APPLICATION OF THE COMBINED CYCLE LWR-GAS TURBINE TO PWR FOR NPP LIFE EXTENSION, SAFETY UPGRADE AND IMPROVING ECONOMY

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ABSTRACT

The unconventional technology to extend the lifetime for the NPPs now in operation and make a construction of new NPPs cheaper — erection of steam-gas toppings to the nuclear power units — is considered in the paper. Application of the steam-gas toppings permits through reducing power of aging reactors to extend lifetime of nuclear power unit, enhance its safety and at the same time to keep full load operation of NPP turbine and other balance-of-plant equipment. Proposed technology is examined for Russian VVER-440 reactor as an example and, also, as a pilot project, for Russian boiling VK-50 reactor now in operation. Heat flow sheets of the power plants, their parameters and economic problems are discussed.

1 INTRODUCTION

The NPP lifetime exhaustion and world-wide financial crisis decreasing the capabilities of capital investments to nuclear power, demand the search for unconventional technologies with the purpose to extend the lifetime of the NPPs now in operation and to make the construction of new NPPs cheaper. In this connection the experience of combined cycle nuclear-gas power plants (CCNGP) may turn out to be useful for solving the NPP problems.

As well as for traditional power engineering two lines of using steam-gas combined cycle are considered:

- at new CCNGP;
- at NPPs now in operation.

A development of the pilot project appears to be reasonable for the demonstration of NSGP capabilities.

The CCNGP problems were previously considered by (Tsiklauri 1996, Kuznetsov 1998, Florido 1998).

Two lines in CCNGP development are examined in the paper:

- making steam-gas toppings to the NPP now in operation with Russian designed VVER-440 reactors;
- working out of CCNGP pilot project on the basis of Russian VK-50 reactor now in operation.

2 STEAM-GAS TOPPING TO OPERATING NPP WITH VVER-440 TYPE REACTORS

2.1 Conceptual statements

At present more than twenty nuclear power units with VVER-440 reactors are operated in Russia, Bulgaria, Slovakia, Czechia, Hungary, Finland. Certain of these units are nearing the end of their service life, their parameters do not comply in some respect with up-to-date requirements for safety ensuring. The analysis carried out by a number of organizations shows

that reactor running at a reduced power level is quite a realizable and effective (including economic aspects) method to extend power unit lifetime (by 10 and more years) with more reliable provision of its safety.

It is suggested to use new technology namely steam-gas topping to the NPPs now in operation aimed to nuclear power unit life extension. Reactor thermal power is reduced to extend plant lifetime and enhance safety while maintaining the electric capacity of NPP turbine. In so doing total power and efficiency of combined cycle with the NPP increase considerably. NPP turbines can be used after the reactor decommissioning.

Reduction in the reactor power, undoubtfully, facilitates the extenuation of lifetime of nuclear power unit that is operating in "sparing" mode. Particularly, the lifetime of reactor vessel is extended due to reducing the rate of fluence build-up.

As the reactor power reduces, the probability for a design-basis accident to develop to a beyond design-basis one reduces because residual heat in the reactor and heat stored in fuel and primary coolant decrease also.

2.2 Schematic diagram and main performance

Schematic diagram of the NPP with steam-gas topping conformably to VVER-440 reactor is presented in Fig. 1.

