120-degree conducting control of permanent magnetic synchronous motor

Algorithm

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Summary

This application note aims at explaining 120-degree conducting control of permanent magnetic synchronous motors used for sample programs of Renesas Electronics Corporation’s microcontrollers.

Operation checking device

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Contents

1. Overview

This application note aims at explaining 120-degree conducting control of permanent magnetic synchronous motors (hereinafter called PMSMs) used for sample programs of Renesas Electronics Corporation's microcontrollers.

2. 120-degree conducting control

If the conduction patterns of each phase are changed at every 60 degrees as shown in Figure 2-1, a torque is generated between coil flux and permanent magnet of a rotor and the rotor rotates synchronously with the flux. As a conduction session of each switching element is 120 degrees, this control method is referred to as 120-degree conducting control.

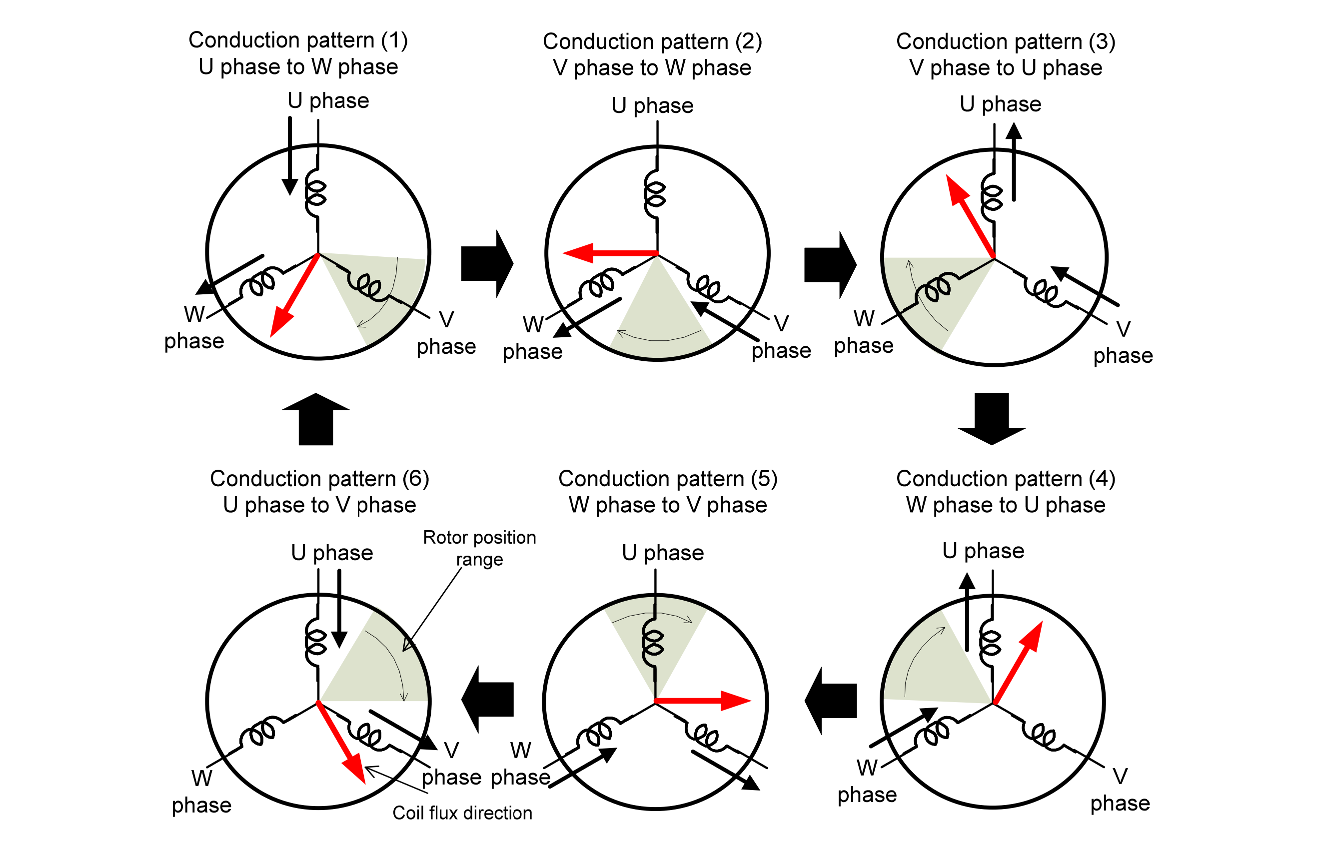

Figure 2-1 Six Conduction Patterns and Rotor Position Ranges (Example)

3. Position/speed calculation by 120-degree conducting control

3.1 120-degree conducting control using hall sensors

3.1.1 Position detection

The hall sensors are used to detect the position of the permanent magnet, and signals from the hall IC (hall sensor signals) are input to the microcontroller as position information.

