Simplified Load Follow Schemes to Simulate Long Term Daily Load Follow Operation

by

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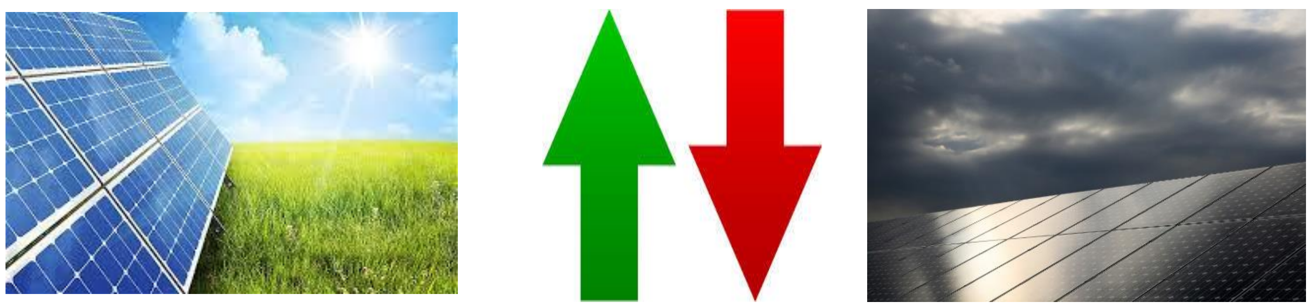
Contents

Introduction

- NPPs are one of the choices of renewable fuel power plants to reduce emissions of greenhouse gasses.
- Because renewal sources like wind and solar can be irregular,



- NPPs are expected to operate under Load Follow (LF) to meet the grid load demand.
- LF operation is the potential for a power plant to adjust its power output as grid load demand fluctuates.
- Control rods are used to achieve the sudden power level adjustment required.

Introduction

- It is necessary to predict NPP reactor core burnup and power distribution at the End of Cycle (EOC) for core reloading and physics input data for safety analysis.

BOC

0.49	0.41			
0	0			
0.79	0.91	0.73	0.47	
32.9	11.9	0	0	
0.89	1.12	1.18	0.84	0.61
1.06	0.99	11.6	35.2	0
1.06	0.99	1.16	1.36	1.14
34.1	45.2	34.5	12.9	14.2
1.3	1.39	1.56	1.26	
24.7	18.3	24.5	32.9	
1.04	1.33	1.16		
45.3	0	40.4		
1.15	1			
24.7	43.4			
0.96				
43.4				

BOC 1/8 Core UO2

1.36	Relative Power
12.9	Burnup (GWd/t)

EOC

0.98	0.82			
14.2	11.9			
1.03	1.2	1.12	0.76	
50.7	32.9	18.3	11.6	
0.96	1.35	1.22	0.88	0.79
58.2	24.7	34.5	51.1	12.9
0.91	0.86	0.96	1.11	1.05
52.1	62.2	53.5	35.3	34.1
0.99	1.06	0.99	0.94	
45.3	40.4	45.2	52.4	
0.86	1.23	0.91		
62.6	24.5	59.1		
0.92	0.85			
43.3	60.3			
0.76				
58.7				

EOC 1/8 Core UO2

1.35	Relative Power
24.7	Burnup (GWd/t)

- EOC Burnup prediction is achieved by the use of computer codes simulations.
- Core depletion simulation at base load power operation and long-term daily load follow operation results in different core burnup and power distribution.

Introduction

- Computer code simulation of a long-term daily load follow operation has detailed tedious input and requires long computational time.
- The purpose of this study is to develop a simplified load follow operation scheme that can simulate long-term daily load follow operation.
- The simplified scheme should:

  I. Have less detailed input

  II. Have reduced computation time

  III. Produce a core state similar to the long-term daily load follow operation at EOC.

Methods & Tools

- CASMO-3 [3] and MASTER [4] are used to simulate load follow.
- The nuclear reactor model used is the Korean Nuclear Fuel (KNF) proposed SMR.

Reactor Type	PWR
Cycle Length	3 ~ 5 years (1000 EFPD ~ 1800 EFPD)
Enrichment	< 5%
Active Core Height	200 cm
No. of Fuel Assemblies	37 (Westinghouse 17x17)
Soluble Boron	No (Target : < 100 ppm)
BP	WABA, PYREX, Gad, Er, IFBA, etc.
Thermal Power	180 MWth
Inlet Temp./Avg. Temp	292 ^{o}C / 307 ^{o}C or 296 ^{o}C / 310 ^{o}C
Coolant Flow Rate (kg/m^{2}sec)	584.17, Natural Circulation

		R6	R21	R71		
	R3	A2	B1	R11	R31	
R7	R1	R4	R51	R41	A21	R61
R2	B	R5	A1	R5	B	R2
R6	A2	R4	R5	R4	R1	R7
	R3	R1	B	A2	R3	
		R7	R2	R6		

SMR CEA configuration.

