Research on the Application of PIR Controller under Fluctuating DC Voltage in High-speed Train Traction Drives

Wei Shi, Fei Lin, Hu Sun and Zhongping Yang

School of Electrical Engineering,
Beijing Jiaotong University, Bei Jing, China.
E-mail: 11121654@bjtu.edu.cn

ABSTRACT

In high-speed traction drive system, a substantial ripple of DC bus voltage decrease the performance of the traction drives, and it may also increase the low frequency harmonics of the input ac current. With or without the second-order LC filter are two different approaches using broadly around the world. Bulky settings are needed for the first approach, and the sampling accuracy may affect the ripple eliminating common method of the second approach. A new method to reject the torque and current ripple (beat components) in induction motor, and to decrease the harmonics of the input current of PWM converter, which resulted from the DC bus pulsation, is presented in this paper. Based on the perfect result to tract some sine-wave signal at its resonant frequency, proportional-integral-resonant (PIR) controller can be set in the ac current controlling loop, to decrease the harmonics of the input ac current in the PWM converter, and it can be used to eliminate the sine-wave disturbances by being applied in the d-q currents loops instead of the PI controllers in the inverter as well, to reject the torque and current ripple in induction motor in the traction drive system. In this paper, a PIR controller is derived and simulated using the parameters of CRH_2 in China. The results of the simulation and experiment show that the harmonics of the input current of PWM converter can be decreased powerfully, the torque and current ripple can also be eliminated obviously by using the new method.

1.INTRODUCTION

The traction drive system is very important in high-speed train system, using the AC - DC - AC structure generally. A substantial ripple of DC bus voltage may negatively affect the performance of the traction drives, and it may also increase the harmonics (especially at 3rd grid frequency) of the input ac current (J.Klima *et al*. 2008, Kevin Lee et al. 2006).

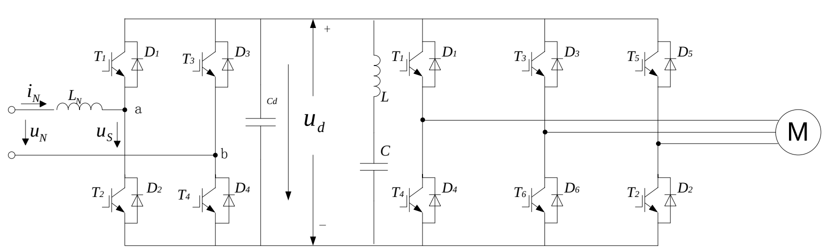


Fig.1 'AC-DC-AC' high-speed train traction drive system

With or without a LC filter set in the DC-link are two main ideas to suppress the impact. The first approach has the disadvantage such as filter size, weight and non-economic, with a LC filter set in the DC link to eliminate the secondary DC-link ripple voltage(A.D.Mansell,J.Shen.1994). Meanwhile, the second idea has been on the research all over the world recently, which focusing on the improvement in four-quadrant converter and traction inverter control strategy to manage the influence of DC-link voltage ripple for four-quadrant converter and traction motor without the bulky LC filter device, for example, there is no LC filter set in the DC link in the $CRH_{2,}$ CRH_5, and CRH380A high-speed rail train in China. Considering how to improve the control strategy of four-quadrant converter, it is common to use a digital filter which is tuned at twice the grid frequency following the sample of the DC link voltage(Rahman M Azizur, et al. 1997, Liaw C M, et al. 1991, Jingquan Chen, et al. 2003), which is mean to minimize the harmonic component of the input current instruction in the controlling loop of the rectifier. However, the filter increased the delay effect in the control loop, and the efficiency for the strategy to eliminate the AC side current harmonics is often less than expected. Considering how to improve the strategy in traction inverter control, the common methods, such as changing the pulse width with the DC link voltage ripple monitored in real-time in the modulation region of the PWM inverter control(M.Chomat, L.Schreier. 2004, P.D. Evans, A.J. Forsyth.1999, Z. Salam, C.J. Goodman. 1996), and another method which monitoring of the DC link voltage variation is to regulate in the phase of the inverter output voltage in order to compensate the DC link voltage ripple on the inverter output voltage waveform in square wave traction conditions(Wenshen Song, et al. 2011), have satisfactory practicability. The significant impact of these methods is mainly involved with the influence from the sample accuracy of the DC-link voltage. So, in some literatures(Hui Ouyang, et al. 2011), a repetitive observer is proposed to predict the DC link voltage for higher performance, so as to overcome the measurement error by low sampling frequency, ZOH and delay.

