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Application of nine point logic control and predictive pid control algorithms in smart grid decision-making

Zhixin Ou*

Department of Urban Rail Transit and Information Engineering, Anhui Communications Vocational & Technical College, Hefei, Anhui 230051, China

Abstract: The smart grid operation and decision-making system has the characteristics of smart power detection, data cloud storage, and information fusion. The disadvantage is that the difficulty of model estimation is high, significant fluctuations in energy storage and transmission, algorithm update iteration delay, and low accuracy of data fusion technology. First, models and algorithms for smart grids, improve the multiple domain value delay problem of output stability. Second, the nine-point logic control strategy is based on the partition of deviation and deviation variation based on pan Boolean operations, effectively solving the frequency and band amplitude issues of power grid transmission load fluctuations. When the integral variable or input signals change, compared with traditional PID control, it is concluded that, just adjusting according to the nine-point logic control strategy, can obtain ideal control and output results. Finally, establishing a simulation model, the results indicate that its control curve performs well in model matching, satisfactory operation in case of model mismatch, and ensures that the fluctuation amplitude and error accuracy meet the requirements. The control strategy has the characteristics of a fast output response, high stability and robustness, and a small overshoot for changing power grid models.

Keywords: intelligent transport; smart grid decision-making; predictive PID control algorithm; nine-point logic control; multi-domain fluctuation; experiment/Simulation

1 Introduction

Power grid fluctuation occurs in power load transmission and distribution systems, has a large fluctuation range, error overshoot, wide range control such as disadvantages, and complex systems subject to multiple input signals/parameters. Its characteristics are the load fluctuation power consumption of the tested object is suitable for online automatic detection, non-static state, accurate measurement of short-term power consumption is required, and good time input/output response characteristics[1]. The continuous time of each power distribution is long during the operation of the power grid, and many factors affect fluctuation control, mainly including transmission line distance, electric energy compensation margin, and current/over-voltage overshoot.

According to the error result of each fluctuation measurement set the control quantity in advance, variable parameter characteristics of load compensation caused by model changes, affect the electric energy compensation effect. Feng et al.[2] analyzed power system fluctuation properties and operating characteristics of electrical equipment, analysis and calculation of electric energy based on circuit connection, prove that the power transmission belongs to a nonlinear, time-varying system and does not allow overshoot[2]. Error accumulation and output delay, affect the safety of power grid operation. It applies to the model features of long-distance power grid transmission and a large amount of prediction calculation.

Usually, manual operator experience sets a control advance, this kind of invariable control model makes it difficult to meet the variable fluctuation disturbance in the field, and the measurement and control results must be inaccurate. Wang et al.[3] analyzed the phenomenon of pure delay caused by the instability of load flow and mechanical inertia of the power grid, improving the stability of the power grid model and handling the uncertainty of load parameters caused by fluctuations[3]. It is

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* *E-mail address*: ozxin2008@126.com

required to measure the accuracy of fluctuation through the control method, error due to over-current impulse, brings great difficulties to the predictive control model.

In summary, the control strategy has low requirements for the prediction model with variable structures and parameters, and relatively stable performance. Ma et al.[4] analyzed according to the traditional PID control principle combined with integral parameter adjustment, differential control feedback regulation, and adjustment Relation of input and output Characteristics[4]. A control method based on an online rolling optimization function and nine-point logic distribution areas are proposed.

2 Predictive PID control algorithm

Parameter estimation of power grid system and establishment of control model, external environment sampling experience is required. For example, the influence of external network fluctuation on the fundamental current, total range of compensation voltage and set power, the control mode of electrical equipment and main wiring, etc.

For some cross-coupled harmonic currents, the establishment of its model is very complicated; or the test device cannot enter the high-voltage area of the input power grid for measurement, so it's difficult to establish an accurate system model[5]. The structural characteristics of the system model can only be analyzed by estimating the parameter characteristics, such as an experienced operator manually adjusting PID control parameters, and observing whether the operation effect of the controlled object reaches the expected result. Only rough prediction results are needed to meet the requirements of the controlled object. Figure 1 Schematic diagram of traditional PID control and predictive (model algorithm control) model feedback structure.