Methods & Tools

- OPR1000 reactor employs Mode-K algorithm [7] for load follow.
- To control axial power and power distribution Mode-K uses:

  I. Regulating CEA groups and boron to achieve reactivity control

  II. Heavy-worth groups are used for axial power shape [7].

Methods & Tools

- The SMR employs only heavy-worth CEA groups, A2 and R1 to achieve criticality and heavily bottom-skewed flux distribution during LF.

		R6	R21	R71		
	R3	A2	B1	R11	R31	
R7	R1	R4	R51	R41	A21	R61
R2	B	R5	A1	R5	B	R2
R6	A2	R4	R5	R4	R1	R7
	R3	R1	B	A2	R3	
		R7	R2	R6		

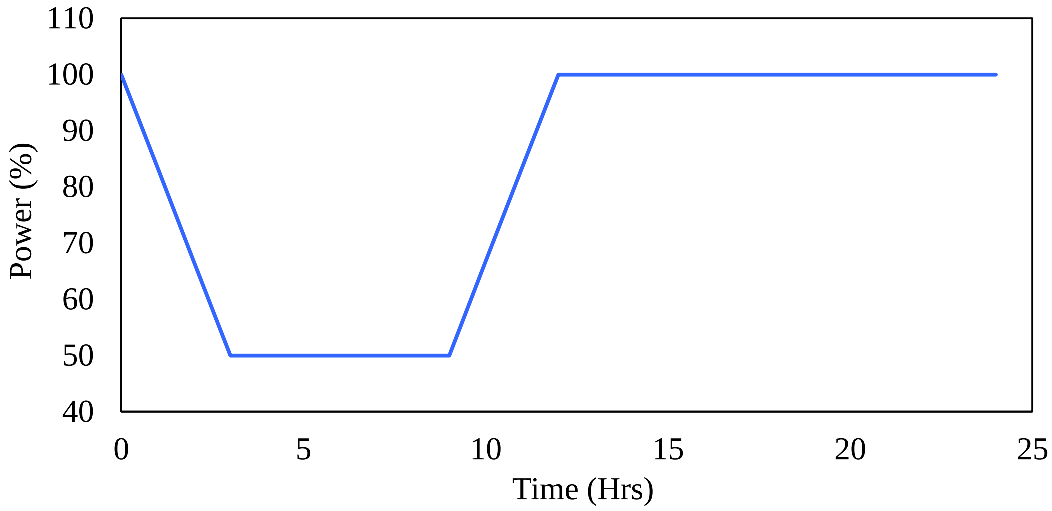
SMR CEA configuration.

- Critical height of the CEAs is searched with every power level change and every burnup step during load follow operation simulation to ensure core criticality.

Methods & Tools

Long-term daily load follow (Reference scheme)

- The Figure below show OPR1000 power level maneuver of a one-day LF operation scheme.



- This one-day load follow operation maneuver is extended to 17 months operation for the SMR and used as the reference scheme.

Simplified load follow schemes

- Unlike the reference scheme the power level of the simplified load follow operation scheme changes a few times in a month.
- Burnup depletion interval with a constant power level is much longer than that of the reference scheme.

Methods & Tools

Simplified load follow scheme requirements

- The simplified load follow operation schemes and the reference scheme should have equal energy production.

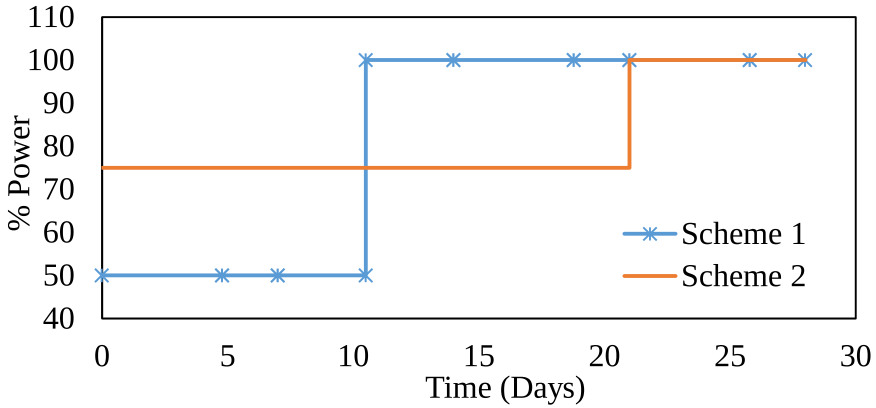
$$E(MWhr) = \sum_{i=1}^{n} (T_1 \times P_1 + T_2 \times P_2)_i \qquad (1)$$