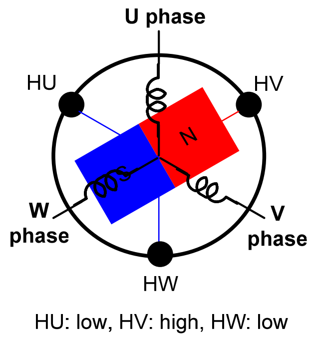

Figure 3-1 Example of Hall Sensors (HU, HV, HW) Position and Position Signals

As shown in Figure 3-1, the hall sensors are allocated every 120 degrees and the respective hall sensor signals are switched depending on change in magnetic poles of the permanent magnet. Combining these three hall sensor signals enables to obtain position information every 60 degrees (six patterns for one cycle). At the switching timing of hall sensor signals, the conduction patterns of each phase are changed as shown in Figure 3-2.

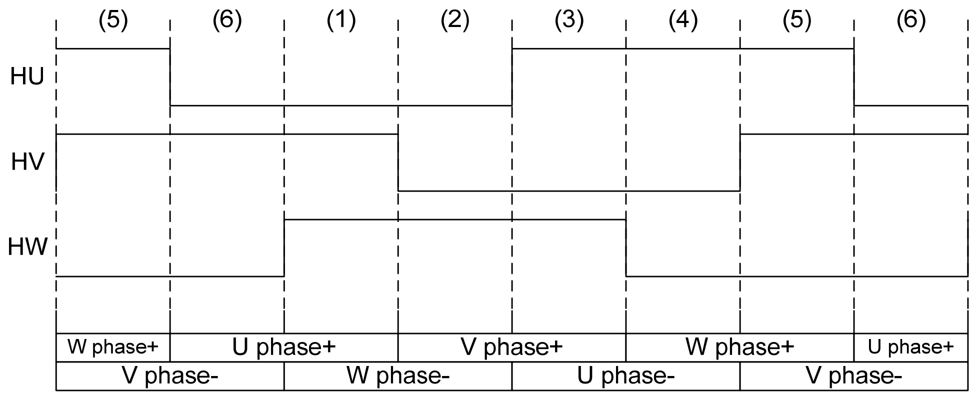

Figure 3-2 Relation between Hall Sensor Signals and Conduction Patterns (Rotation Direction: CW)

Note

1. The above relation between hall sensor signals and condition patterns is in accordance with the application note 'RX62T: 120-degree conducting control of permanent magnetic synchronous motor'. When using other motor specifications, set a conducting pattern according to the system.

3.1.2 Speed calculation

The motor rotation speed is calculated from a difference of the current timer value and the timer value 2π [rad] before. The timer values are obtained through the external interrupt routine by hall sensor signals while having the peripheral function timer of the microcontroller performed free running. This method is applicable even when the hall sensors are placed unequally.

