Regenerative Braking Method of Permanent Magnet Motor System based on Fuzzy Mathematics

Hongqi Zhu
School of Mathematics & Finance, Huainan Normal College, Huainan, 232038, China

Abstract: The traditional motor system problems brake low recovery efficiency of regenerative braking system, and accordingly put forward based on the fuzzy mathematics method of permanent magnet motor regenerative braking system based on fuzzy mathematics observation of stator flux, the amplitude of the stator flux linkage control parameters, and then select the zero vector and non-zero transient slip loss to adjust and control the output torque constant, guarantee the output current harmonic, smooth operation, and on the basis of the structure of regenerative braking control, to achieve the permanent magnet motor regenerative braking system of fuzzy mathematics. Finally, the numerical values of each parameter are input into the ADVISOR, and the simulation experiment is conducted with the ADVISOR software. The experimental results prove that the method is highly effective and practical, and fully meets the research requirements.

Keywords: Fuzzy mathematics; Regenerative braking; Motor

1. Introduction

Electric motors often consume kinetic energy and heat energy on the road, which is wasted. Since the permanent magnet motor can run in four quadrants, regenerative braking can be realized by controlling the motor to run in the second quadrant, and the kinetic energy of the permanent magnet motor can be converted into the power supply storage fed back by electric energy[1]. In this way, the driving range of the permanent magnet motor on one charge can be effectively extended. In the running process of permanent magnet motor, the starting acceleration and braking deceleration are required to be relatively large, and it has good starting and braking performance. Directly using the battery as the driving power, the regenerative braking feedback energy can be directly charged to the battery[2]. There is no need to invert back to the ac power grid like the general ac speed regulation system, and the control structure is relatively simple. ADVISOR is the renewable energy laboratory in Matlab and Simulink software environment and development of advanced simulation software, the permanent magnet motor on the basis of this software is constructed regenerative braking force distribution in the process of simulation model and simulation experiments, the results show that the proposed method can make the permanent magnet motor in the process of driving energy recovery efficiency, harmful gas emissions are reduced.

2. Regenerative Braking of Permanent Magnet Motor System based on Fuzzy Mathematics

2.1. Setting of regenerative braking structure for permanent magnet motors

Regenerative braking control is, in fact, according to the size and direction of the electric potential in the motor control corresponding bridge arm of the on and off of the power switching devices, guarantee of exciting current, but this method is specific to each phase of each bridge arm switch control is more troublesome, but as long as the rotor speed beyond the stator rotating frequency, frequency tracking the rotor speed, stator maintain negative slip, can be implemented in the absence of flow of the regenerative braking[3]. According to the way of thinking, the regenerative braking system is shown in Figure 1, in direct torque control (DTC), the first observation of stator flux linkage, the amplitude of the stator flux linkage control for constant, and then select the zero vector and non-zero transient slip loss to adjust and control the output torque constant, so by the observation of magnetic chain link the amplitude and phase of the stator flux linkage, and choose size chain amplitude vector control; Torque control link (combined with flux control link) selects variables to control the rotation speed of flux.