Figure 1, $R(t)$ is the input reference data/signal, $E(t)$ is the adjustment control error data/signal, $U(t)$ is the

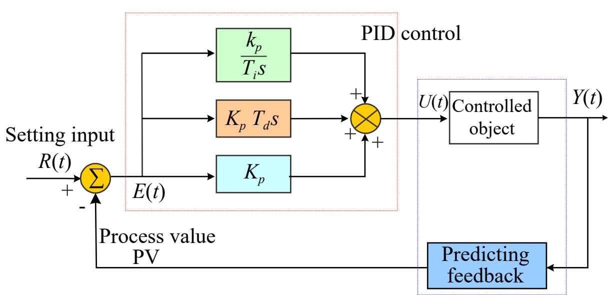

Fig. 1 Block diagram of predictive PID control system

feedback control data/signal, $Y(t)$ is the output data/signal of the controlled system[6]. Among, control error signal $E(t) = R(t) - Y(t)$. Compare the process value (feedback value) with the given value PV, and use this error to adjust the PID controller, and realize the control of the power grid fluctuation system.

The control signal is:

$$U(t) = K_\mathrm{p}E(t) + K_i\int_0^t E(\tau)\mathrm{d}\tau + K_\mathrm{d}\frac{\mathrm{d}E(t)}{\mathrm{d}t}, \tag{1}$$

where, T_i is used to eliminate the static deviation interference of the power grid; improving error control precision has a positive feedback effect; K_p is used to the deviation of the proportional reaction system is adjusted to reduce the deviation; T_d is used to change the rate of reaction deviation, judgment of deviation trend leads to control.

In Equation (1), the three basic adjustment parameters are proportional constant K_p, integral constant T_i, and differential constant T_d. PID control technology is not clear about the controlled object in power grid fluctuation regulation, or it has a good effect when the system parameters cannot be obtained by effective measurement means.

Observe the characteristics of the operator's manual, and intervention of power grid fluctuation using predictive feedback and PID control strategy:

(1) Power grid fluctuation is characterized by active open-loop. If the load power compensation overshoot is caused by the grid fluctuation, manual intervention to adjust excess power[7]. If it only fluctuates within the error range, no feedback closed-loop control, free running eliminated static error *PV* value. It is called a semi-closed loop or active open loop control.

(2) With strong time-varying characteristics. Required within the specified time, the electric energy reaches the specified safe operation value[8]. Adjust the parameters that conform to the operation law through PID control characteristics, the process of directly controlling the input and output.

3 Nine-point logic control strategy and characteristics

3.1 Basic principles

The theoretical basis of logical control is a universal Boolean algebra. The nine-point logic controller adjusts the output of the controller according to the operating state of the system; it is not based on the mathematical model of the control object[9]. Once there is fluctuation and interference in the system feedback process, the use of PID predictive control technology will produce fuzzy control rules for systems with accurate models, and complex control strategies, and cannot be applied in practical projects. As shown in Figure 2, a schematic diagram of its structure.

