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.

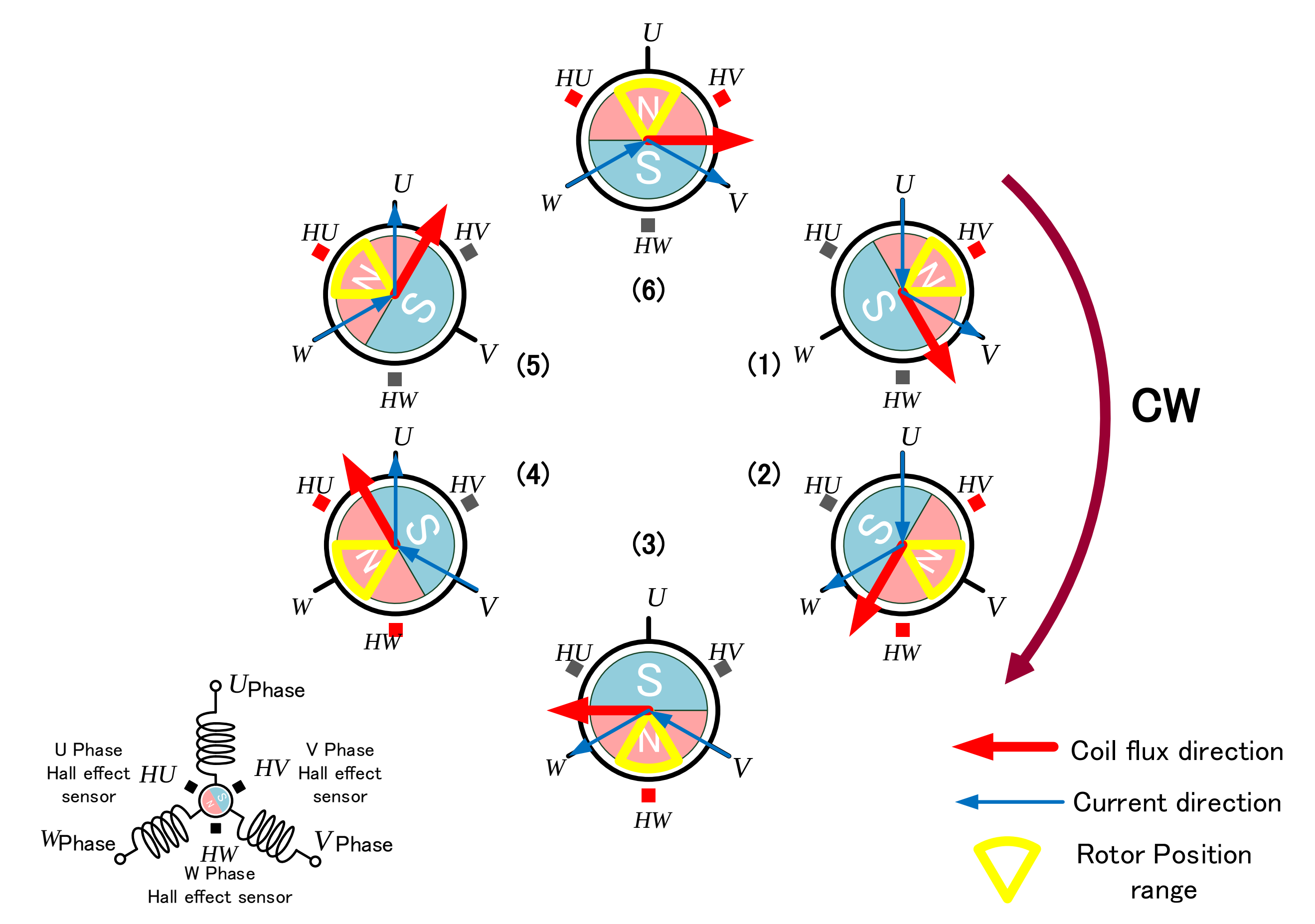


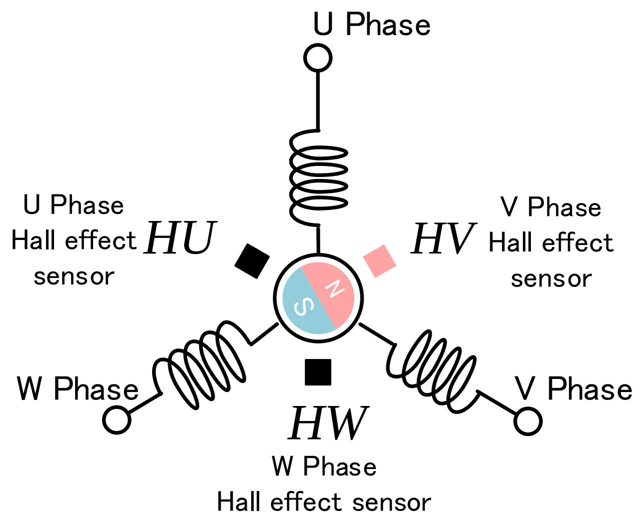
Figure 2-1 Six Conduction Patterns and Rotor Position Ranges (Example)

3. Position detection/speed calculation at 120-degree conducting control

3.1 120-degree conducting control using Hall effect sensors

3.1.1 Position detection

The Hall effect sensors are used to detect the position of the permanent magnet, and the signals from the Hall effect sensors are inputted to the microcontroller as position information.



