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HYBRID COMBINED CYCLE POWER PLANT

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ABSTRACT

In case of re-powering the existing pressurised water nuclear power plants by the proposed HCCPP solution, we can increase the electricity output and efficiency significantly.

If we convert a traditional nuclear power plant unit to a HCCPP solution, we can achieve a 3.2-5.5 times increase in electricity output and the achievable gross efficiency falls between 46.8-52% and above, depending on the applied solution.

These figures emphasise that we should rethink our power plant technologies and we have to explore a great variety of HCCPP solutions. This may give a new direction in the development of nuclear reactors and power plants as well.

1 INTRODUCTION

Considerable development has been achieved in gas turbine and combined cycle technology. Nuclear power plant technology is, however, developing modestly on its independent way in a hostile environment, in which there are a lot of public opponents of nuclear power plants.

There is a limited number of studies presented in literature about the combination of conventional combined cycle technology with nuclear power plant technology.

The aim of this article is to explore the variances of reasonable solutions and systems that integrate the conventional combined cycle and the nuclear power plant into a common cycle in the light of relevance and feasibility.

Beyond the limited number of studies published in technical literature there is a new solution proposed as well. The essence of the proposed new solution is that saturated steam generated in the steam generator of the secondary cycle is superheated and, in case of necessity, reheated in the heat recovery, which utilises the thermal energy of the exhaust flue gas of the gas turbine. Supplementary firing can be applied if steam reheating is required. The proposed name of the system is Hybrid Combined Cycle Power Plant (HCCPP) [1]. (Patent claim Reference No. is P0200252.)

2 HYBRID COMBINED CYCLE POWER PLANT

The efficiency of traditional pressurised water nuclear power plant cycles is low due to the relatively low pressure of saturated steam in the secondary cycle and to the steam temperature because it is saturated steam.

Combined cycle technology has achieved remarkable development due to the developed combustion technologies and high efficiency. Combined cycles represent advanced technology nowadays.

If we replace the economiser and the drum in a conventional single-pressure combined cycle with the steam generator of a traditional pressurised water nuclear power plant, we can create the basis of the hybrid combined cycle power plant. In such a system saturated steam is produced by the steam generator, which is heated by the primary cycle. **Figure 1** shows a simplified scheme of the Hybrid Combined Cycle Power Plant.

