2. Electric Motor Operating Characteristics

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Discussed topics

- Speed
- Torque
- Main load types
- Duty cycles

Speed and Slip in Induction Motors

$$synchronous\ \ speed\,[rpm] = \frac{frequency\ of\ \ the\ applied\ voltage\,[Hz] \times 60}{number\ of\ \ pole\ pairs}$$

$$slip\,[rpm] = Synchronous\ speed\,[rpm] - running\ speed\,[rpm]$$

$$slip\,[\%] = \frac{Synchronous\ speed - running\ speed}{Synchronous\ speed} \times 100$$

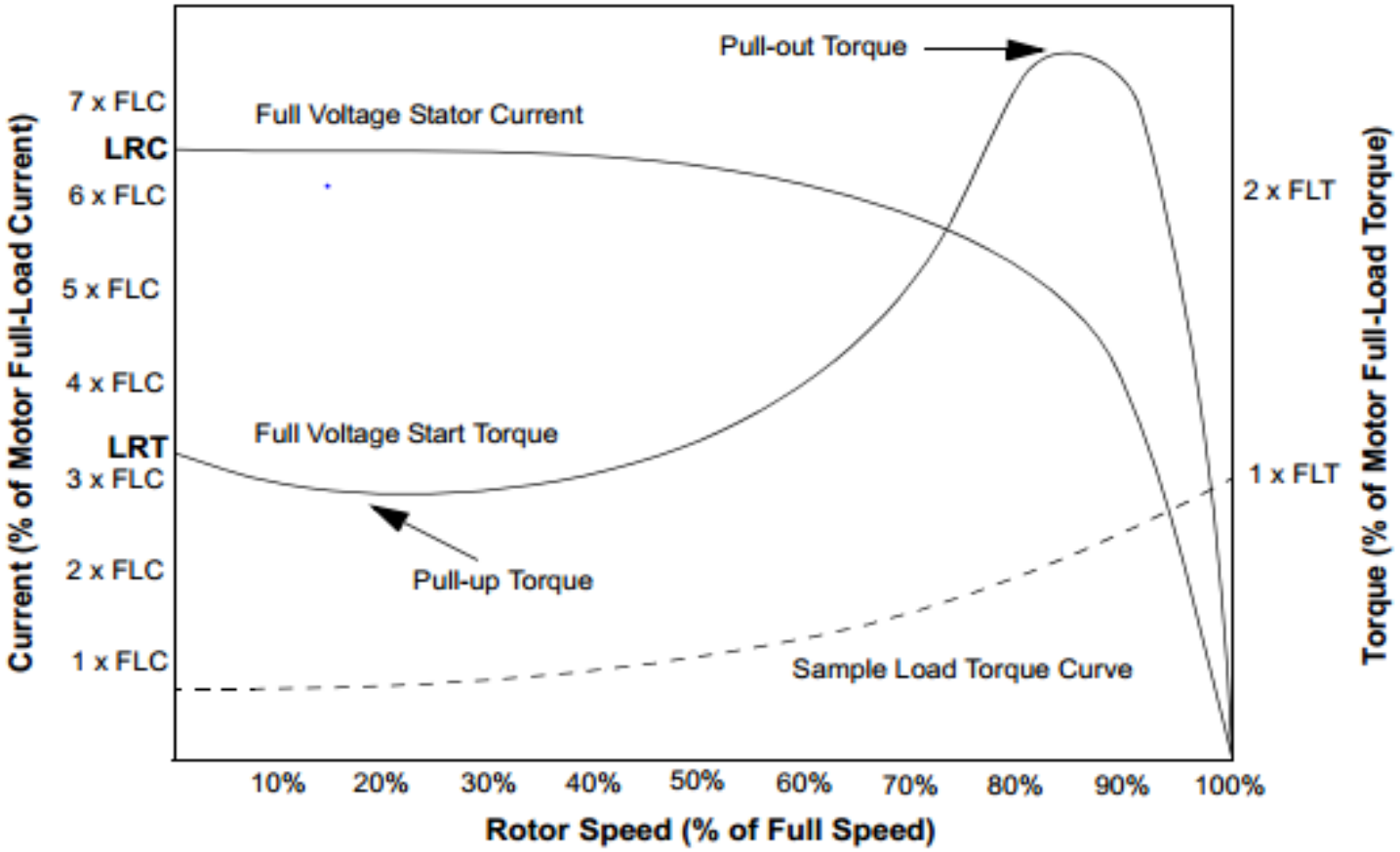
Motor Speed

- n – Rotations per minute (RPM)
- ω – Angular Speed (radians/s)

  $\omega=2\pi f$

  f – frequency (in Hz)

Typical Torque-Speed Curve of 3-phase AC Induction Motor



LRC –Locked Rotor Current, LRT- Locked Rotor Torque, FLC- Full Load Current, FLT- Full Load Torque