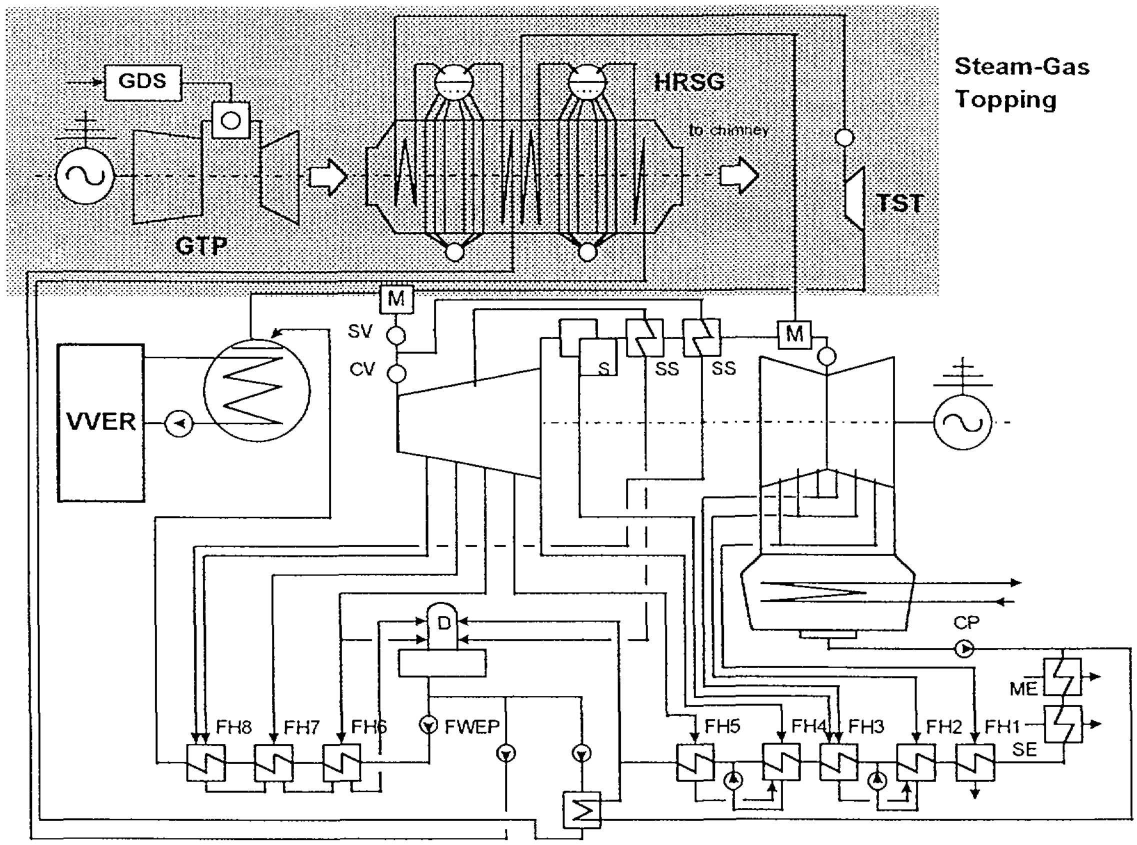

Fig. 1. Heat Flow Sheet of VVER-440 Unit with Steam-Gas Topping:

GTP - gas-turbine plant; GDS - gas-distributing station; SV - stop valve; CV - control valve; S - separator; SS1, SS2 - steam superheaters; FH1, FH1, ... FH8 - feedwater heaters; FWEP - feed water electric pump; D - deaerator; CP - condensate pump; ME - main ejector; SE - sealing ejector; TST - topping steam turbine; HRSG - heat recovery steam generator; M - mixer.

Superheated steam of high and low pressure is generated in two separate circuits of the heat recovery steam generator (HRSG) at the expense of exhaust gases from gas turbine plant (GTP). High pressure steam is directed to topping counter pressure turbine of high pressure which can work on the same shaft as the GTP or with a separate electric generator. Principal limitation - minimum upgrading of the NPP main turbine - should be met. The steam from the topping steam turbine is fed to a mixer (heat exchanger of mixing type), where it is mixed with saturated steam from the NPP steam generator and directed to the NPP turbine inlet. Using heat exchangers of mixing type is a basic distinction from other technologies. Application of diverse heat flow sheets is possible; the CCNGP at supercritical parameters appears to have considerable promise, in so doing the CCNGP efficiency reaches 48 % and more.

Low pressure steam from the HRSG is fed to the inlet of low pressure cylinder of the NPP steam turbine.

The turbine manufactured both in Russia and by foreign firms such as ABB, Siemens, GE with the power of 100 ... 200 MW may be used as gas-turbine plants.

Preliminary estimates have indicated that the placement of steam-gas topping beyond the NPP at a distance of 1 km solves practically the problem of safety ensuring while fuel gas being supplied to the NPP; in so doing, pressure and temperature losses in connecting pipelines are 0.3 MPa and 10 °C, respectively, and the efficiency decreases by 0.04 % (abs.). A cost of the pipelines is about 1 % of the GTP cost.

2.3 Technical-and-economic indices

The option of reactor running is considered for which the full load of the NPP turbine is maintained at the expense of steam-gas topping under decreased reactor power. The Russian gas turbines GTG-110 and GTE-170P and also the turbine GT24 of ABB company are used in the steam-gas topping.

