Introduction to Electrical Drives

Lecture 1 (04-01-2024)

Electrical Drives

Drives are systems employed for **motion control**

Require **prime movers**

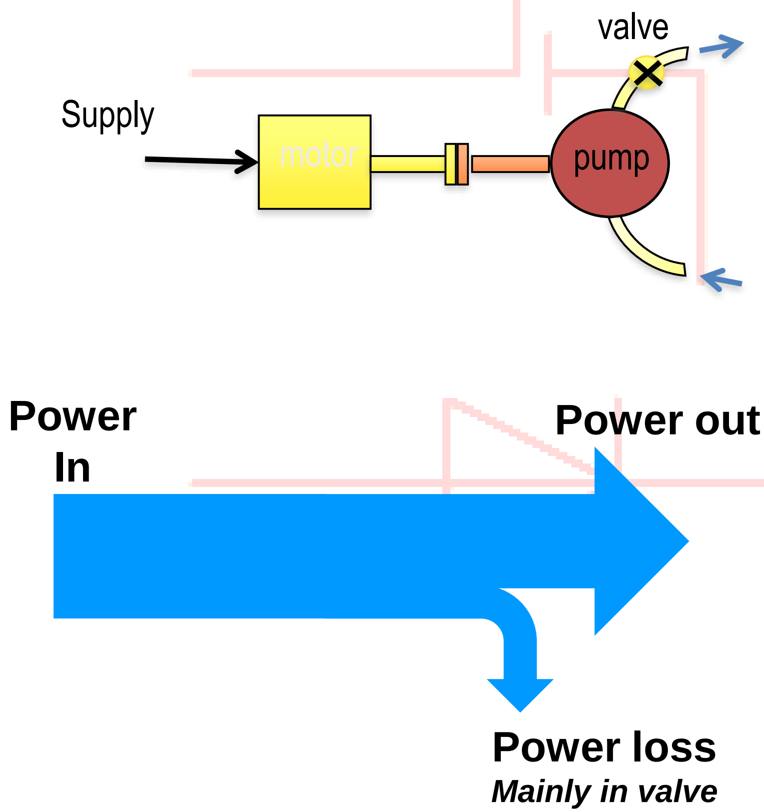
Drives that employ **electric motors** as prime movers are known as **Electrical Drives**

Electrical Drives

- About 50% of electrical energy used for drives
- Can be either used for fixed speed or variable speed
- 75% - constant speed, 25% variable speed (expanding)
- This course will be covering variable speed drives