Motor torque

$$Torque\left[N.m\right] = \frac{Power\left[W\right]}{speed\left[rad/s\right]}$$

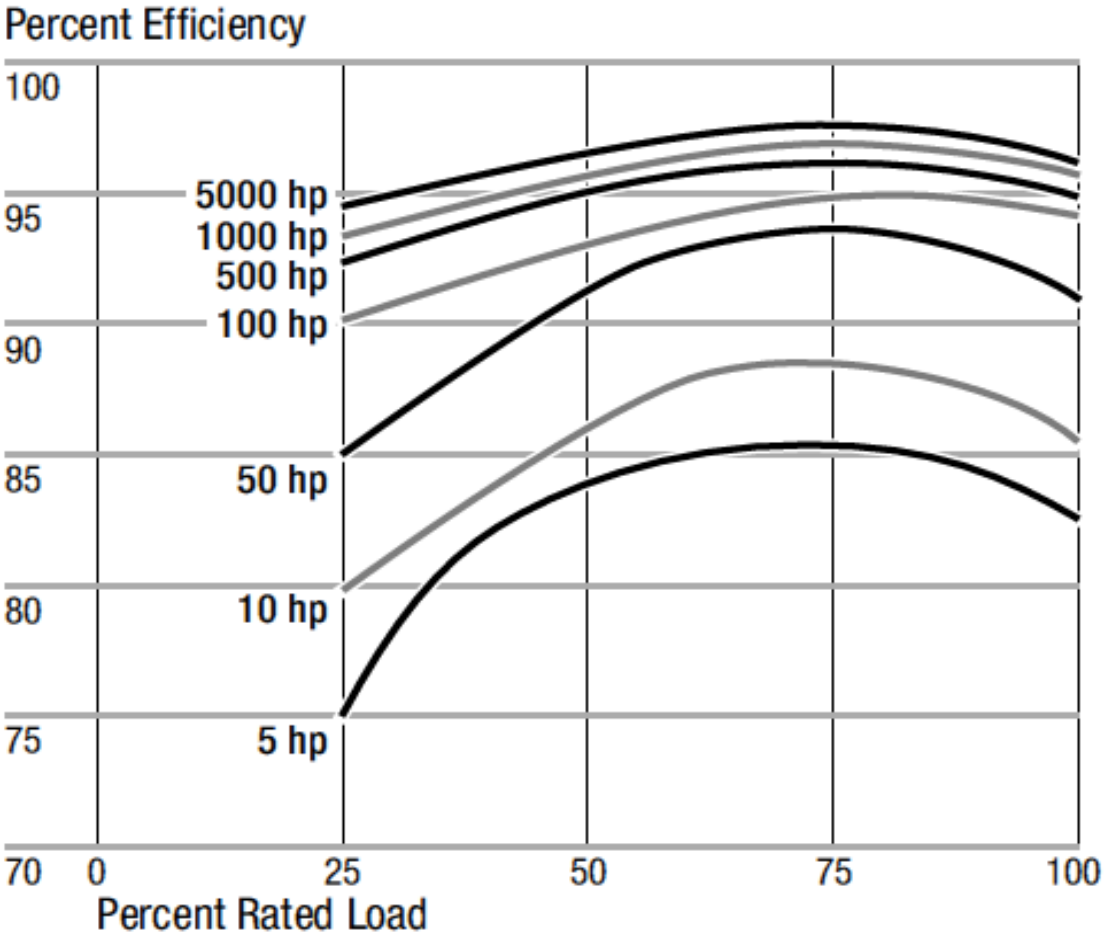
$$Torque\left[N.m\right] = \frac{Power\left[W\right]}{2\pi \times speed\left[rps\right]}$$

$$Torque\left[N.m\right] = \frac{Power\left[W\right]}{2\pi \times speed\left[rpm\right]/60}$$