Hall effect sensor	HU	HV	HW
Signals	L	H	L

Figure 3-1 Example of Hall effect sensors (HU, HV, HW) position and signals

As shown in Figure 3-1, the Hall effect sensors are allocated every 120 degrees and the respective Hall effect sensor signals are switched depending on change in magnetic poles of the permanent magnet. Combining these signals of three Hall effect sensors enables to obtain position information every 60 degrees (six patterns for one cycle).

At the switching timing of Hall effect sensor signals, the conduction patterns of each phase are changed as shown in Figure 3-2.

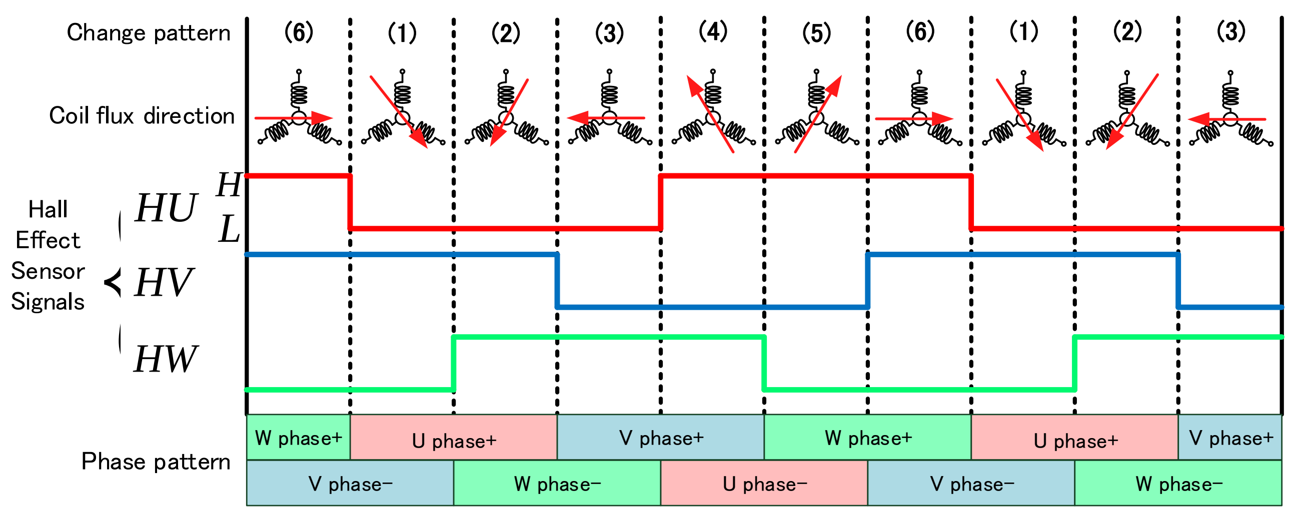


Figure 3-2 Relation between Hall effect sensor signals and conduction patterns (Rotation direction: CW)

3.1.2 Speed calculation

The motor rotational speed is calculated from a difference between the current timer value and the timer value 2π [rad] before. The timer values are obtained through the external interrupt routine by Hall effect sensor signals while having the peripheral function timer of the microcontroller performed free-running. With this method, if the Hall effect sensors are placed unequally, it is possible to calculate the rotational speed without the effect of unequalness.

