Brushless DC Motors (BLDC Motors)

A brushless dc motor is a polyphase synchronous motor with a permanent-magnet rotor. This motor cannot operate without its electronic controller

Therefore, a brushless dc motor is a motor drive system combines into one unit an ac motor, solid state inverter and a rotor position sensor.

The solid state inverter used transistors for low-power and thyristors for high-power drives.

Rotor position sensor monitors the shaft position and sends the control signals for turning on the controlled switches ofthe inverter in an appropriate sequence.

- A BLDC motor has permanent magnets which rotate, and a fixed armature, eliminating the problems of connecting current to the moving armature.

- An electronic controller replaces the brush commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning.

- The controller performs similar timed power distribution by using a solid-state circuit rather than the brush commutator system.

- The function of mechanical commutator in a conventional dc motor is now performed by electronic commutator in a brushless dc motor.

- Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exits the winding) and the third is in a non-energized condition.

- In a BLDC the decrease of field current causes increase in speed like a conventional dc motor that's why its characteristics is similar to conventional DC motor the name given as Brushless DC motor.

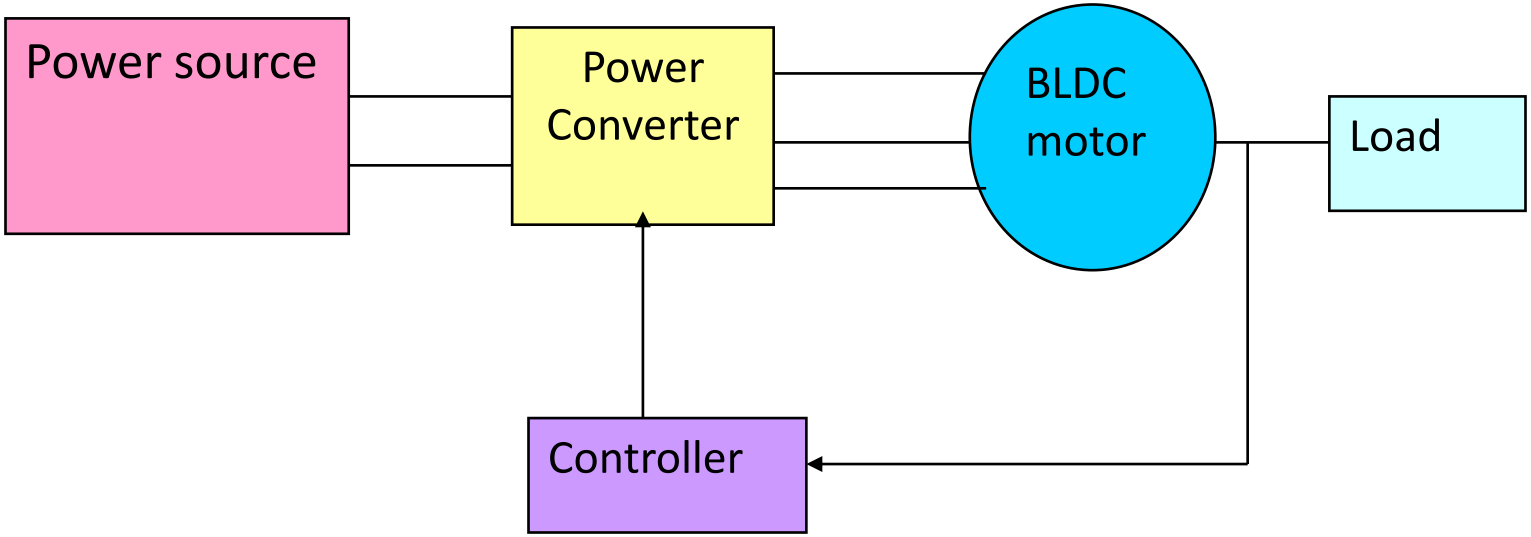
Advantages

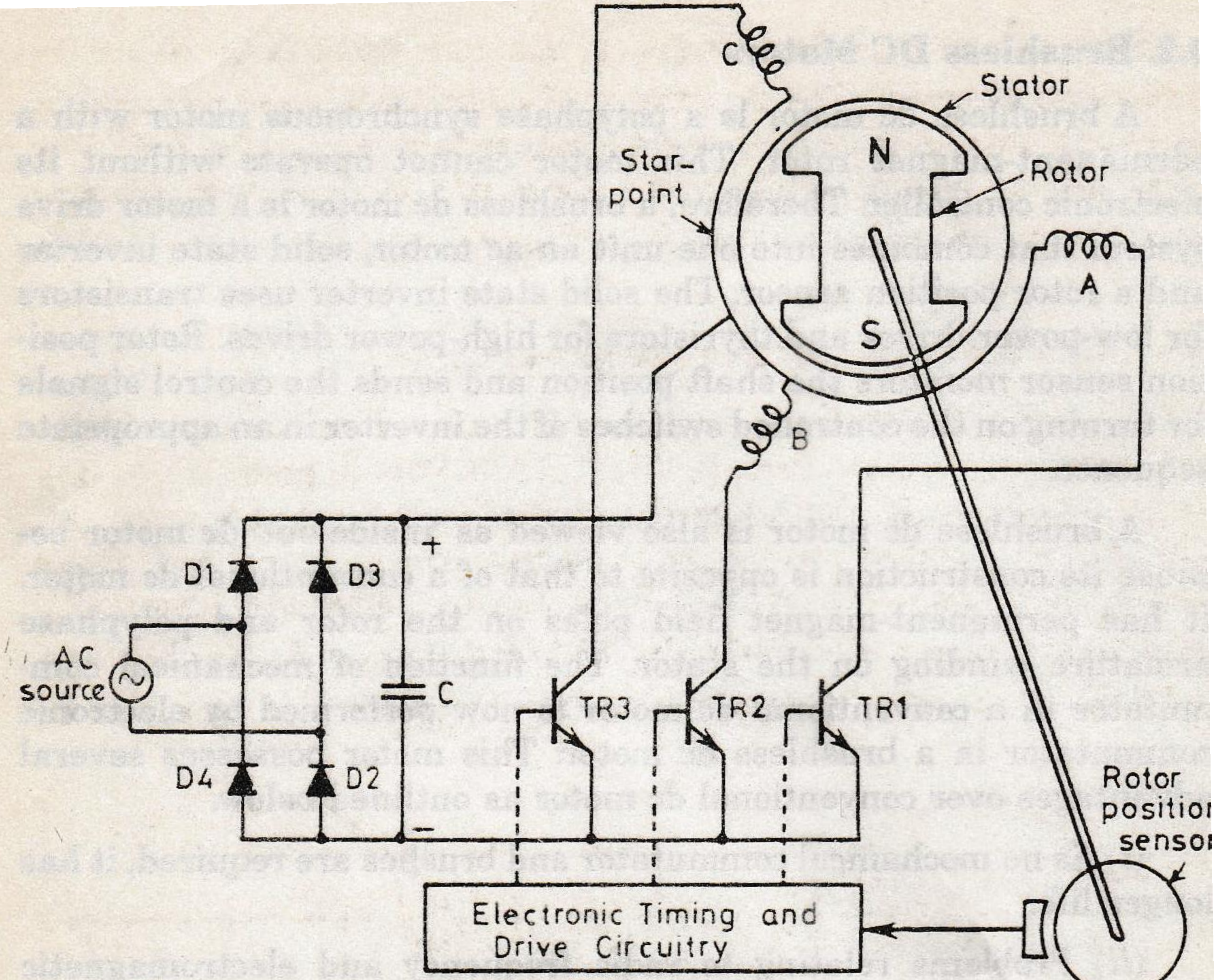
- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges

Table 1 — Comparison between BLDC motor and brushed DC motor

Feature	BLDC Motor	Brushed DC Motor	Actual Advantage
Commutation	Electronic commutation based on rotor position information	Mechanical brushes and commutator	Electronic switches replace the mechanical devices
Efficiency	High	Moderate	Voltage drop on electronic device is smaller than that on brushes
Maintenance	Little/None	Periodic	No brushes/commutator maintenance.
Thermal performance	Better	Poor	Only the armature windings generate heat, which is the stator and is connected to the outside case of the BLDC.;The case dissipates heat better than a rotor located inside of brushed DC motor.
Output Power/ Frame Size (Ratio)	High	Moderate/Low	Modern permanent magnet and no rotor losses.
Speed/Torque Characteristics	Flat	Moderately flat	No brush friction to reduce useful torque.
Dynamic Response	Fast	Slow	Lower rotor inertia because of permanent magnets.
Speed Range	High	Low	No mechanical limitation imposed by brushes or commutator
Electric Noise	Low	High	No arcs from brushes to generate noise, causing EMI problems.
Lifetime	Long	Short	No brushes and commutator

The basic block diagram of BLDC Drive

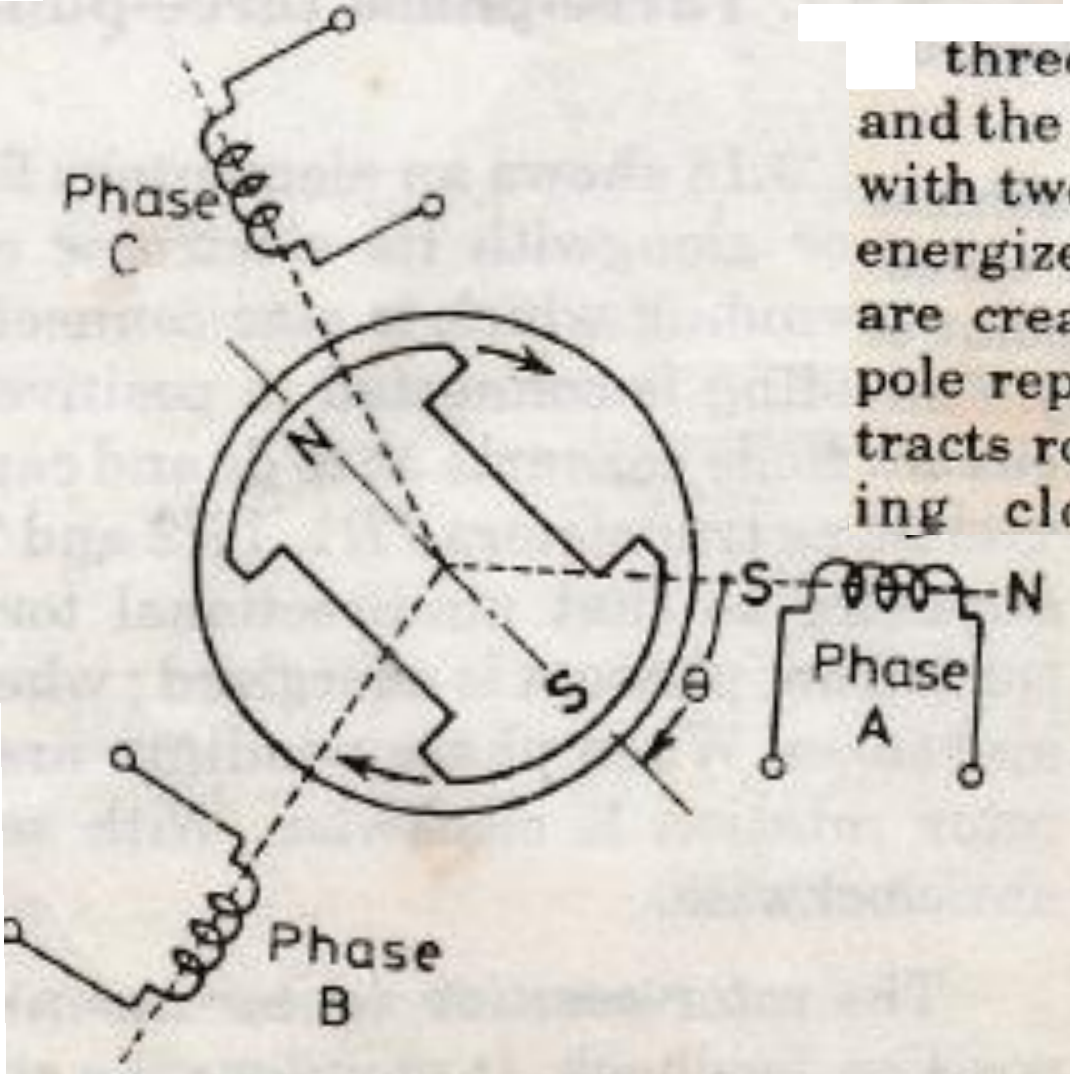




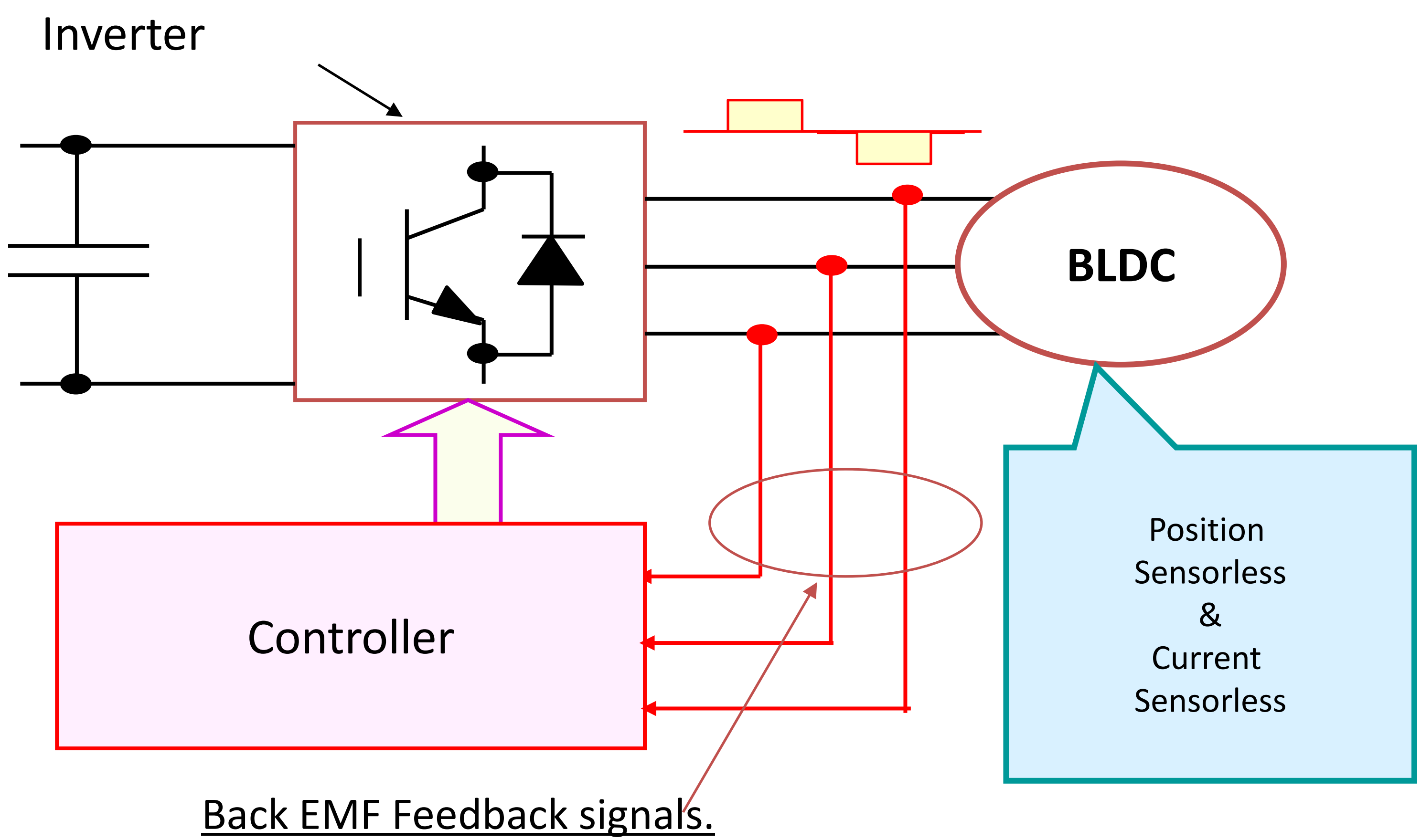
Three-phase three-pulse brushless *dc* motor.

Fig. shows an elementary form of 3-phase, 3-pulse brushless dc motor alongwith its electronic controller. The stator has three-phase winding which is star-connected. The neutral, or star, point of the winding is connected to positive terminal of the dc supply. Full-bridge diode converts ac to dc and capacitor C serves as a filter circuit. The three transistors $TR1$, $TR2$ and $TR3$ are turned on in appropriate sequence so that unidirectional torque is developed. When $TR1$ is turned on, phase A is energized; when $TR2$ is on, phase B is energized and so on. When phase windings are energized in sequence ABC, the rotor rotation is clockwise. With sequence ACB, the rotor revolves anticlockwise.

three-phase stator winding and the permanent-magnet rotor with two poles. When phase *A* is energized, stator *S* and *N* poles are created as shown. Stator *S* pole repells rotor *S* pole and attracts rotor *N* pole, thus producing clockwise torque.



An elementary form of brushless *dc* motor.


Inverter
BLDC
Controller
Position
Sensorless
&
Current
Sensorless
Back EMF Feedback signals.

