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Research on Model Predictive Direct Power Control Strategy Optimization Based on Three Phase PWM Rectifiers

Zian Ren

Nanyang Technological University, Singapore, 639798

ABSTRACT
With the increasing demand for power quality and system efficiency, traditional control strategies have gradually become unable to meet complex application requirements. Traditional control strategies often rely on fixed control algorithms, which may lead to decreased or even unstable system performance under dynamic conditions such as load changes, uncertain system parameters, or external disturbances. Taking the model of a three-phase PWM rectifier as an example, by optimizing the switching sequence, the problems of uneven distribution of the grid side current spectrum and system computational complexity can be solved. Furthermore, the control strategy was validated through simulation experiments. By comparing the results of optimized and unoptimized control strategies, it was found that the development of this strategy can effectively optimize open sequences.

KEYWORDS
Three phase PWM rectifier; Model prediction; Control strategy

With the development of power electronics technology, power quality issues are becoming increasingly prominent. In modern power electronics technology, three-phase PWM rectifier, as an important power conversion device, is widely used in power systems and industrial production, and is the key to improving power quality. In this context, Model Predictive Control (MPC), as an advanced model-based control strategy, has gradually gained popularity due to its excellent dynamic performance and flexible processing capabilities. It can effectively reduce harmonic content and improve overall system performance. Specifically, three-phase PWM rectifiers are commonly used for energy conversion and control. By introducing model predictive control (MPC) methods, especially when the load changes or operating conditions fluctuate, they can improve the power quality of the system, ensuring compliance with national and international standards. In addition, optimizing the three-phase PWM rectifier model prediction direct power control strategy can reduce unnecessary switching operations, thereby reducing switching losses and filter design complexity, improving energy utilization efficiency, and reducing operation and maintenance costs. Among them, Finite Set Model Predictive Control (FCS-MPC) has demonstrated unique advantages in the control of three-phase PWM rectifiers. Therefore, by optimizing the model predictive direct power control strategy based on three-phase PWM rectifiers, especially for the application of FCS-MPC, data support is provided for practical applications, thereby promoting further research and development in the field of control.

1 Mathematical model of three-phase PWM rectifier

Figure 1 is a schematic diagram of a three-phase voltage source PWM rectifier. In the figure, C is the DC side filtering capacitor; S1 to S6 are power switching devices; L is the filtering inductor; A. b and c represent circuits; E is the voltage of the power grid; I is the current; Udc is the output voltage on the DC side; Rs is the equivalent series resistance of inductance.

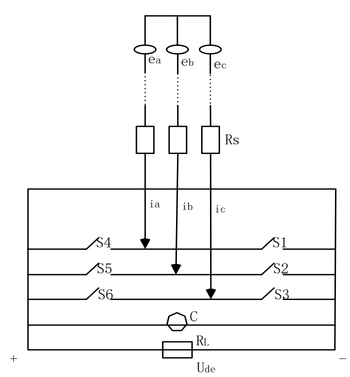

Figure 1 Schematic diagram of three-phase voltage source PWM rectifier

Based on the above graph, construct a mathematical model of a three-phase PWM rectifier.

Firstly, the three phases are transformed into a two-phase stationary coordinate system through Clarke transformation

Secondly, using Kirchhoff's law, a mathematical model is derived for two-phase stationary coordinates.

Finally, using the theory of instantaneous power, under ideal grid conditions, model (1) is constructed:

$$\begin{aligned}\frac{dp}{dt}&=\frac{1}{L}\left(e_\varepsilon^2-e_\varepsilon u_\varepsilon-\mathrm{R}_\lambda \mathrm{e}_\varepsilon i_\varepsilon+e_\omega^2-e_\omega u_\varepsilon-R_\lambda e_\omega i_\omega\right)-\mu(e_\omega u_\varepsilon-e_\omega i_\omega)\\ \frac{dp}{dt}&=\frac{1}{L}\left(e_\varepsilon u_\omega-e_\omega u_\varepsilon-\mathrm{R}_\lambda \mathrm{e}_\varepsilon i_\omega-R_\lambda e_\varepsilon i_\omega\right)+\mu(e_\varepsilon u_\varepsilon+e_\omega i_\omega)\end{aligned} \tag{1}$$

2 Research on model predictive direct power control strategy optimization based on three phase PWM rectifiers

2.1 Optimization design of control strategy

Although a three-phase two-level rectifier only has eight switching states, the number of switches will increase due to changes in topology. FCS-MPC needs to calculate all finite switch states within each sampling period to find the optimal control action for the current cycle. This means that the processor must calculate and evaluate every possible switch state, and calculate its corresponding system output and performance, which is not conducive to reducing the burden on the processor.

