

Energy Saving in Nuclear Power Plant

By

NCE Sustainable Engineering Technology Groups

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Abstract

“Energy saving” is one of the most challenging issue we are now facing, in order to prevent carbon emissions and global warming. Indeed, Energy demand is growing worldwide. This huge demand of energy has a strong negative impact on the environment, the challenge of energy saving is thus not only to reduce our energetic consumption for financial reasons, but as well to save natural resources which are limited.

We believe nuclear energy systems are one of the solutions that will enable us to achieve this goal. Nuclear plants are plants that convert energy from Nuclear fission in something we use, either heat or electricity. For this sytem as for any system, there are two possible ways to save energy.

For a nuclear system, energy input is fuel and some energy to create a fission, energy output is mostly as an electricity. Regarding this system, two ways to save energy are:

- to improve the system efficiency, it is to improve the energy output, with the same input
- to cogenerate energy, as a part of the energy will always be wasted during the process, we can use this wasted energy for other purposes

In our works, we will focus especially on those two aspects. First, s how to improve energy efficiency in a Nuclear plant by applying improvement of the Auxiliary Condenser System. Second, how to recover the heat surplus and use it for district heating and hydrogen production. Comparation of the energy saving achieved with the CO₂ consumption assuming that the saved energy should be generated by any power generation that produce CO₂ is given in the report. With this comparison we can conclude that nuclear power plant is a power full tools to supply the energy and also an eeffective object to make an energy saving to support the sustainable development of the world.

Keywords : energy saving, nuclear power plant, sustainable technlogy, accw, district heating, hydrogen production.

A. Introduction

“Energy saving” is one of the most challenging issue we are now facing, in order to prevent carbon emissions and global warming. Indeed, Energy demand is growing worldwide. This huge demand of energy has a strong negative impact on the environment, the challenge of energy saving is thus not only to reduce our energetic consumption for financial reasons, but as well to save natural resources which are limited. Environmental issues is getting more attention nowadays, people are becoming aware of the critical situation with the way they treat the environment.

Nuclear power plant is one of greatest supplier of the world energy demand. It supply almost 15% of the world energy demand. As of February 2010, there are 436 nuclear power plant units

installed in 30 countries with electric net capacity of about 370 GW, another additional 52 GW is on the way where 56 plants are under construction in 15 countries¹.

Nuclear power plant also known as an environmental friendly energy source. This energy source not releasing any greenhouse gases, avoiding the environmental problems caused by fossil fuel like global warming and acid rain².

In this report, role of nuclear power plant in the view of energy saving is explored. Particularly, measures to achieved energy saving based on the existing nuclear power plant is goal of this work. The measures are divide into two catagories, one is to improving the efficiency of the nuclear over plant, and the other is to re-utilized the waste heat from the existing nuclear power plant. Considering the already large fleet of existing nuclear power plant, this measure, even in a small saving, could make a significant role in energy saving and contribute to the sustainable development of the world.

B. Brief Introduction on Existing NPP

Most of the type of nuclear power plant world wide is light water reactor, or more detailed a pressurized water reactor (PWR). General system of the PWR type shown in figure.1³.

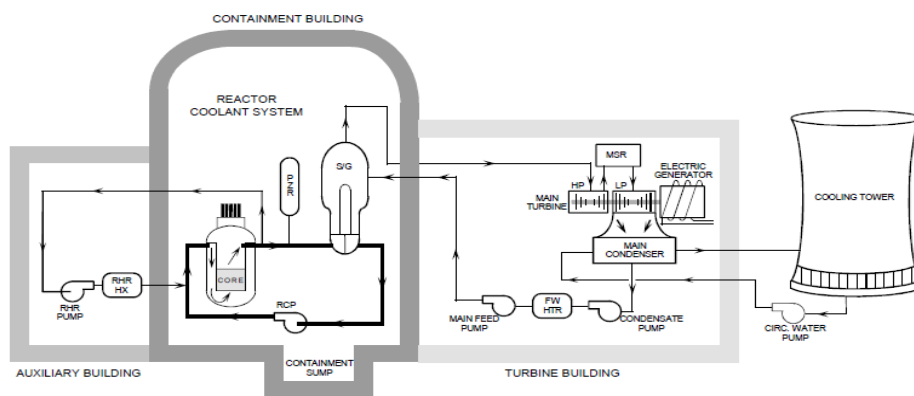


Figure.1 PWR Systems

In this system, energy is generated in the reactor core by nuclear fission. The light water, H_2O , (to make it different with heavy water, D_2O) is passed on the core to take the energy. Pressurizer is installed to avoid the boiling phase of the water. The energy then transfer to the second loop through the Steam Generator. The steam then drive the turbine, which finally make the electric generator producing electricity. The used steam then goes to the condenser system to become a liquid phase and continue the cycle.