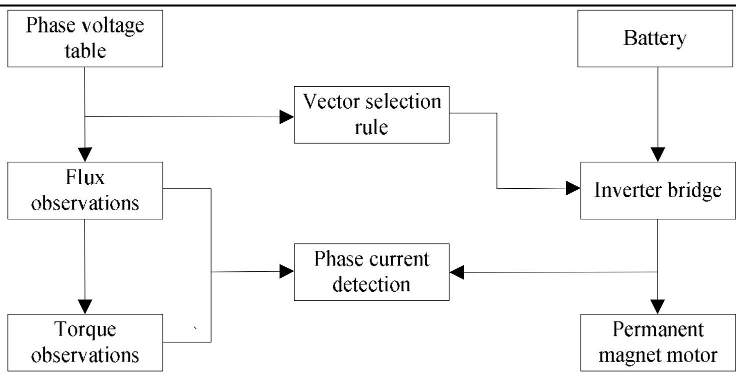

Figure 1. Structure of regenerative braking module

Can be seen from the above, the torque feedback are replaced with the phase of the stator flux feedback, but still retain control of flux amplitude link, at this time the system is through the control of the amplitude of the stator flux linkage size and rotational speed to realize the frequency control of motor speed, because the structure is actually used the DTC control mode, it retains the flux control link, so can effectively control the flux of phase deviation, in this case can guarantee the output current harmonic less, smooth operation, and on the basis of the structure of regenerative braking control, is to make the stator frequency tracking the rotor speed, determine the scope of the negative slip, Can realize the system does not appear in the braking process overcurrent. On the other hand, the braking effect can be achieved by adjusting the slip and stator flux amplitude[4]. Because this method retains the structure and characteristics of DTC, it can be well compatible with the ac drive system of DTC. When large GD2 (flywheel torque) load decelerates, the speed converter deceleration time is set too short; The motor is affected by external force (fan, drafter) or potential load (elevator, crane). For these reasons, the actual speed of the motor is higher than the command speed of the frequency converter, that is to say, the rotor speed of the motor exceeds the synchronous speed, then the slip of the motor is negative, the direction of the rotor winding cutting rotating magnetic field is opposite to the state of the motor, and the electromagnetic torque generated is the braking torque that impedes the direction of rotation. So the motor is actually generating electricity, and the kinetic energy of the load is "regenerated" into electrical energy.

The regenerative energy is used to charge the dc energy storage capacitor of the inverter through the inverter diode, which makes the dc bus voltage rise[5]. This is the regenerative overvoltage. Because the torque generated in the process of regenerative overvoltage is opposite to the original torque and is the braking torque, the process of regenerative overvoltage is also the process of regenerative braking. In other words, by eliminating the regenerative energy, the braking torque is increased[6]. If the regenerative energy is not large, because the inverter and motor itself have 20% regenerative braking capacity, this part of the electrical energy will be used up by the inverter and motor. If this part of energy exceeds the consumption capacity of the converter and the motor, the capacitance of the dc loop will be overcharged, and the over-voltage protection function of the converter will be activated to stop the operation. In order to avoid the occurrence of this situation, this part of energy must be dealt with in a timely manner, but also improve the braking torque, which is the purpose of regenerative braking.

2.2. Setting of motor braking parameters based on fuzzy algorithm

After analyzing the system mentioned above, the braking force of body and frame under various typical conditions is calculated by using fuzzy algorithm. For the suspension mass system (body, frame), take the coordinate xyz through its center of mass. If the system is regarded as a rigid body, it has six degrees of freedom on the suspension system, namely the linear displacement along the x, y and z axes and the angular displacement around the three axes; Correspondingly, there are three forces F_X, F_y and F_z along the x, y and z axes, and the torque T_X, bending moment My and M_z around the three axes. When a car is moving, the general force acting on the car is.

$$F_m = \frac{(G_r + G_e)}{g} a_m = k_m (G_r + G_e) = k_m \sum F_i \qquad (1)$$

Where, km is the dynamic load coefficient in the x, y and z directions, $k_m = \frac{a_m}{g}$; am is the acceleration of the car along the x, y and z directions; g is gravity acceleration; G_r is the load of the suspended body system of an automobile, and refers to the gravity of those parts, such as the body, the frame, and all assembly and equipment fixed on the body or frame, borne by the elastic components of the suspension; G_e is the payload of the car body and refers to the gravity of the passengers and baggage or cargo at the rated loading time.