Motor torque

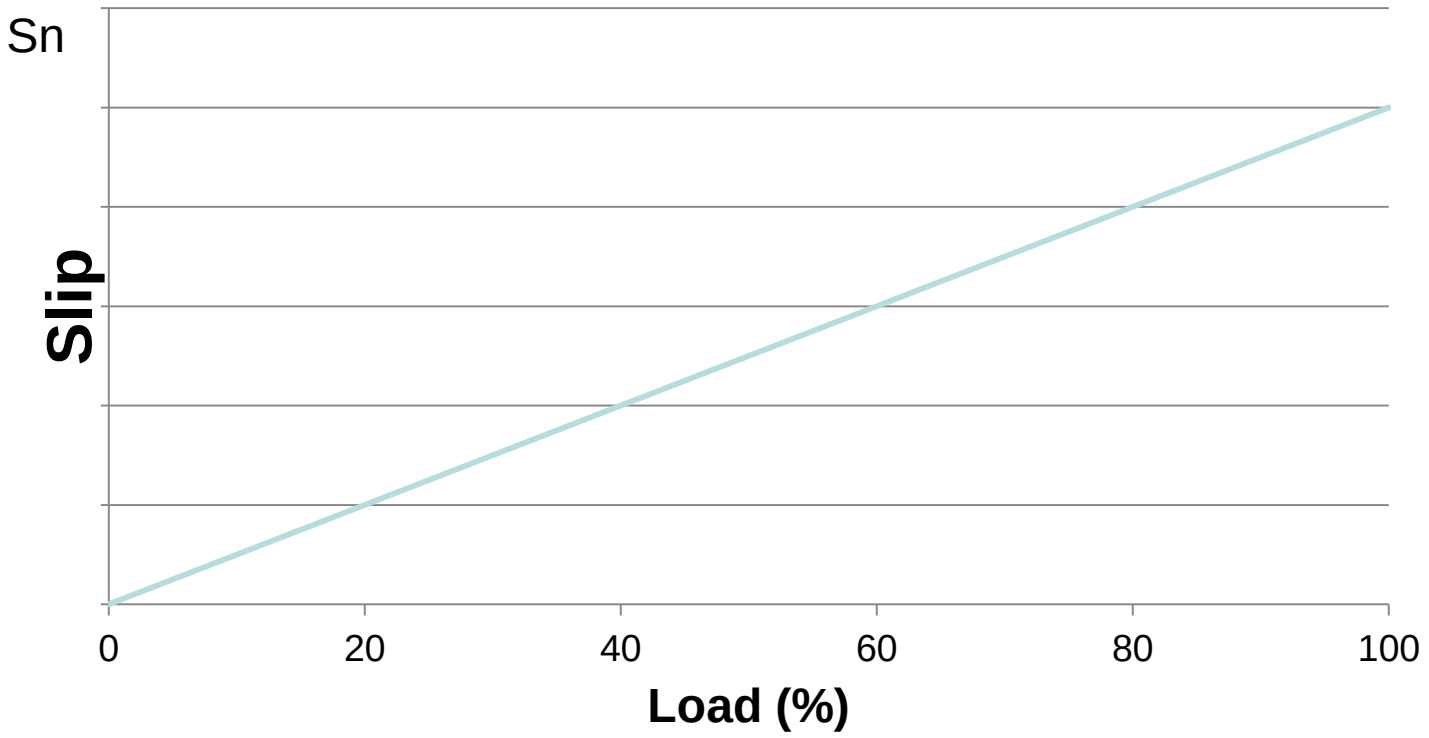
- **Starting torque** – the torque produced at zero speed. If the motor is to turn a load that is difficult to start (a high inertia load) one would choose a motor with high starting torque.
- **Pull-up torque** – the minimum torque produced during acceleration from standstill to operating speed. This may be critical for an application that needs power to go through some temporary barriers before achieving the working level output.
- **Breakdown torque** – the maximum torque that the motor can produce before stalling.
- **Full load torque** (also braking torque) – the torque produced at full load speed that gives the rated output of the motor. At this point the torque times the speed equals the nameplate power rating.

Efficiency vs Load



hp - horsepower

Motor Slip Variation with Load $V=V_n$



Note- For constant power loads slip varies roughly inversely with (Voltage)^2, e.g. Voltage increase of 5%, leads to decrease of about 10% in slip

Load Characteristics

There are three basic types of loads in terms of T=f(w):

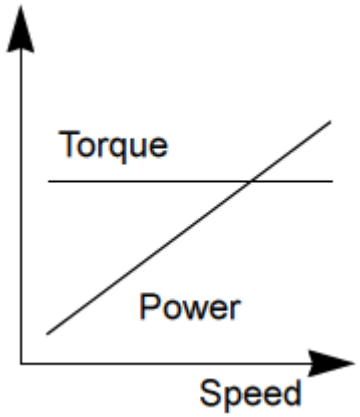
- Variable torque
- Constant torque
- Constant horsepower

In terms load variation the loads can be:

