Current Harmonics Suppression Control for EV Traction Motor

- Development of EV Traction Motor Control -

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ABSTRACT: In recent years, motor-powered automobiles such as hybrid cars, plug-in hybrid vehicles, and electric vehicles have been attracting attention due to growing interest in environmental issues. To further expand the interior space and battery loading capacity of electric vehicles, consideration is underway to increase power density. In this paper, we propose current harmonics control that suppresses current harmonics for high power density. Specifically, we constructed a harmonic voltage model and an optimization environment using harmonic currents as the objective function. As a result, the effectiveness of the harmonic voltage model was confirmed with the actual machine. In addition, it was confirmed with simulation that the current harmonics control suppresses the harmonic current component.

KEY WORDS: EV, Traction Motor, Inverter, PWM, Motor Drive

1. INTRODUCTION

In recent years, motor-powered automobiles such as hybrid cars, plug-in hybrid vehicles, and electric vehicles have been attracting attention due to growing interest in environmental issues.

To further expand the interior space and battery loading capacity of electric vehicles, consideration is underway to increase power density. As an example of compact and high-power density, in-wheel motor vehicles are attracting attention [(1)(2)]. Figures 1.1 and 1.2 show the overview of the in-wheel motor and IWM-EV.

To achieve such compact and high-power density of EV drive systems, smaller and higher power density of inverters are required. To achieve high power density of inverters, it is effective to reduce the number of inverter pulses and suppress heat generation at the short-time rated load. However, when the number of inverter pulses is low, there is a trade-off relationship in which the motor current harmonics increases.

Therefore, this research is aiming to reduce the number of inverter pulses and suppress current harmonics by optimizing the switching shape in inverter control.

In this paper, we propose current harmonics control that suppresses current harmonics for high power density. Specifically, we constructed a harmonic voltage model and an optimization environment using harmonic currents as the objective function.

Fig. 1.1. Overview of developed IWM-EV.

Fig. 1.2. Overview of In-Wheel Motors.

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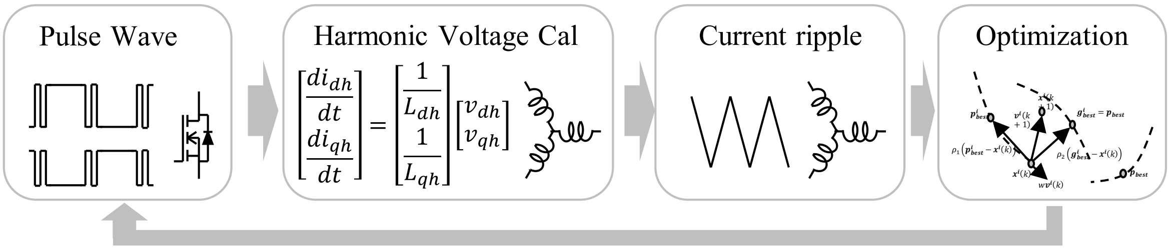

Fig. 2.1. Outline of pulse optimization environment.

2. CURRENT HARMONICS CONTROL

2.1. Outline of current harmonics control

For current harmonics control, we constructed a pulse-optimized environment that suppresses current harmonics, as shown in Fig. 2.1.

For the pulse optimization environment, at first, we created a harmonic voltage model that calculates the current harmonics from the pulse waveform. Next, we constructed an optimization arithmetic unit that optimizes the pulse wave based on the sum of harmonic current of the harmonic voltage model.

2.1.1 Harmonic voltage model

When simulating motor drive states, MATLAB/Simulink models are commonly used. However, if the MATLAB/Simulink motor model calculates the current harmonics, the calculation takes a long time. Therefore, to shorten the calculation time, we constructed an analysis environment based on voltage equations.

Table 2.1. Comparison of the actual machine and the analysis environment.

	Input Voltage	Motor	Output Current
Actual	Measured pulse	Actual motor	Measured current
Analysis	Theoretical pulse	Voltage Model	Theoretical current

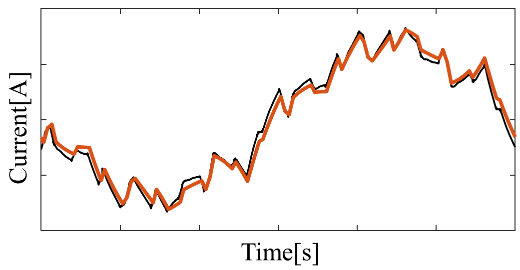

Fig. 2.2. Comparison of actual and analysis current waveforms.

