Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Design of power control system for automatic operation of the Kartini reactor

To cite this article: Sutanto *et al* 2020 *J. Phys.: Conf. Ser.* **1436** 012066

Design of power control system for automatic operation of the Kartini reactor

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Abstract. Kartini research reactor which is located at Yogyakarta Indonesia is intended for research, education and training. Students from universities around the city use the reactor for experiments regularly. Regarding the plan of building the first nuclear power plant in Indonesia, the reactor could be improved as the facility of a nuclear power simulator for personnel training of a nuclear power plant. Some improvements on instrumentation and control system were conducted to support the purpose, such as developments of data acquisition of reactor operation parameters, and internet reactor laboratory for remote experiment through the internet connection. However, a power control system for the automatic operation of the reactor is not developed yet. It is important to design an automatic power control for the improvement of the reactor as a simulator of a light-water nuclear power plant. This paper discusses the design of power control of the Kartini reactor based on the Kartini reactor accident and transient code. The control model refers to that of a light water-cooled nuclear power plant. Calculation results show that the control model is applicable to the Kartini reactor. The criterion of SCRAM actuation of the Kartini reactor is satisfied by a small value (0.1) of a control parameter of b. In the future, the control rod simulator which is available in the Kartini reactor might be used to simulate the control system before it is realized to the real reactor.

1. Introduction

Recently BATAN and PT Indonesia Power had signed a memorandum of understanding (MoU) in collaboration of preparing the first nuclear power plant (NPP) in Indonesia planned to be built in Province of Kalimantan Barat. The reactor technology would be a boiling water reactor (BWR) or a pressurized water reactor (PWR) with the main consideration of its proven technology. These reactor types have been operated in many countries successfully. However, some research activities will be still important to conduct, such as feasibility study of the site, development of safer reactor technology, and provision of a facility for human resource development/training. Considering the experiences of TMI-2, Chernobyl, and Fukushima accidents, availability of simulators gives a key facility to the personnel training of nuclear power plant [1].

Research reactors are being the first gate either for the development of human resources or for personnel training of nuclear power plant. Kartini reactor is a research reactor located in Yogyakarta Indonesia and intended for research, education and training. Students from nuclear and physics departments of universities around the city have utilized the reactor for education purposes. Some improvements were carried out to enhance the utilization of the Kartini reactor as the facility of the nuclear training center. The development of the reactor operation data acquisition system was conducted to enable a more accurate measurement of main reactor operation parameters, such as the reactor power, neutron fluxes, and coolant temperature [2]. Internet reactor laboratory (IRL) which provides remote reactor experiments through internet connection was developed to enhance the reactor utilization for students far away from the reactor site [3]. A Kartini reactor code that can be used for safety analysis of the reactor was also developed [4]. Since an accident is difficult to simulate by using the real reactor, the code is useful as a tool for understanding the reactor response in case of abnormal conditions through simulation. However, so far, the operation of the reactor is still manual. There is no automatic mode to achieve the desired power. The operator pushes the operating buttons up and down to increase or to decrease the power. The availability of both manual and automatic power control is important in the operation of a nuclear power plant through a simulator. This research has the purpose of designing an automatic power control system for the operation of the Kartini reactor. It will be a part of the Kartini reactor improvement as the facility of the nuclear training center regarding the plan of building the first NPP in Indonesia.

2. Description of Kartini Reactor

Kartini reactor is a research reactor with an allowable maximum operating power capacity of 100 kW. It uses two cooling systems consisting of primary and secondary cooling systems. The primary cooling system does not force coolant flow to the core, but it only takes heat from the core by circulating the coolant through a heat exchanger. The secondary cooling system receives the heat from the heat exchanger and releases it into the open air through a cooling tower by natural circulation. Besides the cooling systems, the reactor is facilitated with instrumentation and control systems for reactor operation as shown in figure 1 [5]. It consists of protection and operation control systems. The protection system is used for making sure the safe operation of the reactor. It consists of neutron detectors, reactor trip circuit and control rod holders. The system for reactor operation consists of manual buttons used for moving up and down the safety, shim and regulating rods. The acquisition data system is provided for monitoring the operation parameters of fuel temperature, coolant flow rates, and control rod positions.

