Virtual DC Motor Stability Control Method Considering New Energy Generation Fluctuation

Yilun Tan*, Yucheng Wang
Xi’an modern Control Technology Research Institute, Xi’an, 710065, China
*Corresponding author’s e-mail: Tanyilun@mail.nwpu.edu.cn

Abstract. With the rapid development of new energy generation, the intermittence and randomicity of its power output will have a significant impact on the transmission capacity of DC motor. Therefore, a virtual DC motor stability control method considering the fluctuation of new energy generation is proposed. The natural frequencies and modes of the virtual DC motor shafting rotor are analyzed by means of a steady sinusoidal excitation at zero speed. Considering the transient dynamic response of the shafting rotor of virtual DC motor under the fluctuation of new energy generation, Taylor series and transfer acceleration matrix method are used to calculate the transient dynamic response of shafting rotor under the fluctuation of new energy generation, and the parameters of virtual DC motor are identified and estimated. Based on this, a proportional resonance controller is designed to realize the stability control of virtual DC motor. Experimental results show that the interactive power curve between virtual DC motor and regional distribution network is smoother after optimal control, and this method can effectively improve the power balance ability of virtual DC motor.

1. Introduction
Motor is a kind of electromagnetic equipment which transforms mechanical energy and electric energy according to electromagnetic induction law. In the electricity market environment, the available transmission capacity is an important dispatching basis and market regulation signal for guiding the normal operation of the power system [1]. It can not only indicate the safety and stability margin of power grid operation, but also provide detailed information on power grid usage for system operators and power market participants to guide their market behavior [2]. With the increasingly widespread use of new energy power generation, their permeability in the power system is also increasingly high. The world's new energy power generation is transforming from supplementary energy to alternative energy, and from independent systems to large-scale grid integration. As far as China is concerned, new energy power generation is also developing from decentralized, small-scale development and on-the-spot consumption to large-scale, highly concentrated development and long-distance and high-voltage transmission [3-4]. The large-scale access to new energy power generation and its uncertain characteristics will have a certain impact on all aspects of power system operation. Virtual DC motor stability is one of the important aspects, and is an important research topic for the development of smart grid and power market [5]. With the rapid development of modern motor control theory, the hardware of virtual DC motor is becoming more and more mature, but the load switching control method in the form of software becomes the bottleneck of the application and development of virtual DC motor.
2. Virtual DC motor stability control method considering new energy generation fluctuation

2.1. Natural frequency and modal analysis of virtual DC motor shafting rotor
At zero speed, the rotor of high-speed motor shafting is stimulated by steady sinusoidal excitation, as shown in Figure 1.

![Signal acquisition](image1)

![Fluctuation signal](image2)

![Power amplification](image3)

![Signal analysis](image4)

![Excitation signal](image5)

![Controller](image6)

![Comparison unit](image7)

![Power amplification](image8)

Fig. 1 Specific method of excitation for high-speed motor shafting rotor

The corresponding vibration spectra of 118Hz and 40Hz natural frequencies of rotor of high-speed motor shafting are obtained by excitation. Then the vibration modes and natural frequencies are calculated by finite element method [6], and the magnetic bearings are simulated by spring element, ignoring the influence of small damping.

2.2. Transient dynamic response
The transient dynamic response analysis of virtual DC motor shafting rotor based on fluctuation of new energy generation of shafting rotor under the fluctuation of new energy generation is analyzed by predicting Taylor series and transfer acceleration matrix method, and the instability is avoided by acceleration and force state vector. Firstly, by predicting the Taylor series, the speed and displacement of the rotor of the high-speed motor shafting at the next moment are estimated, and the next moment is expressed by \( t + \Delta t \). The specific formula is as follows:

\[
\begin{align*}
(e)_{n+1} &= (e)_n + \Delta t (\dot{e})_n + 0(\Delta t^2) \\
(\dot{e})_{n+1} &= (\dot{e})_n + \Delta t (\ddot{e})_n + 0(\Delta t^2)
\end{align*}
\]