- Cyclic loads.
- Constant loads

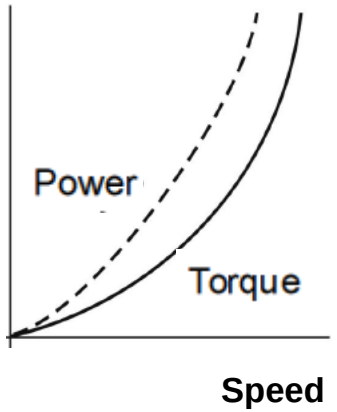
Types of Loads

Constant Torque / Variable Speed



e.g: screw compressors, conveyors and feeders

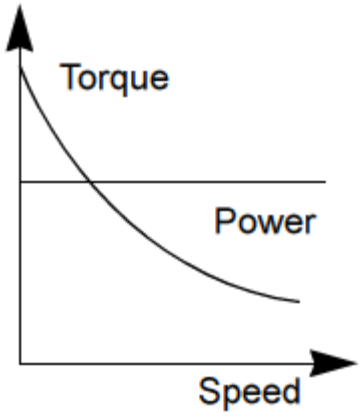
Variable Torque / Variable Speed



e.g: centrifugal pumps, fans

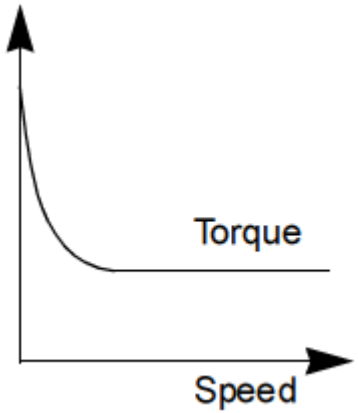
Types of Loads

Variable Torque / Constant Power



e.g. Traction drives, winders, rolling mills

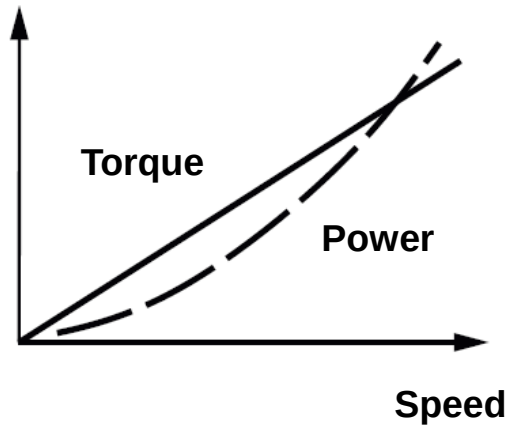
High Starting Breakaway Torque / Constant Torque



e.g. Extruders, screw pumps

Types of Loads

LinearTorque / Power ~ n^2



e.g. Calenders with viscous friction coupling, mixers, eddy current brakes

Duty Cycles (IEC rating - IEC 60034-1)

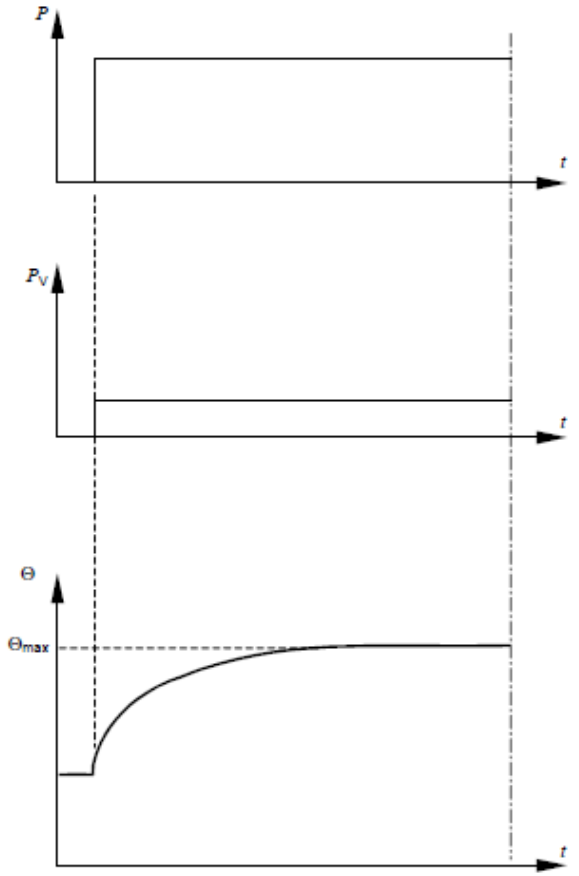
Ref.	Duty Cycle Type	Description
S1	Continuous running duty	Operation at constant load of sufficient duration for the thermal equilibrium to be reached.
S2	Short-time duty	Operation at constant load during a given time, less than required to reach the thermal equilibrium, followed by a rest enabling the machine to reach a temperature similar to that of the coolant (2 Kelvin tolerance)
S3	Intermittent periodic duty	A sequence of identical duty cycles, each including a period of operation at constant load and a rest (without connection to the mains). For this type of duty, the starting current does not significantly affect the temperature rise.
S4	Intermittent periodic with a high startup torque	A sequence of identical duty cycles, each consisting of a significant period of starting, a period under constant load and a rest period.
S5	Intermittent periodic duty with high startup torque and electric braking	A sequence of identical cycles, each consisting of a period of starting, a period of operation at constant load, followed by rapid electric braking and a rest period.
S6	Continuous operation periodic duty	A sequence of identical duty cycles, each consisting of a period of operation at constant load and a period of operation at no-load. There is no rest period.

Duty Cycles (IEC rating - IEC 60034-1)