Therefore, according to the concept of space vector modulation, the effective vector and zero vector of the non grid side voltage sector are synthesized with the vectors of adjacent sectors to achieve accurate tracking of voltage phase by grid side current.

Table 1 shows the finite control set optimization table obtained based on this method. The data in the table shows that reducing the predicted eight switch states to four times can effectively reduce processor burden and improve system processing speed (Table 1).

Table 1 Finite Control set optimization table

Sectors	Effective vector	Zero vector
1	$\mu_1\mu_2$	$\mu_0$orμ_7
2	$\mu_2\mu_3$	$\mu_0$orμ_7
3	$\mu_3\mu_4$	$\mu_0$orμ_7
4	$\mu_4\mu_5$	$\mu_0$orμ_7
5	$\mu_5\mu_6$	$\mu_0$orμ_7
6	$\mu_6\mu_1$	$\mu_0$orμ_7

Based on the system switch status, obtain the output status of the system when the switch is not in use, and obtain the predicted value and reference value. Based on the above two numerical values, establish a cost function to select the optimal switch state to apply to the system. The specific model is as follows:

$$F=\partial_1\left|g_{k+1}-g_{ref}\right|^2+\partial_2\left|h_{k+1}-h_{ref}\right|^2 \tag{2}$$

Among them, k represents time; G represents instantaneous active power; H is instantaneous reactive power; G_{ref} is the reference value for active power; H_{ref} is the given value of reactive power, href =0；∂_1、∂_2 represent the weight coefficient, and $\partial_1=\partial_2=1$.

2.2 Control strategy operation mechanism

In modern power systems, frequent operation of switchgear can significantly affect the harmonic distribution of the system and also lead to energy loss during power transmission. Therefore, introducing a minimum switching frequency constraint in the cost function can effectively control the frequency of switching operations, thereby improving the overall performance of the system.

At the same time, analyze the switch sequence of the previous cycle to identify the switching behavior patterns of the system under different load conditions. On this basis, utilizing the data from the previous week to infer the optimized switch sequence for the next cycle provides a foundation.

On this basis, calculate the cost function corresponding to the combination of switch sequences in all cycles, and apply the switch sequences to the system. The framework diagram of the optimized switch sequence model predictive control system corresponding to the above is shown in Figure 2.

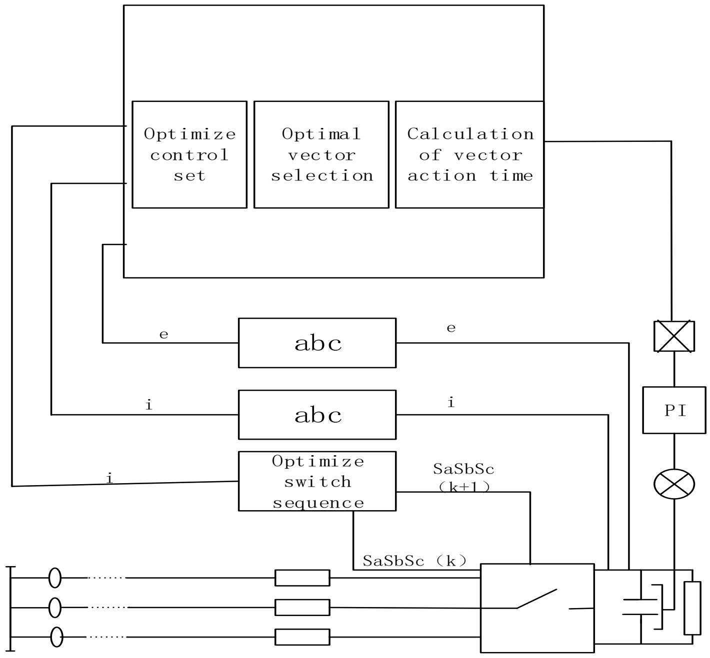

Figure 2 Framework diagram of predictive control system

3 Simulation

Based on the Matlab/Simulink experimental model, the aim is to achieve efficient control of PWM rectifiers in power systems and systematically compare them with existing improvement methods to evaluate their respective advantages, disadvantages and adaptability. The main experimental parameters are shown in Table 2.

Table 2 Main experimental parameters

parameter	numerical value
Effective value of phase voltage in the power grid	210
Grid frequency	40
Grid side filtering inductor	1.27
Equivalent series resistance of inductance	0.6
DC side voltage	660
DC side capacitance	2500
Switching frequency	14

Figure 3~5 shows the statistical graph when the output power is 10kW. As shown in the figure, the current quality under the OSS-MPC strategy has significantly improved compared to the previous two, and meets the national standard for grid side harmonics. From this, it can be seen that the above method can effectively reduce the harmonic content of the grid side current, and the optimization method is effective.

