

# Improvement in Stability of HVDC System by Optimizing PI Control Parameters in PSCAD

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## Abstract

**Background/Objectives:** The stability of High-Voltage Direct Current (HVDC) system is improved by optimization of system's control parameters. The simulation model of HVDC network is designed in Power Systems Computer Aided Design (PSCAD) and the Proportional Integral (PI) parameters optimization are achieved by using simplex algorithm. Simulation based evaluation of Integral Time Absolute Error - Objective function (ITAE-OF) is implemented in this paper. **Methods/Statistical Analysis:** Simulation calculation results are iterated to determine the new values of objective function. The model of three parallel HVDC lines connecting Power system of Central-East China is used as a test network. PI control parameters of San-Chang  $\pm 500$ KV HVDC system line are optimized. **Findings:** Optimized results have been achieved by evaluating ITAE-OF using transient simulation and converged via Simplex algorithm in PSCAD. The performance of system in steady state behavior as well as in fault condition is improved through optimized control parameters as compared to the initial control parameters, which are presented by plotting graphs. **Application/Improvements:** The derived equation can be further optimized using the hybrid system.

**Keywords:** HVDC, Optimization, Objective Function, PI Controller, Simplex Algorithm

## 1. Introduction

The stability of AC/DC system is an important performance evaluator for HVDC systems. System's performance depends on its stability. The response of control system towards abnormal behavior such as fault is an important criterion for evaluating the control system efficiency. HVDC control system is influenced by a number of factors, but PI controller is considered to be most influential on overall HVDC system stability because the performance of current controller is affected by PI controller. PI consists of two parameters  $K_p$  and  $K_i$ . The selection of these values should be very precise to get required results. Optimization of these values will be discussed in this paper.

The reason behind wide spread adoption of PI is its simple structure and easy use in the system error detection and stabilization in real time, which make the system

more robust. The conventional method to obtain PI controller values in a system is trial and error method or just guessing the values by experience as used in<sup>1</sup>. Previously, Z-N method was in use to find PI parameters<sup>2</sup>. There are some intelligence algorithms to find out PI controller values hence enabling the system designer to find the optimal values of control parameters without any extensive experience and significantly save the time, which may have been consumed using trial and error techniques. Simplex algorithm is one of the optimization techniques, which is used in this paper to get the optimal values of PI controller parameters.

The Objective Function to be optimized is first required in such algorithms. The objective function adopted by<sup>3</sup> is Integral time absolute error (ITAE). It is used to find the optimal solution of HVDC system by optimizing  $K_p$  and  $K_i$  values of PI controller. The equation of current error is derived from closed loop of the HVDC

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system by using the transfer function of each component. The derived equation is further optimized in MATLAB. However due to a large system and a lot of approximations, even after the optimization of control parameters, system performance still had a room for improvement.

In this paper, the simulation based current error is formed for objective function, instead of designing equation from closed loop of system by considering transfer function of all components as discussed in reference<sup>4-10</sup>. This method is easy and give accurate values of the control parameters, because of absence of approximations which were used in earlier cases for forming the system equations. However, the computing resource required in this kind of optimization technique is significantly higher. All optimization process is performed in PSCAD<sup>9</sup>.

## 2. Simplex Algorithm

Nelder and Mead introduced nonlinear-simplex method of heuristic optimization, which is based on geometric consideration. Geometric object formed in an n-dimensional space by set of n+ 1 vertex is called a simplex. Simulation software (PSCAD) evaluates the OF from the starting vertices given to simplex. Generate new vertices by reflection, expansion and contraction of vertex. On the basis of solution to the provided by the simulation program, simplex generated new vertices and use them for the evaluation of the objective function by the simulation program once again. By repeating this process for number of times, fitness values of objective function gradually reduce until it reaches in the vicinity of the optimum point<sup>3-5</sup>. Choosing optimized control parameters help to improve the performance of the system by enhancing system's response, which in turn make a system robust. Number of variables can be optimized at a same time in simplex algorithm but it is difficult to choose initial parameters for the system, and also it gets the optimum parameters only in certain range; does not cover the full range<sup>5,6</sup>.

