CG-SPSA based Performance Optimization Strategy for the Steam Generation Water Level Control System of Nuclear Power Plant

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Introduction

Steam generator liquid level control system (SGLCS) is an important energy exchange equipment in nuclear power plant, and its control performance has an important impact on the safety, economy and efficient operation of nuclear power plant. The performance optimization process of this system has prominent problems such as time consuming, experience dependence and difficulty to achieve the best.

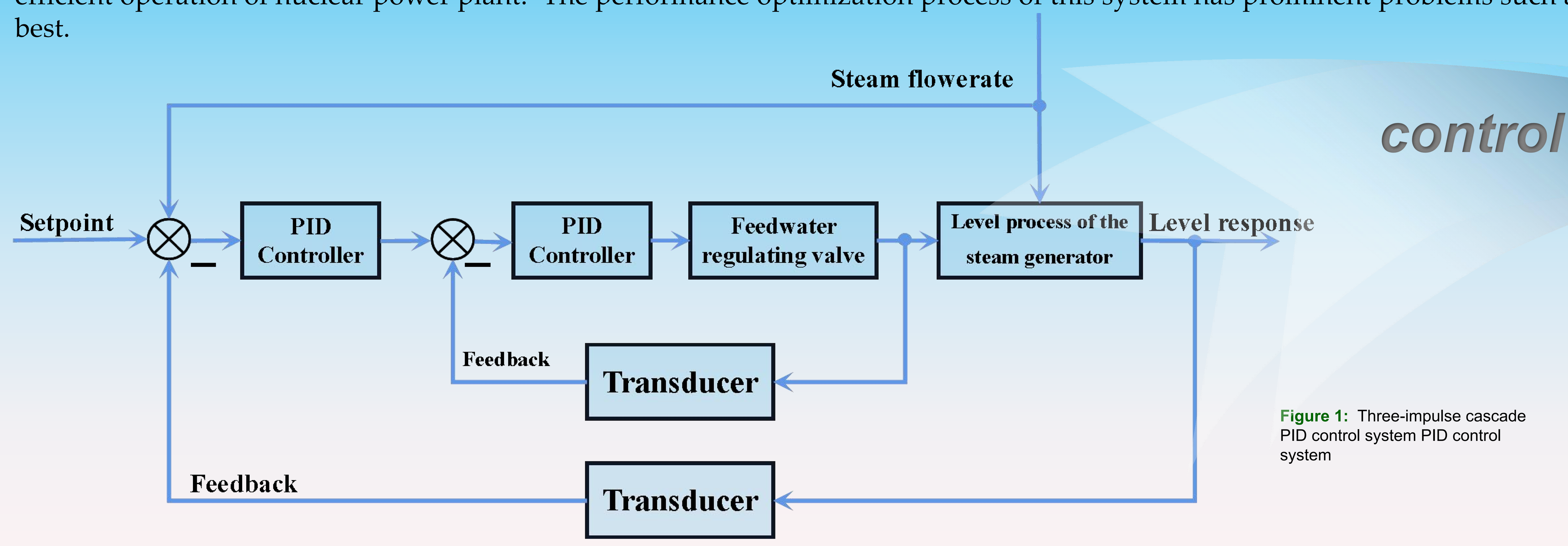


Figure 1: Three-impulse cascade PID control system PID control system

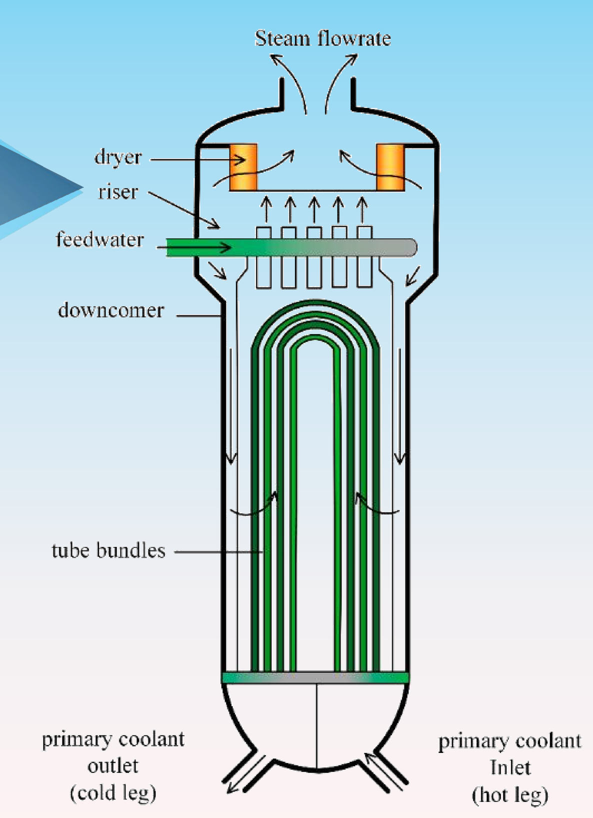


Figure 2: Structure of the U-type SG.

The merits and demerits of SPSA