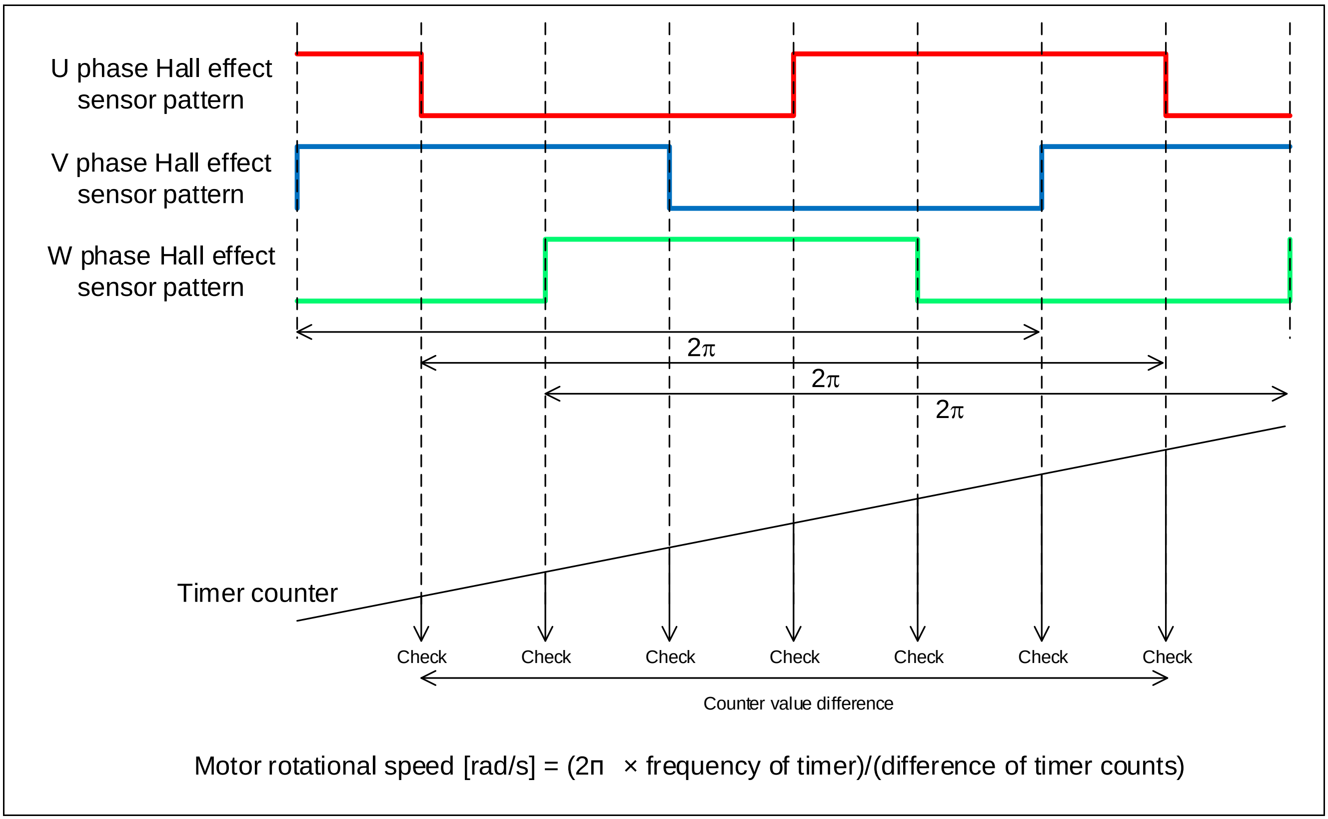


Figure 3-3 Method of calculation for the rotational speed

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 induced voltage.

The induced 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.)

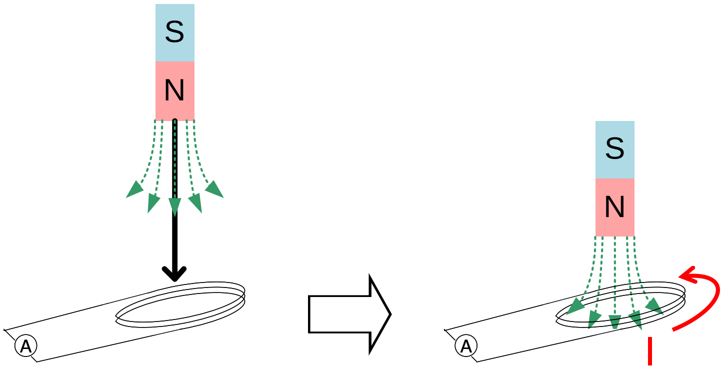


Figure 3-4 Induced voltage generated by coil and magnet

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

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

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

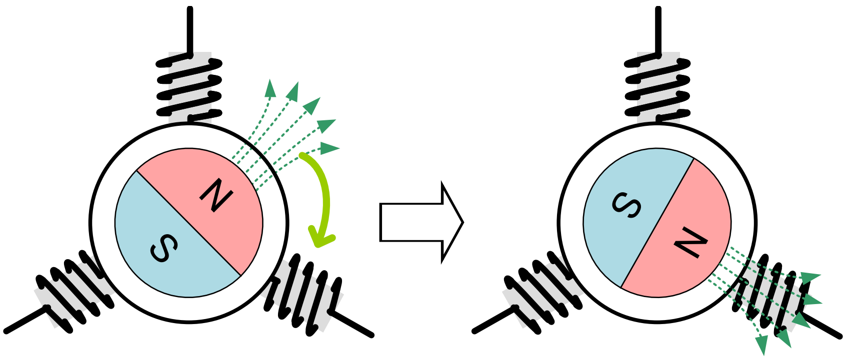


Figure 3-5 Induced voltage in the rotating permanent magnetic synchronous motor

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.