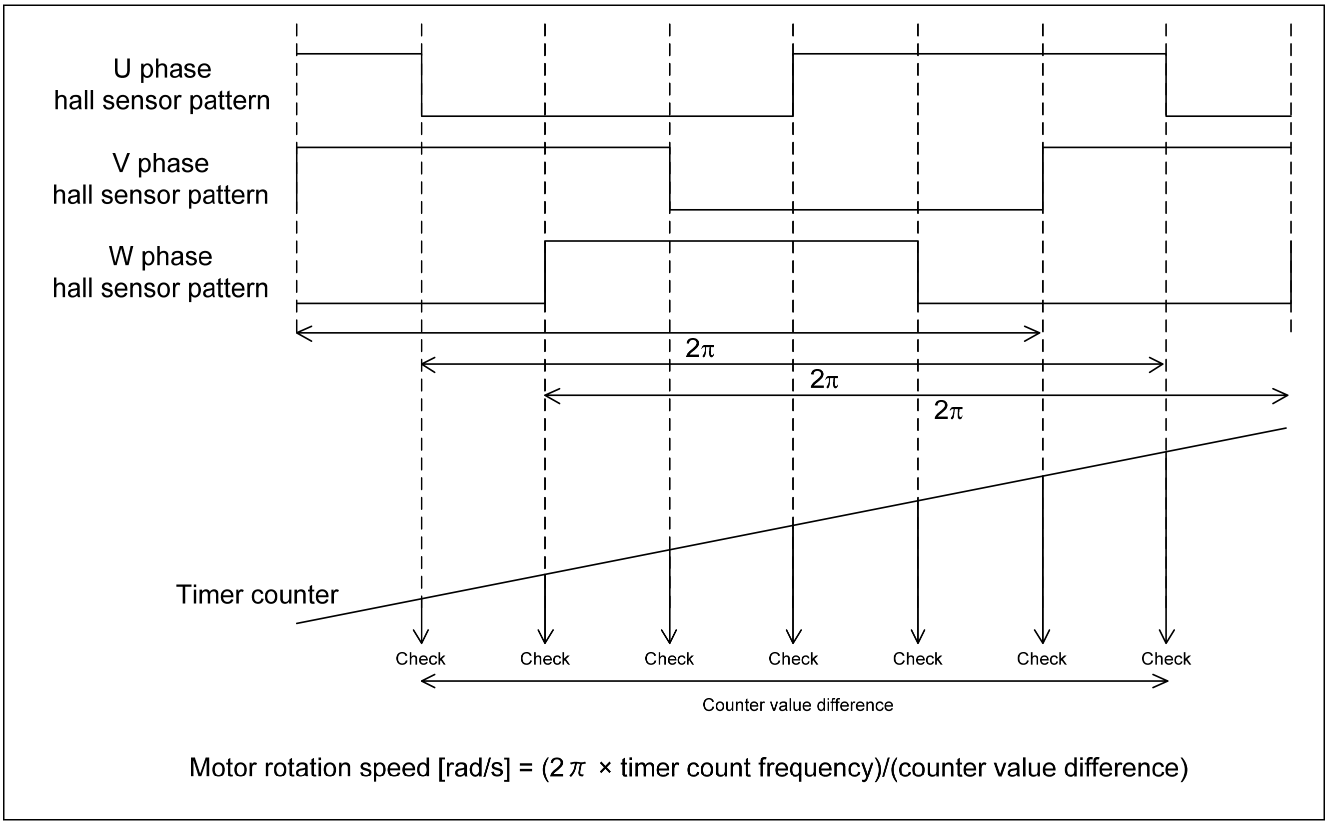

Figure 3-3 Motor Rotation Speed Calculation Method

3.2 Sensorless 120-degree conducting control

3.2.1 Position estimation

The sensorless control does not have a sensor for obtaining the permanent magnetic position, and hence an alternative to the sensor is required. The sensorless control of permanent magnetic synchronous motors generally estimates the position by detecting inductive voltage.

The inductive voltage is generated in proportion to a change rate of magnetic flux passing through a coil, to prevent the change.

For example, consider the case where a magnet gets close to the coil, as shown in Figure 3-4. In this case, since the magnetic flux increases within the coil, the coil generates the electromotive force that runs current in the direction of the figure to prevent the increase of magnetic flux. (The flux of opposite direction of the magnetic flux is generated by the right-handed screw rule.)

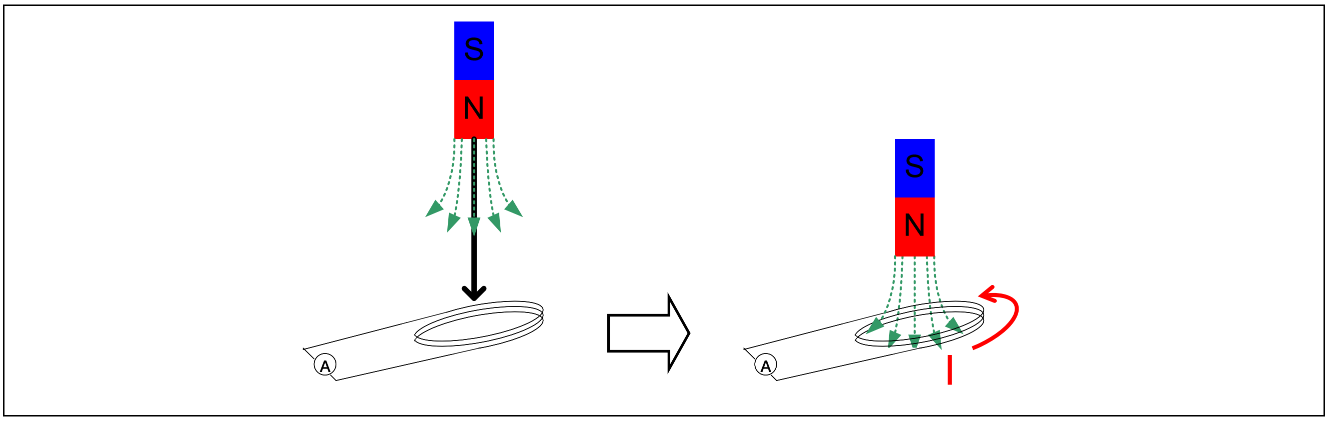

Figure 3-4 Inductive Voltage Generated by Coil and Magnet

This inductive voltage Em is expressed by the magnetic flux φm as the below formula.

$$E_m = \frac{d}{dt}\varphi_m \cdots (1)$$

This phenomenon also occurs in a rotating permanent magnetic synchronous motor. When the permanent magnet is rotating, the inductive voltage is generated by constant change of interlinkage magnetic flux of each phase.