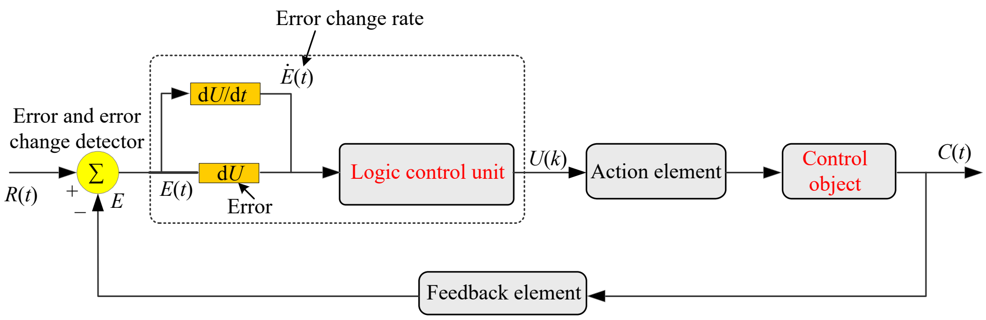

Fig. 2 Block diagram of nine-point logic control structure

As shown in Figure 2, the basic rule is that the ratio of input error (e_0) and error change rate ($\&e_0$) conforms to the estimated model reference value, Analysis of the operation mechanism of logic control form using pan Boolean, the control rules are shown in that the stability is reasoned and judged by nine phase planes composed of errors and error changes, whether there is deviation and overshoot in the control process, due to error and error change rate deviation, closed-loop logic adjustment of system feedback and state results.

The Control field of Pan Boolean Operations, based on constraints and simplified input factors, is the act of controlling the results according to a specific Boolean function, it is unnecessary to consider complex and changeable process model variables. There are two basic elements:

(1) The input quantity can show variable motion characteristics, and can also be an abstract concept.

(2) Characteristics of factors in the system control process, whether the judgment basis for output results is accurate, there are two relationship state variables with different logical values 0, 1.

For any j, k, provided $1 \leqslant j \leqslant k \leqslant n_i$, musthave $x_i^j \cdot x_i^k = 0$

$$x_i^1 + x_i^2 + \cdots + x_i^n = 1 \tag{2}$$

In Equation (2), let X_1, X_2, $\cdots$, X_n represents multiple factors in the system; the state of X_n displayed by any factor is called the state number. In Equation (1) above, j is the number of states and i is the factor to which X belongs[10]. In a universal Boolean operation, each factor can only present one state number n_i.

Defined by Boolean operation concepts and criteria, the divided states do not interfere with each other, and the operation effect will not be affected mutually. Exert influence on control results in nine different regions; keep each force tending to the correct logical value and error control range, and form a nine-point logic control strategy based on universal Boolean operation.

3.2 Control strategy and characteristics

Boolean operation is a control error state strategy based on the four planes of 0, 1 expression function K_{1-} (0, 0, first quadrant); K_{2-} (0, 1, second quadrant); K_{3-} (1, 0, third quadrant); K_{4-} (1, 1, fourth quadrant) [11]. Pan Boolean introduces the error rate of change into the phase plane space, and expands to a nine-point partition operation, including K_{1+}, k_{1-}; K_{2+}, k_{2-}; K_0; K_{3+}, k_{3-}; K_{4+}, k_{4-}. Its nine-point control strategy and definition are shown in Table 1.

$K_{3+/-}$ impact delay time ($K_{3+/-}\uparrow \rightarrow t_d\downarrow$), K_{2+} affects the

Table 1 PID parameter performance index (Gain, Delay time, Rise time, Overshoot)

Gain parameter K_i	Performance index						
	ω_d	ε	e_{ss}	t_d	t_r	t_s	Σ(%)
1	2.871	0.451	0.574	1.680	1.069	6.020	48.699
5	4.082	0.263	0.214	0.476	0.689	6.020	36.577
10	6.123	0.482	0.148	0.275	0.455	6.020	26.486
150	25.067	0.150	0.019	0.168	0.167	6.040	65.530
300	11.260	0.045	0.014	0.068	0.275	6.040	69.514

fast rise time of the system (K_{2+}↑→t_r↓), but it should be less than K_{3+}). $K_{1+/-}$ with damping effect ($K_{1+/-↑}$→t_s↓), $K_{4+/-}$ has a strong effect on inhibiting overshoot (K_{4-}↑→σ↓), it is the only control strategy that has a direct control effect on interference, K_{2-} influences on system oscillation times (K_{2-}↑→N↓), K_0 influences the higher harmonic component in steady state.

