Optimal Control Method of Power System based on Computer Aided Technology

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Abstract: With the gradual progress of electricity, the problem of power system transient stability has become increasingly prominent. The emergency fault in the operation of power grid has a great damage to the security of power grid, some tools are used to control the stability of electricity. In this paper, aiming at the problem of power system control, combined with computer replication technology and dynamic optimization method, the related theoretical research is carried out and the optimal control is realized. The multiple shooting method and GrHDP algorithm are applied to the optimization of power system control, and the emergency control calculation under transient stability constraints is realized, which provides theoretical and application reference value for the dynamic optimization of power system. The results show that the dynamic equivalence algorithm based on GrHDP can track the change trend of the total system more accurately than the coherency equivalence method under different operation conditions and fault modes.

Key words: computer aided design; Power system; NLP
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1. INTRODUCTION

Power system is a system of power generation, transmission, transformation, distribution and consumption. It can convert the natural disposable energy into electric energy through power generation device. Power system is dimensional and nonlinear. Modeling is the basis of its analysis, calculation and control [1]. A large number of experiments and calculations indicate that the accuracy of modeling may affect the voltage stability, short circuit calculation and safety analysis in varying degrees, and even change the qualitative conclusion completely when it is in a critical state. Previous studies usually focus on a fixed component or a fixed operating point. At the same time, with the fast expansion of the scale of the power grid, the power system has become a large high-dimensional system, and the substantial increase of system nodes has a huge pressure on modeling. It is very difficult to realize the accurate modeling of power system because of the changeable operation state and the uncertainty of some system parameters. On the other hand, the modern power is a big-scale system, and the appropriate and effective control is the key to guarantee the safety and stable operation of the system. However, there are many saturated, hysteresis, nonlinear and delay components. The controller is often designed based on a certain operating point, and the control effect largely depends on the accuracy of the model and parameters of each component in the power system. When the operating conditions change greatly, the system model is not accurate enough or the system parameters are uncertain, the controller is difficult to achieve effective control of the system, or even to ensure the safety of the system [2]. The new energy represented by photovoltaic and wind power has the characteristics of intermittence and volatility. After a large number of new energy is connected to the power system, the volatility of weather will cause the irregular input and exit of new energy power stations, which is easy to have a greater impact on the active power balance of the power grid and cause frequency offset. With the increasing proportion of new energy in modern power grid, a large number of traditional generating units will be replaced. However, the existing new energy technology does not have mature frequency regulation measures. In the absence of high power, it is easy to cause frequency problems. In addition, compared with the traditional generating units, the frequency tolerance of new energy generating units is insufficient. When serious disturbance occurs in the power system, it is easy to cause large-scale new energy unit off grid, resulting in serious cascading failure. Since the 21st century, computer technology has been advancing rapidly, especially the development and popularization of computers and workstations. In addition, the appearance of powerful peripheral equipment, such as large-scale graphic display, plotter and laser printer, greatly promoted the development of CAD technology [3]. It aims at taking standardized management as the basis, information construction as the means, highlighting and strengthening the work process management as the focus, standardizing and unifying the work processes of power supply station as the core, and improving the management performance and work quality as the purpose, so as to continuously promote the power supply management work to gradually achieve the requirements of standardization, procedure, refinement and institutionalization.

2. RELATED RESEARCH

Emergency control is an effective means to guarantee the stable operation of power system after failure. In the formulation of emergency control strategy, Buonamici et al. [4] put forward various control methods. Generally speaking, there are three kinds of emergency control measures for power system transient stability: first, automatic reclosing is widely used as the main means to remove faults; The second is to increase the transportation capacity of the system as the main means; The third one is based on the principle of balancing the receiving end, with the main means of cutting off the generator and load, electric braking and quick closing the steam valve of the steam turbine . When the emergency control scheme is formulated based on the above measures, the minimum economic cost of system operation is usually taken as the objective, and the optimal strategy is calculated under the time scale of electromechanical transient process. There are several kinds of strategies. The second is intelligent algorithm. This kind of algorithm simulates intelligence, and the model has strong adaptability, and it is easy to get feasible solutions in complex problems. Kiselyova et al. [5] and Mukherjee et al. [6] respectively use neural network algorithm and ant colony algorithm to calculate the machine and load shedding. The heuristic algorithm is intuitive and simple, and it is easy to obtain feasible solutions, but it costs a lot of calculation.

