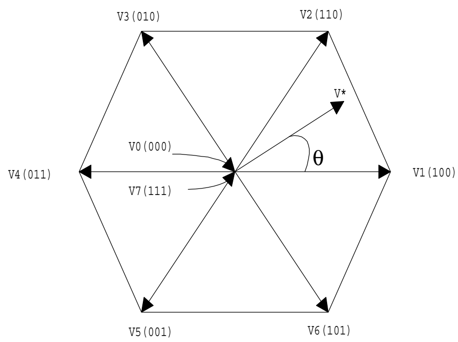
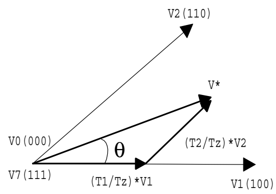
- ***Sinusoidal Pulse Width Modulation*** In many industrial applications, Sinusoidal Pulse Width Modulation (SPWM), also called Sine coded Pulse Width Modulation, is used to control the inverter output voltage. SPWM maintains good performance of the drive in the entire range of operation between zero and 78 percent of the value that would be reached by square-wave operation. If the modulation index exceeds this value, linear relationship between modulation index and output voltage is not maintained and the over-modulation methods are required.

- ***Space Vector Pulse Width Modulation*** A different approach to SPWM is based on the space vector representation of voltages in the d, q plane. The d, q components are found by Park transform, where the total power, as well as the impedance, remains unchanged.
Fig. 1 shows 8 space vectors in according to 8 switching positions of inverter, V* is the phase-to-center voltage which is obtained by proper selection of adjacent vectors V1 and V2.





The reference space vector V* is given by Equation (1), where T1, T2 are the intervals of application of vector V1 and V2 respectively, and zero vectors V0 and V7 are selected for T0.

$$V^* T_z = V_1 * T_1 + V_2 * T_2 + V_0 * (T_0/2) + V_7 * (T_0/2) \qquad (1)$$

Fig. 1 Inverter output voltage space vector

Fig. 2 Determination of Switching times

- ***Space Vector Pulse Width Modulation (continued)***

- ***Comparison of SPWM and Space Vector PWM***

Fig. 3(a) shows that the inverter switching state for the period T1 for vector V1 and Fig. 3(b) is for vector V2, resulting switching patterns of each phase of inverter are shown in Fig. 4.

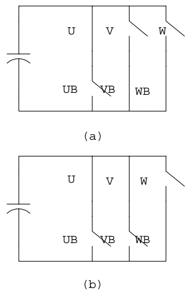


Fig. 3 Inverter switching state for (a)V1, (b) V2

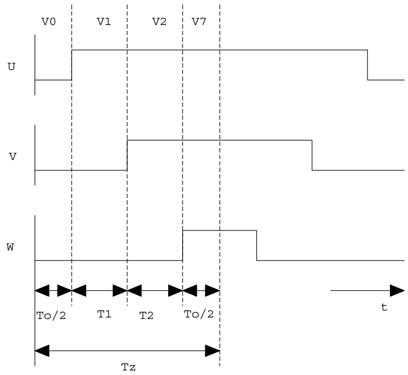


Fig. 4 Pulse pattern of Space vector PWM

In Fig. 5, U is the phase-to-center voltage containing the triple order harmonics that are generated by space vector PWM, and U1 is the sinusoidal reference voltage. But the triple order harmonics are not appeared in the phase-to-phase voltage as well. This leads to the higher modulation index compared to the SPWM.

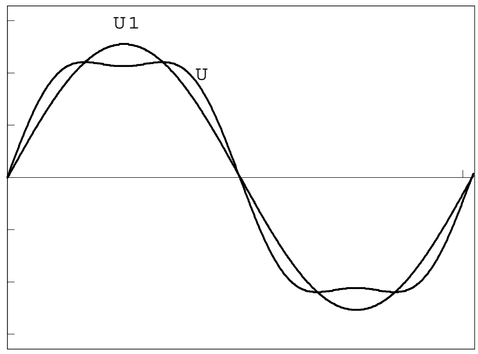


Fig. 5 Phase-to-center voltage By space vector PWM

As mentioned above, SPWM only reaches to 78 percent of square-wave operation, but the amplitude of maximum possible voltage is 90 percent of square-wave in the case of space vector PWM.
The maximum phase-to-center voltage by sinusoidal and space vector PWM are respectively ;

Vmax = Vdc/2 : Sinusoidal

PWM
Vmax = Vdc/√3 : Space Vector PWM
Where, Vdc is DC-Link voltage.

This means that Space Vector PWM can produce about 15 percent higher than Sinusoidal PWM in output voltage.

