Concept of Organic Rankine Cycle in Nuclear Power Plant as an Alternative Generator

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1. Introduction

To keep a nuclear power plants safe, a variety of safe-related systems are applied to a nuclear power plant. Among these systems, the shutdown cooling system is one of essential systems to prevent core damage from the residual heat and the decay heat after reactor shutdown. Normally, after reactor shutdown, electronic pumps circulate water to remove the residual heat and the decay heat. However, in case electrical power for the electric pumps is unavailable, the temperature of the core will go up high and, lastly, the core would be damaged severely. So the Emergency Diesel Generator (EDG) is installed for the Station Blackout (SBO). Nonetheless, the EDG may not be guaranteed absolutely. Also, even if, there are several systems to back up the EDG, they have some their own weaknesses.

To deal with this problem, the Organic Rankine Cycle (ORC) will be discussed in this paper.

2. Previous studies

Except for nuclear field, lots of studies was performed in a variety of fields to improve the efficiency of energy use, to reduce CO^2 emission, to work the systems that have low-grade heat sources, etc. [1,2]. Let's see what the ORC is and then what kinds of studies on the ORC were performed in this section.

2.1 ORC

The ORC enables the systems that have low-grade heat sources to change its heat sources to electric power. In fossil power plants and nuclear power plants, steam is generally used to rotate steam turbine. Steam is generated at more than 100 C^o at atmospheric pressure. In contrast, the ORC uses organic fluids of which boiling point is around 30 C^o at atmospheric pressure. So the turbine of the ORC could produce electricity at lower temperature than the steam turbine. In industrial uses, the temperature range of the ORC varies 60 ~ 200 C^o [3-6]. Figure 1 presents the general schematic diagram of the ORC.

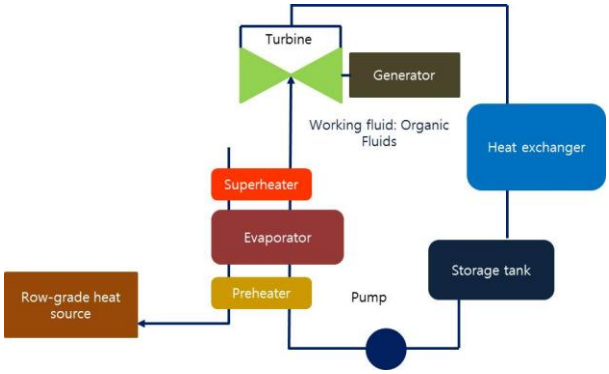

Fig. 1. Schematic diagram of the ORC

2.2 Previous studies

Many researchers have evaluated the ORC with a wide range of electric capacity, organic fluids, turbines and components. According to electric capacity, the kinds of organic fluids and the type of turbines each ORC systems shows different efficiency [1-6]. Among the organic fluids, seeing the properties of R123, R123 presents good cycle efficiency in the ORC, but it is toxic. Therefore, R245fa is considered as a desirable working fluid for the cycle though R245fa have somewhat lower performance in the ORC than R123 [7].

3. Concept of the System

Nuclear power plants in operation are designed to start up the EDG automatically in a few seconds when a nuclear power plant is in the SBO. However, there is always a possibility of EDG failure, so another system, such as a mobile diesel generator and a battery, are adopted in nuclear power plants to back up the EDG. But these systems still has some problems.

The EDG could produce electricity in a few seconds, but it has limited working time due to its fuel storage. The mobile diesel generator rather takes a long time to replace the function of the EDG and has limited working time like the EDG. In case of the battery, it has very short working time compared to the mobile diesel generator in volume.

If we adopt the ORC system as an alternative generator in addition to the EDG, the mobile diesel generator and the battery, advantages are as follows.

1) It has unlimited working time.

2) It is a semi-passive system.
3) It could be available in a few seconds.
4) It fulfills its duties independently.
5) It strengthens the level of defense-in-depth.

Figure 2 shows how the ORC is applied to a nuclear power plant as an alternative generator. The residual heat and the decay heat is used as a heat source of the ORC when the plant is in the SBO. Steam of the steam generator goes through the hot side of the ORC while energy is being transferred from steam to the ORC and then steam is exhausted to the condenser. The heat exchanger of the cold side could be connected to the condenser or the cooling water pool. The generator of the ORC supplies electricity to nuclear power plants. Interesting thing in this combined system, the electric output is very dependent on the temperature of steam in the steam generator. If the core is cooled enough, the electric output is relatively low because the temperature of the steam generator is low. On the other hand, the electric output is high when the core isn't well cooled.

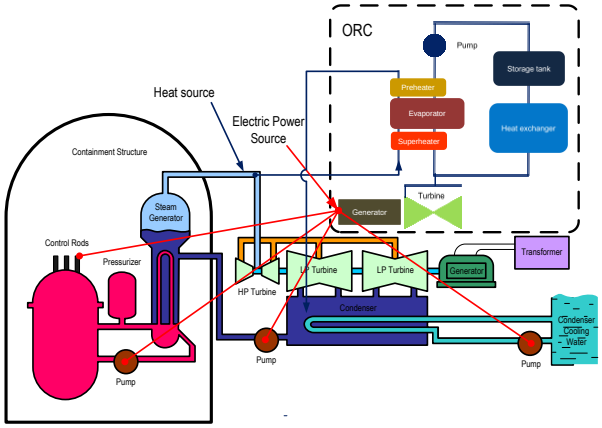

Fig. 2. Concept of the ORC in a nuclear power plant as an alternative generator

3. Conclusions

In industry, the ORC is widely used in a variety of systems to produce electricity from low-grade heat. Many ORC components are already developed and optimized in the cycle. However, adopting the cycle in nuclear power plants as an alternative generator should be examined. To realize this combined system, first of all, feasibility study should be performed and then conceptual design will be followed.

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