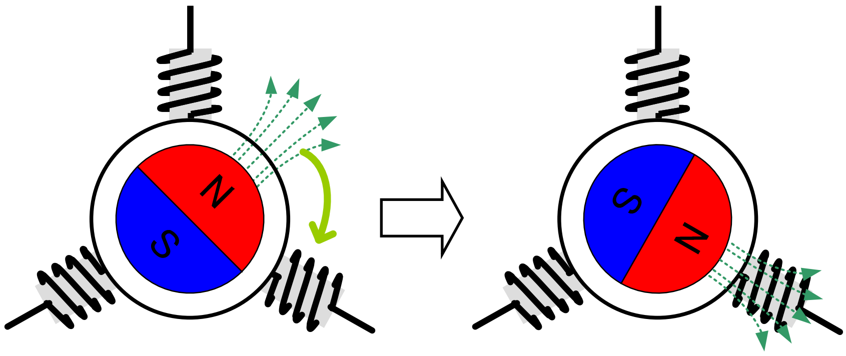

Figure 3-5 Inductive Voltage in the Rotating Permanent Magnetic Synchronous Motor

Figure 3-6 shows the change of interlinkage magnetic flux in the U phase. Size of the interlinkage magnetic flux is shown on the vertical axis and the phase of the permanent magnet is shown on the horizontal axis. Also, a position where the N pole of the permanent magnet points the coil of the U phase is defined as θ = 0.

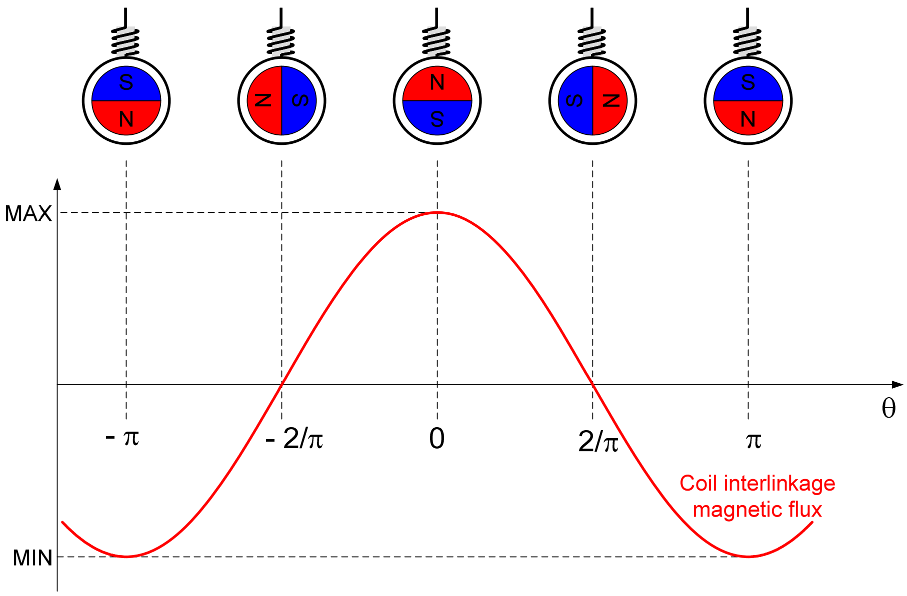

Figure 3-6 Change of the Interlinkage Magnetic Flux

The interlinkage magnetic flux of the U phase changes in a cosine wave format.

If considered similarly for the V phase and W phase, they deviate respectively by 2π/3 and 4π/3 phase from the U phase. The interlinkage magnetic fluxes of the three phases are expressed by the following formula.

$$\varphi_u = \varphi_m \cos\theta$$
$$\varphi_v = \varphi_m \cos(\theta - \frac{2}{3}\pi)$$
$$\varphi_w = \varphi_m \cos(\theta - \frac{4}{3}\pi)$$

Also, the inductive voltage of the three phases is expressed by the following formulas, by using the above formula, when the angle speed is considered as ω.

$$E_u = \frac{d}{dt}\varphi_u = \frac{d}{dt}\varphi_m \cos\theta = -\omega\varphi_m \sin\theta = \omega\varphi_m \cos(\theta + \frac{\pi}{2})$$
$$E_v = \frac{d}{dt}\varphi_v = \frac{d}{dt}\varphi_m \cos(\theta - \frac{2}{3}\pi) = -\omega\varphi_m \sin(\theta - \frac{2}{3}\pi) = \omega\varphi_m \cos(\theta - \frac{\pi}{6})$$
$$E_w \frac{d}{dt}\varphi_w = \frac{d}{dt}\varphi_m \cos(\theta - \frac{4}{3}\pi) = -\omega\varphi_m \sin(\theta - \frac{4}{3}\pi) = \omega\varphi_m \cos(\theta - \frac{5}{6}\pi)$$

These formulas show that the inductive voltage leads of π/2 phase from the permanent magnetic flux. This means that if the inductive voltage can be detected, position of the permanent magnet can be estimated.

