Unit 4 switched Reluctance motor

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SRM

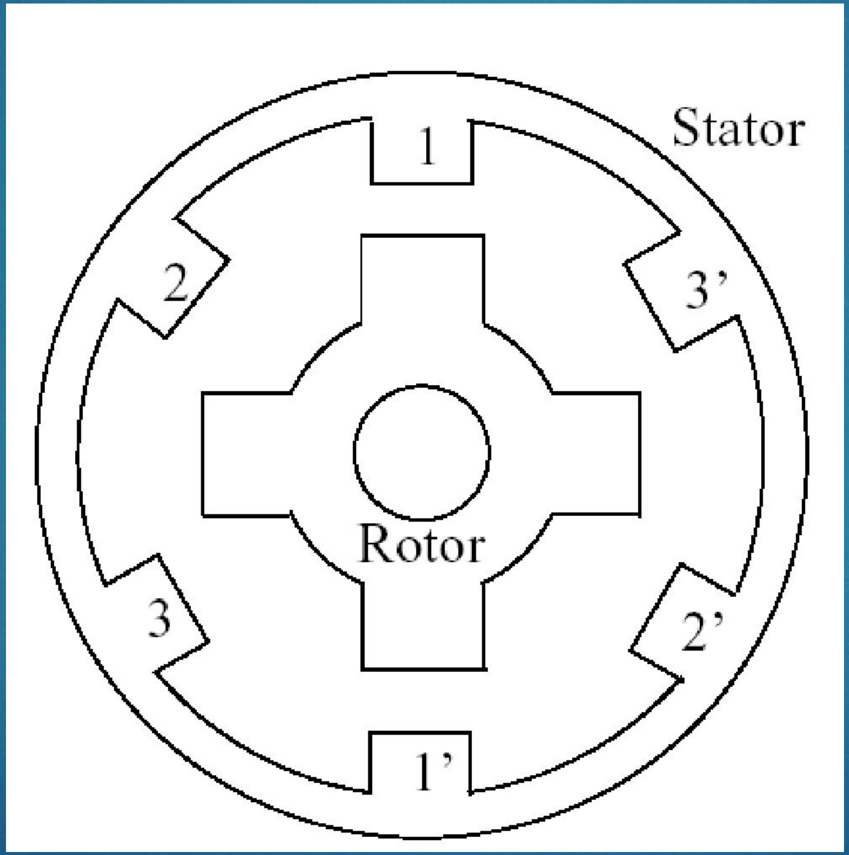
- The concept of switched reluctance motor was established in 1838
- power electronics and computer aided electromagnetic design.
- SRM's are electrically commutated AC machines and are known as variable reluctance motor
- They are more than a high-speed stepper motor, lacking the usual expensive permanent magnets.
- It combines many of the desirable qualities of Induction-motor drives, DC commutator motor drive, as well as Permanent Magnet (PM) brushless D.C systems

- SRM is rugged and simple in construction and economical when compared with the synchronous motor and the induction motor.
- They are known to have high peak torque-to-inertia ratios and the rotor mechanical structure is well suited for high-speed applications.
- The advantages of switched reluctance motor are
    - production cost,
    - efficiency and
    - the torque/speed characteristics
- Due to the above advantages and since SRM is becoming the competitor for induction and DC machines
- this work aims in developing better control scheme for SRM.

CONSTRUCTION OF SWITCHED RELUCTANCE MOTOR

- The switched reluctance motor has both salient pole stator and rotor
- It is a doubly salient, singly excited motor.
- That is, the SRM has salient poles on both the rotor and the stator, but only the stator poles carry windings.

- SRM make use of :
  - Power semiconductor switching circuitry and
  - Rotor position sensor.
- Figure shows a typical 6/4 SRM.
- It is a three-phase machine
- 6 poles on the stator and 4 poles on the rotor.
- The number of poles on the stator and on the rotor is usually not equal.
- This is to avoid the eventuality of the rotor being in a state of producing no initial torque,


Stator
1
2
3'
3
2'
Rotor
1'

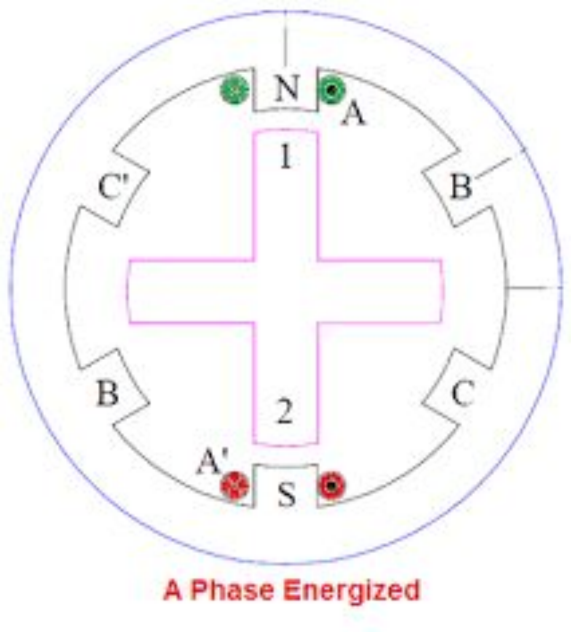
- Here, the diametrically opposite stator pole windings are connected in series and they form one phase. Thus, the six stator poles constitute three phases.
- When the rotor poles are aligned with the stator poles of a particular phase, the phase is said to be in an aligned position.
- Similarly, if the interpolar axis of the rotor is aligned with the stator poles of a particular phase, the phase is said to be in an unaligned position.
- It has wound field coils of a dc motor for its stator windings and has no coils or magnets on its rotor

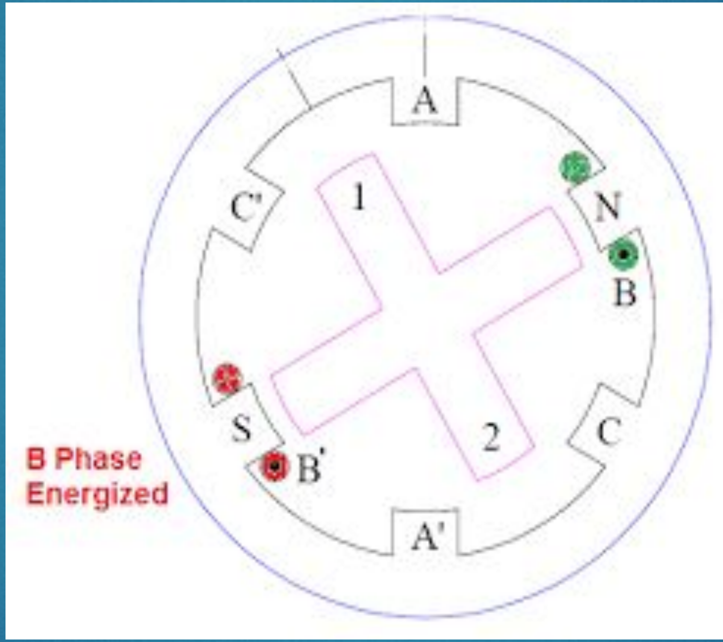
Principal of operation

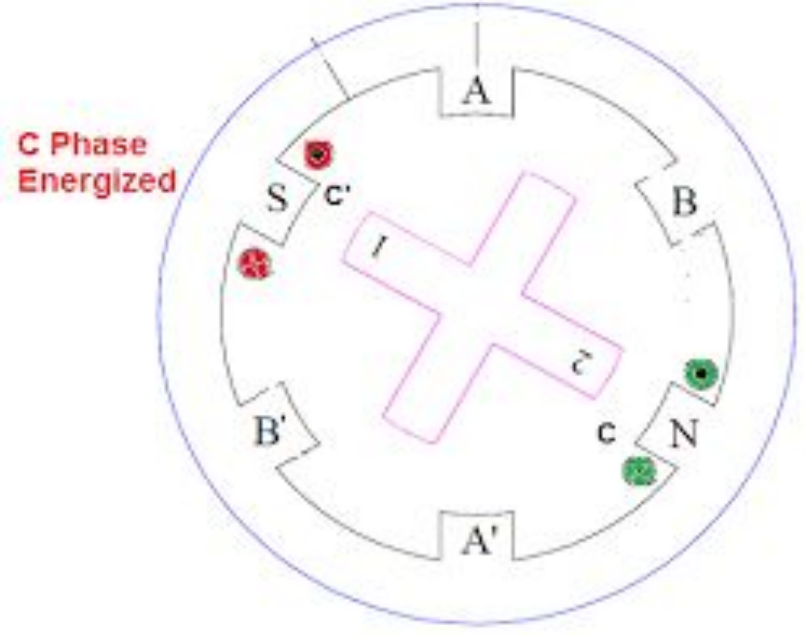
- The rotor tries to get to a position of minimum reluctance by aligning itself with the stator magnetic field.
- In the presence of a rotating magnetic field, the rotor tries to rotate along with the rotating magnetic field to be always in a position of minimum reluctance.
- Thus, exciting the stator phase windings of the motor in a particular sequence consequently,controlling the rotating magnetic field, the movement of the rotor can be controlled.

- The rotor is aligned whenever diametrically opposite stator poles are excited. In a magnetic circuit, the rotating member prefers to come to the minimum reluctance position at the instance of excitation.
- While two rotor poles are aligned to the two stator poles, another set of rotor poles is out of alignment with respect to a different set of stator poles.
- Then, this set of stator poles is excited to bring the rotor poles into alignment. Likewise, by sequentially switching the currents into the stator windings, the rotor is rotated.
- The movement of the rotor, hence the production of torque and power, involves switching of currents into stator windings when there is a variation of reluctance; therefore, this variable speed motor drive is referred to as a switched reluctance motor drive.

