Application of FCS-MPC Model Predictive Control Strategy in High Power Multilevel NPC/H Inverter

Guifeng Wang*, Yanli Chai, Junrong Yan and Fei Wang

School of Electrical Engineering and Automation, Jiangsu Normal University, Jiangsu, China

*Corresponding author e-mail: wgfmy@163.com

Abstract. Aiming at the current oscillation and delay of traditional limited control set model predictive control (FCS-MPC), an improved FCS-MPC is proposed. Eliminate current oscillation by using two adjacent voltage vectors and zero voltage vector to work together in one sampling period. In order to reduce the switching frequency, the effects of the voltage vectors are sequentially ordered to obtain an optimal voltage vector sequence (OVVS). In the high-power five-level NPC/H-bridge inverter, the modulation control experiment is carried out, and the simulation model is built by Simulink software. The simulation results verify that the proposed improved FCS-MPC model is in the high-power multi-level NPC/H inverter. Predictive control effectiveness.

1. Introduction

Compared with the traditional two-level inverter, the multi-level inverter can output a higher voltage level, a lower output voltage, and better harmonic characteristics of the output waveform with a combination of lower-voltage power switching devices. More and more attention has been paid to high power and high voltage. A five-level diode clamped H-bridge cascade (NPC/H) inverter topology is combined with a topology of a midpoint clamp (NPC) inverter and an H-bridge cascade inverter. Present [1], as shown in Figure 1. It can be seen from Figure 1 that the NPC/H type inverter consists of three H-bridges, each of which is powered by an independent power supply. The two bridge arms of each H-bridge are diode-clamped three-level structure, and each bridge arm can output three levels of E, 0, and -E, where E is the DC side voltage, so the output of the two bridge arms Any combination of voltages can output up to 5 levels of 2E, E, 0, -E, and -2E. The five-level NPC/H type inverter has more levels than the three-level NPC inverter, with lower and THD. This kind of inverter has no equipment in series, which eliminates the problem of equipment dynamic voltage and static voltage distribution [2].
The traditional limited control set model predictive control (FCS-MPC) has certain deficiencies. The literature [3] is the traditional FCS-MPC, and its output current has a delay. Literature [4] considers reducing switching loss and delay compensation on the basis of traditional FCS-MPC, but cannot solve the phenomenon of output current oscillation. Reference [5] uses two-step prediction and simultaneously analyzes the optimal combination of switching function and suboptimal switching function, which can overcome current oscillation to a certain extent, but the calculation amount is large. The traditional FCS-MPC has a certain error between the predicted current and the reference current under the selected optimal control state. Especially when the reference current peak-to-valley changes slowly, the output current is easy to oscillate. This paper presents the concept of an optimal voltage vector sequence. In one sampling period, the circuit is operated with an optimal voltage vector sequence to achieve zero error between the output current and the reference current. At the same time, the delay caused by the calculation and sampling will be compensated. In addition, based on the analysis of the amount of algorithm operation, the operation process is optimized. Finally, the simulation results show that the improvement of FCS-MPC in static and dynamic performance is significantly better than the traditional FCS-MPC.

2. Improved finite control set model predictive control model

2.1. FCS-MPC control for delayed sampling

The traditional FCS-MPC control process is to first sample the data, predict the evaluation, and finally control the output. This sampling and calculation process introduce a delay, which is determined by the sampling circuit and the controller's calculation speed. The systemic expression is as follows.

\[ x(k+1) = (A + \Delta A)x(k) + (B + \Delta B)u(k) \]  \hspace{1cm} (1)

Where \( x(k) \in R^n \) and \( u(k) \in R^m \) represent the state and control inputs, respectively, \( \Delta A \) and \( \Delta B \) represent the time-varying parameter uncertainty function, which satisfies.

\[ [\Delta A \quad \Delta B] = DF(K)[E_1 \quad E_2] \]  \hspace{1cm} (2)

Where \( D, E_1, \) and \( E_2 \) represent the known real parameter matrices, respectively, and \( F(K) \) is the unknown matrix function that Lebesgue can measure, satisfying \( F^T(K)F(K) \leq I \)

Input and state constraints are met

\[ x(k) \in X^\Delta = \{ x(k) | A_x x(k) \leq 1 \}, \forall k \geq 0 \]  \hspace{1cm} (3)
\[ u(k) \in U = \left\{ u(k) \mid A_1 u(k) \leq \bar{1} \right\}, \forall k \geq 0 \] (4)

Where \( \bar{1} \) represents a column vector with an element of 1.

The nominal model corresponding to the system is defined as

\[ x^*(k+1) = Ax^*(k) + Bu^*(k) \] (5)

The FCS-MPC design goal is to design an optimal control input at each sampling time under the conditions of equations (2) to (4), to drive the state of the system to the origin and minimize the performance indicators.

\[ \max_{F^*(k) \mid x(k) \in [0, \bar{1}]} J_F(k) = \sum_{i=0}^{\infty} \left( \|x(k+i|k)-F_k\|^2_t + \|u(k+i|k)\|^2_u \right) \] (6)

2.2. Optimal voltage vector sequence FCS-MPC model predictive control strategy

It is found by simulation that when the reference current changes slowly in 1 sampling period, the inverter output current is easy to oscillate [6]. The current oscillation process is shown in Figure 2. The expressions of the control system are as follows.

