

ECE 8830 - Electric Drives

Topic 11: Slip-Recovery Drives for Wound-Field Induction Motors

Spring 2004

Introduction

In a **wound-field** induction motor the slip rings allow easy recovery of the slip power which can be electronically controlled to control the speed of the motor.

The oldest and simplest technique to invoke this **slip-power recovery** induction motor speed control is to mechanically vary the rotor resistance.

Introduction (cont'd)

Slip-power recovery drives are 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

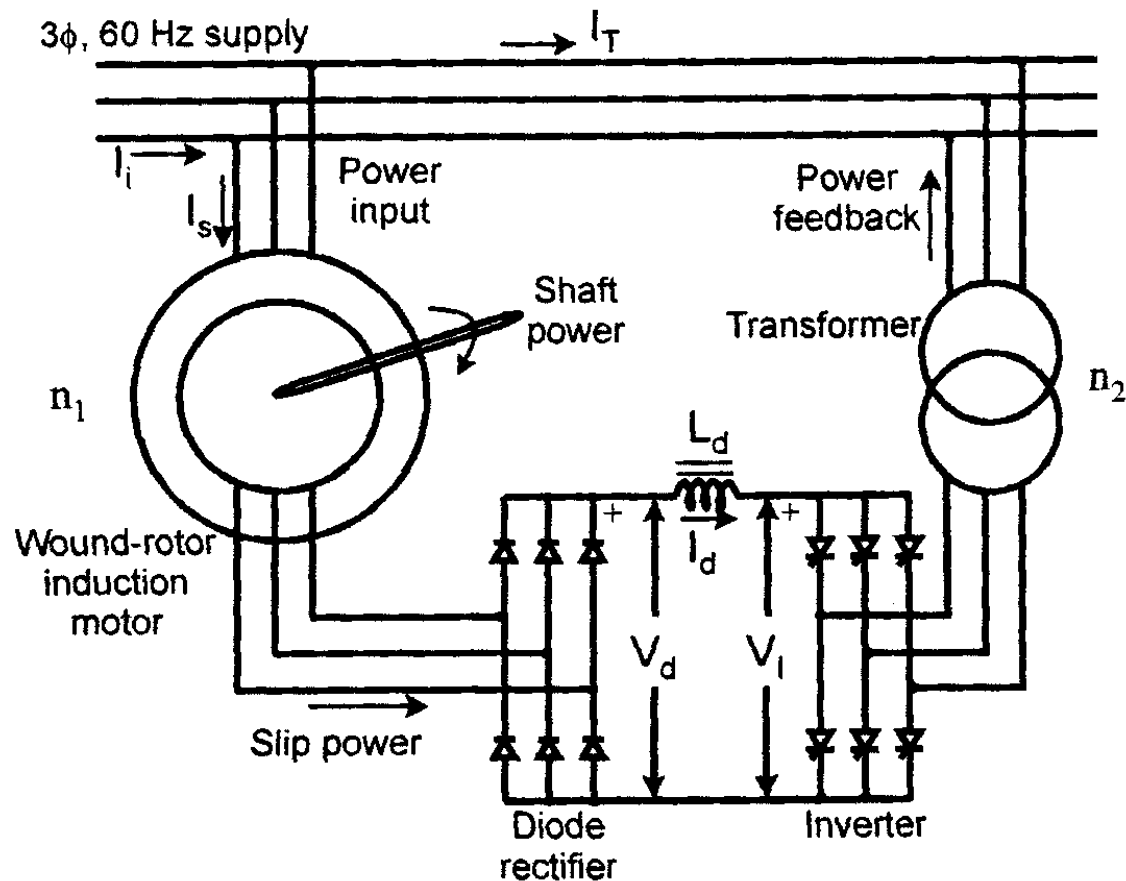
Static Kramer Drive

Instead of wasting the slip power in the rotor circuit resistance, a better approach is to convert it to ac line power and return it back to the line. Two types of converter provide this approach:

- 1) **Static Kramer Drive** - only allows operation at sub-synchronous speed.
- 2) **Static Scherbius Drive** - allows operation above and below synchronous speed.