From the perspective of improving the control strategy, this article focused on the rejection method of the rectifier and inverter control strategy without a DC-link hardware secondary filter set, to eliminate the harmonics in converter input current and motor torque pulsation caused by the secondary ripple in DC-link voltage. A new method based on PIR controller is proposed in this paper, and the principles and how to set up the resonant segment has been analyzed and simulated.

2 .IMPACT ON THE TRACTION DRIVE SYSTEM FROM DC-LINK VOLTAGE

2.1Impact on the rectifier

In high-speed train traction drive system, the single-phase input rectifier produces the DC-link voltage as a DC component, as well as harmonic components, including the harmonics at twice the grid frequency most. In the analyze below, the input current harmonic components will be considered under the case with no DC-link voltage secondary pulse firstly, then taking the secondary pulse of the DC-link into account, the impact on the rectifier can be concluded.

In single-polar modulation, the AC side PWM voltage contains not only the fundamental part but also the cross-modulation high harmonic components in the two-level single-phase four-quadrant converter (Yasuyaki Nishids, et al. 1997, Hasan Komurcugil, Osman Kukrer. 2000).

$$MU_d \cos(\omega_m t+\beta)+\sum_{m=2,4\cdots}^{\infty}\sum_{n=\pm1,\pm3\cdots}^{\infty}\frac{4U_d}{m\pi}J_n(\frac{mM\pi}{2})$$
$$\cos\frac{m}{2}\pi\sin\frac{n}{2}\pi\cos(n\omega_m t+m\omega_c t+n\beta+m\alpha) \tag{1}$$

Assume the input AC voltage as:

$$u_N(t) = \sqrt{2}U_N \cos\omega_m t \tag{2}$$

To the control destination, the fundamental component of the input current in phase with the input voltage, as the following equation:

$$i_{s1}(t) = \sqrt{2}I_{s1} \cos\omega_m t \tag{3}$$

According to Kirchhoff's law, the voltage fundamental component should meet the following equation:

$$u_N = u_{L1} + u_{ab1} = L_N \frac{di_{s1}}{dt} + u_{ab1} \tag{4}$$

The fundamental component of the input current may be derived as follows considering equation (1) and (2):

$$I_{s1} = \frac{MU_d \sin\beta}{\sqrt{2}\omega_m L_N} = \frac{\sqrt{(MU_d)^2 - 2U_N^2}}{\sqrt{2}\omega_m L_N} \tag{5}$$

The harmonics in the input current may be expressed as follows:

$$L_N \frac{di_{sn}}{dt} = -u_{abn} \tag{6}$$

The input current can be expressed as the following equation considering equation (1),(3)and (4):

$$i_s(t) = \frac{\sqrt{(MU_d)^2 - 2U_N^2}}{\omega_m L_N}\cos(\omega_m t + \beta) - \sum_{m=2,4\cdots}^{\infty}\sum_{n=\pm1,\pm3\cdots}^{\infty} \begin{matrix} \dfrac{4U_d}{m\pi L_N(n\omega_m + m\omega_c)} J_n(\dfrac{mM\pi}{2}) \\ \cos\dfrac{m}{2}\pi \sin\dfrac{n}{2}\pi \cos(n\omega_m t + m\omega_c t + n\beta + m\alpha) \end{matrix} \tag{7}$$

Taking the DC-link ripple voltage into account, the DC-link voltage can be expressed as following equation:

$$u_d(t) = U_{dc} + U_{ac}\cos(2\omega_m t + \gamma) + u_{dn} \tag{8}$$

The AC side PWM voltage can be derived after in a single-phase two-level rectifier:

$$u_{ab} = MU_{dc}\cos(\omega_m t + \beta) + MU_{ac}\cos(\omega_m t + \gamma - \beta) + MU_{ac}\cos(3\omega_m t + \gamma + \beta) + U_{abn} \tag{9}$$

Where γ is determined by the parameters of the rectifier, no relationship with β. There is some content which initial phase different from the fundamental at the same frequency and a third harmonic content in the AC side PWM voltage, in addition to the fundamental and cross-modulation high harmonic components, considering the DC-link secondary pulse. The role of the control loop will make the fundamental amplitude of the input power is consistent , this third harmonic component will allow the AC side current increase in the third harmonic component.