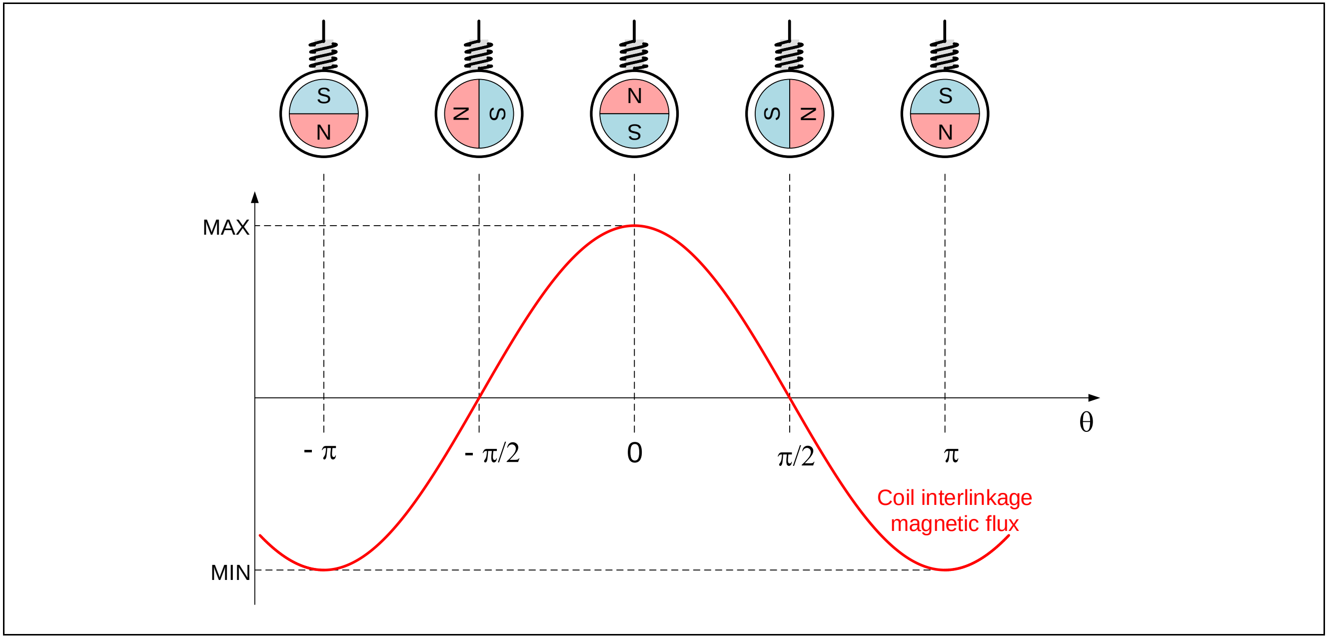


Figure 3-6 Change of the interlinkage magnetic flux

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

If considered in same way about the V phase and W phase, they deviate respectively by 2π/3 and -2π/3 phase from the U phase. The interlinkage magnetic fluxes of the three phases are expressed by the following formula.

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

Also, the induced voltages of the three phases are expressed by the following formulas, by using the above formula (1), when the angle speed is considered as ω.