Simulation based optimization by using simplex algorithm is elaborated with the help of flowchart as shown in Figure 1<sup>7,8</sup>. First step is to provide the initial values of control parameters to the simplex algorithm. Objective function is evaluated for those initial parameters by simulation and the results for current error are stored in the simplex algorithm's storage. On the basis of these results, new value of system parameter are provided by the simplex algorithm and system runs once again for the new value of control parameters and results for

current error are once again evaluated. Simplex than see's whether the objective function is converging or diverging and based on this provides new values of control parameters. This process keeps on running until the optimal value of control parameter is obtained.

## 3. Objective Function

The idea of simulation based objective function is being applied in this paper. In this technique, the objective function for specific problem can be designed in a simulation program such as PSCAD. The ITAE is adopted as objective function, which is expressed in references<sup>6,10</sup> as,

$$J_{ITAE} = \int_0^T t |e(t)| \quad (1)$$

The current error is directly taken from transient simulation run of the system and then it is introduced to Objective Function to find fitness value. This provides an easy handling in finding Kp and Ki value of PI. Initially, it was applied on CIGRE Benchmark HVDC model, and then finally used in San-Chang HVDC System. Moreover, the results are more accurate and there is no need to write up equation for finding current error using transfer function of all components as it was used in conventional methods. The Objective Function used for the optimization of San-Chang HVDC is,

$$O.F. = \int_0^{ts} t \cdot |\Delta I| \cdot dt \quad (2)$$

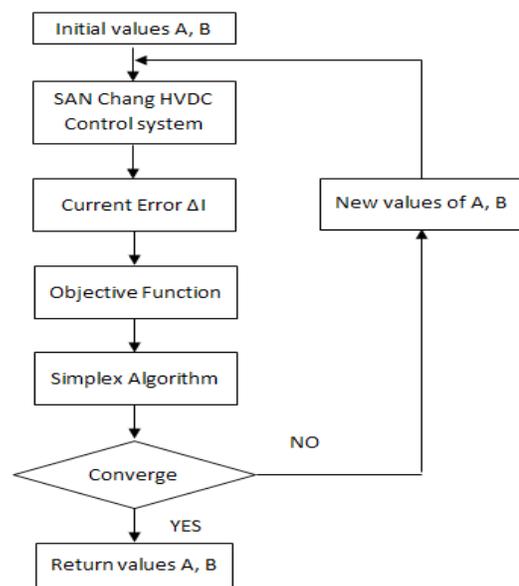


Figure 1. Flow Chart of Simplex Optimization.

$$OF = \int_0^t t \cdot |(I_{ord} - I_m)| \cdot dt \quad (3)$$

where,  $\Delta I$  represents the current error in an equation. ' $I_{ord}$ ' is the order current and ' $I_m$ ' is DC measured current. ' $t$ ' is usually set to settling time (when a system attains steady state)

The equivalent model of objective function used in an optimization system is given below. Integration of multiple of  $\Delta I$  and time gives an objective function, which is given to simplex algorithm for optimization and generating new values for PI. ITAE objective function is shown in Figure 2. It consists of time and integral. The current error  $\Delta I$  from transient simulation is given to its input; the absolute of  $\Delta I$  multiplies with time as well as integrate with respect to time and generate fitness value at its output. The block diagram of a optimization using network simulation through converging fitness value of objective function is shown in Figure 3.

The convergence in fitness value of objective function is shown in Figure 4. It can be observed that initially the fitness value is high, which then reduced to minimal fitness value after being converged through simplex algorithm. The objective function is converged after 130 numbers of iterations.

### 4. Experiment and Observations

The simulation model of three lines HVDC interconnecting Central-East China Power system is used as a test

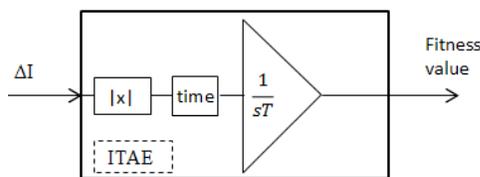


Figure 2. ITAE Objective Function.