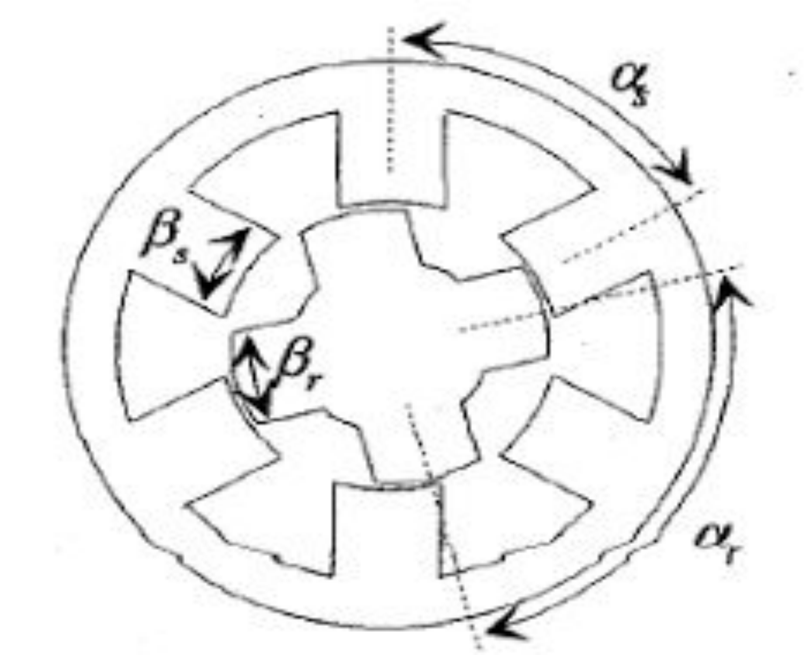
Working principle:

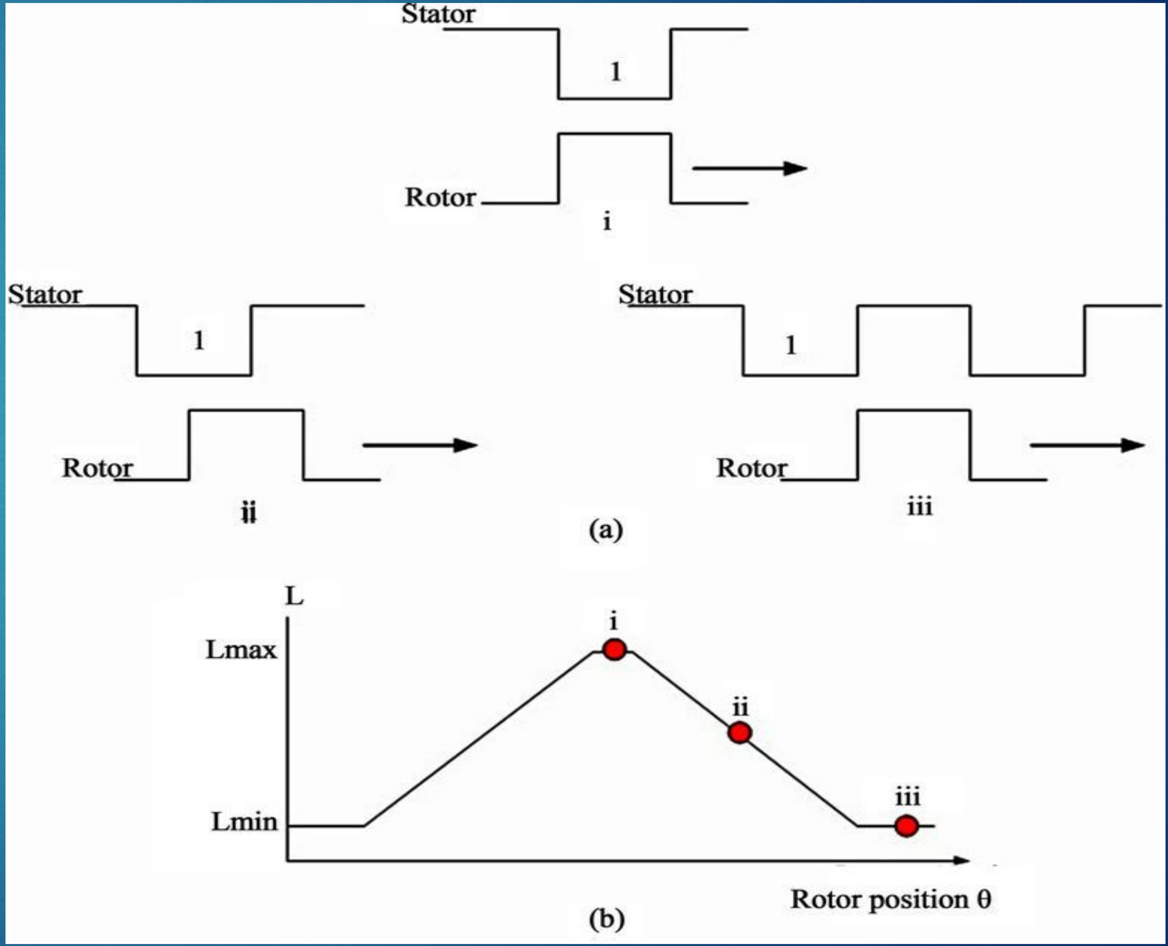






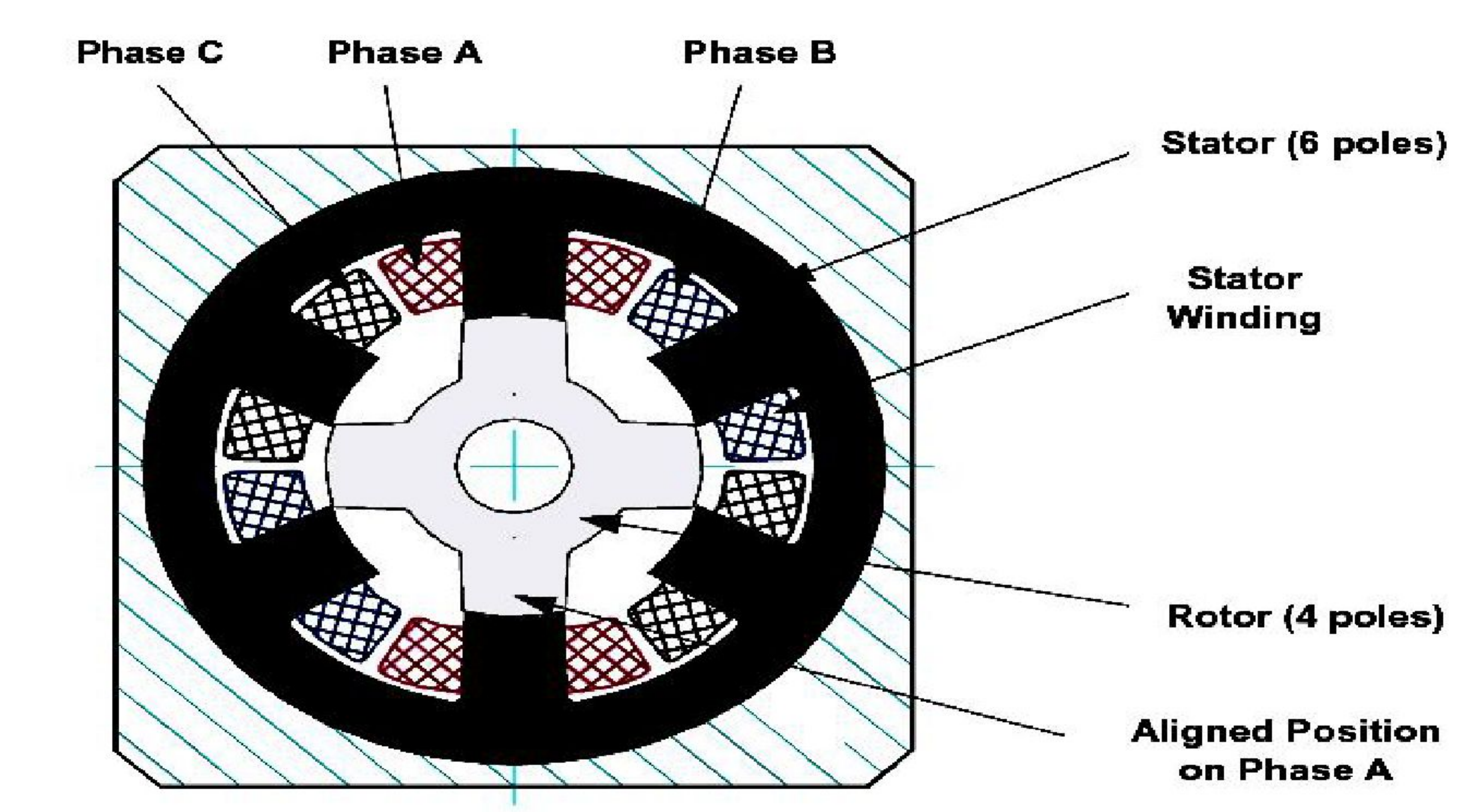
Pole and pole arc design:





- example of an SRM with 6 stator poles and 4 rotor poles.
- let us try to drag the poles here. it poles means they are receipted by 360 by 6 that is 60 degree. So, the stator pole peach is equal to 360 by 6 that is equal to 60 degrees.
- the rotor has got 4 poles, 4 pole means the pole peak which 360 by 4 the rotor pole pitch here is equal to 360 by 4 is equal to 90 degrees.
- Rotor does not have any winding
- In switched reluctance motor the torque is produced by the variation of reluctance or permeance of air gap.