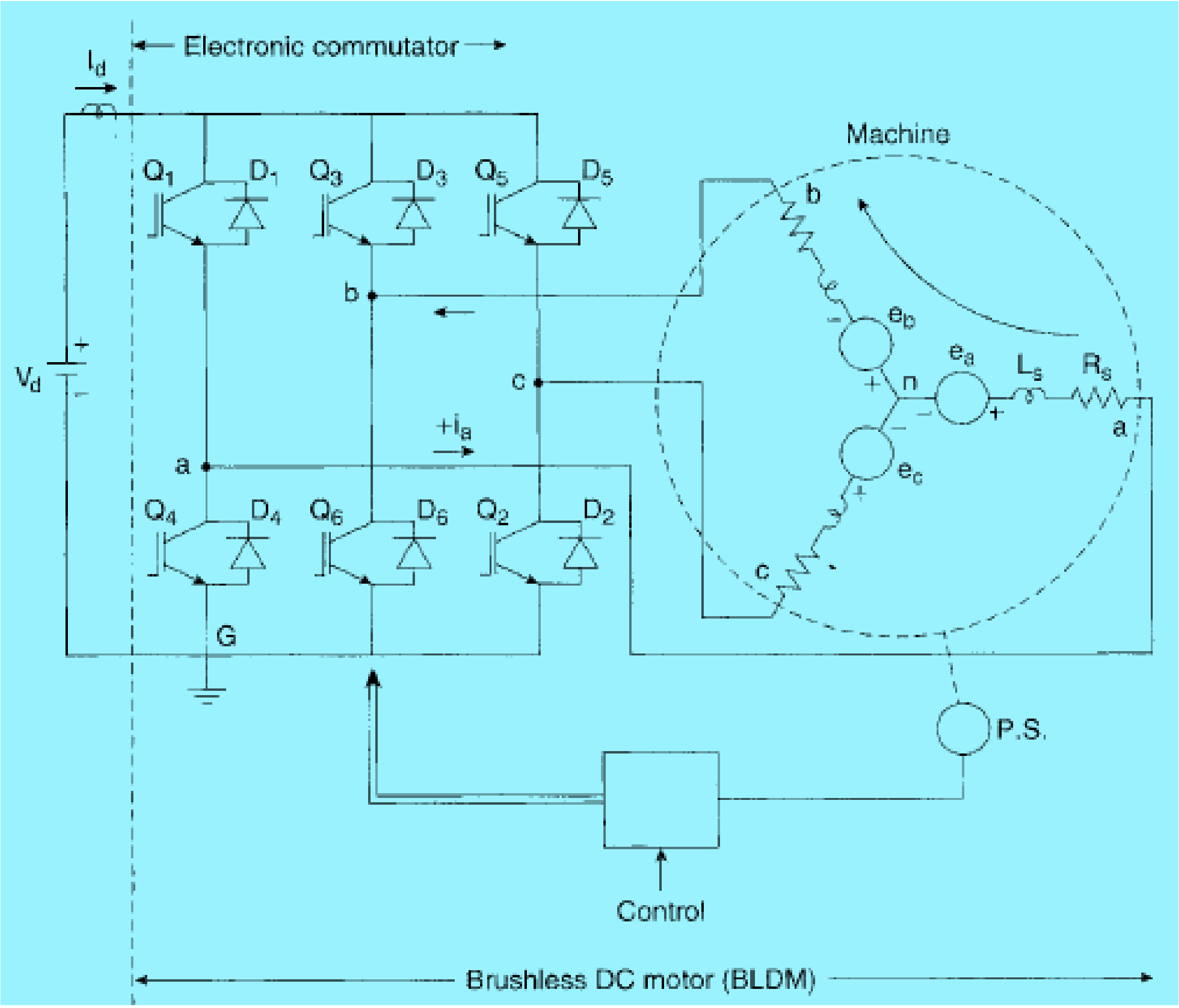
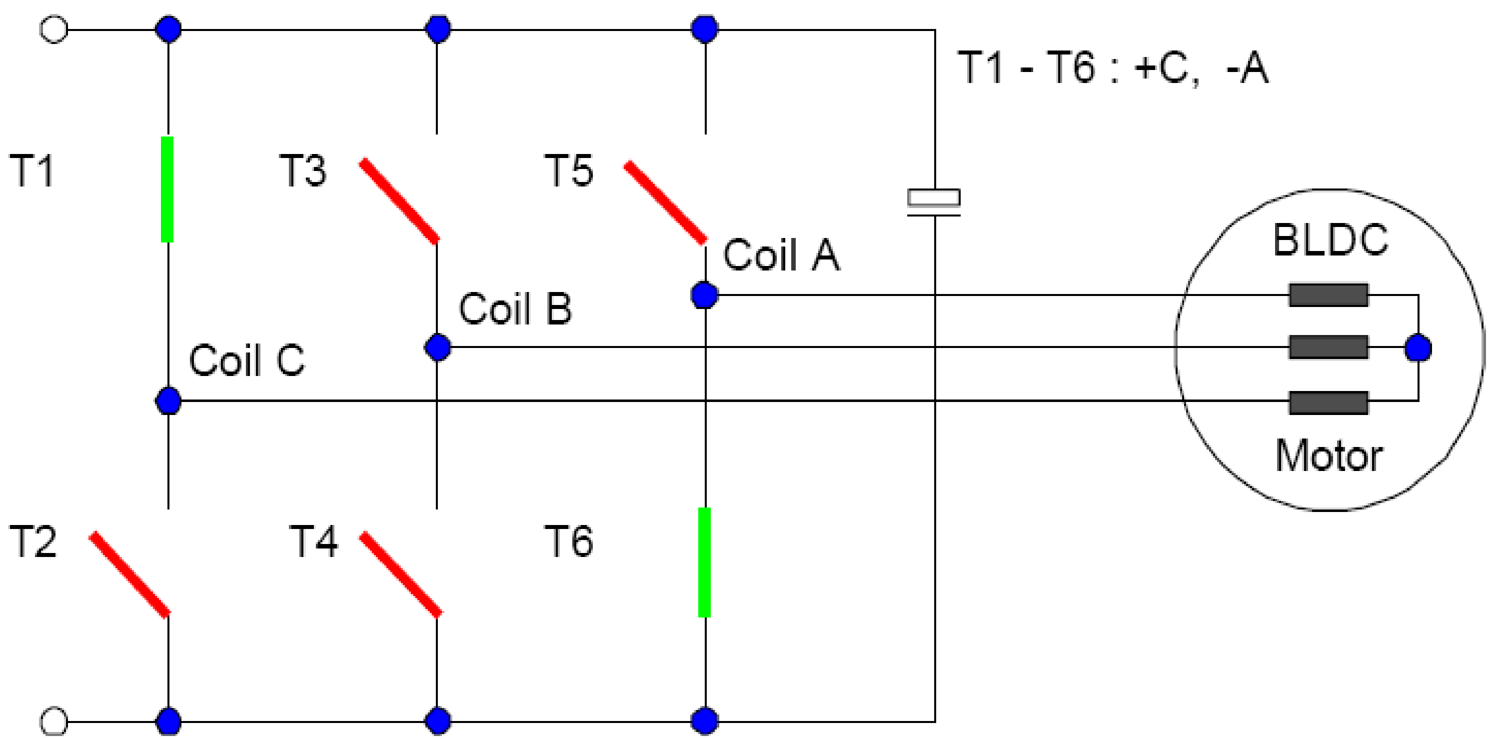


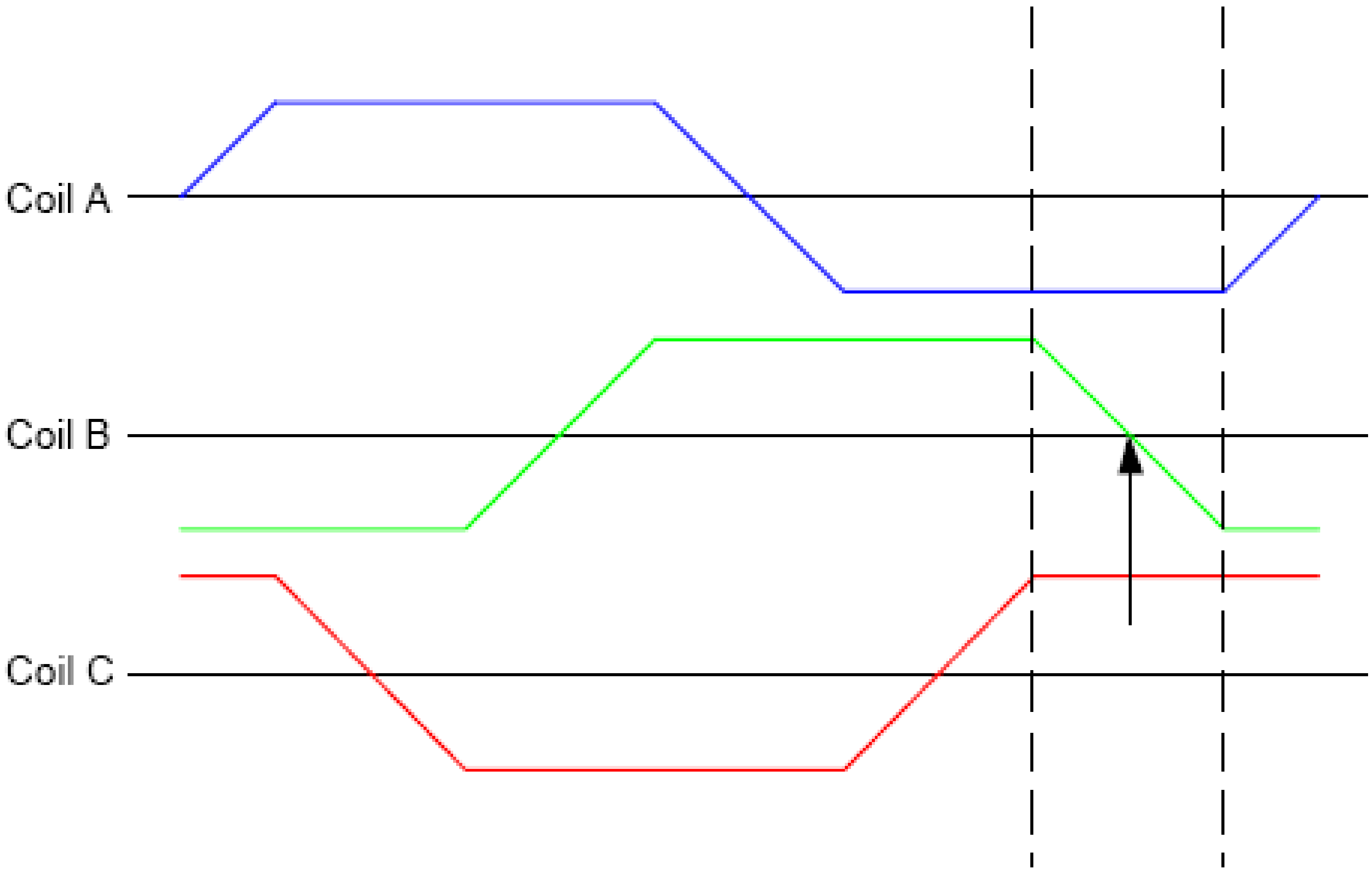
Fig. A Typical BLDC Motor Drive

Position ‘ 0° ’

The voltage-energizing coils C and A (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil B. The active switches of the B6 bridge.

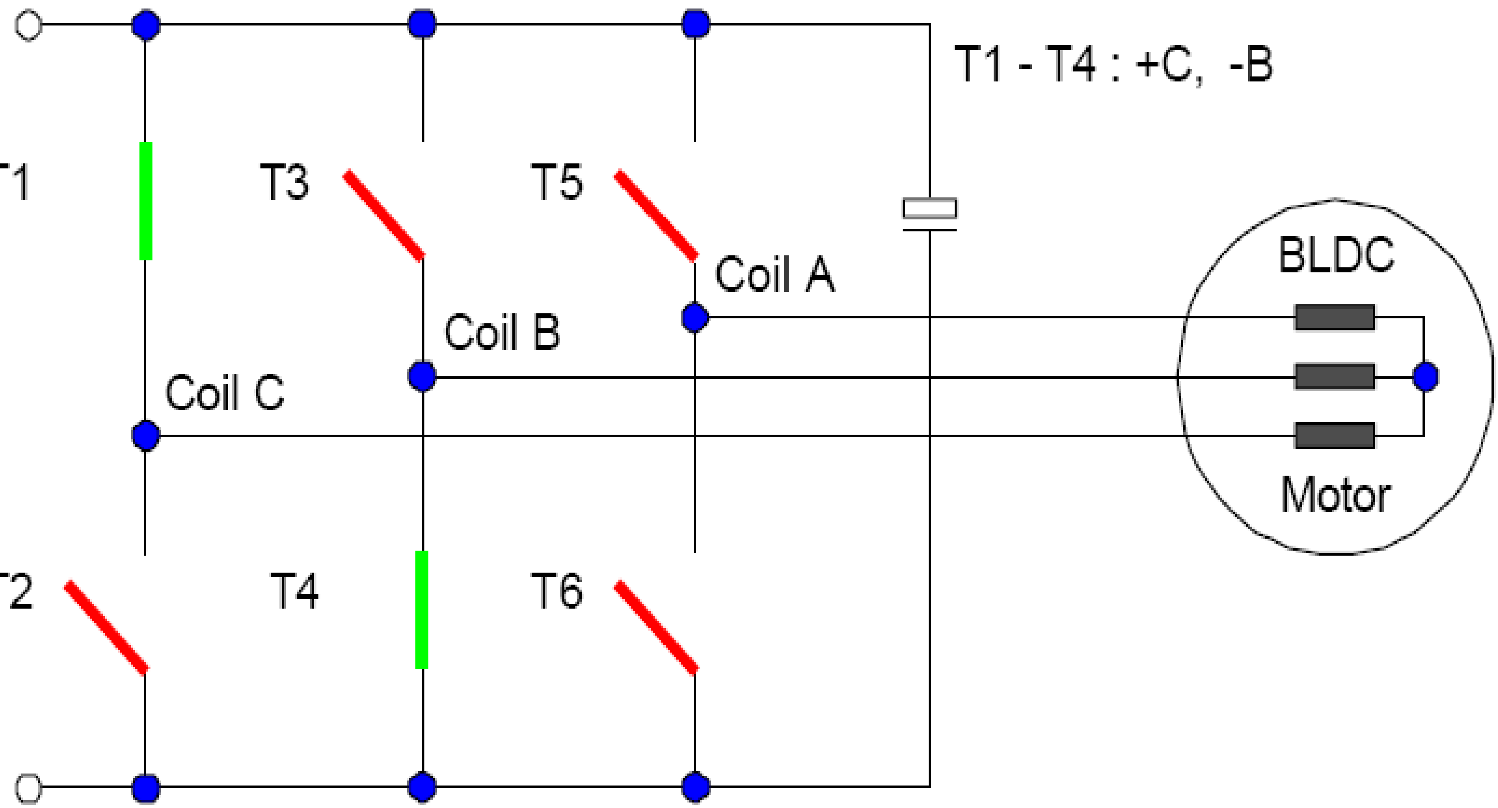


Appropriate switches T1, T6 of the B6 full-bridge (coil C : pos., coil A : neg.)

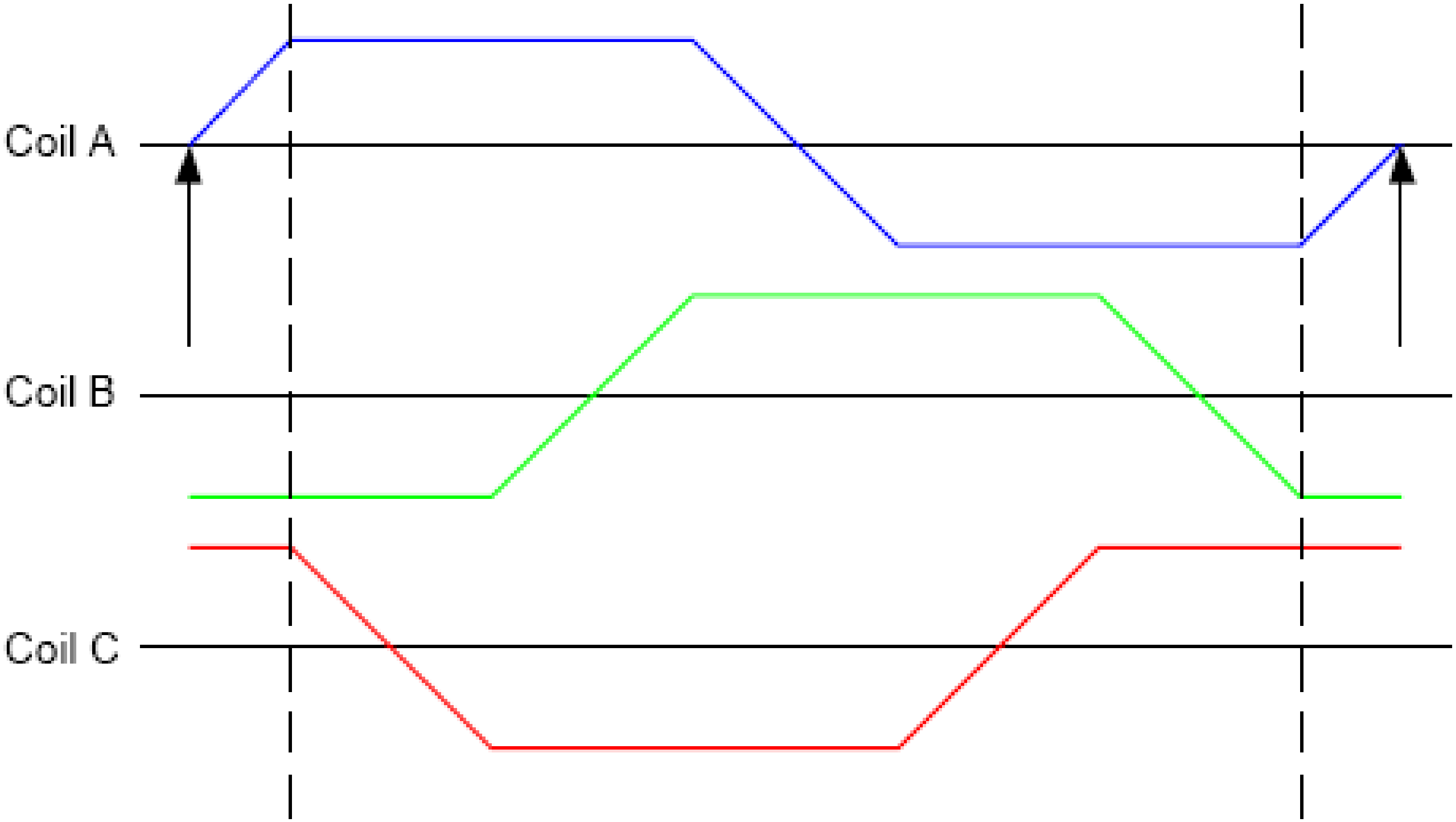

Coil A
Coil B
Coil C

Position ' 30° '

The voltage-energizing coils C and B (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil A. The active switches of the B6 bridge,.