In the PMSM voltage model, it is possible to evaluate the current harmonic component by using the following voltage equation [3].

$$\begin{bmatrix} v_{dh} \\ v_{qh} \end{bmatrix} = \begin{bmatrix} L_{dh} \cdot \frac{di_{dh}}{dt} \\ L_{qh} \cdot \frac{di_{qh}}{dt} \end{bmatrix} \quad \cdots\cdots (2.1)$$

In the formula, v_{dh}, v_{qh} are voltage harmonics, L_{dh}, L_{qh} are differential inductance, $\frac{di_{dh}}{dt}, \frac{di_{qh}}{dt}$ are differential current harmonics.

In PMSM drive, a PWM pulse form of inverter is an input voltage, and a motor current is generated as an output by the voltage. To input the voltage harmonic component of the PWM pulse waveform and evaluate the generated current harmonic component as the output, the equation is modified as follows.

$$\begin{bmatrix} \frac{di_{dh}}{dt} \\ \frac{di_{qh}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{1}{L_{dh}} \\ \frac{1}{L_{qh}} \end{bmatrix} \begin{bmatrix} v_{dh} \\ v_{qh} \end{bmatrix} \quad \cdots\cdots (2.2)$$

To verify the constructed harmonic voltage model, we compared the model output with the actual motor drive output. Table 2.1 shows a summary of the comparison conditions.

First, as shown in the upper part of Table 2.1, the voltage and current waveforms were obtained from the actual machine. As the waveform from the actual machine, a PWM pulse was input to the actual motor and the motor current was output from the actual motor.

Next, as shown in the lower part of Table 2.1, the analysis waveform was generated under the actual machine driving conditions. A theoretical pulse was generated from the voltage amplitude and phase under the actual machine drive conditions. The theoretical pulses generated were input to the harmonic voltage model (eq. 2.2) as model input and the harmonic current components were calculated as model output.

Finally, we compare the actual current waveform with the analysis current waveform generated by the harmonic voltage model as shown in the right side of Table 2.1. Fig. 2.2 shows the comparison of actual and analysis current waveforms. In Fig. 2.2,

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the black line shows the actual waveform, and the red line shows the analysis waveform.

From Fig. 2.2, it was confirmed that the actual current waveform and the analysis current waveform show the same trend.

From the above, we conducted a comparative verification of the harmonic voltage model using an actual machine and confirmed the model's effectiveness. In the next section, we report on the construction of an optimized environment using this harmonic voltage model.

2.1.2. Optimization environment

In this section, we describe the construction of an optimization environment using a harmonic voltage model.

In motor drive control, the suppression of the motor harmonic current enables the suppression of harmonic loss and motor vibration. Therefore, it is expected to construct an optimization environment that minimizes the harmonic current component. The objective function is shown in eq 2.3.

$$\min E = \min \sum i_{dqh} \quad \cdots\cdots (2.3)$$

In general, as an optimization method, the operation is performed with gradient information of the objective function. However, it is difficult to generate gradient information between the PWM pulse waveform of the input and the harmonic current of the output. Therefore, we constructed an optimization environment using the Particle Swarm Optimization (PSO) method (4), which is one of the metaheuristic optimization methods that does not use gradient information.

The PSO method is developed by J. Kennedy and R. Eberhart, inspired by the behavior of birds and fish flocks. The PSO is a method of obtaining a global optimal solution from the best information of the individual (personal-best) and the best information of the group (global-best) formed from the individuals (Swarm). The basic formula is as follows.

$$\boldsymbol{x}_i(k+1) = \boldsymbol{x}_i(k) + \boldsymbol{v}_i(k+1) \quad \cdots\cdots (2.4)$$

$$\boldsymbol{v}_i(k+1) = w\boldsymbol{v}_i(k) + c_1 r_1\big(gbest(k) - \boldsymbol{x}_i(k)\big) + c_2 r_2(pbest(k) - \boldsymbol{x}_i(k)) \quad \cdots\cdots (2.5)$$

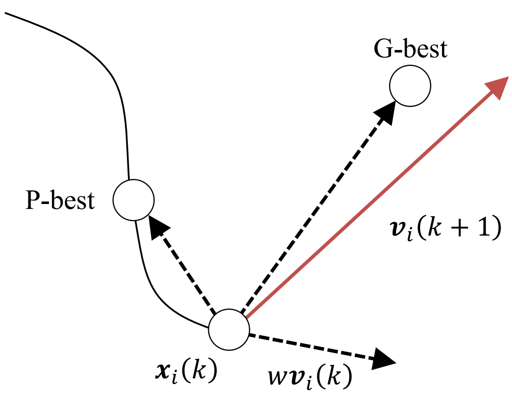

Fig. 2.3. Schematic diagram of the PSO configuration.

