Progress and Future Prospects of Motor Drive Technology in Society

Authors: *Akira Satake** and *Hisanori Yamasaki**

1. Introduction

Two key needs for drive systems today are lower costs and high energy efficiency, for which control technologies can contribute greatly. This paper introduces a sensor-less servo technology and a multi-windings motor drive technology as control technologies that can reduce costs.

The paper also introduces the application of SiC to products for driving rolling stock, and technologies for driving and controlling permanent magnet synchronous motors.

2. Various Motor Drive Technologies

2.1 Sensor-less control technologies

2.1.1 Sensor-less drive technology in all speed ranges

Sensor-less servo products detect and control the positions of magnetic poles based on sensor-less vector control of permanent magnet (PM) motors, without using magnetic position sensors. Such a product has a motor model in its drive unit and estimates and controls the speed and position with an adaptive flux observer that calculates the magnetic flux from the voltage and current. However, such estimation becomes impossible in the low-speed range where the voltage is low. Therefore, a different method is required in the low-speed range: a high-frequency voltage is applied to the motor and motor inductance is detected based on the generated current to estimate the position using the inductance's dependency on position (saliency).

These two position estimation methods need to be switched depending on the speed. However, in a simple method (e.g., weighted average), when the method is switched at the time of sudden acceleration and deceleration, the discontinuity of the speed and position signals may cause a shock, so a more sophisticated switching method is required. Figure 1 illustrates the configuration of such a control system where an observer and saliency-based position estimator are combined. The observer estimates speed and position and the saliency-based position estimator adds assistance signals regarding the estimated magnetic pole position in the low-speed range. Thanks to this, even in the low-speed range where the voltage is low, the magnetic pole position estimated by the observer can accurately follow the actual magnetic pole position. By varying the magnitude of assistance signals based on the rotation speed, it is possible to estimate the position mainly based on the saliency in the low-speed range and mainly based on the voltage data in the high-speed range.

In 2014, Mitsubishi Electric Corporation's sensor-less servo products developed using these technologies won an R&D100 Award (by R&D Magazine in the U.S.) which is given to innovative technologies.