There are three cycle in the PWR system. First cycle, also called primary cycle where the light water flow between the core reactor, steam generator, and pumped back to the core. Second cycle, also called secondary cycle where the water flow between the steam generator, the turbine system, condenser system, and pumped back to the steam generator. Third cycle, where the water taken from outer sources, like sea or big river, flow between the condenser system and cooling tower, and pumped back to the condenser system.

The turbine system comprise of main turbine and auxiliary turbine, in which both related to the main and auxiliary condenser, respectively. Thermal efficiency of the turbine effected by the vaccum condition of the related condenser.

C. Proposed Energy Saving Measures

By understanding the above system of the PWR we might realizes that many thing can be optimized to obtain the energy saving, also to combine another system to take advantage from the wasted wasted. The energy saving measure propose based on the existing nuclear power plant are as follow

1. Efficiency Improvement

There are many option to improve the energy efficiency of the PWR type nuclear power plant. We can improve the way the nuclear fuel burn to have more energy with the same fuel, or we can improve the heat transfer in the steam generation, turbine, and also on the auxiliary system. For this time, we analysed the later option to optimized the energy production by improving the auxiliary condenser system.

First measure is to reduce circulating-water flow to auxiliary condenser, this will increase the circulating water flow to the main condenser and improve its vacuum. Finally it will improve the turbine electricity output. This measure is illustrated in figure.2.

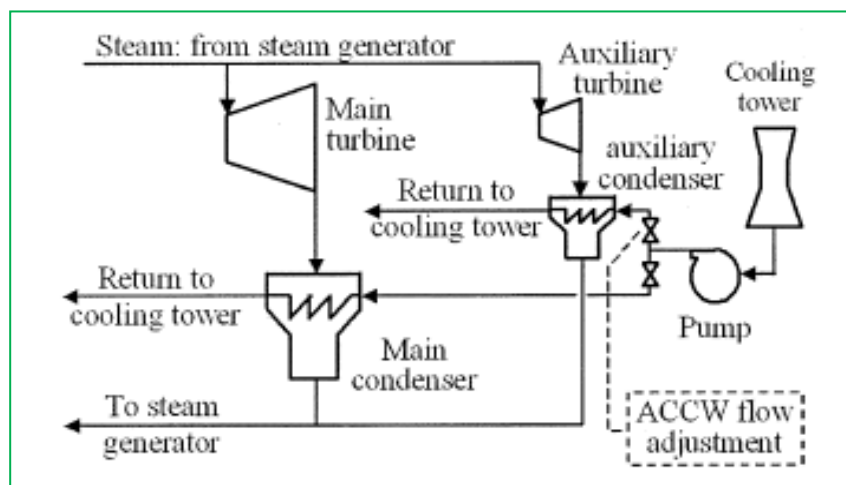


Figure.2 ACCW Flow Reduction

Using the Integrated Optimization Procedure (IOP)⁴, the above measure can achieve net electricity increase of 838, 227, and 0 kW at circulating water temperature of 30°C, 22.4°C, and 15.6°C, respectively.

Second measure is to redirect the circulating water discharge to the main condenser instead of to the cooling tower. Basically the circulating water temperature increase in the auxiliary condensers is no more that 50% of that in the main condenser under all conditions. This means that the circulating water discharge from the auxiliary condensers can still be used in the main condenser, and hopefully can improve the thermal gain of the system. This measure is illustrated in figure.3