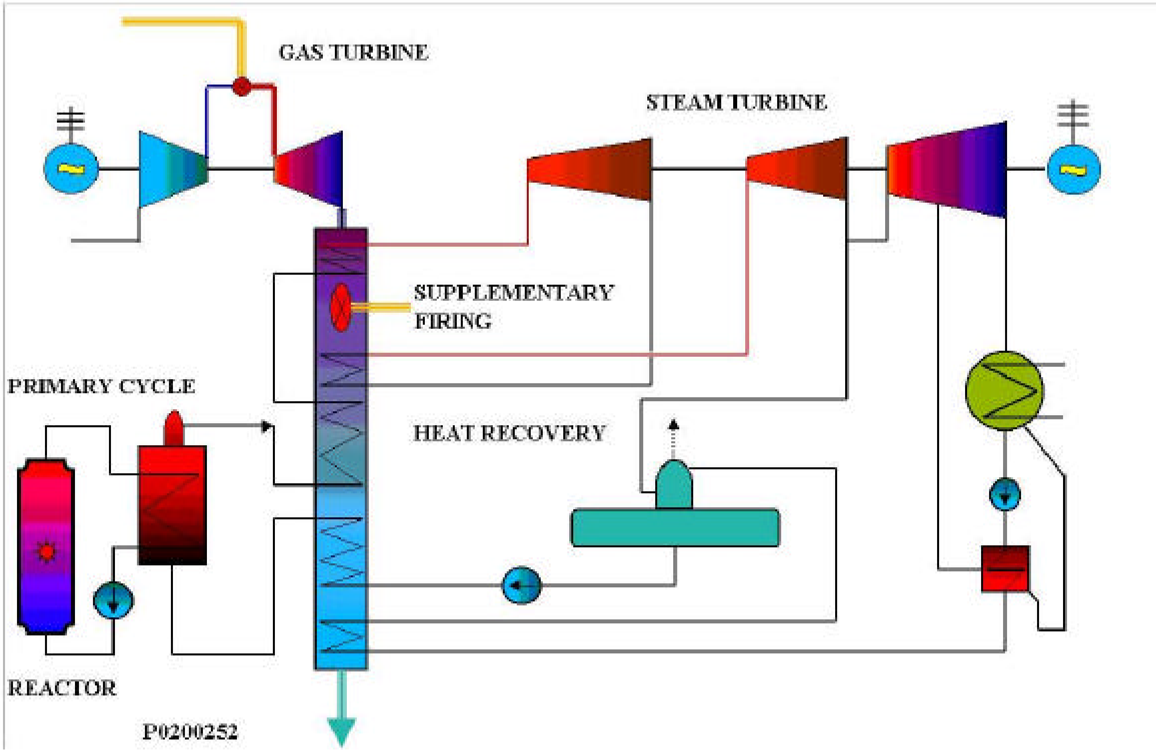

Figure 1: Hybrid Combined Cycle Power Plant

The primary cycle is generally a closed cycle that consists of a nuclear reactor, circulating pumps and heat exchanger surfaces implemented in steam generators. Water circulated in the primary cycle heats up and evaporates the water of the secondary cycle. Saturated steam generated in the steam generator is fed into the superheaters installed in the heat recovery. There saturated steam is superheated in one or more stages. The heat recovery utilises the heat energy of exhaust gas from the gas turbine. Superheated steam is fed into a multi-casing steam turbine. At the appropriate pressure steam can be reheated in the heat recovery. A supplementary firing facility can be implemented in the heat recovery as well, to increase the temperature of the flue gas at the inlet of the steam reheater. Then steam passes through the intermediate- and low-pressure steam turbine casings and condenses in the condenser. Condensate is pumped through a steam-heated heat exchanger and the last stage of the flue gas heat exchanger installed in the heat recovery into the feed water tank. The feed water tank can be heated with extracted steam taken from the steam turbine. Feed water is heated up in the feed water heater located in the heat recovery. The whole combined cycle is controlled in such a way that the appropriate temperature of feed water is ensured at the inlet of the saturated steam generator. Thus we can control the inlet water temperature of the reactor. Flue gas exits to the atmosphere through a stack.

The attributes of HCCPP are as follows:

- Saturated steam is superheated and reheated in the heat recovery. At an appropriate superheating temperature no steam reheating is required.
- There is no evaporation in the heat recovery. Consequently, the average temperature of heat transfer increases.
- Due to the implementation of the gas turbine and heat recovery, the steam flow does not change. Therefore, the heat energy of flue gas is utilised without additional condensing loss.
- The reactor's heat energy determines the output of the gas and steam turbines. We can control the system with sliding parameters.
- No change is required in the primary cycle of the nuclear power plant.
- Due to the increased live steam temperature a new steam turbine shall be implemented.
- The temperature of reheated steam is controlled with supplementary firing.
- The electric power and the cycle efficiency increase significantly.
- Emission decreases as a result.

2.1 Promising Advantages of HCCPP

With the purpose of demonstrating the effectiveness of HCCPP we did some calculations for a VVER 440 nuclear power plant and a European Pressurised Water Reactor. The live steam pressure was not changed in either case.

Table 1 shows the performance data of a VVER 440 nuclear power plant unit converted to HCCPP.

Table 1: Performance data of a VVER 440 converted to HCCPP

Live steam		
Pressure	bar	47
Temperature	ºC	517
Mass flow	kg/s	740
Reheated steam		
Pressure	bar	12
Temperature	ºC	517
Mass flow	kg/s	740
Reactor power	MWth	1375
Gross output	Mwe	1560
Gas Turbine	Mwe	580
Steam Turbine	Mwe	980
Efficiency	%	46.8

We can achieve higher power output and gross efficiency by a minor modification of the cycle and by using advanced gas turbines. The main guideline is to keep the primary cycle untouched. At the life extension and capacity improvement of nuclear power plants a minor increase of working pressure is often considered as a means of increasing the efficiency of the unit besides many other technical tools. In case of converting a pressurised water nuclear unit into HCCPP, the steam turbine shall be replaced because of high steam temperature and increased steam flow in the low-pressure turbine section. During the development of HCCPP a lot of variations have been analysed. In **Table 2** there are some examples to demonstrate the effectiveness of a HCCPP unit.

Table 2: Examples of performance data for a VVER 440 converted to HCCPP

Reactor power	**Gas turbine output**	**Steam turbine output**	**Gross efficiency**	**Gross fossil efficiency**
MWth	Mwe	Mwe	%	%
1375	580	980	46.8	57.2
1375	940	1090	50.8	60.8
1375	840	945	50.1	61.4

Table 2 shows gross fossil efficiency, which is calculated as excess electricity output divided by fuel gas power.