As shown in Table 2, according to the combined state of the nine-point controller structure error e and error change rate de, nine different working conditions are formed. A corresponding control strategy shall be adopted for each zone in the phase plane[12]. Compensation or consumption of load electric energy by the controlled object of the power grid fluctuation model makes the electric energy operate near the set value and fluctuate slightly.

Table 2 Control rule table of nine-point logic phase plane partition controller

Grid fluctuation deviation e	Grid fluctuation deviation change rate de_0		
	$e \geqslant de_0$	$\lvert e\rvert \leqslant de_0$	$e \leqslant -de_0$
$e \geqslant e_0$	Imposition of K_{4+} (Positive deviation from set-point trend)	Add slightly K_{3+} (Directed set point approaching trend)	Weak heater K_{2+} (Tendency to approach the set value)
$\lvert e\rvert < e_0$	Micro addition K_{1+} (Trend with positive offset set-point)	Keep (K_0) (Balance with set value)	Subtract K_{1-} (Trend with negative offset set-point)
$e \leqslant -e_0$	Weak decrement K_{2-} (Tendency to approach the set value)	Slightly reduce K_{3-} (Directed set point approaching trend)	Forced decrease K_{4-} (Tendency to exceed the set value)

There is only one control strategy for each working condition, for example, X_1X_2 is a working condition. Its logic control means that the error is negative, the error change rate is also negative, and the control strategy is $K_{4-} = X_1X_2$, which is the state of excessive subtraction.

Similarly, the adjustment of other logic states in Table 1 also follows similar control relationship expressions. Its characteristics are that there is no need to establish a clear mathematical model, low requirements for an object model, its structure is simple and easy to adjust, its control action is not related to time delay, and the results show that the control strategy can maintain good robust stability.

As shown in simulation Figure 3, amplified figure

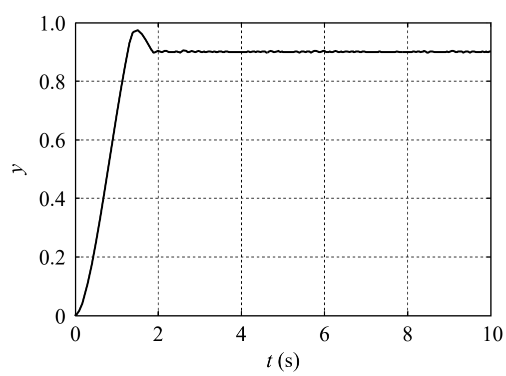

Fig. 3 Logic control fluctuation simulation diagram

some fluctuations will be found in the logic control, this is a disadvantage of the main logic control strategy. Impulse is the input parameter of the simulation model; its control process has second-order system characteristics. Such as overshoot, fast response time, ascending cycle, delayed output and feedback regulation, damping oscillation, and harmonic interference.

K_0 is the stable value to keep the balance. K_{1+} is a weak positive control force, the system needs to overcome the overshoot descent inertia when operating K_{1+}. K_{2+} is the second strong positive control force, the performance index of rise regulation time that mainly affects the system[13]. K_{3+} is a strong positive control force, performance indicators affecting system output delay time. K_{4+} is a strong positive control force, negative overshoot performance index affecting the system.

K_{1-} is the minus control force, the system needs to overcome its inertia when operating here. K_{2-} refers to weak decreasing control force, the performance index of rise regulation time that mainly affects the system. K_{3-} slightly reduced negative control force, performance indicators affecting system output delay time. K_{4-} refers to forced reduction control force, positive overshoot performance index affecting the system.

4 Control algorithm and analysis of data

Error and over-shoot result of load power compensation caused by grid fluctuation, describe system model structure and parameter changes, affect the safety and stability of power grid operation. The implementation of the nine-point control strategy is: The decrease of delay time T_d depends on $K_{3+/-}$ increasing strength. The rise time T_r of system rapidity depends on the positive force of K_{2+} enhancement. $K_{1+/-}$ has the function of reducing damping oscillation. $K_{4+/-}$ has the function of restraining over-shoot σ adjustment and direct control effect on interference in the control strategy.