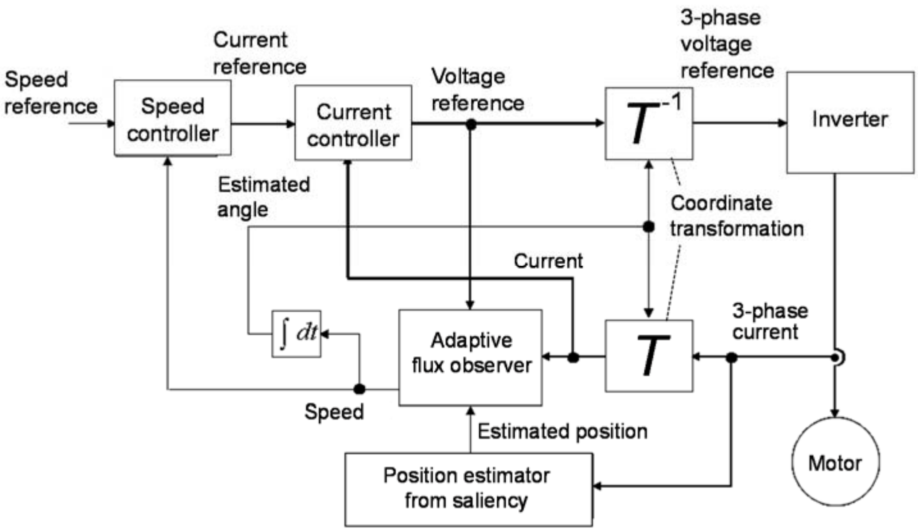


Fig. 1 Configuration of sensor-less servo control system

*Advanced Technology R&D Center

2.1.2 Automatic tuning technology

To enable heavy load operation in sensor-less vector control, it is necessary to grasp changes in inductance due to flux saturation. Inductance can be detected from changes in the current when a pulse voltage is applied, but applying excessive voltage may result in overcurrent. Therefore, Mitsubishi Electric has developed a function for automatically controlling pulse width, making it possible to detect inductance without generating overcurrent even on other companies' motors whose parameters are unknown, enabling stable operation up to 150% of the rated torque. In addition, to control the speed and position control system of a sensor-less servo product stably at high speed, data on the load inertia connected to the motor shaft is required. Figure 2 shows the effect of the online automatic tuning technology installed onto the sensor-less servo E700EX series. This technology estimates the load inertia connected to the motor shaft during driving and adjusts the speed and position control system automatically based on this estimated inertia.

As the series has no rotation angle sensor, the estimated motor speed and torque values at the time of a change in acceleration of the equipment during driving are used to estimate the inertia. This technology eliminates the need for prior adjustment of the control system based on equipment and ensures a stable response even when the load inertia changes during driving.

2.2 Multi-windings motor drive technology

Motors and inverters require larger capacity to satisfy market needs. One existing technology to drive a large-capacity motor by multiple inverters is the multiple inverter method (Fig. 3(a)) using reactors, but the cost and size of reactors were problems. On the other hand, the method in which a multi-windings motor is driven by multiple inverters (Fig. 3(b)) does not have such problems. However, the magnetic connection between the windings in the motor causes coupling behavior,

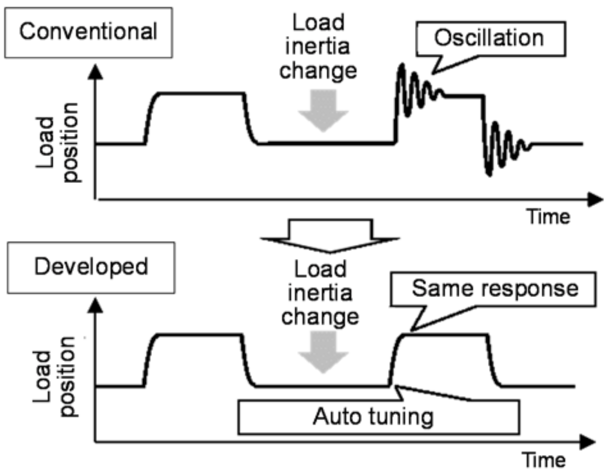


Fig. 2 Effect of online auto tuning

which makes it impossible to control the output torque responsively. To solve this problem, Mitsubishi Electric has developed a control system that suppresses the influence of coupling components by adding components that cancel such coupling components to the output voltage in advance. Figure 4 shows its effect. The comparison shows that in a situation where the current control becomes vibratory due to windings coupling and thereby highly-responsive setting is impossible, the afore-mentioned suppression control reduces the influence of the coupling components and thereby improves the response.

This technology has been applied to large-capacity drives and various other systems since FY2016.

2.3 Drive control technologies for SiC-applied power inverters

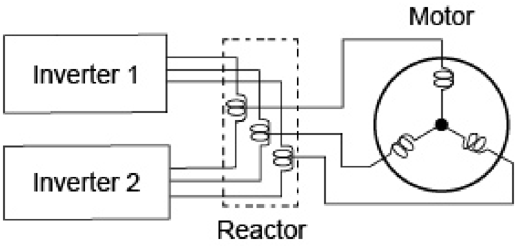
Conventionally, silicon (Si) has been used for power devices for conventional inverters for the propulsion system of rolling stock. Recently, the application of silicon carbide (SiC) has been increasing. Mitsubishi Electric introduced a 1.7-kV hybrid-SiC to commercial rolling stock in 2012 and 3.3-kV full-SiC in 2015. Generally, losses can be reduced with SiC compared to Si, which enables the semiconductor packages themselves and accompanying cooling systems to be made smaller. This downsizing has allowed the external shape and weight of power inverters to be reduced by 40–80% compared with the conventional type with Si. Some proposals have been made using this low-loss characteristic of SiC for motor control technologies. The examples of (1) diversification of pulse width modulation (PWM) modes and (2) improved regenerative ratio thanks to large-current motor design are described below.