The third is based on dynamic optimization problem model. Salman et al. [7] use constraint transformation method and control vector parameterization method to solve the problem. The emergency control problem with transient stability constraints is decomposed into sensitivity calculation and nonlinear programming problem. Cruz et al. [8] use implicit trapezoidal integration algorithm and finite element orthogonal collocation algorithm to discretize the transient stability constraints and solve the generated problems. The solving strategies of optimal control problems include indirect method (variational method) and direct method. The latter has good convergence and can easily deal with inequality constraints, which has become the main research direction of optimal control.

3. ANALYSIS OF MATHCAD-ASSISTED MATHEMATICS EXPERIMENTS INTO HIGHER MATHEMATICS TEACHING MODE

3.1. Dynamic Equivalence of Power System based on GrHDP Algorithm

With the gradual progress of electricity, the power system structure is gradually developing to the trend of large power grid, large units and AC/DC hybrid transmission. The dimension and complexity of power system simulation calculation, off-line analysis and on-line analysis are greatly improved [9]. If the detailed model of the system is adopted, the problem of "dimension disaster" will appear. However, in practical research, usually only focus on the dynamic characteristics of a certain region, called internal system or research system. For other regions, we usually only care about whether it has an impact on the internal system and the extent of the impact. The process of keeping the dynamic process of the original system unchanged and properly simplifying the external system is called dynamic equivalence of power system. The system is running near the stable operation point, and the existing dynamic equivalence method has good accuracy. However, when the system operating conditions change greatly or faults occur, the existing dynamic equivalence method will have a large deviation. So, this section proposes a dynamic equivalent method of power system based on GrHDP algorithm.

According to the rotor swing curve obtained by time-domain simulation, the coherent units are divided. The main design idea of coherency equivalence is formed by adding generator bus aggregation, network simplification and dynamic aggregation of coherency generators [10]. Usually, this method calculates the rotor angle curve of the original system model and adjusts the disturbance to determine whether it is a coherent unit, which saves a lot of time and makes it possible to calculate the equivalent value of small computer. The mode equivalence method is a mode equivalence method. Firstly, the key modes of the system are found through modal analysis, and the corresponding generator groups are found according to the modes, and the key modes are retained. Then, the order of the system is reduced by reducing the number of modes to reduce the amount of calculation. Estimation equivalence method is a kind of calculation method to identify and estimate according to the measurement results or the actual system response. This method is mainly suitable for complex system or model free system. There are two main types of online estimation methods, one is to simulate the system with deterministic excitation, get the output of the system, and estimate the equivalent system parameters accordingly. Another method is to simulate the system by random excitation, and estimate the parameters of the equivalent system after a certain filter. The advantages and disadvantages of the three equivalence methods are shown in Table 1.

	Superiority	Inferiority
Simultaneous adjustment method	For steady state analysis Suitable for mathematical analysis Very malleable	Post processing is complex Difficulty in early design High cost
Module consistent method	Related to disturbance location Fuzzy mathematics concept The external system is simple	High cost It takes a long time Large amount of calculation
Evaluation consistency method	Suitable for physical analysis Suitable for complex structures External system integrity	The results are not stable Large amount of calculation Higher level required

Table 1：Comparison of superiority and inferiority of three equivalence methods.

