Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

A Study on Automatic Turbine Control System using Neural Network for Small Modular Reactor

Kun-Young Han [a*], Dong-Han Yoo [a], Sa-Kil Kim[a], Gee-Yong Park [a]
[a]*Korea Atomic Energy Research Institute, Republic of Korea*
[*]*Corresponding author: kyhan-akane@Kaeri.re.kr*

1. Introduction

The Government of the Republic of Korea has been submitted its intended Nationally Determined Contribution (NDC) and recently, further unveiled the 10th Basic Plan for Electricity Supply and Demand. According to the current policy scenarios, as of the end of 2036, the nuclear energy take up 34.6% of the total power mix [1]. As presented in Fig.1, the nuclear energy has been gaining attention as an alternative for realizing of the carbon neutrality by 2050 because it has the high supply stability compared to the renewable energies such as the solar and wind powers. In addition, it has the low generating cost compared to the coal and LNG powers and advantages to build a power production network linked to the renewable energies with the utilizing of a load follow operation.

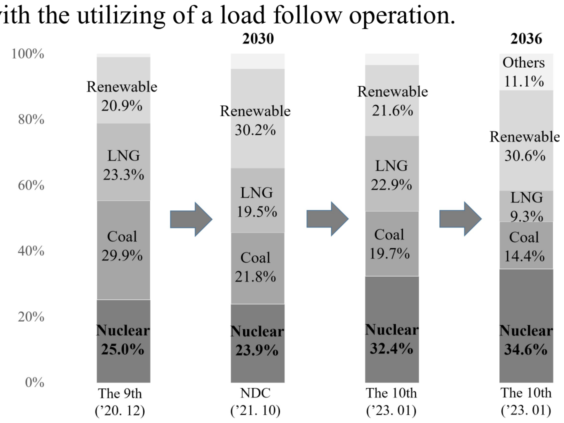

Fig. 1. The Republic of Korea Power mix Outlook

In particular, Small Modular Reactors (SMRs) which has been spotlighted recently can significantly improve the safety and utility compared to the large nuclear power plants since the main components such as a steam generator and a pressurizer are integrated into the reactor vessel(Fig.2). However, the unit cost of construction per kW is driven up by the size reduction of nuclear power plant normally and the growth in the number of operating personnel owing to the number of SMRs is reflected in the generating cost [2]. It is necessary to consider an operation method to minimize the generating cost to secure the economic efficiency for the commercialization of SMRs.

On the one hand, Neural Network is again drawing attention in the era of the fourth industrial revolution. Since it has a generalized learning ability to adapt to unknown environments such as the characteristics and various driving scenarios of SMRs, the application of Neural Network to a turbine control system can help to operate SMRs at low cost.

This paper reviews major considerations during the design of an automatic turbine control system using Neural Network, and introduces the representative control systems using it.

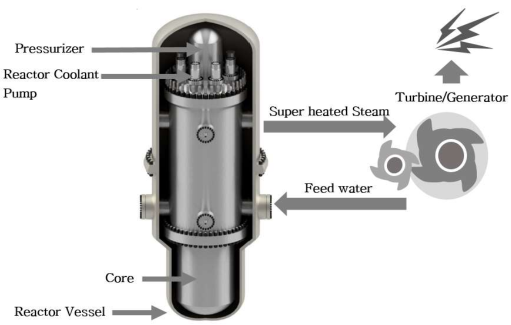

Fig. 2. Schematic Diagram of an SMR

2. Automatic Turbine Control System using Neural Network

The PID Controller is still widely used for many real world applications, including the power plants due to its simplicity and reliability. The fine-tuning of PID controller parameters is an inconvenient task in the conventional control system. This is because if any negative effects such as characteristic changes of SMRs caused by environmental condition or changes in the temperature, pressure, flow rate occur the mathematical model must be re-build and a new control law for the new mathematical model must be re-designed.

Since Neural Network has a generalized learning ability to overcome above issues, an automatic turbine control system using its learning ability as an operation method to minimize the generating cost can be a solution. Recently, numerous researches using its learning ability have been actively conducted in various control fields [3-6].

2.1 Consideration during the design of an automatic turbine control system using Neural Network

2.1.1 Continuity

Typically, the control inputs and outputs deals in the continuous values while Neural Network deals in two signals, 0 or 1. It is necessary to consider the characteristics of Neural Network that deals in the continuous values. It is known that Neural Network has the ability to approximate an arbitrary static nonlinear functions by using enough neurons [7]. Therefore, it is possible to design a controller using Neural Network that deals with the signals using the continuous signals defined as $-\infty$ to $+\infty$.

2.1.2 Dynamic Characteristics

In order to compensate of the dynamic characteristics of nonlinear controlled system, it is necessary to add the dynamic characteristics to a static Neural Network. Two methods can be considered for the adding of dynamic characteristics. One is to use a recurrent type with feedback loop inside Neural Network and another one is to use a buffer type which is added time delay elements outside it [8].