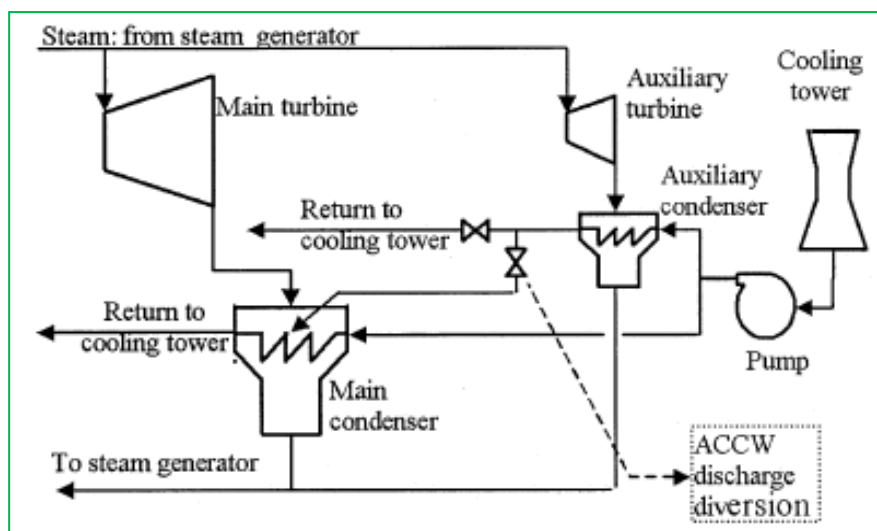


Figure3. ACCW discharge division.

Using the Integrated Optimization Procedure (IOP)⁴, the above measure can achieve net electricity increase of 1138, 770 and 263 kW at circulating water temperature of 30°C, 22.4°C, and 15.6°C, respectively, with full ACCW discharge diversion.

2. Reutilization of waste energy

Another strategy to have an energy saving from nuclear power plant is to use the waste heat or generally heat provided by the system for another application. This side application will replace another energy source without building a new energy sources or power plant.

a. District heating.

The efficiency of a power station, that converts the energy of a fuel to electricity, is quite low, about 40%⁵. This means that more than the half of the energy (heat) available from fluid is in fact released to the environment, as low temperature heat, for instance through a cooling tower or releasing heat to seawater, without actually being converted into electricity.

District heating can be, under certain conditions, convenient, as well as it allows to recover “waste heat”^{6,7}. Low pressure steam that is close to the end of its expansion inside of a turbine, can be used to produce hot water: this can be pumped through some pipelines and then finally satisfy the heating energy demands of a city that is close to the power station. It is required that the city has a high density population, but also that the winter season is quite long and cold. Just in this way the investment is fully justified. The distance between the power station and the city is usually of several kilometers, but actually it is possible to provide some re-pumping stations and hot water storage, according to the network extension and the pressure drop.

To produce hot water at a temperature suitable for district heating, it is possible to bleed a certain amount of steam from the turbine. As well as the steam mass flow in the turbine is decreased, the overall electricity production will decrease, but the condensation heat that is possible to recover from steam is enough for district heating purposes. Steam bled from turbine (about 150 °C), after having passed through a suitable heat exchanger, can heat up a flow of pressurized water from 70 °C to 120°C, this is the most common practice^{5,8}.

If we want to evaluate the potential of this kind of heat recovery, we should first evaluate the energy demand of a “standard” apartment or house; usually the discussion is also

extended to other kind of buildings, depending on existing one and future development of the area ⁹.

To make an example, it is possible to make a rough evaluation on a 50 m² dwelling, located in a plain at 45° degrees of latitude (such an European big city), considering the following assumptions:

- ✓ Overall heat transfer coefficient through opaque structures: 0.8 W/m²K;
- ✓ Overall heat transfer coefficient through transparent structures: 2.4 W/m²K;
- ✓ Height from floor to ceiling: 3 m;
- ✓ Air change rate: 0.5 vol/h.
- ✓ Minimum winter temperature: -5 °C;
- ✓ Annual hours of heating: 2160 h.

The energy demand for heating this standard apartment is calculated⁵ about 4,700 kWh. This means that is about 100 kWh/ m² per year. At present, many efforts, including new materials and technology, allow for new building construction to achieve an energy demand of less than 50 kWh/ m² per year ⁹. Time needed for renewal of buildings is quite long, but still necessary to reduce the whole energy demand.

Considering a 1,000 MWe power station, it is possible to bleed about 170 MWt of hot steam from the turbine, with almost a negligible loss of power at the turbine (in this case about 4% less electricity).

These numbers derive from the mass flow and the enthalpy of steam that are generally used for this kind of application⁵.