$$T_{reference}(hrs) = \sum_{i=1}^{n} (T_1 + T_2)_i \qquad (2)$$

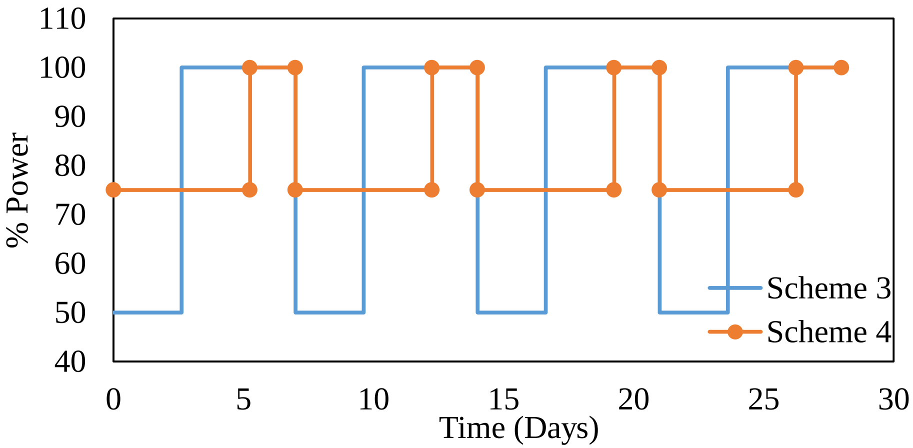
- n is the number of power level maneuvering period in a simplified LF operation scheme.
- Three power levels are considered for the simplified LF operation schemes, 50%, 75% and 100%.

Methods & Tools

Power level maneuvering of the simplified load follow schemes



Scheme 1 & Scheme 2



Scheme 3 & Scheme 4

Results

Evaluation of the simplified load follow schemes

- The following parameters of the simplified LF schemes and the reference scheme are compared at EOC.

  I. Core radial plane burnup distribution

  II. Core radial plane power distribution

  III. CEAs critical height

  IV. Axial Offset (AO)

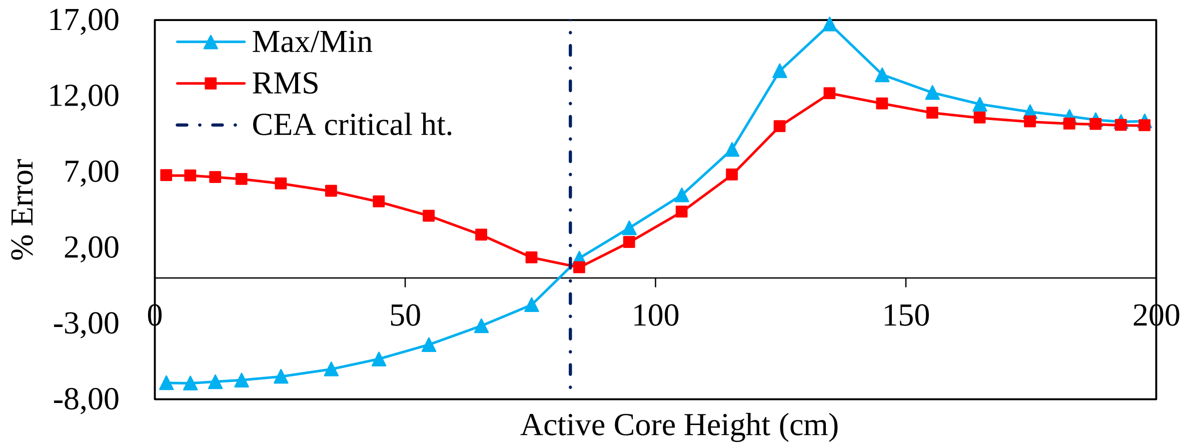
Results

Core radial plane comparison summary of the reference scheme and the simplified schemes at EOC.

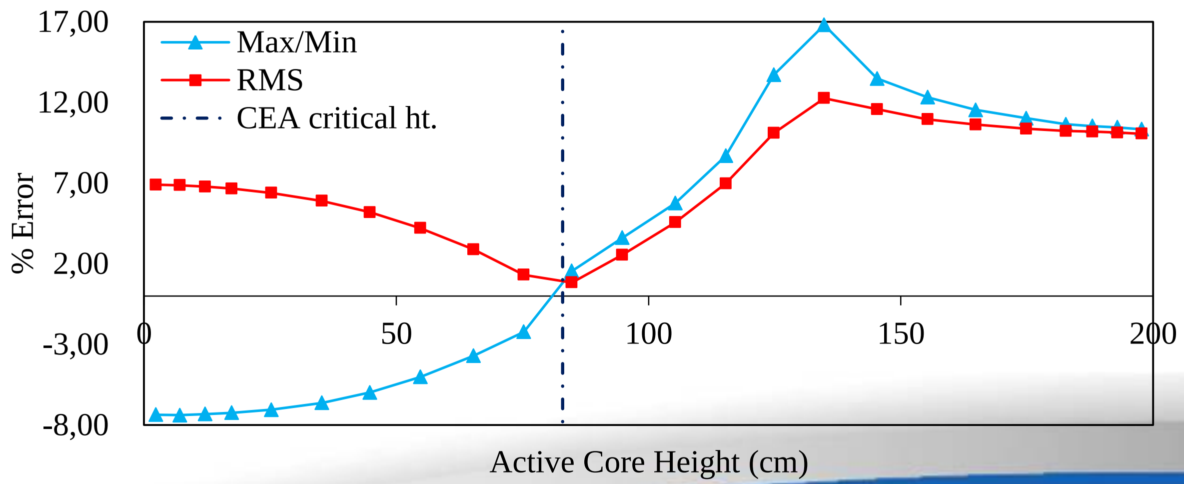
Scheme	Reference	1	2	3	4
Time (minutes)	1034	8	7	33	29
EOC AO	-0.69	-0.69	-0.68	-0.69	-0.68
Max. RMS error of the core radial burnup distribution	-	12.2	1.89	12.3	1.61
Abs. Max error of the core radial Burnup distribution	-	16.7	2.91	16.8	2.51
Max. RMS error of the core radial power distribution	-	2.1 (1.99)	8.86 (8.24)	2.88 (2.69)	9.06 (8.41)
Abs. Max error of the core radial power distribution	-	4.37 (4.60)	17.4 (17.9)	5.93 (6.15)	17.7 (18.2)
CEACH at EOC (cm)	86	83	88	83	88

