Channel Power Distribution Optimization and Physics Modeling for Wolsong-3 NPP

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1. Introduction

In CANDU reactors, the Regional Overpower Protection Trip (ROPT) system protects the reactor against overpowers in the reactor fuel resulting from localized power peaking within the core. Therefore, the ROPT system ensures that, in the event of a slow loss-of-regulation (SLOR) accident, the reactor will be tripped before damage occurs in the fuel channels. Due to Primary Heat-Transport System (PHTS) aging the ROP trip setpoint is decreasing over time. Reductions in ROP trip setpoints are required to maintain the required trip-probability and ROP trip effectiveness, and results in a decrease of the ROP margin-to-trip during normal operation. In addition, full power operation can be threatened. In this study, we try to improve the ROPT margins through core REFORM and physics modeling of reformed channel power distribution will be evaluated using RFSP code. Finally, the feasibility of modeling and the economics are reviewed.

2. Reform Modeling

2.1 Reform Methodology

The REFORM process modifies the reference channel power distribution in order to optimize the ROP operating margins. The application of REFORM factors to the channel power map tunes the overall power shape of the core to enhance the ROP margin. This power shape may be used as a target power for refueling. REFORM adjusts the critical power ratio in each channel in the core so that probabilistic ROP coverage is uniform throughout the core and is maximized over all limiting ROP cases. To accomplish this power shape, some channel power is adjusted to have power shape such that channels for which the limiting ROP case has lower trip probability will have higher trip probability. Typically high powers in the center of core are redistributed to the outer channels.
Equation to calculate the trip setpoint is given by equation (1).

$$TSP(j_p) \le D_0 \frac{\Phi(k, j_{p,i})}{\left[\dfrac{CP(k,m)}{CP_0(m)}\right]} \left(\frac{CCP(k,m)}{CP_{ref}(k,m)}\right)_{Lim} \frac{1}{1+EA} \quad (1)$$

where $\Phi(k,j_{p,i})$ is the normalized detector reading for the limiting detector, CCP is the critical channel power, CP is the channel power, $TSP(j_{p,i})$ is the detector trip setpoint and EA is error allowance. The REFORM factor $R_{ref}(m)$, the factor by which a fuel channel should be modified, is given by equation (2)

$$R_{ref}(m) = \min_k \left\{ \frac{\Phi(k, j_{p,i})}{\alpha TSP(j_{p,i})} \left(\frac{CCP(k,m)}{CP(k,m)} \right)_m \right\} \quad (2)$$

where α is the change value in the detector trip setpoint after the REFORM. Thus the process is iterative: as the detector trip setpoint changes, the REFORM factor for each channel also changes. This process converges to a solution. Then the reformed reference channel powers can be calculated with equation (3)

$$CP_{ref}(m) = R_{ref}(m) \cdot CP_o(m) \quad (3)$$

2.2 Calculation Results of Reform

The REFORM module were performed by ROVER-F code for Wolsong-3 NPP at 2600EFPD using the design basis flux shapes (232 cases)[2]. The nominal and reformed channel power maps were shown as Figure 1 and 2, respectively. Figure 3 shows the difference of two channel power maps. The channel powers in the left and lower core except the CPPF region were increased about 3~10%, and the channel powers of the right and lower core were decreased by the same amount. Although reformed trip setpoint has been increased ~5% compared against that for the nominal reference channel power, the maximum channel power is increased about 200kW. Typically, in CANDU 6 cores, the REFORM results in an increase of the channel powers in the outer core and a decrease in the inner core.

2.3 Physics Modeling of Reformed Channel Power

The REFORM solution is bounded by the channel power distribution attainable by practical refueling. There are limits to the power flexibility because refueling engineer will have difficulty in simultaneous satisfaction of target channel power and target zone power. In this study physics modeling[3] was performed using the RFSP code against reformed channel power distribution. The result is summarized in this paper along with current Wolsong-3 Time-average model as shown in Table 1, 2, and Figure 4.

3. CONCLUSION

In this study, the REFORM for a specific burnup stage of Wolsong-3 was performed. The result shows an improvement of ROP margin by 5%. And the physics modeling was performed. The dwell time and average discharge burnup were decreased by 10FPD and 8Wh/kgU, respectively. The potential drawbacks of the REFORM are the amount of analysis required due to large changes in core flux shape, and the dependence of the revised core map on other inputs to the ROP calculation. It will be a big burden to the fuelling engineer's task. In the future the optimized reformed channel power distribution for feasible and economic channel power distribution will be considered.

REFERENCES

1. V. Caxaj, "ROVER-F Version 2-04 Manual", AECL Report CW-117390-MAN-003, 20 05 April.
2. F. A. R. L. Laratta, et. al., "Design and Assessment of the Replacement ROPT Systems for Wolsong-1", TTR-289 Part 1 (W1), AECL, Aug. (1995)
3. D. Jenkins, et. Al., "AMAD for Physics Simulations", TDAI-440 Part I , AECL, May (1991)

Table 1. Zonal Power of reformed Power Shape

Zone No.	Wolsong-3 (MW)	Reformed CP (MW)	Physics Model (MW)
1, 8	133.8	134.6	134.7
2, 9	133.3	134.1	134.0
3, 10	173.6	174.2	173.9
4, 11	153.0	151.5	151.0
5, 12	170.8	174.2	174.0
6, 13	133.3	131.6	132.2
7, 14	132.9	130.5	130.9

