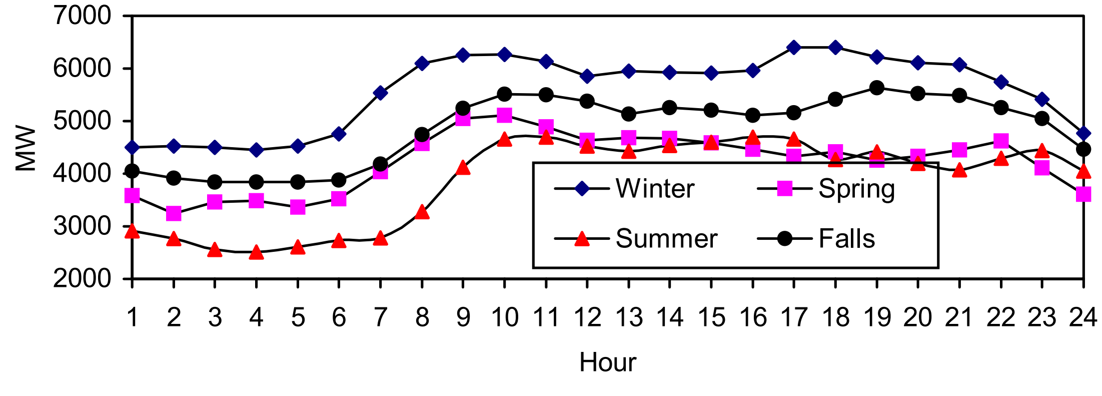

Figure 3 Typical Hourly Load Data for Working Day, MW (1998)

3 SCENARIOS FOR ELECTRICITY SYSTEM EXPANSION

To select the least cost scenario for electricity generation system expansion improved computer code WASP-IV for Windows had been used. As so far WASP-IV code do not allow finding out optimal solution for electricity generation system with high share of co-generation directly the methodology of application of this program for this case had been developed. Methodology is based on utilization of code WASP-IV for simulation condensing turbines and module BALANCE for modeling co-generation part of the system. The scenarios for the electricity system expansion plan included only conventional technologies. Presently, the works connected with the preparations for NPP construction in the Republic including site survey for NPP are being carried out. The first stage of siting process according to the IAEA classification has been completed. It was based on a set of criteria answered to A Safety Guide of the IAEA "Site Survey for Nuclear Power Plants" and requirements to be accepted in Russia for NPP placement sites. The result of the preliminary studies had shown that there are at least three suitable sites for construction of the NPP. It allows including nuclear power option in the list of possible technologies for electricity generation.

Optimal expansion plan of the electricity generation system based on installation of new combined cycle units, co-generation units and nuclear power plants has been developed. The optimal least cost expansion plan has been chosen as a result of comparative analysis of the three scenarios.

Characteristic	Scenario 1	Scenario 2	Scenario 3
Technology	Steam turbine, Combined cycle, Gas turbine, Co-generation turbine	Steam turbine, Combined cycle, Gas turbine, Co-generation turbine	Steam turbine, Combined cycle, Gas turbine, Co-generation turbine
Fuel type	Natural gas	Natural gas, Coal	Natural gas, Nuclear

Using WASP IV and BALANCE computer codes optimal electricity generation system expansion plan for each scenario had been determined. Calculations had been carried out for discount rate equal to 8%.

The results of calculation show that electricity system expansion plan based on utilization of coal as a fuel has the highest generation cost. Implementation on nuclear power will allow decreasing generation cost up to 3.26 cents/kWh. In accordance with calculation the optimal solution includes construction of four nuclear units and first unit has to start up in 2014 year. The scenario based on natural gas and nuclear fuel mix is expected to have the lowest total electricity generation cost and is economically the most attractive option.

Technical and economical parameters of the power generation candidates used for the WASP analyses are summarized in Table 2 and Table 3, respectively. These parameters are typical for technologies that are expected to be available during the planning period.