Results

Core radial plane burnup distribution errors



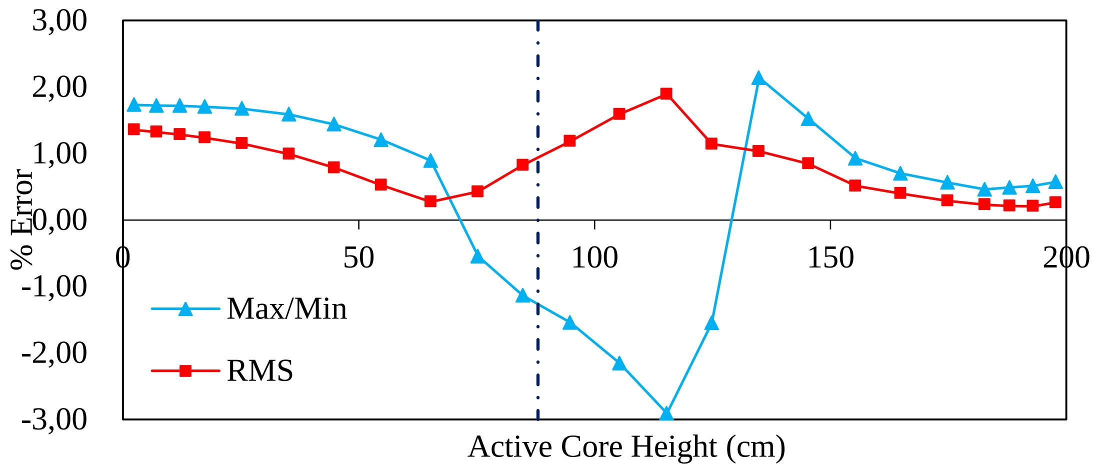
Scheme 1



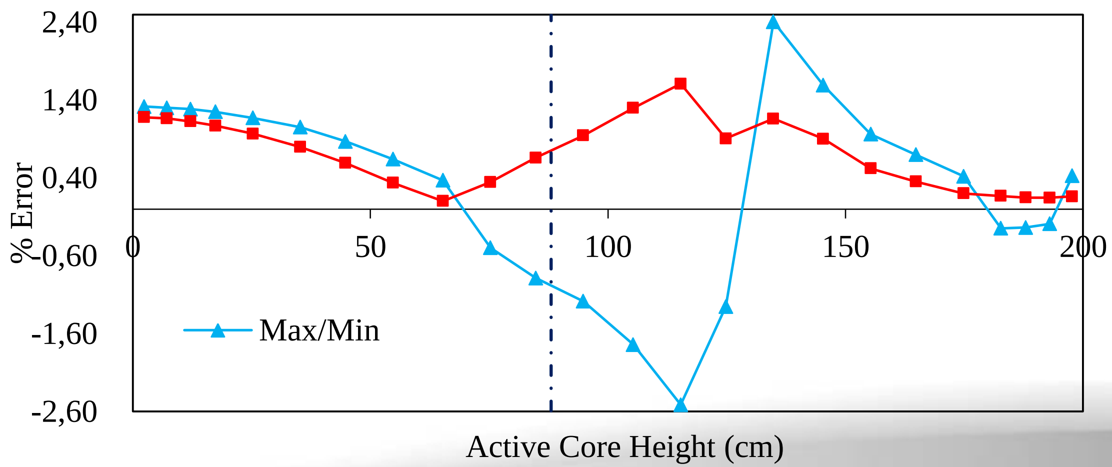
Scheme 3

Results

Core radial plane burnup distribution errors



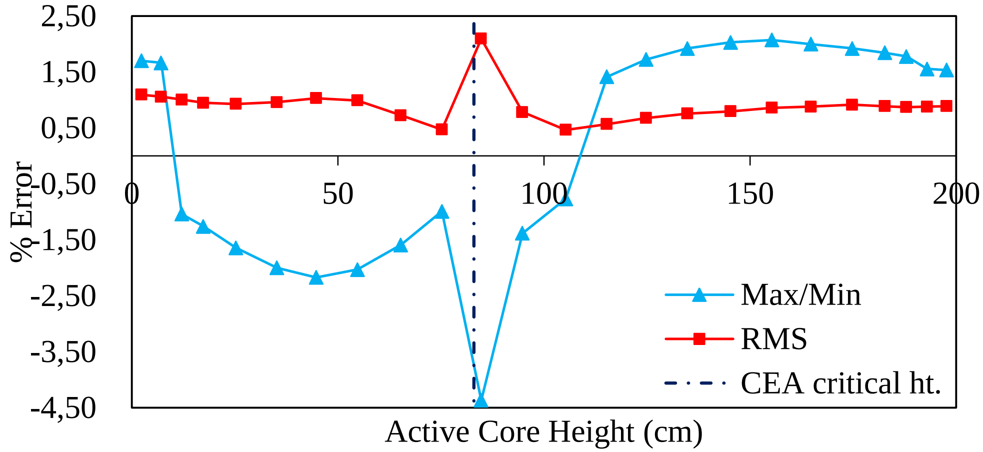
Scheme 2



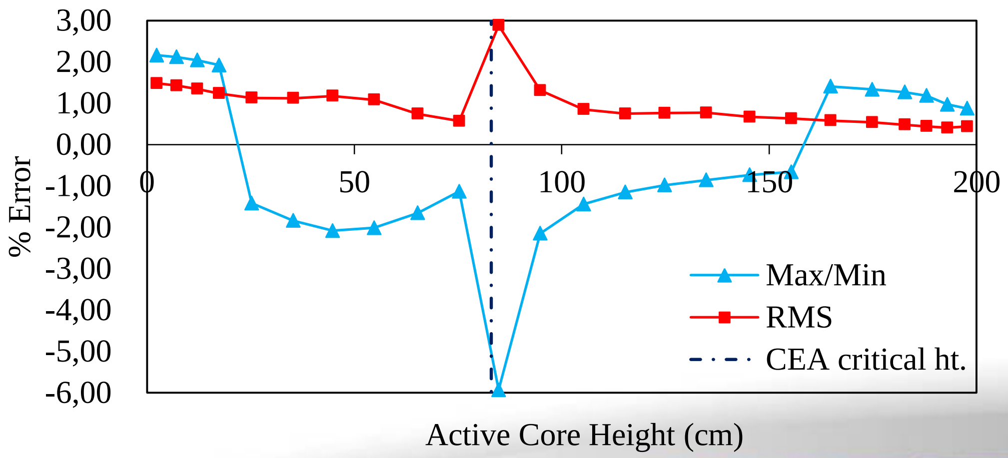
Scheme 4

Results