Then,

$$i_s(t) = MU_{dc}\cos(\omega_m t+\delta) - \frac{MU_{ac}}{3L_N\omega_m}\sin(3\omega_m t+\gamma+\beta)+i_{sn} \tag{10}$$

It`s obvious that the DC voltage ripple may produce additional harmonics in the input AC current at low frequencies. In addition, the voltage pulse may produce the harmonics in the input current through the closed-loop control because that the secondary ripple may be sampled together with the DC-link voltage increasing the harmonics in the current instruction.

At present, the transient direct current double closed-loop control is used generally in four-quadrant converter in high-speed train traction (Omar Stihi, Boon Teck Ooi. 1988, Osman Kukrer, Hasan Komurcugil. 1997). The control strategy enables the system has the advantages of stable DC voltage and satisfactory dynamic response. The control strategy is expressed as shown in equation(11). Where Kp, Ti for the PI regulator parameters; the U_d^* for DC voltage for a given value, I_d and U_d for DC current and voltage respectively, and K for the current loop proportional amplification factor.

$$\begin{cases} I_{N1} = K_p(U_d^* - U_d) + \frac{1}{T_i}\int (U_d^* - U_d)dt \\ I_{N2} = \frac{I_d U_d}{U_N} \\ I_N^* = I_{N1}^* + I_{N2}^* \\ u_{ab}(t) = u_N(t) - \omega L_N I_N^* \cos(\omega t) - R_N I_N^* \sin(\omega t) - K[I_N^* \sin\omega t - i_N(t)] \end{cases} \tag{11}$$

In the voltage loop with PI controller, the actual DC voltage secondary pulse makes the magnitude I_n^* of the output i_n^* contain twice the grid frequency harmonics, multiplied by the sinusoidal signal from the phase-locked loop keeping pace with the grid input voltage. Then, the proposed current value i_n^* may contain the third harmonic, and the actual AC input current of the rectifier should contain some third harmonic tracking the given current value (Rahman M Azizur, et al. 1997, Liaw C M, et al. 1991,Jingquan Chen, et al. 2003). Analyze more in depth, the input current of the rectifier may contain 3rd, 5th, 7th and other odd harmonic. In transient direct current control method, due to the presence of $I_{N2}=I_dU_d/U_N$, the I_d component of the second pulse may also be introduced into the control loop, participating in the generation of low harmonic in the current as well.

2.2 The impact on the traction motor

Under natural-sampling PWM process in a three-phase voltage source inverter, the phase lag of its three-phase sinusoidal reference signals is 120^o.

$$\begin{cases} u_{an}^* = Mu_d\cos\omega_o t \\ u_{bn}^* = Mu_d\cos(\omega_o t - \frac{2\pi}{3}) \\ u_{cn}^* = Mu_d\cos(\omega_o t + \frac{2\pi}{3}) \end{cases} \tag{12}$$

A double-edge natural-sampling PWM harmonic analytical expression can be derived as follows throughout the Bilateral Fourier analysis of the PWM pulse:

$$\begin{cases} u_{an}(t) = u_d + Mu_d \cos\omega_o t + \dfrac{4u_d}{\pi}\sum_{m=1}^{\infty}\sum_{n=-\infty}^{\infty}\dfrac{1}{m}J_n(m\dfrac{\pi}{2}M)\sin[(m+n)\dfrac{\pi}{2}]\cos(m\omega_c t + n\omega_o t) \\ u_{bn}(t) = \sqrt{3}Mu_d\cos(\omega_o t + \dfrac{\pi}{6}) + \dfrac{8u_d}{\pi}\sum_{m=1}^{\infty}\sum_{n=-\infty}^{\infty}\dfrac{1}{m}J_n(m\dfrac{\pi}{2}M)\sin[(m+n)\dfrac{\pi}{2}]\sin n\dfrac{\pi}{3}\cos[m\omega_c t + n(\omega_o t - \dfrac{\pi}{3}) + \dfrac{\pi}{2}] \end{cases} \tag{13}$$

Ignoring the high-order harmonics in equation (8), the output line-line voltage of the inverter can be derived as:

$$u_{ab}(t) = \sqrt{3}MU_{dc}\cos(\omega_o t + \theta) + \frac{\sqrt{3}}{2}MU_{ac}\cos[(2\omega_m - \omega_o)t + \gamma - \theta] + \frac{\sqrt{3}}{2}MU_{ac}\cos[(2\omega_m + \omega_o)t + \gamma + \theta] \tag{14}$$

When a secondary pulse is considered in the DC-link voltage, the AC output voltage of the inverter contains not only the component at the desired frequency, but also the two harmonic frequencies $2\omega_m \pm \omega_o$.