Table 2 demonstrates that the performance of a VVER 440 pressurised water nuclear power plant unit can be significantly increased if we convert it into HCCPP.

A VVER 440 pressurised water nuclear power plant unit traditionally has two steam turbines. **Figure 2** shows the simplified scheme of such a HCCPP unit.

A similar calculation has been done for the performance data of a European pressurised water reactor. The main data of the European reactor are summarised in **Table 3**. [2]

Table 3: Main data of a European pressurised water reactor

Reactor power	MWth	4250
Gross output (approx.)	MWe	1600
Operating pressure	bar	155
RPV inlet/outlet temperature	°C	291.5/326.5
Gross efficiency (approx./calculated)	%	37.6

Table 4 shows the performance data of a HCCPP unit after the conversion of the European pressurised water reactor.

Table 4: Main data of HCCPP in the case of a European pressurised water reactor

Gross output	MWe	7260
Steam turbine output	MWe	3860
Gas turbine output	MWe	3400
Gross efficiency	%	52
Gross fossil efficiency	%	60

The given figures prove that we have the opportunity to improve the performance of the existing nuclear power plants and to develop new generations of HCCPP units.

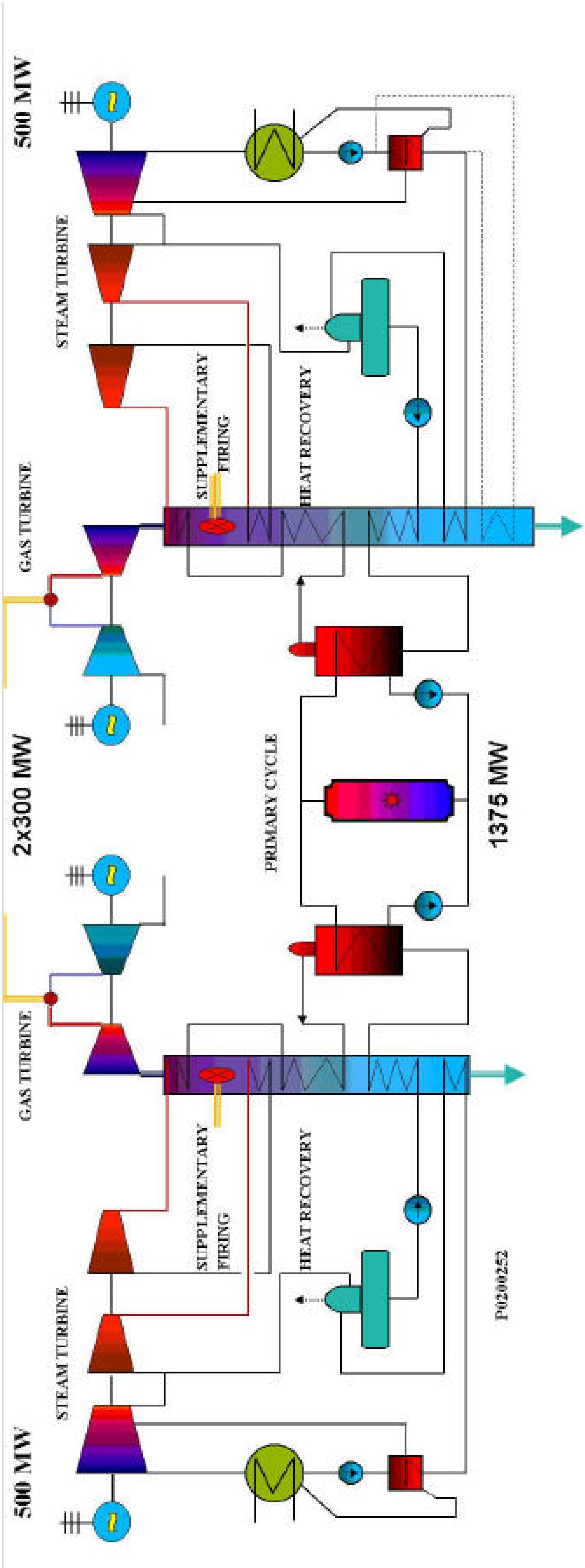

Figure 2: Simplified scheme of a VVER 440 converted to HCCPP

2.2 A Modified Version of HCCPP

Supplementary firing may not be advantageous at a relatively low saturated steam pressure. In such a case it is better to apply simple superheating of saturated steam in the heat recovery.

The efficiency of HCCPP can be increased if we replace the extraction steam of make-up water tank heating with water extracted from the steam generator.