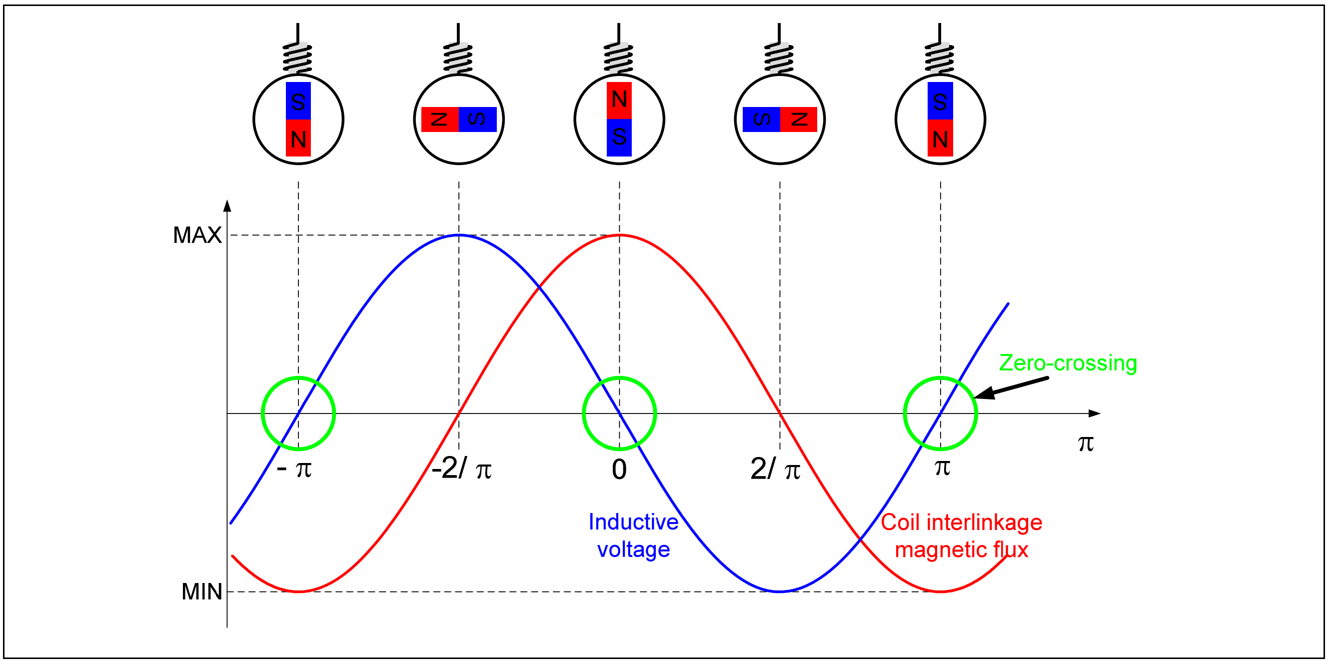

Figure 3-7 Zero-crossing of the Inductive Voltage

However, the inductive voltage of each phase may not be always detected while the motor is rotating.

While driving in 120-degree conduction, conduction is performed to two phases among the three. Therefore, only the remaining one phase, to which conduction is not performed, can detect the inductive voltage. Actually, position information is obtained by detecting a change point of sign of inductive voltage (zero-crossing) occurring in non-conducting phase which can detect the inductive voltage.

In a three-phase motor, this zero-crossing occurs for total six times, i.e. twice in each phase, in one rotation (electrical angle) of the motor. This means that the position for every 60 degrees can be detected by this process with resolution equivalent to hall sensors.

In this system, the virtual center point voltage of the motor is calculated by the sum of A/D conversion voltage of each phase in every PWM control. By comparing the virtual motor center point voltage with each phase voltage, the patterns of ‘1’ ‘0’ are created according to the positional relation.

In addition, the virtual hall sensor pattern is created by shifting the created pattern by π/6 phase. “π/6” is a value estimated from the present speed estimation value.