A secondary pulse ($2\omega_m$) in the DC link voltage exists resulted from the single-phase PWM rectifier, Therefore, the inverter output AC voltage contains not only the voltage of the desired frequency(ω_o), it also contains harmonics at the two frequencies of ($2\omega_m \pm \omega_o$).

When the harmonics frequencies of the motor voltage supply are ($2\omega_m \pm \omega_o$), the current will contain the same frequency harmonics, according to the expression of the phase voltage the fundamental current can be assumed as:

$$i_{ai} = I_i \sin(\omega_o t - \varphi) \tag{15}$$

The lower-frequency harmonics of the stator currents expressions are as follows:

$$\begin{cases} i_{h1} = k_1 I_i \cos\left[(\omega_o - 2\omega_m)t - \varphi\right] \\ i_{h2} = k_2 I_i \cos\left[(\omega_o + 2\omega_m)t - \varphi\right] \end{cases} \tag{16}$$

Where φ is the fundamental power factor angle, k_1 and k_2 are the amplitude ratios of the lower-frequency harmonics of the fundamental current.

Then the motor phase currents can be derived to the following expressions through coordinate transformation：

$$\begin{cases} i_d = -I_i\sin\varphi + k_1 I_i\cos(2\omega_m t + \varphi) + k_2 I_i\cos(2\omega_m t - \varphi) \\ i_q = I_i\cos\varphi - k_1 I_i\sin(2\omega_m t + \varphi) + k_2 I_i\sin(2\omega_m t - \varphi) \end{cases} \tag{17}$$

It`s obvious that the harmonic component in the d-axis current and q-axis current contains the same frequency ($2\omega_m$) as the secondary ripple frequency of the DC link voltage.

Known by the model of the motor synchronous rotating coordinate system, the motor torque can be expressed as:

$$T_e = \frac{n_p L_m^2}{L_r} i_{sq} i_{sd} \tag{18}$$

$$T_e = \frac{n_p L_m^2}{L_r} \times I_i^2 \left[-\frac{1}{2}\sin 2\varphi + \frac{k_3 k_4}{2}\sin(\alpha-\beta) + k_3\cos\varphi\cos(2\omega_m t-\alpha) - k_4\sin\varphi\sin(2\omega_m t-\beta) + \frac{k_3 k_4}{2}\sin(4\omega_m t-\alpha-\beta) \right] \tag{19}$$

Where $k_3 = \sqrt{(k_1+k_2)^2\cos^2\varphi + (k_2-k_1)^2\sin^2\varphi}$, $k_4 = \sqrt{(k_2-k_1)^2\cos^2\varphi + (k_1+k_2)^2\sin^2\varphi}$, $\tan\alpha = \frac{k_2-k_1}{k_2+k_1}\tan\varphi, \tan\beta = \frac{k_1+k_2}{k_1-k_2}$.

It can be seen from the motor transient torque formula that the motor output torque containing the pulsating torque component with the frequency at $2\omega_m$ and $4\omega_m$, due to the existence of the DC link secondary ripple voltage.

3 PIR CONTROLLER APPLIED TO THE TRACTION DRIVE SYSTEM

3.1Introduction of PIR controller

In the closed-loop control system, if the feedback loop contains a description of the mathematical model of the external signal dynamic characteristics, then the system has the desired command tracking characteristics and disturbance rejection capability. If the external command signal or the disturbance signal is periodical, then to achieve the signal without static error tracking or inhibition, the mathematical model of the periodic signal in the closed-loop control system must be introduced (R.Teodorescu, et al. 2006, Y.Sato, et al. 1998). Control system input signal is sinusoidal, the introduction of the proportion-resonant link in the control loop is necessary.

$$C_p(s) = k_p + \frac{k_i}{s} + \frac{k_r s}{s^2 + n^2\omega_r^2} \tag{20}$$

The parallel PIR controller can be expressed as equation(21). Where k_p, k_i and k_r for the proportional, integral and proportional coefficient of the resonant link respectively. PI controller can track step signals with no static error, while the resonant link gain can be achieved toughly high at the designed frequency tracking AC signal at the resonant frequency without static error. Similarly, the AC component of the feedback signal can be filtered accurately throughout the resonant aspect.