Core radial plane power distribution errors



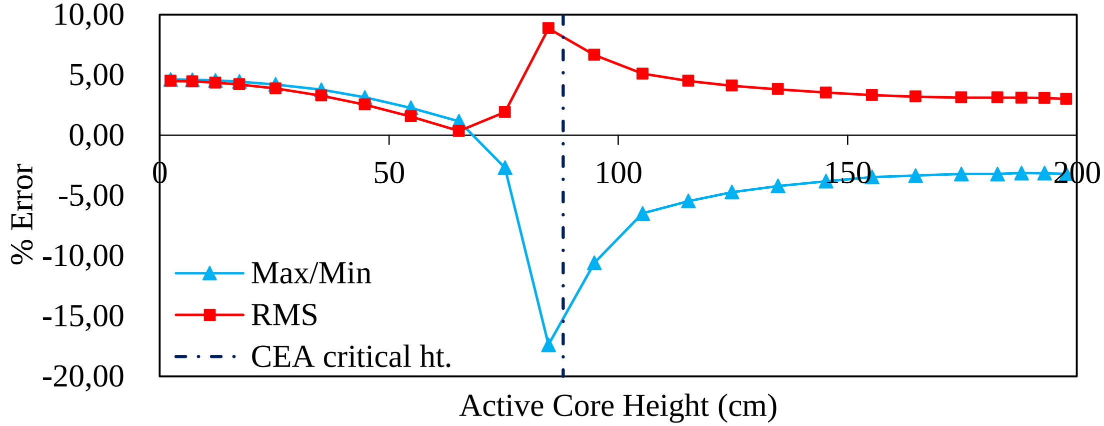
Scheme 1



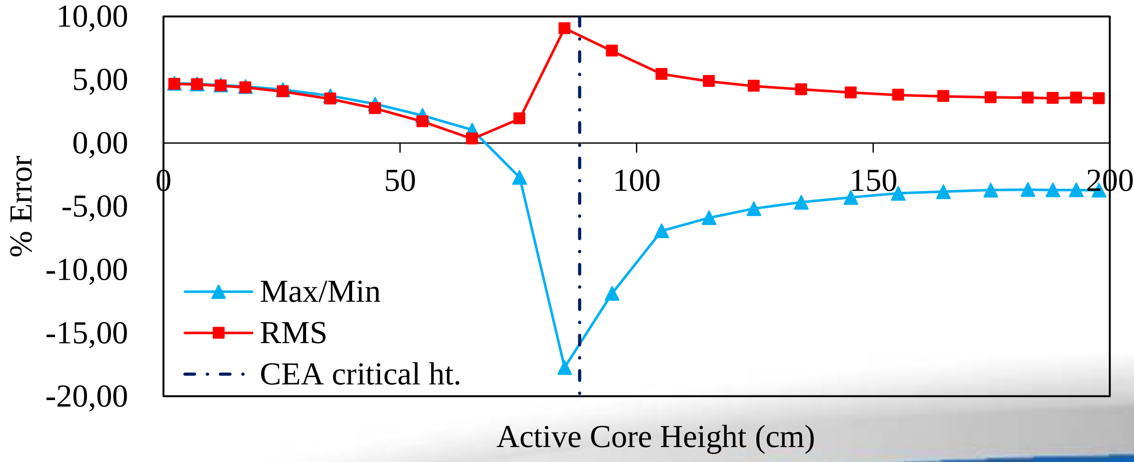
Scheme 3

Results

Core radial plane power distribution errors



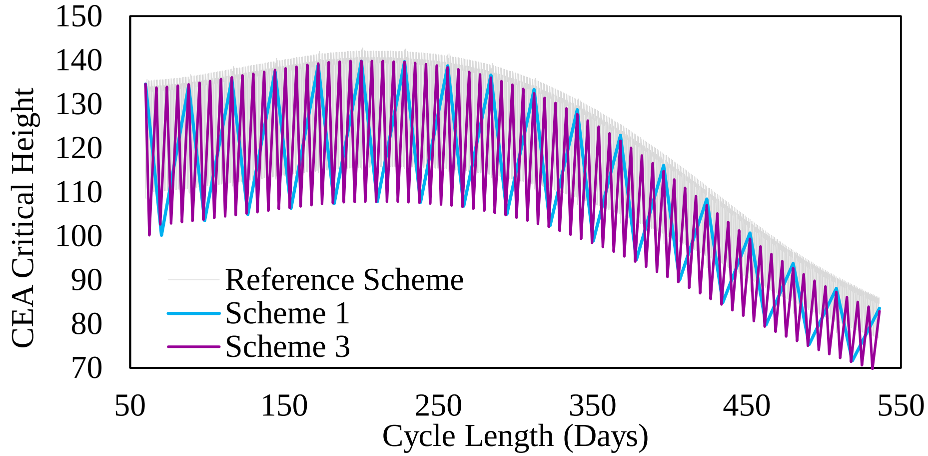
Scheme 2



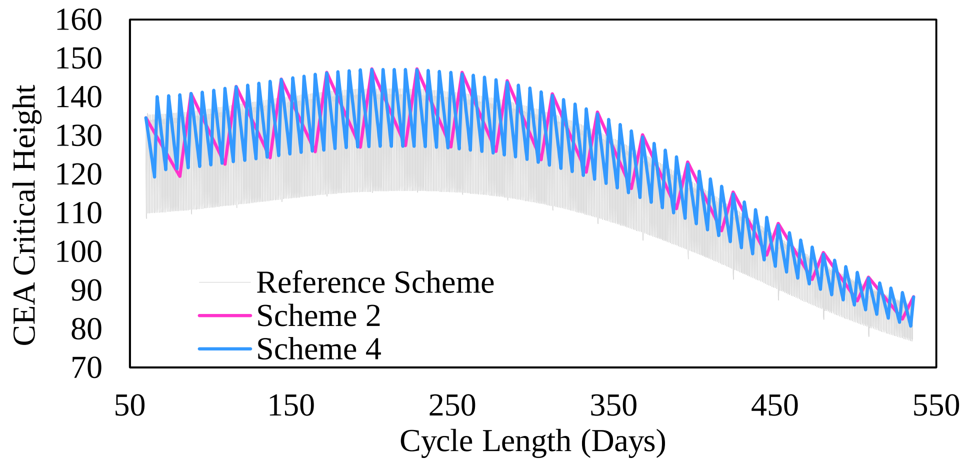
Scheme 4

Results

CEA critical heights of the schemes