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

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

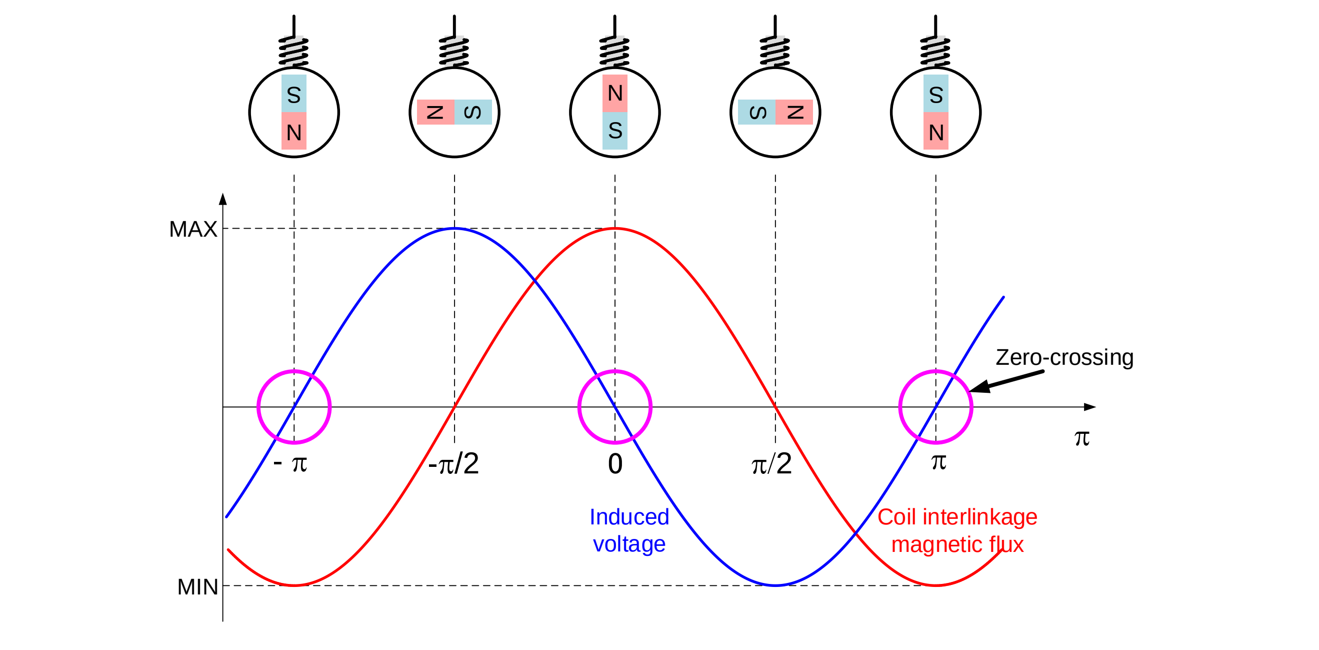


Figure 3-7 Zero-crossing of the induced voltage

However, the induced 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, in only the remaining one phase, to which current is not injected, the induced voltage can be detected. Actually, position information is obtained by detecting a change point of sign of induced voltage (zero-crossing) occurring in non-conducting phase.

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 effect sensors.

In this system, by comparing the pseudo motor center point voltage with each phase voltage, the patterns of ‘1’ and ‘0’ are created according to the positional relation.

In addition, the pseudo Hall effect sensor pattern is created by shifting this created pattern by π/6 phase. “π/6” is a value calculated from the estimated rotational speed.