3.2 PIR controller applied to the rectifier control

Throughout the analysis in section 2.1, there are some 3^{rd}, 5^{th}, 7^{th} harmonics in the input current of the rectifier resulted from the second DC-link voltage ripple. On one hand, the role of the PWM cross-modulation produces the harmonics, the other hand, there is much harmonic in the current instruction in the control loop. Because of the different phases of the harmonics from the two ways, the harmonics should be added considering their vector phases. The common method of inhibition of the low harmonics in the AC input current is to use digital notch or low-pass filter tuned at the second pulsation frequency in the DC-link voltage, reducing harmonics in the current instruction, however, to a certain extent, the digital filter may increasing the controlling delay and the phase lag of the control signal, affecting the dynamic performance of the controller. At the same time, some of the low frequency harmonic throughout the PWM modulation process may increase due to the slow current controlling performance. Therefore, in some cases the traditional methods of suppression cannot achieve good results.

Applying the resonant controller to the four-quadrant converter, on the one hand, it can be set at the voltage loop (Huang Ruhai, Xie Shaojun. 2012), tuning the resonant frequency at the DC-link voltage secondary pulse frequency, if we neglect the high frequency harmonics generated by the PWM modulation process, its transfer function can be equivalent to 1, the control block diagram of the control loop can be expressed as follows:

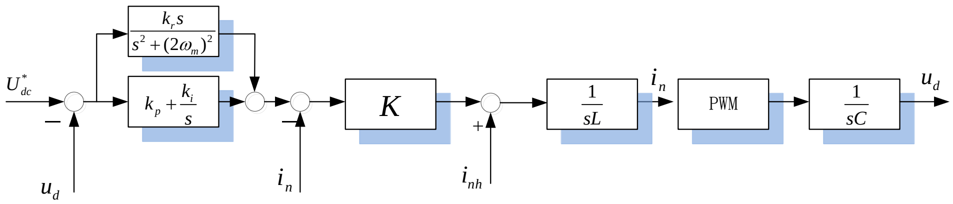


Fig.2 Voltage loop with resonant controller for four-quadrant converter control block diagram

Considering the secondary pulse of the DC-link voltage, the second harmonic after the resonant controller can be expressed as:

$$u_{ac2} = U_2 \sin(2\omega_m t + \gamma) \tag{21}$$

The harmonics in the U_{ab} modulation wave at the output may be converted to 3rd harmonic:

$$u_{abr3} = \left[I_N^* \sin(\omega_m t) \times U_2 \sin(2\omega_m t + \gamma) \right]_{3n} = \frac{I_N^* U_2}{2} \cos(3\omega_m t + \gamma) \tag{22}$$

Ignoring the control delay in the process and simplifying the PWM modulation process, the third harmonic component in the AC input current can be expressed as:

$$i_{n3c} = \frac{I_N^* U_2}{2 L_N \omega_m} \sin(3\omega_m t + \gamma + \pi) \tag{23}$$

The difference between the phases of the third harmonic in equation(23) and (10) which is produced from the main circuit into the AC input current is:

$$\Delta\varphi = (\gamma + \pi) - (\gamma + \beta) = \pi - \beta \tag{24}$$

Where β is the phase difference between the grid side voltage and the AC side PWM output voltage, although it`s obvious that the third harmonic can be eliminated by this control strategy partly, the 3rd offset cannot make the 2nd harmonics in the DC-link voltage be weakened at the same time, to complete the feedback loop. The final results to be achieved for the control of closed loop in Fig.2 is that the 2nd pulse of the DC-link voltage can be eliminated, while the AC side current 3rd harmonic can be eliminated as well, but it is contradicted to the basic control theory of four-quadrant converter. This design method will destroy the stability of the original system and deteriorate the controller performance.

Another method is to set the resonant controller in the current loop, not specifically set up for the secondary ripple filter in the sampling of the DC-link voltage, the current instruction may contain a small amount of 3rd,5th,7th harmonic. Therefore, the resonant frequency of the resonant controller in the current loop should not be set at the frequencies of the harmonic proposed to be eliminated in order to avoid counter-productive.