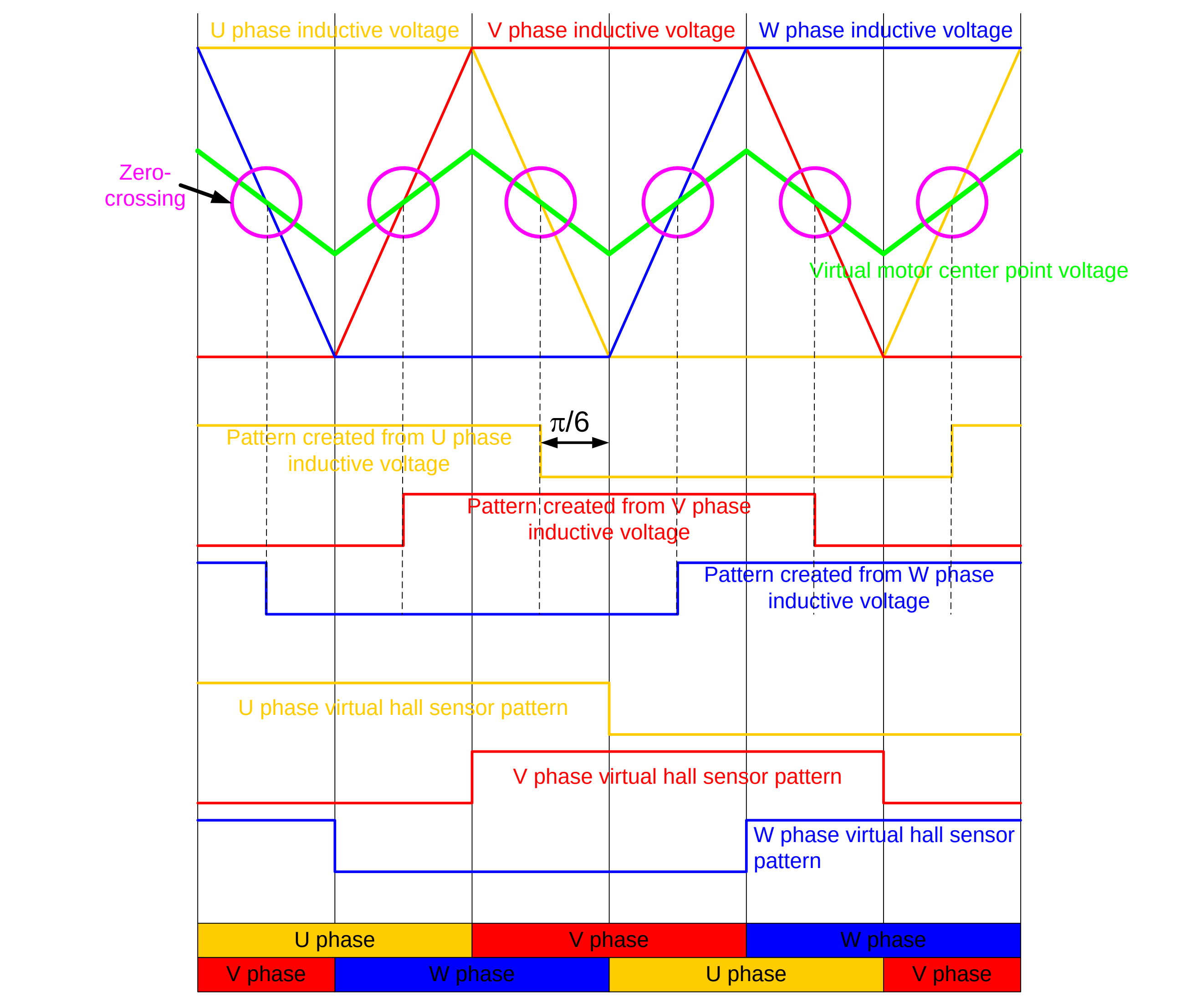

Figure 3-8 Virtual Hall Sensor Pattern (In Case of Upper Arm Chopping)

Of some zero-crossing detection methods, this part introduces a method to detect the zero-crossing by comparing the inductive voltage value with the center point voltage value by software, using the A/D converter of microcontroller. Since there is no need for a comparator to compare voltage, this method is called ‘comparatorless method’.

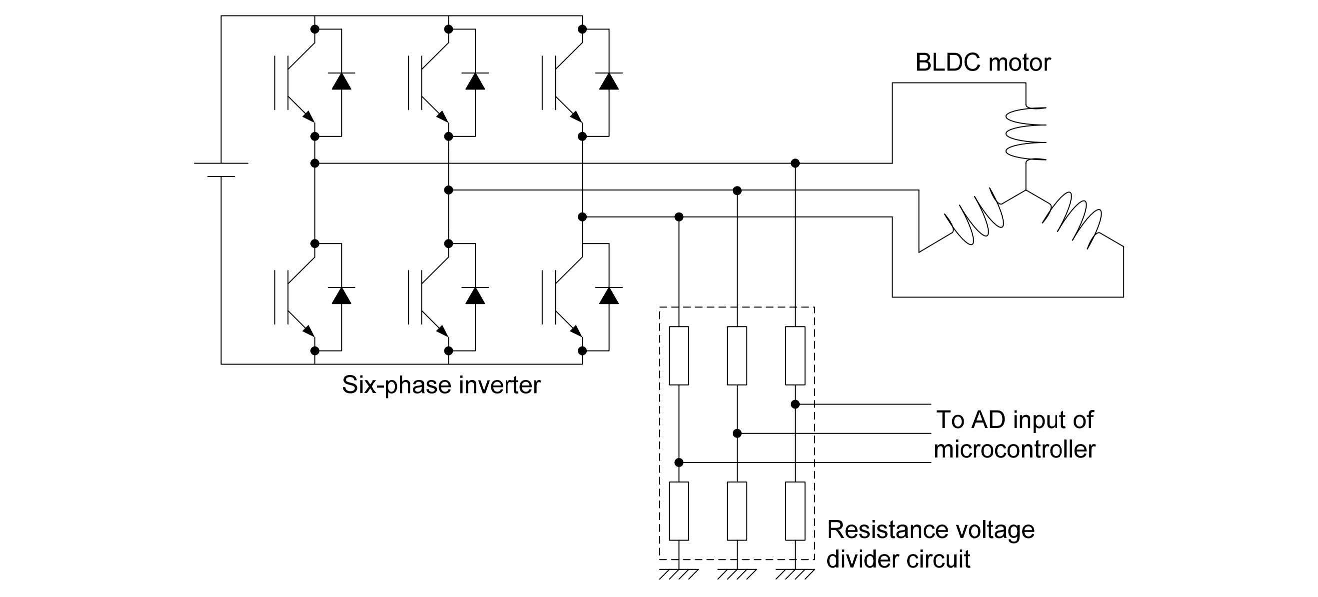

Figure 3-9 Comparatorless Method

As for inductive voltage to be detected actually, impact of commutation voltage generated when switching conducting patterns and PWM of other phases must be considered. The impact is expressed as shown in Figure 3-10. To reduce the impact, some countermeasures such as a method using a simple filter circuit or software filtering can be taken.