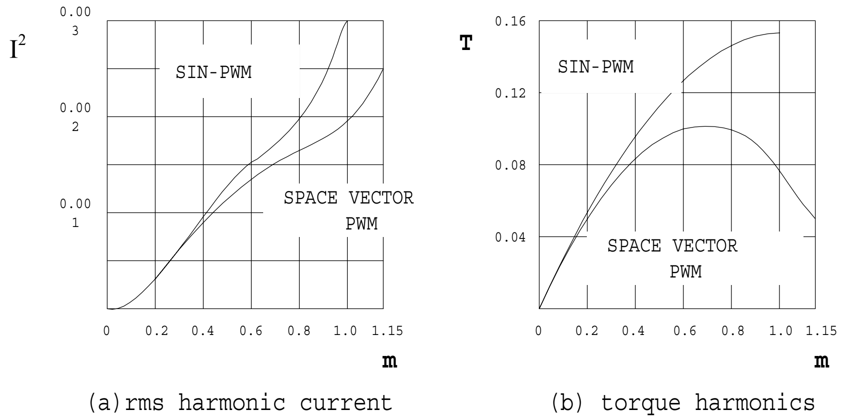


Fig. 6 Current and torque harmonics

Simulation results in Fig. 6 show that the higher modulation index is, the less the harmonics of current and torque by space vector PWM are than those of sinusoidal PWM.

■ ***Volts/Herts Control***

■ ***Sensorless Vector Control***

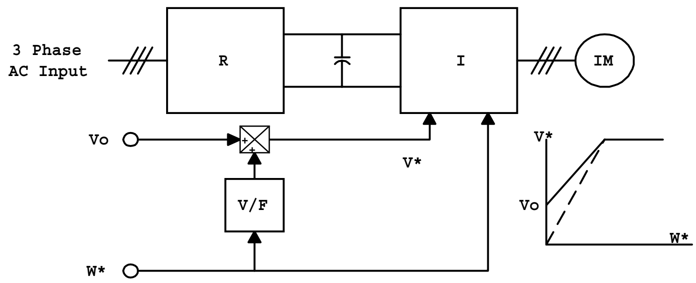


Fig. 7 Open loop volts/hertz control

V/F
A simple and popular open-loop volts/herts(V/F) speed control method for an induction motor is shown in Fig. 7. The scheme is defined as V/F control because the output voltage command V* is generated directly from the frequency command W* through the linear conversion of V/F.

Torque Boost
As the frequency approaches to low speed near zero, the stator voltage of motor will tend to be zero and it will be absorbed by the stator resistance. Therefore, an auxiliary voltage Vo is required to overcome the effects of stator resistance so that full torque become available up to zero speed.
Some of inverter including LG's SV-iS3 provide Auto-Torque Boost functions that automatically determines the magnitude of Vo by using phase current feedback.

Dynamic Performance
During steady-state operation, if the command frequency is increased by a step, the slip will exceed that of breakdown torque and the motor will become unstable. Similar instability will occur if the frequency is decreased by a step. Therefore, it is necessary that during both acceleration and deceleration, the frequency should track the speed so that slip does not exceed that of the breakdown torque.

Overview
Open loop control of the machine with variable frequency may provide a satisfactory variable speed drive when the motor has to operate at steady torque without stringent requirements on speed regulation.
But when the drive requirements include fast

dynamic response and accurate speed or torque control, and open loop control is unsatisfactory. Hence it is necessary to operate the motor in a closed loop mode, when the dynamic operation of the induction machine drive system has an important effect on the overall performance of the system.

Vector control techniques have made possible the application of induction motors for high-performance applications where traditionally only dc drives were applied. The vector control scheme enables the control of the induction motor in the same way as a separately excited dc motor. As in the dc motor, torque control of the induction motor is achieved by controlling the torque current component (i^*ds) and flux current component (i^*qs) independently as shown in Fig. 8.

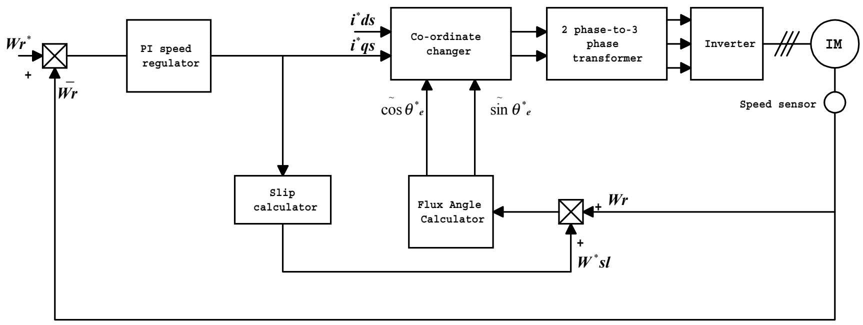


Fig. 8 Block diagram of vector control system with speed sensor.

- ***Sensorless Vector Control (continued)***

The above vector control schemes in Fig. 8 require a speed sensor for closed loop operation. The speed sensor has several disadvantages from the standpoint of drive cost, reliability, and noise immunity.

