SFR Control Logic and Performance Evaluation for a Large Load Rejection Event

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1. Introduction

If the function of a turbine or one feed water pump is lost during the power operation of the nuclear power plant, the reactor power needs to be rapidly reduced by Reactor Power Cutback System (RPCS) to prevent the reactor trip. The Steam Bypass Control System (SBCS) performs the role of transporting the generated surplus steam to the condenser through the steam bypass line during the large load transient. At this time, the reactor power is to cutback the core power by the RPCS, and maintain the reactor power between 20% and 75% with the Reactor Regulating System (RRS). Typically, steam bypass systems are designed to handle 55% steam capacity. In light water reactors, if the reactor is shut down in an emergency, it cannot be restarted immediately due to xenon poisoning. Due to this, the plant availability can be reduced, therefore, the RPCS and SBCS is applied to improve the availability. Although there is no such xenon poisoning in the Sodium-cooled Fast Reactor (SFR), it takes a lot of time to shutdown and restart operation to reduce thermal shock after an emergency shutdown of the reactor, and the plant availability can also be decreased. Therefore, the RPCS and SBCS of the SFR can improve both structural reliability and availability by solving the failure without emergency shutdown of the reactor.

In this study, the control logic for load runback operation is set for Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR), and the plant operation performance is evaluated in case of sudden transient such as full load rejection event.

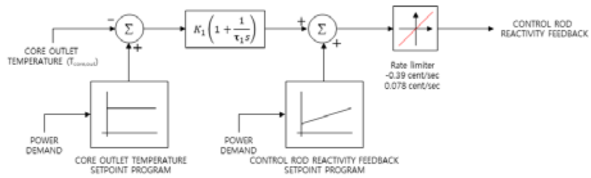
2. Methods and Results

2.1 Control Logic for Reactor Power Cutback System

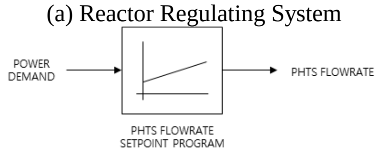
In the case of Clinch River Breeder Reactor (CRBR) [1], the capacity of the steam bypass system is designed to handle 80% capacity. In the event of a turbine trip, the turbine bypass valve is fully opened within 3 seconds, allowing 80% capacity heat to be removed from the steam generator. CRBR reduces the power at a rate of 3%/min by the general reactor control system, not the RPCS. The reactor power is reduced to 90% after 200 seconds, and then equilibrated with the heat removal of the steam bypass system at the new operating condition.

In the event of a sudden transient such as a turbine/generator trip of Prototype Fast Breeder Reactor (PFBR), a SFR under construction in India, the scenario of the event is as follows. When the steam pressure rises at the turbine or generator trips and rises above the set pressure, the turbine bypass valve is opened to bypass steam flow. If the pressure continues to rise and becomes above the set pressure, the atmospheric release valve is opened. The atmospheric release valve generates a reactor cutback signal and the control rod starts to be inserted, reducing the reactor power. When the outlet temperature of the sodium side of the steam generator decreases due to the decrease in the reactor power, the water flow rate is reduced by the steam generator sodium outlet temperature controller. If the steam pressure is restored to the set value, the atmospheric release valve is closed, and the power between the reactor and the BOP becomes to balanced states.

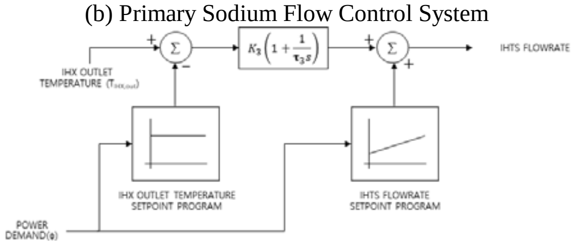
When a large load transient such as a turbine trip occurs, the light water reactor opens the turbine bypass valve from SBCS and sends a Reactor Power Cutback (RPC) signal for RPCS. On the other hand, in the case of PFBR, there is a difference in that the RPC signal is generated by the opening of the atmospheric release valve, not the SBCS. The capacity of the light water reactor's steam bypass system is 55% of rated power, which is allocated 40% to the condenser exhaust and 15% to the atmospheric dump. On the other hand, the PFBR is designed to handle 100% steam of rated power, which allocated 60% capacity to the steam bypass system and 40% to the atmospheric release valve. Therefore, PFBR secured the capacity to respond to 100% power from the BOP side in case of a large load transient. The difference in such design may be resulted from the steam generator type. In the case of a light water reactor, a large volume of the evaporation part of steam generator can absorb the pressure transient to some extent by using a drum-type steam generator, whereas in the case of a once-through steam generator such as PFBR, the pressure transient is much larger than drum-type steam generator during sudden transients such as turbine trip. Therefore, in the case of using the once-through steam generator, it is judged that a larger capacity of steam bypass and dump capacity is secured compared to the drum-type steam generator in order to cope with large pressure transients.