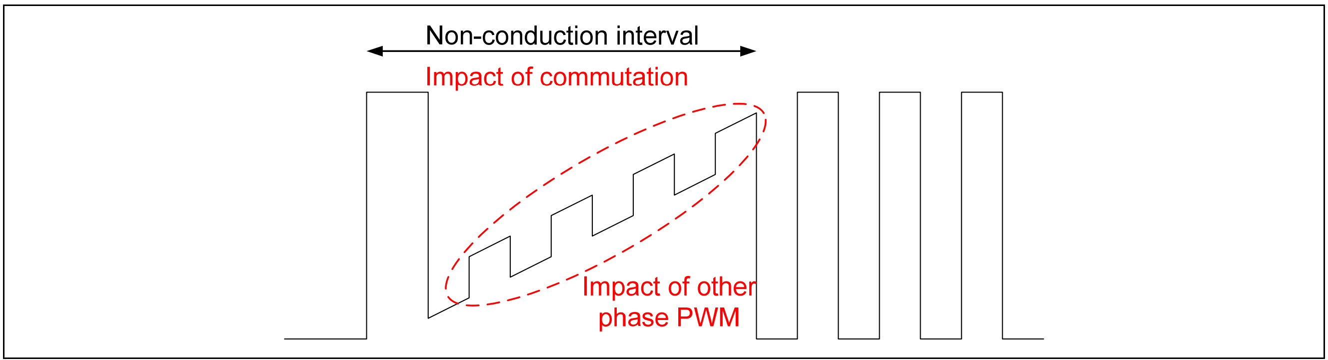

Figure 3-10 Conceptual Diagram of Impact of Commutation and Other Phase PWM

3.2.2 Speed calculation

The motor rotation speed is calculated from a difference between the timer value confirmed 2π [rad] before and the current timer value. The timer values are incorporated at the time of switching the patterns while having the peripheral function timer of the microcontroller performed free running and detecting zero-crossing.