2.3.1 Diversification of PWM modes

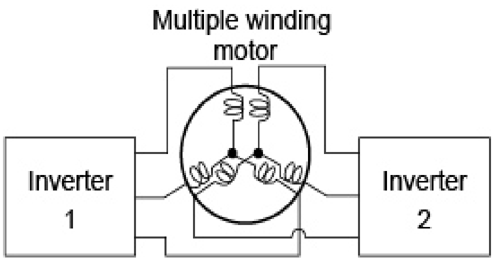
In the design of inverters for railways, the upper limit of the switching frequency is determined based on the downsizing of cooling systems and reduction of loss in inverters. Formerly, various synchronous PWM modes were switched based on the acceleration and deceleration to reduce the switching loss and synchronous 1-pulse operation was used in the high-speed range. Low-loss SiC overcomes this restriction, and so this advantage has been applied to all-range asynchronous PWM. In this example, the switching frequency was improved to approximately double that of the conventional type and asynchronous PWM was achieved in all the ranges. As a result, the distortion of motor currents and magnetostrictive noise were reduced and the harmonic loss was reduced by up to 40%.

2.3.2 Improved regenerative ratio thanks to large-current motor design

Meanwhile, for designing the performance of motors

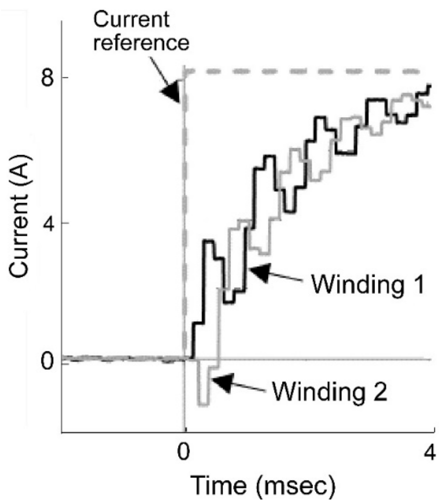


(a) Multiple inverter method

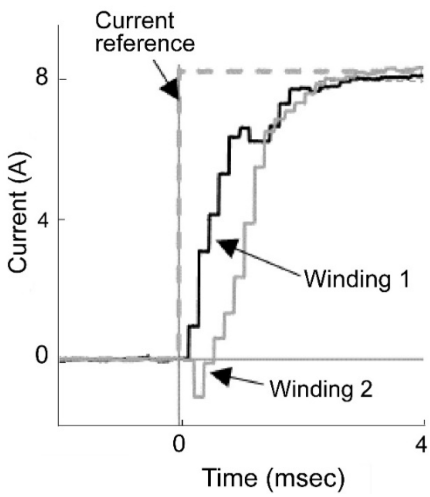


(b) Multiple winding motor method

Fig. 3 Motor drive system controlled by multiple inverters



(a) Without suppression control



(b) With suppression control

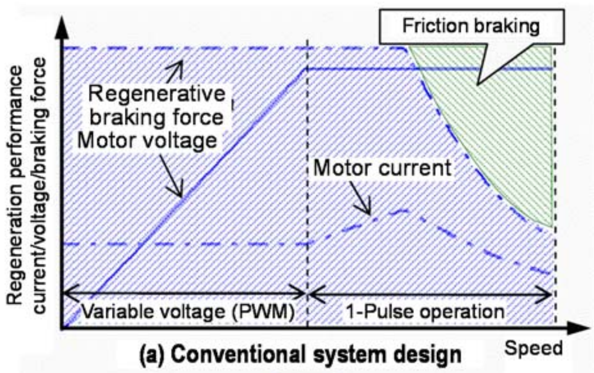
Fig. 4 Suppression control of windings coupling

to be combined with inverters, in addition to the matters noted in 2.3.1, the torque output performance needs to be secured in consideration of the upper limit of the current in terms of the loss in inverters.