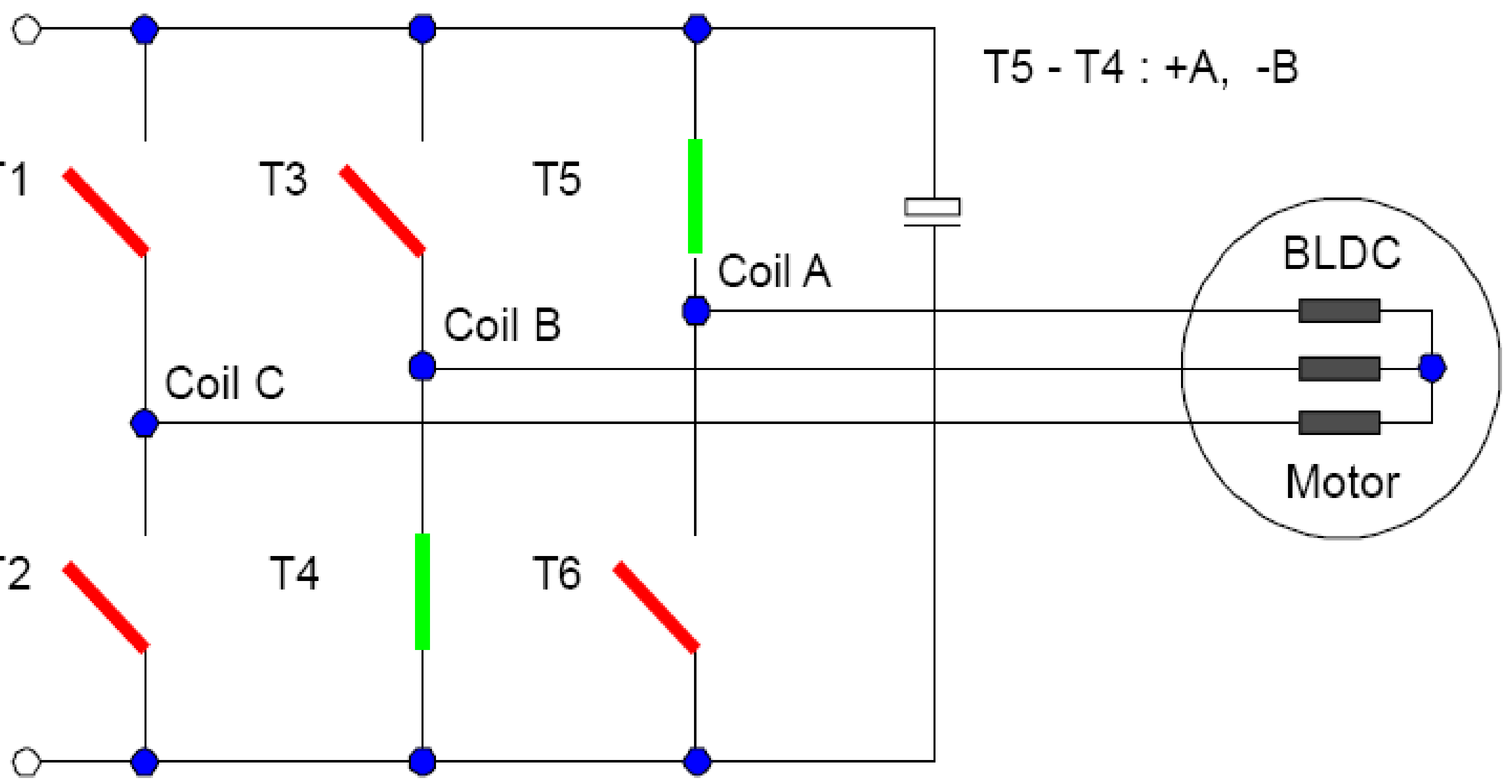


Appropriate switches T1, T4 of the B6 full-bridge (coil C : pos., coil B : neg.)

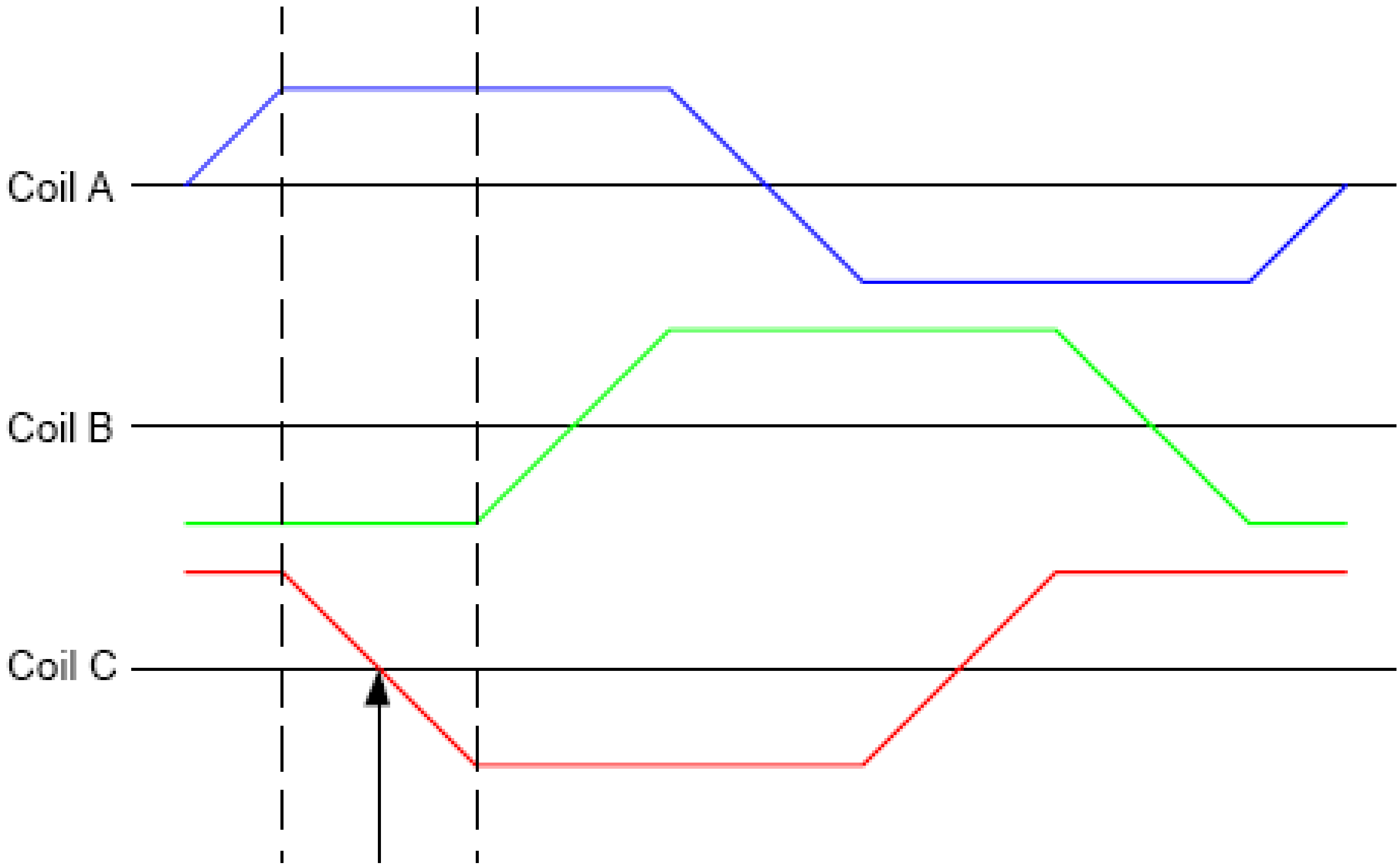

Coil A
Coil B
Coil C

Position ‘ 60° ’

The voltage-energizing coils C and B (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil C. The active switches of the B6 bridge.

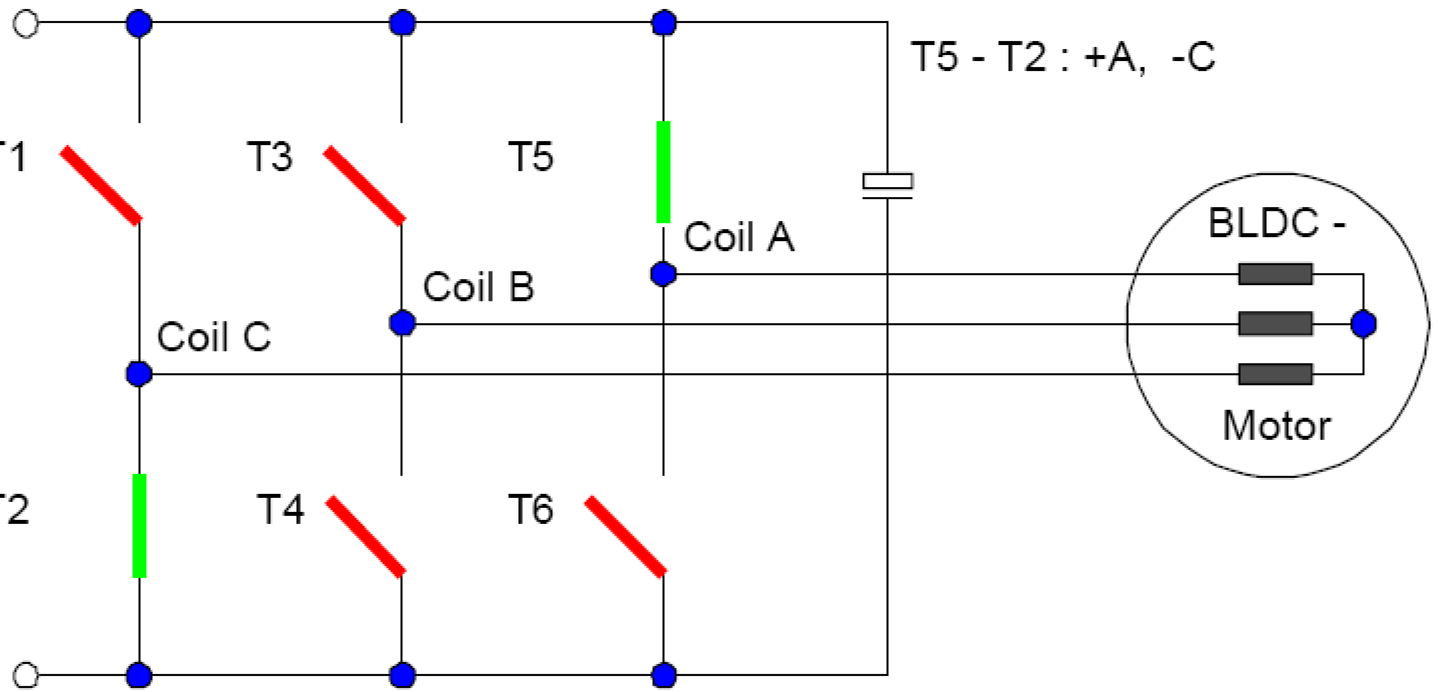


Appropriate switches T4, T5 of the B6 full-bridge (coil A : pos., coil B : neg.)

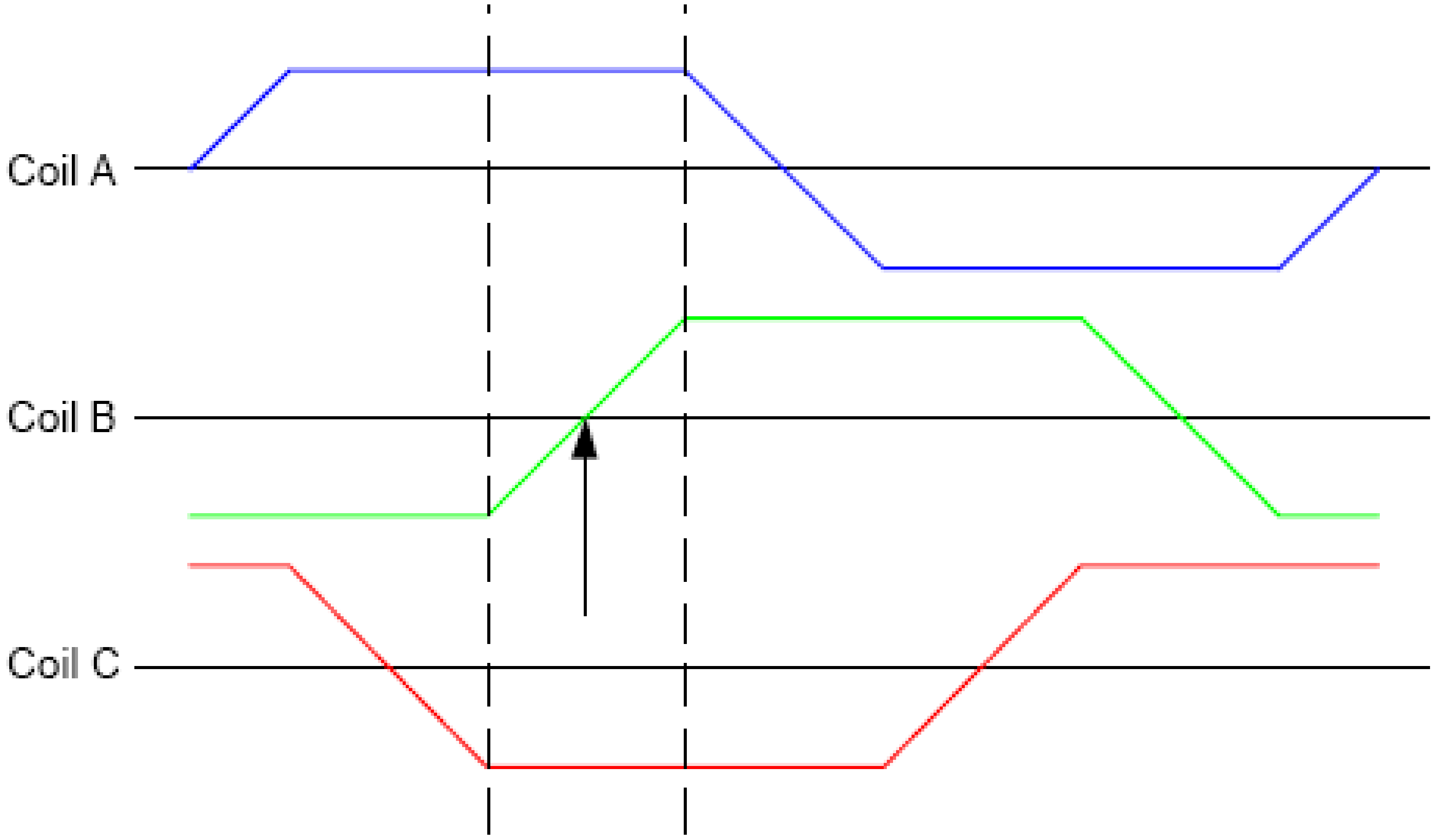

Coil A
Coil B
Coil C

Position ‘ 90° ’

The voltage-energizing coils A and C (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil B. The active switches of the B6 bridge.



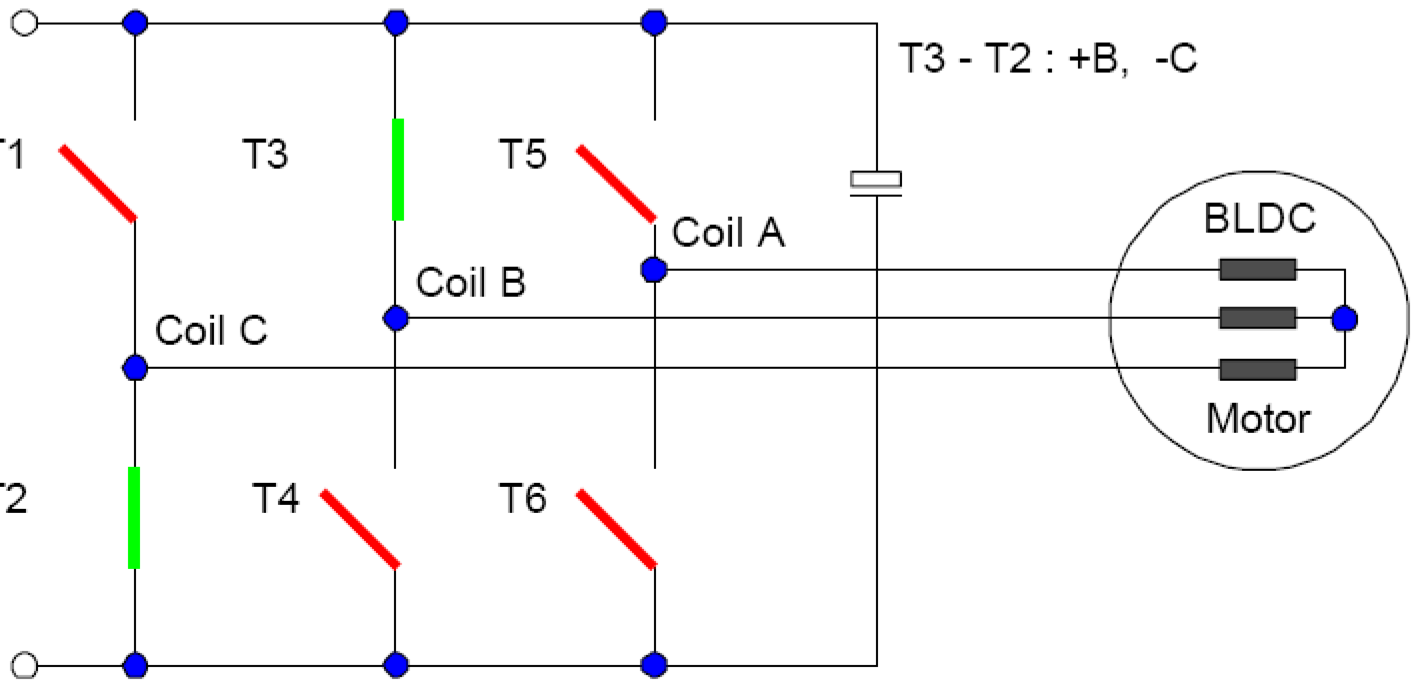
Appropriate switches T2, T5 of the B6 full-bridge (coil A : pos., coil C : neg.)