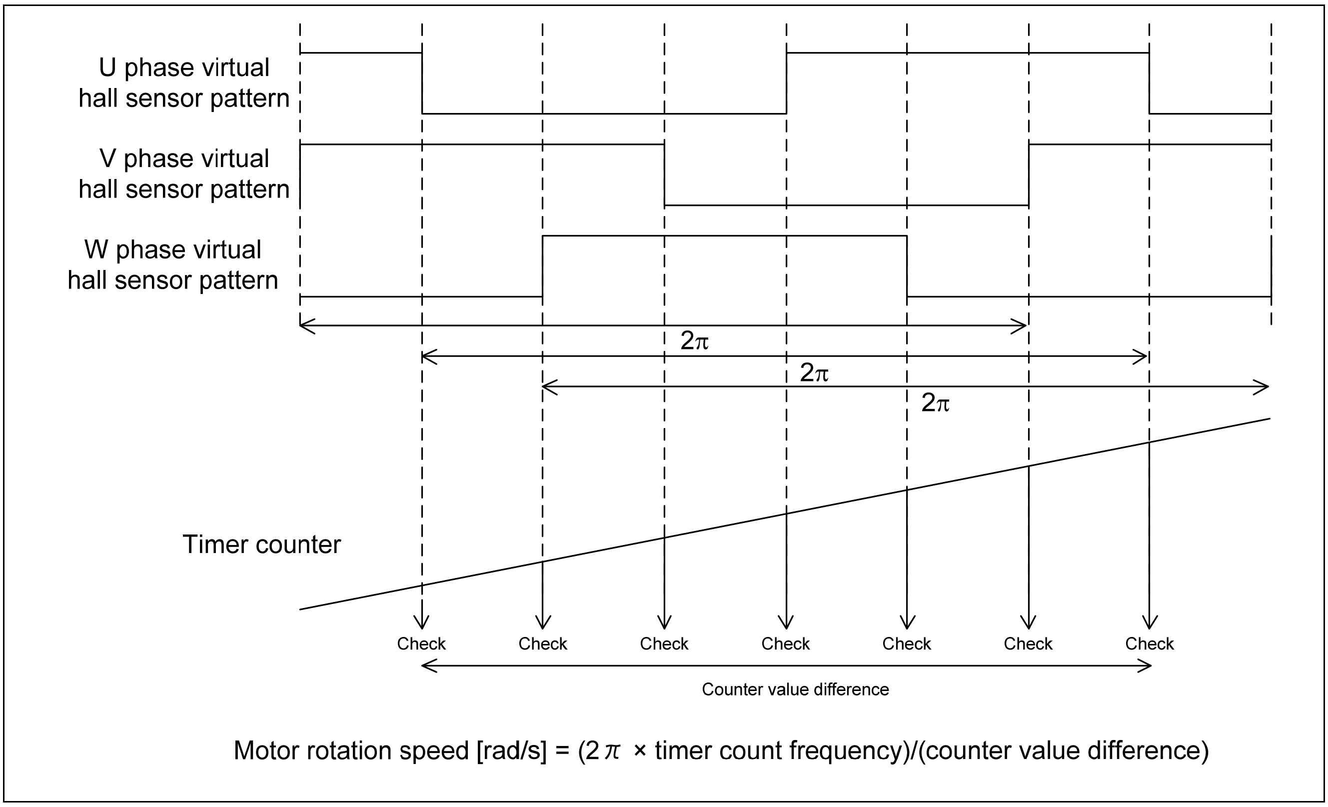

Figure 3-11 Motor Rotation Speed Calculation Method

3.2.3 Start-up method

Inductive voltage does not occur unless the permanent magnet is rotating. This means that position of the magnet cannot be estimated by using inductive voltage at the time of start-up.

Therefore, as a start-up method, there is a method to lead the synchronous speed by generating a rotating magnetic field by forcibly switching conduction patterns regardless of position of the permanent magnet.

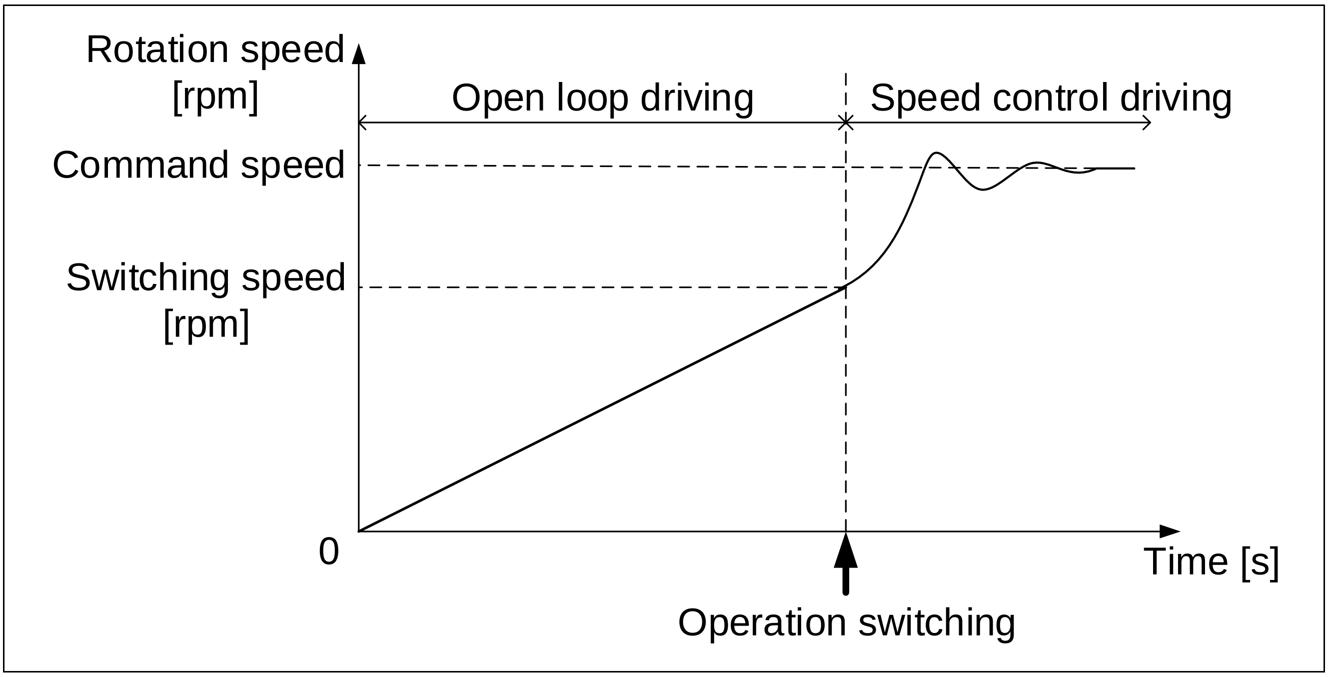

Figure 3-12 Start-up Method (Example)

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Revision Record

Rev.	Date of issue	Descriptions	
		Page	Summary
1.00	2015.03.31	—	First edition issued

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins
   Handle unused pins in accord with the directions given under Handling of Unused Pins in the manual.
   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.
2. Processing at Power-on
   The state of the product is undefined at the moment when power is supplied.
   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.
3. Prohibition of Access to Reserved Addresses
   Access to reserved addresses is prohibited.
   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.
4. Clock Signals
   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.
   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.
5. Differences between Products
   Before changing from one product to another, i.e. to a product with a different type number, confirm that the change will not lead to problems.
   — The characteristics of an MPU or MCU in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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