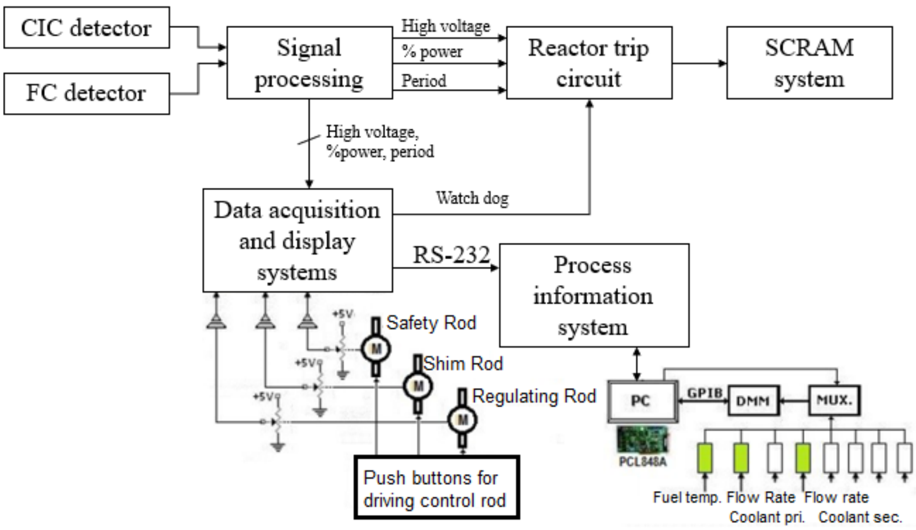


Figure 1. Instrumentation and control system of the Kartini reactor

3. Method

It is difficult to design the operation control directly using the real Kartini reactor. A code called the Kartini Reactor Accident and Transient (KRAT) was developed in the previous study [4]. It has the ability both to simulate abnormal conditions and to simulate the plant dynamics of the Kartini reactor. Power and coolant temperature calculations were validated based on the experimental data of the Kartini reactor operation. The structure of the KRAT code is shown in figure 2. The main governing equations of the code are mass and energy conservation, point kinetics and fuel rod heat conduction.

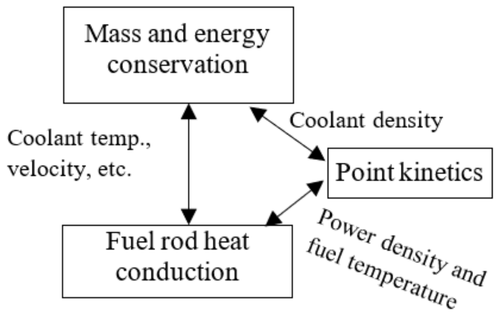


Figure 2. Structure of the KRAT code [4]

In this study the code is modified by adding a power control system. Since the Kartini reactor is a water coolant-based reactor and intended for the training facility of a light-water nuclear power reactor, the model of power control system refers to that of a light water-cooled nuclear power plant as shown in equation 1 [6, 7]. The power is controlled by adjustment of the control rod position. The speed of the control rod (v) is calculated based on the actual power (q_{set}) deviation from the desired value (q). The value of b is taken as the control parameter. V_{max} defines the allowable maximum speed of the control rod movement and it is set of 0.85 cm/s based on the current operation of the Kartini reactor. The calculation model of the modified code for the power control design is shown in figure 3. The performance of the power control system is examined by changing the desired power, and the actual power is observed whether it follows the desired power well. In this design, it is assumed that the initial condition of the reactor is at rated power operation. The criterion of the reactor operation is the SCRAM actuation level of 105 kW.

$$v = \begin{cases} v_{max} \frac{q_{set}-q}{q_{set}} \left(\frac{1}{b}\right) & \text{if} \quad \left(\frac{q_{set}-q}{q_{set}} < b\right) \\ v_{max} & \text{if} \quad \left(\frac{q_{set}-q}{q_{set}} \geq b\right) \end{cases} \tag{1}$$

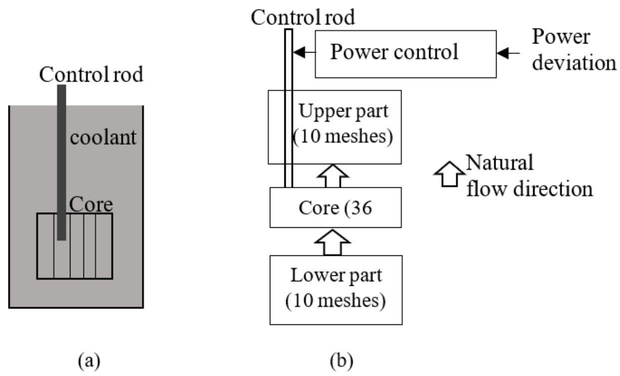


Figure 3. (a) Schema of the Kartini reactor, (b) Calculation model of the control system design

4. Results and Discussion

4.1. Reactor Plant Dynamics

Figure 4 shows the plant dynamics of the Kartini reactor without a power control system based on the KRAT code simulation. The power decreases significantly due to the 5% decrease in the control rod. The change of power is more than 25% of its initial value. It means that the power is sensitive to the change of the control rod due to high regulating control rod worth. The increment of the control rod position gives similar results. Five percent increment of the control rod position results in the power increment of more than 25%. It confirms that the control rod can be taken as the actuator for the power control.