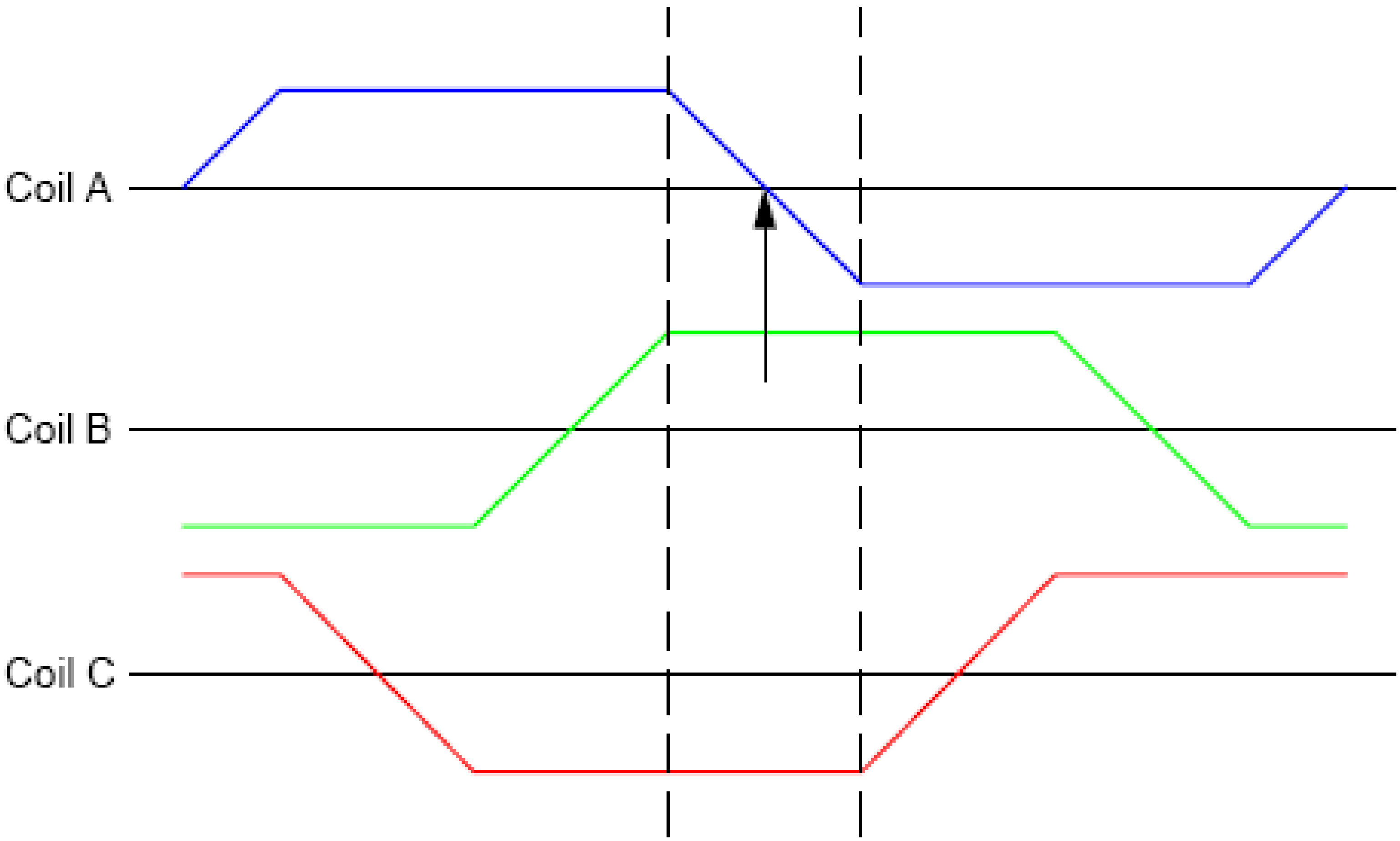
Coil A
Coil B
Coil C

Position ' 120° '

The voltage-energizing coils B and C (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil A. The active switches of the B6 bridge.

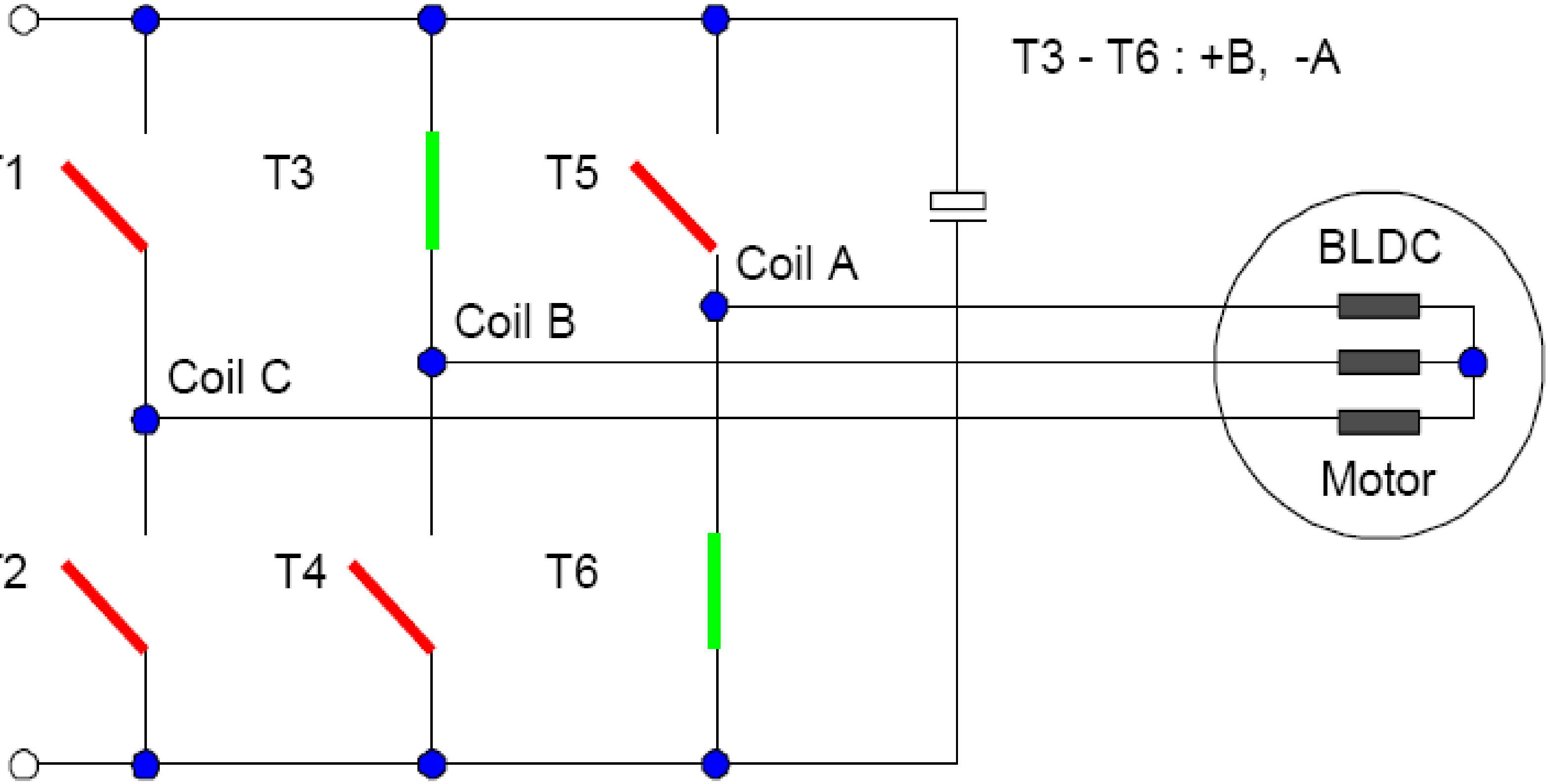


igure 12: Appropriate switches T2, T3 of the B6 full-bridge (coil B : pos., coil C : neg.)

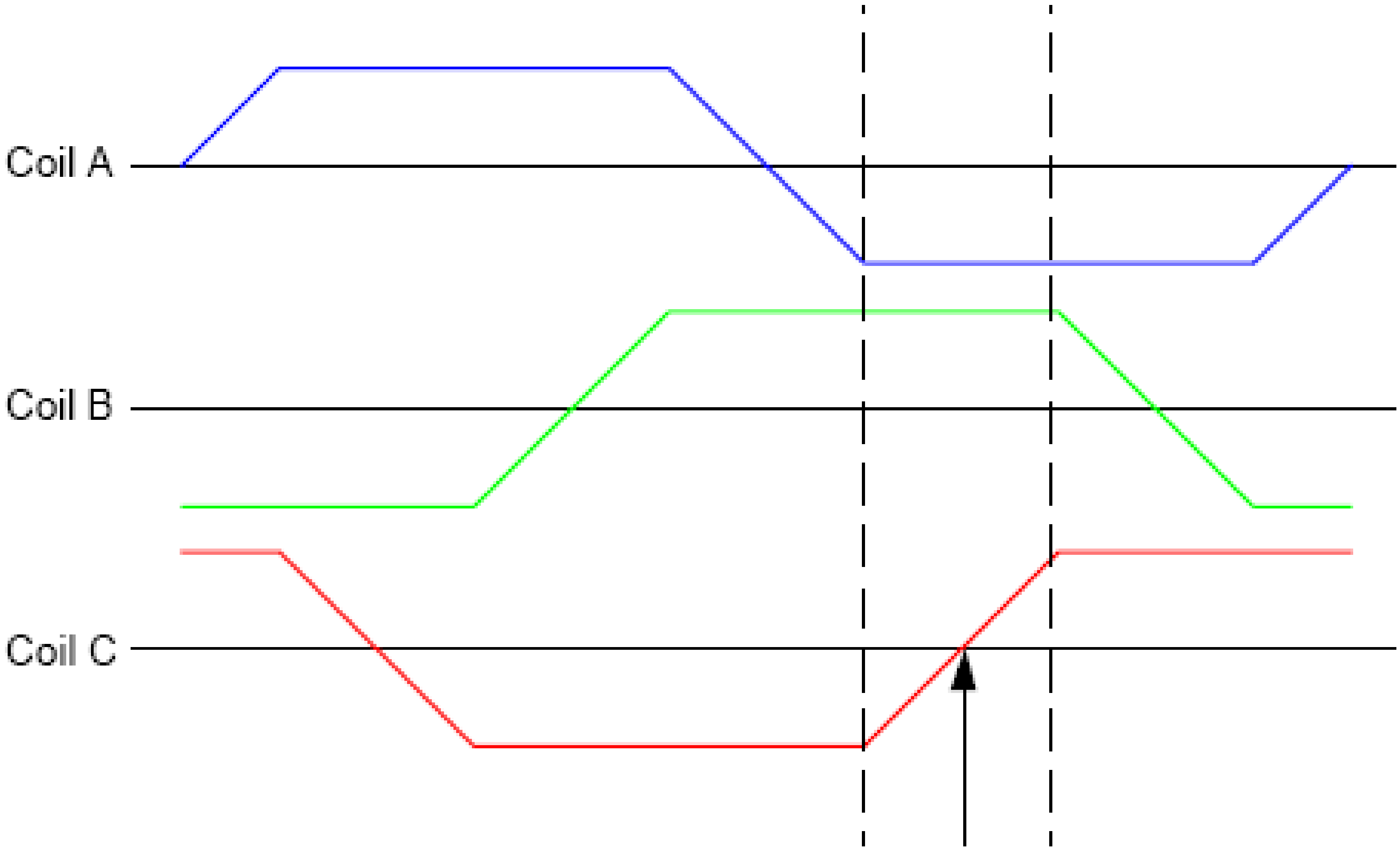

Coil A
Coil B
Coil C

Position ‘ 150° ’

The voltage-energizing coils B and A (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil C. The active switches of the B6 bridge.

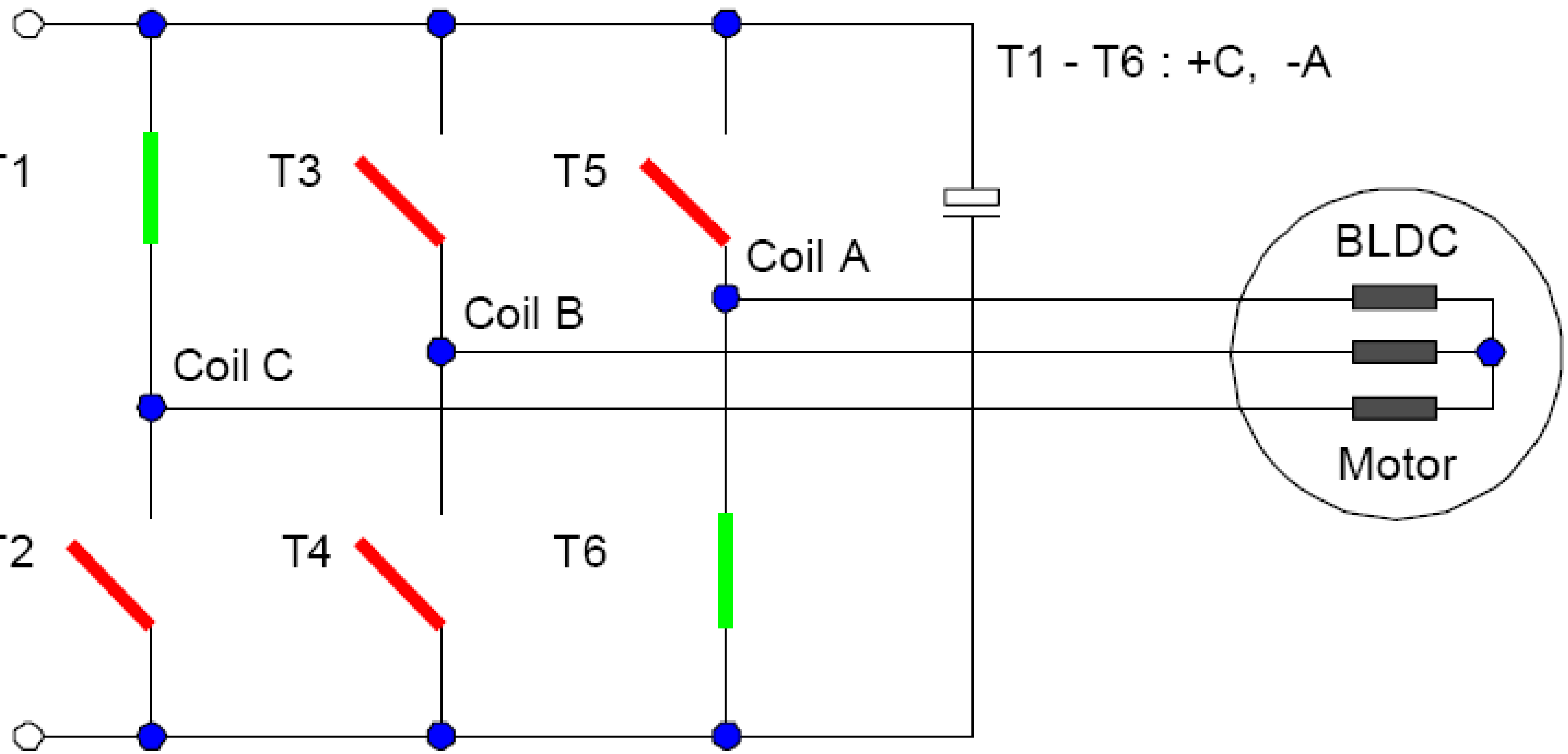


Appropriate switches T3, T6 of the B6 full-bridge (coil B : pos., coil A : neg.)