It can be seen from table 1 that the conventional equivalence method lacks universality, and has their own obvious shortcomings. This paper presents a dynamic equivalence method of power system based on grhdp algorithm. This method needs less calculation, does not need to rely on experience, and has no requirements for disturbance location and disturbance type. This method does not need the system model, does not produce the "dimension disaster" problem, and can also predict the future state of the system. The flow chart of dynamic equivalence method based on GrHDP is shown in Figure 1 and Figure 2.

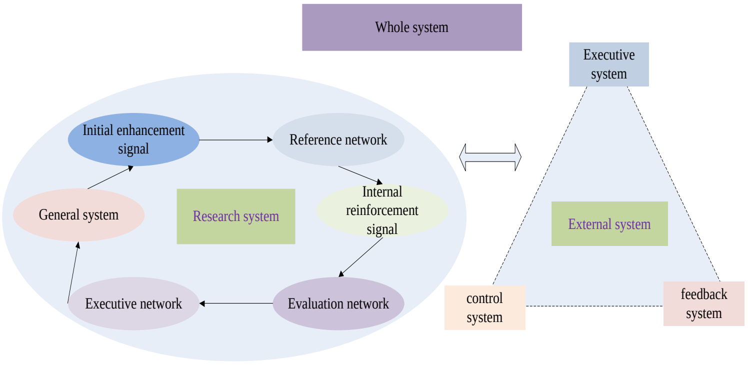


Figure 1: Structure of the original system.

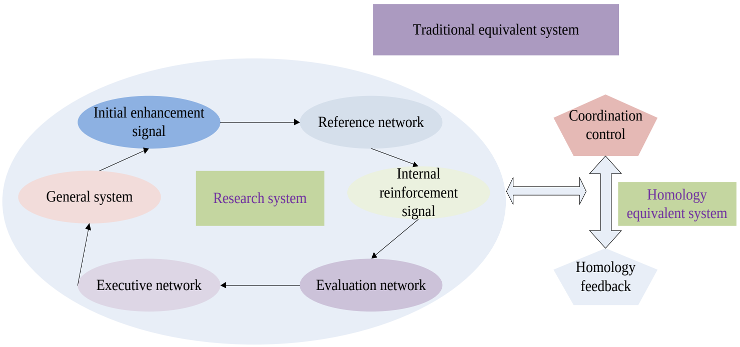


Figure 2: Structure diagram of equivalent system.

The whole system is divided into the research system and the external system. The homology equivalent method is used to equivalent the external system to obtain the equivalent system with simple structure, as shown in Figure 2. The dynamic equivalence method based on GrHDP proposed in this paper adds a compensation link based on GrHDP algorithm on the basis of homology equivalence system, it can compensate the difference between the original system and the homology equivalent system, and better track the dynamic characteristics of the original system, as shown in Figure 3.

3.2. Transient Stability Emergency Control based on Multiple Shooting

The development of modern industry makes the scale and behavior of the system more and more complex, which improves the requirements of the control system. For large-scale systems, optimization technology has brought great economic benefits, and dynamic optimization of control process has become an important engineering research direction. In the optimization of steady state process, researchers only focus on some steady state of the system.

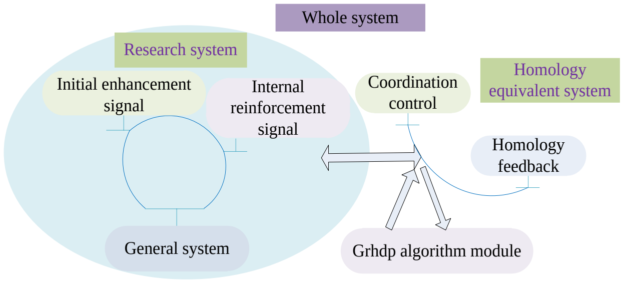


Figure 3: Structure diagram of equivalent system based on GrHDP algorithm.

