Lecture-16

AC DRIVES -Speed Control of Induction Motors from the Rotor Side

1) Speed control by changing rotor –circuit resistance

It has been shown previously that the slip of an induction motor equals the ratio of rotor copper loss to rotor input. Therefore, changing total resistance of the rotor circuit can change the slip .This may achieved by inserting a three-phase rheostat in the rotor circuit as shown in Fig.16.1 (a). This method is only possible for wound rotor applications, and not be possible for squirrel – cage rotor. The changing total resistance of the rotor circuit can change the speed can also:

The equation of torque for three- phase induction motor is given previously in lecture -13 as

$$T \alpha \frac{sE_2^2 \quad R_2}{R_2^2 + (sX_2)^2}$$

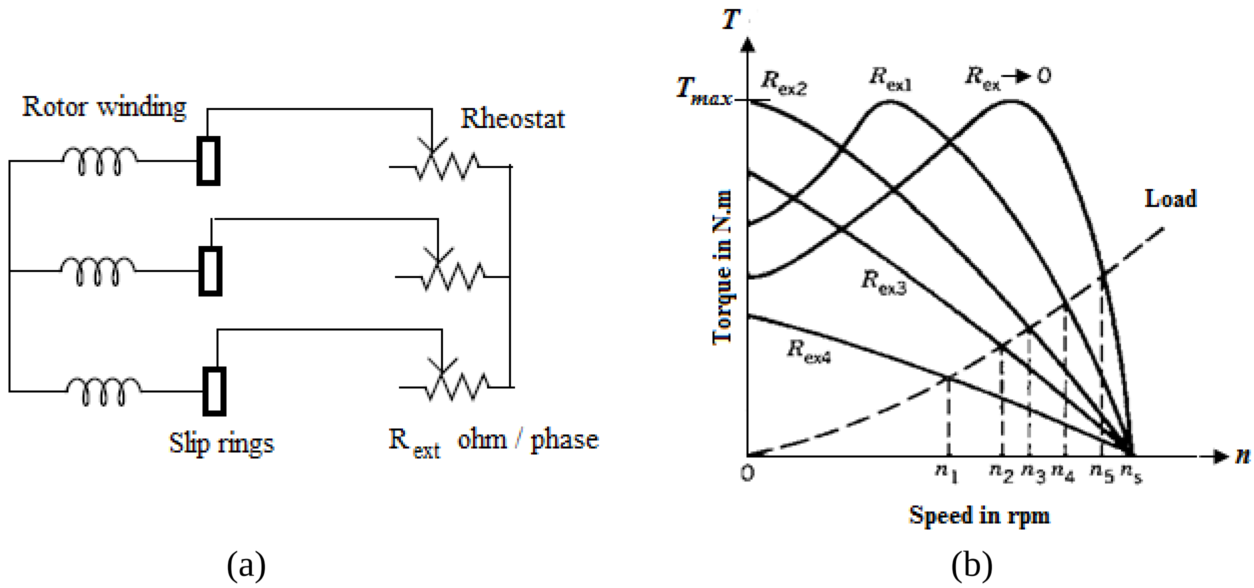


Fig.16.1 Three-phase induction motor speed control by changing rotor-circuit resistance method.

In general, the three- phase induction motor operates in low slip region, hence the term $(sX_2)^2$ becomes very small as compared to R_2^2 , so it can be neglected. Also if we consider that E_2 is constant, then the equation of torque may be written as,

$$T \alpha \frac{s}{R_2}$$

It is clear that from the above equation, the torque is inversely proportional to the rotor resistance. Hence, if we increase rotor resistance R_2 , torque decreases. Thus by adding additional resistance in rotor circuit we can decrease the speed of motor. The main advantage of this method is that with addition of external resistance starting torque increases. However, this method of speed control of three phase induction motor suffers from some disadvantages:

(a) This method can only reduce the speed below the maximum value correspond to zero external resistance , hence , the speed above the normal value is not possible. Obviously the method is characterised by low efficiency due to high waste of energy. For example, to reduce the speed to 50% of its normal value, one has to dissipate 50% of the power absorbed from the source in the added resistor.