When K_{2-} increases, the number of oscillations N decreases. K_0 can restrain harmonic increment in a steady state. Reduce the distortion of model parameters caused by high-frequency harmonics invading the power grid. The time and frequency of fluctuation regulation is a multi-combination control strategy, the nine-point control phase plane based on Boolean operation will combine various factors to judge the best state and select strategies.

The interaction strategy of logic control and predictive PID control is adopted, such as processing model parameter distortion, external influences such as interference noise, and the detection process of load power consumption must require rapid response and high accuracy.

Specifically, if the grid fluctuation deviates from the normal value, overshoot is difficult to effectively adjust in a short time, and then the control mode is switched to nine-point logic phase plane partition control, bringing load electric energy compensation into normal operation state[14].

When the load fluctuates, it needs to be stable, or it is necessary to overcome the rising and falling inertia of the system and switch to PID control. Manually adjusting the characteristics of grid output and input, when the model is distorted by the operator's experience will have a good adjustment effect on interference and oscillation.

In the flowchart of Figure 4, the humanoid thinking of its control strategy is more consistent with the combination of circuit closed-loop control and strong time-varying control, and making appropriate structural adjustment through a certain experience, manually setting the controlled object with fuzzy parameter adjustment, the control effect is ideal. It has three characteristics:

The control strategy is adopted to restore and destabilize the power grid system in case of fluctuation, maintain its operation stability, adjustment speed, and measurement accuracy can achieve the best match.

It can effectively restrain and overcome the delay and oscillation harmonic phenomena in the power grid system. Function and mutual switch through PID control and logic control, grid fluctuation parameters, and power compensation can be fast and accurate. The fluctuation error can reach or approach the set value quickly, stably, and accurately.

5 Experimental methods and Simulink model

To verify the effect of the above control methods, under linear conditions, the mathematical model of the servo system of the controlled plant can be described by the second-order coefficient linear differential equation. Although the parameters of the system model differ greatly, there are fluctuations and errors at the same time. Assume its transfer function is:

$G_i(s) = \dfrac{\varpi_d^2}{s^2 + 2\varepsilon\varpi_d s + \varpi_d^2}$, (Among, damping coefficient ε, natural frequency ω, analog in unit step signal, d =1, 2, $\cdots$, m. Parameter $\varepsilon = 0.2 - 0.4$, $\varpi_1 = 4 - 20$ the selection is shown in Table 1 PID performance indicators).

As shown in Table 2, each parameter index of PID control, damping coefficient ε, natural frequency ω_n, and damped oscillation frequency ω_d.

(1) Overshoot: $\sigma = e^{-\pi\varepsilon} / \sqrt{(1-\varepsilon^2)} \times 100\%$

(2) Steady-state error: $e_{ss} = C / [K_i \times K + C]$, K is the original system gain, K_i is the adjustment gain.

(3) Rise time: $t_r = [\pi - \arccos \varepsilon] / \omega_d$.

(4) Adjusting time: $t_s = 3.5 / \omega_n \cdot \varepsilon$.

(5) Delay time: $t_d = [1 + 0.6\varepsilon + 0.2\varepsilon^2] / \omega_n$.

Analyze the reference model and compare the results of the nine-point logic control algorithm PID regulation control process, and experiment/Matlab simulation description.

$$G_1(s) = \frac{3}{2s^2 + 3s + 4} \text{(Model matching)}$$

According to the value rules in Table 2, analyze various performance indicators of the system, and zoning control in phase plane. Its two poles are: $s_1 = -0.750\,0 + 1.199\,0i$, $s_2 = -0.750\,0 - 1.199\,0i$, the system is stable.