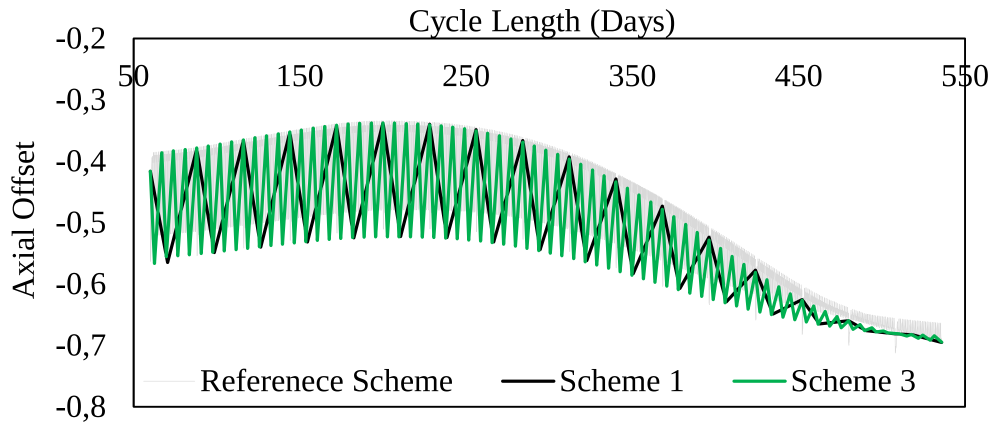
Reference Scheme, Scheme 1 & Scheme 3

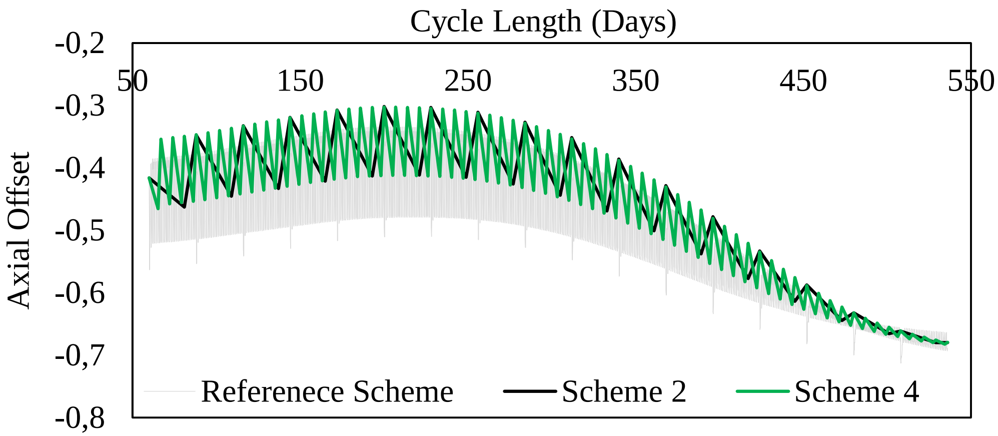


Reference Scheme, Scheme 2 & Scheme 4

Results

Axial Offset (AO) of the schemes





Reference Scheme, Scheme 1 & Scheme 3

$$AO = \frac{P_t - P_b}{P_t + P_b} \qquad (3)$$

Reference Scheme, Scheme 2 & Scheme 4

Results