The resonant frequency of the resonant controller can be set at the frequency ω_m, improving the tracking capabilities of the fundamental current command in the current loop, in order to reduce the harmonic proportion. The control block diagram can be expressed as:

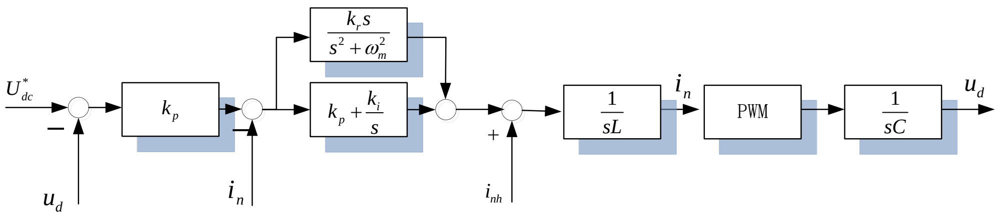


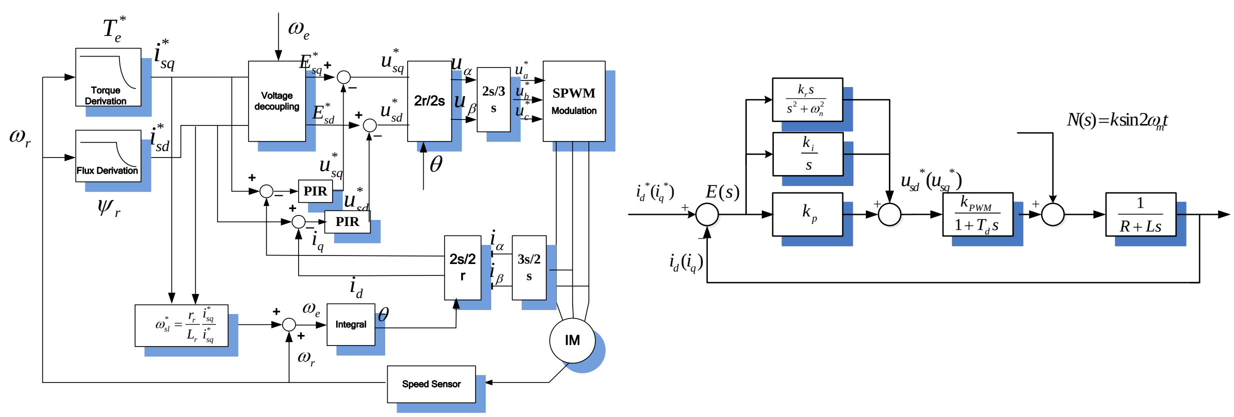
Fig.3 The current loop with resonant controller for four-quadrant converter control block diagram

In addition, applying the PIR controller to the current loop, will help to suppress the DC component resulted from the parameters like the open-off-time difference between the rectifier bridge arm IGBTs in the AC input current, which may reject powerfully the DC component caused by the traction transformer magnetic bias.

3.3 PIR controller applied to the inverter control

From the perspective of filtering the harmonics in the d-q axis currents caused by the DC-link ripple, considering adding a resonant link tuned at the frequency of secondary pulsation in the d-q axis currents control loop, improving the PI regulator to the PIR regulator.

Analyzing the I_d control loop transfer function shown in Figure 4, the frequency response of the i_d^*-input-id-output system achieves an infinite gain at the resonant frequency of 100Hz.



(a) (b)

Fig.4 (a) filed-oriented control block with PIR controller, (b) control block of d-q currents loop with PIR controller

Suppose the harmonic at the frequency of twice the grid input frequency in d-axis current as follows:

$$i_{d2} = I_{d2}\cos(2\omega_m t + \varphi) \tag{25}$$

Ignoring the controller delay, the output modulation wave of the inverter output voltage may be expressed as equation (26):

$$\begin{bmatrix} u_a^* \\ u_b^* \\ u_c^* \end{bmatrix} = \left[\frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \right]^{-1} \begin{bmatrix} u_d^* \\ u_q^* \\ u_0^* \end{bmatrix} \tag{26}$$

If the transfer function of the PWM modulation process is 1, the inverter output voltage can be expressed as follows throughout the coordinates change:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} u_a^* \\ u_b^* \\ u_c^* \end{bmatrix} \tag{27}$$

Therefore, the coordinate transformation can be ignored, and the twice the grid frequency pulse in the d-axis voltage can be derived, which is passed by the resonant link control commands.

$$u_{d2-} = -K\cos(2\omega_m t + \varphi) \tag{28}$$

The harmonic offset component increasing in the d-axis current may be expressed as follows:

$$i_{d2-} = -K\cos(2\omega_m t + \varphi + \delta) \tag{29}$$

Where δ is the equivalent circuit delay of the motor load.

