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REFORM Optimization to Improve ROPT Margins for Wolsong-1

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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 , whether due to localized peaking within the core. of a general increase in core power levels. Therefore the ROPT systems ensure that in the event of a slow loss-of-regulation (SLOR) accident, the reactor will be tripped before damage occurs to 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 high trip-probability and ROP trip effectiveness, and which results in a decrease to of the ROP margin-to-trip during normal operation. In addition to that, Full power operation can be may require threatened. operation below full power. So in this study, we try to improve the ROPT margins through core REFORM

2. CALCULATION OF REFORM

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 maximize the ROP margin. This power shape may then 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 diverted adjusted to have power shape such that from channels for which the limiting ROP case has lower trip probability to channels for which the limiting cases have higher trip probability. Typically these resultsing power shapes are in such that high powers in the center of core are redistributed to being redistributed within the high-power region of the core and also being diverted from the centre of the core to the outer channels.

The REFORM module in ROVER-F (version 2-04)[1] begins its task by determining the ROP trip setpoint for each ROP flux shape being optimized. Each channel power is then adjusted, in turn, until the setpoint for the most limiting flux shape for that channel is reduced to the minimum setpoint. The power for limiting channels is maintained, while the power for other channels is increased to match the limiting channel power. These individual channel powers are then re-normalized - all channel powers are increased or maintained, so the effect is a decrease in power to each limiting channel - to attain the same overall reactor power. The theory of the REFORM calculation is conceptually simple. It is desirable to increase the power of each fuel channel to reach a CPR such that any further increase in power in that channel would have a negative effect on the trip probability for the flux shape that is the most limiting for that channel. Typically, only a few fuel channels will be limiting to the core as a whole, allowing all other channels to be increased in power, relative to the limiting channels. By normalizing to the overall reactor power, the reference power in these limiting channels is decreased. This decrease, as these cases are limiting, results in an increase in the overall limiting CPR, and thus in the trip probability and in ROP setpoint.

Equation to calculate the trip setpoint is given by equation (1).

$$\mathrm{TSP}(j_p) \le D_0 \frac{\Phi(k, j_{p,i})}{\left[\dfrac{\mathrm{CP}(k,m)}{\mathrm{CP}_0(m)}\right]} \left(\frac{\mathrm{CCP}(k,m)}{\mathrm{CP}_{\mathrm{ref}}(k,m)}\right)_{\mathrm{Lim}} \frac{1}{1+\mathrm{EA}} \qquad (1)$$

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, $\mathrm{TSP}(j_{p,i})$ is the detector trip setpoint and EA is error allowance. The REFORM factor $R_{\mathrm{ref}}(m)$, the factor by which a fuel channel should be modified, is given by equation (2)

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

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. The reformed reference channel powers can then be calculated as equation (3)

$$\mathrm{CP}_{\mathrm{ref}}(m) = R_{\mathrm{ref}}(m) \cdot \mathrm{CP}_o(m) \qquad (3)$$

And then tThe results of the REFORM optimization are shown in the next chapter.

3. RESULTS OF REFORM

REFORM module calculations were performed by ROVER-F code for TTR-289[2] design basis flux shapes (232 cases). The nominal and REFORMed channel power map for TTR-289 is shown as Figure 1 and 2, respectively. And the two channel power map is compared as shown in Figure 3. The channel powers in the outer and upper core except the CPPF region was were increased about 4%, and the channel powers of the inner and lower core was were decreased as by the same amount. As shown in Table 1, REFORMed trip setpoint has improved more 5% margin by more than 5% comparing compared with the setpoint using for the nominal reference channel power neglecting regardless of the additional reduction of margin due tofrom the practical considerations. But the maximum channel power is increased about 30kW. Typically, in CANDU 6 cores, this normalization results in an increase of the channel powers in the outer core and a decrease of the channel powers in the inner core. The REFORM solution is practically bounded by the channel power distribution attainable by credible 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.that may be set as a target for any channel, the variation in power from channel to channel, and the overall shape of the power distribution. These limitations must be dealt further with through the use of physics and fuelling simulation codes. New phi-nom is presented in this paper along with current Wolsong-1 phi-nom as shown in Table 2.Therefore we compared the phi-nom[3] which was the input of automatic zone control in RRS. It is shown as Table 2.