(b) Another objection against this method is the departure of the torque - speed characteristic from its original shape of small slop to a new characteristic of considerable slop and the speed regulation is degraded. The slop is dependent on the value of the added resistance as shown in Fig. 16.1 (b).

Example 16.1

A 75 kW, 4-pole, 440V, 50Hz, star-connected, three-phase induction motor has the following parameters per phase referred to the stator side:

$R_1 = 0.1\Omega$, $R_2 = 0.083\ \Omega$, $X_1 + X_2 = 1.83\ \Omega$, $a_{eff} = N_p / N_s = 2.5$

If the rotor is star connected, determine the external resistance inserted in series with the rotor winding per phase such that the motor develops an output shaft torque of 150 Nm at a speed of 1250 rpm.

Solution

The synchronous speed of the motor is

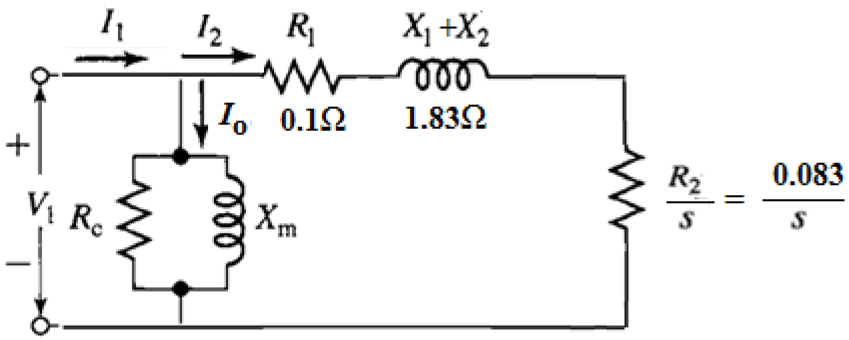
$$n_s = \frac{120f}{p} = \frac{120x50}{4} = 1500 \text{ rpm}$$

the slip is

$$s = \frac{n_s - n}{n_s} = \frac{1500 - 1250}{1500} = 0.167$$

The approximate equivalent circuit of the motor referred to the stator side is shown in Fig.16.2.

Fig.16.2



Let R_{ext} be the additional resistance inserted in each rotor phase at s = 0.167 such that the new rotor resistance becomes R_x , hence from the torque equation,

$$T=\frac{3V_1^{\,2}}{s\omega_s}\times\frac{R_2}{(R_1+\frac{R_2}{s})^2+(X_1+X_2)^2}$$

$$T=150=\frac{1}{2\pi(\frac{1500}{60})}x\frac{3(\frac{440}{\sqrt{3}})^2 x\, R_x}{\left[(0.1+\frac{R_x}{0.167})^2+(1.83)^2\right]}x\frac{1}{0.167}$$

This leads to the following quadratic equation

$$35.86\, R_x^2-48R_x+3.359=0$$

From which we get,

$$R_x=\frac{48\pm\sqrt{(48)^2\,-4x35.86\,x3.359}}{2x35.86}$$

∴ $R_x=1.264\ \Omega$ and 0.074Ω

Neglecting the smaller value, hence $R_x=1.264\ \Omega$.

$R_{ext}=1.264-0.083=1.1816\ \Omega$, referred to the stator

This resistance referred to the rotor side as

$$R_{ext}=\frac{1.1816}{a_{eff}^2}=\frac{1.1816}{2.5^2}=0.19\Omega$$

Other method of achieving rotor – circuit resistance variation

The three-phase resistor shown in Fig.16.1 (a) may be replaced by a single resistor and d.c. chopper. The slip power from the rotor is converted to d.c current by rectification. The average resistance across the rotor slip rings will vary from (0-R) depending on the rate of switching of the rapidly pulsed thyristor. There is need only for one main thyristor and an auxiliary thyristor for turn-off. The fact that there is only one resistance is another advantage and this also provides perfect circuit balancing between the three phases. Schematic diagram of the method is shown in Fig.16.3.

