Mechanical Shim core operational strategy designed for CPR1000 nuclear power plant

Y.W. Zhang a, W.J. Zeng b,*

a Department of Nuclear Science and Technology, Xi’an Jiaotong University, X’ian City 710049, China
b Department of Nuclear Science and Technology, University of South China, Hengyang City 421001, China

HIGHLIGHTS

- Power control analysis method is used to design MSHIM core control strategy for CPR1000.
- Control rod parameters are reconfigured to implement MSHIM control strategy.
- A one dimensional two-groups quasi static calculation program is developed to simulate the reactor core.
- The MSHIM core control strategy operating chart is designed to ensure the operation safety of the reactor.

ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 20 June 2017
Accepted 26 June 2017

Keywords:
CPR1000
MSHIM core control strategy
Load follow operation
Power control analysis method

ABSTRACT

The CPR1000, one of the water-cooled reactor types in China, employ MODE-G core control strategy through control rods and soluble boron to control the reactivity change during load follow operation. In spite of this, it has load follow capability for only 80% of cycle life, and also a large amount of radioactive waste liquid will be produced. In order to solve this problem, the MSHIM core control strategy was designed for CPR1000 in this paper. The MSHIM core control strategy has two independently moving RCCA groups are utilized for essentially simultaneous control of reactivity/temperature control and axial power distribution with complete boron-adjustment free load follow operation for up to more than 95% of cycle life.

The prime objective of core control is to simultaneously manage core power level and power distribution to ensure the reactor operation safety. In the MSHIM core control strategy in CPR1000, reactor power control includes power level control and power distribution control. Power level control uses the reactivity balance analysis method; the objective of power distribution control is to ensure the safety related parameters, such as DNBRs and $F_Q$ within its design limit, AO control analysis method is used. According to the reactivity balance analysis method, the control rods inserted in reactor core to offset the positive reactivity during load follow operation, and in CPR1000 core, part G1-bank is lifted to supply the positive reactivity prior to load follow operation. AO analysis result shows that the axial burnup distribution can affect the AO target value, AO control ability is enhanced with the increase of R-bank worth. Changing burnup history and redesigning the RCCAs are employed.

1. Introduction

It is inevitable that the nuclear power plant will perform load follow operation with the rapid development of nuclear power in China. The CPR1000 is one of the main reactor types in China employing the MODE-G core control strategy developed by AREVA NP (Hou et al., 2009). G mode is “gray rods” operation mode with superior load follow ability, which can reduce or increase the reactor power rapidly according to the network load change. Four groups power compensation rods G1,G2, N1,N2-banks have been designed to control the power specifying as a simple function of the power level and moving with a fixed overlap. R-bank is used not only to provide a further control of the average temperature of core coolant, but also to control the axial offset (AO) during load follow operation, and its insertion depth is limited between the bite position and the maximum insertion limit position. Boron works with the control rods to control the reactivity change during load follow operation (Park, 1990). It is nearly impossible to perform load follow operations at the end of cycle life (EOL) when
the dilution of soluble boron concentration cannot compensate the negative reactivity introduced by the accumulation of xenon poison during load change transients. According to the relevant design report, the MODE-G control strategy enables the CPR1000 to have load follow capability for only 80% of cycle life.

To improved load follow capability, the MSHIM (Mechanical Shim) strategy, which has been developed to AP1000 by Westinghouse, is performed through the control banks movement only, without soluble boron adjustment, and maintaining power peaking factors within the acceptable range during load follow operation (Onoue et al., 2003).

As in AP1000, the MSHIM control strategy utilizes two independent operable control groups which control the reactivity/temperature and axial power distribution respectively and complete more than 95% boron-adjustment free load follow operation during the cycle life. Reactivity/temperature control is provided primarily by a series of control rod banks which will be referred to as M-Banks. The M-Banks consist of several control banks moving with a fixed overlap. Before any anticipated load follow operation, MA and MB-Banks will have been fully inserted into the core. The initial M-Banks insertion permits compensation for both negative and positive reactivity insertions during the power changing maneuvers. Axial power distribution control is provided by what will be referred to as the AO-Bank. In order to have a reasonable impact on axial offset with a small degree of bank motion, the AO-Bank must have relatively high worth bank (Morita et al., 2003).

Study of the load follow without boron adjustment was performed for M310 PWR by using Westinghouse core design software package (Ma et al., 2004). Intermediate Reactor Innovative and Secure, which is an advanced medium-size Integral Primary System Reactor using soluble boron, provides improved operation by enabling load follow through MSHIM (Franceschini and Petrovic, 2008). In this paper, the MSHIM core control strategy is successfully designed to CPR1000 by changing the position of control rod banks, which still maintains power peaking factors within the acceptable range.

The primary benefits are as follows: Depending on MSHIM control strategy, the CPR1000 reactor can perform full load follow operations for 90% of cycle life, and the economical performance of the plant is greatly improved as the significant reduction in daily effluent is processed. The main work of this paper is to design the MSHIM control strategy for CPR1000 according to its characters.

This paper presents the implementation of MSHIM to CPR1000. Section 2 describes the CPR1000 core design, the software and the calculation model. Section 3 discusses the basis of MSHIM operation, while Section 4 presents the design of control rod banks to enable MSHIM operation. MSHIM performance for several load follow scenarios is demonstrated in Section 5. Section 6 is the conclusion.

2. Mathematical models and software

2.1. Features of CPR1000

The CPR1000 reactor core is comprised of 157 AFA-3G fuel assemblies (17 x 17 lattice design), each fuel assembly contains 264 fuel rods, 24 zirconium alloy guide tubes which can be placed in control rod, neutron source or thimble plug assembly, and one gadolinium rod. The CPR1000 reactor consists of 264 fuel rod, 24 zirconium alloy guide tube which can be placed in control rod, neutron source or thimble plug assembly, and one gadolinium rod. In this paper, the MSHIM core control strategy is successfully designed to CPR1000 by changing the position of control rod banks, which still maintains power peaking factors within the acceptable range.

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