	Temperature [°C]	Pressure [bar]	Enthalpy [kJ/kg]	Mass flow [kg/s]
Turbine inlet	280	60	2,805	4,900
Bleeding	150	2.5	2,720	80
Turbine outlet	40	0.08	2,580	4,900/4,820
Electricity power output (no bleeding)	1,010 MWe			
Electricity power output (with bleeding)	960 MWe (-4%)			
Heat power output	170 MWt			

Accordingly with the energy need of one apartment, it is easy to calculate that the heat output of 170 kWt, multiplied per the 2160 hours of heating, that is about 380,000 kWh is enough to satisfy the requirements of 78,000 apartments. Obviously, the evaluation should be performed backward, in order to size the appropriate amount of steam to be bled from the turbine.

Considering that now the outputs of the power station are two (electricity and heat), it is easy to calculate the overall efficiency, defined as the ratio between energy outputs and energy inlet from fuel. The overall efficiency changes from 40% (as assumed for the power station) to 45%. In other words we can say that is possible to save fuel and then natural resources.

District heating is also more “energy efficient” than a common heat pump air conditioner, which is probably one of the most efficient heating systems. Using recovered

heat in fact, we can save all of the electricity needed to make the heat pump working. In this case, the estimated annual saving is about 1,350 kWh per apartment (considering a COP=3.5, that is 1kWh of electricity can produce 3.5 kWh of heat ⁸), that is about 110,000 MWh (referred just for winter season). This is 4% of the electricity produced by the power station (during the considered winter season), in the optimistic hypothesis that everyone is using an efficient heat pump instead of a gas boiler or furnace. The benefits have then a large improvement horizon, considering that hot water can be used to produce or sanitary water, instead of burning gas. The saved amount of electricity and gas can then be used for other purposes.

Finally, considering that electricity is generated from many kind of power station, we should consider that some of them emit carbon dioxide, while some others don't. This is the case of nuclear power stations, that, if compared with renewable energy fueled power stations (like hydro-power, wind, or sun) have a larger power output, exactly the same as a oil or gas fired plant, about 1,000 MW. Considering the mix of power stations, their efficiency and the fuel they use, it is possible to evaluate the specific ratio between emitted CO₂ kg for 1 kWh of electricity, depending on the mix of the power stations and their conversion efficiency. We assume that this coefficient is equal to 0.5 ^{5,8}, but depends on the Country we are investigating. Obviously, the more power station that use no-carbon emission fuels, like nuclear power plants, the smaller will be the coefficient.

The expected avoided emissions are then 670 kg of CO₂ per apartment, which means about 50,000 tons for a city with the previous heating energy demand.

b. Hydrogen production

Reutilization of heat energy can also be done by coupling an electrolysis plant with nuclear reactor (PWR) to produce Hydrogen. Hydrogen efficiency production is valued using high temperature electrolysis. Electrolysis for hydrogen production can be performed with significantly higher thermal efficiencies by operating in the steam phase than in the water phase. A research from AREVA ¹⁰, shown that the coupling of HTE plant with a PWR is possible in the auto-thermal mode which means that In this mode the energy input to the electrolyser exceeds the energy necessary to split the water molecule at the selected operating temperature. Thus, the gas outlet temperatures are higher than the steam inlet temperature. The electric power supplied to the electrolyser provides the excess energy released by Joule effect. Illustration of the measure shown in figure.4.

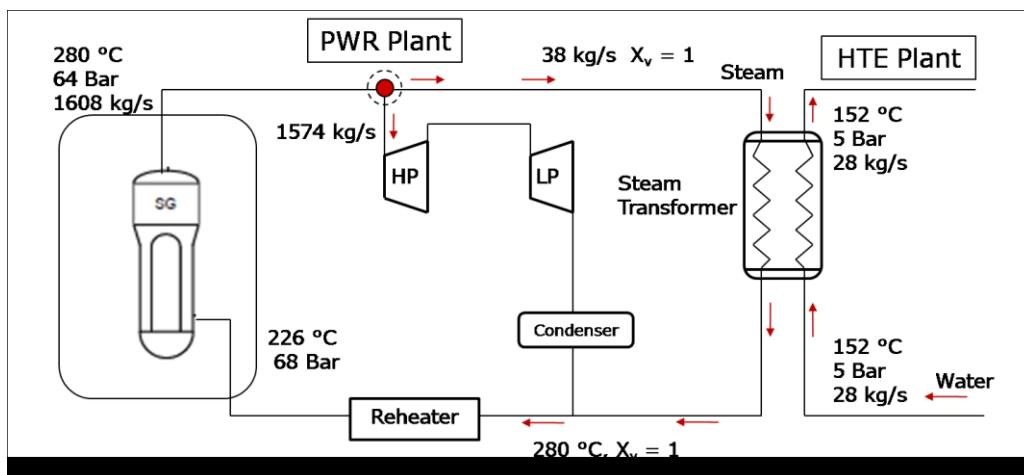


Figure.4 Hydrogen Production on PWR System.