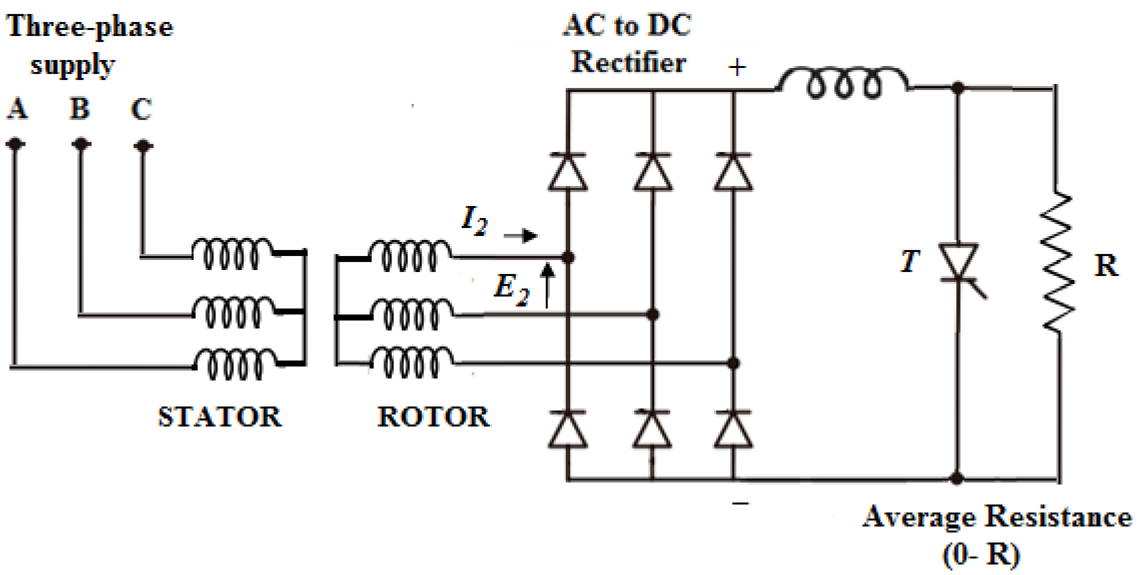


Fig.16.3 Slip control by d.c. chopper.

The external resistances R_{ex} = 0 during chopper conduction (γ = 0) , where γ is the chopper duty cycle and R_{ex} = R during chopper extinction with variation. Therefore,

$$R_{ex} = \frac{t_{off}}{t_{on} + t_{off}} R \quad = (1-\gamma)R \tag{16.1}$$

Disadvantages: high losses in the commutating circuit at high chopping frequency. At high motor speeds E_2 is low and may be insufficient to provide commutating voltage. So small range of speed can be achieved.

(2) Injecting slip frequency *emf* into rotor side

When the speed control of three-phase induction motor is done by adding resistance in rotor circuit, some part of power called, the slip power is lost as I^2R losses. Therefore the efficiency of the motor is reduced by this method of speed control. This slip power loss can be recovered and supplied back in order to improve the overall efficiency of motor and this scheme of recovering the power is called slip power recovery scheme. This is done by replacing the d.c. chopper and resistor R in Fig.16.2 by a three-phase bridge converter as shown in Fig. 16.3. The converter operates in inversion mode with firing angles $90° \leq \alpha \leq 180°$ thereby returning energy to the source. The variation of the triggering angle α results in variation of speed, hence speed control is achieved by this technique. Therefore, one feature of wound rotor machine is that the slip power becomes easily available from the slip rings, which can be electronically controlled to control speed of the motor.

