Verification of Advanced SAM Using Constrained Simulated Annealing

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1. Introduction

SAM (Shape Annealing Matrix) is an ex-core detector calibration constant matrix installed in CPC (Core Protection Calculator). SAM is generated and installed once at the beginning of each cycle. Thus, the accuracy of an ASI simulation by CPS is wholly dependent on the accuracy of SAM constants. However, the inaccuracy of conventional SAM using the least squares methodology has been a pending problem of OPR1000 plants in Korea.

OPR1000 plants have experienced the problem of increased CPC axial power distribution RMS (Root Mean Square) error at the EOC (End of Cycle), leading to a decrease of the operational margin. To address these conventional SAM generation method problems, the Constrained Simulated Annealing method was recently developed by KHNP [Ref. 1]. With Constrained Simulated Annealing, the accuracy of SAM was dramatically increased and EOC RMS error was also decreased, and improved operational margin was achieved.

SAM constants are calculated by the computer software CEFAST (Combustion Engineering FAst STartup)[Ref. 2]. Thus, the Constrained Simulated Annealing algorithm was applied to CEFAST software. Compared to the conventional SAM method, the new methodology shows a 50% decrease of the whole cycle CPC axial power distribution RMS error.

For verification of the new methodology, we used operational plant data for the cases where plants exceeded the 8% RMS error recommendation limit (CPC uncertainty penalty is applied to this limit).

2. Comparison of SAM Value using Least Squares and Constrained Simulated Annealing

Generally, a " test value" is used to confirm the validation of SAM results. The test value should satisfy the recommendation limit to be incorporated in the CPC. The definition of a test value is the sum of the absolute values of each Tv matrix element values.

$$T_V = \begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix} \begin{pmatrix} S_{11} & 0 & 0 \\ 0 & S_{22} & 0 \\ 0 & 0 & S_{33} \end{pmatrix}^{-1} \quad (1)$$

- Test value acceptance criteria : 3.0 < Test value < 6.0
- The most appropriate OPR1000 test value is 4.0 ~ 4.1

In spite of the application of test value acceptance criteria, the conventional SAM method has experienced frequent CPC axial power distribution RMS error limit violations at the end of cycle. This means that while the test value may be satisfactory with criteria, the calculated SAM does not satisfy physical meaning. To resolve this problem, constraint conditions are applied to the newly developed method. The constraints built in the new SAM method are as follows:

① The SAM elements S_{11}, S_{22}, S_{33} must be positive values

② The SAM elements S_{12}, S_{21}, S_{23}, S_{32} must be negative values

For verification of the new SAM method, we conducted a comparison of CEFAST results in terms of the SAM matrix and its test values. The outcomes are summarized in Table 1.

Table 1. SAM Values obtained using Least Square and Constrained Simulated Annealing (UCN 3 Cycle 8)

Least Square			Constrained Simulated Annealing		
Channel A SAM					
3.3880	0.8226	-1.9902	4.7019	-0.7999	-1.0362
0.9052	1.9766	0.4691	-0.6956	3.9459	-0.6811
-1.2929	0.2006	4.5213	-0.8397	-0.3564	4.8461
Inverse SAM					
0.4283	-0.1995	0.2092	0.2304	0.0518	0.0566
-0.2276	0.6173	-0.1642	0.0481	0.2675	0.0479
0.1326	-0.0844	0.2883	0.0435	0.0287	0.2197
Test Value =	**4.7104**				**3.9739**
Channel B SAM					
3.6350	0.6489	-2.0137	4.5085	-0.4987	-1.2631
0.9068	1.9195	0.5372	-0.2653	3.4824	-0.5076
-1.5418	0.4316	4.4764	-0.9304	-0.3758	5.0082
Inverse SAM					
0.4084	-0.1843	0.2058	0.2374	0.0409	0.0640
-0.2387	0.6432	-0.1846	0.0248	0.2946	0.0361
0.1637	-0.1255	0.3121	0.0460	0.0297	0.2143
Test Value =	**4.8064**				**3.8699**
Channel C SAM					
4.6883	-0.7878	-1.0442	4.8062	-0.9539	-0.9222
0.8789	2.0013	0.4546	-0.4981	3.9370	-0.9660
-2.5675	1.7867	3.5894	-1.1511	-0.2031	5.0482
Inverse SAM					
0.2425	0.0366	0.0659	0.2266	0.0576	0.0524
-0.1645	0.5385	-0.1161	0.0418	0.2671	0.0587
0.2554	-0.2419	0.3835	0.0533	0.0239	0.2124
Test Value =	**5.4390**				**4.0110**
Channel D SAM					
4.0838	-0.1575	-1.2671	4.5273	-0.7478	-0.8800
0.8983	2.0678	0.2892	-0.7166	4.1726	-1.0472
-1.9819	1.0896	3.9779	-0.9930	-0.2000	4.7972
Inverse SAM					
0.2982	-0.0284	0.0971	0.2399	0.0456	0.0540
-0.1563	0.5178	-0.0874	0.0542	0.2525	0.0651
0.1914	-0.1560	0.3237	0.0519	0.0200	0.2223
Test Value =	**4.6996**				**4.0065**

As c methods satisfy the test value, but the conventional SAM

constants violate physical meaning constraints. It is also verified that the test values of the improved method better converge around the optimal value of 4.0. This means that the new SAM method is physically more accurate and will be more robust to the problem of increased EOC RMS error.
Figure 1 and figure 2 show the trends of the RMS error for the conventional and suggested method, respectively.