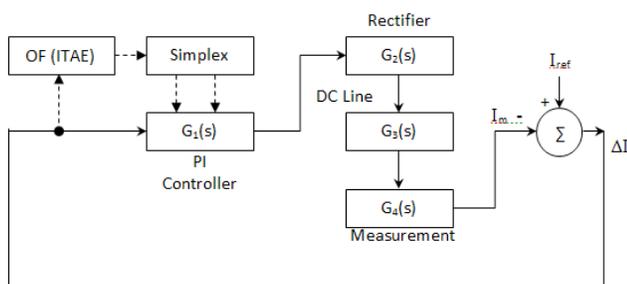


Figure 3. Close-loop of HVDC system and Objective Function.

network shown in Figure 5. Power capacity of three lines is 3000MW, 3000MW and 1200MW. Improvement in stability of San-Chang interconnection HVDC line (first HVDC line of Figure1), which connects Three Gorges to Changzhou is presented in this paper. San-Chang HVDC system has bipolar HVDC configuration spread on 940Km long line with rated voltage of  $\pm 500$ KV. Total capacity of San-Chang HVDC line is 3000 MW (Upper and Lower side of bipolar 2x1500).

Inspection of rectifier and inverter power of HVDC line 1(San-Chang) is considered. After completing the simulation, it was observed that the results were very good and optimized. The transient overshoot in current was 2.0 p.u, which was changed to 0.6 p.u. Stabilizing time of voltage was improved. The active and reactive power of rectifier and inverter side of San-Chang HVDC line is taken under consideration. Symbol  $\pi$  represents AC transmission. To observe the response of system under fault condition, the fault is applied near the rectifier side of third line as shown in Figure 5. The optimized PI parameters value obtained after multi-runs of simulation by using simplex algorithm are shown in Table 1.

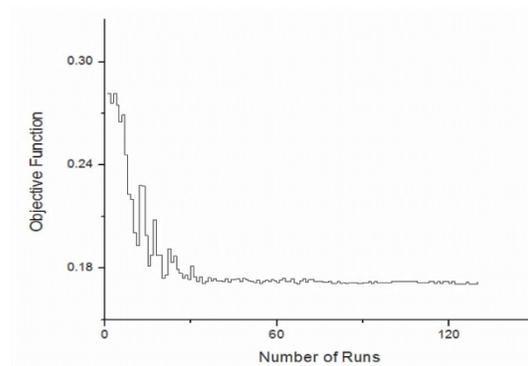


Figure 4. Convergence curve of Objective Function.

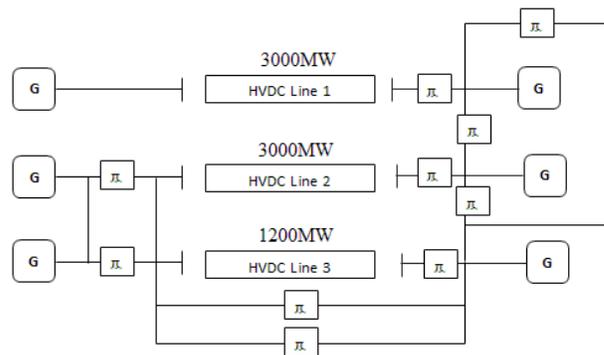


Figure 5. Test network model.

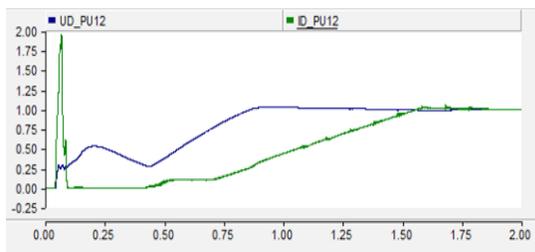
### 4.1 Pre Fault Analysis

The transient response of the rectifier side of the system running in the normal condition is being observed in Pre-Fault Analysis; as rectifier side is showing apparently difference in the comparison graph of two different control parameters. Comparison of voltage and current graphs are shown in Figure 6 and Figure 7. The DC current and voltage of first line rectifier side when the system is simulated with initial control parameters are shown in Figure 6. In graph, the green curve represents the DC current while the blue curve represents the DC voltage.