Methods of slip energy recovery

The two well known types of converter use the slip energy recovery technique are:

1. Static Kramer drive: allows operation at subsynchronous speed only.
2. Static Scherbius Drive: allows operation above and below synchronous speed.

Static Kramer drive

A static Kramer drive is a method to obtain an injected voltage that is in phase with the rotor current. The voltage at the slip rings is forced to be in phase with the rotor currents by the diode rectifier. The magnitude of the slip ring voltage is set by the d.c. link voltage, which is in turn set by the inverter connected back to the a.c. supply. The schematic diagram of the converter is depicted in Fig.16.4.

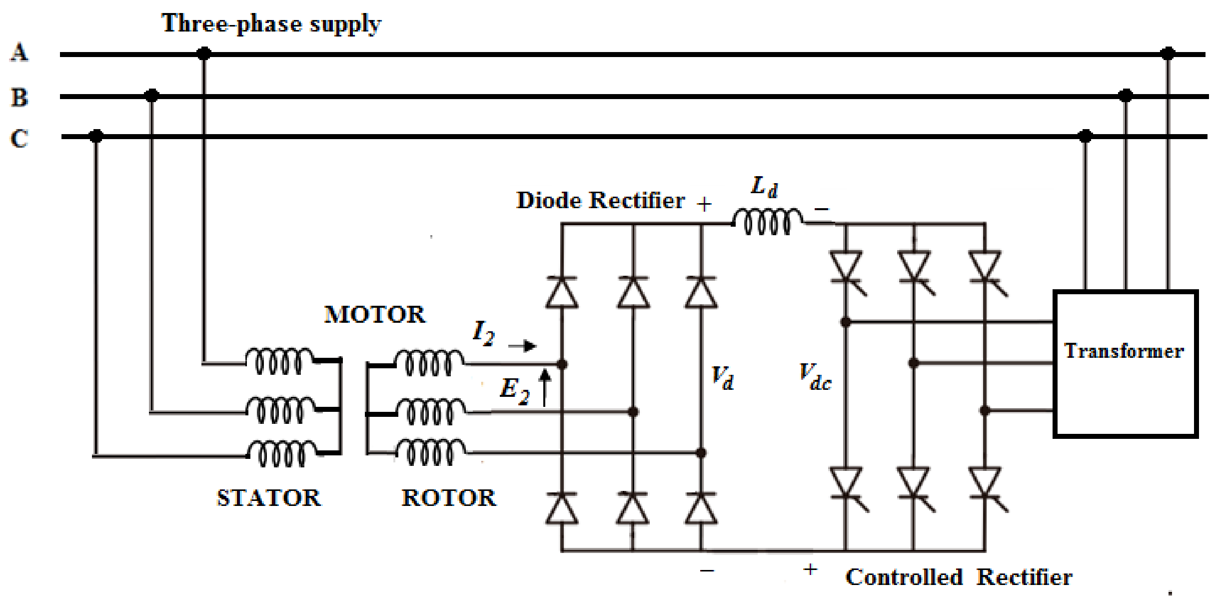


Fig. 16.4 Static Kramer drive.

The static Kramer drive has been very popular in large power pump and fan-type drives, where the range of speed control is limited near, but below the synchronous speed. The drive system is very efficient and the converter power rating is low because it has to handle only the slip power. The additional advantages are that the drive system has dc machine-like characteristics and the control is very simple. These advantages largely offset the disadvantages of the wound-rotor induction machine.