Applying SiC can increase the output (current) of inverter systems, so motors can be designed to reduce the rating flux and to increase the current per torque. This is equivalent to designing to reduce the impedance of motors. It means that the torque output limit (stall torque characteristic) existing in the high-speed range can be moved to the higher speed range and the regeneration torque output range can be expanded (Fig. 5). For the propulsion system of rolling stock drawing on this advantage, the operation range in which friction braking is used conventionally, can be covered by the regenerative braking of motors. It has been demonstrated that energy consumption can be reduced by up to 40% for the run-curves of subways and conventional lines where frequent stops are involved.

2.4 Permanent magnet synchronous motors for rolling stock

Although induction motors that can drive multiple motors in parallel by a single inverter are standard for rolling stock, recently, some railway companies have started using PM motors to save energy. Mitsubishi Electric promoted development and has commercialized inverters for PM motors for rolling stock. In the magnetic pole position sensor-less vector control in PM motors, when high-frequency voltage is applied to detect the



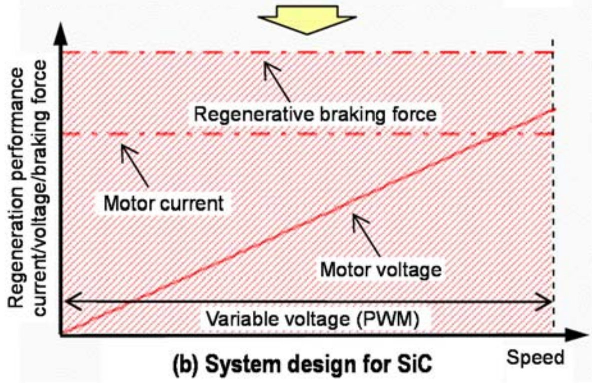


Fig. 5 Comparison of regenerative braking performance setting

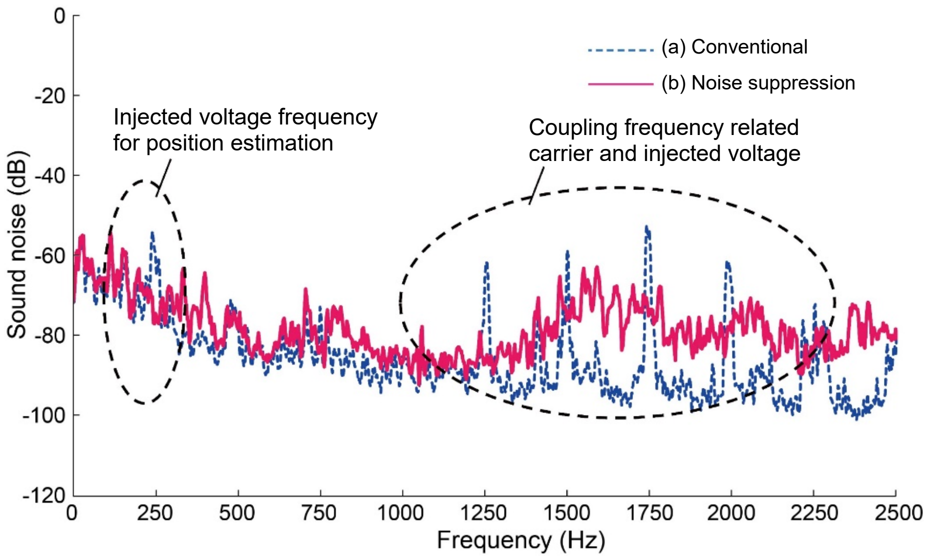


Fig. 6 Noise suppression of high-frequency injection in sensor-less control of low-speed range

magnetic pole position in the very-low-speed range, unique magnetostrictive noise is generated. Generating a PWM voltage waveform in a random manner in the range where the magnetic pole position estimation function can be secured improves the sound noise feeling (Fig. 6).

3. Conclusion

This paper outlined example control technologies in recent drive systems to satisfy the needs of society. Mitsubishi Electric will continue working to secure and improve the functions of products by control technologies to flexibly meet increasingly diverse and sophisticated needs.