4. CONCLUSION

In this study, we have performed the REFORM for a specific burnup stage of Wolsong-1 unit. The result shows an improvement of ROP margin about 5%. 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. Moreover, the benefit may be eroded by practical considerations such as burnup, BP/CP limitations, etc. It is a large change will be a big burden to the fuelling engineer's task, and will have to be carried out in consultation with the site staff in fulldetailed refueling simulation is necessary for validation of the REFORMed power shape presented in this paper.

REFERENCES

1. V. Caxaj, "ROVER-F Version 2-04 Manual", AECL Report CW-117390-MAN-003, 2005 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. Results of REFORM

Parameter	Initial (before REFORM)	Results (after REFORM)
Setpoint	125.91%	131.08%
Max. Channel Power	6665.4kW	6694.6kW

Table 2. Phi-nom of the REFORMed Channel Power

Zone No.	Initial (before REFORM)	Results (after REFORM)
1, 8	0.9473	0.9609
2, 9	0.9433	0.9300
3, 10	1.0317	1.0498
4, 11	1.1795	1.1763
5, 12	1.0139	1.0072
6, 13	0.9436	0.9503
7, 14	0.9407	0.9255

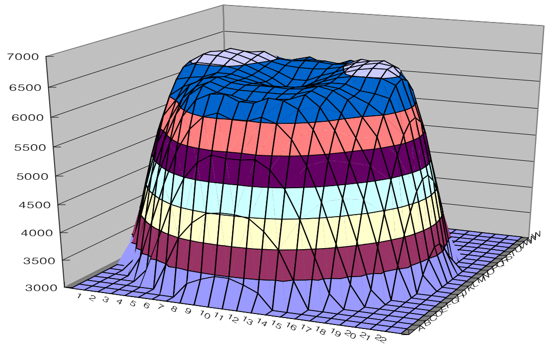


Figure 1. Distribution of Nominal Channel Power

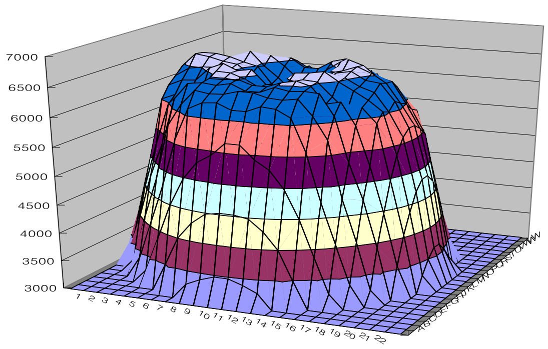
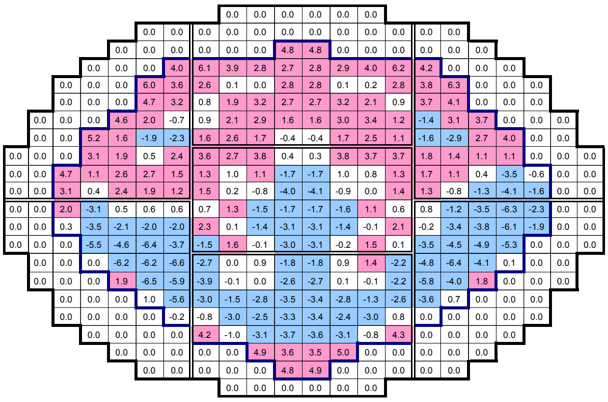