Static Scherbius Drive

Another technique that employs the principle of slip power returns to the supply is kown as static Scherbius drive shown in Fig. 16.5 In this system the bridge rectifier in Fig.16.3 is replaced by cycloconverter (or by three-phase duel converter). For limited-range speed control applications, where the slip power is only a fraction of the total power rating of the machine, Kramer and Schrebius drives (slip-power recovery drives) have been used in the following applications:

- Large-capacity pumps and fan drives
- Variable-speed wind energy systems
- Shipboard VSCF (variable-speed/constant-frequency) systems
- Variable-speed hydro pumps/generators
- Utility system flywheel energy storage systems

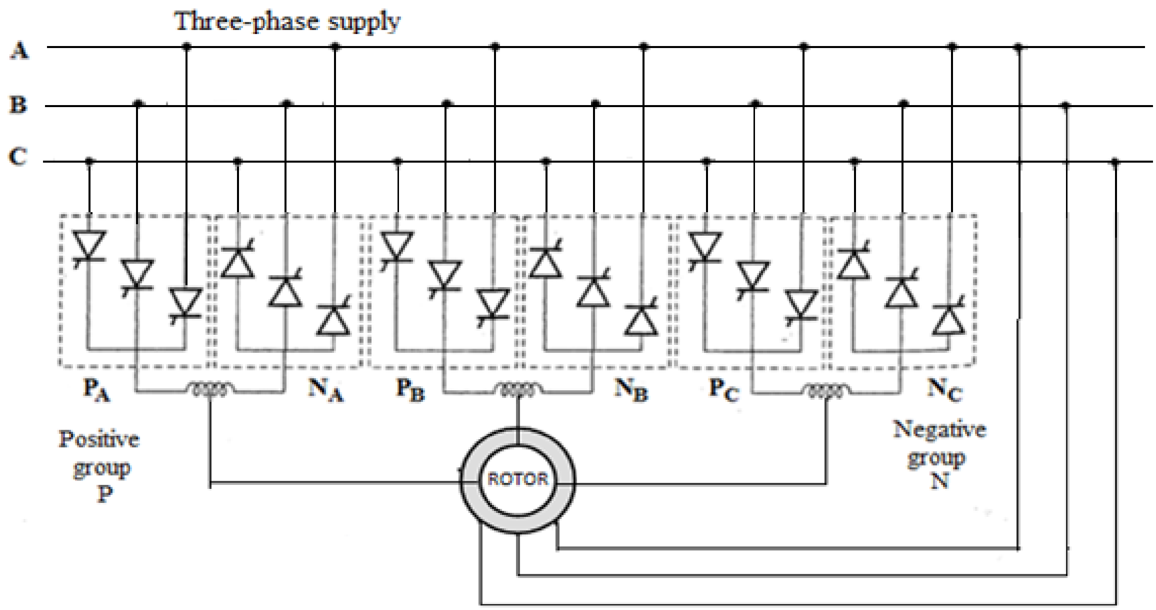


Fig. 16.5 Static Scherbius drive.

(3) Cascade control method

In this method of speed control of three -phase induction motor, two motors are required one of them should be a wound rotor type. These two motors are connected on common shaft and hence called cascaded motor as shown in Fig.16.6. One motor is the called the main motor and another motor is called the auxiliary motor. The three- phase supply is given to the stator of the main motor while the auxiliary motor is derived at a slip frequency from the slip ring of main motor.