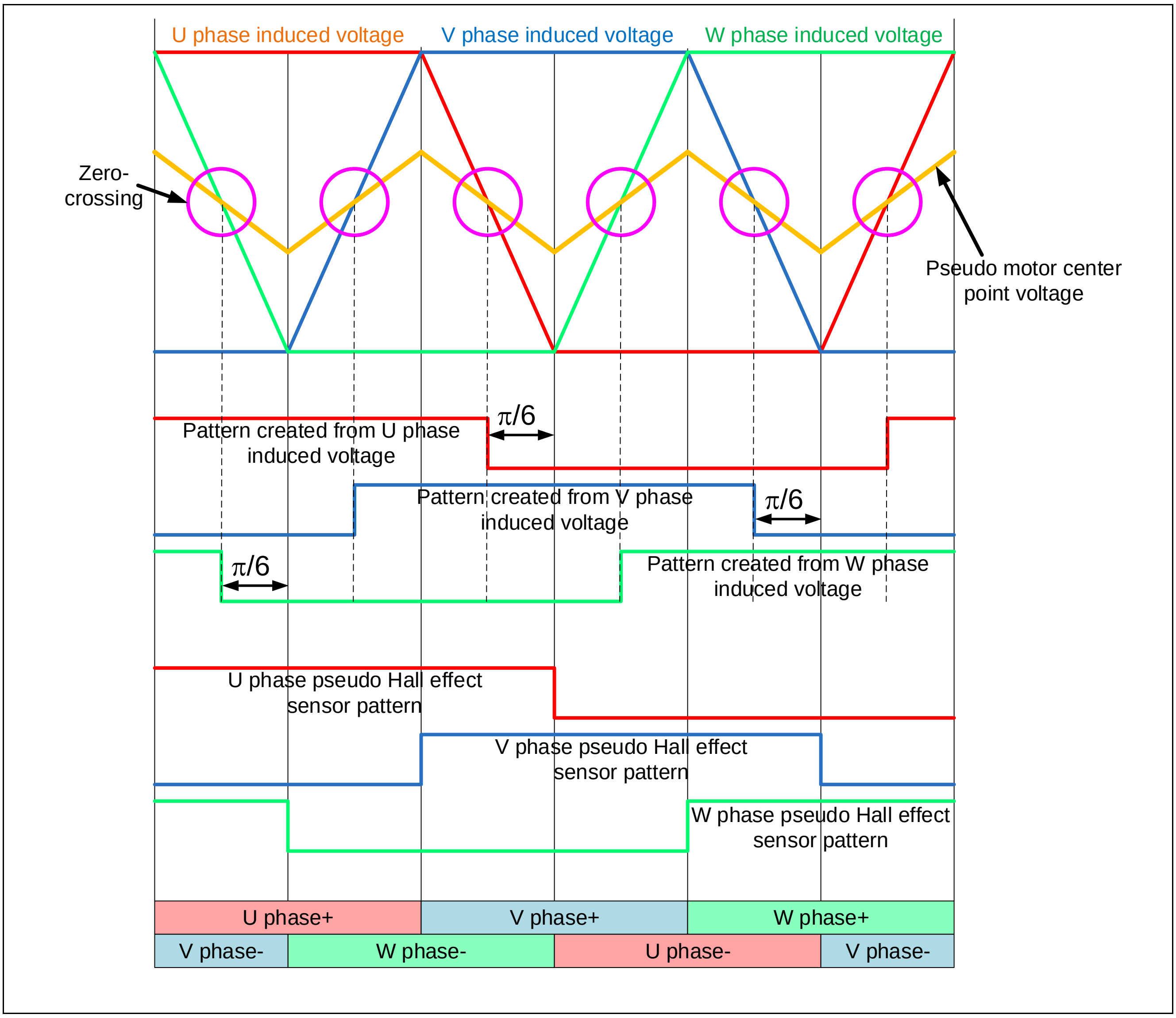


Figure 3-8 Pseudo Hall effect sensor pattern (In case of upper arm chopping)

There are some kinds of method to detect the zero-cross.

For example,

(1) Using A/D converters in a microcontroller

(2) Using the comparators

and so on.

Some representative examples are explained below.

(1) Using A/D converters in a microcontroller

In this method, at first actual voltage on each U/V/W phases are converted by A/D converter. Then pseudo center voltage is generated with the sum of these values. The zero-cross is detected by comparing this pseudo center voltage and voltage of each phases.

Since there is no need for a comparator to compare voltages, this method is called 'comparator-less method'. Basic image of this method is shown below.

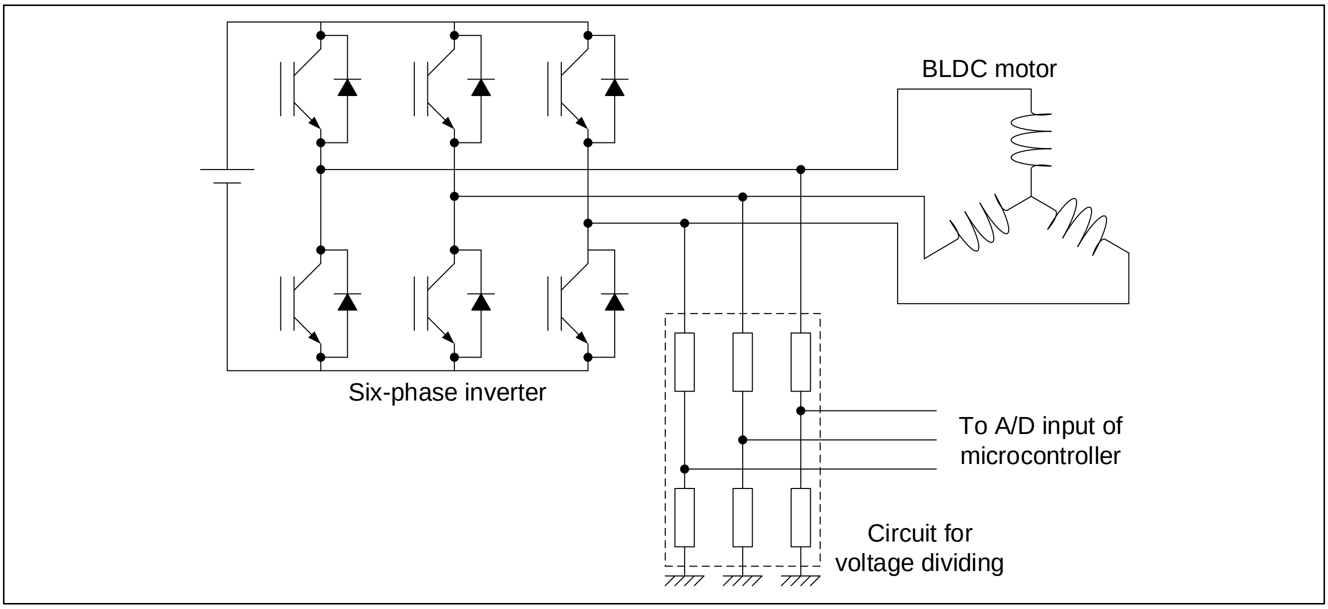


Figure 3-9 Comparator-less method

(2) Using the comparators

In the method with using the comparators, the zero-cross is detected by the comparators with comparing the actual voltage of each U/V/W phases and a pseudo center voltage which is generated by an electrical circuit. Then, the outputs of the comparators are input as external interrupts into a microcontroller.

Basic image of this method is shown below.