\[ x_i(k+1) = [A_i + \Delta A_i(k)]x_i(k) + B_i u_i(k) + s_i(k) \] (7)

![Figure 2. Current oscillation process](image)

The above is an uncertain state space model of the circuit, indicating the actual background of the uncertain system. This uncertainty refers to the model uncertainty. On the one hand, it is brought about by the simplification of the model; on the other hand, some characteristics of the system or lack of sufficient understanding of the link (i.e., the part that is difficult to model), changes in system behavior due to factors such as changes in the system environment, aging of components, drift of certain physical parameters, or unknown changes over time. This leads to the generation of model uncertainty [7]. In
addition, the uncertainty can also be expressed as external disturbance or state estimation error [5]. In addition, the uncertainty can also be expressed as external disturbance or state estimation error [2]. The research of uncertain systems has developed from the basic to the depth, from linear to nonlinear, from continuous to discrete, from no time delay to time. The lag, from the linear quadratic optimal control to the control and other topics. The research work on the uncertain system has achieved fruitful results.

3. Experimental analysis
In order to further verify the feasibility of the control strategy, an experimental test platform based on the five-level NPC / H bridge inverter experimental platform was developed. The experimental test platform is shown in Figure 3. The simulation environment is MATLAB/Simulink. The traditional FCS-MPC and FCS-MPC based on duty cycle optimization are simulated. In this paper, the same speed loop PI parameters are used in simulation and experiment to test different current control modes. Low speed and high-speed performance.

Inverter output current adopts German VAC company current sensor 4646-X400, DC bus positive terminal voltage, DC bus negative terminal voltage acquisition through the operational amplifier to form a differential circuit. The inverter current signal and the DC bus voltage signal are sent to the 12-bit A/D converter inside the TMS320F2808 chip. The PWM pulse signal of the inverter is generated by the internal event manager of the TMS320F2808 chip and extended by the Complex Programmable Logic Control Device (CPLD) EPM7256. The five-level NPC / H bridge inverter power switch tube uses Vincotech's IGBT 600V-50A module. The DC power supply uses a programmable DC analog power supply, the TopCon Quadro. In order to verify the correctness and effectiveness of the fast finite control set model predictive control, the steady-state and dynamic experiments of the fast finite control set model predictive control are carried out, and compared with the traditional finite control set model predictive control. The load is a resistive load, $R = 20 \, \Omega$, $L = 5 \, \text{mH}$, using a star connection; the reference voltage is $50 \, \text{Hz}$; the modulation is $M = 0.90$. Set the switching frequency $f_s = 1\, \text{kHz}$ and $f_s = 5 \, \text{kHz}$ respectively, run the DSP program of the space vector modulation strategy in the rotating coordinate system on the five-level NPC / H bridge inverter experimental platform, and use the Fluke power quality analyzer to obtain the output waveform. As shown in Figure 4.
The method of selecting the first vector in the combination is the same as the method in the single vector FCS-MPC. When selecting the second vector, taking into account the switching frequency of the inverter switch, it is necessary to limit the selected second vector to the maximum extent. The number of switches is reduced, and the switching operation is reduced at a time when the load current is large to reduce the switching loss. Therefore, the switching state of the inverter is limited to only one change per control period, that is, its adjacent vector. When the model predictive controller selects the first voltage vector (1) through the value function, the second vector should be two vectors or zero vectors adjacent to 5, for example, if 1 is selected by scrolling, it is selected as 5 (100). The second vector should be selected among the three vectors $u_2$ (110), $u_6$ (101) and $t_0$ (000), and the principle of selecting the second vector and the duty ratio of its two vectors should be based on the evaluation function is based on the principle of minimum. For non-zero voltage vectors, there are always three alternative voltage vectors and their combination, so $6 \times 3$ and $18 \times 18$ evaluation calculations are required in each control cycle, and the system control set is established as 18 sets of switching sequences.

After selecting the vector combination, it is also necessary to determine the action time of a single voltage vector in each vector combination. The vector action period proposed in this paper is calculated based on the value function.

It can be seen from Fig. 4: At the modulation degree $M = 0.9$, the output line voltage of the five-level NPC / H bridge inverter has 9 levels, and the load current is very close to a sine wave. The experimental results verify the feasibility of improving the FCS-MPC model predictive control strategy.

4. Conclusion
This paper proposes a fast finite control set model predictive control method for five-level NPC / H bridge inverter systems. The dynamic voltage equation of the five-level NPC / H bridge inverter in the stationary coordinate system, the midpoint voltage of the DC bus and the output current of the inverter are established. The model control prediction and the fast finite control set model predictive control of the traditional finite control set are established. Steady-state and dynamic contrast experiments were carried out, and the following conclusions were drawn: (1) The fast finite control set model predictive control reduces the voltage vector involved in the objective function evaluation from the traditional 27 to 12, greatly reducing the computational complexity of online calculation and evaluation. Improve system computing efficiency. (2) The fast finite control set model predictive control and the traditional finite control set model predictive control are basically similar in steady state performance and dynamic performance. (3) The fast finite control set model predictive control has good steady state performance and superior dynamic performance. In short, the fast finite control set model predictive control makes
full use of the finite control set model to predict the control and control flexibility, and overcomes the deficiencies of the finite control set model predictive control calculation. The fast finite control set model predictive control has a good application prospect in multi-level multi-phase inverters.

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