(a) Reactor Regulating System



(b) Primary Sodium Flow Control System



(c) Intermediate Sodium Flow Control System

Fig. 1. Control logics of power operation mode for PGSFR.

The logic for RPCS of PGSFR is set to use the RRS. If reactor power cutback signal is generated from SBCS, the setpoint of reactor power is set to 55% and the reactor power is reduced as quickly as possible by RRS. At the same time, the primary system flow rate is reduced to a flow rate corresponding to the core power, and the intermediate system flow rate is controlled to maintain the cold pool temperature at a set point. The control logic of PGSFR in reactor power cutback operation is shown in Figure 1. Since PGSFR is a pool type, the heat capacity of the hot/cold pool is very large, therefore, the power that can be absorbed by the system is also very large compared to the light water reactor. Therefore, even if the control rod subgroup is not dropped as in the case of light water reactors, it is expected that the large load transient can be accommodated by the reactor regulating system and the SBCS.

2.2 Control Logic for Steam Bypass Control System

In the case of PGSFR, there are differences in the type and design of steam generator of the light water reactor, however, the function of quick open mode of the SBCS serves the same function of preventing the reactor trip in case of sudden transients such as large load rejection and removing excess energy generated from the reactor. Figure 2 shows the control logic of the quick open mode of the SBCS of PGSFR. The bias signal of the reactor power and the steam flow rate passes through the high-pass filter to derive the degree of sudden change as an output signal. If this output signal exceeds the setpoint of the quick opening of the

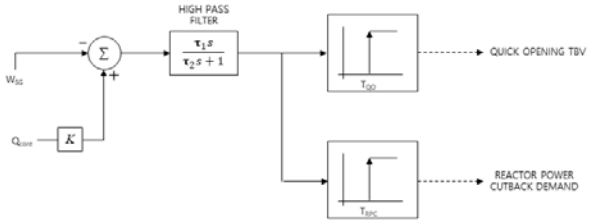


Fig. 2. Control logic of steam bypass control system for PGSFR.

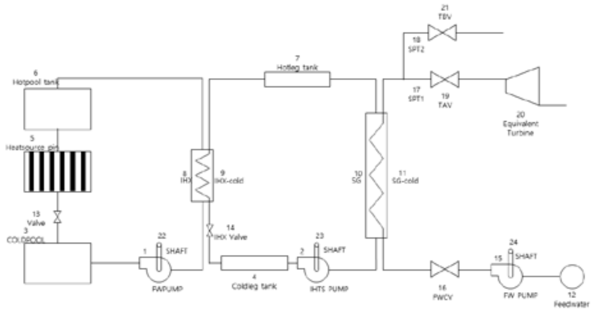


Fig. 3. Network model for GPASS code.

Turbine Bypass Valve (TBV), a demand signal for quick opening of the TBV is generated. If the output signal exceeds the setpoint of the RPC, a demand signal for RPCS is generated.

2.3 Performance evaluation of control systems

To confirm the control performance of the control systems of PGSFR in large load transient, a performance analysis was performed on the full load rejection event. Performance analysis was performed using GPASS (general plant analyzer and system simulator) [2] code. The GPASS code is developed by Argonne National Laboratory that can analyze the plant dynamic behavior of the Brayton Cycle-based power conversion system as well as the Rankine Cycle-based SFR. Figure 3 shows the PGSFR network model for the analysis of full load rejection event using GPASS code.

The scenario for full load rejection assumes that a disconnection from the power grid has occurred during full power operation with all plant systems being automatic control mode. In the event of a full load rejection, the turbine system rapidly reduces the power and operates in a house load. In this analysis, the house load was assumed to be 20% of rated power. The steam flow rate through the turbine is reduced at a rate of 1%/sec, and the bias signal between the reactor power and the steam flow rate increases rapidly, generating a TBV quick opening signal and RPC signal in the SBCS.

By the quick opening of the TBV, steam generated from the steam generator is discharged to the condenser through the TBV. The reactor power is reduced to 55%. The power of reactor, SBCS and turbine stabilized at 55%, 35%, and 20%, respectively.

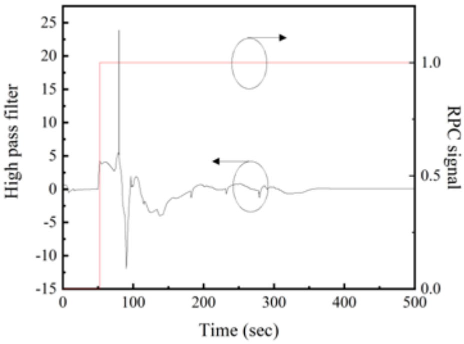


Fig. 4. Transient behavior of high pass filter and reactor power cutback signal.

