Assessment of CPPF Reduction After Adapting Our Own Power Distribution Prediction Method

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1. Introduction

CANDU reactor which uses natural Uranium as a fuel requires daily on-power refueling due to its insufficient excess reactivity. So its power distribution changes unceasingly. Reactor physicists identify the change twice a week using RFSP (Reactor Fuelling Simulation Program) code, and check if it is operated within power limitation (380 channels and 4560 bundles). We also calculate ROP (Regional Overpower Protection trip system) detector calibration target value (DC, Detector Calibration) and determine refueling channels and their order. DC is composed of CPPF (Channel Power Peaking Factor), Plant ageing penalty and the factor considering PHT (Primary Heat Transport system) condition, etc. The lower CPPF means the lower DC, and the lower DC means the larger operating margin. If the reactor is not operated in full power state as Wolsong Unit #1, the additional operating margin can be converted to the additional operating power directly.

2. CPPF reduction through the precise prediction of power distribution

2.1 ROP (Regional Overpower Protection trip) system

CANDU reactor has ROP (or ROPT) system which keeps fuel from undergoing OID (Onset of Intermittent Dryout) during not only normal operation but transient condition comprising LORC (Loss Of Reactivity Control). ROP system is composed of two independent SDS (Shut Down System), SDS1 & SDS2 ROP system. There are 58 detectors (34 for SDS1, 24 for SDS2). Detectors for each ROP system are divided into 3 groups, or 3 safety channels. If two of them are in tripped condition, then each ROP system will trip the reactor (2/3 trip Logic). And the trip condition for each channel will be activated if any detector's signal belonging to the channel reaches to ROP trip setpoint. All of the ROP detectors are calibrated periodically to ROP DC (Detector Calibration) value. If there is no additional penalty or gain, basically ROP DC equals to CPPFmax (Maximum Channel Power Peaking Factor).

2.2 CPPF (Channel Power Peaking Factor)

CANDU has 380 fuel channels, and each channel has 12 fuel bundles. Considering uncertainty, the operating limits for channel and bundle power are 7.07 MW and 898 kW respectively. And it should be checked at least twice a week that the operating limit is being observed.

There is an ideal channel power shape which we call Nominal power shape or Reference power shape. It is time-averaged value, so it is a smooth shape. On the contrary, the actual shape is not a smooth one. Rippled shape will be induced by refueling. The ratio of the actual channel power to reference channel power is CPPF. From the fuel integrity point of view, the peripheral low power channel region is not important. So we calculate 236 CPPFs for the channels in the CPPF region. Adapting safety related conservatism, we consider all of the CPPFs are CPPFmax. In another words, the reactor is being operated at CPPFmax power. So, all of the ROP detectors are calibrated to CPPFmax value. For convenience, we usually call CPPFmax as CPPF too.

2.3 RFSP (Reactor Fuelling Simulation Program)

RFSP is a reactor physics code which is a base for core management. There are two methods for RFSP to gain power distribution. The one is to solve the 2-Group diffusion equation. The other is power mapping which combines 2-Group diffusion calculation result and flux mapping result. Since the uncertainty of power mapping result is much smaller than that of 2-Group calculation, we use power mapping result.

Flux mapping is the least square fitting which minimize the difference between 102 mapped fluxes and 102 actual vanadium detector readings. The mapped flux is the flux produced by superposition of the modes (normally 15 modes). The 1st mode called fundamental mode occupies the most part of the flux shape, and the rest modes of higher order are to represent perturbation. For each simulation, in order to reflect the history of refueling and fuel burn-up, RFSP reproduces the 1st mode which is called Rippled Fundamental Mode. In summary, RFSP produces Rippled Fundamental Mode by solving 2-Group diffusion equation, and then does flux mapping with Rippled Fundamental and higher modes and 102 vanadium detector readings. Finally, it calculates the power distribution (power mapping) considering fluxes at bundle position (flux mapping result) and fuel burn-up (2-Group result).

2.4 Development of power distribution prediction method WOLPRESIM

The more exactly we predict the power distribution after refueling, the better combination of refueling channels can be selected. But it is not easy to predict after refueling situation, because we cannot have 102 vanadium signals for flux mapping yet, even though it is possible to obtain 2-Group diffusion calculation result using RFSP's prediction function. So, it was the question how to translate the 2-Group calculation result to power mapping result.