Single Control Element Assembly (SCEA) ejection

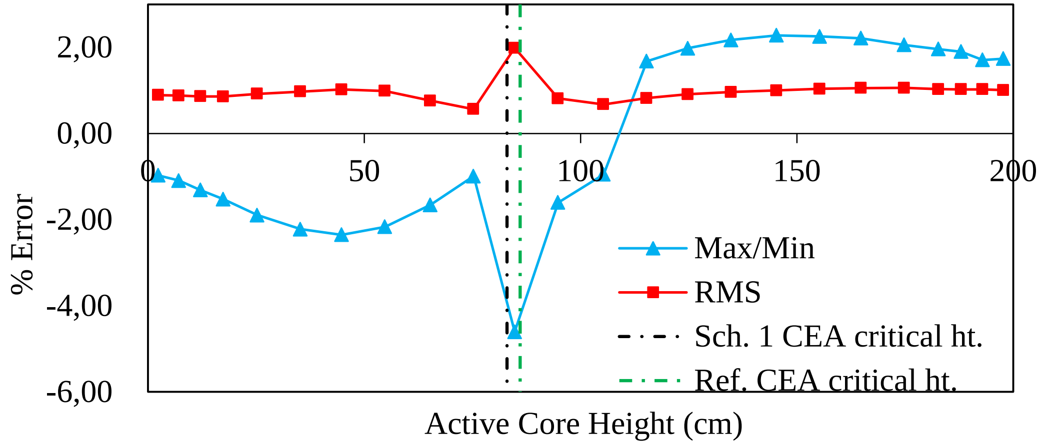
- To validate the simplified LF schemes, SCEA ejection accident is simulated at EOC.
- R11 CEA is used to simulate SCEA ejection at 100 % power.
- Core power distribution of the simplified schemes and reference scheme is compared after SCEA ejection.