Both of the solutions are shown in **Figure 3**.

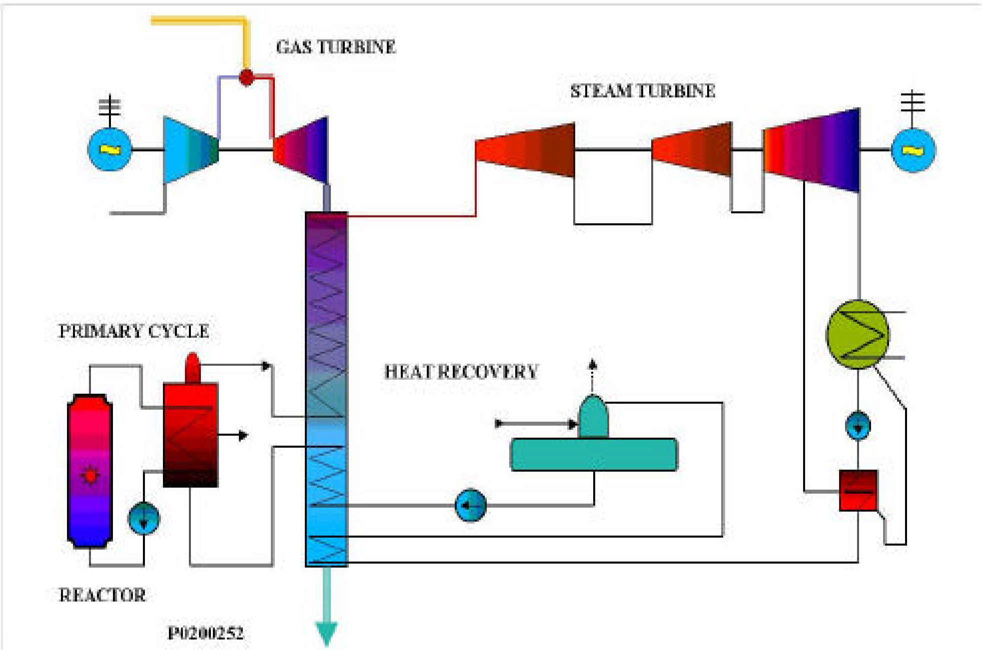

Figure 3: HCCPP without reheating, and deaerator is heated with water from the steam generator

2.3 Other Reasonable Solutions

While the name of Hybrid Combined Cycle Power Plant was designed for the solutions shown in Figure 1, under the name HCCPP we can collect all kinds of solutions that endeavour to increase the power output and efficiency of a pressurised water nuclear power plant unit by implementing a gas turbine and heat recovery.

Figure 4 and Figure 5 [3] show solutions where steam is produced in the traditional pressurised nuclear power plant unit as well as in the heat recovery steam generator of the single- or double-pressure combined cycle. The produced different kinds of steam are fed into the appropriate stages of the steam turbine or steam turbines depending on the pressures and temperatures.