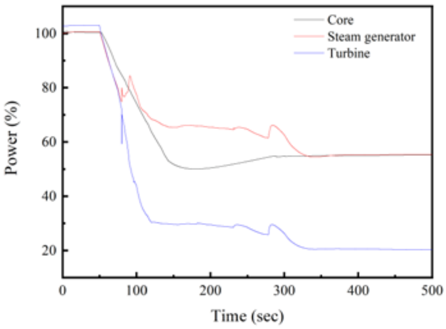


Fig. 5. Transient behavior of power of core, SG and turbine.

Figure 4 shows the behavior of high pass filter and RPC signal in the SBCS in case of full load rejection. In the event of a full load rejection, the bias signal increases sharply between the reactor power and the main steam flow rate, and such a sudden change passes through the high pass filter and increases the amplitude of the signal rapidly. It can be confirmed that the RPC signal occurs approximately 2 seconds after the event.

Figures from 5 to 8 show the transient behavior of major process variables in the event of a full load rejection. It can be seen that the power of the reactor and steam generator in Figure 5 decreases rapidly after the occurrence of a full load rejection and converges to 55% power. It can be seen that the turbine power is reduced to 20% which is excluding the amount of SBCS by 35% removed from steam generator of 55%.

Figure 6 shows the transient behavior of the main steam pressure in the event of a full load rejection. The main steam pressure increases rapidly for a certain period due to a rapid decrease in the flow rate on the turbine side after the event. The steam pressure is rapidly relieved by opening the TBV by the quick open mode of steam bypass line.

Figure 7 shows the transient behavior of the main steam temperature in case of a full load rejection. The main steam temperature rises for a certain period due to

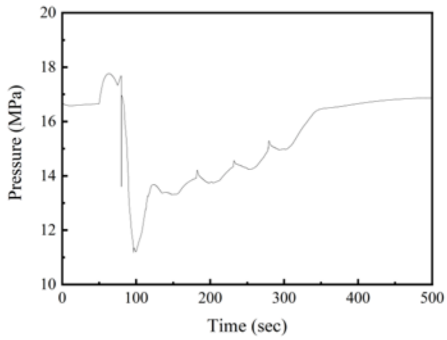


Fig. 6. Transient behavior of SG outlet pressure.

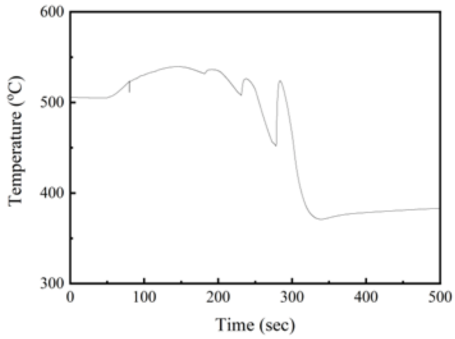


Fig. 7. Transient behavior of SG outlet temperature.

the rapid decrease in the main steam flow rate at the beginning of the accident. As the reactor power decreases and the steam flowrate stabilised tue to quick open of SBV, it can be seen that the main steam temperature decreases and stabilizes.

Figure 8 shows the transient behavior of the main steam flow rate in case of full load rejection. After the event, the main steam flow rate rapidly decreased due to the closing of the turbine control valve and then increased again for a certain period due to the quick opening of the TBV. Since then, the main steam flow rate stabilized at about 55%, and it can be seen that about 35% and 20% flow rates are formed to the steam bypass system and the turbine side, respectively.

3. Conclusions

Unlike light water reactors that drop subgroups of control rods by RPCS, the control logic of PGSFR in reactor power cutback is set to reduce the reactor power to a setpoint by RRS when an RPC signal is generated by SBCS. The control logic of SBCS for the quick open mode is set to cope with the large load transient.

The performance of the control systems at the full load rejection event was analyzed. In the event of full load rejection, it was confirmed that the RPCS and the quick opening of the TBV valve were activated after 2

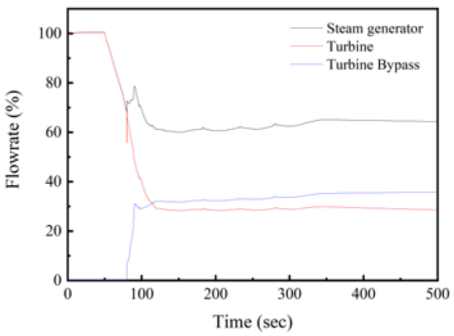


Fig. 8. Transient behavior of flowrate of steam generator, turbine and turbine bypass line.

seconds. After the event, the reactor and turbine power are stabilized at 55% and 20%, respectively. It was confirmed that the main process parameters were well controlled within the operating limit conditions.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP). (No. 2012M2A8A2025624).

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