In Fig. 2.3 illustrates the relationship of the above equation. As shown in the figure, the individuals in the group move as if they are attracted to P-best and G-best position $\boldsymbol{x}$.

In such a PSO method, a PWM pulse optimization environment was constructed as the input $\boldsymbol{x}$: PWM pulse waveform, objective function E : sum of harmonic current $\sum i_{dqh}$. As a result, it is possible to construct an optimized environment for searching for PWM pulse waveforms with small current harmonics.

2.2. Analysis results of optimization

In this section, we examined the optimization of the PWM waveform using the constructed optimization environment.

To confirm the harmonic current suppression effect of the optimization, we optimized the PWM pulse with the same number of pulses as the conventional synchronous PWM 5 pulses.

In Fig. 2.4 and Fig. 2.5, the current waveform result is shown. Fig. 2.4 shows the current waveform of the conventional

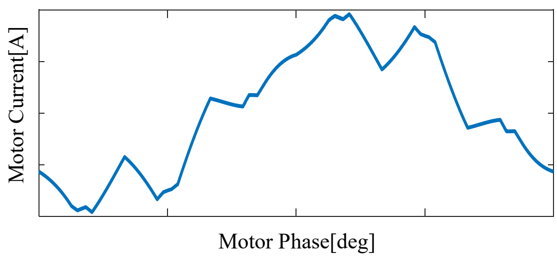

Fig. 2.4. Conventional synchronous PWM waveform.

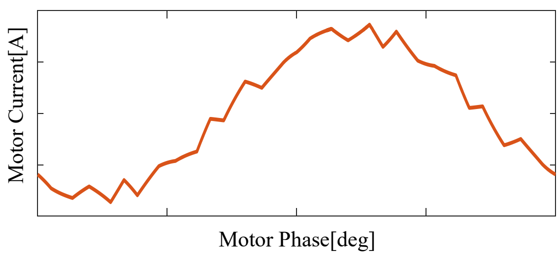

Fig. 2.5. Proposed current harmonics control waveform.

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synchronous PWM 5 pulses. Fig. 2.5 shows the current waveform of the proposed current harmonics control 5 pulses.

From Fig. 2.4 and Fig. 2.5, It was confirmed that the harmonic current was suppressed by the proposed current harmonics control method.

From the above, it was confirmed that it is possible to generate a pulse waveform that suppresses the harmonic current by the constructed harmonic voltage model and the optimization environment.

As a control method to suppress harmonic currents, Model Predictive Control (MPC) method has been proposed. The MPC methods suppress current harmonics by calculating the optimal output voltage online during the feedback loop. Since the MPC method calculates the optimal voltage online, the computational load tends to increase. In the proposed method in this paper, the optimal pulse waveform is calculated offline, and the information is stored in table data. So, the increase of the computational load can be suppressed. On the other hand, since the pulse waveform is generated offline, the proposed methods have optimal pulse error due to the motor model error. We plan to consider such issues in the future.

3. CONCLUSIONS

In this paper, we investigated the current harmonics control. For current harmonics control, we constructed a pulse-optimized environment. First, we constructed a harmonic voltage model. In this model, input is the harmonic voltage, and output is the harmonic current which is calculated based on the harmonic inductance. The effectiveness of this model was confirmed by comparing the analysis waveform with the actual machine waveform. Next, an optimization environment was constructed with the harmonic voltage model. In the optimization environment, the harmonics current was used as the objective function and the PSO was used as the optimization method. The pulse waveform was optimized with the synchronous PWM 5 pulse using the optimization environment. As a result, we confirmed that the harmonic current suppression effect can be obtained with the same number of pulses by simulation.

ACKNOWLEDGMENT

This paper is based on results obtained from Green Innovation Fund Projects/Next-generation Motor Development (JPNP21026), commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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