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# Development of a simulation platform for studying on primary frequency regulation characteristics of nuclear units

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ABSTRACT

With the rapid development of nuclear units, the primary frequency regulation (PFR) characteristics of nuclear units have a significant affect on the frequency stability of power system. Power system will suffer great challenge if nuclear units do not participate in PFR, so study on the PFR characteristics of nuclear units has becoming a pressing issue. A detailed, nonlinear, time-varying dynamic mathematical model of a whole pressurized water reactor (PWR) nuclear power plant has been established in the present study. The simulation platform for studying on the PFR characteristics of nuclear units has been developed according to the model established. Using the simulation platform, the operation and control mode of PWR nuclear units participating in PFR of power system is simulated and studied. The simulations results show that PWR nuclear units are feasible in participating in PFR from safety and economy by adopting the operation and control mode presented in the study, which can contribute to the practical operation of power system.



## 1. Introduction

Keeping frequency stability is a goal for power system operation. Primary frequency regulation (PFR) is one of the vital methods to maintain frequency stability, especially when power system suffers a sudden load disturbance. Power system frequency is regulated by primary frequency regulation (PFR) and secondary frequency regulation (SFR) (Dai et al., 2008; Du et al., 2011). PFR regulates the system frequency in a dynamic process, and SFR regulates the frequency as close as its nominal value by adjusting the loads of units according to AGC (Automatic Generation Control) signal. Since PFR is a feedback regulation related to all the units in a power system, it is vital to eliminate the system frequency deviation, as quickly as possible, when power system suffers a sudden load disturbance.

To a power system, the more power units participating in PFR, the frequency stability will be controlled better. Now, there is a rapid development of nuclear units in China, especially in Guangdong power system. According to the plan, the nuclear power proportion of Guangdong power system will reach 20% by 2020. It will be challenging to the frequency regulation if nuclear units do not participate in PFR. However, to the best of the author's knowledge, since nuclear units usually run at rated-load, the studies on the PFR characteristics of PWR nuclear units have been little carried out, and there are little public data or research about the PFR characteristics of PWR nuclear units. So in the present study, Daya Bay nuclear plant, which is a PWR, is chose as the object to research the PFR characteristics of PWR nuclear units. A detailed, nonlinear, time-varying dynamic mathematical model of the whole Daya Bay plant is established in this study, including reactor, pressurizer, steam generator, steam-turbine, condenser, and turbine-generator rotor. By using MATLAB/SIMULINK, the control systems of the whole unit are built, and the possible operation and control mode of nuclear units participating in PFR is simulated and discussed. Based on the simulation platform, the affect of PFR parameters are also simulated and analyzed in this study.

## 2. Operation and control mode of nuclear units in PFR

The operation and control mode of Daya Bay nuclear unit participating in PFR is shown as Fig. 1. Actually, the frequency regulation of power system is realized by controlling the turbine speed. Nowadays, nuclear units widely adopt digital-electro-hydraulic (DEH) control system to control the turbine speed. As shown in Fig. 1, turbine speed control is based on two signals: one is the load reference, and the other is the frequency deviation of power system. The load reference will be unchanged if nuclear units only participating in PFR, and nuclear units will compensate

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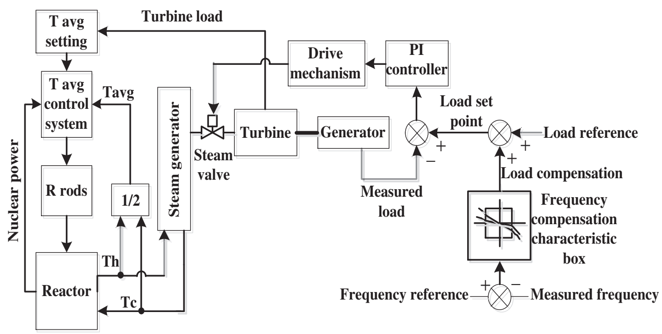


**Fig. 1.** Schematic diagram of the operation and control mode of nuclear units.

the turbine load according to the frequency deviation. And the reactor power should follow the turbine load as quick as possible if the turbine load is changed.