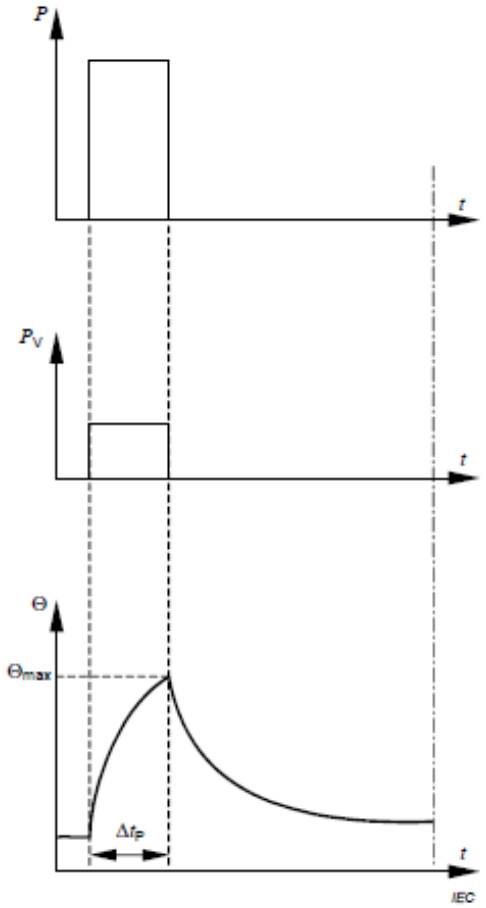
Ref.	Duty Cycle Type	Description
S7	Continuous operation periodic duty with electric braking	A sequence of identical duty cycles, each consisting of a period of starting, a period of operation at constant load, followed by an electric braking. There is no rest period.
S8	Continuous operation periodic duty with related load and speed changes	A sequence of identical duty cycles, each consisting of a period of operation at constant load corresponding to a predetermined speed of rotation, followed by one or more periods of operation at another constant load corresponding to the different speeds of rotation (e.g., duty). There is no rest period. The period of duty is too short to reach the thermal equilibrium.
S9	Duty with non-periodic load and speed variations	Duty in which, generally, the load and the speed vary non-periodically within the permissible range. This duty includes frequent overloads that may exceed the full loads.
S10	Duty with discrete constant loads and speeds	A duty consisting of a specific number of discrete values of load (or equivalent loading) and if applicable, speed, each load/speed combination being maintained for sufficient time to allow the machine to reach thermal equilibrium. The minimum load within a duty cycle may have the value zero (no-load or de-energized and at rest).

Duty Cycles (IEC rating - IEC 60034-1)

S1



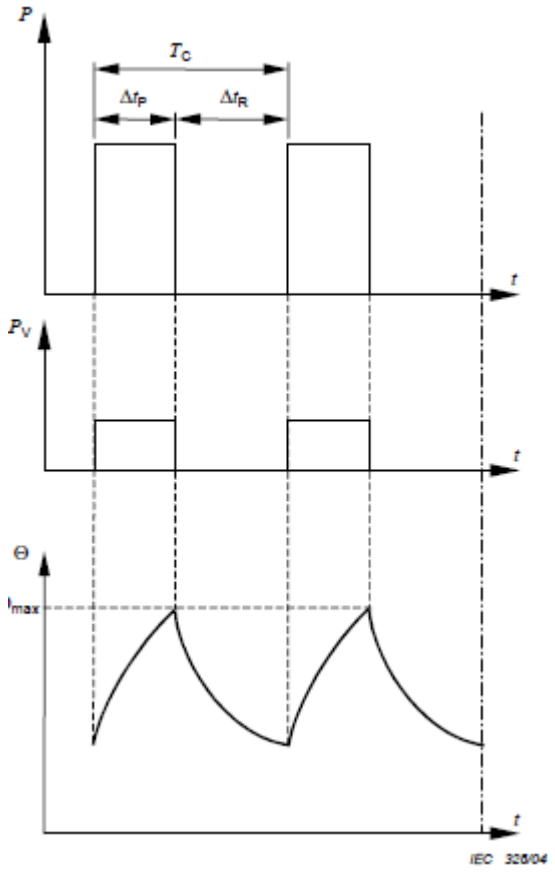
S2



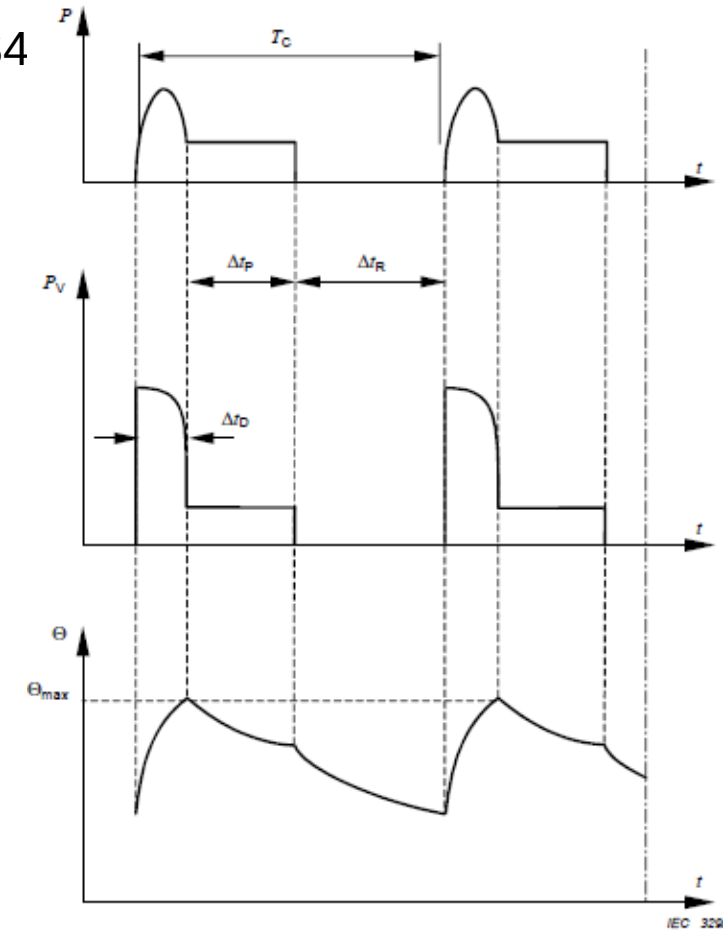
Key	
P	load
P_V	electrical losses
$Θ$	temperature
$Θ_{max}$	maximum temperature attained
t	time
$Δt_P$	operation time at constant load