The constraints and objectives of the optimization are fixed at a specific time point, and the dynamic process of the system is not considered. In the actual industrial process, various forms of fluctuations and disturbances are always difficult to avoid, destroying the original steady-state process, forcing the system to move to a new equilibrium point, or making the system balance collapse. In order to study the dynamic changes of the system, the dynamic model of the system is established to simulate the behavior of the system in a period of time, and the optimal control strategy of the system under the relevant constraints is obtained. In the industrial models of aerospace, energy, chemical industry and electric, the mathematical description of dynamic process is mainly in the form of differential algebraic equations (DAE) and inequality constraints. Differential equations describe the change of state variables with time. Algebraic equations indicate the equality relationship between state variables and algebraic variables and control variables in dynamic process. Inequality constraints specify various constraints in dynamic process. Generally speaking, control variables include time variables and non-time variables, which are called static parameters. For dynamic optimization of all non-time variables, it is also called trajectory optimization. The state variable of power system components can be described by differential equation or difference equation. The model of dynamic process is the model of transient stability control of power system. Dynamic optimization method is to set the control variables in the dynamic process, and make the control target reach the optimal under the premise of satisfying the constraints of dynamic model. Numerical methods are usually used to solve complex dynamic optimization problems. In the 1950s, Behrman studied dynamic optimization problems. Today, many methods for solving dynamic optimization problems have been produced, and the complexity of the problems is also growing. The principle of optimal control has been applied to all branches of Engineering Science. There are two numerical methods for solving optimal control problems: indirect method and direct method. The indirect method uses the variational method as a mathematical tool to derive the first-order optimal conditions of the original dynamic optimization problem, and obtains a multi-point boundary value problem. The solution of the problem is the possible optimal trajectory, corresponding to the extreme value of the original problem. In the direct method, the state variables or control variables are discretized in a certain way, and the original problem is transformed into a nonlinear optimization problem (NLP), which is solved by conventional optimization techniques.

In the indirect method, if the system of differential equations satisfying the end point and interior point constraints has a solution, the dynamic problem will be solved indirectly; In contrast, direct method means that an infinite dimensional optimization problem is directly transformed into a finite dimensional optimization problem. The former came into being earlier, and its research field focused on differential equation theory, while the latter is the mainstream research direction of dynamic optimization, and its research field focused on optimization technology. At the same time, there are some researches on the correlation between the two. The differences between the two methods in research fields are shown in Figure 4.

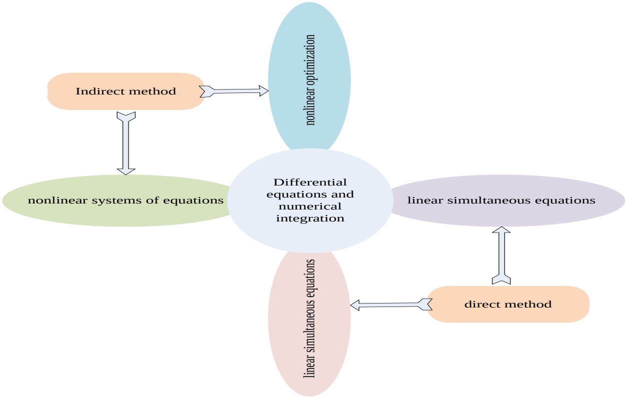


Figure 4: Research fields of indirect method and direct method.