In the present study, R control rods are adopted to control the reactor power to follow the turbine load when the unit participates in PFR. The R rods control system (also called average temperature control system) is a closed loop control system, which can regulate the power of the reactor automatically. As shown in Fig. 1, the R rods control system takes the turbine load signal to set the reference of the coolant average temperature. The amount of steam leaving the steam generator will be altered if the turbine load is changed, then the average temperature of the coolant will be altered, by using R rods to regulate the coolant average temperature to the set point, there will be a quick power change of the reactor, and the load-following of the reactor to the turbine is realized.

R control rods are poison rods which have large absorption cross-section. To limit the impact to the axial power distribution caused by the R rods moving, R rods are constrained in a narrow regulation band which in the upper part of the core. In Daya Bay core, the removable distance of control rods is 3.658 m, which is divided into 225 steps and the regulation band of R rods is 24 steps. Due to the regulation band, the power regulation capacity of the R rods is limited, usually within 3%FP (full power), but it is enough for the unit to participate in PFR because of that the sudden load disturbance of power system is small usually.

As shown in Fig. 1, based on the frequency deviation, power units calculate power compensation value according to frequency compensation characteristics box. Dead band and frequency bias coefficient are set by the box, and the two parameters have a great affect on the PFR.

(1) Dead band

Dead band is in order to overcome the frequent load change of power units caused by tiny frequency deviation, but the dead band should not be too big, or it will weaken the PFR ability of power system.

(2) Frequency bias coefficient

Frequency bias coefficient has a great affect on the dynamic process of PFR, which determines power compensation rate of power units. The relation between the frequency bias coefficient and the power compensation is given as follows:

$$\frac{\Delta P}{P_0} = -\frac{1}{\delta}\frac{\Delta f}{f_0} \tag{1}$$

Where $P_0$ is the full power of nuclear units; $\Delta P$ is the power compensation; $\delta$ is the frequency bias coefficient; $f_0$ is the frequency set point; $\Delta f$ is the frequency bias.

## 3. Modeling and control systems of nuclear plant

The modeling and simulation of nuclear plants have received many attentions since the 1960s, however, due to the complexity and non-linearity, many simplified models established and simulation codes developed are centered on the primary loop system or even isolated part of the nuclear plant (Kerlin et al., 1976; Han, 2000; Dong et al., 2009; Wu et al., 2010; Wang et al., 2012). In the present study, a detailed, nonlinear, time-varying dynamic model of the whole plant is built, including reactor model, pressurizer model, steam generator model, steam turbine model, condenser model and turbine-generator rotor model. Fig. 2 shows the nodalization of the Daya Bay plant schematically.

### 3.1. *Core model and R rods control system*

#### 3.1.1. *Core model*

Since the point reactor kinetics model can not reflect the axial power deviation, a two-node reactor model is established in the study. The reactor is divided to two nodes along the axial, and calculation equation of the neutron leakage rate between the two nodes is also derived. Since the reactor power change is small and the duration is also very short during PFR, the affect of xenon is neglected for the convenience of calculation. Fig. 3 shows the

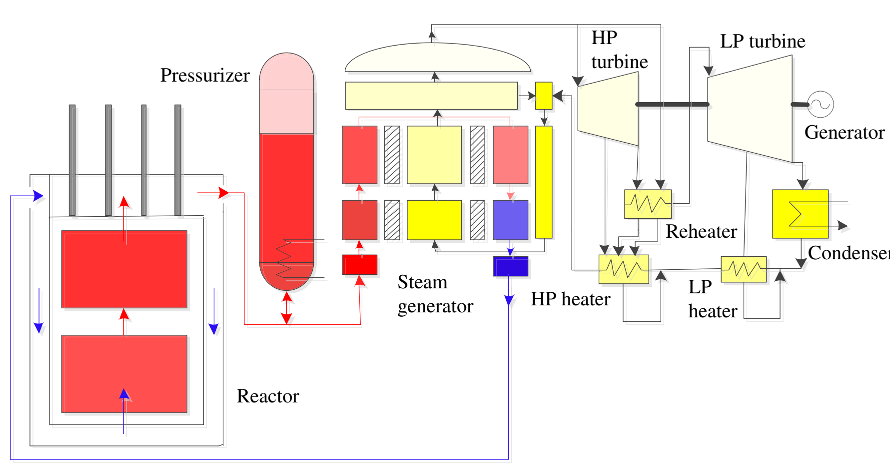


**Fig. 2.** Systematic diagram of the nodalization of Daya Bay plant.