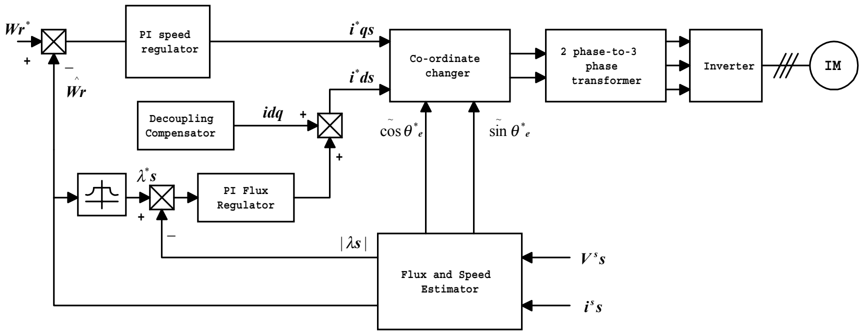


Fig. 9 Block diagram of sensorless vector control system.

In Fig. 9, without speed sensor, the motor speed $\hat{Wr}$ and the flux λs are directly estimated by using terminal voltage, phase current, and motor parameters including stator resistance, rotor resistance and total leakage inductance. These parameters also can be obtained by several of tuning method such as conventional DC and Locked-rotor test, or Auto-tuning.

Next sections present the sensorless flux vector methods classified to rotor or stator flux vector control.

- ***Sensorless Vector Control (continued)***

Rotor Flux-Oriented Control

To avoid the use of speed sensors or flux sensors in a field-oriented induction machine drive system; the terminal quantities of the motor are used to estimate the rotor flux. The block diagram of the rotor flux estimation without using a speed sensor is shown in Fig. 10. The output of the rotor flux estimator is used for closed-loop flux regulation.

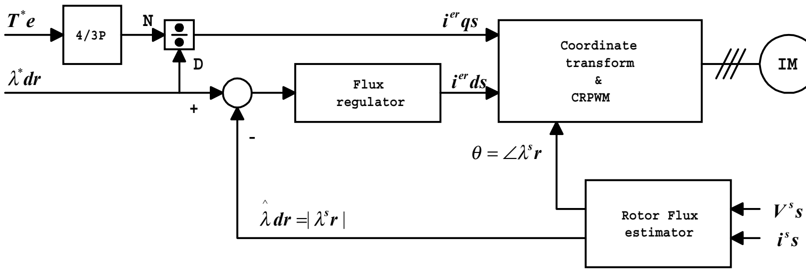


Fig. 10 Block diagram of rotor flux oriented system with rotor flux estimator.

The rotor flux is estimated by first calculating the stator flux as given by

$$\hat{\lambda} s = \int (v_s - R_s i_s) dt$$

$$\hat{\lambda} r = \frac{L_r}{L_m} (\lambda s - \sigma L_s i_s)$$

where $\hat{\lambda} s$ is the estimated stator flux, $\hat{\lambda} r$ is the estimated rotor flux, and

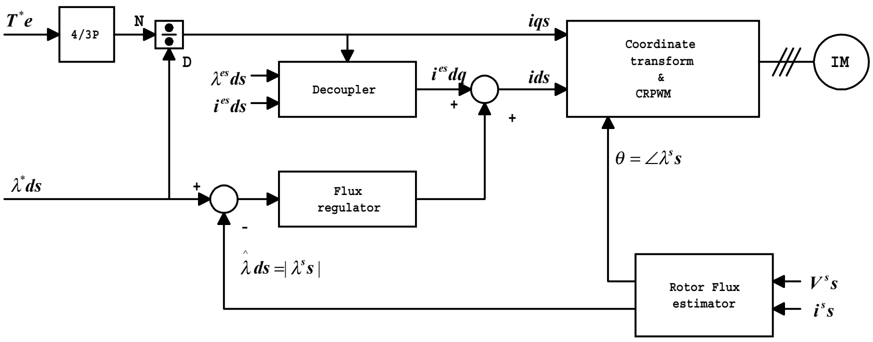
$\sigma = 1 - \frac{L_m^2}{L_s L_r}$ is the total leakage factor.

■ ***Sensorless Vector Control (continued)***

Stator Flux-Oriented Control

The accuracy of the estimated rotor flux depends on the accuracy of the estimated stator resistance and the inductance values. The resistance varies with frequency and temperature. The leakage inductance changes with current and flux level. The field oriented control scheme is made insensitive to stator leakage inductance variations by using stator flux orientation, the stator flux being calculated using only the terminal quantities and stator resistance. A typical block diagram of a stator flux oriented control scheme is shown in Fig. 11.

Fig. 11 Block diagram of stator flux oriented system.



$$\hat{\lambda} s = \int (v_s - R_s i_s) dt$$

$$\hat{\omega}_s = \frac{(1+\sigma T_r p) L_s i_{qs}}{T_r (\lambda_{ds} - \sigma L_s i_{ds})}$$ is the estimated slip frequency.