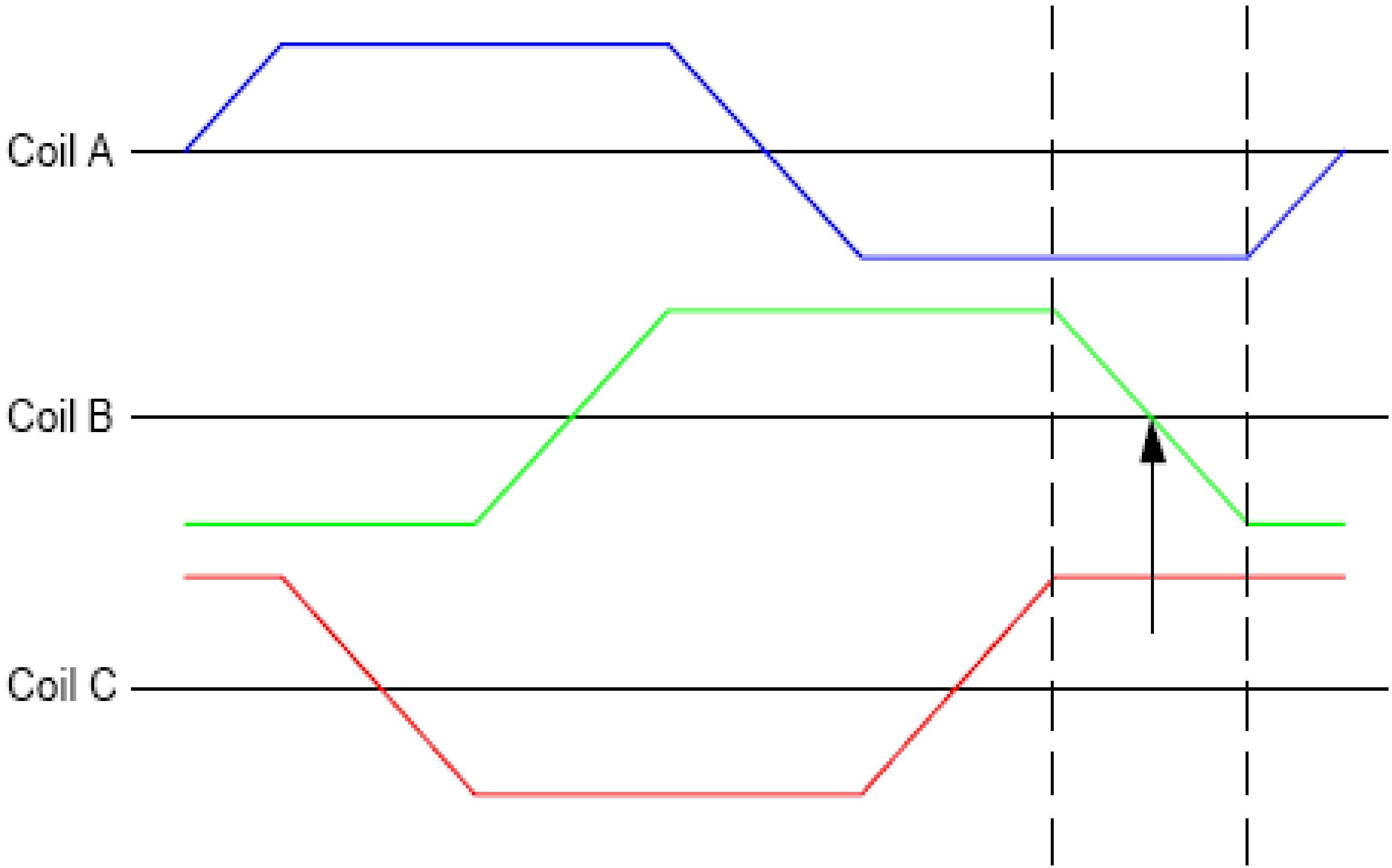

Coil A
Coil B
Coil C

Position ‘ 180° ’

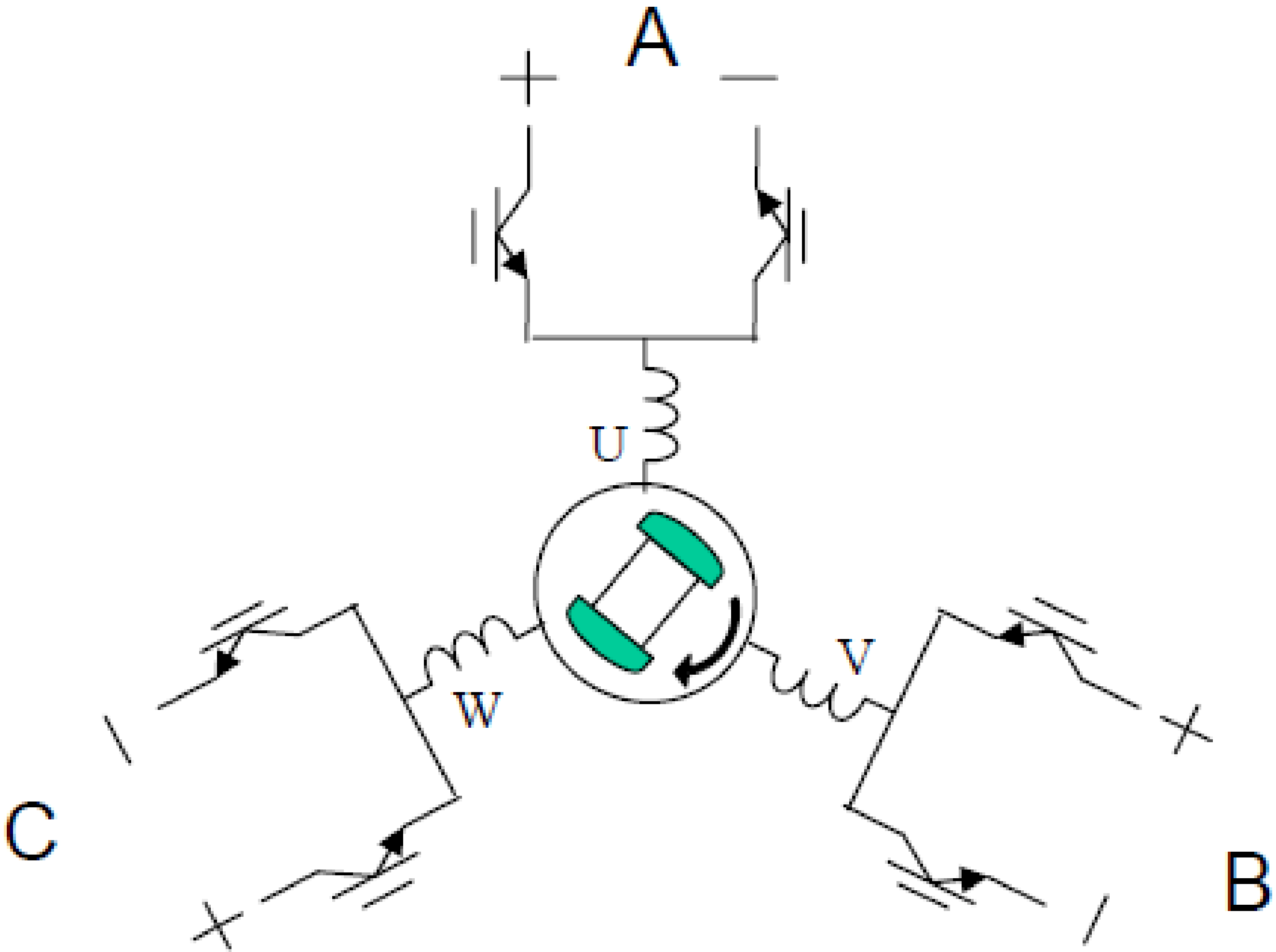
The voltage-energizing coils C and A (stator) and the permanent magnet realized with two pole pairs (rotor), as well as indicating the zero-crossing detection coil B. The active switches of the B6 bridge.

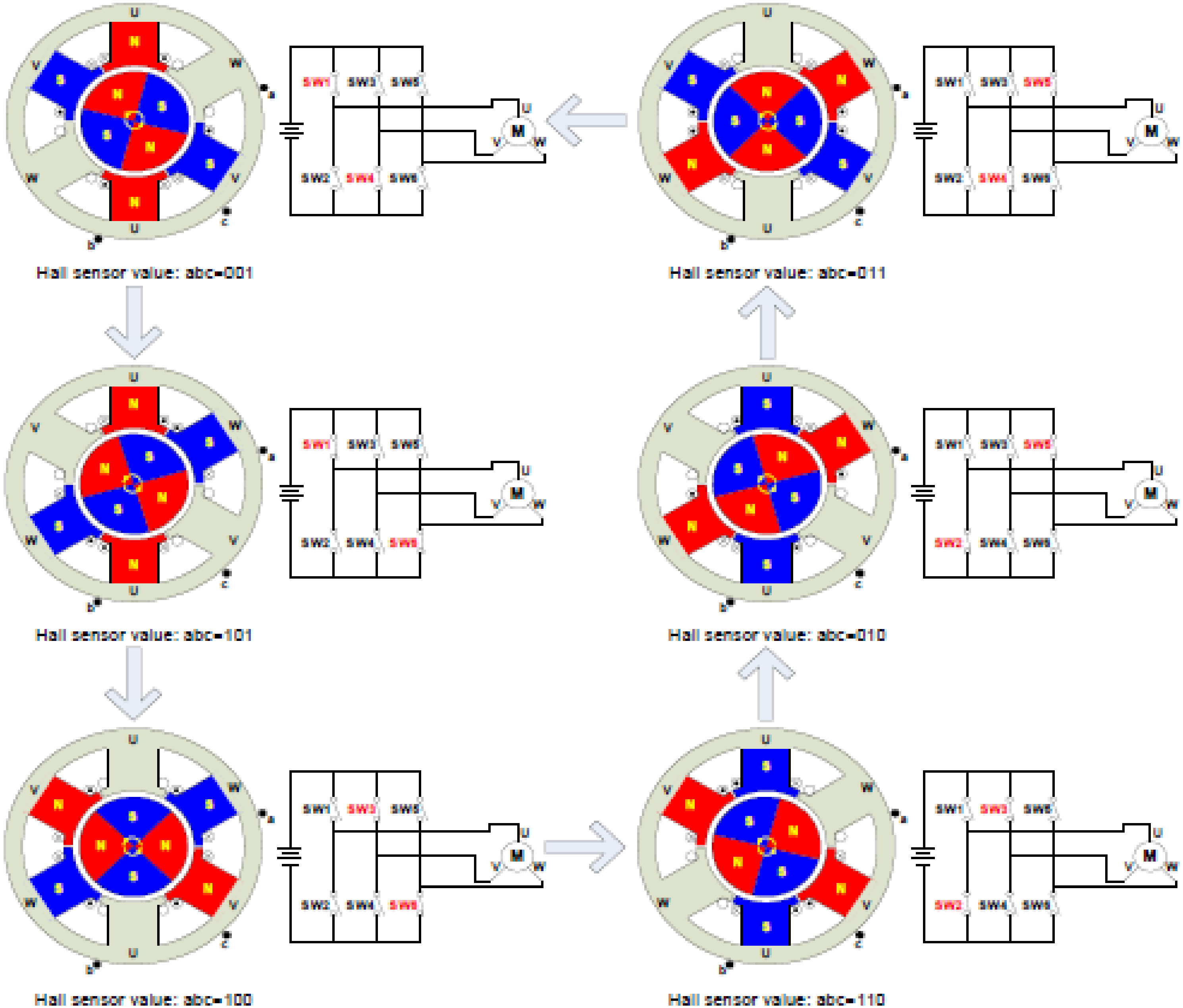


Appropriate switches T1, T6 of the B6 full-bridge (coil C : pos., coil A : neg.)


Coil A
Coil B
Coil C

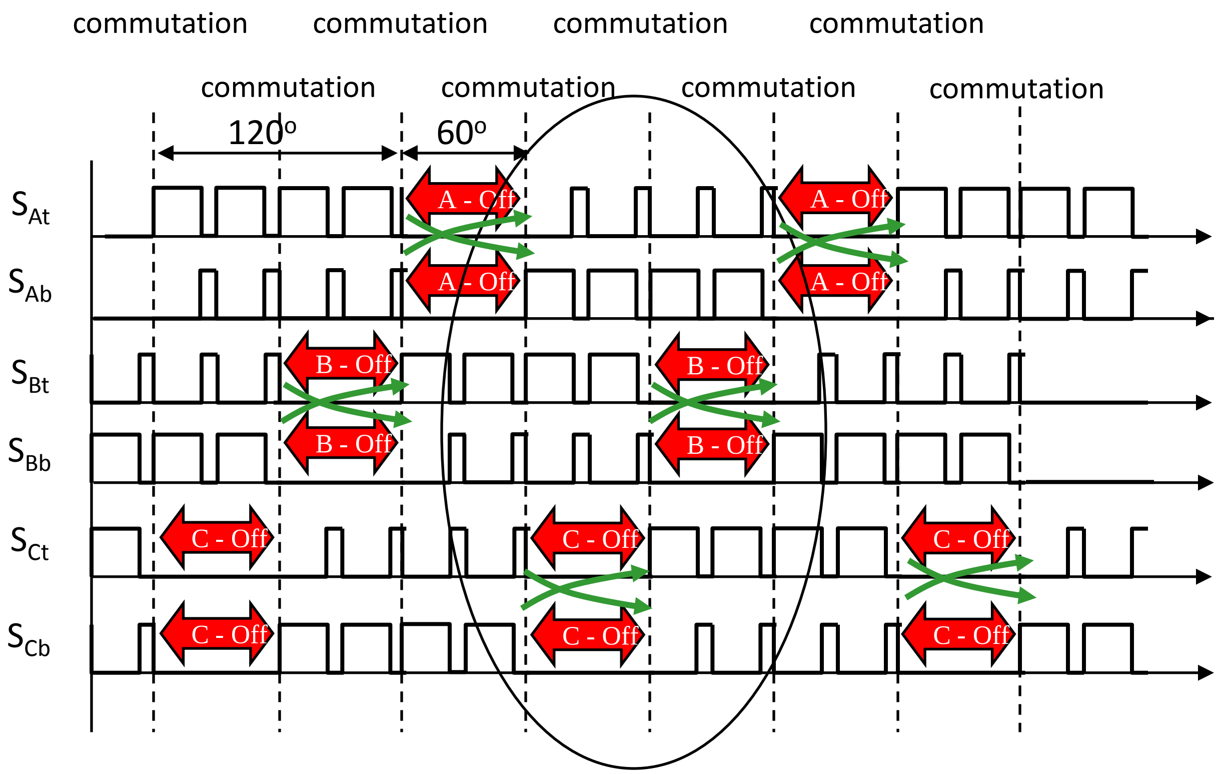
Equivalent circuit : Y connected BLDC Motor and power Converter

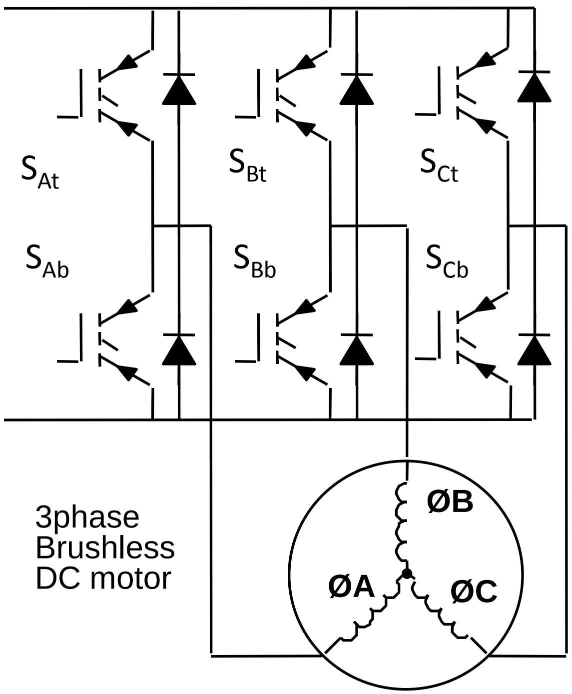



Hall sensor value: abc=001
Hall sensor value: abc=011
Hall sensor value: abc=101
Hall sensor value: abc=010
Hall sensor value: abc=100
Hall sensor value: abc=110
SW1
SW2
SW3
SW4
SW5
SW6
M
U
V
W

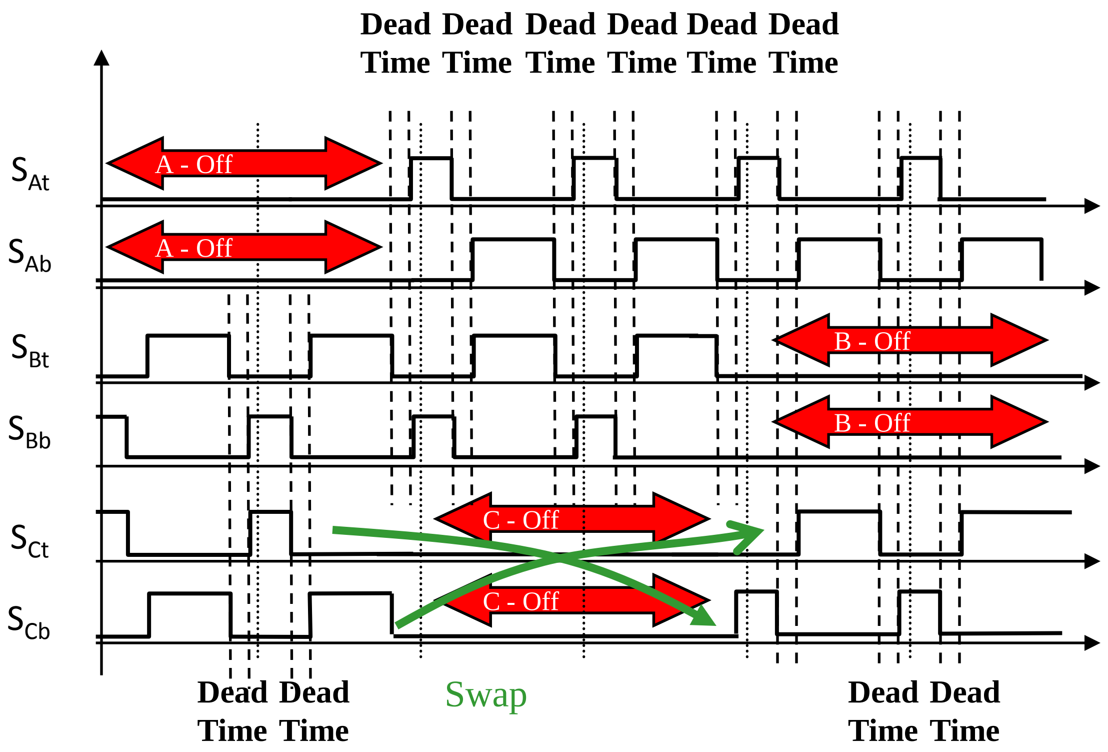
Bipolar BLDC Commutation
(PWM pairs)

- Requires sophisticated PWM support





Bipolar BLDC Commutation (Complementary PWMs) Detail



Torque Equation

$$T_e = K_1 \phi_s \phi_r \sin\theta$$

where ϕ_s = stator field flux

ϕ_r = rotor field flux

θ = torque angle

and K_1 = torque constant.

$$T_{ea} = KI_a \sin\theta$$

where I_a is the constant stator current in phase A.