Static Kramer Drive (cont'd)

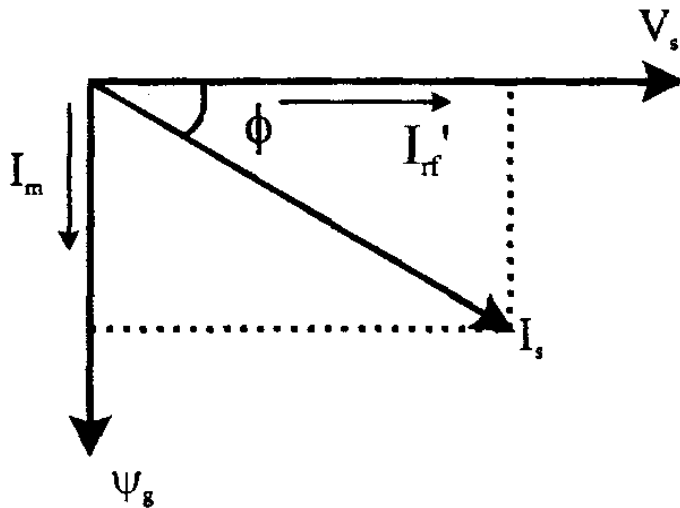
A schematic of the static Kramer drive is shown below:



Static Kramer Drive (cont'd)

The machine air gap flux is created by the stator supply and is essentially constant. The rotor current is ideally a 6-step wave in phase with the rotor voltage.

The motor fundamental phasor diagram referred to the stator is as shown below:



V_s = stator phase voltage,
 I_s = stator current, I_{rf}' =
fundamental rotor current
referred to the stator, ψ_g = air
gap flux, I_m = magnetizing
current, and ϕ = PF angle.

Static Kramer Drive (cont'd)

The voltage V_d is proportional to slip, s and the current I_d is proportional to torque. At a particular speed, the inverter's firing angle can be decreased to decrease the voltage V_1 . This will increase I_d and thus the torque. A simplified torque-speed expression for this implementation is developed next.

Static Kramer Drive (cont'd)

Voltage V_d (neglecting stator and rotor voltage drops) is given by:

$$V_d = \frac{1.35sV_L}{n_1}$$

where s =per unit slip, V_L =stator line voltage and n_1 =stator-to-rotor turns ratio. The inverter dc voltage V_I is given by:

where n_2 =transformer turns ratio (line side to inverter side) and α =inverter firing angle.

$$V_I = \frac{1.35V_L |\cos \alpha|}{n_2}$$

Static Kramer Drive (cont'd)

For inverter operation, $\pi/2 < \alpha < \pi$. In steady state $V_d = V_1$
(neglecting ESR loss in inductor)

$$\Rightarrow s = \frac{n_1}{n_2} |\cos \alpha|$$

The rotor speed ω_r is given by:

if $n_1 = n_2$

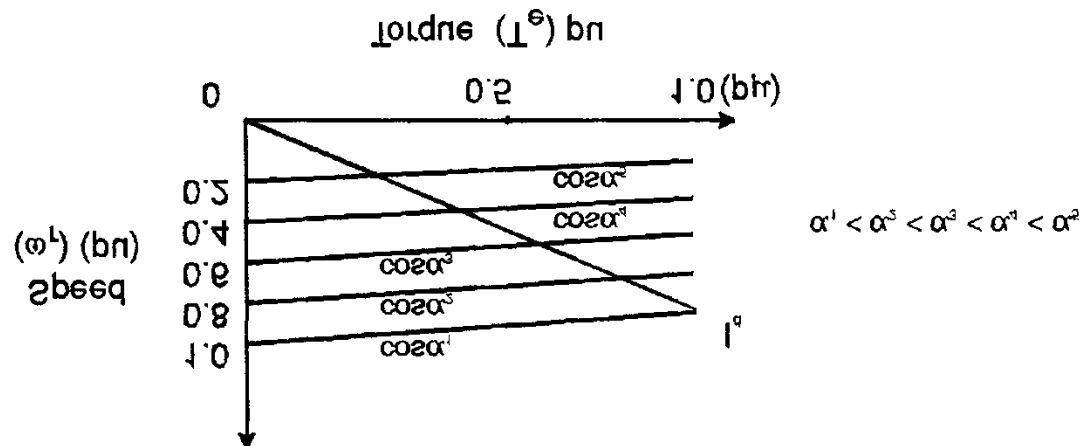
Thus rotor speed can be controlled by controlling inverter firing angle, α .
At $\alpha = \pi$, $\omega_r = 0$ and at $\alpha = \pi/2$, $\omega_r = \omega_e$.