Figure 1. RMS error Trend using Least Square (FPA)
(UCN 3 Cycle 8)

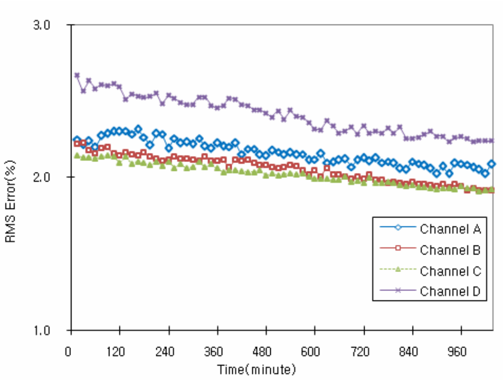
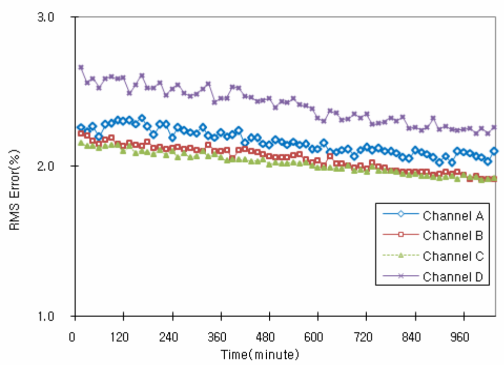


Figure 2. RMS error Trend using Constrained Simulated Annealing(FPA)
(UCN 3 Cycle 8)



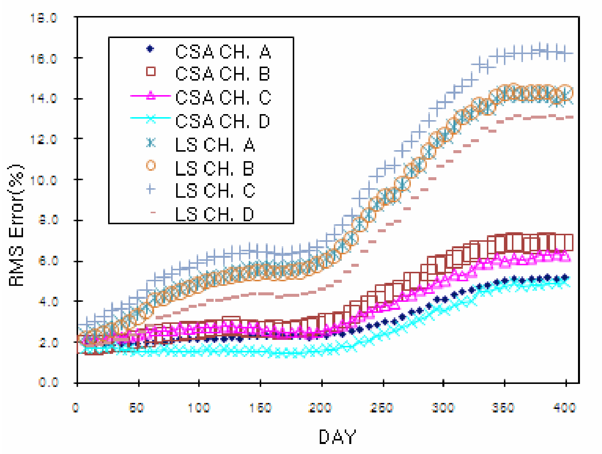
- FPA : Fast Power Ascension

The figures show that the RMS errors of the conventional and suggested methods are similar at the beginning of the cycle. They also verify that both methods are optimal solvers at the BOC.

3. Comparison of RMS error using Least Square and Constrained Simulated Annealing

To verify that the new method offers improved performance, we must confirm its capability to deal with the problem of increased EOC RMS. Using the plant’ s real snapshot data file, we can conclude that the accuracy of the suggested constrained simulated annealing method offers an improvement in performance of more than 50% relative to the conventional method in terms of CPC power distribution RMS error. Figure 3 and Figure 4 show the RMS error trends through the cycle.

Figure 3. RMS Error Trend between least square (LS) and Constrained Simulated Annealing (CSA) for U3C8



From Figure 3, the RMS error of the conventional method increased to 16%, while the RMS error of the improved method remains below 7%. The RMS error of the former continuously increased with increment of cycle burn-up due to inaccurate SAM constants. In contrast, the improved SAM constants, which have physical meaning by newly applied constraints, show relatively small CPC power distribution RMS error increment at the end of cycle.

4. Conclusion and Future Study

Currently, the improved CEFAST code using a constrained simulated annealing method was applied to Ulchin Unit 3 and Younggwangs Unit 4, 5. Through operation experience it has been verified that this new method offers improved performance. This is globally the first attempt at using this approach, and it is expected that it will be of benefit to CE type plants that experience the same problem in the SAM.

Nevertheless, continuous CPC power distribution RMS error monitoring is required for the constrained simulated annealing method when applied to OPR1000 to comprehensively verify that the improved SAM method offers enhanced performance.

REFERENCES

[1] William L. Goffe, Gary D. Ferrier and John Rogers, Global optimization of statistical functions with simulated annealing, Journal of Econometrics, Volume 60, Issues 1-2, 65-99 (1994)
[2] CEFAST User’s Manual (2008.05)