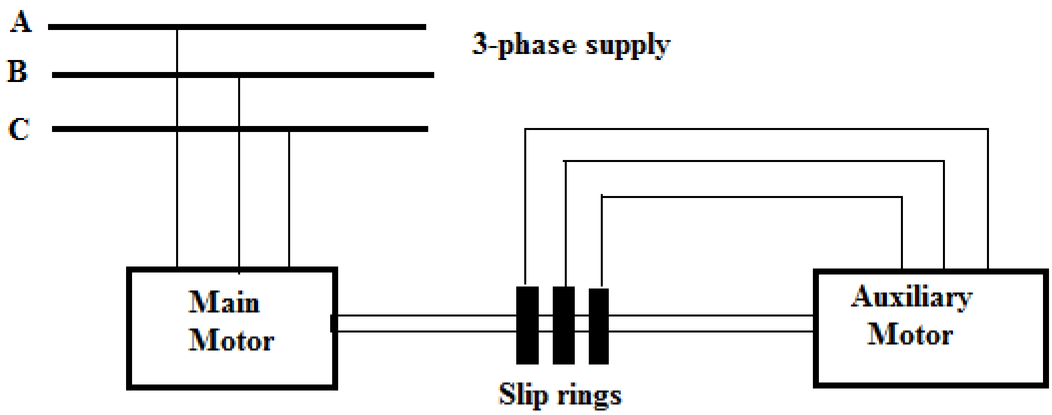


Fig.16.6 Cascade connections of induction motors for speed control.

CYCLOCONVERTER DRIVES

Cycloconverters provide variable frequency variable voltage supply using large number of power switching devices. They are mainly used in large induction and synchronous motor drives in low frequency applications such as steel rolling mill end tables, cement mill furnaces, mine hoists and ship propulsion drives. These drives are called **gearless drives** since low speed operation is obtained without a reduction gear thus reducing the cost compared to the conventional drives.

A full-wave cycloconverter drive configuration with two three-phase thyristor bridges per motor phase is shown in Fig. 16.7 The output of a poly-phase controlled rectifier is approximately $V_d = V_{do} \cos \alpha$,where V_{do} is the output of the rectifier with zero firing delay , and α is the delay angle.

Voltage and current waveforms for squirrel cage medium power motor driven by cycloconverter drive are shown in Fig.16.8 .This type of drive has limitation that waveforms become distorted above 40% of input frequency (i.e., 20 Hz from 50Hz supply). However, it has an advantage that high power factor is obtained when used with synchronous motors.