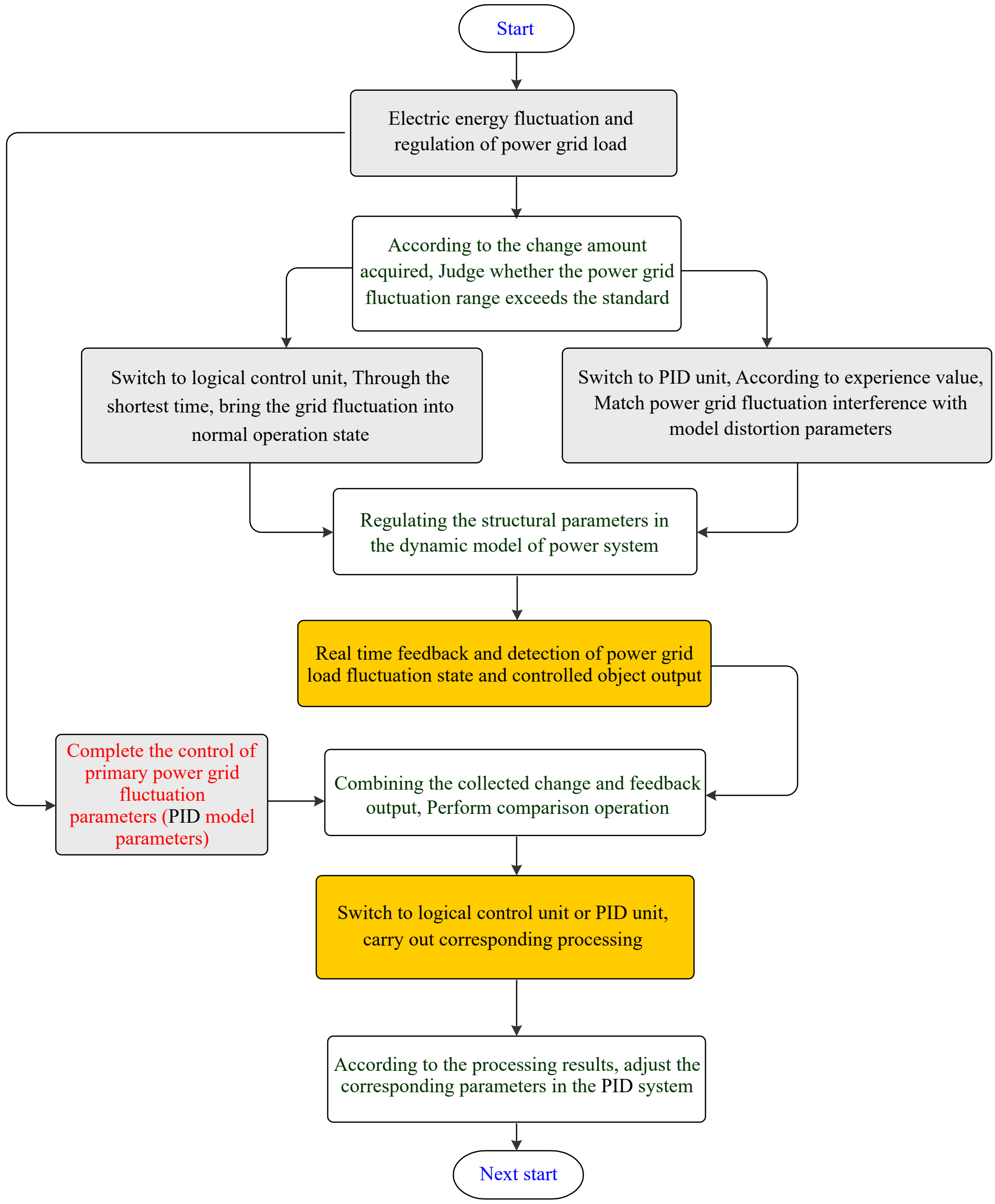

Fig. 4 The logic control and predictive PID Control flowchart

Adopt nine point controller strategy, the value of phase plane partition control parameter is: $K_{1+} = 1$, $K_{2+} = 3$, $K_{3+} = 8$, $K_{4+} = 10$, $K_0 = 0$, $K_{1-} = -1$ $K_{2-} = -3$, $K_{3-} = -8$, $K_{4-} = -10$, The value of error and error derivative change rate is: $e_0 = \pm 0.1$, $de_0 = \pm 0.1$.