Table 2 Technical Parameters of the Candidate Units [3]

Unit Type	Capacity single unit	Fuel type	Heat rate, kcal/kWh		FOR	Sched. Maint.	O&M Costs	
	MW		base	INCR	%	days	Fixed $/kWm	variable $/MWh
Gas turbine	120	Gas	4518.77	1936.62	10.7	22	0.233	1.68
Combine cycle	150	Gas	2154.04	1566.84	7.3	53	0.514	3.7
Combine cycle	320	Gas	2048.23	1515.50	10.1	64	0.442	3.18
Combine cycle	450	Gas	2145.74	1560.79	8.8	71	0.494	3.56
Steam turbine	250	Gas	2642.10	1782.32	7.8	66	0.667	4.8
Co-generation	250	Gas	2450.61	1653.12	8.3	69	0.567	4.08
Coal fired PP	500	Coal	2277.19	1567.48	8.5	73	0.609	4.39
Nuclear PP	640	Nuclear	2570.00	2570.00	11	50	5.000	1

Table 3 Economical parameters of the candidates for expansion of the Belarus electricity system, [4]-[6]

Unit Type	Capital cost Inclusive IDC (Depreciable part)		IDC	Construction time	Plant Life
	Domestic	Foreign	%	Years	Year
Gas turbine	24.2	656	8.08	2	20
Combine cycle	100.5	724.7	10.02	2.5	25
Combine cycle	142.2	639.1	11.92	3	25
Combine cycle	86.9	652.2	11.92	3	25
Steam turbine	252	1140	11.92	3	25
Co-generation	215.6	966.7	13.79	3.5	25
Coal fired PP	282	1552	15.63	4	25
Nuclear PP	0	1880	29.22	8	30

4 FUEL PRICE FORECAST

The Government in the Republic of Belarus regulates prices for energy resources to a considerable extent. With the aim of social protection of the population prices for natural gas, electric energy and heat are increased for industry and reduced for the population.

A considerable growth of natural gas cost within 1998 - 2010 is connected, first of all, with the forecast of its lower production. The reason of this is, first of all, the exhaustion of the deposits and the necessity to master the new and almost inaccessible ones. It is also necessary to take into account of the possibility to introduce a tax for incineration of organic fuels aimed at diminishing the danger of global warming. For Belarus the forecast of prices for natural gas supplied from Russia, which up to the present moment and probably in the nearest future, is the main and even the only supplier of natural gas to Belarus is of the more important significance. Fuel prices for analysis are summarized the Table 4.

Table 4 Fuel Price forecast, $/Gcal, [7]-[11]

Year	Coal	Fuel oil	Nuclear	Natural gas
1998	11.6	8.8	2.33	10.6
2000	12.3	9.6	2.33	11.7
2005	13.3	10.7	2.38	13.8
2010	14.4	11.9	2.44	15.3
2015	15.6	13.3	2.51	16.8
2020	16.8	14.8	2.57	19.1

Using WASP IV and BALANCE computer codes optimal electricity generation system expansion plan for each scenario had been found. Calculations had been carried out for discount rate equaled 8%. Expected electricity generation cost for scenarios is shown below.

Scenario 1 3.60 cents/kWh

Scenario 2 3.62 cents/kWh

Scenario 3 3.26 cents/kWh

The results of calculation are shown that electricity system expansion plan based on utilization of coal as a fuel has the highest generation cost. Implementation on nuclear power will allow decreasing generation cost up to 3.26 cents/kWh. Optimal solution includes construction of four nuclear units.The first unit has to start up in 2010 year.

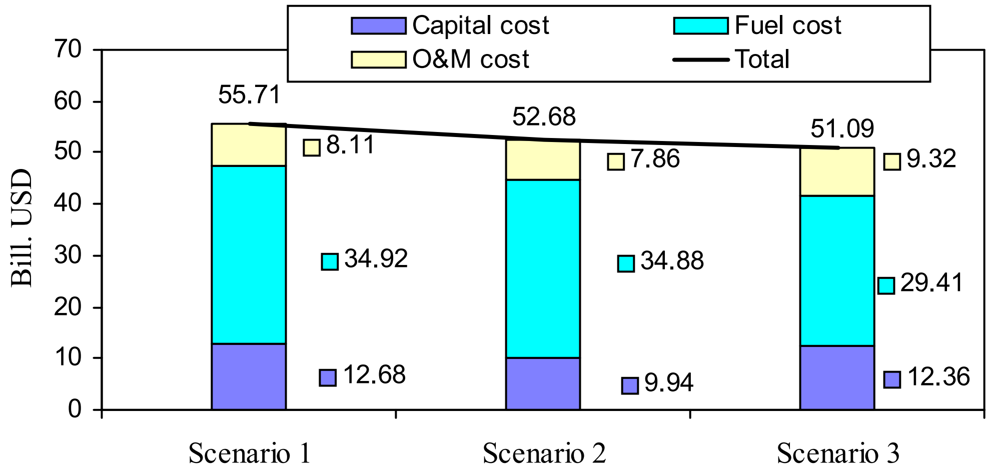

Figure 4 Total Cost of Electricity Generation during 25 Years

The comparative analysis of the different scenarios is presented on Figure 4. For Scenario 3 based on natural gas and nuclear fuel mix is expected to give the lowest total electricity generation cost and is economically the most attractive option. Realization of the Scenario 3 first of all allows decrease of the annual natural gas purchase and saves up to 259×10^6 dollars per year.