Example on VSD application

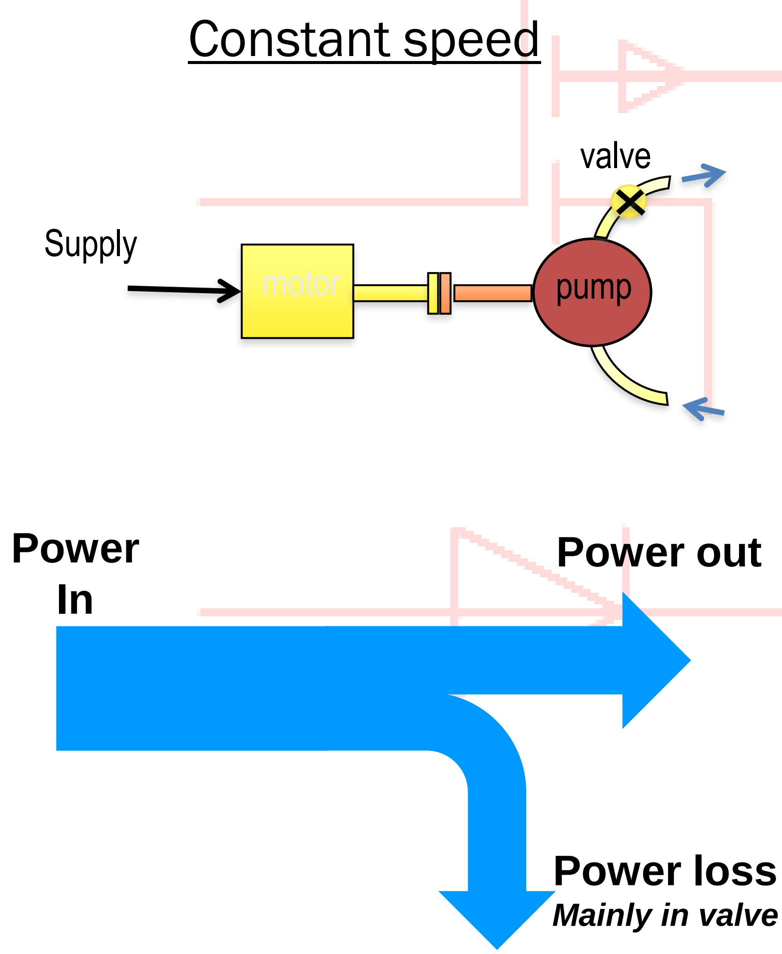
Constant speed

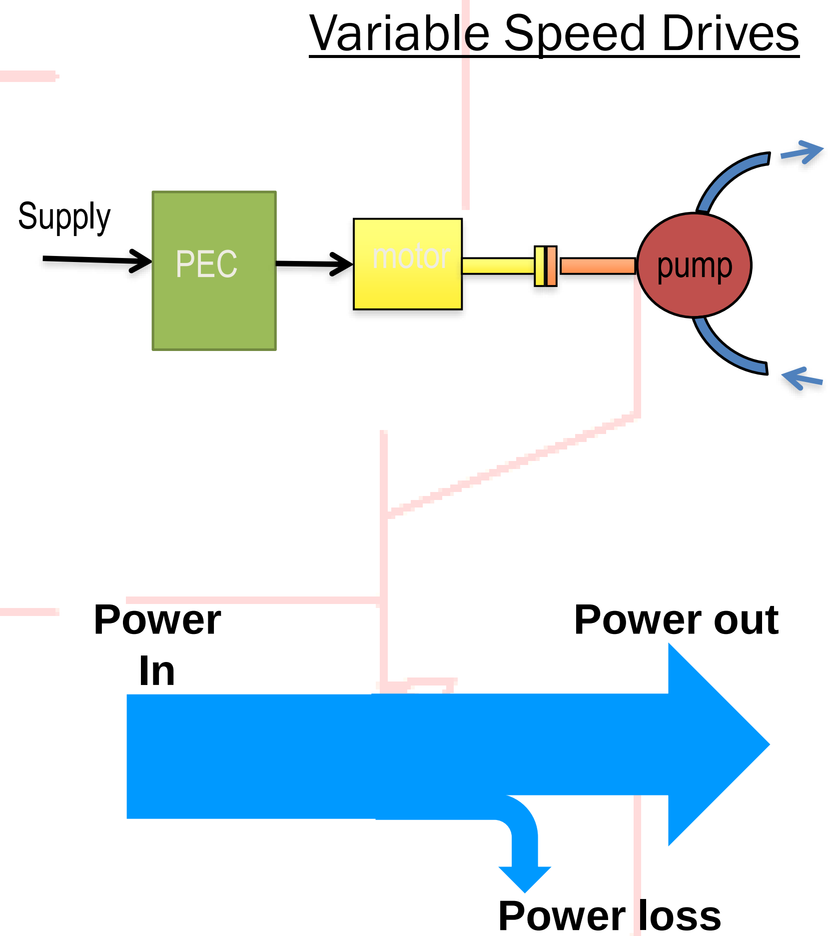


Variable Speed Drives

Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