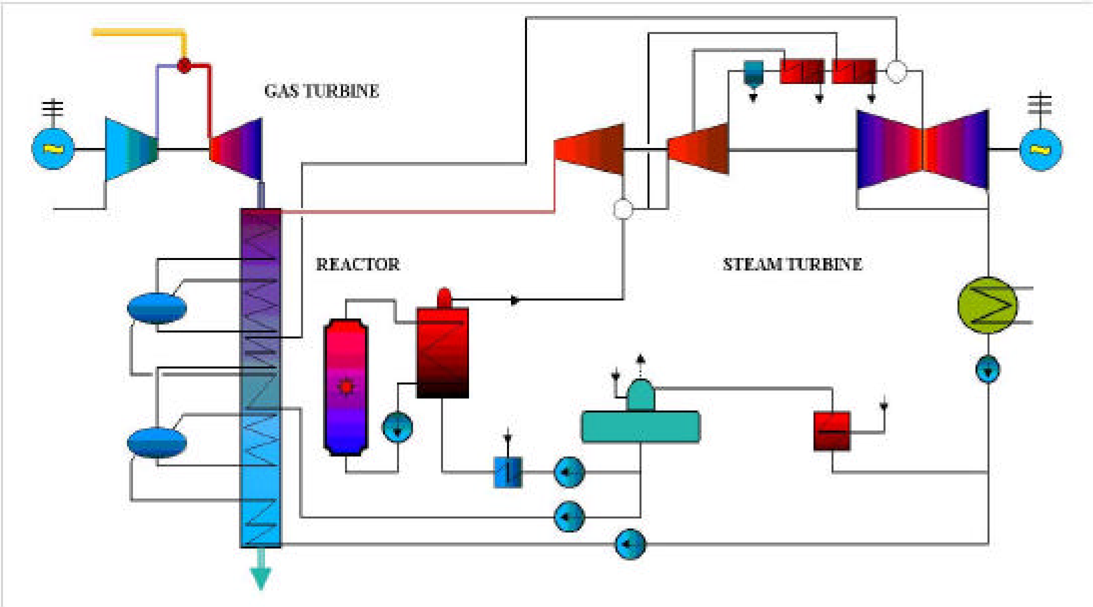

Figure 4: HCCPP with double pressure heat recovery steam generator

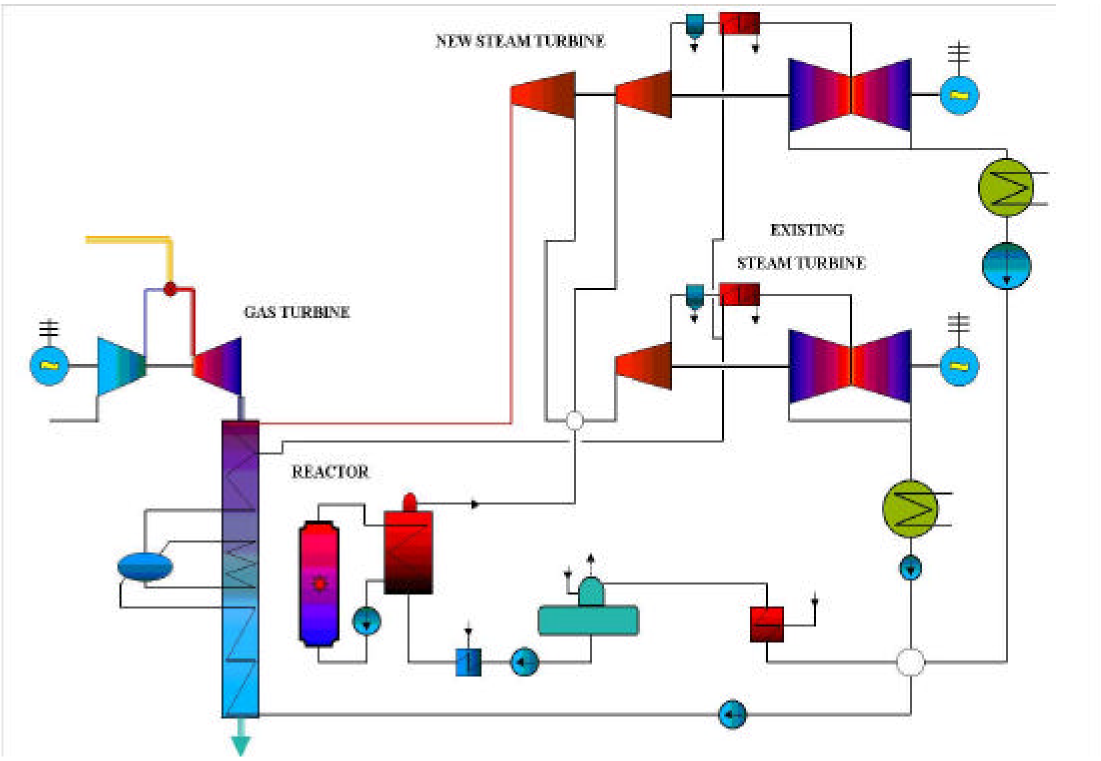

Figure 5: HCCPP with the combination of new and existing steam turbines

3 CONCLUSIONS, QUESTIONS AND RECOMMENDATIONS

The results of the calculations and the demonstrated simplified cycles clearly prove that HCCPP gives promising alternative solutions in nuclear power plant development. HCCPP opens a new direction of power plant development as well.

We, engineers, have not explored the opportunities involved in HCCPP yet.

At the same time HCCPP generates a lot of questions, which shall be analysed and answered. These include, without being limited to, the following:

- Safety
- Operation
- Load change
- New generation of reactors
- Most advantageous cycles
- Most advantageous size of HCCPP
- Most advantageous size of pressurised water nuclear reactor
- Most advantageous prevalence of HCCPP in Europe
- Most advantageous network connections between the European countries
- Continuous fuel supply
- Interdependence between countries
- Environmental effects
- etc.

The numerous questions must not discourage us from HCCPP solutions.

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