Duty Cycles (IEC rating - IEC 60034-1)

S3



S4

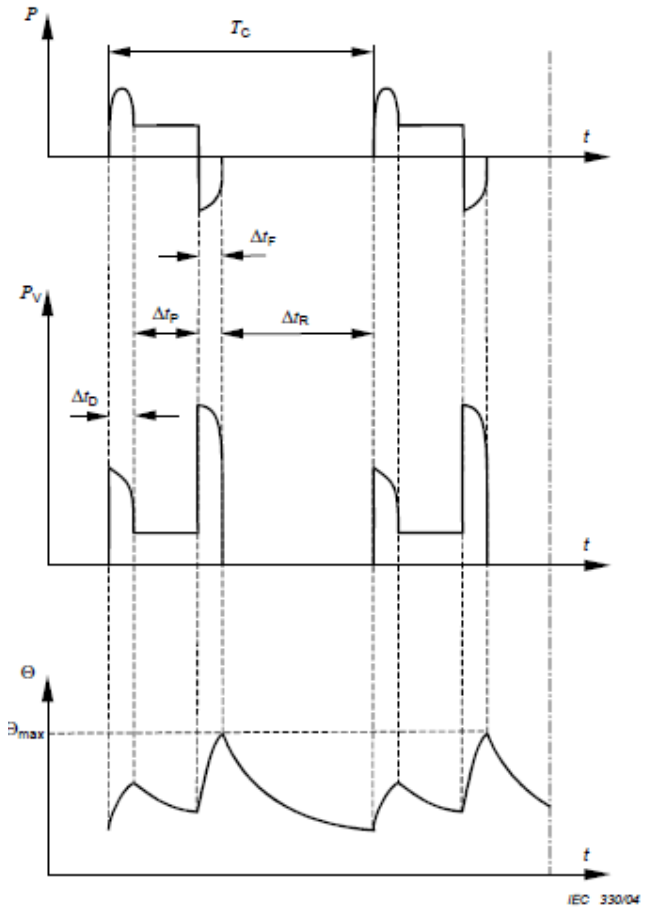


Key

P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
t	time
Δt_P	operation time at constant load

Duty Cycles (IEC rating - IEC 60034-1)

S5



Key

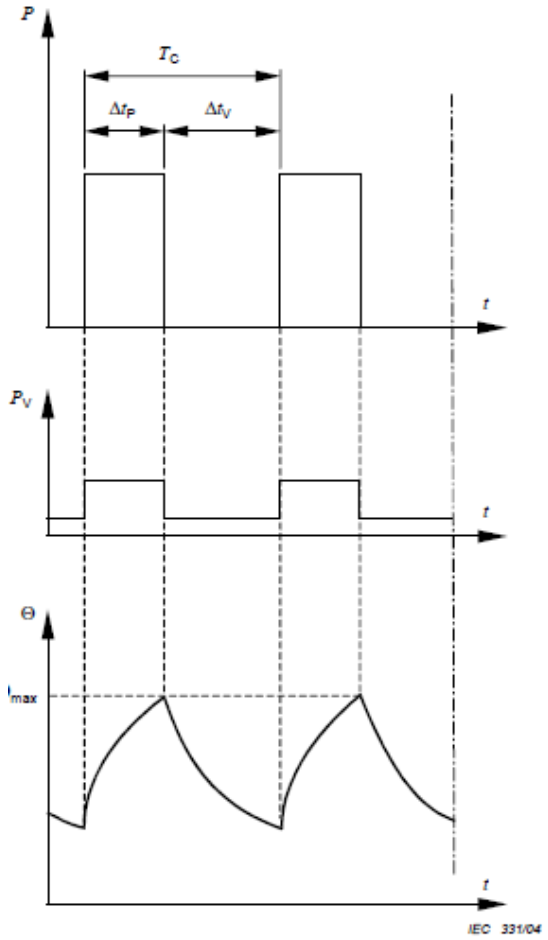
P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
t	time

Cyclic duration factor = $(\Delta t_D + \Delta t_P + \Delta t_F)/T_C$

T_C	time of one load cycle
Δt_D	starting/accelerating time
Δt_P	operation time at constant load
Δt_F	time of electric braking
Δt_R	time de-energized and at rest

Duty Cycles (IEC rating - IEC 60034-1)