Heat extracted in the form of steam from the main steam header of PWR (64 Bar, 280 °C). The steam condenses in the primary side of steam transformer at the same temperature. In the secondary side steam transformer operates as steam generator (Water is evaporated). In the secondary side of steam transformer water is evaporated in the same temperature (152 °C) then this evaporated water is fed into the electrolyser to endure electrolysis process.

By the application of this technology the specific electricity consumption of HTE coupled with PWR is 3.2 kWh/Nm³ H₂ which is less than the specific electricity consumption of conventional electrolysis¹¹, Alkaline Water Electrolysis (AWE) that is 4.7 kWh/Nm³ H₂. Also, we can save the electricity consumption around 1.5 kWh/Nm³H₂ with Global efficiency 41.60%.

D. Discussion

Nuclear power plant utilization to feed the world hunger of energy still warn by the waste nuclear fuel handling. Today's, many recycling procedures are investigated and some are already proved and applied to reutilize the nuclear waste and prevent it used for unpeace intention. Basic strategy to handle the uncycled part of the nuclear fuel is by using underground repository. Although this waste nuclear fuel is excluded from our works.

Our not only show the role of nuclear power plant in supplying the energy. Additional energy achieved by certain measure on the existing nuclear power plant might prevent another energy source utilization. Considering that most energy production is from fossil fuel, this means that the additional energy gain from the above measures can avoid additional greenhouse effect gas. In this view we can compare that the energy saving per hour of production for each measure :

- Efficiency improvement
 - ACCW flow reduction
Additional production of 839 kWh ~ save 419.5 kg CO₂
 - ACCW discharge diversion
Additional production 1,138 kWh ~ save 569 Kg CO₂
- Reutilization of waste heat :
 - District heating
Save production of 48 MWh ~ save 24,000 kg CO₂
 - H₂ production
Save production of 17.721 MWh ~ save 8,860 kg CO₂

E. Conclusion

Energy saving measures on the existing NPP could be effective and make a significant role in supporting the sustainable development. These measures, as of today, are still not implemented in most of the existing plants.

F. References

- 1 <http://www.euronuclear.org/info/npp-ww.html>
- 2 <http://alternate-energy-source.com/advantages-of-nuclear-energy.html>
- 3 USNRC, Reactor Concepts Manual : PWR System
- 4 Huang Z, Edwards RM, Power Generation Efficiency Improvement Through Auxiliary System Modifications, IEEE Transaction on Energy Conservation Vol.18, No.4, December 2003.

- 5 Corso di energetica applicata – Prof. Alberto Mirandola – Mechanical engineering Department (University of Padua)
- 6 Nuclear district heating plants AST-500. Present status and prospects for future in Russia Samoilov O. B. ⁽¹⁾; Kurachenkov A. V. ⁽¹⁾ ; ⁽¹⁾ OKMB Mechanical Engineering, 603 074 N., Novgorod, Federation de Russie
- 7 Nuclear District Heating: The Swiss Experience Sugiyama Kenichiro (Hokkaido Univ.) Shimazu Yoichiro (Hokkaido Univ.) Kumaki Atsushi (Mitsubishi Heavy Ind., Ltd., JPN) Ishitani Noboru (Hokkaidoenajitoku21) Journal of the Atomic Energy Society of Japan Vol.48; no.2; page.119-124 (2006)
- 8 Manuale del Termotecnico - Rossi Nicola - fondamentali - riscaldamento - condizionamento – refrigerazione - HOEPLI (Handbook for evaluation and calculation of heat energy demand of buildings, containing data of construction
- 9 Materials from Edilportale, Italian website on building construction and real estate www.edilportale.com
- 10 Py, J.P., and Capitaine, A., *hydrogen production by high temperature electrolysis of water vapour and nuclear reactors*, Available on www.cder.dz/A2H2/WHEC2006/S05.pdf, Accessed February 23, 2010
- 11 Parson Inc., 2000, *Fuel Cell Handbook*, Fifth Edition, U.S. Department of Energy, Morgantown, West Virginia