In equation (1), \((e)_{n+1}\) represents the pre-estimate of the speed at the next moment; \((\dot{e})_{n+1}\) represents the pre-estimate of the displacement at the next moment; \((e)_n\) represents the velocity at \( t \) moment; \( \Delta t \) represents the increment of the time from \( t \) moment to the next moment; \((\dot{e})_n\) represents the displacement at \( t \) moment; and \((\ddot{e})_n\) represents the increment of the displacement at \( t \) moment to the next moment. The oil film characteristic coefficients of Taylor series are obtained by dynamically analyzing the oil film characteristic coefficients of the rotor, and the nonlinear oil film force is calculated. Thus, the point matrix constructed by the method of transfer acceleration matrix at the neck of the shaft rotor is obtained.
\[
\begin{align*}
\Delta Q_x &= k_{xx} x + c_{xy} \dot{y} \\
\Delta Q_y &= k_{yy} y + c_{yx} \dot{x} 
\end{align*}
\] (2)

In formula (2), \( \Delta Q_x \) and \( \Delta Q_y \) respectively represent the left and right coordinates of the nonlinear oil film force of the shaft rotor neck; \( k_{xx}, k_{xy}, k_{yx} \) and \( k_{yy} \) respectively represent the four components of the oil film stiffness matrix \( K_g \), namely, the main stiffness oil film coefficient; \( c_{xx}, c_{xy}, c_{yx} \) and \( c_{yy} \) respectively represent the four components of the oil film damping matrix \( C_g \), namely, the main damping oil film coefficient; \( x \) and \( y \) represent the original coordinates of the shaft rotor neck; and \( \dot{x} \) and \( \dot{y} \) represent the left and right coordinates of the shaft neck after it deviates from its original position due to the disturbance of new energy generation.

2.3. Parameter identification and estimation of virtual DC motor

In order to improve the performance of virtual DC motor speed regulation, the motor parameters need to be accurately identified and estimated, the specific process is as follows: A neural network model is used to identify and estimate the parameters of the virtual DC motor, as shown in Figure 2.

![Fig. 2 Schematic diagram of parameter identification and estimation of virtual DC motor](image)

As shown in Figure 2, the specific steps of parameter identification and estimation of virtual DC motor are as follows:

- Step 1: distribute all network weights randomly and evenly, and extract the smaller value;
- Step 2: collect the measured input and output data, which together constitute the training samples;
- Step 3: input the training samples obtained in step 2 into the neural network model, calculate and output;
- Step 4: error function calculation, the calculation formula is:

\[
\epsilon' = (T - Y)^2 = (T - UX)^2
\] (3)

- Step 5: modify the network weight according to a variety of weight learning and adjustment algorithms;
- Step 6: calculate the network weight error before and after training, and the calculation formula is:

\[
\epsilon'' = U_{i+1} - U_i
\] (4)

Compare the result of formula (4) with the given error, if \( \epsilon'' \leq \epsilon' \), the training of neural network model is stopped. At the same time, comparing the training times, if the training time \( n \) is greater than or equal to the given termination time, the training of the neural network model is stopped. This prevents the model from converging.
Step 7: The trained neural network model is used as the model of virtual DC motor parameter identification and estimation.

2.4. Motor digital signal processing
Based on the above identified and estimated virtual DC motor parameters, DSP chip 28335 is used to process the virtual DC motor digital signal for the final virtual DC motor speed control. The 28335 DSP chip has many functions, and it includes many pins.

The 28335 DSP chip adopts the format to calibrate the operation value, and the conversion relationship between the floating-point number and the fixed-point number is as follows:

\[
\begin{align*}
L' &= (\text{int}) x \cdot 5^e \\
L^n &= (\text{float}) x \cdot 5^e
\end{align*}
\] (5)

In equation (5), \( x \) represents floating point number; \( e \) represents the number of fixed points; \((\text{int})\) and \((\text{float})\) represent the conversion function.

2.5. Realization of low error control
According to the proportional resonance controller designed above, when the DC component in the current passes through the proportional resonance controller, there are:

\[
\begin{align*}
&u_{d*} = \left(k_{dd} + \frac{1}{s}\right)(i_d^* - i_d) \\
&u_{q*} = \left(k_{qq} + \frac{1}{s}\right)(i_q^* - i_q)
\end{align*}
\] (6)

In Formula (6), the upper angle * represents the control variable, the lower angle a represents the output of the DC component, and the \( k_{dd} \) and \( k_{qq} \) represent the integral coefficient and the scale coefficient in PI respectively. The transfer function of virtual DC motor load switching control is expressed as follows:

\[
I_L = \frac{KG(s)}{SZ + KG(s)}r_{ref} - \frac{1}{SZ + KG(s)}
\] (7)