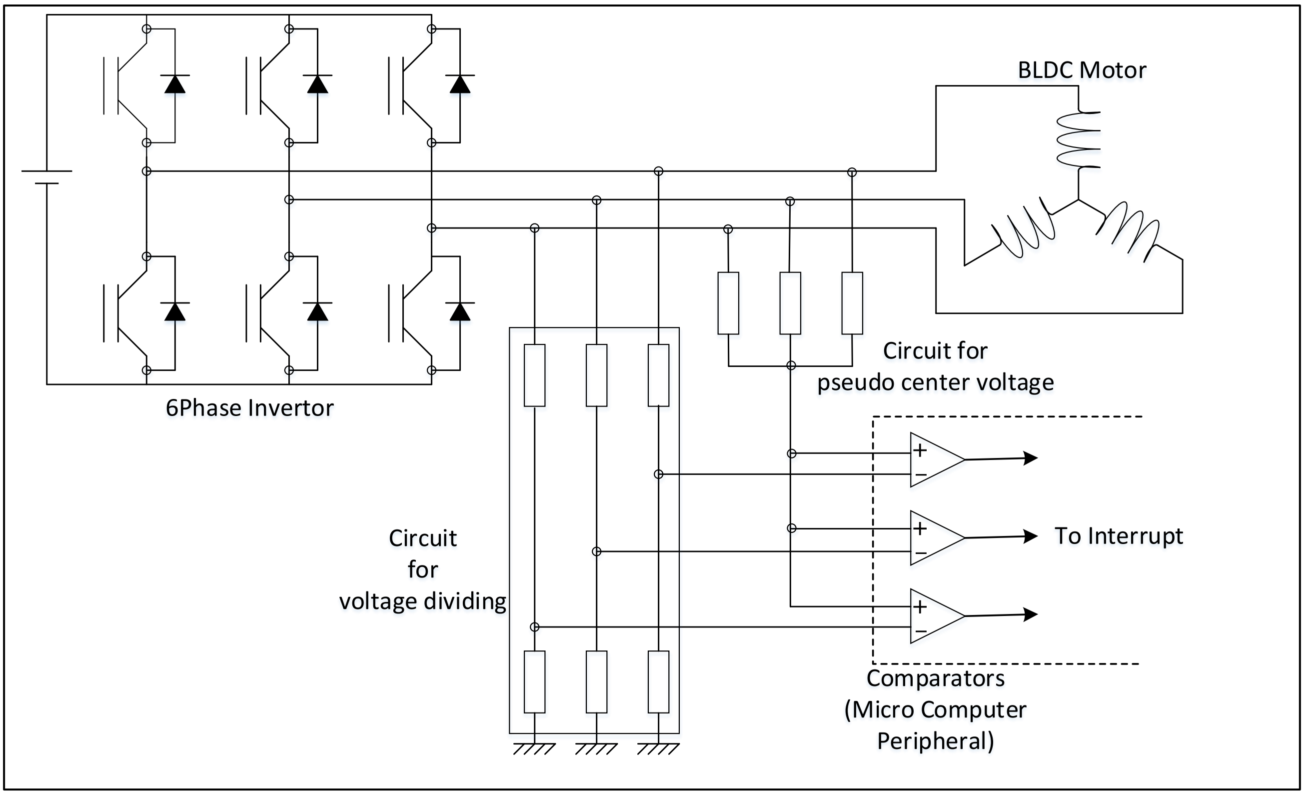


Figure 3-10 Method with using comparators (with a circuit for pseudo center voltage)

As for induced 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 3-11. To reduce the impact, some countermeasures such as a method using a simple filter circuit or software filtering can be taken.

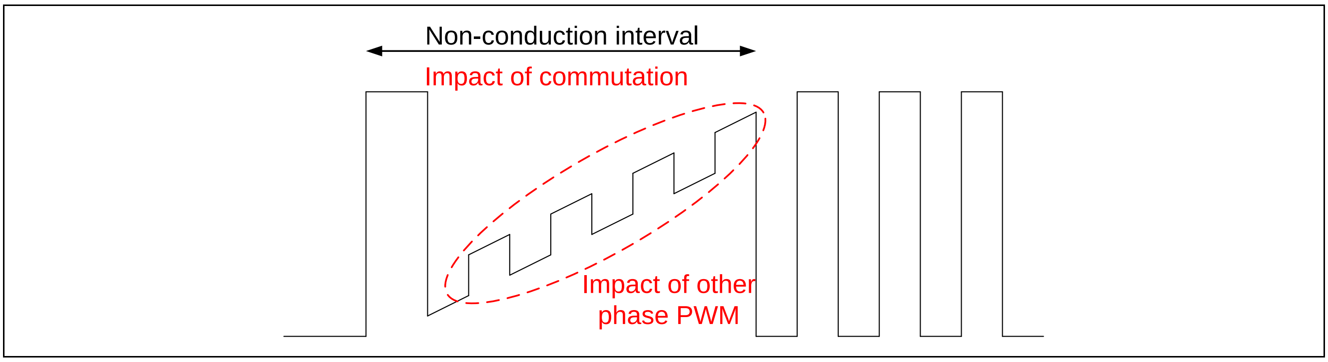


Figure 3-11 Conceptual Diagram of Impact of Commutation and Other Phase PWM

3.2.2 Speed calculation

The motor rotational speed is calculated from a difference between the timer value confirmed 2π [rad] before and the current timer value. The timer values are generated with a free-running timer in a microcontroller at the zero-cross point in which the conductive pattern change.