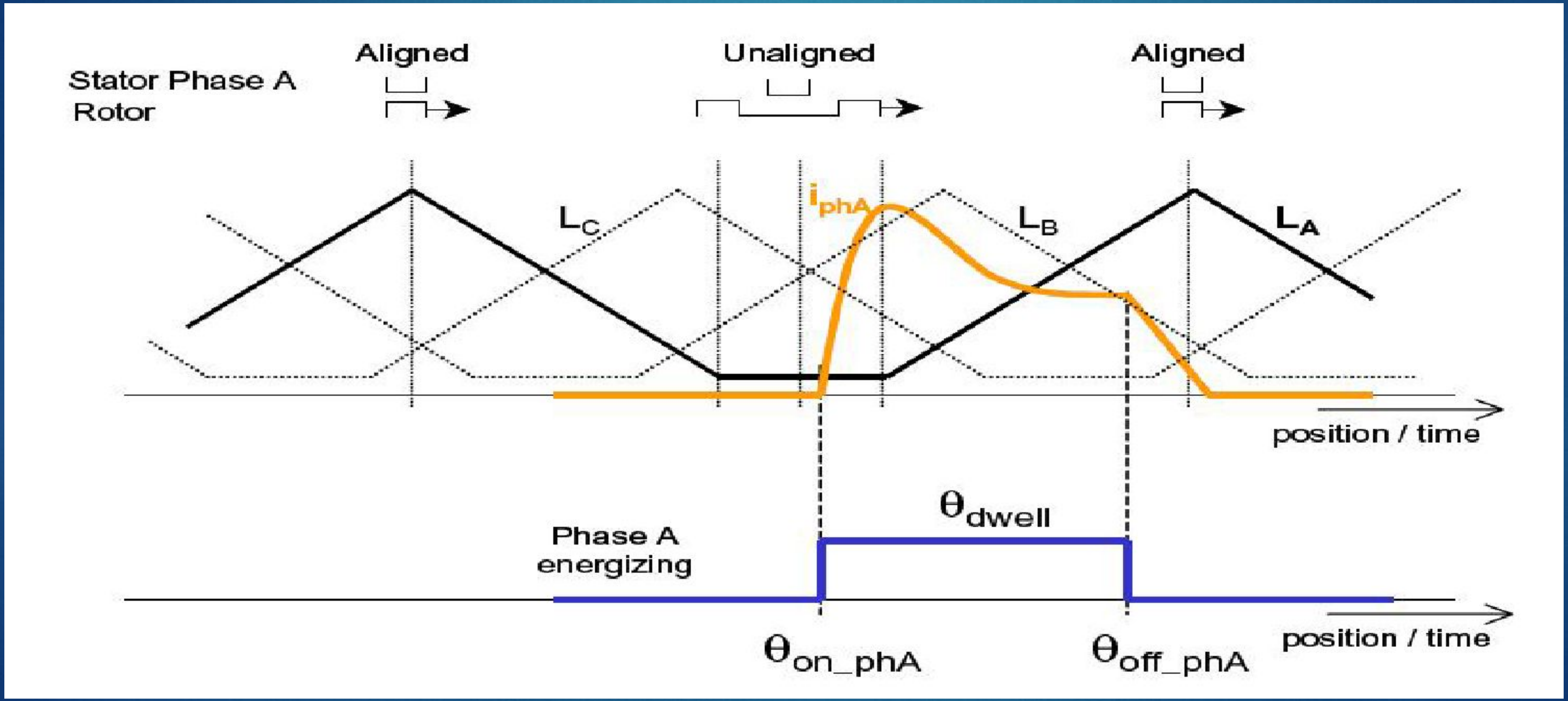
6 /4 SRM



Phase C
Phase A
Phase B
Stator (6 poles)
Stator Winding
Rotor (4 poles)
Aligned Position on Phase A

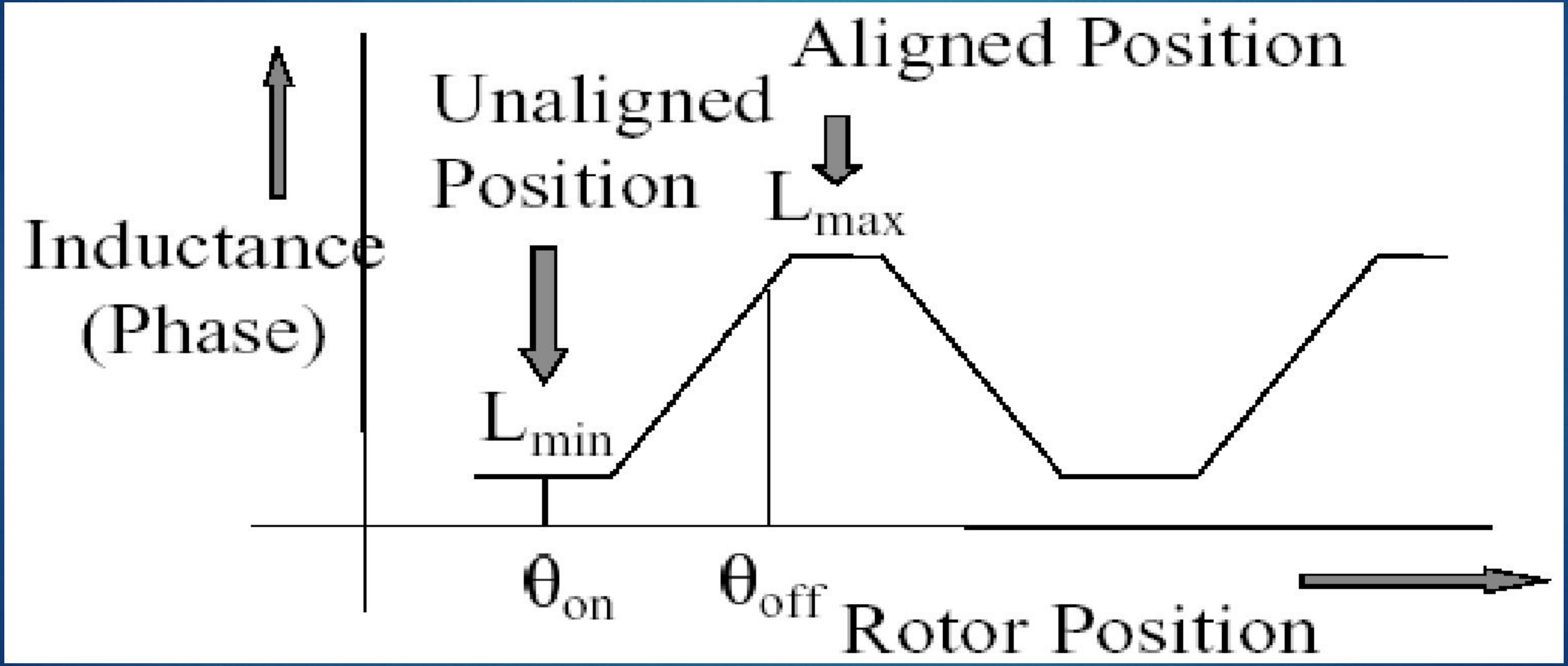
- The inductance profile of SRM is triangular, with maximum inductance when it is in an aligned position and minimum inductance when unaligned.
- with phase A highlighted.
- The interval, during which the respective phase is powered, is called the dwell angle, (θdwell). It is defined by the turn-on (θon) and the turn-off (θff) angles.
- When the voltage is applied to the stator phase, the motor creates torque in the direction of increasing inductance. When the phase is energized in the minimum inductance position, the rotor tends to attain the forthcoming position of maximum inductance. This movement is defined by the magnetization characteristics of the motor

Phase Energizing



- For a constant phase voltage, the phase current has its maximum value in the position when the inductance begins to increase.
- When a phase is turned off, the current flowing in that phase reduces to zero. The phase current present in the region of decreasing inductance generates negative torque. The torque generated by the motor is controlled by the applied phase voltage and the appropriate definition of switching turn-on and turn-off angles
- In many cases, this requirement is addressed by using position sensors
- Positive torque is produced when the phase is switched on while the rotor is moving from the unaligned position to the aligned position as shown in Figure

Inductance Profile of One Phase SRM



Torque equation of SRM

$$V = iR + \frac{d\lambda}{dt}$$

$$V = L(\theta)\frac{di}{dt} + i\frac{dL(\theta)}{d\theta} * \omega$$

$$Vi = Li\frac{di}{dt} + i^2 \frac{dl}{d\theta} * \omega$$

$$P = \frac{d}{dt}\left(\frac{1}{2}Li^2\right) + \frac{1}{2}i^2\frac{dl}{d\theta} * \omega$$