In Formula (7), \( I_L \) represents the load switching control transfer function of the motor; \( K \) represents the control coefficient; \( G(s) \) represents the frequency of the proportional resonance controller as the gain; \( Z \) represents the discrete factor; and \( r_{ref} \) represents the gain approximate equivalent. The difference equation of the proportional resonance controller is obtained by finishi

\[
S(\cdot) = b_0e(h) + b_2e(h - 2) - a_1y(h - 1) - a_2y(h - 2)
\] (8)

In conclusion, based on the proportional resonance controller, the steady-state control of load switching of virtual DC motor is realized, and the control program is relatively simple, which provides effective support for the application of virtual DC motor.

3. Design and analysis of simulation experiment
To verify the effectiveness of the proposed model, the following numerical examples are designed. The virtual DC motor used in the experiment is a new energy and cogeneration unit, which can interact with the electric energy in the distribution network. Based on the internal power interaction characteristics of the new energy virtual DC motor, three virtual DC motors are selected as W1, W2 and W3, respectively. Among them, W1 and W2 are the maximum of combined power supply
capacity lower than the maximum of load demand, and $W_3$ is the maximum of combined power supply capacity higher than the maximum of load demand. The configuration of the three virtual DC motors is shown in Table 1.

| Virtual DC motor | Fan installed capacity / MW | PV installed capacity / MW | Power storage capacity / MW·H | Heat storage capacity / MW·H | Electric load max / MW | Heat load max / MW |
|------------------|----------------------------|---------------------------|-------------------------------|-----------------------------|-----------------------|-------------------|
| W1               | 30                         | 30                        | 62                            | 20                          | 15                    | 28                |
| W2               | 40                         | 40                        | 45                            | 25                          | 45                    | 80                |
| W3               | 40                         | 40                        | 95                            | 0                           | 37                    | 60                |

The new energy output, thermoelectric unit output and combined electric load of three virtual DC motors W1, W2 and W3 in winter are shown in Figure 3.

The interactive power curve between the new energy virtual DC motor and the regional distribution network after optimizing the operation mode of the new energy virtual DC motor by using the optimization method in this paper is shown in Figure 4.
As can be seen from Fig. 4, the interactive power curves of W1, W2 and W3 with the regional distribution network are more smooth after optimization by the method presented in this paper, and the improvement effect is especially obvious in late peak hours. Through the optimization and coordination of the operation mode of the new energy power generation system, the surplus power of R3 is first allocated to R1 and R2, which can effectively improve the power balance ability of the virtual DC motor with new energy.

4. Conclusion

In order to solve the instability of virtual DC motor operation under the fluctuation of energy generation, a method of virtual DC motor stability control is proposed. Considering the transient dynamic response of the rotor of the virtual DC motor, the parameters of the virtual DC motor are identified and estimated. Based on the above analysis results, a proportional resonance controller is designed to achieve the virtual DC motor stability control. The experimental results show that the power balance ability of the virtual DC motor with new energy is improved effectively after the optimal control method is adopted.

References

[1] Rahman A, Zulkifli S A, Pathman E . (2020) A new energy exploration for Malaysia's future electric supply based on waste kinetic energy: ideas, concepts, and possibilities[J]. Electrical Engineering, 102(16).

[2] Dudurych I M . (2021) The Impact of Renewables on Operational Security: Operating Power Systems That Have Extremely High Penetrations of Nonsynchronous Renewable Sources[J]. IEEE Power and Energy Magazine, 19(2):37-45.

[3] Bao J, Yuan T, Song C, et al. (2019) Thermodynamic analysis of a new double-pressure condensation power generation system recovering LNG cold energy for hydrogen production[J]. International Journal of Hydrogen Energy, 44(33):17649-17661.

[4] Kandasamy N K . (2020) Prosumer Site Power Interruption Attacks: Exploiting the Reactive Power Control Feature in Smart Inverters[J]. IET Renewable Power Generation, 14(23):5372.

[5] Gyanwali K, Komiyama R, Fujii Y . (2020) Representing hydropower in the dynamic power sector model and assessing clean energy deployment in the power generation mix of Nepal[J]. Energy, 202(11):117795.

[6] R Vennell, R Major, R Zyngfogel, et al. (2020) Rapid initial assessment of the number of turbines required for largescale power generation by tidal currents[J]. Renewable Energy, 162:1890-1905.