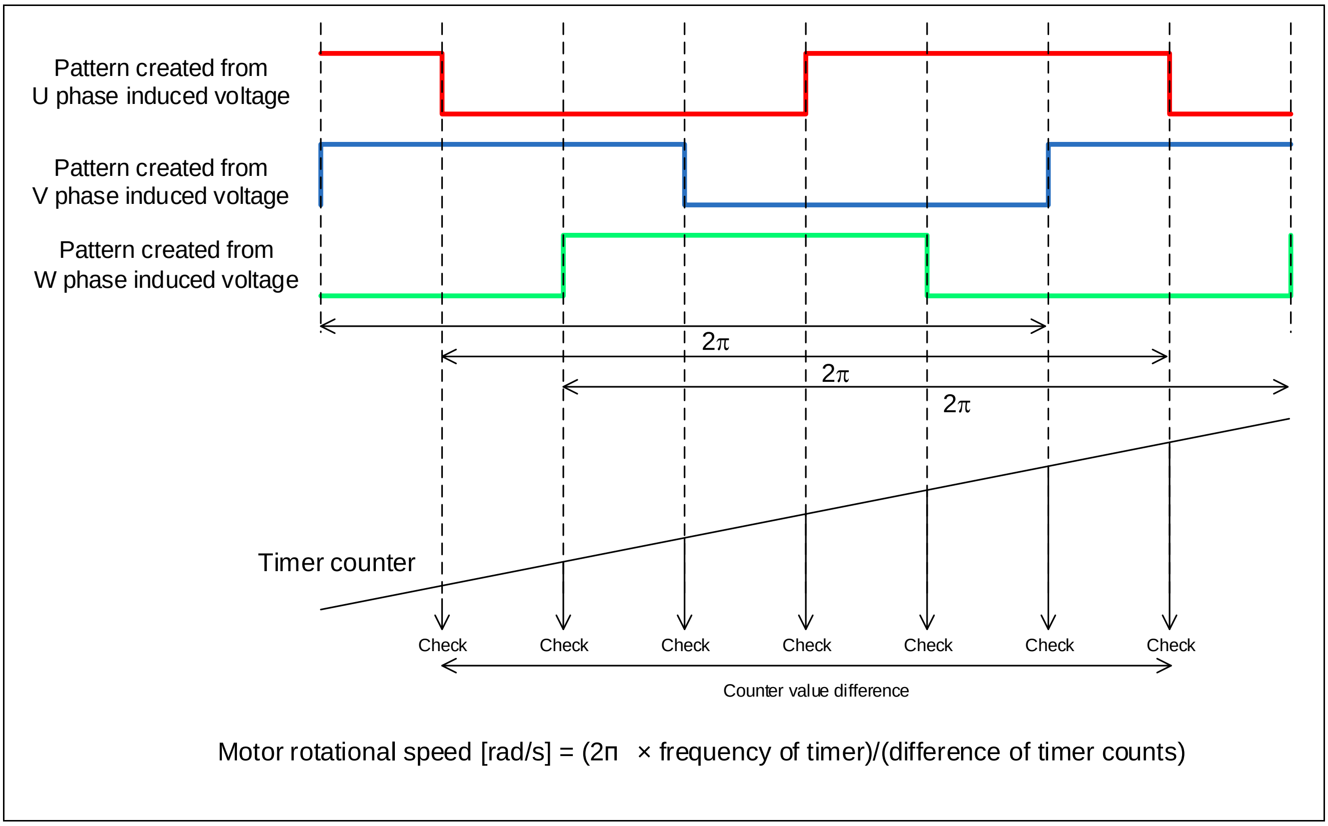


Figure 3-12 Method of calculation for the rotational speed

3.2.1 Start-up method

Induced voltage does not occur unless the permanent magnet is rotating. This means that position of the magnet cannot be estimated by using induced 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.

For more details, please refer to the Implementation (application note).

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Revision History

Rev.	Date	Description	
		Page	Summary
1.00	2015.03.31		First edition issued
1.10	2016.03.24		Issued in accordance with the revision '24V Motor Control Evaluation System for RX23T'.
1.20	2016.10.07	10	・Addition of the explanation about the detection zero cross by the comparator. ・Reconsideration of the sentences

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit 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 accordance 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 part number, confirm that the change will not lead to problems.

   — The characteristics of Microprocessing unit or Microcontroller unit products 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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