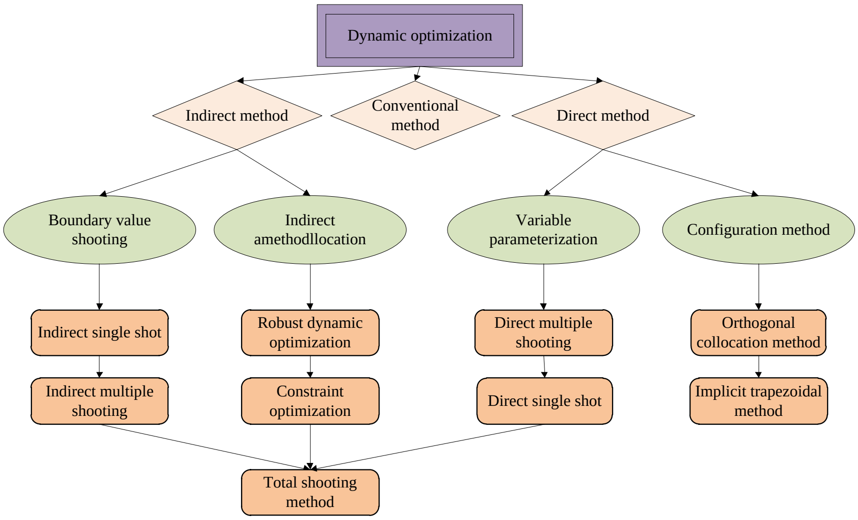


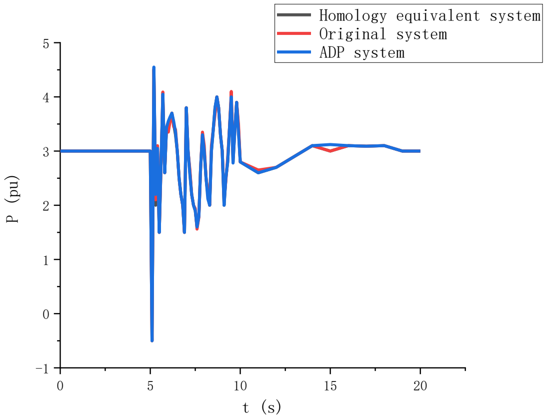
Figure 5: Numerical solution of dynamic optimization.

The direct method approximates the state variables and control variables to some extent. In direct method, the method that only control variables are discretized is called control variable parameterization, also called sequential method, including direct single shot method and direct multiple shot method. The method that controls variables and state variables are all discretized is called simultaneous method, including implicit trapezoidal integration method, finite element orthogonal collocation method, pseudo spectral method and so on. The solutions of dynamic optimization are classified as follows. The direct method is the main content of this paper. Figure 5 is the numerical solution of dynamic optimization.

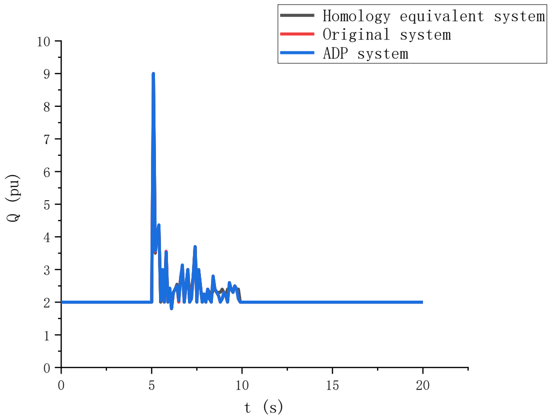
4. ANALYSIS AND RESULTS

4.1. Analysis based on GrHDP Algorithm

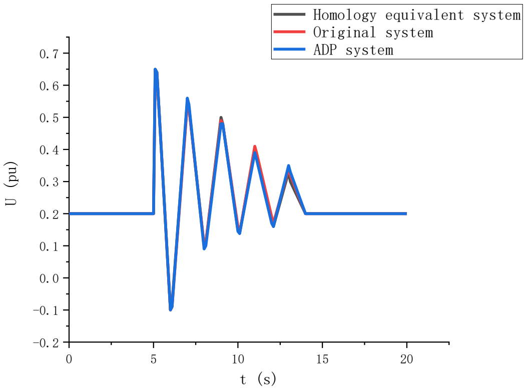
The dynamic equivalence algorithm based on GrHDP and the homology equivalence method are compared and simulated. The working condition is: when t = 5s, the three-phase short circuit fault occurs at node 3, the duration is 0.1s, and the transmission power of external system 2 is 1.0pu. The dynamic characteristic comparison and simulation results of unit 1 are shown in Figure 6. The red line is the output of the original system, the black line is the output of the coherent equivalent system, and the blue line is the output of the dynamic equivalent algorithm based on GrHDP, the same below. Because the equivalent parameters of the coherency equivalent system are calculated under this condition, the control effect is very good. In this case, the dynamic equivalent system based on GrHDP and coherency equivalent algorithm can quickly track the dynamic response of the original system.