While Wolsong Unit #1 used the prediction method developed by Canada Gentilly-2, Wolsong Unit #2 attempted to develop our own method. In the first stage, we proposed somewhat bothersome method that power mapping is done with the reproduced vanadium signal which is obtained from the combination of the current vanadium signal and anticipated flux change at the detector's position. Then, after some tests, it was converted to much simpler equivalent method. It is just adding the change (bundle or channel power's) between current 2-Group post-simulation result and anticipated 2-Group pre-simulation result to the current power mapping result. Through a few months' investigation, it was identified that this method predicted the power distribution after refueling fairly well. So this method which we call WOLPRESIM has been adapted in actual core management of Wolsong Unit #2 since 1999.

2.5 Assessment of CPPF reduction with WOLPRESIM

Because of plant ageing penalty, ROP trip setpoint for Wolsong Unit #1 is lowered to 107 %, while 122 % is for Wolsong Unit #2, 3 and 4. So, for Wolsong Unit #1 which cannot be operated at full power due to the lack of ROP margin like other old Canadian Plant (e.g. Gentilly-2), we pay more and more attention to CPPF than any other factor. So assessment of CPPF reduction is done for Wolsong Unit #1.

About two years ago, we investigated for two months which prediction method is more precise (Comparison was done for Wolsong Unit #2 too). Because the investigation told us that our own method is better than G-2 method, we changed the prediction method for Wolsong Unit #1. The change of prediction method has lowered CPPF more than 0.8 %, which means it has increased operating power more than 0.8 %.

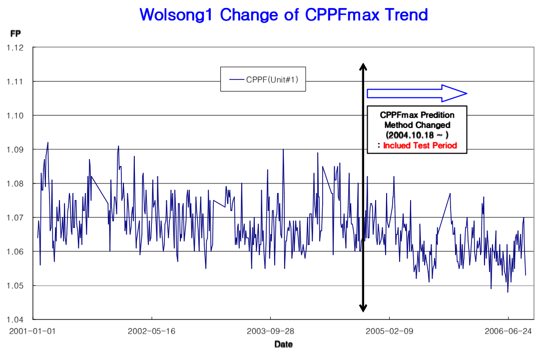

Figure 1. The Comparison of CPPF Trend for Wolsong Unit #1 Before and After the Change of Prediction Method

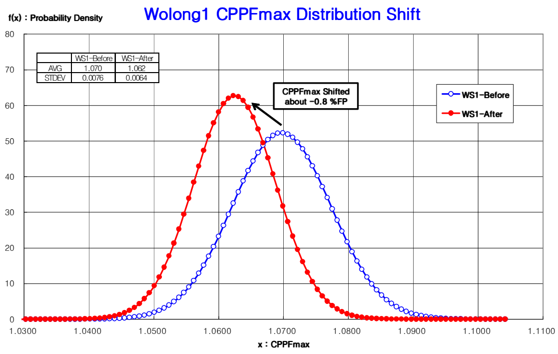

Figure 2. The Comparison of CPPF Distribution for Wolsong Unit #1 Before and After the Change of Prediction Method

Recent one year's operating data tells us that the refueling management for Wolsong Unit #1 and #2 based on WOLPRESIM's precise prediction is excellent.

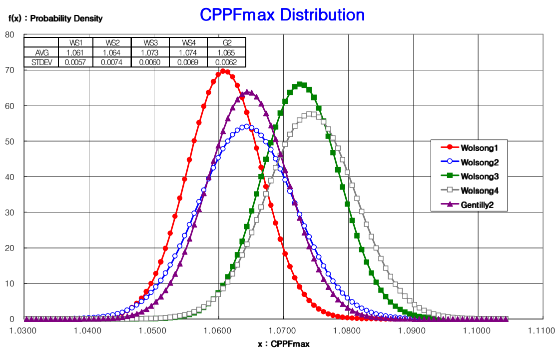

Figure 3. The Comparison of CPPF Distribution for Wolsong Unit #1, #2 and other Plant (Recent one year's distribution)

3. Conclusion

It is very important in core management to predict power distribution after refueling exactly. Unfortunately, however, power mapping requires detector readings which are obtainable only in the future. So, we developed our own prediction method WOLPRESIM which combines current RFSP's power mapping and pre-simulation result. At first, we applied it to Wolsong Unit #2 in 1999. And then, in late 2004, we extended its application to Wolsong Unit #1, after a few months' test. The change of prediction method came to a CPPF reduction. And other core management factors are well predicted. The operating power of Wolsong Unit #1 has been increased about 0.8 % through our constant efforts to reduce uncertainty for future.

REFERENCES

[1] Canada AECL, D.A. Jenkins and A.C. Mao "RFSP User's Manual" COG-93-104 Revision 1