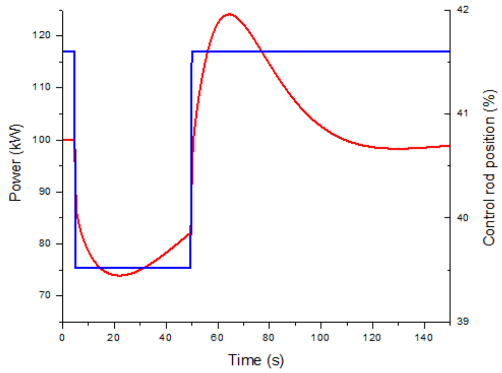
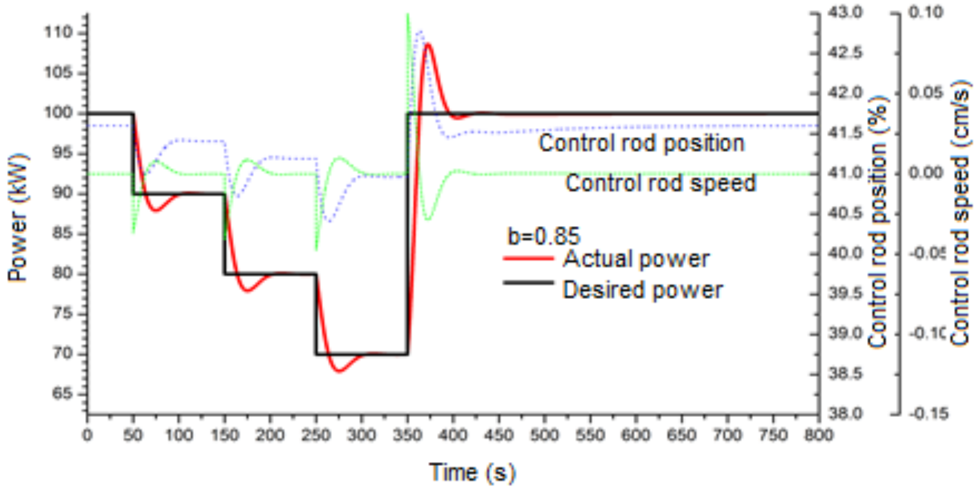


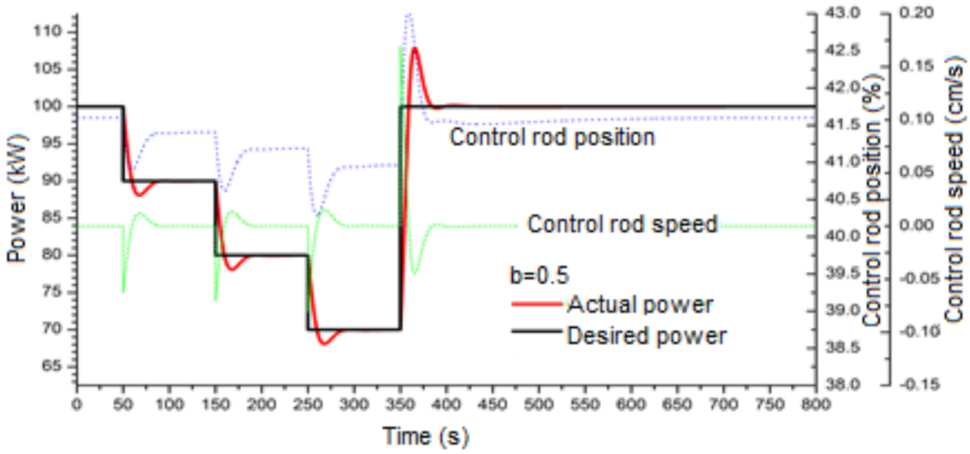
Figure 4. Plant dynamics of the Kartini reactor without power control system