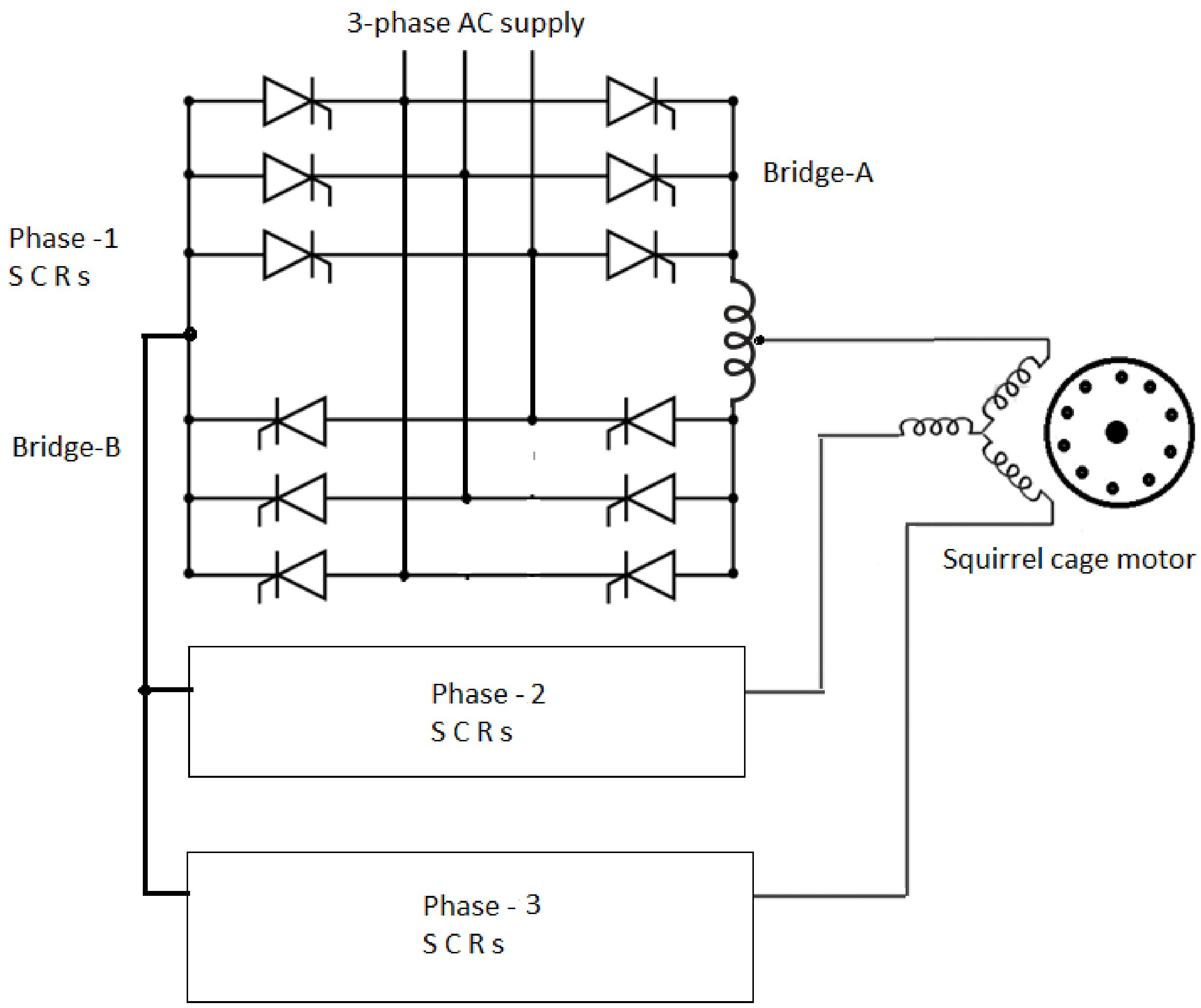


Fig.16.7 Cycloconvertor drive circuit.

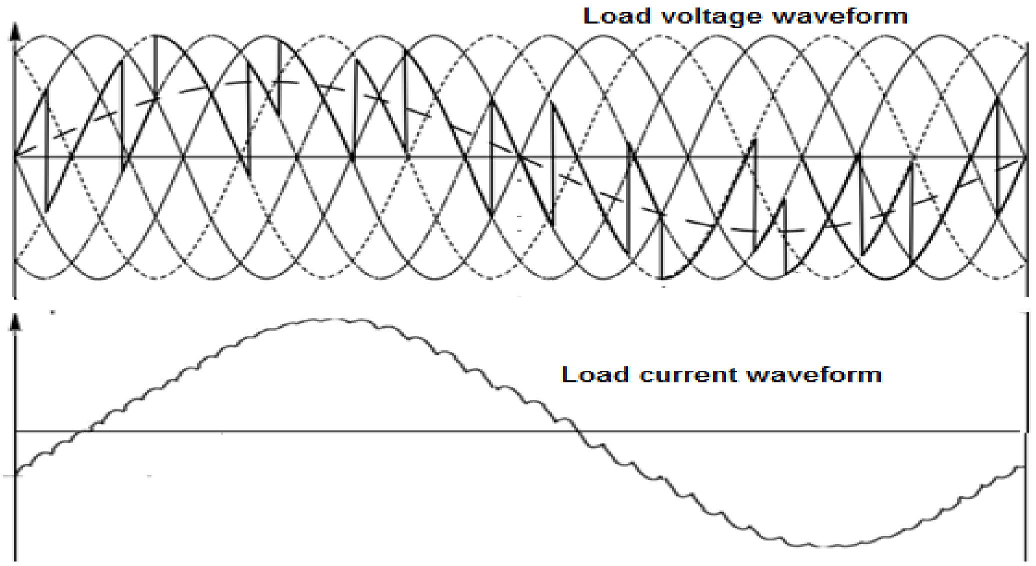


Fig.16.8 Stator phase voltage and stator phase current for squirrel cage induction motor driven by cycloconverter drive.