The calculations had shown that in the case of reducing reactor power, for example, by 50 % (presumably, this will allow to extend the unit lifetime by 10 ... 15 years), combined power unit with the steam-gas topping for VVER-440 power unit can have the parameters presented in the table.

CCNGP Main Characteristics

Name	NPP with VVER-440	CCNGP with VVER-440		
		4×GTE-170P	4×GT24	2×GTG-110*
Reactor thermal power, MW	1324	662	662	662
Electrical power of the power unit (net), MW	414	1275	1160	507
Electrical power of the steam-gas topping, MW	—	861	756	229
Efficiency (net), %	30.115	48.3	49.3	37.9

* – the option with partial load of NPP turbines

Availability of proposed technology of the CCNGP extends the capabilities for owners of aging NPPs; for example, they will have the chances:

- either to shut the NPP down and start the works on power unit decommissioning;
- or to extend the NPP lifetime through the construction of steam-gas topping and the decrease in reactor power while maintaining NPP turbine power. In so doing, the lump-sum capital investments in the steam-gas topping amount to US $ 40...60 million per one module (gas turbine - heat recovery steam generator) depending on an installed capacity; construction duration is no more 1 year.

In the case of the difficulties with investments in the construction of steam-gas toppings an option of the CCNGP construction by stages may be realized.

Initially, 1...2 modules of the steam-gas topping are mounted with simultaneous decrease in reactor power and certain underload of NPP turbine. Total power of the unit remains the same practically (column 5 of the table). Further, as the term of unit decommissioning draws on, the construction of additional steam-gas modules is made possible so, that by the time of reactor decommissioning the turbine of nuclear power unit would be loaded fully and later could operate coupled with gas-turbine plants similarly to a conventional combined cycle gas turbine plant (CCGT).

Net present value for the project of the CCNGP with full load of NPP turbine (column 3 of the table) within the service life of 30 years including the period of using the nuclear turbine coupled with the steam-gas topping after the reactor decommissioning, is positive and amounts to US $ 700 million approximately, while in alternative option (immediate start of reactor decommissioning) this parameter is negative and constitutes minus US $ 150...300 million.

Feasibility study has shown the capital investments into conventional CCGT constructions are approximately two-folded as compared with those into CCNGP with VVER-440 reactor of the same capacity and with the same gas turbine equipment. It is related with the necessity to erect the proper turbine hall for CCGT and the appropriate infrastructure.

3 PILOT PROJECT ON THE BASIS OF VK-50 REACTOR

It is suggested to apply the CCNGP technology to Russian boiling water reactor VK-50 with nominal power of 50 MW now in operation near Dimitrovgrad as a pilot project to demonstrate this technology. Technical state of the power unit equipment permits to use the available reserves for the steam turbine and thereby increase the benefit of the project.

When choosing a heat flow sheet of the VK-50 reactor plant with the GTP the following initial conditions have been adopted:

- AK-70-13 steam turbine is used without any changes in its scheme and structure;
- steam temperature at the turbine inlet does not exceed 260 °C with steam pressure ahead of the turbine of 2.0...2.1 MPa;
- gas temperature at the gas turbine inlet, outlet and at the HRSG outlet are taken equal to 1120, 535 and 90 °C, respectively;
- steam flowrate and the temperature of steam superheated in the HRSG are set equal 75 t/h and 450 °C, respectively.

Schematic diagram of the VK-50 reactor plant with the GTP and the HRSG is presented in Fig.2.

Main steam flow is fed to the turbine from the reactor. After steam drying in the low-pressure steam separators, its parameters are as follows: pressure — 2.1 MPa, temperature - about 214 °C, steam flowrate — 260 t/h.

The steam superheated up to 450 °C (pressure 3.0 MPa) at a rate of 75 t/h is generated in the HRSG at the expense of the heat of GTP exhaust gases. This steam is mixed with the steam from the reactor in the heat exchanger of mixing type. Steam temperature at the turbine inlet increases up to 258.3°C.

The estimates performed indicate that the connection of the HRSG and the gas-turbine plant with electric power about 50 MW to the operating VK-50 reactor plant permits to increase the NPP efficiency from 23 to 36.5...37 % and provide the additional generation of electric power at the reactor plant turbogenerator equivalent to the increase in its power by 23 MW including by 8.6...8.8 MW at the expense of steam superheating.