Both G_r and G_e are static loads, distributed in the appropriate position of body and frame I (I = 1,2... , n), namely

$$(G_r + G_e) = k_m \sum F_i \quad (2)$$

The dynamic load coefficient mainly depends on three factors: road conditions, vehicle driving conditions (such as speed) and vehicle structure parameters. Because these factors are very complex, it is difficult to determine the dynamic load coefficient by mathematical analysis. Therefore, in the past, some simple pavement conditions were studied separately in the analysis, and the dynamic load coefficient was taken as the semi-empirical value combined with theoretical research and experimental correction. When the car on the sections II I and section. When the front and rear wheels pass through the ridges or pits at the same height at the same time, it is assumed that the automobile structure is symmetrical left and right, then the bearing system will experience the vertical force F_{ZS}, which is the main dynamic load component of the automobile under normal driving conditions, i.e

$$F_{zs} = k_{zs} \sum F_i \quad (3)$$

Where, K_{ZS} is symmetric vertical dynamic load coefficient.

When the front and rear wheels of the car drive up the bump from the flat road surface and the left and right wheels have height difference hn at the contact point, the load bearing system will act on the vertical load which is asymmetric to the longitudinal axis of the car[7]. At this time, the load can be decomposed into the symmetrical vertical force under load and the vertical load Fzn, which is only symmetrical to the vertical axis of the car due to the road bump, forming the torque Tx of the car body around the x axis.

$$F_{zn} = k_{zn} \sum F_i \quad (4)$$

$$Tx = k_{zn} (F_{1L} - F_{1R}) \frac{B_1}{2} \quad (5)$$

The braking force is calculated by the above formula, and the braking moment is obtained. The braking force values in subsequent simulation experiments can be calculated. Through the above analysis, the regenerative braking method of permanent magnet motor system based on fuzzy mathematics is adopted[8]. This method is to control the on and off of a power tube by detecting the dc bus voltage by connecting a brake resistor in parallel in the dc circuit of the frequency converter. When the dc bus voltage rises to about 700V, the power tube conducts, and the regenerative energy is fed into the resistance, which is consumed in the form of thermal energy, thus preventing the rise of dc voltage. Because regenerative energy cannot be used, it belongs to the energy consumption type[9]. It is the same type of energy consumption. The difference between it and dc braking is that the energy is consumed on the braking resistance outside the motor. The motor will not overheat, so it can work frequently.

2.3. Realization of regenerative braking of permanent magnet motor

Regenerative braking energy absorption device mainly USES IGBT inverter to absorb regenerative braking energy of permanent magnet motor into large-capacity capacitor bank or flywheel motor. When the train starting or accelerating in the power supply area needs to take the current, the device will release the stored electric energy and reuse it[10]. The electrical system of the absorber mainly includes energy storage capacitor bank or flywheel motor, IGBT chopper, dc quick circuit breaker, electric disconnector, sensor and microcomputer control unit, etc. The device makes full use of the regenerative braking energy of the train, has good energy saving effect and can reduce the capacity of the braking resistance of the train.

When the permanent magnet motor with regenerative braking ability releases energy near the energy storage system of the substation, the traction network pressure rises. The regulator of the energy storage system can detect this situation, and temporarily excess energy in the traction network system is stored in the capacitor to keep the traction network pressure within a limited range. If the permanent magnet motor starts or accelerates near the energy storage system of the substation and the traction network pressure drops, at this time, the regulator of the energy storage system will transfer the energy from the storage system back to the traction network system to maintain the stability of the traction network pressure. In the no-load state of dc traction network, the energy storage system absorbs some energy from the traction system, which can help the permanent magnet motor start in this way. The regenerative braking process is shown in the Figure below.

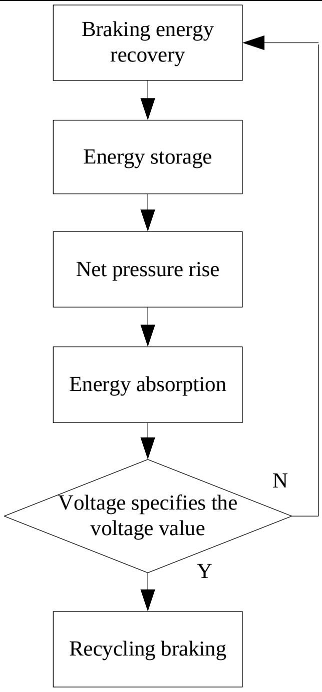

Figure 2. Regenerative braking process

As can be seen from the above process, when regenerative braking is applied, multiple inverters share a network-side converter, and all inverters are connected to a common dc bus. In such a system, one or more motors usually work normally in the braking state, and the motor in the braking state is dragged by other motors to generate regenerative energy, which is then absorbed by the motor in the electric state through the parallel dc bus.