It`s obvious that the harmonics resulted from the DC-link voltage secondary pulse in the inverter output voltage can be partly eliminated with the gradual regulation of the controlling loop, then, considering the delay of the controller, the harmonics can be weakened to a low pulse within a certain range with the specific harmonics in the stator current and torque can also be effectively inhibited.

Analyzing the d-q axis current control loop, the disturbance inhibition frequency response of the error transfer function at the frequency of 100Hz (twice the grid frequency) produces a very small gain, the inhibitory efficiency of the sinusoidal nature disturbance from the DC-link voltage ripple is satisfactory.

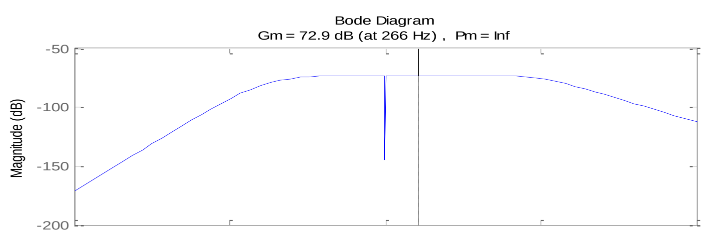


Fig.5 harmonics eliminating frequency response of promoted controlling loop

4 SIMULATION RESULTS

The simulation model is built in Psim under the main parameters of the Chinese CRH_2 EMU traction drive system, and a series of simulation and analysis are shown as follows.

The DC-link voltage waveforms are shown as following figures. The 2^{nd} pulsation in the DC-link voltage can be seen from the spectrum analysis. The AC side input current waveforms are shown in the following figures, the low-order harmonics (especially 3^{rd} harmonic) can be recognized in the spectrum analysis. Comparing the simulation results of the two methods of setting the resonant controller in the voltage loop and current loop as shown in following three figures, it`s obvious that setting the resonant link at voltage loop will not achieve a suppression role of the 3^{rd} harmonics of the AC input current, and the 3^{rd} harmonic can be inhibited to some extent with a resonant link in the current loop. (In the FFT of the simulated waveform in three circumstances described above, the 3^{rd} harmonic amplitude of the converter input current are 35.5V、44.2 and 18.4V respectively.

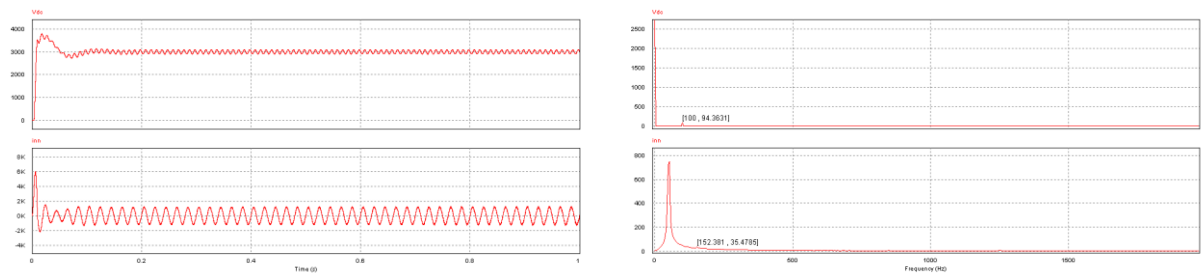


Fig.6 The waveforms and FFT of DC-link voltage and AC input current with no resonant controller

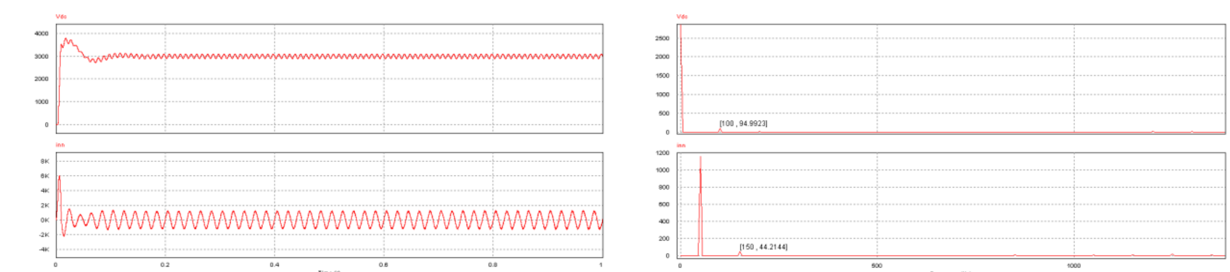


Fig.7 The waveforms and FFT of DC-link voltage and AC input current with a resonant controller in the voltage control loop as Fig.2 did