(a)



(b)



(c)

Figure 6: Comparison of dynamic characteristics of unit 1: (a) Comparison diagram of active waveform of unit 1, (b) Comparison diagram of reactive power waveform of unit 1, (c) Voltage waveform comparison diagram of unit 1.

4.2. Algorithm Analysis based on Multiple Shooting

(1) Test example parameters

Theoretically, the stability of partial discretization scheme is lower than that of global discretization scheme, and the imprecise matrix updating method introduces more instability factors. This limits the application of the multiple shooting method described in this chapter. Therefore, in the actual calculation, the example of the multiple shooting method is changed on the basis of the pseudo spectral method in Table 2.

Demonstration	Number of nodes	Number of generators	Number of loads	Number of fault lines	Fault clearing time（s）
48	38	9	18	25-28	0.3
160	162	23	88	25-70	0.3
180	180	34	66	18-33	0.3
198	198	47	75	14-28	0.3
211	211	33	121	23-33	0.1
288	288	68	188	9-15	0.3
665	665	145	105	3-23	0.3
1223	1223	439	212	21-53	0.3
2108	2108	320	105	20-150	0.2

Table 2: Test examples of multiple shooting method.

(2) Parallel testing

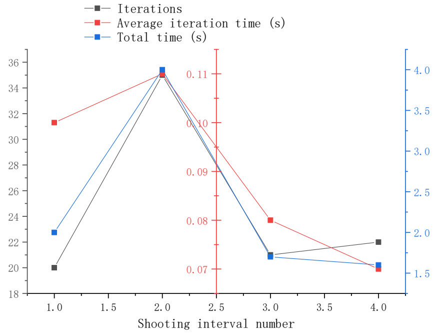
The optimization period is divided into two shooting intervals to test the multiple shooting method. When only one shooting area is selected, the multiple shooting method degenerates to single shooting. At this time, only one thread is called for calculation. The calculation results are shown in Table 3.

Demonstration	Interval	1	2	3	4
48	Iter Ts/Tp	11 2.3	23 3.6	34 5.5	22 7.1
160	Iter Ts/Tp	11 11.5	23 15.6	33 16.1	28 22.8
180	Iter Ts/Tp	56 5.5	52 8.6	45 11.3	33 22.5
198	Iter Ts/Tp	35 32.1	24 17.4	27 22.3	43 18.9
211	Iter Ts/Tp	18 1.22	33 6.01	25 5.04	13 2.66
288	Iter Ts/Tp	18 2.22	FAIL -	16 4.04	9 3.45
665	Iter Ts/Tp	21 2.73	22 6.33	24 6.93	FAIL -
1223	Iter Ts/Tp	46 7.44	66 23.22	95 12.55	77 12.08
2108	Iter Ts/Tp	22 22.21	45 11.87	63 33.22	33 17.22

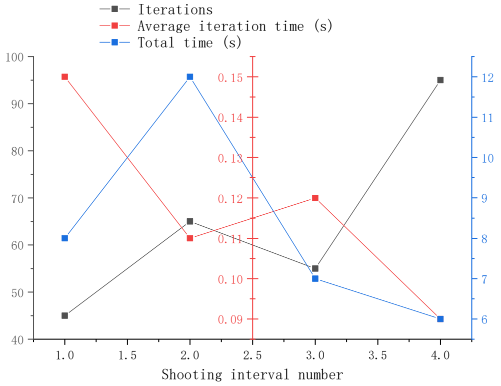
Table 3: Calculation results of multiple shooting in multithreading.