$$T_{ea} = K\, i_a \sin\theta$$

$$T_{eb} = K\, i_b \sin(\theta - 120°)$$

$$T_{ec} = K\, i_c \sin(\theta - 240°)$$

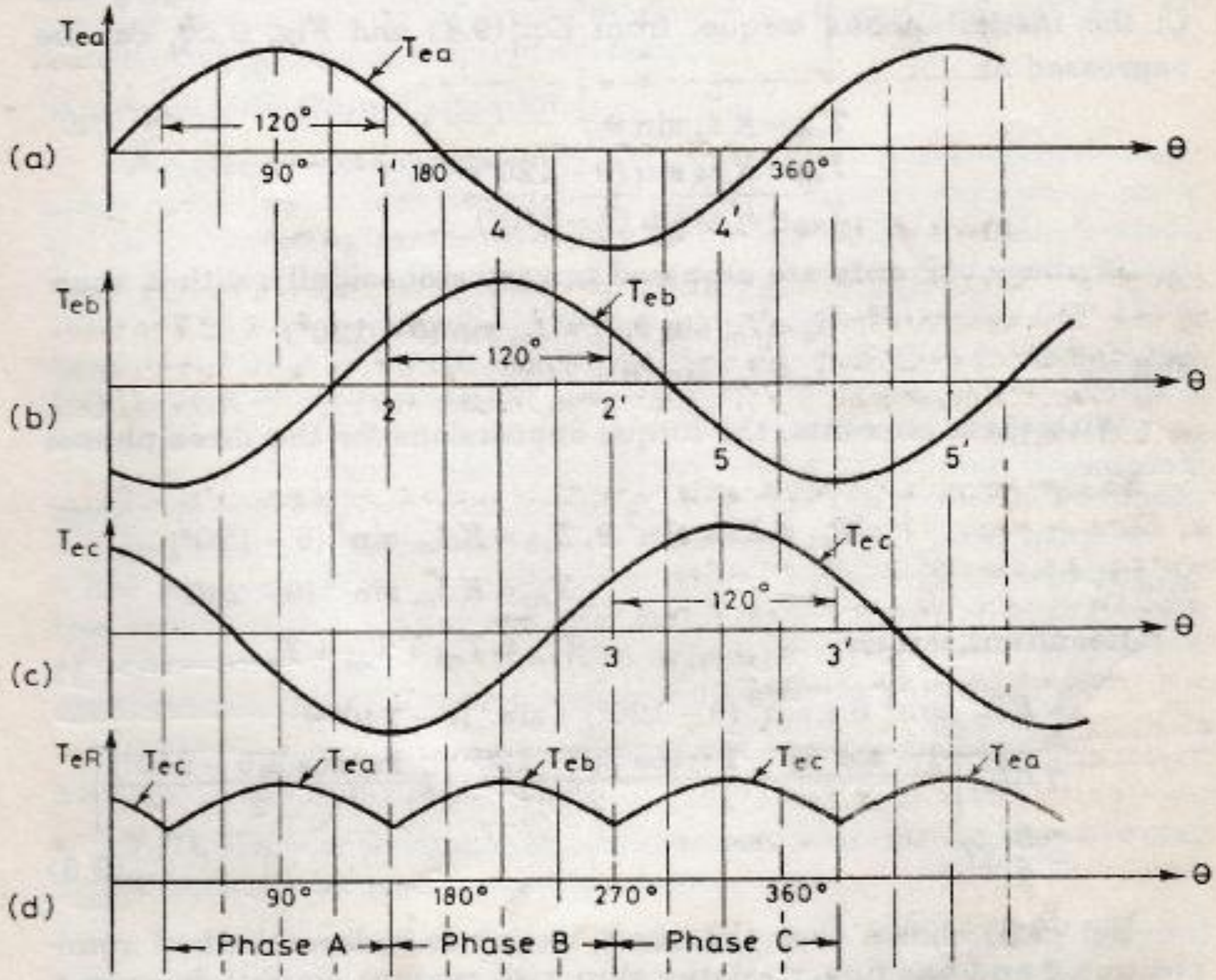


Fig. 9.20. Static torque-angle characteristics for a brushless *dc* motor.

If phase currents are assumed to vary sinusoidally with θ, then

$$i_a = I_m \sin\theta,\ i_b = I_m \sin(\theta - 120°)$$

and

$$i_c = I_m \sin(\theta - 240°)$$

With these currents, the torque expressions for the three phases become,

$$T_{ea} = KI_m \sin^2\theta,\ T_{eb} = K I_m \sin^2(\theta - 120°)$$

and

$$T_{ec} = K I_m \sin^2(\theta - 240°)$$

Resultant torque, $T_{eR} = T_{ea} + T_{eb} + T_{ec}$

$$= KI_m [\sin^2\theta + \sin^2(\theta - 120°) + \sin^2(\theta - 240°)]$$

$$= KI_m \left[\frac{1 - \cos 2\theta}{2} + \frac{1 - \cos 2(\theta - 120°)}{2} + \frac{1 - \cos 2(\theta - 240°)}{2}\right]$$

$$= \frac{3}{2} KI_m$$

Brushless dc motors are therefore, able to display a wide variety of operating characteristics. As these characteristics can be controlled easily and the price of power electronics controllers are falling sharply brushless DC motors find increasing applications. in drives previously dominated by conventional dc motors.

Typical applications

Turn-table drives for record players, hard-disc drives for computers, low-cost instruments, small fans for cooling electronics equipment etc.

Brushless dc motors of somewhat higher ratings find applications in aircraft and satellite systems.

In future as a power ratings of these motors rise, these may perhaps be considered for use in traction systems.

Switched Reluctance Motor

Construction

The switched reluctance motor is a doubly-salient, singly-excited motor"

This means that it has salient poles on both the rotor and the stator, but only one member (usually the stator) carries windings.

The rotor has no windings, magnets, or cage winding, but is built up from a stack of salient-pole laminations, There are two essentials that distinguish the SR motor from the variable-reluctance stepper.

One is that the conduction angle for phase currents is controlled and synchronized with the rotor position, usually by means of a shaft position sensor. In this respect the SR motor is exactly like the PM brushless d.c. motor,

But unlike the stepper motor, which is usually fed with a squarewave of phase current without rotor position feedback.

•The stator is made up of silicon steel stampings with inward projected poles.

•The number of poles of the stator can be either an even number or an odd number.

•Most of the motors available have even number of stator poles (6 or 8). All these poles carry field coils.

•The field coils of opposite poles are connected in series such that their mmf's are additive and they are called phase windings.

Individual coil or a group of coils constitute phase windings.

Each of the phase windings are connected to the terminal of the motor.

These terminals are suitably connected to the output terminals of a power semiconductor switching circuitry, whose input is a d.c. supply.

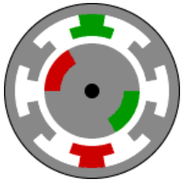
The rotor is also made up of silicon steel stampings with outward projected poles.

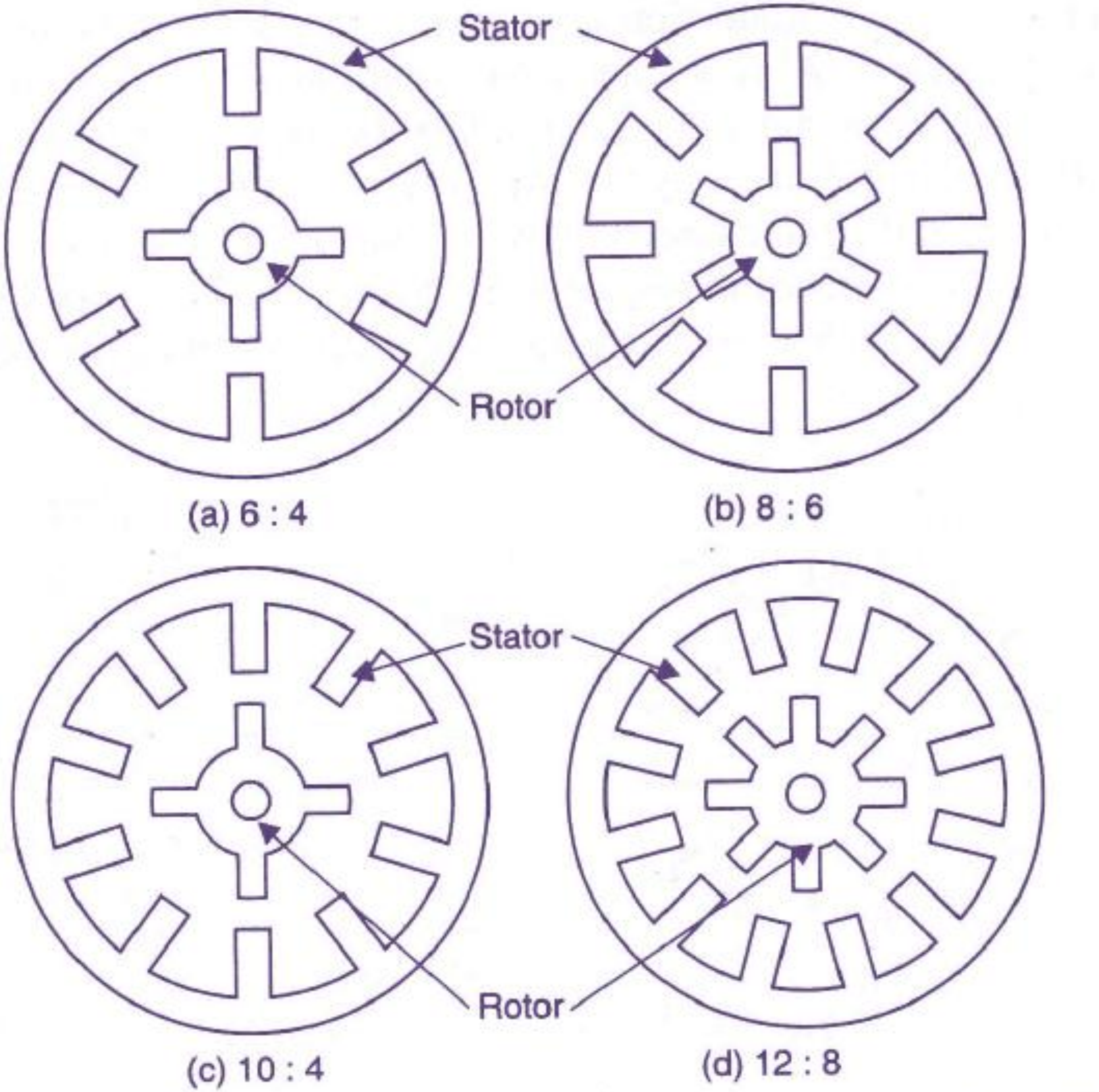
Number of poles of rotor is different from the number of poles of the stator.

In most of the available motors the number of poles of the rotor is 4 or 6 depending upon the number of stator poles 6 or 8.

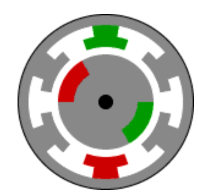
The rotor shaft carries a position sensor.

The turning ON and turning OFF operation of the various devices of the power semiconductor circuitry are influenced by the signals obtained from the rotor position sensor.



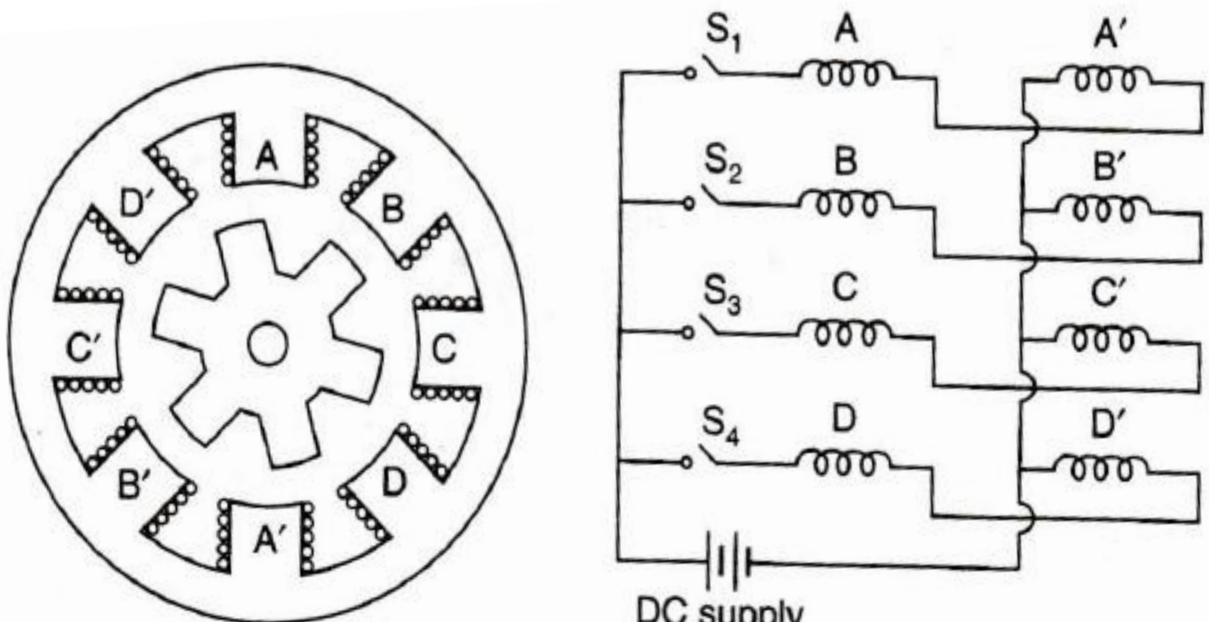


Different configurations of SRM with stator to rotor pole ratios

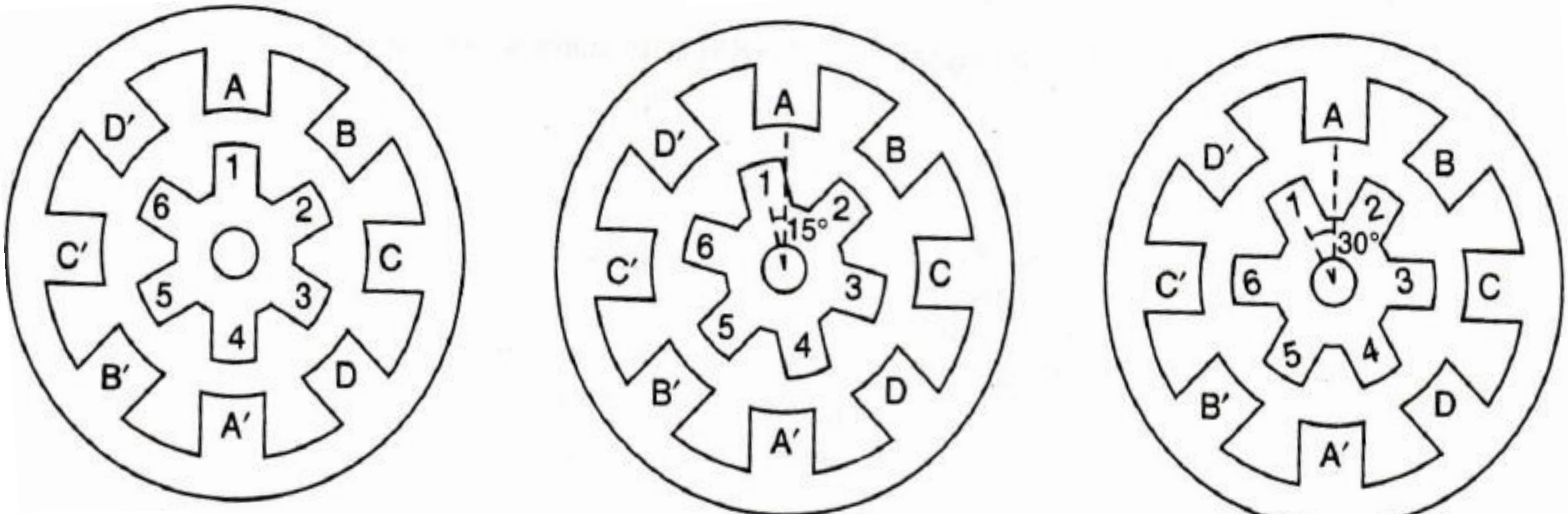


Principle of Operation

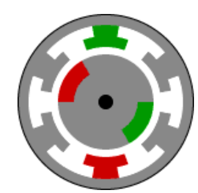
Consider an SRM with eight stator poles and six rotor teeth. It has four-phases. A–A′, B–B′, C–C′, D–D′. These phases can be excited by DC supply through switches S_1, S_2, S_3 and S_4



Four-phase, eight-pole SRM



Phase A excited Phase B excited Phase C excited



SRM has no windings on its rotor. Its only source of excitation consists of stator windings.