The phase voltage of the switched reluctance motor can be written as

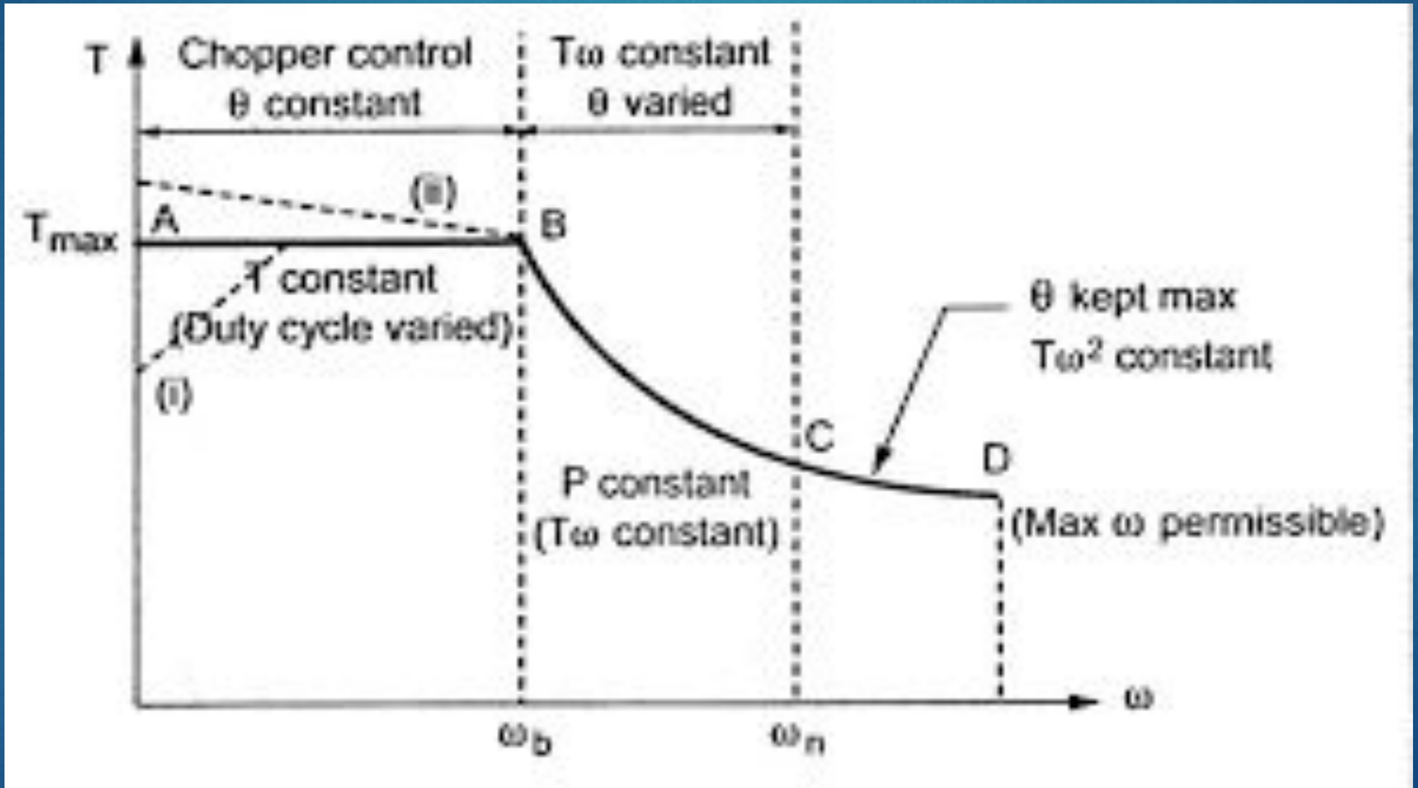
- Ignoring stator résistance, the above equation can be written as EQ-2
- as λ=L*I
- where ω is the rotor speed and L (θ) is the instantaneous phase résistance
- The rate of flow of energy can be obtained by multiplying the voltage with current and can be written as EQ-3
- The equation given above can also be given in the form EQ-4

- where, the first term of the above equation represents the rate of increase in the stored magnetic field energy while the second term is the mechanical output. Thus, the instantaneous torque can be written as

$$T(\theta, i) = \frac{1}{2} i^2 \frac{dL}{d\theta}$$

- Thus positive torque is produced when the phase is switched on during the rising inductance. Consequently, if the phase is switched on during the period of falling inductance, negative torque will be produced.

SPEED TORQUE CHARACTERISTICS OF SRM



Torque speed characteristics of SRM

- Currents in the stator circuits are switched on and off in accordance to the rotor position.
- This first mode is the natural one with fixed supply voltage and fixed switching angles.
- The operating region is the constant torque region, below rated speed.
- Base speed (ωb) is defined as the highest speed at which maximum current can be supplied to the motor (Imax) at rated voltage, with fixed switching angles.
- The chopping voltage control is able to control an SRM drive only in the mode below rated speed

- If fixed switching angles are maintained at speeds above ωb, the torque falls as $1/\omega$. This is the second important mode of operation, when the machine speed is above base speed (ωb).
- A control alternative for the switched reluctance motor is to reduce the conduction angle $\theta c = \theta off - \theta on$ at constant voltage.
- In this mode, the voltage generated is fully applied across the phase till θoff and the current decreases.
- There is a practical limitation for increasing the conduction angle. If it is increased the turn-off angle corresponds to the next cycle turn-on angle, then the flux level would not return to zero at the end of each pulse.
- In this case, the net flux in the phase winding would increase until the machine gets continuously saturated. This corresponds to a rotor speed ωp, above which the fall of the torque production is $1/\omega 2$.

- Like other motors, torque is limited by the maximum allowed current, and speed is limited by the available bus voltage. With increasing shaft speed, a current limit region persists until the rotor reaches a speed where the back EMF of the motor is such that, given the DC bus voltage limitation we can get no more current in the winding, thus no more torque from the motor. At this point, called the base speed, and beyond, the shaft output power remains constant at its maximum. At higher speeds, the back EMF increases and the shaft output power begins to drop. This region is characterized by the product of torque and the square of speed remains constant

3 modes of operation of SRM

- 1.chopping mode –Torque constant mode

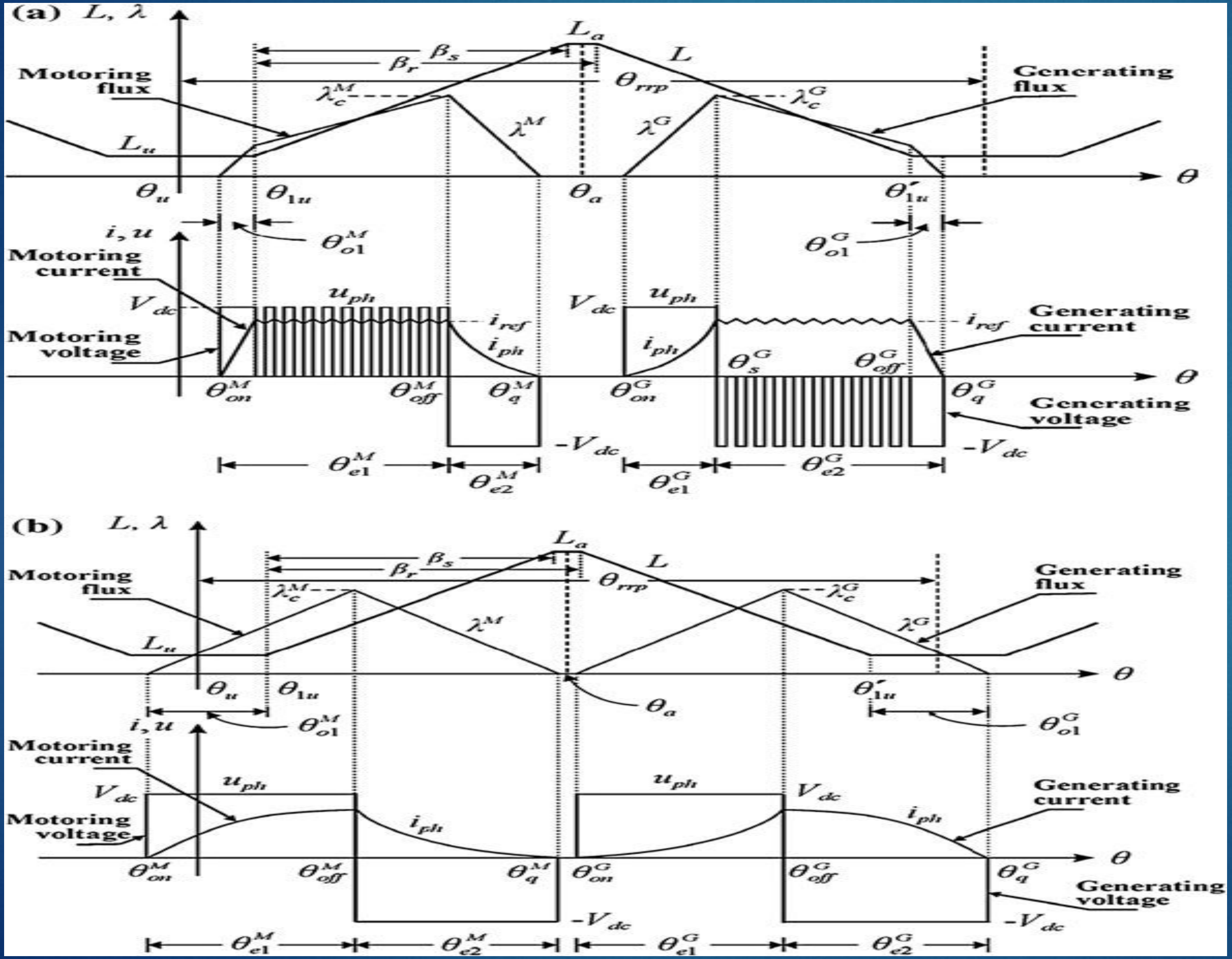
$$T(\theta, i) = \frac{1}{2} i^2 \frac{dL}{d\theta}$$