The traditional SPSA method performs gradient estimation by using perturbation points in random two directions. Since there are six input parameters, there are six directions, while the SPSA method uses a random direction and an opposite reverse vector to approximate the gradient. The two vectors are of equal size and in opposite directions.

Although SPSA can only use two directions in one gradient estimation, in a large sample, the spsa considers all directions when calculating the gradient due to the statistical principle.

- Effectively avoid computing true gradients and thus have superiority in the face of high-latitude optimization problems.
- At a single iteration, the gradient can only be calculated in the random two directions

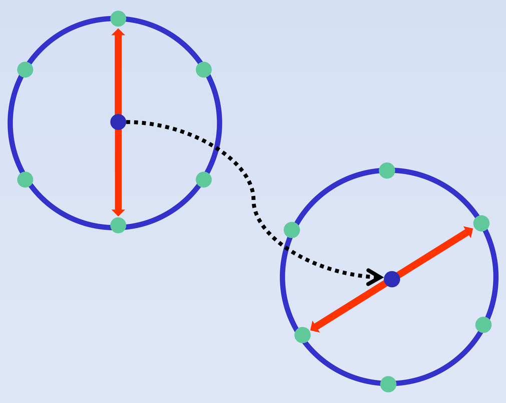


Figure 5: Schematic representation of the principle of the iteration points for gradient estimation

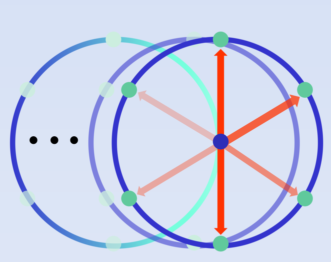
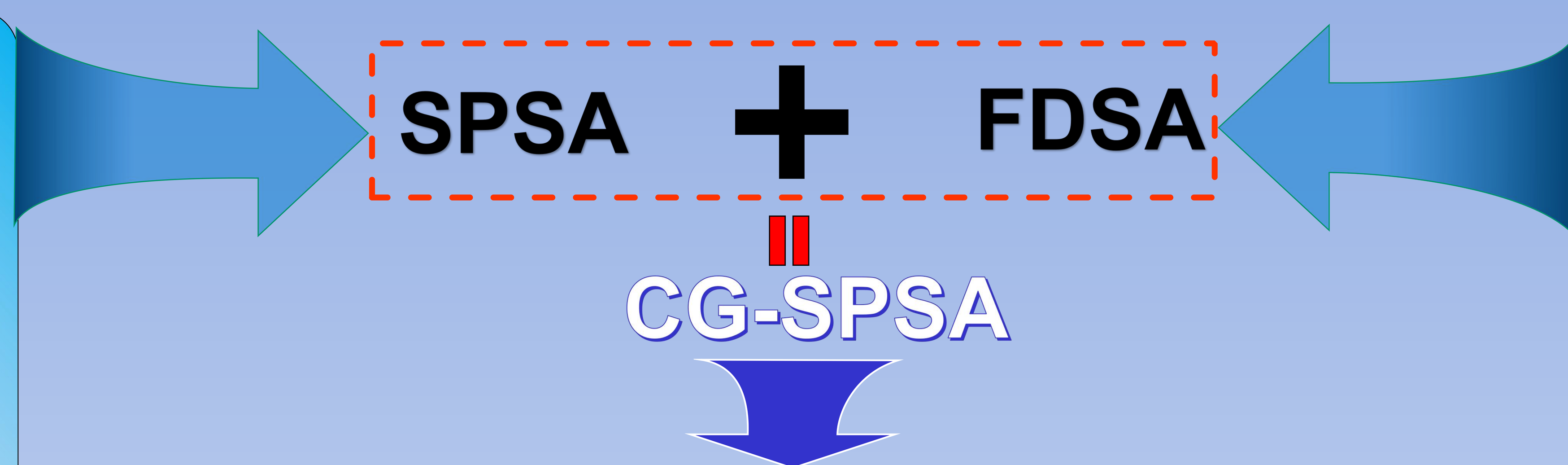