When regenerative braking makes the dc voltage exceed the specified value, the inverter starts and absorbs current from the dc bus, and feeds the regenerative dc energy into ac power back to the ac power grid. The electrical system of the absorber mainly includes thyristor inverter, inverter transformer, balance reactor, ac circuit breaker, dc quick circuit breaker, electric disconnector, dc voltage converter and control cabinet. The device makes full use of regenerative braking energy, improves the utilization rate of regenerative energy, has good energy saving effect, and can reduce the capacity of train braking resistance.

After the above process analysis, the working mode of regenerative braking system can be summarized as follows:

2.3.1. Startup

The vehicle is driven separately by the hydraulic accumulator to the motor first, and the engine can be started after having a certain initial speed, or it can be driven by the engine and the hydraulic storage together, which can improve the working condition of the engine, save fuel and avoid exhaust emissions.

2.3.2. When driving normally

The engine can drive the vehicle alone, and the hydraulic accumulator can adjust the charging and discharging function to make the engine work in the lowest fuel consumption ratio range and reduce the emission at the same time.

2.3.3. When accelerating

The engine can drive the vehicle at the same time with the hydraulic motor, improve the vehicle's acceleration performance, and adjust the engine power peak.

2.3.4. Deceleration braking

The drive shaft drives a hydraulic motor to recover braking energy and store it in a hydraulic accumulator for the next start-up and acceleration. The accumulator releases energy to drive the car together with the engine of the car when the car starts up, accelerates, runs at high speed, or goes uphill. In this way, the engine load can be improved and the emission pollution caused by the short-term deterioration of the engine working condition can be avoided. The accumulator can also drive the car alone when the car is in a slow speed, such as traffic jam. It can not only reduce the consumption caused by insufficient fuel combustion when the engine is idling, but also reduce the exhaust emission when the engine is idling, thus protecting the urban atmospheric environment. By using the accumulator to adjust the peak power of the engine, the power of the engine can be reduced without affecting the power performance of the whole vehicle, and energy saving and consumption reduction can be realized.

3. Experimental Results and Analysis

Through the above analysis, to further verify the feasibility of the method, ADVISOR simulation software was used to conduct a simulation experiment on the method. The control group and the experimental group were set respectively to compare the experimental results. The main simulation parameters are shown in the following table.

Table 1. Main simulation parameters

Parameter name	Numerical value	Unit
Type of motor	Permanent magnet synchronous motor	
Peak power	118	Kw
Rated power	35	Kw
Rated voltage	312	V
Peak torque	266	Nm
Rated torque	140	Nm
Peak speeds	7000	r/min
Basic velocity	2500	r/min
Rated speed	3000	r/min

According to the above analysis, the original module was modified and a new regenerative braking control module was established in the Advisor. The simulation results are shown in the Fig.3.

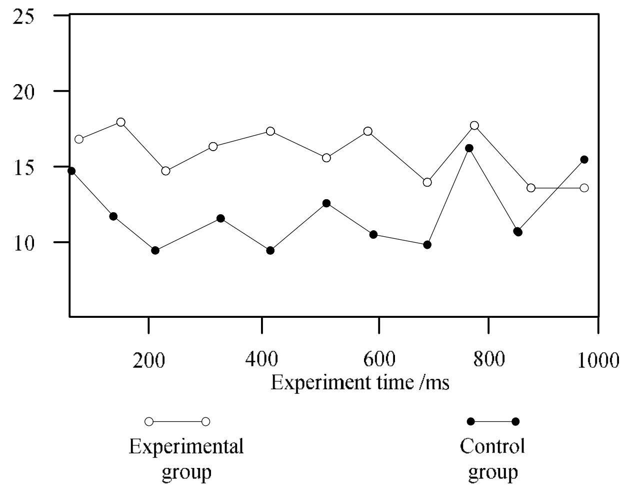

Figure 3. Simulation results

As can be seen from the results, the simulation results show that the method adopted by the experimental group has an obvious advantage over the original method in recovering braking energy (it has obvious advantages in recovering braking energy). In the whole cycle, the storage energy of the battery increases, the emission is also improved, and the working efficiency of the motor is also significantly improved.