4.2. Power Control System

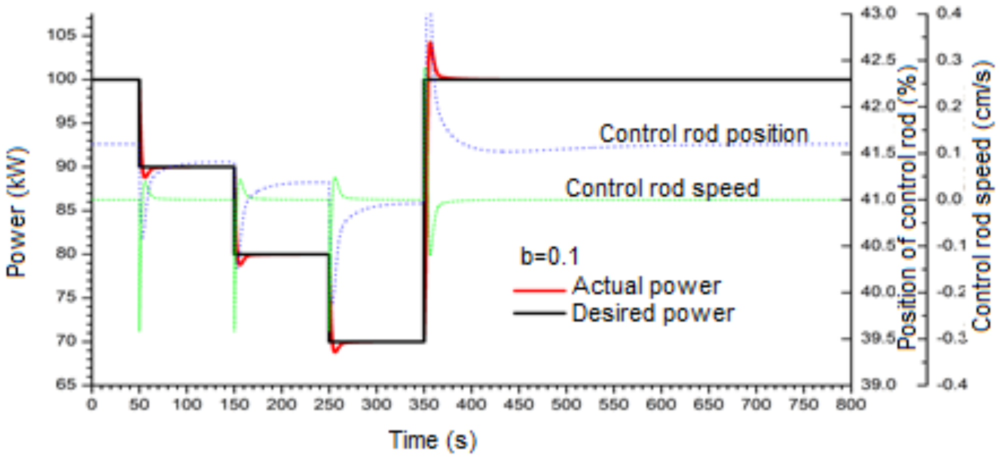
The same power control model as that of a light water-cooled nuclear power reactor is applied to the Kartini reactor. Figure 5 shows the performance of the control system application. Power deviation is taken as the input signal of the control and the control rod speed is calculated based on the input signal. Negative power deviation will result in negative speed which means that the control rod is inserted. Positive control rod speed means that the control rod is withdrawal due to positive power deviation.



(a)



(b)



(c)

Figure 5. Performance of the power control system of the Kartini reactor

Figure 5(a) shows the performance of the power control with a high value of the control parameter (b=0.85). The desired power is changed and the actual power could follow the change with large undershoot and overshoot. Smaller control parameter of b results smaller undershoot and overshoot as shown in figure (b) and (c). Based on the SCRAM criteria of the Kartini reactor, the maximum allowable power is 105 kW. Therefore, the high value of b will cause a SCRAM when the desired power is changed to the rated power of 100 kW. The higher value of b will cause more sensitive to the control rod movement. Figure 5(c) shows that b value of 0.1 results in a small overshoot when the power is changed to the rated power. SCRAM should be not actuated in this control system.

5. Conclusion

A power control system for automatic operation of the Kartini reactor has been designed by referring to that of a light water-cooled nuclear power plant. Based on the KRAT code simulation, the control model can be used to control the power-up and down well. The high value of control parameter b leads to high sensitivity of the control rod movement towards the power deviation. The small value of the control parameter b of 0.1 might satisfy the criterion of SCRAM actuation of the Kartini reactor. Currently, the Kartini reactor has been facilitated with the physical simulator of the control rod. It can be used to simulate the realization of the control design physically before it is implemented to the real reactor.

Acknowledgments
Authors wishing to acknowledge Prof. Yoshiaki Oka from Japan for permission of using SPRAT code which was used as a reference of the KRAT code development.

References

[1] T. Liu, E. G. Moya, Generic PWR simulation suite for nuclear training improvement after Fukushima. Journal of Energy Procedia Vol. 127 p. 148-153, 2017.
[2] A. Abimanyu, Syarip, E. S. Supriyatni, Wagirin, D. G. Gunawan, Marsudi, The development of Kartini reactor data achquisition system to support nuclear training center (NTC). The 3rd International Conference on Nano Electronics Research and Education & The 8th Inter. Conf. on Electrical, Electronics, Communications, Control and Informatics System, Royal Orchids Garden Hotel, Batu, Indonesia, October 31-November 2, 2016.
[3] Syarip, A. Abimayu, U. S. Hidayat, Taxwim, P. I. Wahyono, Development of internet reactor laboratory using Kartini reactor for training and education. Inter. Conf. on Electrical Power, Electronics, Communications, Controls and Informatics Seminar, Batu, East Java, Indonesia, 9-11 Oct. 2018.
[4] Sutanto, A. M. D. Suryana, Syarip, Development of Kartini reactor code to support nuclear training center and safety analysis. 4th International conference on Science and Technology, Yogyakarta Indonesia, 7-8 August 2018.
[5] Anonymous, Instrumentation and Control of the Kartini reactor, Center for Education and Training, National Nuclear Energy Agency of Indonesia, 2017 (in Indonesian).
[6] Y. Ishiwatari, Y. Oka, S. Koshizuka, Control of a high temperature supercritical pressure ligh water cooled and moderated reactor with water rods. Journal of Nuclear Science and Technology, Vol. 40, No. 5, p. 298-306, 2003.
[7] Sutanto, J. Wu, Control system of a super-fast reactor with single flow pass core. Int. Journal on Advanced Science Engineering Information Technology, Vol. 8 , No. 5, 2018.