Figure 2. Distribution of REFORMed Channel Power



								0.0	0.0	0.0	0.0	0.0	0.0								
					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
				0.0	0.0	0.0	0.0	0.0	0.0	4.8	4.8	0.0	0.0	0.0	0.0	0.0	0.0				
			0.0	0.0	0.0	4.0	6.1	3.9	2.8	2.7	2.8	2.9	4.0	6.2	4.2	0.0	0.0	0.0			
		0.0	0.0	0.0	6.0	3.6	2.6	0.1	0.0	2.8	2.8	0.1	0.2	2.8	3.8	6.3	0.0	0.0	0.0		
		0.0	0.0	0.0	4.7	3.2	0.8	1.9	3.2	2.7	2.7	3.2	2.1	0.9	3.7	4.1	0.0	0.0	0.0		
	0.0	0.0	0.0	4.6	2.0	-0.7	0.9	2.1	2.9	1.6	1.6	3.0	3.4	1.2	-1.4	3.1	3.7	0.0	0.0	0.0	
	0.0	0.0	5.2	1.6	-1.9	-2.3	1.6	2.6	1.7	-0.4	-0.4	1.7	2.5	1.1	-1.6	-2.9	2.7	4.0	0.0	0.0	
0.0	0.0	0.0	3.1	1.9	0.5	2.4	3.6	2.7	3.8	0.4	0.3	3.8	3.7	3.7	1.8	1.4	1.1	1.1	0.0	0.0	0.0
0.0	0.0	4.7	1.1	2.6	2.7	1.5	1.3	1.0	1.1	-1.7	-1.7	1.0	0.8	1.3	1.7	1.1	0.4	-3.5	-0.6	0.0	0.0
0.0	0.0	3.1	0.4	2.4	1.9	1.2	1.5	0.2	-0.8	-4.0	-4.1	-0.9	0.0	1.4	1.3	-0.8	-1.3	-4.1	-1.6	0.0	0.0
0.0	0.0	2.0	-3.1	0.5	0.6	0.6	0.7	1.3	-1.5	-1.7	-1.7	-1.6	1.1	0.6	0.8	-1.2	-3.5	-6.3	-2.3	0.0	0.0
0.0	0.0	0.3	-3.5	-2.1	-2.0	-2.0	2.3	0.1	-1.4	-3.1	-3.1	-1.4	-0.1	2.1	-0.2	-3.4	-3.8	-6.1	-1.9	0.0	0.0
0.0	0.0	0.0	-5.5	-4.6	-6.4	-3.7	-1.5	1.6	-0.1	-3.0	-3.1	-0.2	1.5	0.1	-3.5	-4.5	-4.9	-5.3	0.0	0.0	0.0
	0.0	0.0	0.0	-6.2	-6.2	-6.6	-2.7	0.0	0.9	-1.8	-1.8	0.9	1.4	-2.2	-4.8	-6.4	-4.1	0.1	0.0	0.0	
	0.0	0.0	0.0	1.9	-6.5	-5.9	-3.9	-0.1	0.0	-2.6	-2.7	0.1	-0.1	-2.2	-5.8	-4.0	1.8	0.0	0.0	0.0	
		0.0	0.0	0.0	1.0	-5.6	-3.0	-1.5	-2.8	-3.5	-3.4	-2.8	-1.3	-2.6	-3.6	0.7	0.0	0.0	0.0		
		0.0	0.0	0.0	0.0	-0.2	-0.8	-3.0	-2.5	-3.3	-3.4	-2.4	-3.0	0.8	0.0	0.0	0.0	0.0	0.0		
			0.0	0.0	0.0	0.0	4.2	-1.0	-3.1	-3.7	-3.6	-3.1	-0.8	4.3	0.0	0.0	0.0	0.0			
				0.0	0.0	0.0	0.0	0.0	4.9	3.6	3.5	5.0	0.0	0.0	0.0	0.0	0.0				
					0.0	0.0	0.0	0.0	0.0	4.8	4.9	0.0	0.0	0.0	0.0	0.0					
								0.0	0.0	0.0	0.0	0.0	0.0								

Figure 3. Difference of CP_{ref} from CP_o