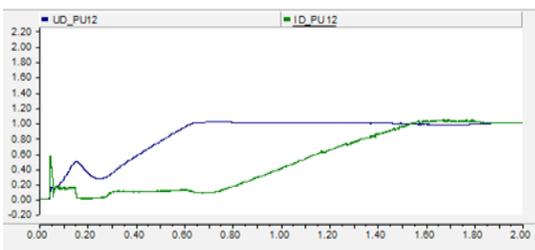
DC current and voltage of first line when the system is simulated with optimized control parameters are shown in Figure 7. It can be noticed that current overshoot and voltage settling time has been improved in optimized results. Power Comparison graphs obtained from initial and optimized control values are displayed in Figure 8 and Figure 9 respectively. The rectifier's side active and reactive powers when initial PI control

**Table 1.** Comparison of Init. & Opt. Control Parameters

Control Parameters	Initial Values	Optimized Values
Kp	2.8	7.03125
Ki	23	33.3664



**Figure 6.** V and I of Rectifier Side with initial control values.

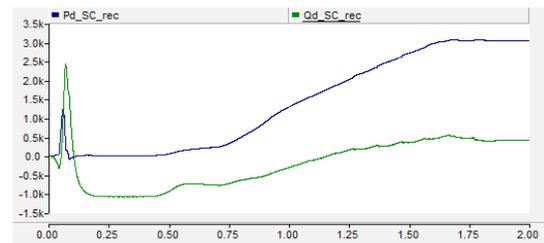


**Figure 7.** V and I of Rectifier Side with optimized control values.

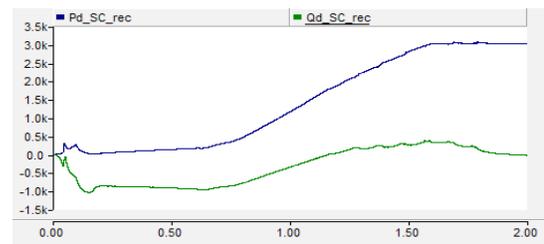
parameters were set are shown by green and blue curves respectively in Figure 8. The results displayed when the optimized control parameters were set are shown in Figure 9. Active Power as well as reactive power overshoots, which can be seen in Figure 8, has been reduced in optimized result.

### 4.2 Post Fault Analysis

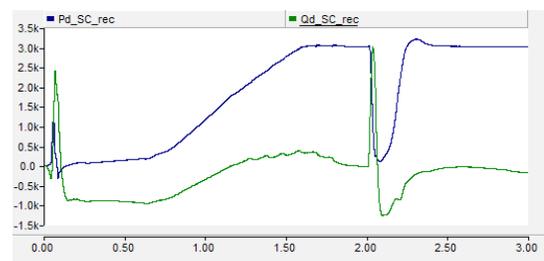
Three phase to GND fault; A, B, and C with ground near the rectifier side of the third HVDC line is introduced in a system. The results are gathered from experiments with initial and optimized parameters of the system. The fault is introduced for a period of 0.04 seconds from 2 - 2.04 seconds. The results appeared after using Optimized control parameters are shown in Figure 10 to Figure 13. Power



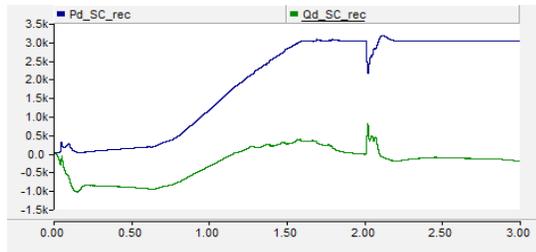
**Figure 8.** Power of Rectifier Side with initial control values



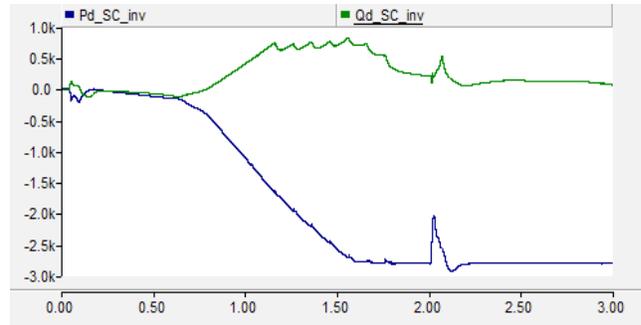
**Figure 9.** Power of Rectifier Side with optimized control values.



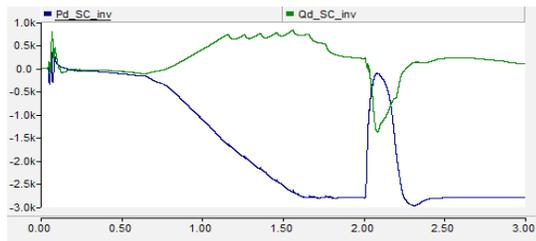
**Figure 10.** Rectifier Power in fault condition with Initial control parameters.