The logic control has no definite restrictions on the structure and model of the controlled object, nine-point logic controls can be well applied to control models with variable inputs and uncertain structural parameters. This controller is based on multi-valued logic control, open loop control within the allowable error range, resulting in small range oscillation of the operation curve. The reason is that the controller is completely controlled according to the operating state, and ignores the self-regulating characteristics of the system.

In Figure 5, among them, Figure 6 is the PID parameter structure, the parameter setting parameters of the PID closed-loop feedback control model are obtained according to the simulation control object: $P = 3$, $I = 2$, $D = 1$. Figure 7 is A point logic control parameter structure. The power load compensation of logical nine-point phase plane partition control is completed by the interaction of nine control forces. The final trend is stable near K_0.

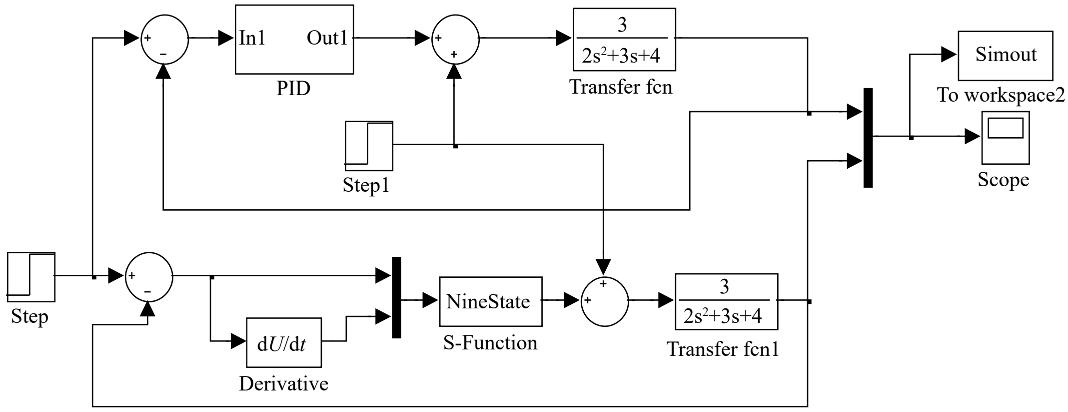

Fig. 5 comparison diagram of simulation results of nine-point logic control and PID control

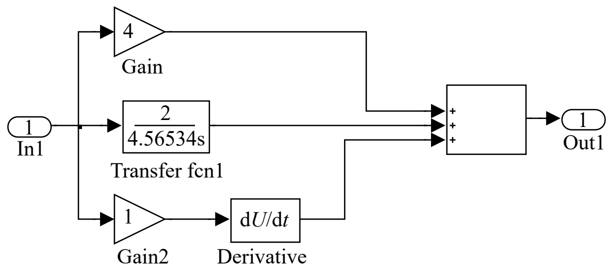

Fig. 6 PID parameter structure

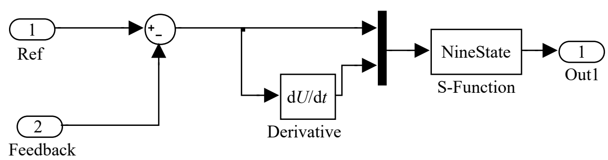

Fig. 7 Nine-point logic control parameter structure (S-Function Nine-State)