- 2.power constant mode – $T\omega$ constant -ϴ is variable

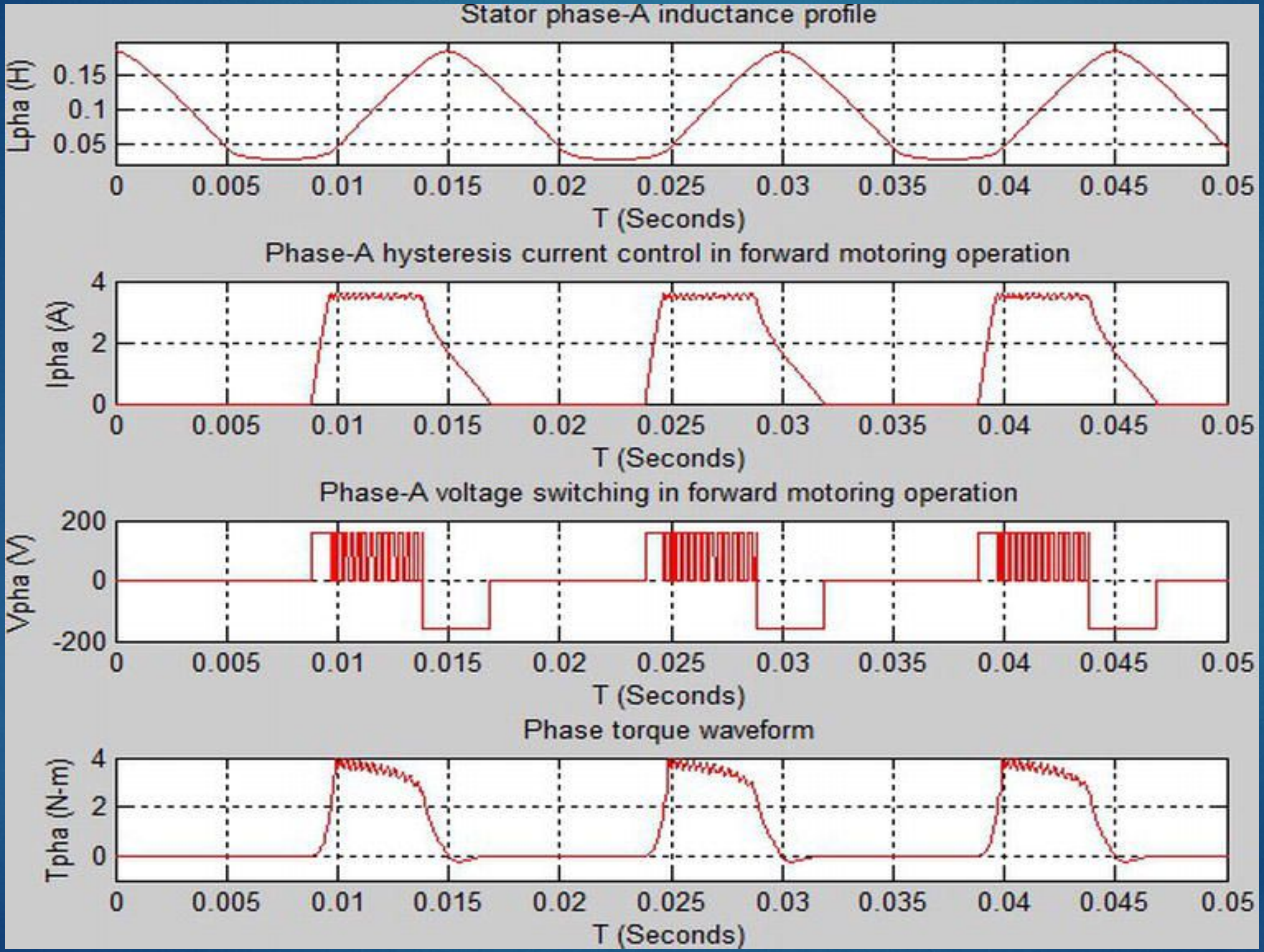
  Power = Torque * angular speed

- 3. normal mode $T\omega^2$ constant – ϴ is kept at max value

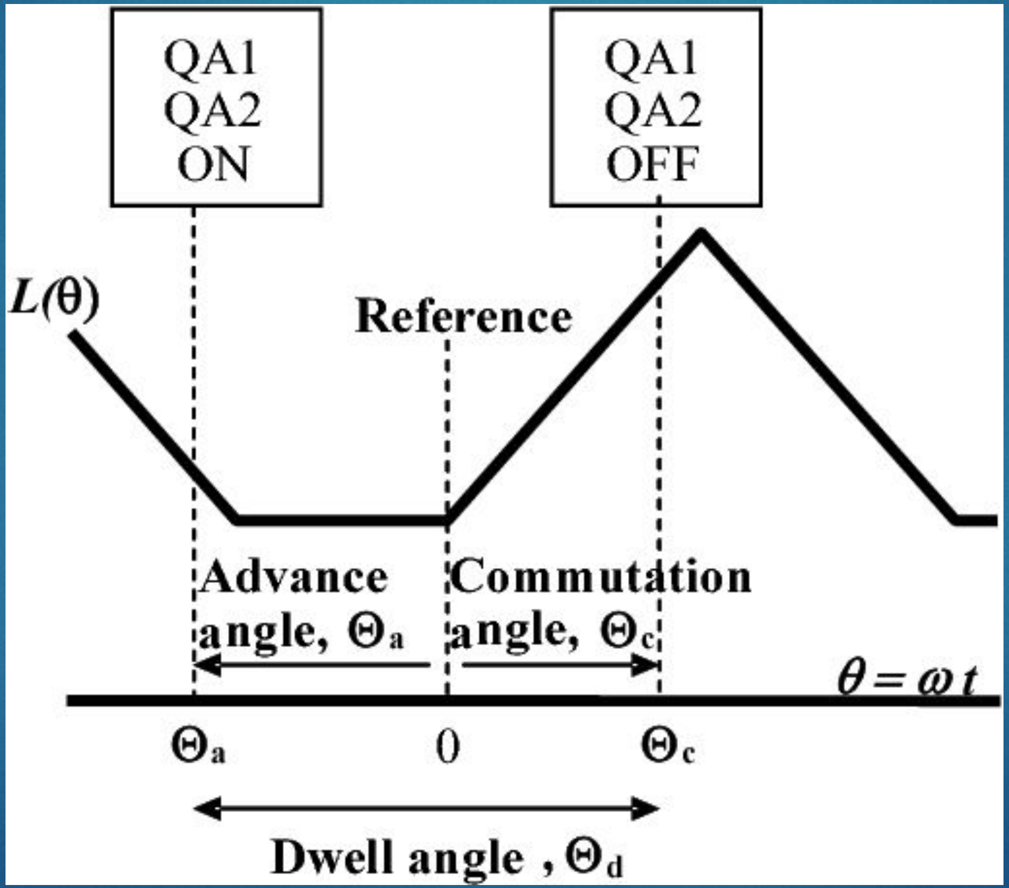
PWM soft chopping current control and b single pulse control



Current and torque waveforms for SRM



Advansed angle variation -constant power mode

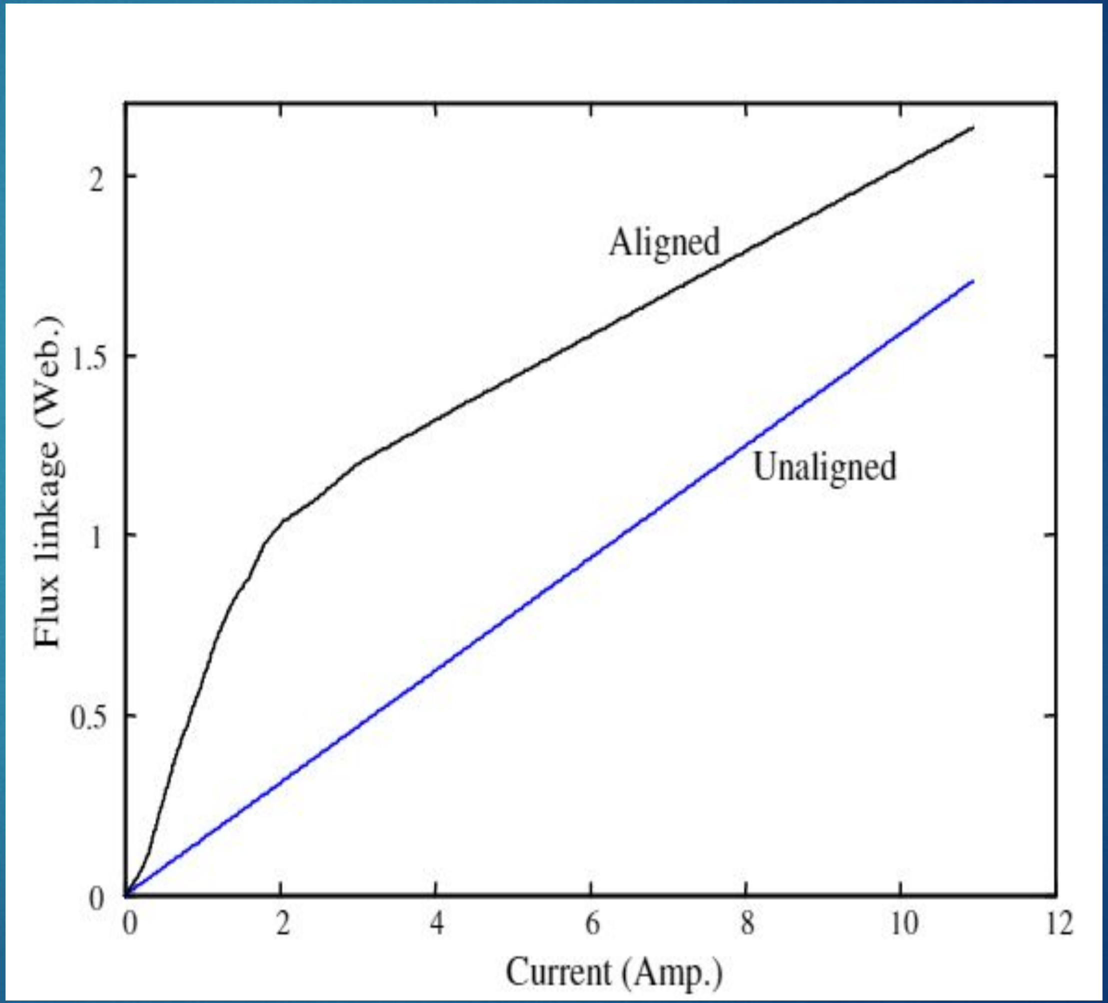


Static Characteristics of SRM

- Static Characteristics of the SRM The static characteristics of SRM include
- the flux linkage current curves,
- co-energy curves, and
- the static torque curves.