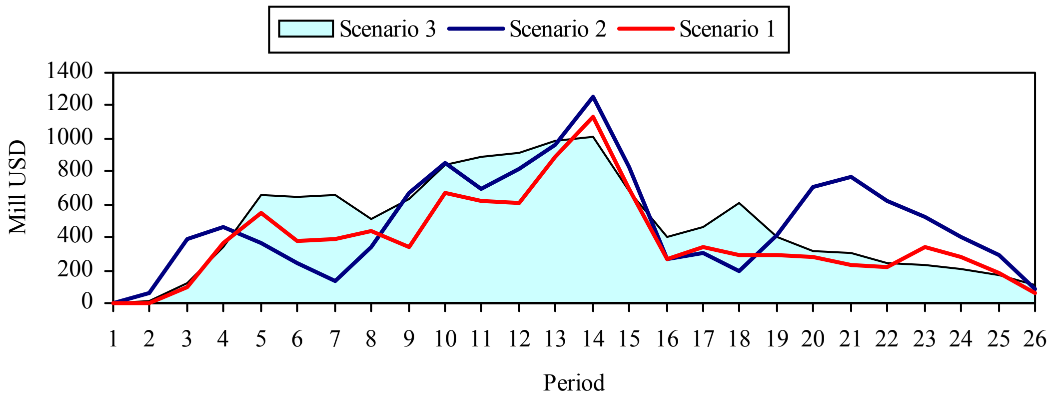

Figure 5 Capital Cash Flow for Different Scenarios

Capital cash flow for different scenarios is shown on Figure 5. For all scenarios annual capital cost is not very different. It means that irrespective of scenario to be chosen money requirement for electricity system expansion is approximately the same. Thus, there is no reason to turn down nuclear option on the bases of high cost of the nuclear power plant construction.

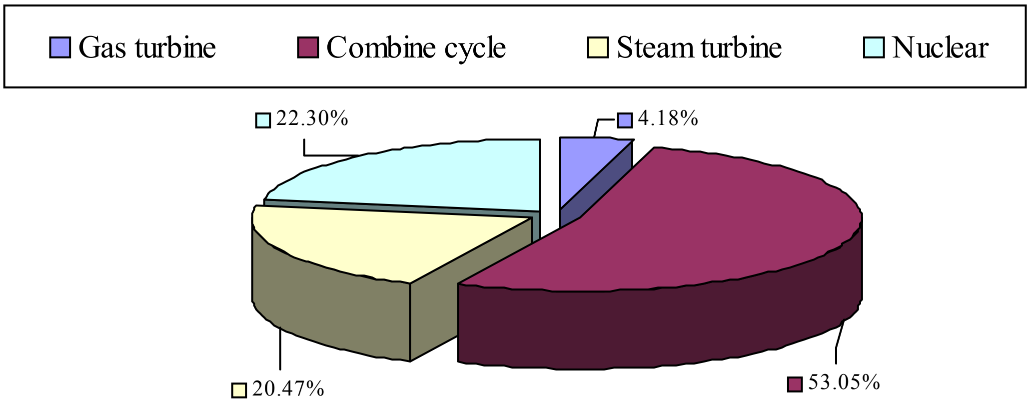

Figure 6 Optimal structure of the Belarus electricity generation system by technologies type

Optimal structure of the electricity generation system depends on the historical hourly load and available fuel resources. The morning peak is at 10 am and the afternoon peak is at 6 p.m. Both peaks are close to each other, the morning peak is slightly higher. To cover peak load demand only 15-20% of the installed capacities use to be needed. Most of the units in Belarus electricity generation system works in a base load regime. Therefore, the optimal structure of the technologies for electricity generation includes units, which traditionally are considered as a most attractive for covering base load.

In accordance with results of the WASP runs only 4 - 5% of the total capacity can be covered by gas turbines. Optimal structure of the Belarus electricity generation system is shown on Figure 6. Optimal share of nuclear energy doesn't exceed 23% and approximately equals the share of steam turbines. As it is presented on Figure 5-3 combine cycle technology can provide about 55% of the required capacity.

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