Figure 6: Schematic representation of the principle of gradient estimation under large sample conditions



Optimisation strategy based on CG-SPSA

This method focuses on system performance measurement. Firstly, the dynamic reconstruction mechanism of iterative performance data is designed; Then, the gradient approximation is realized; then, the organic fusion of model gradient approximation and data gradient approximation at the dynamic confidence level is realized, and the optimal estimation of SPSA gradient approximation value is realized. Under the data-driven framework, this method provides a unique idea and implementation mechanism of data-driven and model-driven fusion, which maximizes the use of iterative measurements and effectively improves the efficiency of SPSA method.

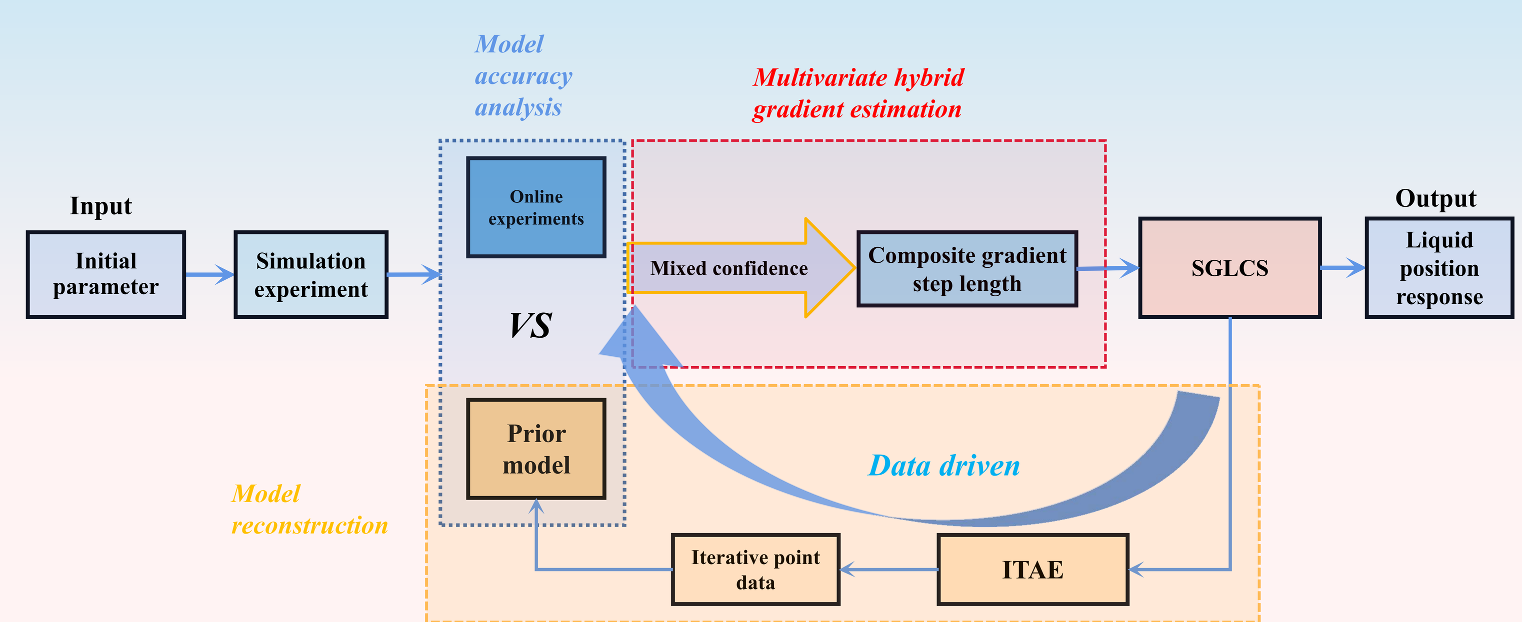


Figure 7: Optimizing Strategy

The merits and demerits of FDSA

The FDSA uses a finite difference method to calculate the gradient. Specifically, the FDSA algorithm uses the difference between the functional values at two consecutive different positions to estimate the gradient.

In each iteration round, the FDSA algorithm computes the partial derivatives of all independent variables and then updates the values of them with a simple update formula.

- The directional gradient for each variable can be calculated
- Each iteration takes too long a time and is not suitable for massive optimization problems