Flux linkage current curve

Flux linkage current curves represent the relationship between the phase flux linkage and phase current at different rotor positions. The two curves at the extreme aligned and unaligned rotor positions are considered



Flux linkage current curves at intermediate rotor positions

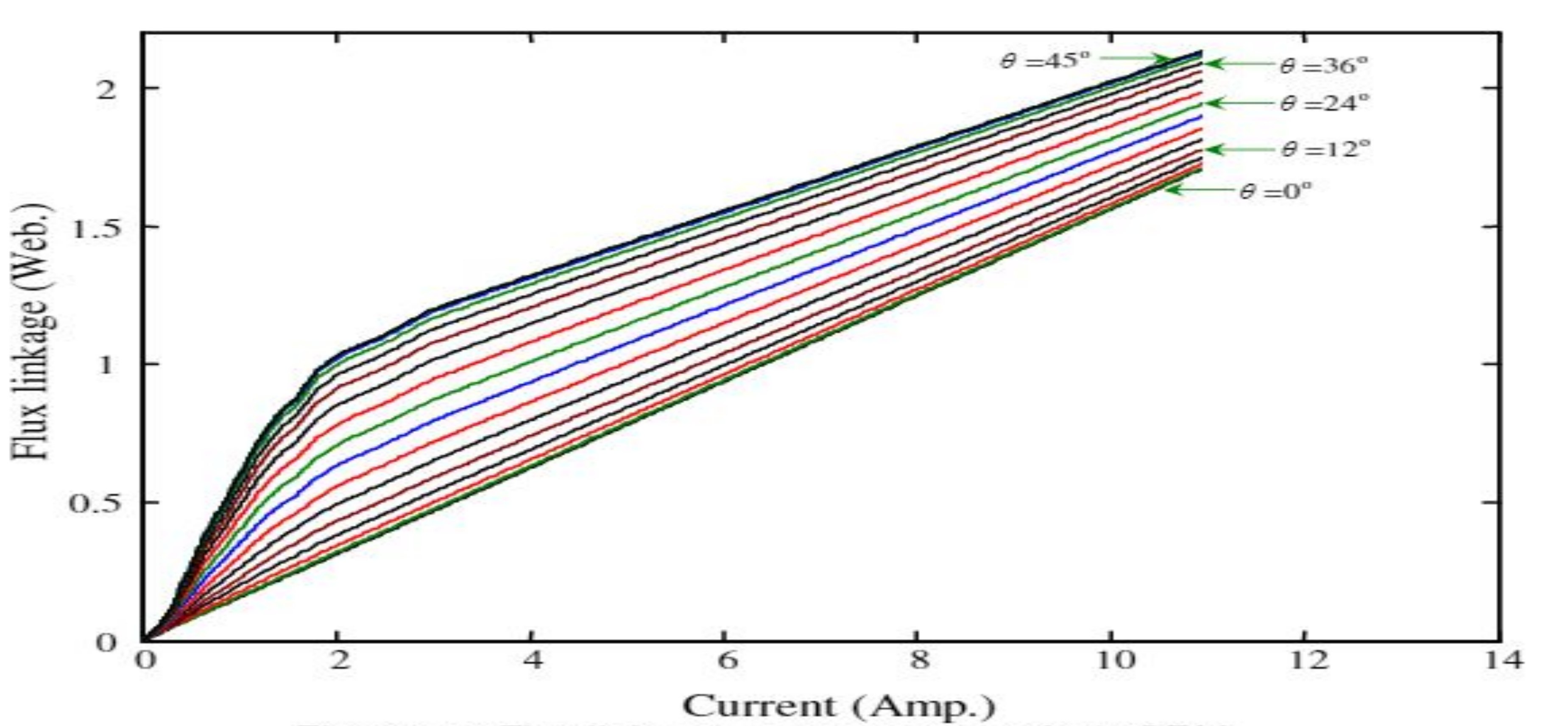
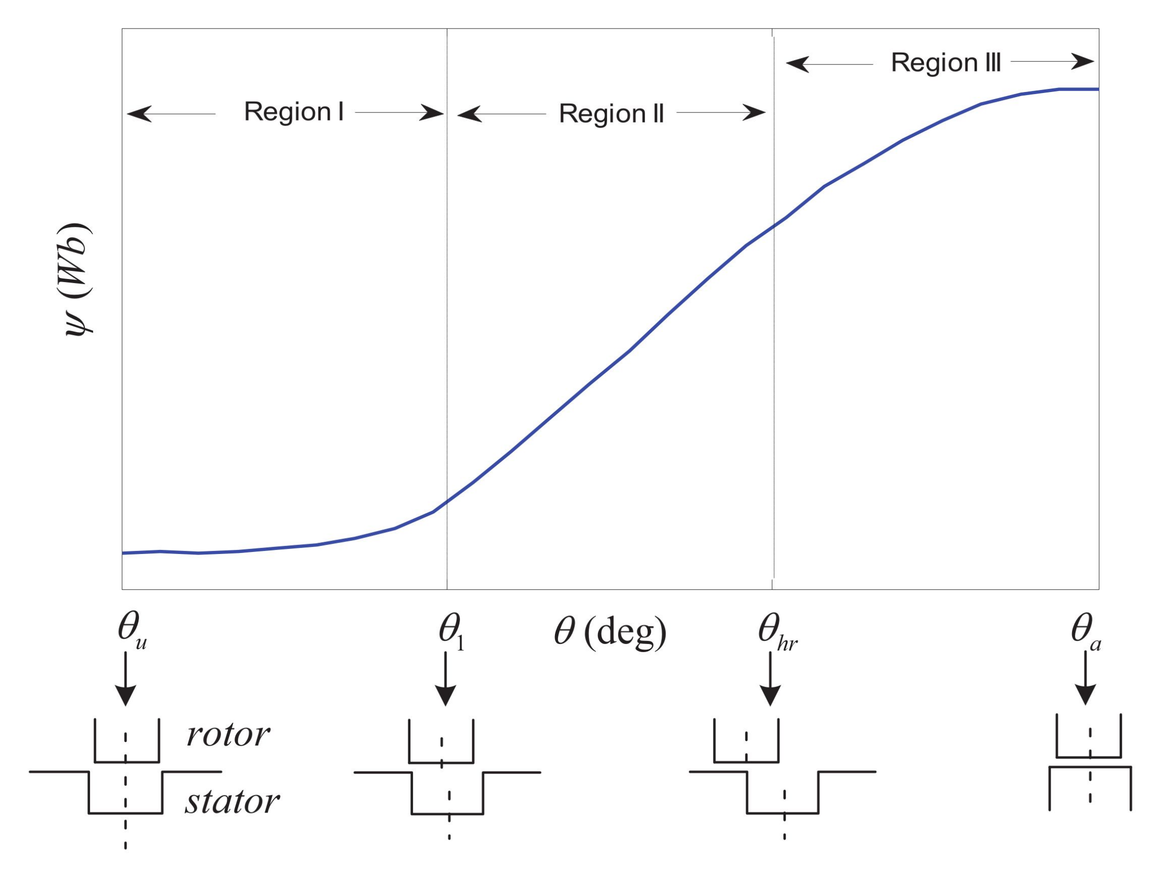
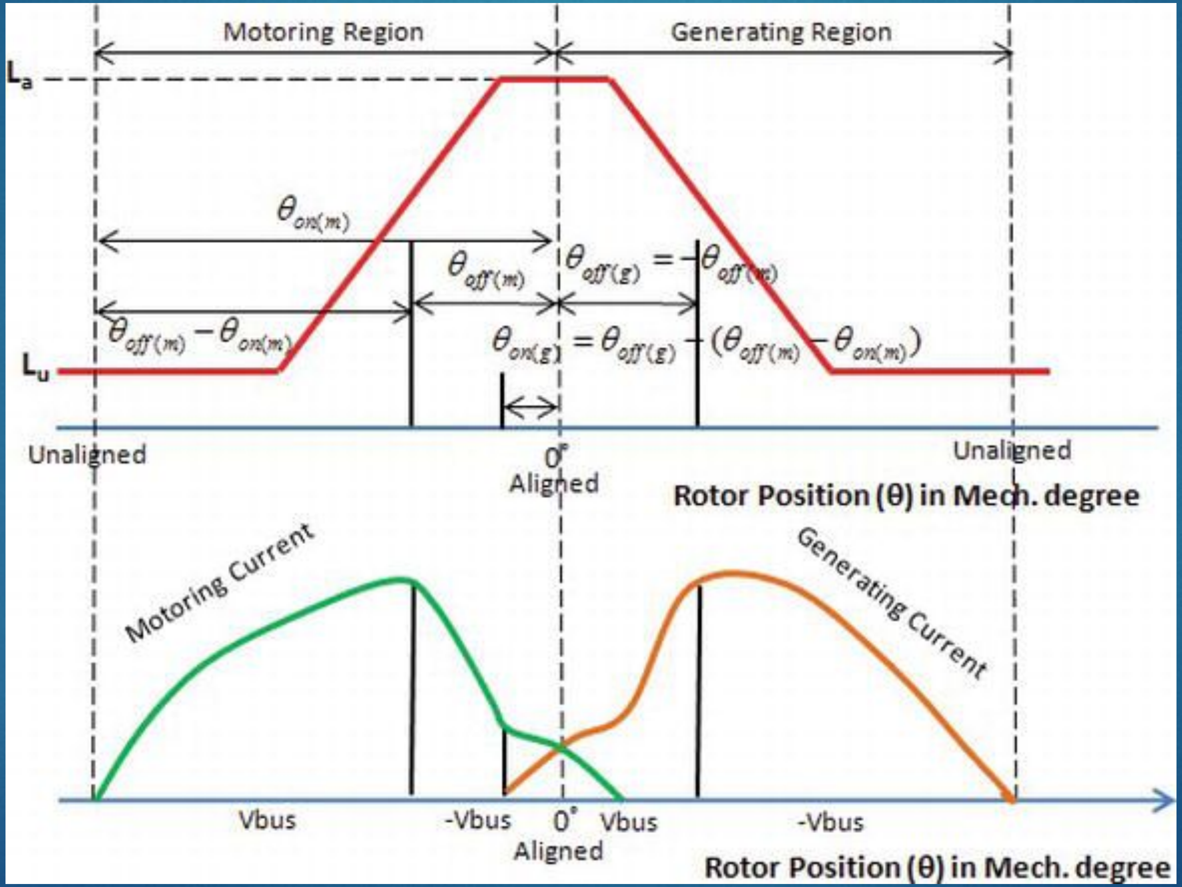