		R6	R21	R71		
	R3	A2	B1	R11	R31	
R7	R1	R4	R51	R41	A21	R61
R2	B	R5	A1	R5	B	R2
R6	A2	R4	R5	R4	R1	R7
	R3	R1	B	A2	R3	
		R7	R2	R6		

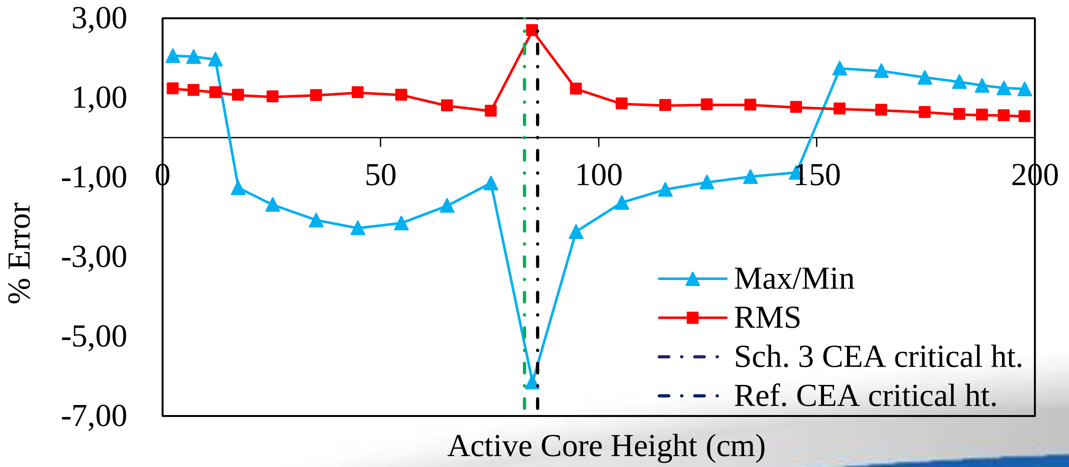
SMR CEA configuration.

Results

Single Control Element Assembly (SCEA) ejection



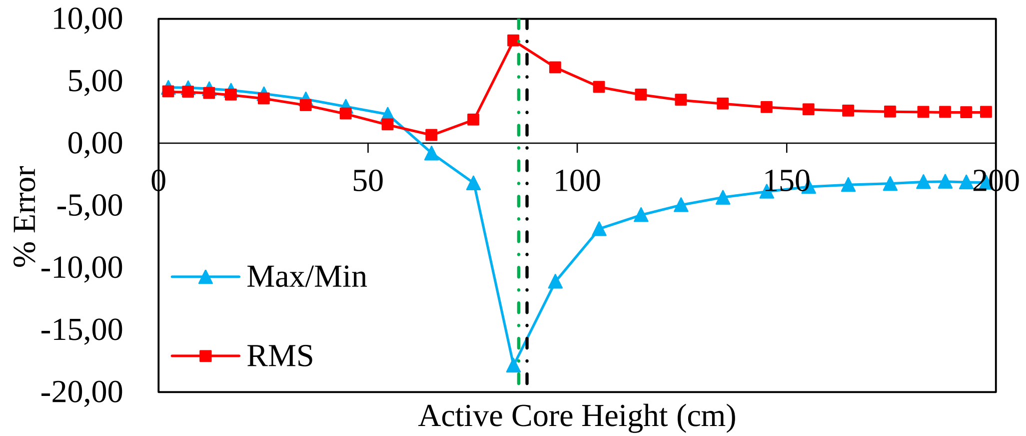
Scheme 1



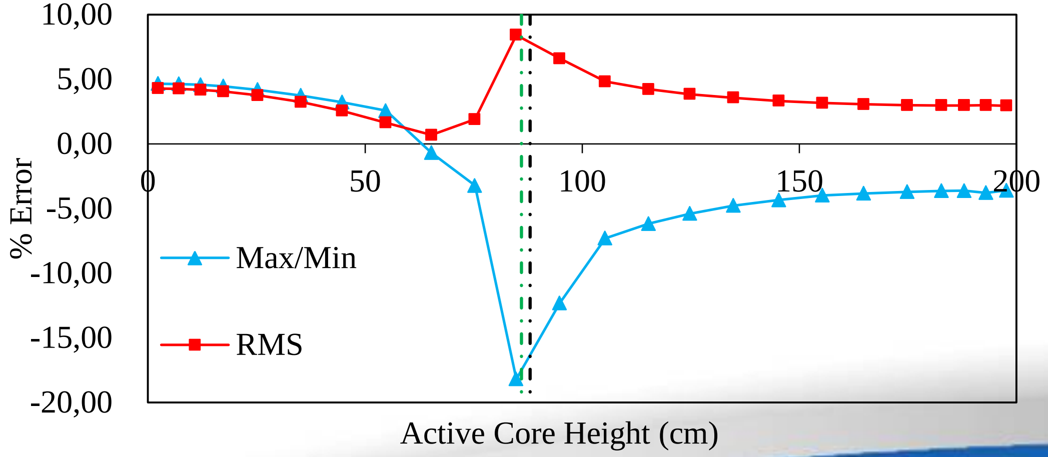
Scheme 3

Results

Single Control Element Assembly (SCEA) ejection



Scheme 2



Scheme 4

Conclusion

- The computational time of the simplified schemes is more than 29 times smaller than that of the reference scheme.
- The simplified LF schemes have maximum errors of 4.4% and 6% in core power distribution across the core height.
- They also have maximum errors of 2.5% and 3% in core power distribution across the core height.
- The simulation of SCEA ejection accident shows core radial plane power distribution errors less than 6%.
-

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KINGS

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