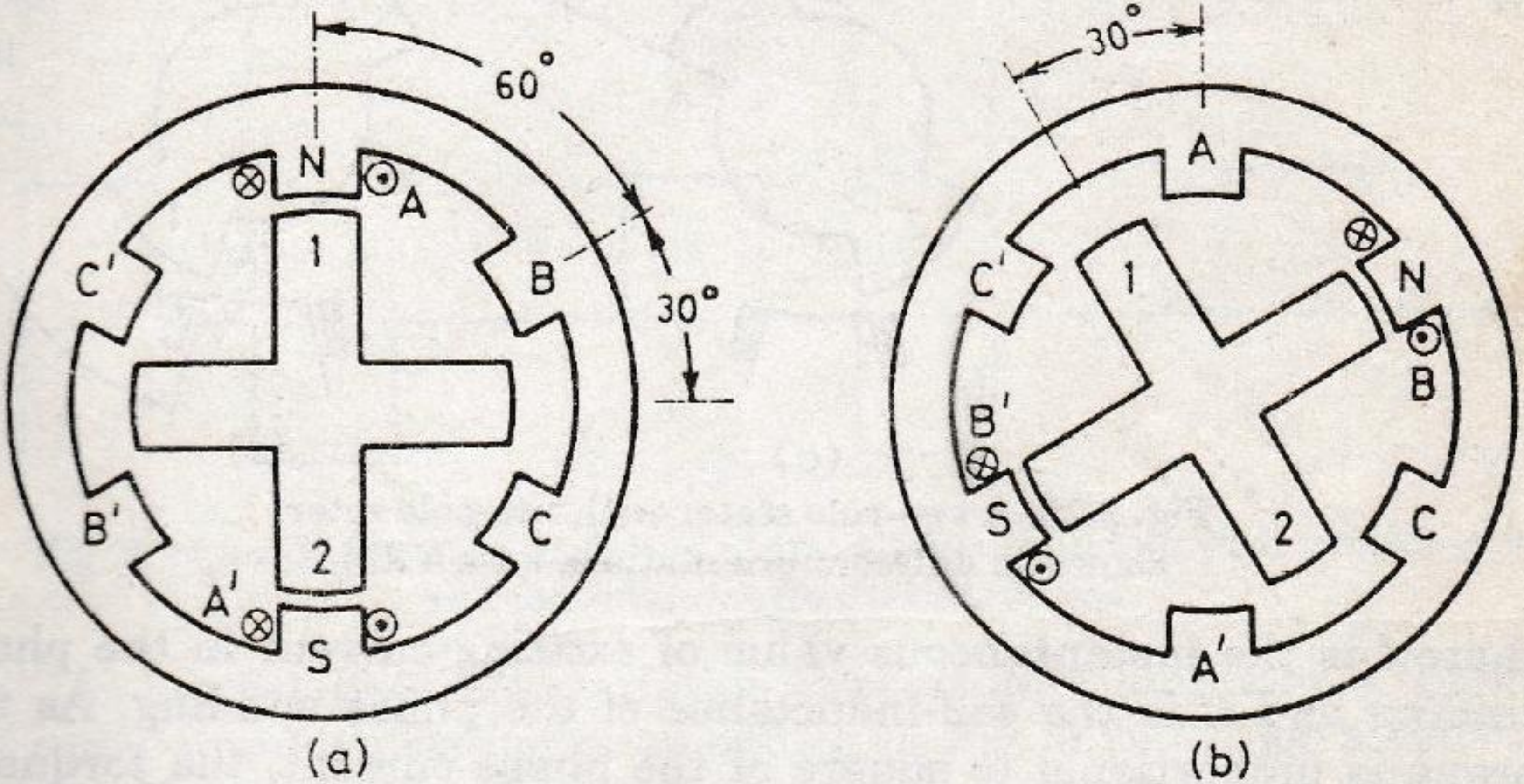
This is an important feature as it requires that all the resistive winding losses occur on the stator.

This makes the cooling easy and more effective. This results in smaller motor for a given rating and frame size.

To produce torque, SRM should be designed in such a way that the stator winding inductance vary with the position of rotor teeth.

Double saliency of the motor satisfies this requirement.

The inductance of the stator winding varies with rotor position such that the inductance is maximum when the rotor axis is aligned with the magnetic axis of that phase and minimum when the two axes are perpendicular.

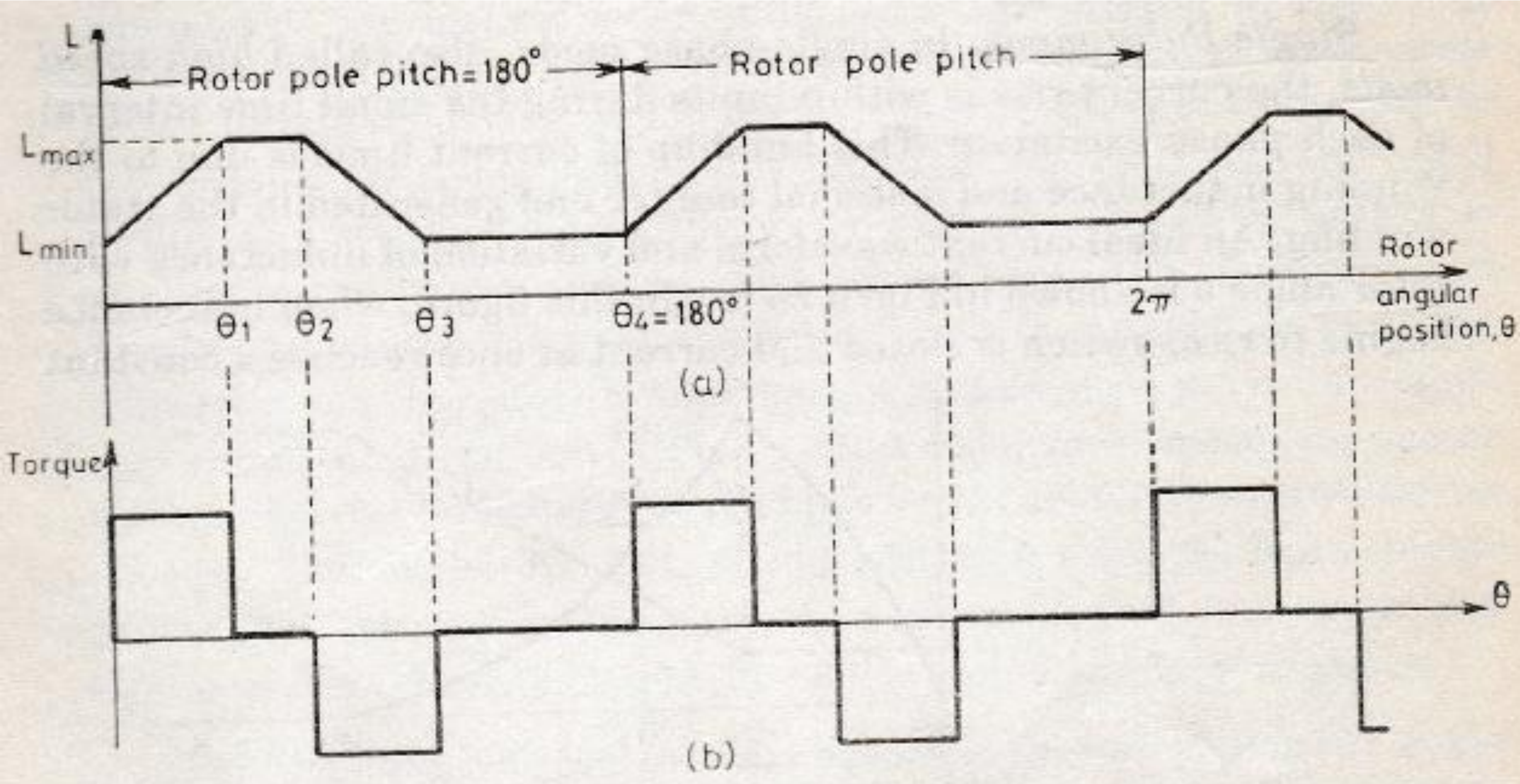


Three-phase 6/4 VRM.

Torque Production

Under the assumption of magnetic linearity, the reluctance torque* developed in SRM is given by

$$T_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$$



(*a*) Inductance variation of stator phase winding with respect to θ and (*b*) torque-angle characteristics.

Operating Modes

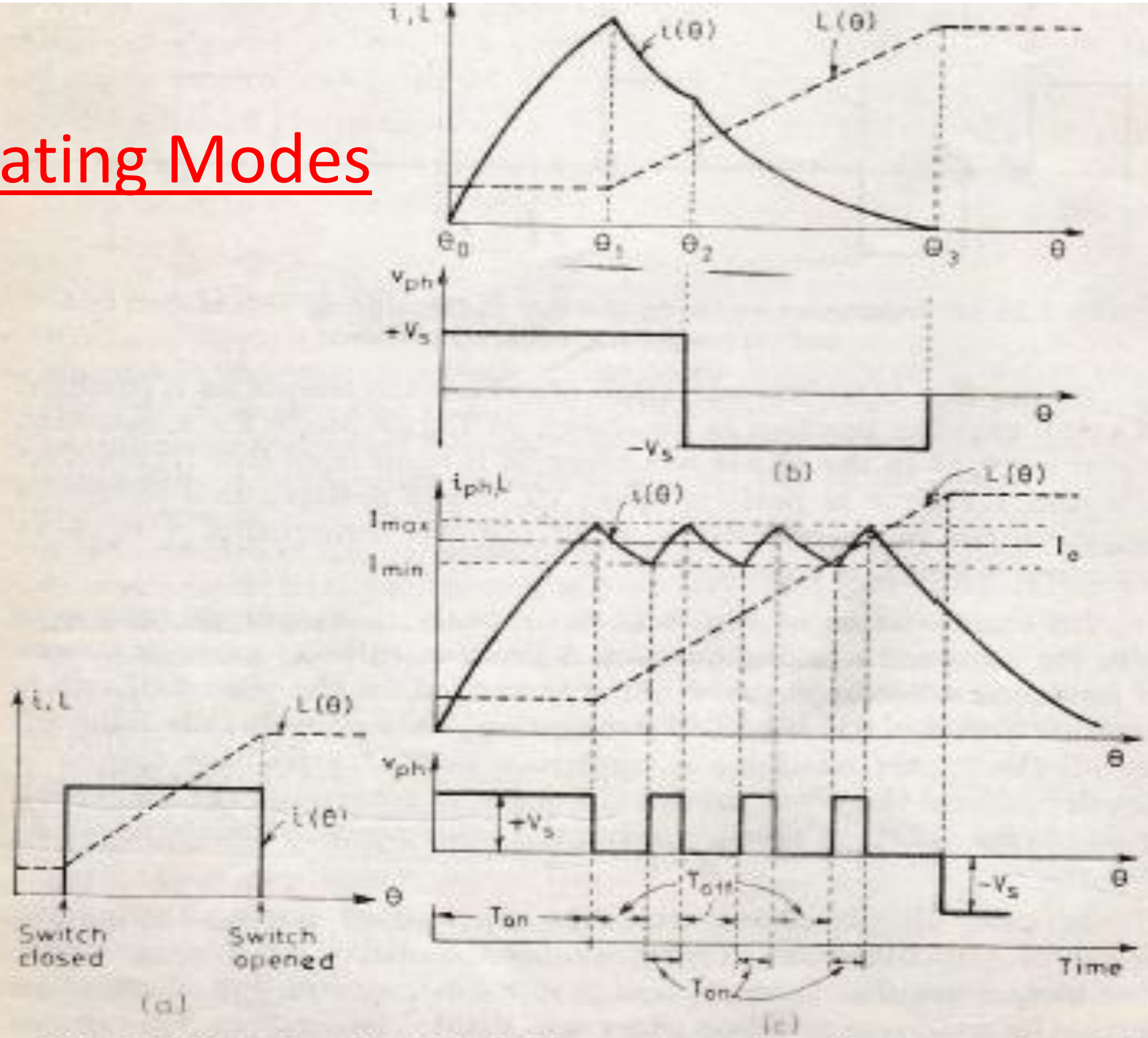
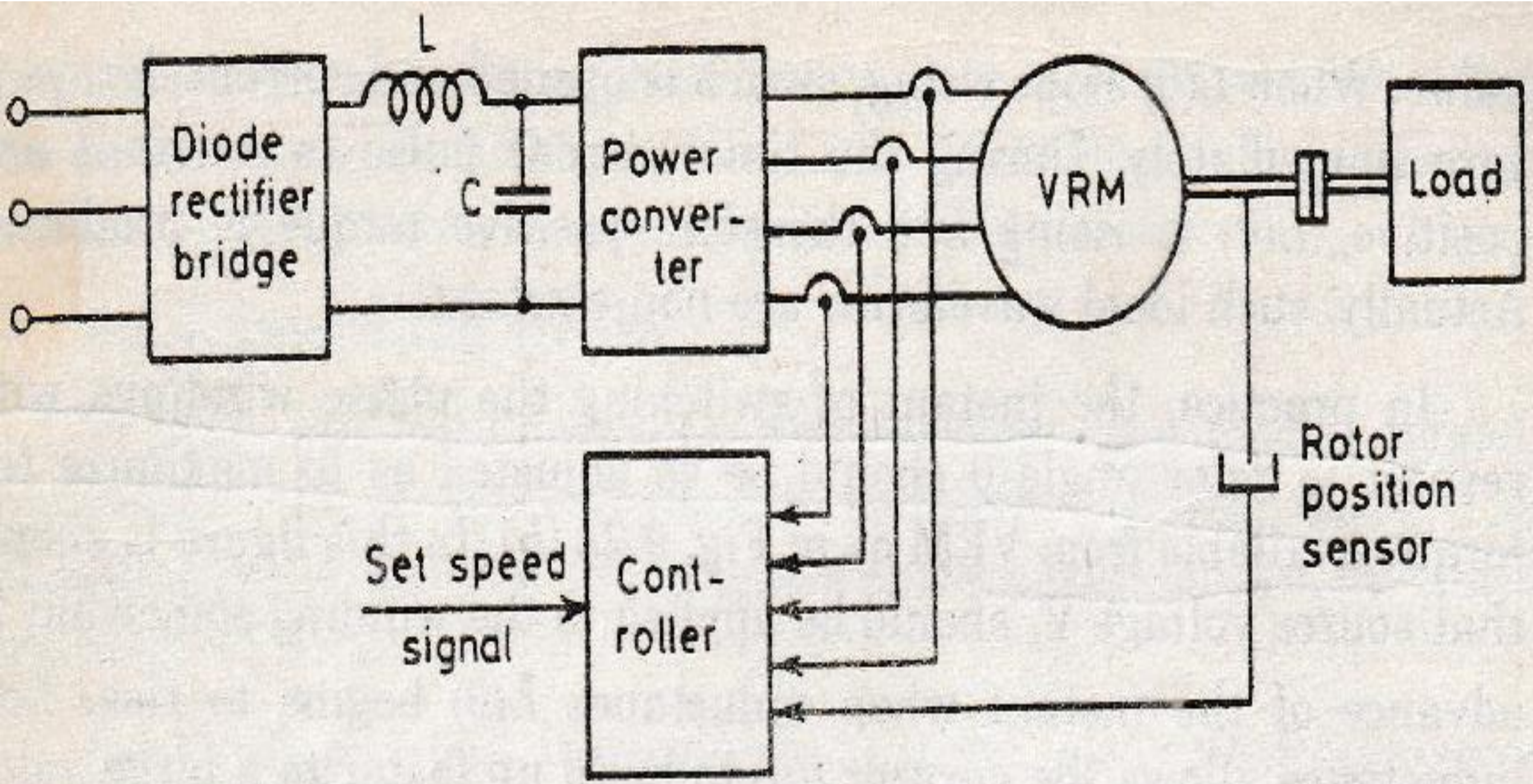


Fig. 9.25. Operation of VRM (a) ideal current waveform. Typical waveforms for phase current and phase voltage for (b) single-phase mode and (c) chopping mode.

Single-Pulse mode. In single-phase mode, also called *high-speed mode*, the current rise is within limits during the small time interval of each phase excitation. This build-up of current limit is due to the winding inductance and motional counter emf generated in the stator winding. An ideal current waveform and variation of inductance with rotor angle θ is shown in Fig. 9.25 (a). In this figure, when inductance begins to rise, switch is closed and current at once reaches a constant

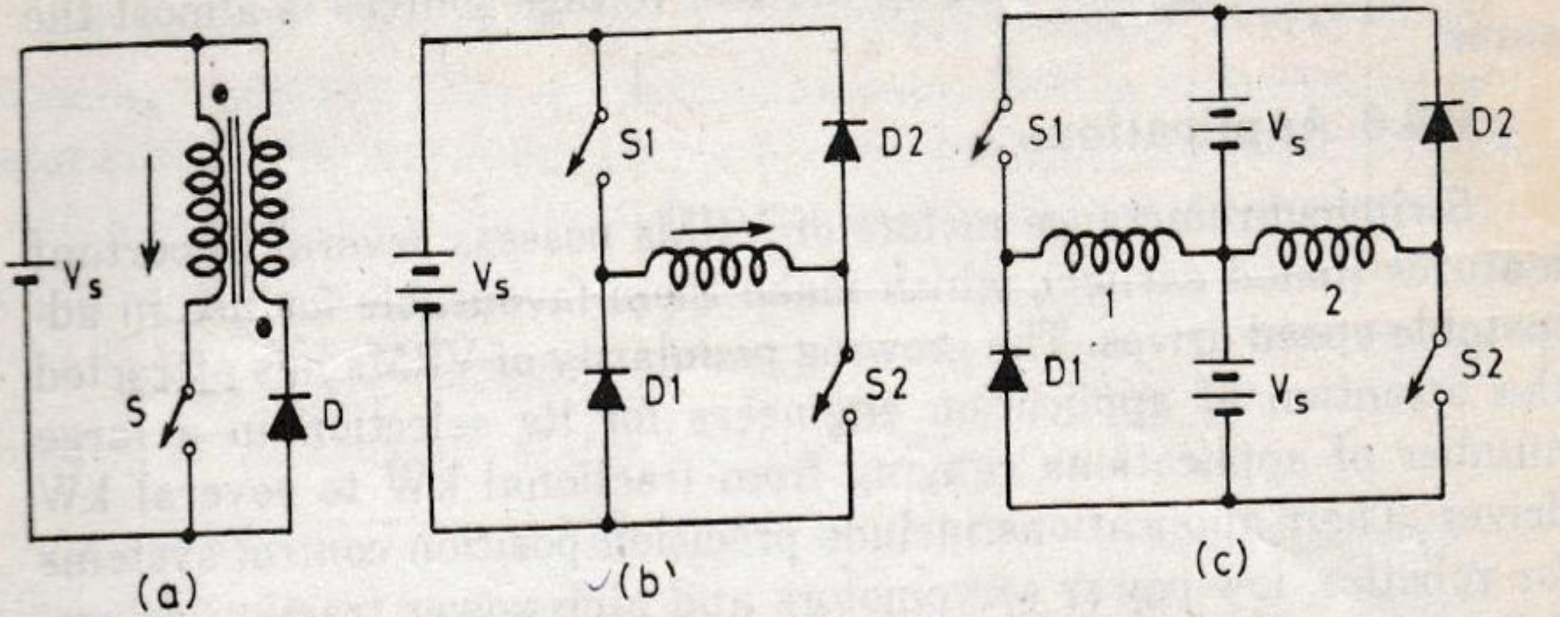
PWM (or chopping) mode. In this mode, also called low-speed mode, each phase winding gets excited for a period which is sufficiently long. The current build up during this long period of time may be prohibitively high. In order to keep the current rise within acceptable ratings of the motor and the inverter components, a current-limiting device is incorporated before VRM as shown in Fig. 9.26. This is achieved by installing a current sensor in each phase so as to monitor current. This current sensor then controls alternately the on and off instants of power-converter components in order to hold the current between permissible upper and lower levels. The chopped phase cur-

Block diagram for 4-phese SRM or VRM drive system



Block diagram for 4-phase VRM drive system.