In addition, this method can also extend the deceleration time, control the charging speed of the inverter with the regenerative voltage of the load, and make the 20% regenerative braking capacity of the inverter be used reasonably. The load that makes the motor in the regenerative state due to the action of external force (including potential energy down) can effectively store the regenerative energy because it normally operates in the braking state.

4. Conclusion

Regenerative braking is an important difference between electric vehicles and conventional vehicles. In the research of electric vehicle, regenerative braking has become a technical means to reduce energy consumption and improve driving range. The original regenerative braking method has the problem of low energy recovery efficiency, so the regenerative braking method of permanent magnet motor system based on fuzzy mathematics is proposed. Based on the regenerative braking simulation module of ADVISOR software, the regenerative braking simulation model of electric vehicle regenerative braking system is built based on fuzzy mathematics. The simulation results show that the model is correct and the ADVISOR simulation function is expanded, which provides convenience for the simulation and research of regenerative braking system of electric vehicles.

References

[1] Zhang Bingyi, He Gongfei, Feng Guihong. Study on Starting Performance of Self-starting Permanent Magnet Motors with Capacity Similar to Transformer. Journal of Motor and Control. 2017, 21(1), 85-89.

[2] Shangguan Xuanfeng, Jiang siyuan, Li zhengxiu. Comparative Study of Permanent Magnet Induction Motor and Self-starting Permanent Magnet Motor. Micro Motor. 2017, 45(10), 4-8.

[3] Lin Chuanlin, Lin Zhen. Summary of Influence of Permanent Magnet Motor Structural Parameters on Slot Torque. Electrical Technology. 2018, 19(2), 6-10.

[4] Tian Mengmeng, Wang Xiuhe, Wang Daohan, et al. Parameter Calculation and Torque Analysis of a New Type of Pole-Changing Starting Permanent Magnet Synchronous Motor. Journal of China Electrical Engineering. 2017, 37(24), 32-34.

[5] Zhu Xingwang, Huang Kaisheng, Lai Wenhai, et al. Slot Pole Selection and Radial Force Analysis of Fractional Slot Concentrated Winding Permanent Magnet Motors. Micromotors. 2017, 45(8), 46-49.

[6] Wang Yong, Zhang Junyong, Yang Haipeng, et al. Study and Application of Energy Saving for Belt Conveyor Equipped with Permanent Magnet Motors. Energy Technology and Management. 2017, 42(1), 170-172.

[7] Guo Jin. Study and experimental analysis on synchronous dragging characteristics of permanent magnet motor in vinegar fiber production line. Technology Innovation and Application. 2017, (4), 123-123.

[8] Zhu Gaojia, Zhu Yinghao, Zhu Jianguo, et al. Design and Analysis of Permanent Magnet Traction Motor Cooling System based on Finite Formula Method and Fluid-solid Coupling. Journal of Electrical Technology. 2017, 32(5), 70-77.

[9] Zhao Jinyue, Guan Xin, Xu Delong, et al. Research on Speed Sensorless Control System of Permanent Magnet Synchronous Motor for Electric Vehicles based on Model Reference Adaptive. Electrical Technology. 2017, 18(2), 36-40.

[10] Liu Mingji, Zhang Yupeng. Flux-weakening Torque Control of Embedded Permanent Magnet Synchronous Motors Considering Changes in Permanent Magnet Flux Linkage. Journal of North China Electric Power University (Natural Science Edition). 2017, 44(5), 69-73.