Example on VSD application

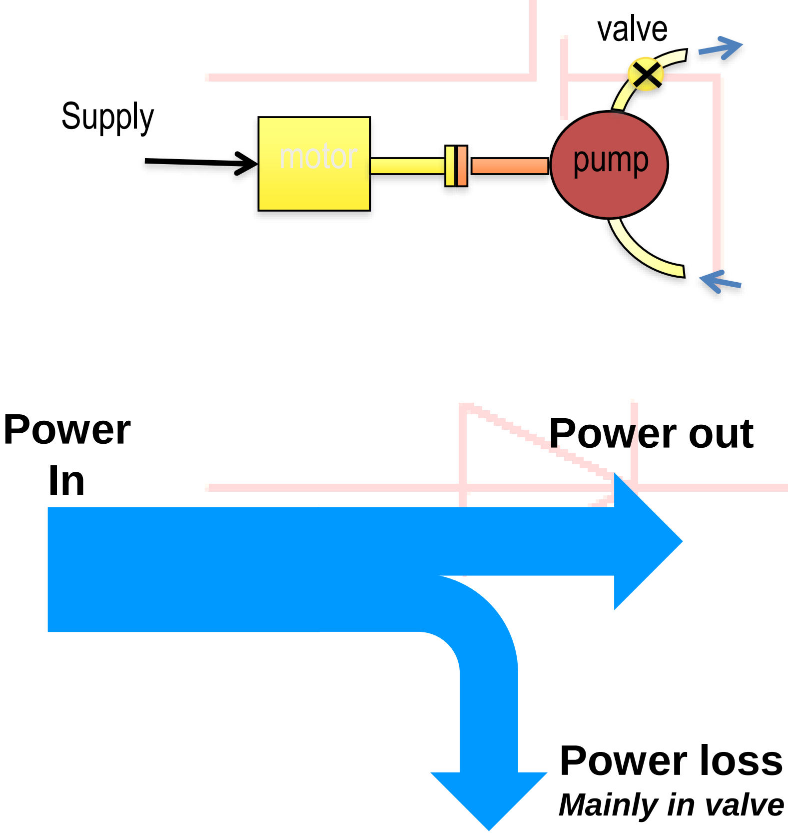




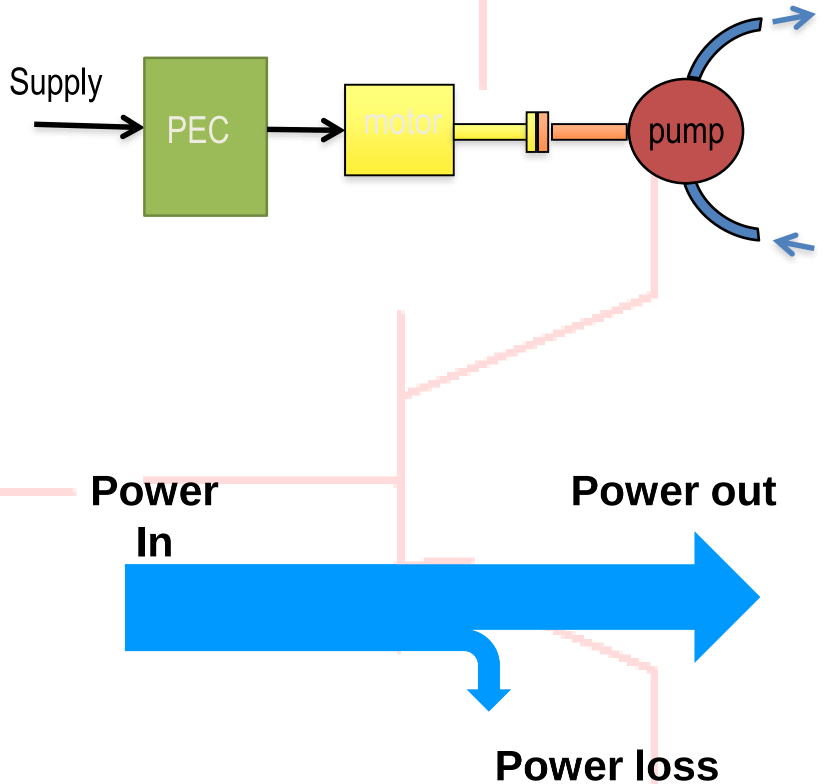
Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