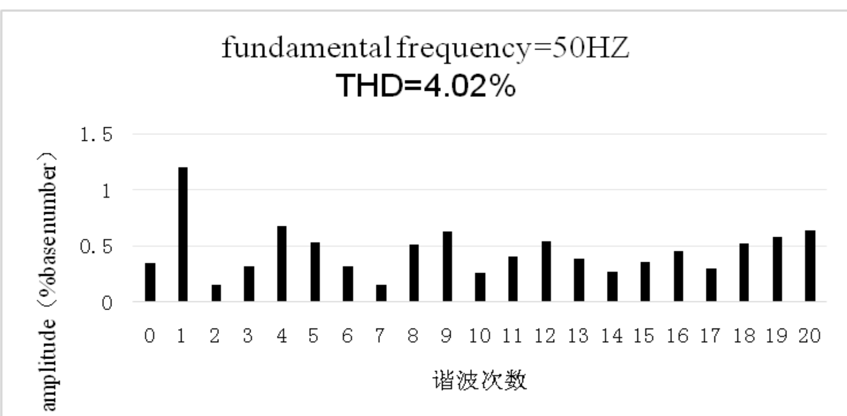

Figure 3 FCS-MPC strategy network side THD statistical chart

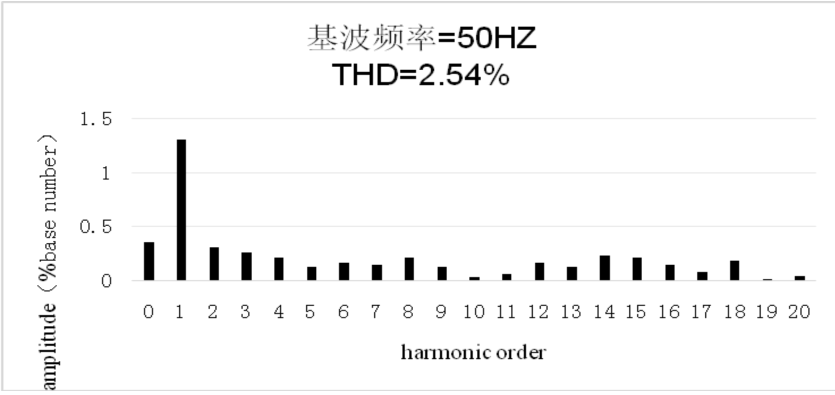

Figure 4 SVM-MPC Strategy Network Side THD Statistical Chart

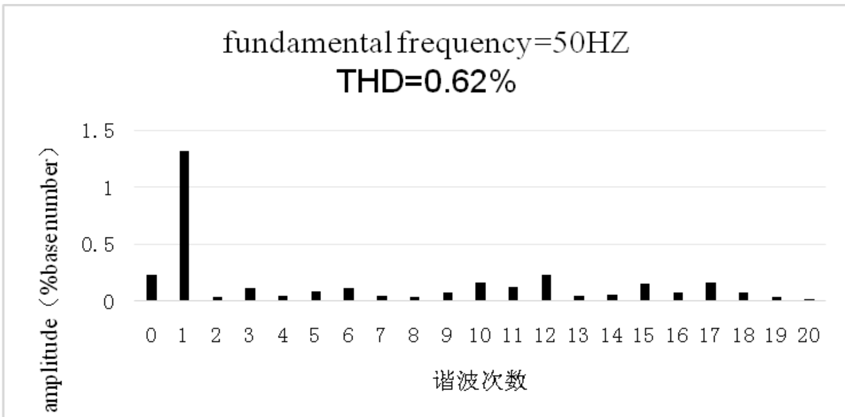

Figure 5 OSS-MPCC Strategy Network Side THD Statistics

4 Conclusion

Research based on three-phase PWM rectifiers can not only promote the development of control theory, but also facilitate the widespread application of power electronics technology in renewable energy, tram charging stations, and industrial applications, contributing to the achievement of sustainable development goals. For this reason, research has shown that using Model Predictive Control (MPC) strategy can effectively achieve model prediction of three-phase PWM rectifiers, improve current quality, reduce harmonic content, and is of great significance for meeting national standards. Further, through simulation experiments, it has been proven that the optimized control strategy can effectively balance the switching frequency and the computational burden of the system, significantly improve system performance, and provide a solid foundation for the promotion of three-phase PWM rectifiers in industrial applications. In the future, efforts can be made to improve control algorithms, reduce system complexity, and enhance robustness to further optimize the practicality and economy of this control strategy.

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