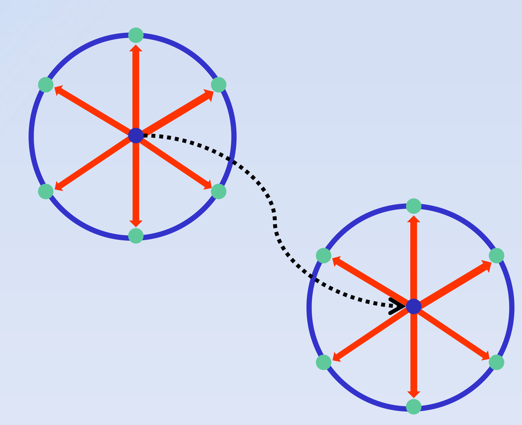


Figure 3: Each variable directional gradient was calculated at each iteration

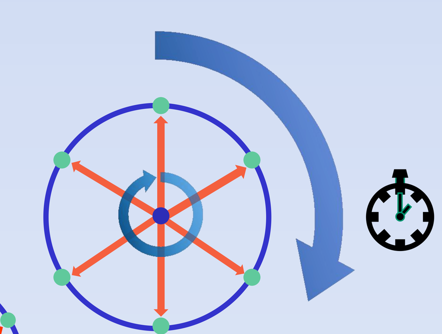


Figure 4: Each iteration is more time-consuming

Experimental results diagram

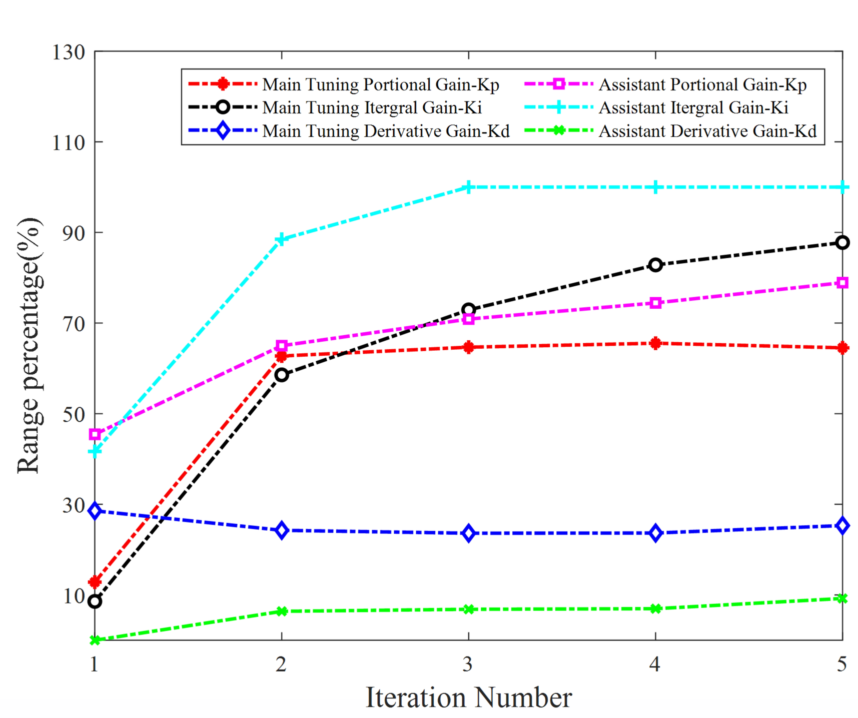


Figure 8: Parameter optimization trajectory plots

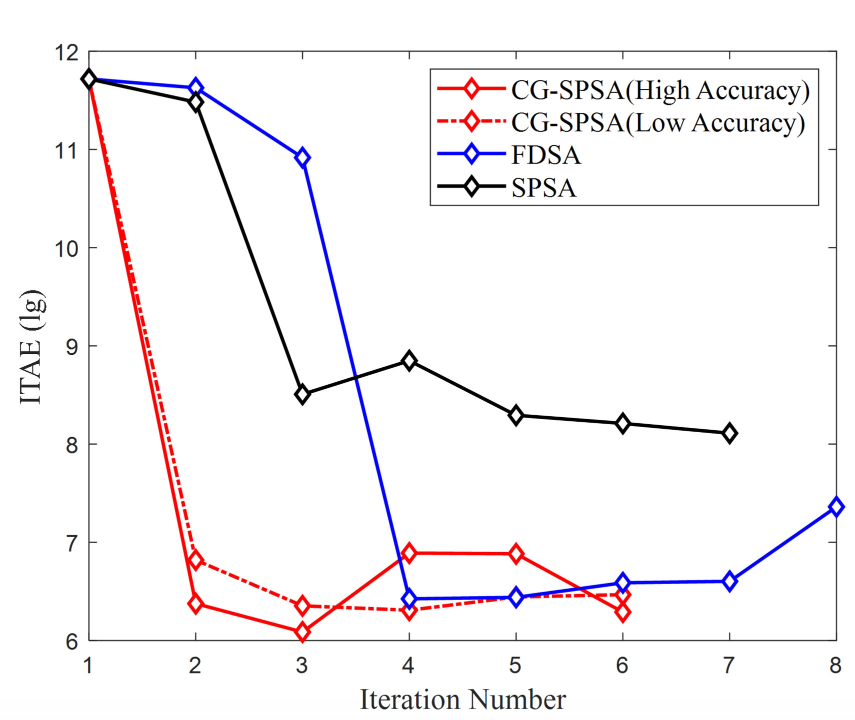


Figure 9: Comparison diagram of optimization of different methods

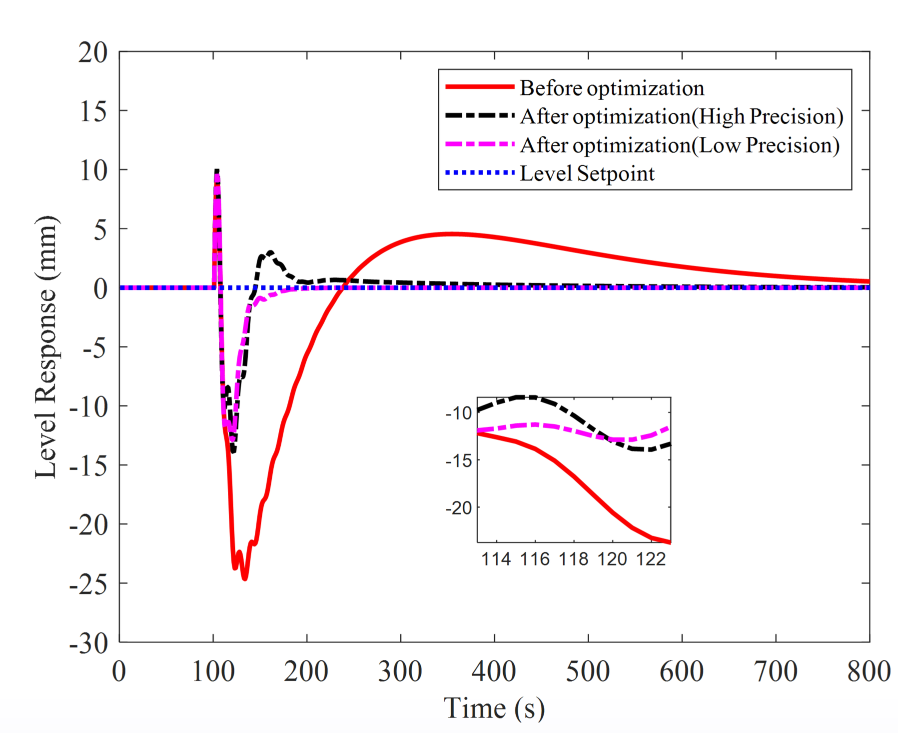


Figure 10: Comparison of liquid level before and after optimization

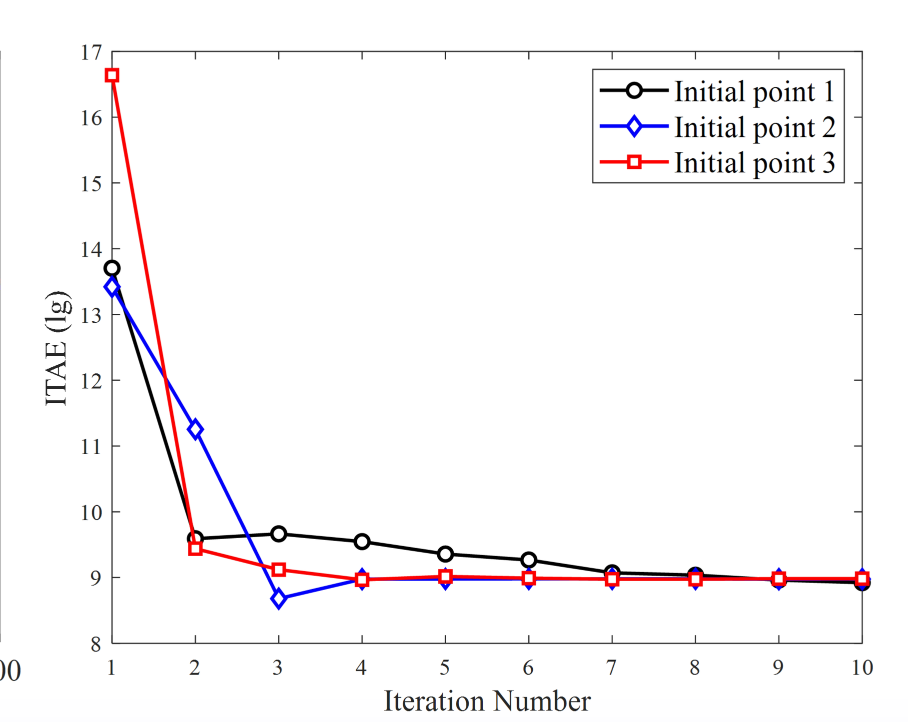


Figure 11: Different initial point optimized comparison Fig

Conclusion

According to the characteristics of the CG-SPSA optimization strategy, the parameters of the control system will be improved as the iterative optimization advances. The trajectory of the controller parameters can be seen in Figure 8.

According to the Figure 9, the ITAE value becomes smaller and smaller with the iteration, indicating that the controller parameters are being optimized. At the same time, it can be seen that the improved CG-PSPSA optimization curve is more stable, because it uses the mixed confidence method to make the gradient calculation more accurate, thus improving the optimization efficiency.

According to the above curve analysis, the model established by CG-SPSA method can optimize the liquid level output at different accuracy levels, and the optimized system stability is enhanced, indicating that the accuracy of the model can affect the system output.

According to the Figure 11, for the three random initial points, they can be optimized, and the effect can be the same, and the same optimal value is found. This proves that the optimization performance of the algorithm is still effective at different initial parameters.