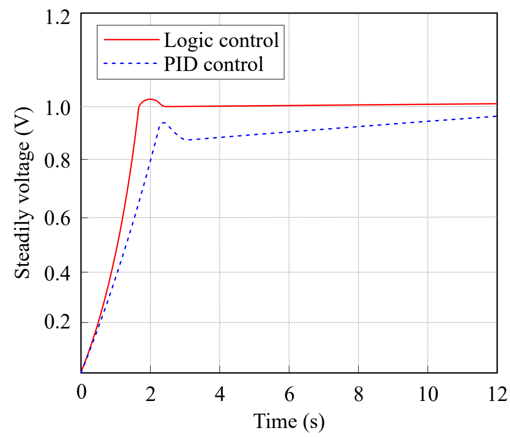

Fig. 8 PID control and logic control simulation diagram Comparison

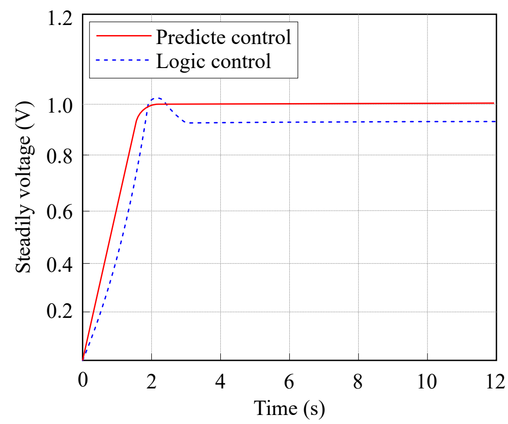

Fig. 9 Comparison between predictive control and logic control diagram

As shown in Figure 8, when the system fluctuates or the oscillation deviates from the normal operation state, through nine-point logic control judge its operation state, prefer K_{4+}, K_{3+} and K_{4-}, K_{3-}, switch the control quantity to the logic state. When the system operates at K_{1+}, K_{1-}, and K_0, the control quantity is switched to PID control state, manual intervention by an experienced operator of deviation control. Instead, it can achieve a good control effect.

As shown in Figure 9, amplified figure fluctuations will be found in the logic control, this is a disadvantage of the main logic control strategy. When the fluctuation range is controllable, its essence is to simulate the thinking characteristics of the operator for manual intervention, and calculation without imposing feedback. Small fluctuation is normal, and will not affect the overall operation performance of the system.

In Figure 9, when the model structure matches the parameters, the result of PID predictive control is ideal, fast response time to stable state is short. PID control is an optimal control strategy with strong time-varying.

6 Conclusions

The power grid operation is characterized by fluctuation and variable model structure parameters. There are certain difficulties in accurately estimating and establishing the structural model. This paper uses the traditional predictive PID algorithm, the simulation analysis of its inherent structure model shows that the control strategy is ideal. If the sampling parameters or structure opacity, manual intervention based on a nine-point logic control strategy, and experienced operators, the limit value of overshoot can be switched quickly, the essence of its control is to correct the time-varying model as a closed-loop control structure.

(1) Comparison of simulation models and analysis of experiment results, PID parameter setting, and tuning are convenient. Judge whether the system is in the normal operating range, no feedback is required and just open loop control. The nine-point logic control strategy switches control partitions according to the output-input regulation relationship. Its controller structure is simple, physical background and clear mathematical concepts. Control strategy has the characteristics of humanoid thinking. Industrial application and practice can be carried out where complex models are difficult to establish.

(2) Have a certain understanding and control experience on the characteristics of power grid structure. The common point is that intervention through strong time-varying, Keeps the load current and compensation power within a certain error range. The difference is that experienced operators can make the error of load regulation infinitely smaller with the fluctuation of the power grid, fluctuating within the operating safety range, will not affect the system stability. This control method is to have a certain understanding of the system characteristics.

Declaration of competing interest

The author has no competing interests to declare that are relevant to the content of this article.

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