Note: “Iter” is the number of iterations, “TS / TP” is a single thread computing time, multi thread computing time, and “FAIL” is the no convergence of the example.

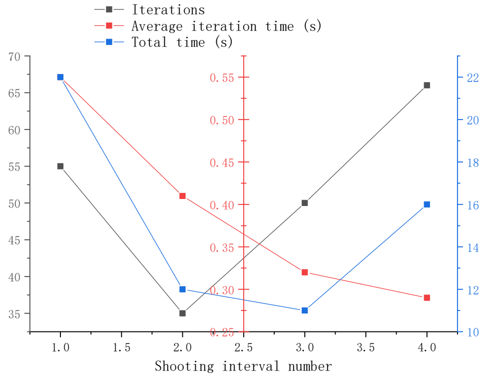
When the target area is 4, the Case 288 does not converge. Because the scale of Case38 is slightly small, in order to reflect the influence of the change of shooting interval on the calculation process of multiple shooting method, the relationship between the number of iterations, average iteration time, total calculation time and shooting interval of Case160, Case665 and Case2108 is drawn as follows (Figure 7). When switching from single shooting algorithm to two interval shooting algorithm, the average iteration time of other examples increases except Case2108. After that, with the increase of shooting interval, the average iteration time decreases. The total calculation time curve and iteration number curve of multiple shooting method have roughly the same change rule. Although the increase of shooting interval shortens the single iteration time, the change of iteration number caused by the change of shooting interval is the main factor affecting the total calculation time. Compared with the single shot method, the multiple shot method needs to complete more sensitivity calculation, which directly leads to the increase of the average iteration time. In addition, the single shooting method has the special case mentioned in the previous paper that the adjoint sensitivity calculation of inequality constraint can be omitted, while the sensitivity of equality constraint in multiple shooting method always needs to be calculated. Although the computing time can be shortened by parallelization, it is also affected by the efficiency of parallelization. The change of iterative convergence is restricted by the inexact matrix, and has no obvious correlation with the iterative interval. The average iteration time of multiple shooting algorithm is shortened, which makes it possible to become an efficient algorithm for emergency control calculation. However, in practical application, the convergence problem of imprecise matrix method remains to be solved.



(1) Sample 160



(2) Sample 665



(3) Sample 2108

Figure 7: Relationship between shooting interval number and calculation results.

5. CONCLUSION

Power system is a dynamic system with expanding scale and increasing complexity. Its analysis, calculation and control need to be realized through modeling and simulation, so it plays an important role. However, due to the randomness of the system, accurate modeling is very difficult. On the other hand, the power system is a nonlinear dynamic system, which needs a specific control strategy to ensure the security and stability of the system. However, it is very difficult to ensure the effective control due to the variability of the actual system operation state and the uncertainty of the model. In this paper, the importance of power system dynamic equivalence is studied, and the existing dynamic equivalence methods are compared. The principle of dynamic equivalence algorithm of power system based on GrHDP is analyzed, and the controller structure is designed. The results show that the dynamic system based on GrHDP can compensate the deviation between the original system and the original system, and can track the dynamic characteristics of the original system. When the operation condition and fault location are changed, the algorithm has good adaptability. Then, this section discusses the principle of multiple shooting method, using the partial discretization method to divide the transient stability emergency control problem into modules and modules. Based on the sensitivity analysis method, the direct sensitivity model and the adjoint sensitivity model of transient stability are proposed. Using these two models, the calculation processes of imprecise first-order and second-order degree information are derived respectively. Based on the research of multiple shooting, the parallel solution framework of the module is presented. In the module, the reduced space method and the dense block matrix structure of the model are used to reduce the computational time complexity. Finally, different scale power system examples are tested to verify and analyze the characteristics of the multiple shooting algorithm.

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