S6



Key

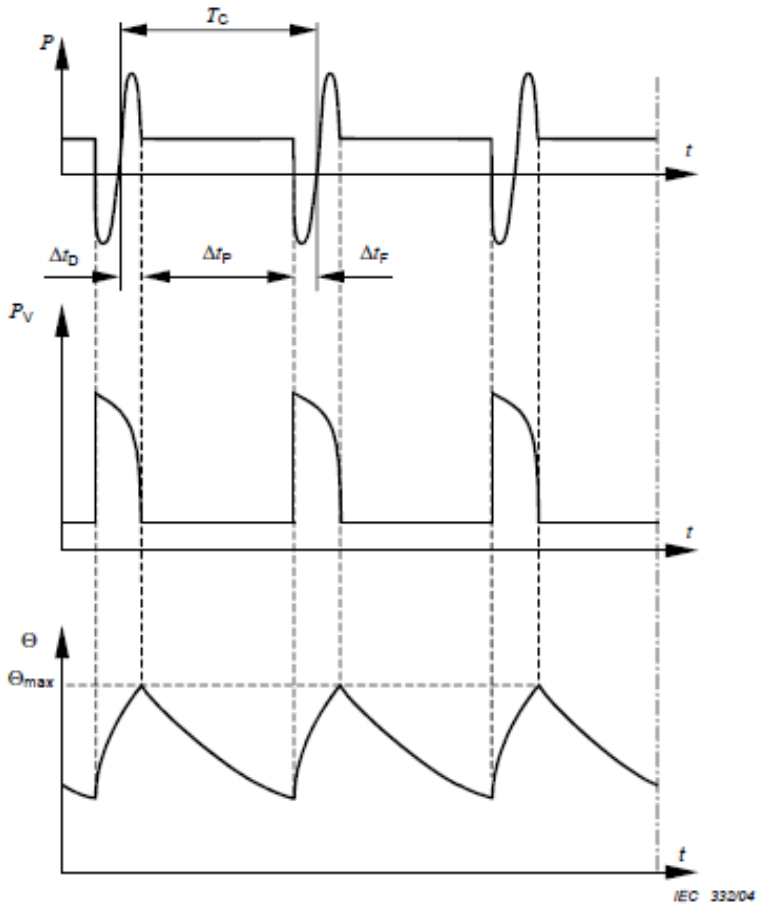
P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained

Cyclic duration factor = $\Delta t_P / T_C$

t	time
T_C	time of one load cycle
Δt_P	operation time at constant load
Δt_V	operation time at no-load

Duty Cycles (IEC rating - IEC 60034-1)

S7



Key

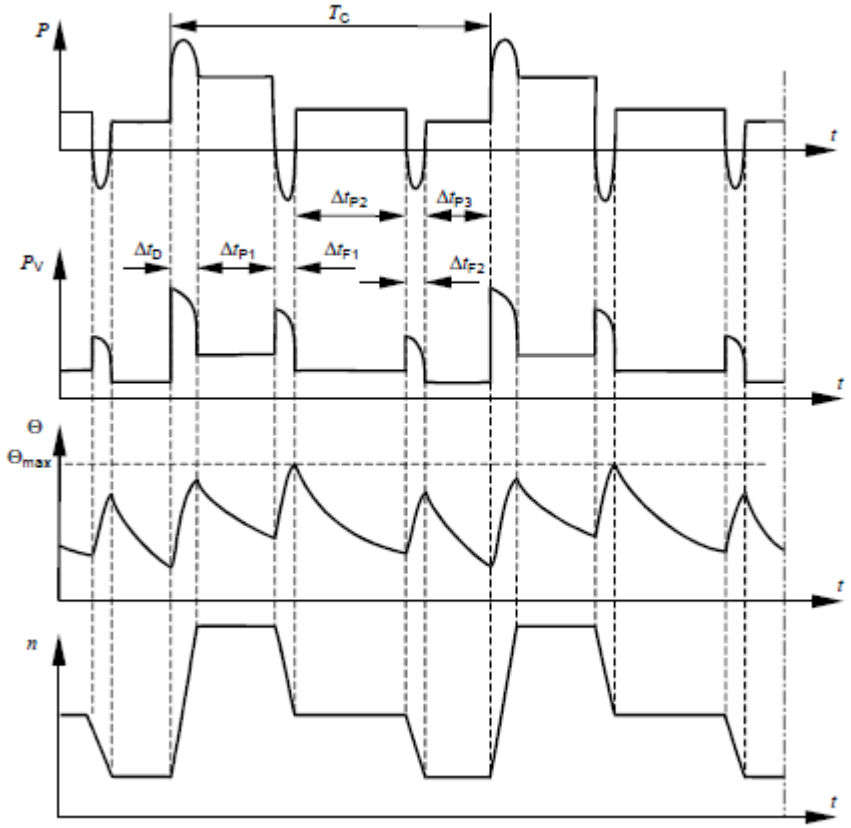
P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained

Cyclic duration factor = 1

t	time
T_C	time of one load cycle
Δt_D	starting/accelerating time
Δt_P	operation time at constant load
Δt_F	time of electric braking

Duty Cycles (IEC rating - IEC 60034-1)