Table 2. Summary of Physics Modeling

Item	TTR-289	Reformed Channel Power	Physics Model
Max. Ch. Power (kW)	6665(N-06)	6879(M-5)	6705(O-06)
Max. Bundle Power (kW)	814(O-05/6)	-	817(S-11/6)
Avg. Discharge Burnup (MWh/KgU)	181.9	-	173.7
Bundles/FPD	14.79	-	15.59
Channels/FPD	1.85	-	1.95
Avg. Ch. Dwell Time (FPD)	205.6	-	195

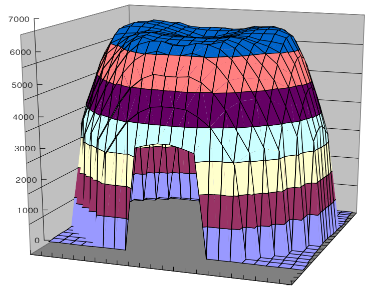

Figure 1. Distribution of Nominal Channel Power

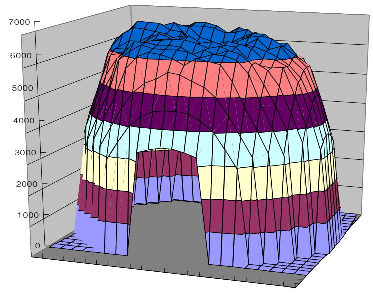

Figure 2. Distribution of Reformed Channel Power

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A									0	0	0	0	0	0								
B						0	0	0	0	0	0	0	0	0	0	0	0					
C					0	0	0	0	0	0	4.81	3.85	0	0	0	0	0	0				
D				0	0	0	5.66	4.32	2.8	0.66	0.6	−2.6	−0.4	−0.1	2.79	1.91	0	0	0			
E			0	0	0	8.09	4.02	2.09	−1	−1.4	0.42	−0.3	−4.4	−2.2	−0.9	2.59	4.9	0	0	0		
F			0	0	0	2.14	2.5	−0.2	0.55	1.28	1.74	−1.6	0.01	−2.5	−1.6	−0.4	0.97	0	0	0		
G		0	0	0	1.51	0.08	−2.4	−0.1	1.62	2.83	2.92	1.57	−0.5	0.43	−3.1	−4.1	−2.8	0.39	0	0	0	
H		0	0	2.99	−1	−5.4	−3.1	0.08	1.07	1.43	3.95	0.66	1.78	0	−1.5	−6	−6.9	−3.9	2.04	0	0	
J	0	0	0	0.75	−1.9	−1.9	0.25	3.07	1.75	3.65	−0.3	−1.8	0.5	1.72	0.16	−1.1	−4.4	−2.8	−3.3	0	0	0
K	0	0	3.91	−2.1	0.27	−0.1	1.7	1.02	1.04	−0	−2.8	−6	−1.4	−2.3	−0.5	−1	−1.5	−3.7	−6.5	−3.4	0	0
L	0	0	4.58	1.15	2.93	2.64	1.79	1.73	−0.3	−0.9	−5.5	−7.5	−4.4	−1.6	−1.7	0.93	−4	−2.3	−7.2	−2.7	0	0
M	0	0	7.37	0.17	3.8	3.64	3.93	2.04	3.16	−2.3	−2.3	−5.6	−3.9	−0.1	0.79	0.59	−1.2	−4.6	−6.5	−2.3	0	0
N	0	0	6.03	0.09	0.79	1.26	1.88	4.81	0.13	−1.9	−4.1	−6.1	−5.1	−1.1	1.28	0.16	−4.5	−3.6	−7.1	−0.5	0	0
O	0	0	0	−1.3	−2.1	−3.2	0.27	2.59	2.97	−1	−2.3	−5.7	−2.5	−0.1	0.71	−3.8	−5.5	−6.1	−5.6	0	0	0
P		0	0	4.18	−1.5	−3.6	−1.7	1.38	3.01	3.55	2.45	0.43	1.46	2.67	−2.3	−3.9	−6.9	−4.2	0.46	0	0	
Q		0	0	0	3.52	−1.1	−0.8	1.08	5.11	5.13	3.33	0.01	3.67	1.49	−1.2	−4.8	−3.8	−0.3	0	0	0	
R			0	0	0	5.05	−0.9	0.96	3.21	2.42	0.51	−1.2	−0.5	0.82	−2.8	−3.8	1.01	0	0	0		
S			0	0	0	0	4.76	3.04	2.02	1.17	0.47	−2.5	0.31	−1.3	0.12	0.44	0	0	0	0		
T				0	0	0	0	9.27	4.36	2.27	0.7	−1.6	−1.1	1.76	4.76	0	0	0	0			
U					0	0	0	0	0	11.8	10.9	6.87	8.76	0	0	0	0	0				
V						0	0	0	0	0	15.6	12.6	0	0	0	0	0					
W									0	0	0	0	0	0								

Figure 3. Difference of CP_{ref} from CP_o

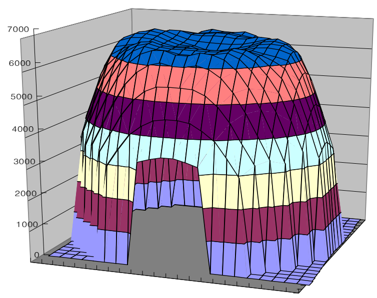

Figure 4. Physics Modeling for Reformed Cannel Power