Static Kramer Drive (cont'd)

It can be shown (see text) that the torque may be expressed as:

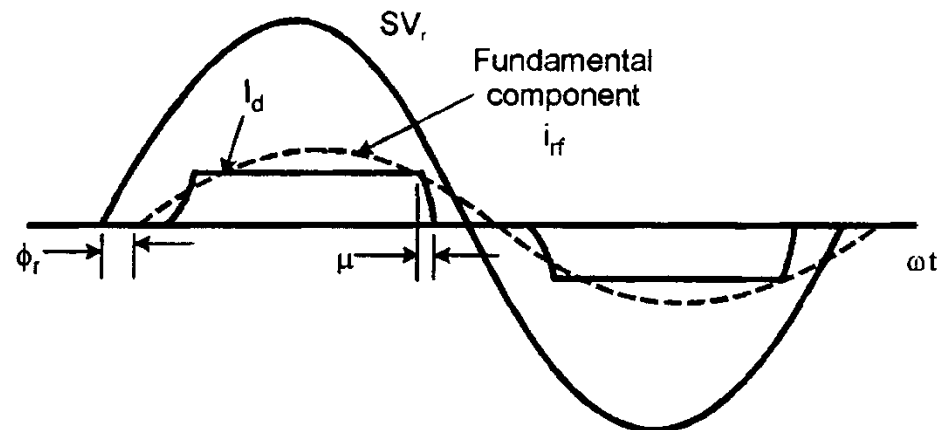
$$T_e = \left(\frac{P}{2} \right) \frac{1.35 V_L}{\omega_e n_1} I_d$$

The below figure shows the torque-speed curves at different inverter angles.



Static Kramer Drive (cont'd)

The fundamental component of the rotor current lags the rotor phase voltage by ϕ_r because of a commutation overlap angle μ (see figure below). At near zero slip when rotor voltage is small, this overlap angle can exceed $\pi/3$ resulting in shorting of the upper and lower diodes.



Static Kramer Drive (cont'd)

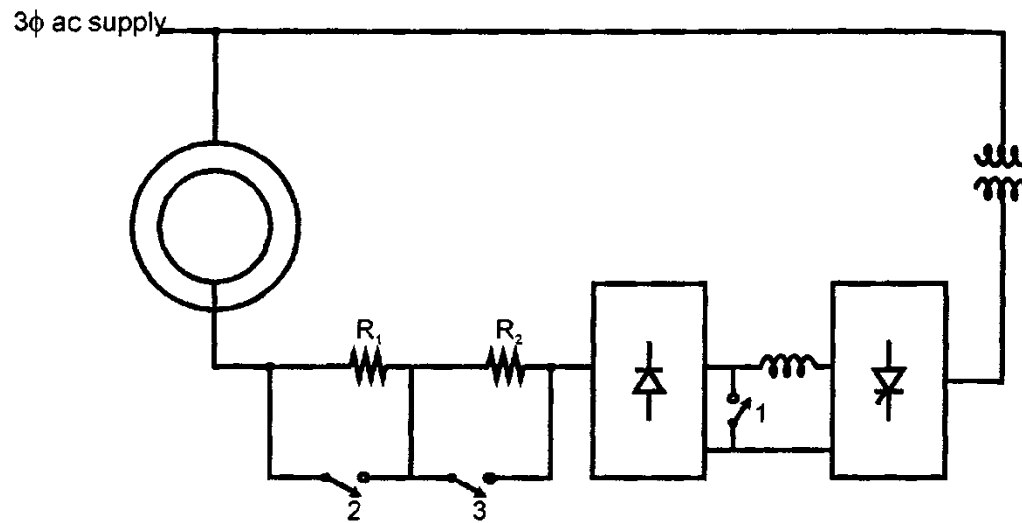


Figure 7.9 Motor starting method

The motor starts with switches 2 and 3 open. As the motor builds up speed, switches 2 and 3 are sequentially closed until desired s_{max} value is reached after which switch 1 is opened and the drive controller takes over.

Harmonics in a Static Kramer Drive

The rectification of slip-power causes harmonic currents in the rotor which are reflected back into the stator. This results in increased machine losses. The harmonic torque is small compared to average torque and can generally be neglected in practice.