2.1.3 Versatility

A trajectory of control target, that is, the dependence on the control target value degrades the control characteristics. To this end, a design method that does not depend on the control target value after learning process of Neural Network is required. For this issue, a linear plant has already been reviewed in the adaptive control theory [9], and the design of control system using Neural Network as an extension of the adaptive control can be a solution.

2.1.4 Stability

The stability of control system using Neural Network should be examined through the analyzing its output range. The stability analysis is an important issue in the conventional control field such as the adaptive control and has been becoming a guideline to make a discrimination between superiority and inferiority of the designed control system. B. Karg [10] demonstrated a stability and feasibility of control system using Neural Network through its output range analysis.

2.2 Representative control systems using Neural Network

2.2.1 Serial type Controller

The output of Neural Network is used as the input of controlled system. After learning process, the inverse characteristics of controlled system are configured by Neural Network. By compensating the dynamics of controlled system, it is expected to coincide the values of control target and controlled system output.

2.2.2 Parallel type Controller

The addition of values of Neural Network output and the conventional controller output is the input of controlled system. The learning objective of Neural Network is to minimize the difference value between the total control output and Neural Network output.

2.2.3 Self-tuning type controller

Neural Network is used for directly adjusting of the conventional controller parameters. In other words, the learning objective of Neural Network is to determine the conventional controller parameters to minimize the feedback error.

Apart from these controller types, controller types using Neural Network in combination with Fuzzy and Genetic algorithms have been proposed [11, 12].

3. Conclusions

It is necessary to consider an operation method to minimize the generating cost to secure the economic efficiency for the commercialization of SMRs. This paper reviewed major considerations during the design of an automatic turbine control system using Neural Network, and introduced the representative control systems using it. The application of Neural Network to a turbine control system can be a solution in a operation method of SMRs at low cost and the automatic turbine control system using its learning ability for unknown environments is expected to contribute to the economic efficiency of SMRs.

REFERENCES

[1] S. M. Lee, Role and Challenges of the Nuclear Industry for Energy Security and Carbon Neutrality, National Assembly Research Service Current Issues Analysis, No. 274, pp. 1-9, 2022.

[2] M. W. Song, S. K. Kim, Y. D. Koo, K. I. Jeong, J. K. Lee, A Study on Methodology of Developing AI-Based Operator Decision Support System for Small Modular Reactor, Proceedings of the Ergonomics Society of Korea Conference, pp. 130-131, 2021.

[3] K. Y. Han and H. H. Lee, Multi-Connected Neuro PID control of Ultra-Compact Binary Power plant, The Ins. of Elec. Eng. of Japan, Vol.139, No.4, pp.504-513, 2019.

[4] K. P. Gama, C. E. Tengum, W. Hao, Deep Neural Network Based Self-Tuning PID Control for Quadrotor Attitude, North American Academic Research, Vol. 3, No. 11, pp. 465-480, 2020.

[5] F. Xu, D. Tang, S. Wang, Research on parallel nonlinear control system of PD and RBF neural network based on U model, Journal for Control, Measurement, Electronics, Computing and Communications, Vol. 61, No. 2, pp. 284-294, 2020.

[6] D. H. Kim, The level control of Steam Generator in NPPs by Neural network-PI Controller, Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, Vol. 12, No.4, pp. 6-13, 1998.

[7] K. Funahashi, On the Approximate Realization of identity Mapping by Three-Layer Neural Networks, Electronics and Communications in Japan, Vol. 73, No. 11, pp. 61-68, 1990.

[8] T. Yabuta and T. Yamada, Neural Network Controller Characteristics with Regard to Adaptive Control, IEEE Transaction on Systems, Man, and Cybernetics, Vol. 22, No. 1, pp. 170-177, 1992.

[9] K. Ichikawa, K. Kanai, T. Suzuki, S. Tamura, Adaptive Control, Japan: Shokodo, 1984.

[10] B. Karg, S. Lucia, Stability and feasibility of neural network-based controllers via output range analysis, in Proceeding of the 59th IEEE Conference on Decision and Control(CDC), pp. 4947-4954, 2020.

[11] Y. K. Choi, J. H. Park, Control Gain Optimization for mobile Robots Using Neural Network and Genetic Algorithms, Journal of the Korea Institute of Information and Communication Engineering, Vol. 20, No. 4, pp. 698-706, 2016.

[12] M. Fouzia, N. Khenfer, N.E. Boukezzoula, Robust Adaptive Tracking Control of Manipulator Arms with Fuzzy Neural Networks, Engineering, Technology, Applied Science Research, Vol. 10, No. 4, pp. 6131-6141, 2020.