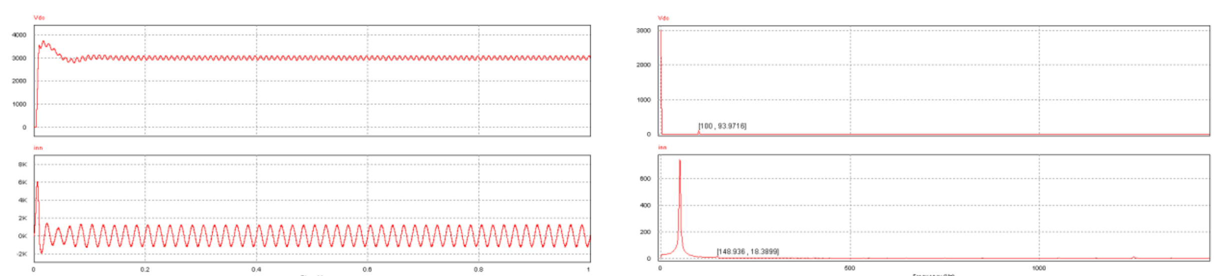


Fig.8 The waveforms and FFT of DC-link voltage and AC input current with a resonant controller in the current control loop as Fig.3 did

Meanwhile, in the simulation of the improved d-q axis current loop of inverter control, the specific harmonics resulted from the DC-link ripple of the stator current and torque are analyzed and compared, with and without the suppression strategy, coming to a conclusion of the strategy`s efficiency.

Fig.9 shows the simulation results without and with the new control method, when the motor speed is 1200r/min, the inverter output frequency is 40Hz , and the modulated carrier wave ratio is N = 9, including the simulation waves of the stator line-line voltage, stator current, output torque and d-q current. The wave above shows the simulation results when taking no restraining measures, and the following one shows the results when taking the proposed rejection method.

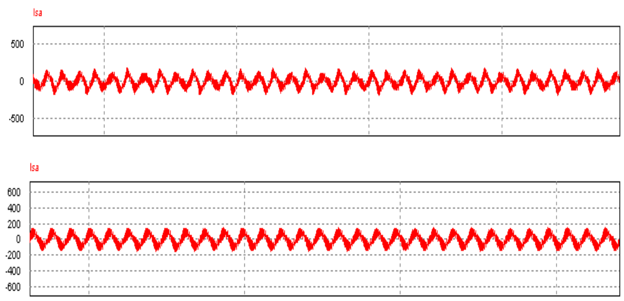


Fig.9

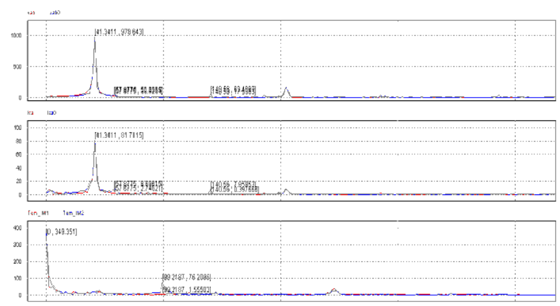


Fig.10

Fig.9 comparison of the stator voltages and currents simulation results

Fig.10 FFT comparison of the simulation waves

In the rated load CRH_2 high-speed train simulation model, the proposed suppression method has good inhibitory effect on the harmonics caused by the DC link secondary ripple, in the stator current and motor output torque, and the harmonics can be reduced to a negligible level with 10% voltage ripple in the DC link.

5 CONCLUSION

In the traction drive system, the DC-link 2^{nd} ripple voltage may produce specific harmonics in the four-quadrant converter input current and output torque of traction motor. With the special performance of the resonant controller at the resonance point, it can be applied to the traction drive system. In this thesis, throughout the theoretical derivation and analysis of simulation, how the resonant controller can be applied to the four-quadrant converter and the traction inverter has been researched, It may be conclude as that to select out appropriate location and parameters for the set of the resonant controller are very important, which will achieve the desired goals.

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