Inverter Drive Circuits for SRM



Inverter drive circuit configurations for VRMs.

Switched-reluctance motors or VRMs possess several important features (listed earlier), which make them favourable for use in adjustable-speed drives. The growing popularity of VRMs has attracted the attention of application engineers for its selection in a large number of applications ranging from fractional kW to several kW drives. Their applications include precision position control systems for robotics, low-power servomotors and high-power traction drives. Adjustable speed drive systems based on VRMs are becoming competitive with converter-fed dc drives and inverter- controlled induction-motor drives.

As rotor in a VRM carries no winding, VRMs with rotor speed more than 2×10^5 rpm have been built. VRMs with ratings upto about 25 kW are available at present.

Advantages of SRM

The advantages of SRM are summarised as follows:

1. The rotor construction is simple. Rotor has low inertia.
2. Rotor has no winding and permanent magnet and hence higher permissible temperature.
3. Major losses occur in stator and hence it is easy to cool the motor.
4. The stator is easy to wind, end turns are short and no phase-to-phase crossover.
5. The torque is independent of the polarity of phase current and hence less number of switching devices can be used for certain applications.
6. Under fault, the short-circuit current and open-circuit voltage are zero or small.
7. Starting torque is high.
8. Suitable for high-speed applications.
9. SRM can be used in generating and motoring modes.
10. SRM is self-starting.
11. No shoot-through fault occurs in power circuits.

Disadvantages of SRM

1. Presence of ripples in torque.
2. Developes acoustic noice.
3. Undesirable harmonics in current waveforms for high speed.
4. An accurate position-sensing mechanism is eesential.

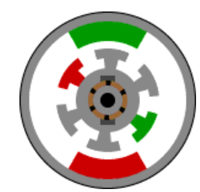
PMSM

PERMENANT MAGNET SYNCHORONUS MOTOR

- A PMSM provides rotation at a fixed speed in synchronization with the frequency of the power source regardless of the fluctuation of the load or line voltage.

- The motor runs at a fixed speed synchronous with mains frequency, at any torque up to the motor’s operating limit. PMSMs are therefore ideal for high-accuracy fixed-speed drives.

- A 3-phase PMSM is a permanently excited motor.



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- A PMSM is largely maintenance free, which ensures the most efficient operation.
- Precise speed regulation makes a PMSM an ideal choice for certain industrial processes.
- The permanent magnet synchronous motors are widely used in low and mid power applications such as computer peripheral equipments, robotics, adjustable speed vehicles.

- Precise speed regulation makes a PMSM an ideal choice for certain industrial processes.
- PMSM has speed/torque characteristics ideally suited for direct drive of large-horsepower, low-rpm loads.
- Synchronous motors operate at an improved power factor, thereby improving the overall system power factor and eliminating or reducing utility power factor penalties.

- An improved power factor also reduces the system's voltage drop and the voltage drop at the motor terminals.

- Sinusoidal pmsm are more and more popular for new drives, replacing brushed DC.
- A pmsm motor rotates because of the magnetic attraction between the rotor and stator poles.

- When the rotor poles are facing stator poles of the opposite polarity, a strong magnetic attraction is set up between them.

- The mutual attraction locks the rotor and stator poles together, and the rotor is literally yanked into step with the revolving stator magnetic field.

- At no-load conditions, rotor poles are directly opposite the stator poles and their axes coincide

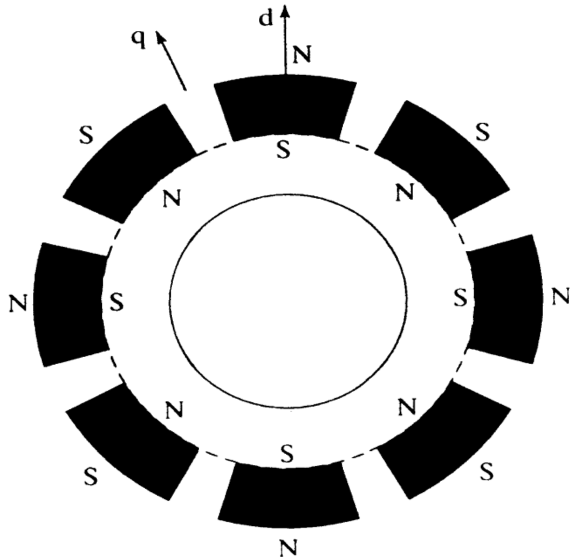
- At no-load conditions, the rotor poles lag behind the stator poles, but the rotor continuous to turn at synchronous speed.
- The mechanical angle (a) between the poles increases progressively as we increase the load.
- The permanent magnet synchronous machine drive has emerged as a top competitor for a full range of motion control applications.

Machine Configurations

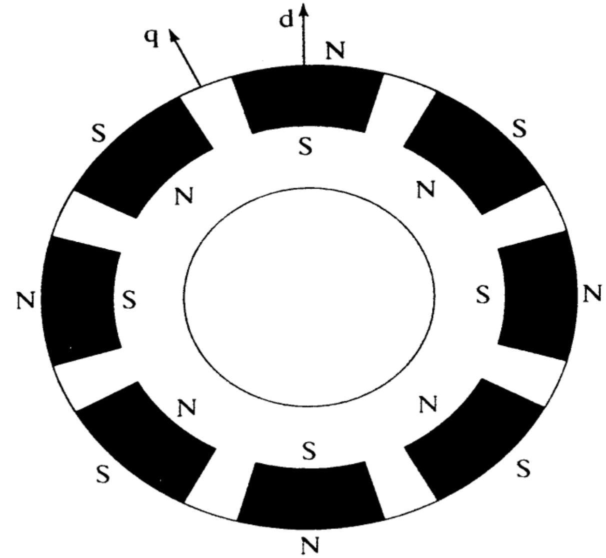
The permanent magnet (PM) synchronous machines can be broadly classified on the basis of the direction of field flux, as follows:

1. Radial field: the flux direction is along the radius of the machine.
2. Axial field: the flux direction is parallel to the rotor shaft.

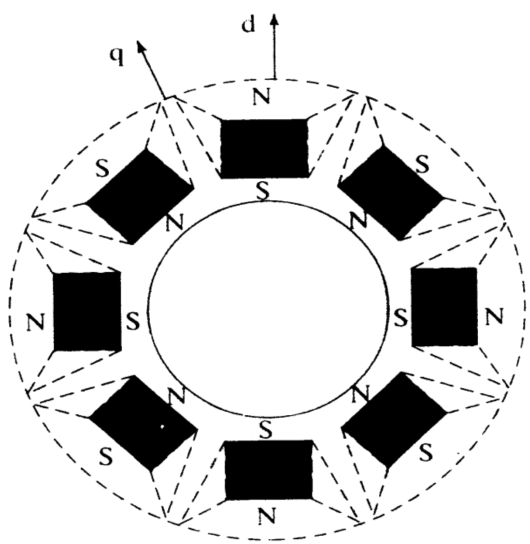
The radial-field PM machines are common; the axial-field machines are coming into prominence in a small number of applications because of their higher power density and acceleration. Note that these are very desirable features in high-performance applications.



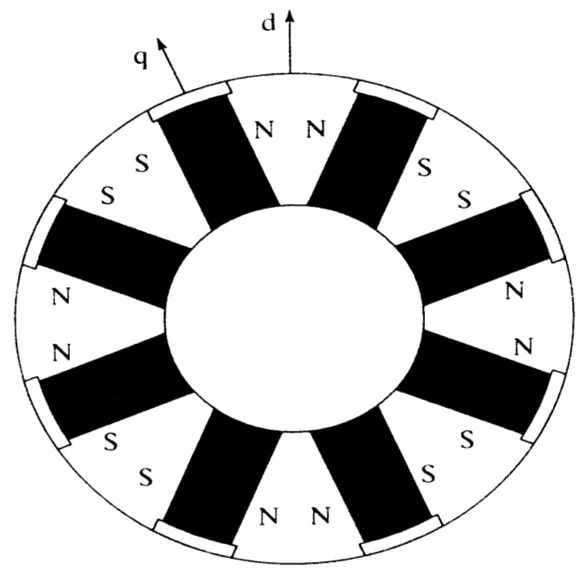
(i) Surface PM (SPM) synchronous machine



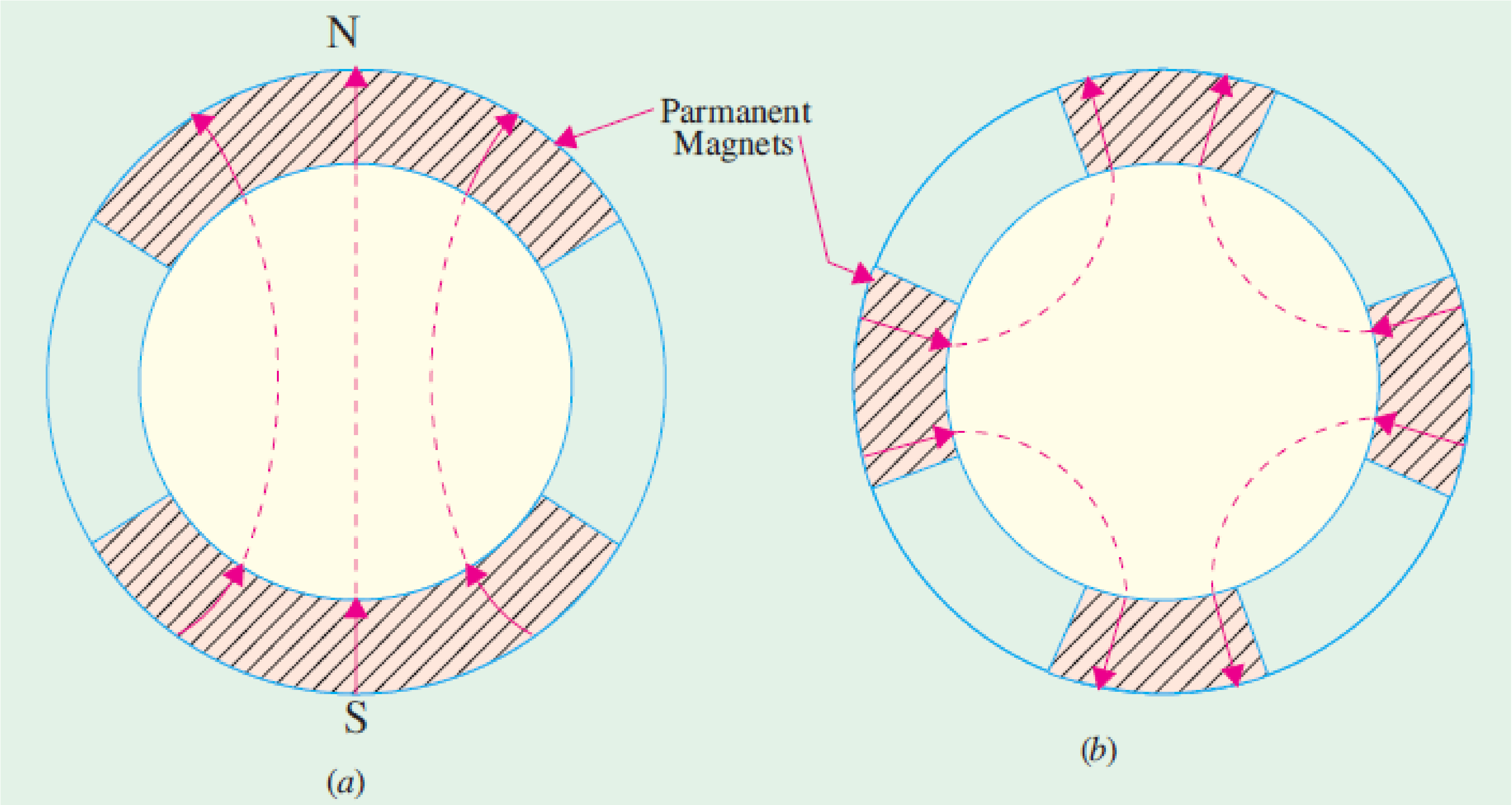
(ii) Surface inset PM (SIPM) synchronous machine



(iii) Interior PM (IPM) synchronous machine



(iv) Interior PM with circumferential orientation synchronous machine



A typical 2 – pole and 4 – pole rotor versions of PMSM

Principle of Operation of PM Machine

- To produce torque, in general, a rotor flux and a stator mmf has to be present that are stationary with respect to each other but having a nonzero phase shift between them.

- In PM machines, the necessary rotor flux is present due to rotor PMs.

- Currents in the stator windings generate the stator mmf.

- The zero relative speed between the stator mmf and the rotor flux is achieved if the stator mmf is revolving at the same speed as the rotor flux, that is, rotor speed and also in the same direction.

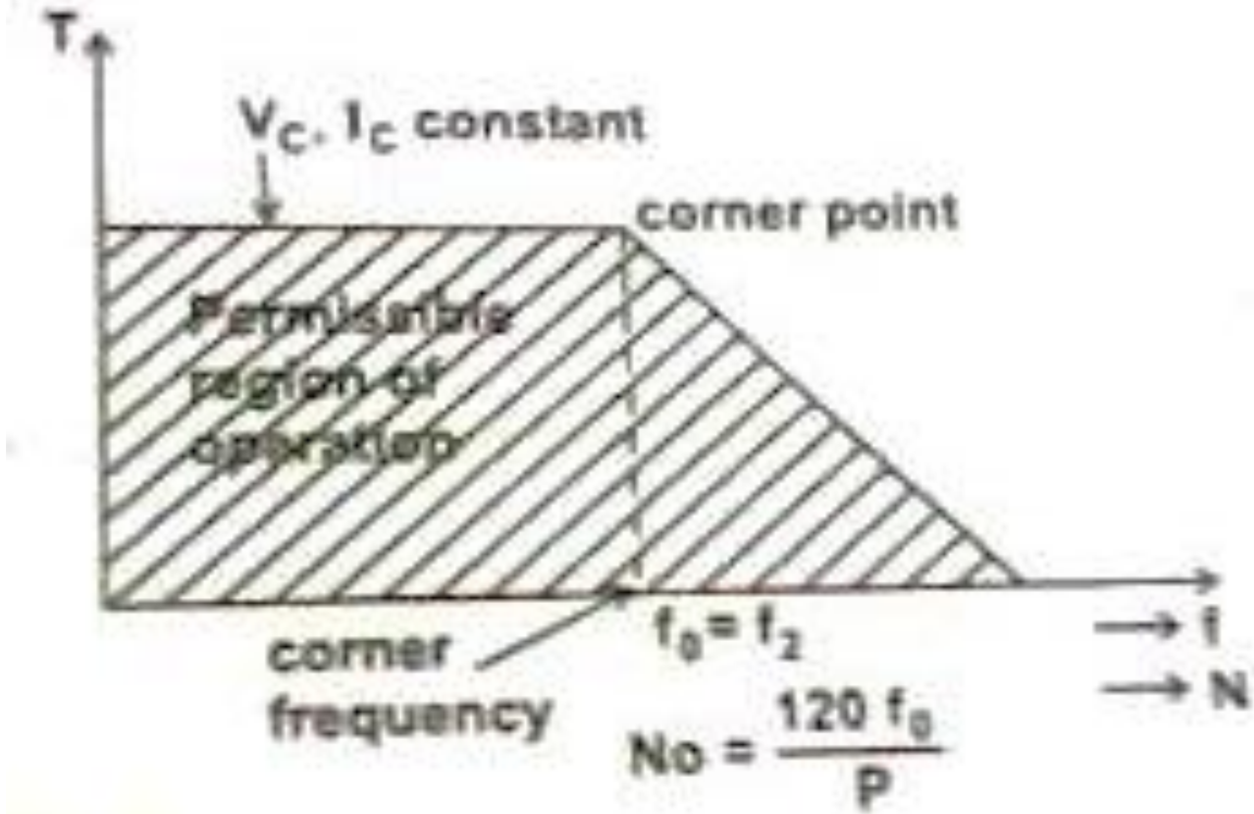
- The revolving stator mmf is the result of
- injecting a set of polyphase currents phase shifted from each other by the same amount of phase shift between the polyphase windings.

- For example, a three phase machine with three windings shifted in space by electrical 120^o between them produces a rotating magnetic field constant in magnitude and travelling at an angular frequency of the currents (just as in case of Induction machines).

- The rotor has permanent magnets on it, hence the flux produced by the rotor magnets start to chase the stator mmf and as a result torque is produced.

Since the relative speed between the stator mmf and rotor flux has to be zero, the rotor moves at the same speed as the speed of the stator mmf.

Hence, the PM machines are inherently synchronous machines.


T
V_C, I_C constant
corner point
corner frequency
$f_0 = f_2$
→ f
→ N
$No = \frac{120 f_0}{P}$

(*b*) *Advantages*

Since there are no brushes or sliprings, there is no sparking.

Also, brush maintenance is eliminated. Such motors can pull into synchronism with inertia loads of many times their rotor inertia.

It runs at constant speed.

No field winding, no field loss, better efficiency.

No sliding contacts. So it requires less maintenance.

demerits

Power factor of operation cannot be controlled as field winding cannot be controlled.

It leads to losses and decreases efficiency.

applications of PMSM

Used as a direct drive traction motor.

Used as high speed and high power drives for compression, blowers, conveyors, fans, pumps, conveyors, steel rolling mills, main line traction, aircraft test facilities.

Fiber spinning mills.

All the Best

take care

Better future ahead

Thank you