Example on VSD application

Constant speed

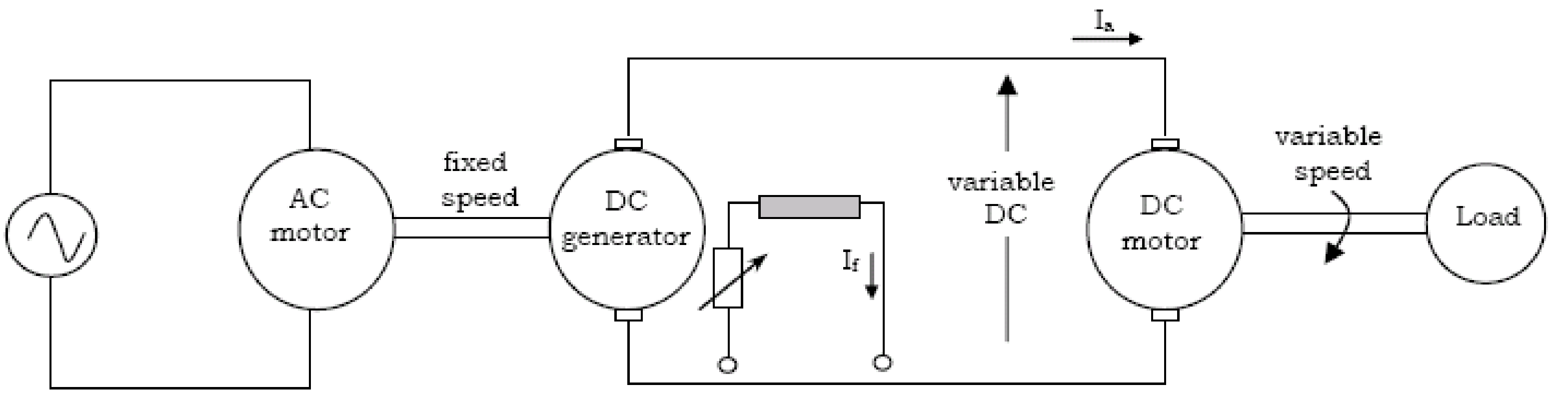


Variable Speed Drives



Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

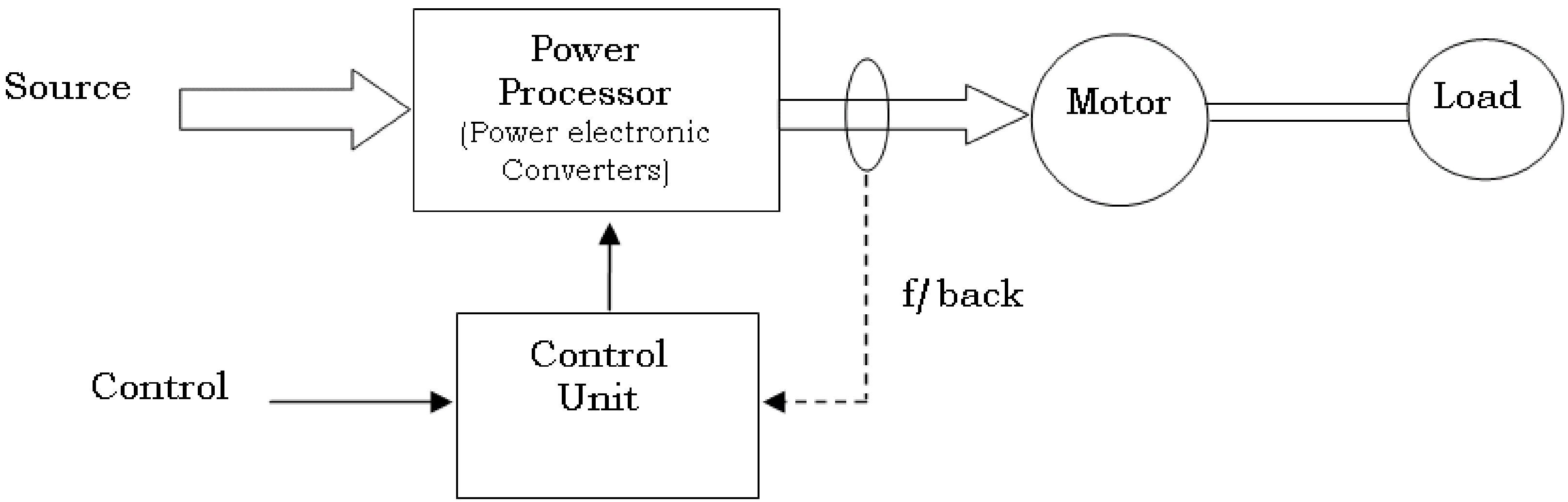
Conventional electric drives (variable speed)



- Bulky
- Inefficient
- inflexible

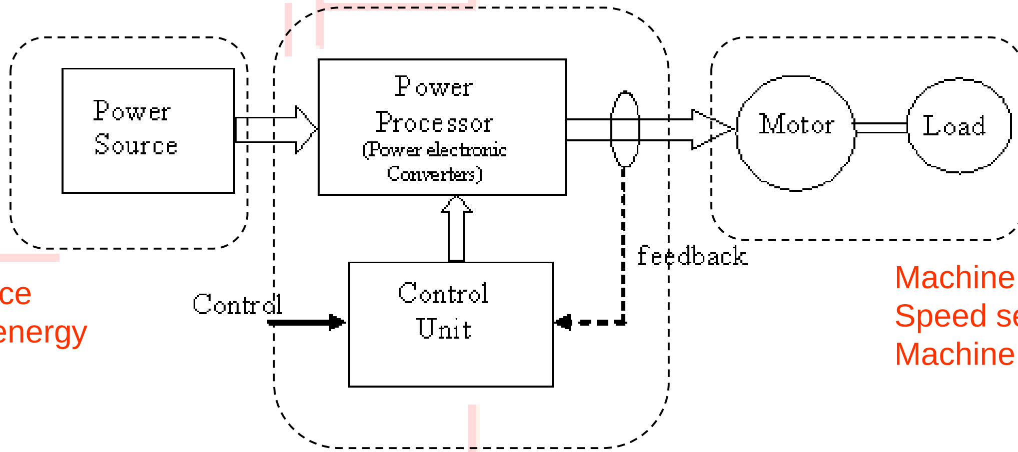
Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