**Figure 11.** Rectifier Power in fault condition with Optimized control parameters.



**Figure 13.** Inverter Power in fault condition with Optimized control values.



**Figure 12.** Inverter Power Response in fault condition with initial control values.

**Table 2.** Performance Comparison without fault

System Parameters	Current Overshoot	Voltage Settling time
<b>Initial Result</b>	2 (p.u)	0.88 (sec)
<b>Optimized Result</b>	0.6 (p.u)	0.6 23(sec)

**Table 3.** Performance Comparison in fault

System Parameters	Current O.S.	AC voltage difference Rectifier	Min AC Power(P) Rectifier	Variation in AC Power(P) Rectifier	Variation in AC Power(Q) Rectifier	Variation of AC Power(P) Inverter	Variation of AC Power(Q) Inverter
<b>Initial Result</b>	2 p.u	1.5 p.u	86 W	3006	4580	2735	2192
<b>Optimized Result</b>	1.4 p.u	0.06 p.u	1336 W	1665	2048	1515	1414

drop on the rectifier side has been improved in optimized result as compared to the initial result, as shown in Figure 10 and Figure 11 respectively. The variation in power drop is shown in Table 3.

## 5. Results

Results are showing improvement in system’s parameters as shown in Table 2 and Table 3. In Table 2, the starting characteristics of system are reported; when no fault is applied in a system. In Table 3, the response of system under fault condition is reported. Variations in different parameters of system are significantly reduced, when system is operated with optimized control values. The improvement in number of system’s parameters are observed, which is presented in Table 3. Approximately 30 percent current overshoot is improved and voltage

variation is reduced to very minimal value during fault condition from optimized control parameters. Also, the variation in power is lessened in optimized results as compared to initial results. The comparison table of system’s parameters in normal and in fault condition is shown in Table 3.

## 6. Conclusion

Simulation based optimization method is presented in this paper. Finding fitness value of the Objective Function is very feasible when system parameters values taken directly from simulation results specially in complex networking, which in turn avoids to make tough mathematical equations. The results obtained from optimization process are very satisfactory. System has become more robust with optimized control parameter values. The improvement

in Settling time, Overshoot, and variation of Power drop (in case of fault condition) are observed. After precisely observing other results of system, it is noted that the some system parameters have inferior results, but overall the system has become more strong and stable.

## 7. References

1. Ziegler Z, John G, Nathaniel B, Nichols N. Optimum settings for automatic controllers. *Trans ASME*. 1942; 64(11):1–9.
2. Gole AM, Filizadeh S, Menzies RW, Wilson PL. Optimization-enabled electromagnetic transient simulation. *IEEE Trans Power Del*. 2005; 20(1):512–8.
3. Zhang Y, Liu C. Parameters Optimal Design of HVDC PI Controller Based On APSO Algorithm. *IEEE Power and Energy Engineering Conference (APPEEC)*, Asia-Pacific. 2012.
4. Jia Z, Zhao C, Lu X, Li G. Parameters Optimization of VSC-HVDC Control System Based on Simplex Algorithm. *IEEE Power Engineering Society General Meeting*. 2007; 1–7.
5. Mumtaz M, Mumtaz A, Khan MN. Energy Aware Routing Using Improved LEACH Protocol. *Universal Journal of Communications and Network*. 2015; 3(3):64–7.
6. Yong J, Zhen R, Kaijian O et al. Parameter estimation of regulators in Tian-Guang HVDC transmission system based on PSCAD/EMTDC. *Proceedings of 2002 International Conference on Power System Technology*, Kunming. 2002; 538–41.
7. Filizadeh S, Gole AM, Dennis A. An optimization enabled electromagnetic transient simulation-based methodology for HVDC controller design. *IEEE Trans Power Del*. 2007; 22(4):2559–66.
8. PSCAD/EMTDC User's Manual Winnipeg, Canada: Manitoba HVDC Research Center.
9. Haripiya, Sreedevi A. Optimization of HVDC controls with PSO algorithm developed in MATLAB/SIMULINK. *IEEE International conference Circuits, Controls and Communications (CCUBE)*. 2013; 1–6.
10. Gole AM, Filizadeh S, Wilson PL. Inclusion of robustness into design using optimization-enabled transient simulation. *IEEE Transactions on Power delivery*. 2005; 20(3):1991–7.