S8



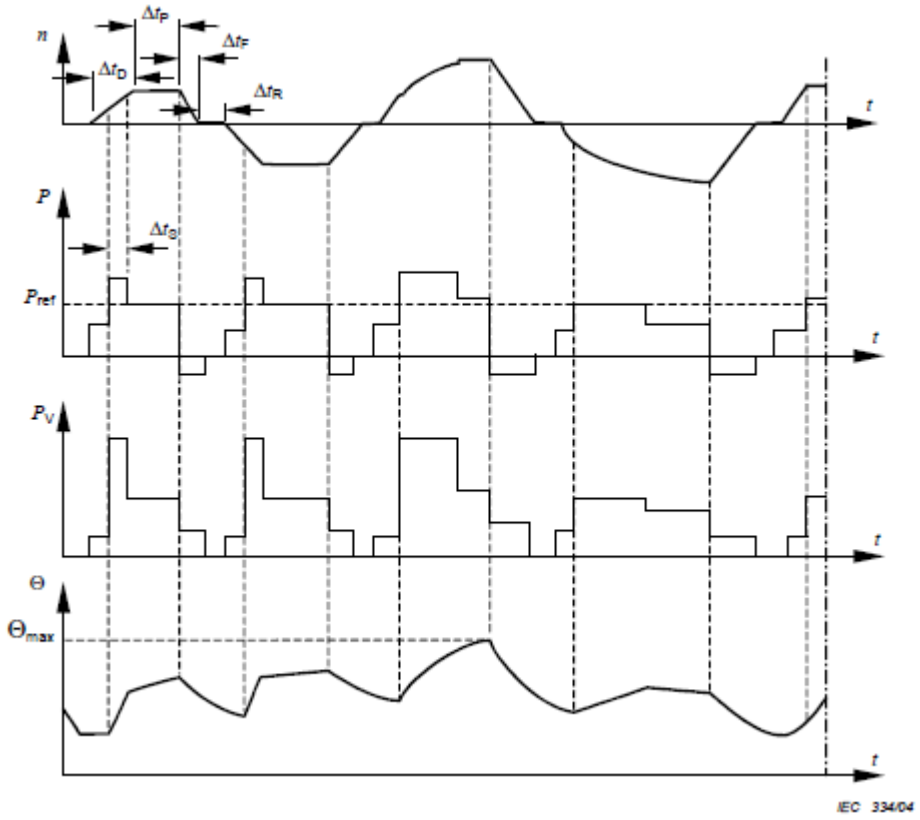
Key

P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
n	speed
t	time
T_C	time of one load cycle
Δt_D	starting/accelerating time
Δt_P	operation time at constant load (P1, P2, P3)
Δt_F	time of electric braking (F1, F2)

Cyclic duration factor = $(\Delta t_D + \Delta t_{P1})/T_C$; $(\Delta t_{F1} + \Delta t_{P2})/T_C$; $(\Delta t_{F2} + \Delta t_{P3})/T_C$

Duty Cycles (IEC rating - IEC 60034-1)

S9

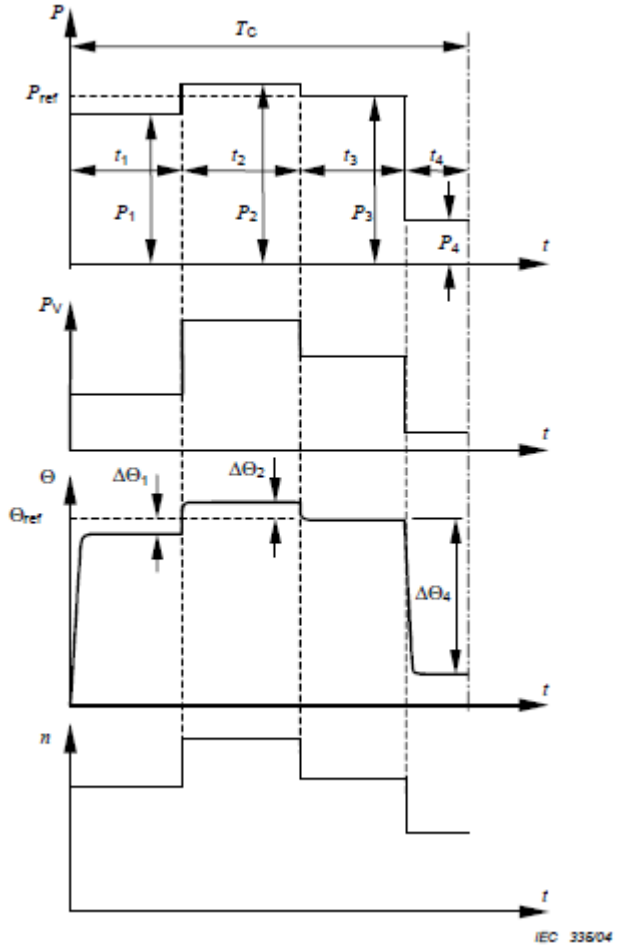


Key

P	load
P_{ref}	reference load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
n	speed
t	time
Δt_D	starting/accelerating time
Δt_P	operation time at constant load
Δt_F	time of electric braking
Δt_R	time de-energized and at rest
Δt_S	time under overload

Duty Cycles (IEC rating - IEC 60034-1)

S10



Key

P	load
P_{ref}	reference load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
n	speed
t	time
Δt_D	starting/accelerating time
Δt_P	operation time at constant load
Δt_F	time of electric braking
Δt_R	time de-energized and at rest
Δt_S	time under overload

Thank you