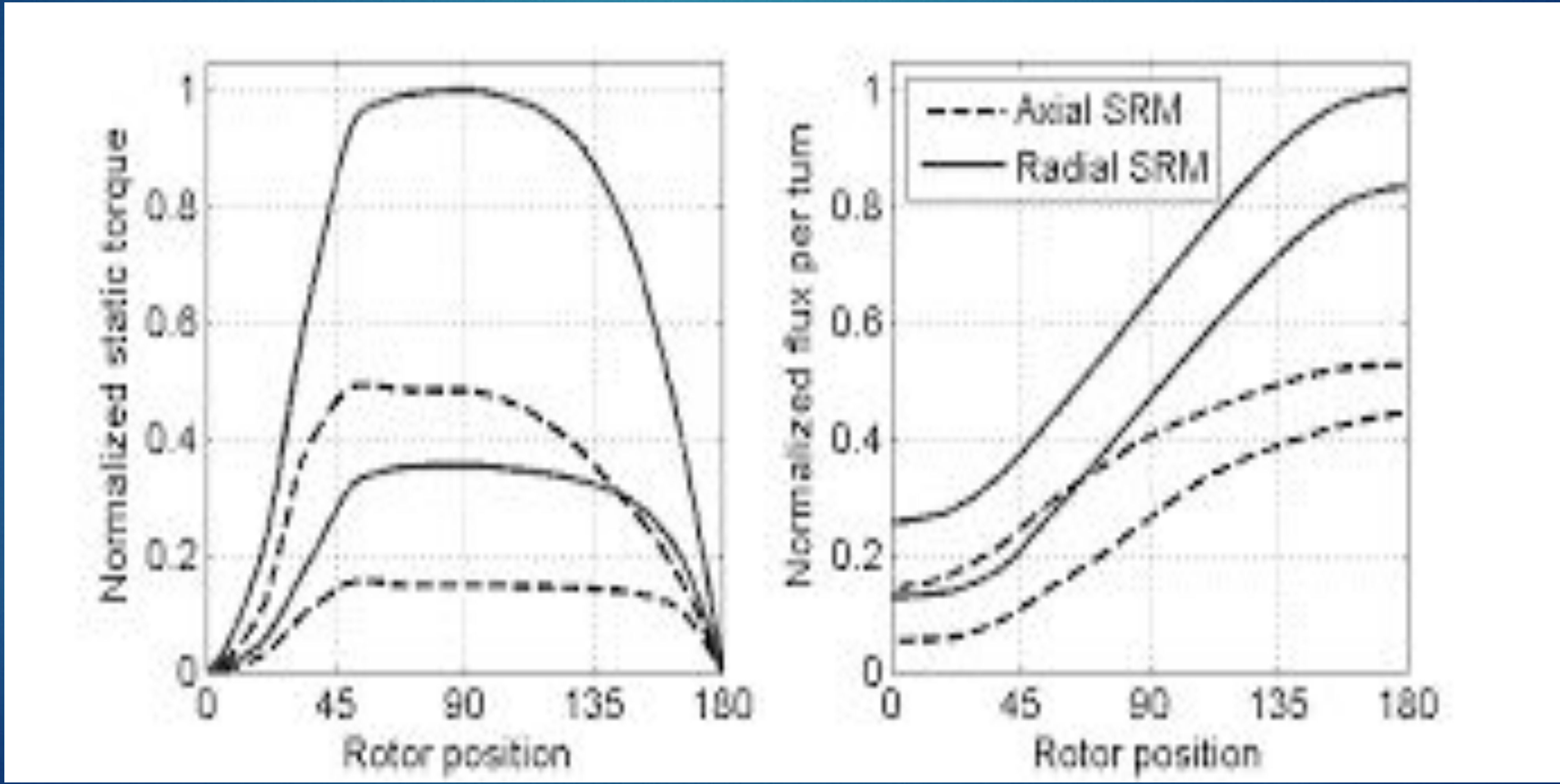
Figure 3.7 Flux linkage-current curves of 6/4 SRM.



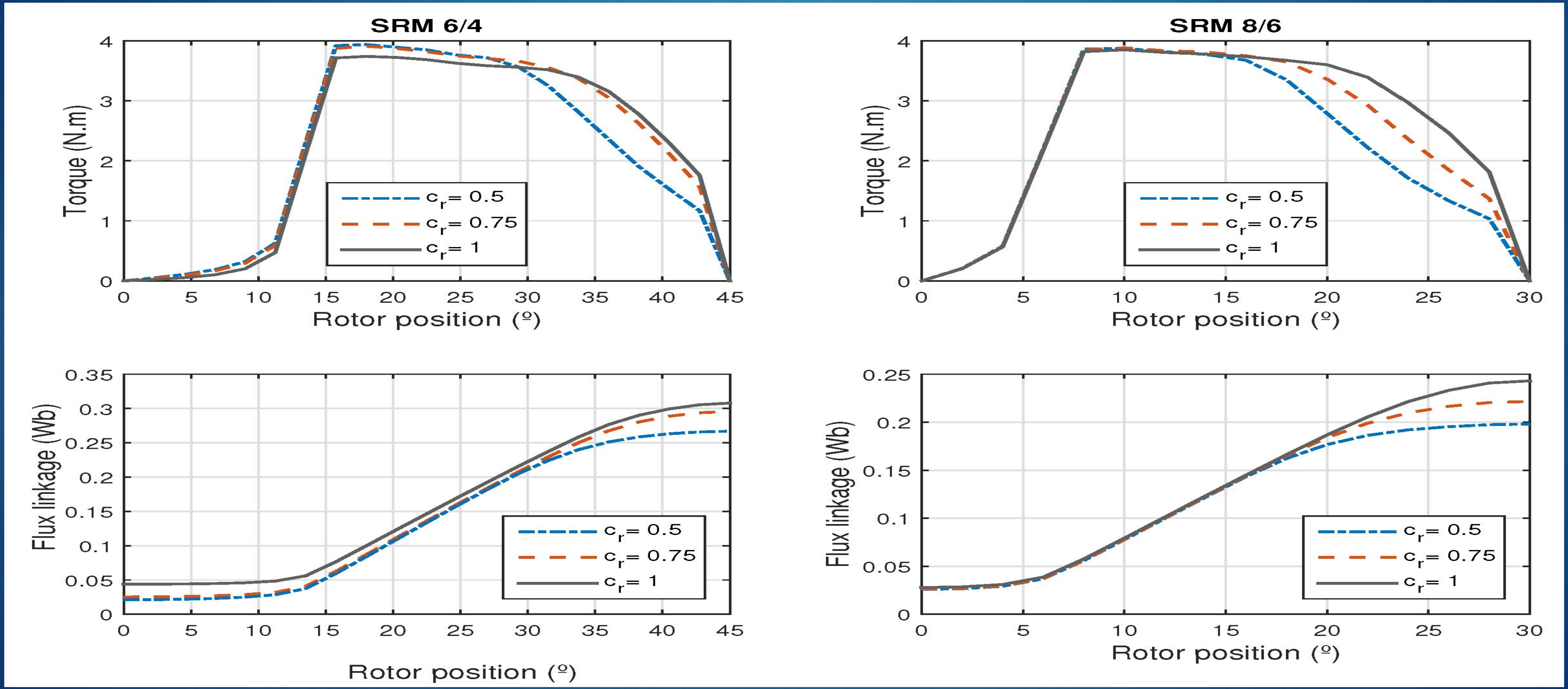
Region I
Region II
Region III
ψ (Wb)
θ (deg)
θu
θ1
θhr
θa
rotor
stator