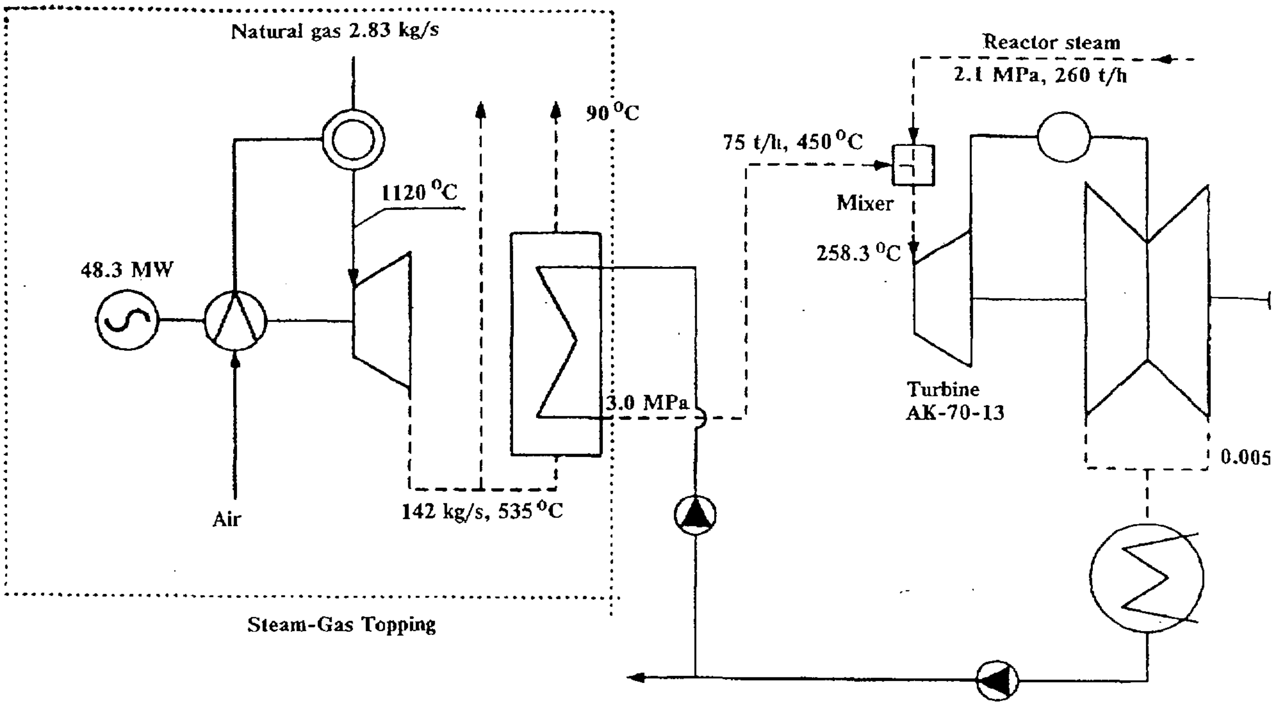

Fig.2. Schematic Diagram of VK-50 Reactor Plant with Steam-Gas Topping

In total the additional electric power of the power unit with the steam-gas topping will make up 71 MW (including the power of the gas-turbine plant — 48 MW). Additional annual output of electric power will constitute 0.5 billion kW·hours.

The capital investments in the steam-gas topping (including the GTP, HRSG, building and other) will constitute US $ 18...20 million.

Net present value over service life of the pilot project will be about US $ 60 million.

4 CONCLUSIONS

Application of the steam-gas topping permits:

- extend the service life of aging VVER-440 reactor by 10...15 years;
- use the turbine and other NPP balance-of-plant equipment at full power;
- increase the efficiency of combined cycle up to 48 % and more;
- enhance the safety of NPP operation;
- utilize NPP balance-of-plant equipment after reactor decommissioning;
- perform the cost-effective operation in maneuvering modes;
- increase capacity factor of the plant.

The construction of pilot project on the basis of the VK-50 reactor will allow not only to demonstrate new technology but also to attain appreciable economic effect including that obtained due to using the available reserves of the NPP turbine.

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