Motoring Region
Generating Region
L_a
$\theta_{on(m)}$
$\theta_{off(m)}$
$\theta_{off(g)} = -\theta_{off(m)}$
$\theta_{off(m)} - \theta_{on(m)}$
$\theta_{on(g)} = \theta_{off(g)} + (\theta_{off(m)} - \theta_{on(m)})$
L_u
Unaligned
0°
Aligned
Unaligned
Rotor Position (θ) in Mech. degree
Motoring Current
Generating Current
Vbus
-Vbus
0°
Vbus
-Vbus
Aligned
Rotor Position (θ) in Mech. degree

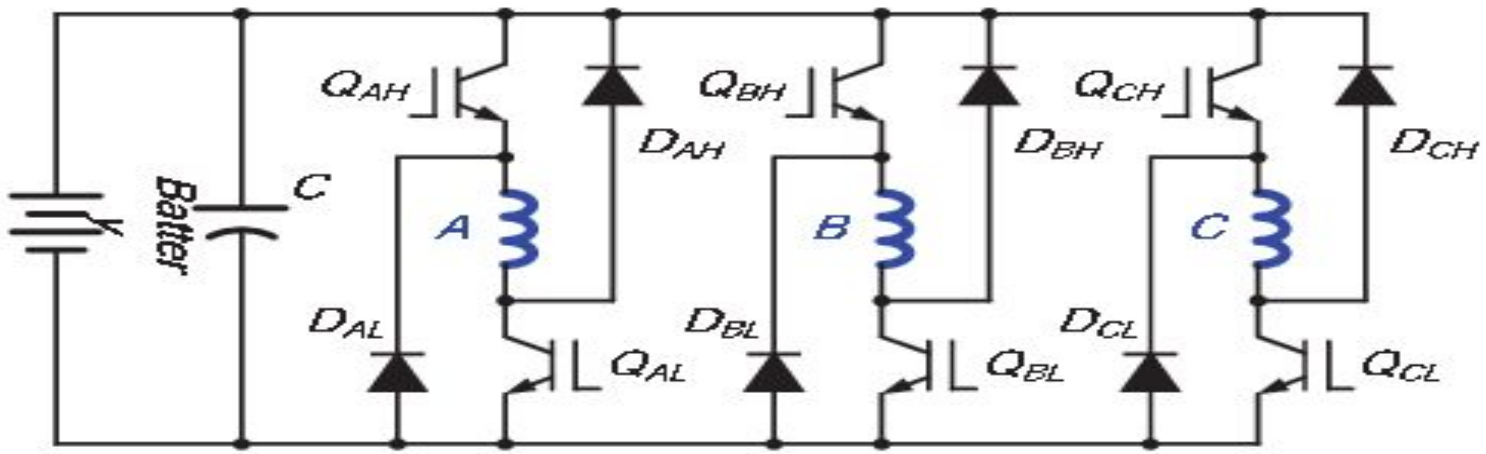


Normalized static torque
Rotor position
Normalized flux per turn
Axial SRM
Radial SRM
Rotor position

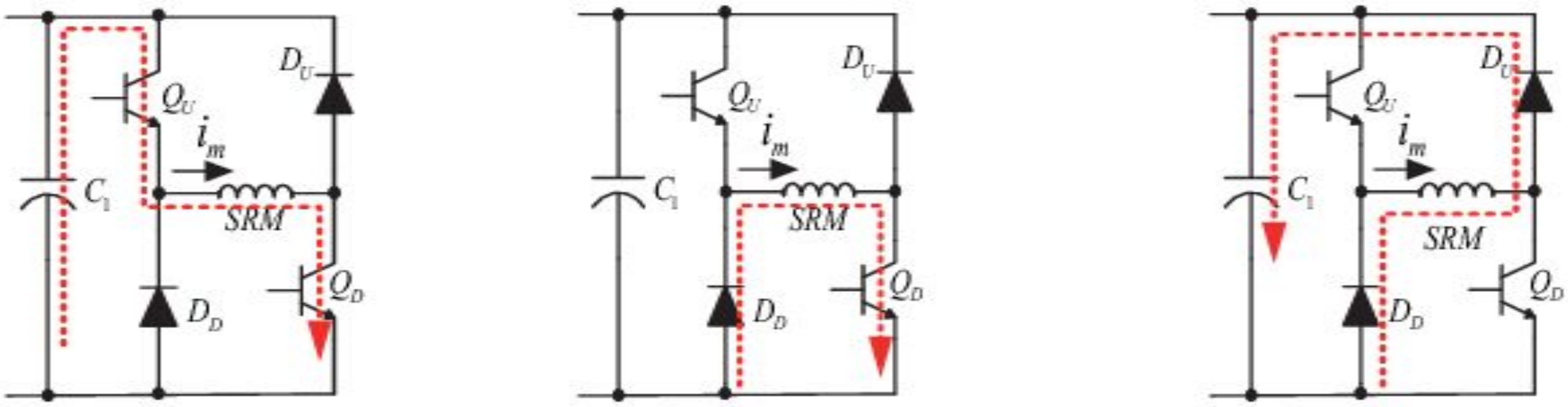

SRM 6/4
SRM 8/6
Torque (N.m)
Flux linkage (Wb)
Rotor position (º)
c_r= 0.5
c_r= 0.75
c_r= 1

Converter topology

nd demagnetization mode as shown in Fig. 2.

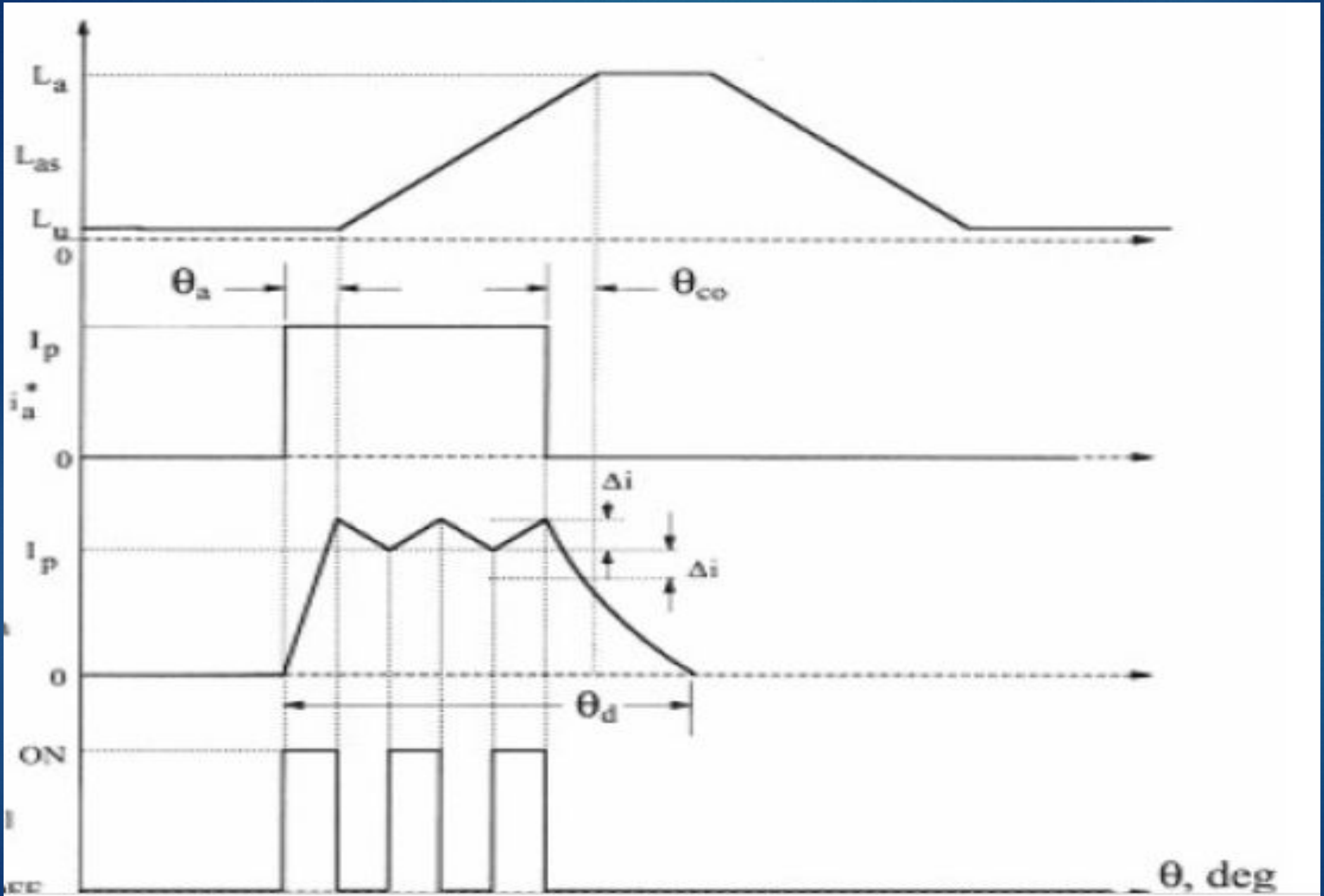


(a) General converter topology of SRM



(b) Magnetization (c) Freewheeling (d) Demagnetization

Fig. 2 Conventional 3-phase SRM drive and its operation mode



L_a
L_{as}
L_u
0
θ_a
θ_{co}
I_p
i_a^*
0
Δi
I_p
Δi
0
θ_d
ON
θ, deg

- Webinar on SRM
- https://youtu.be/xlfhUT8OtxY
- SRM in marathi
- https://youtu.be/LzJbMYUPOQI