Modern electric drives (With power electronic converters)



- Small
- Efficient
- Flexible

Modern electric drives



Utility interface
Renewable energy

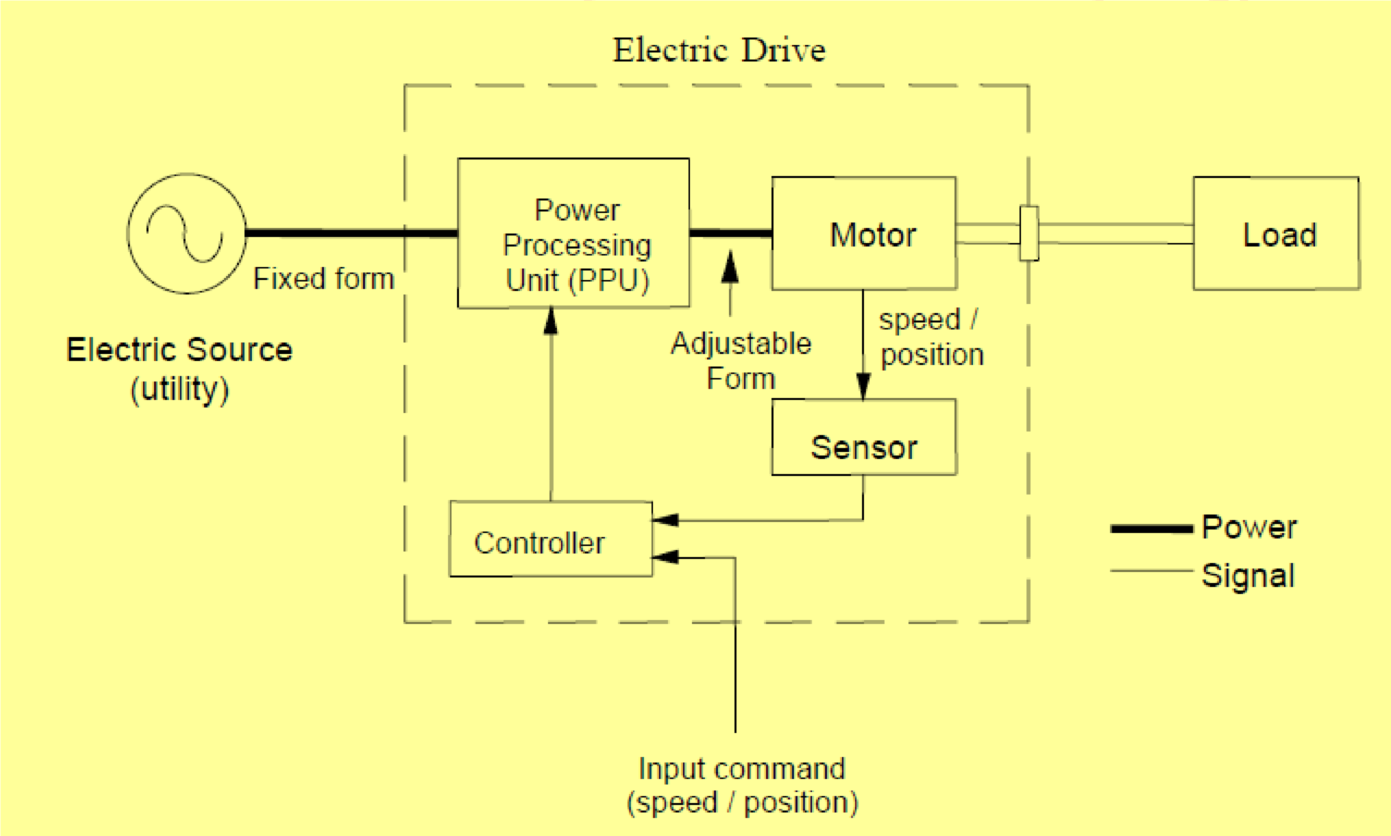
Non-linear control
Real-time control
DSP application
PFC
Speed sensorless
Power electronic converters

Machine design
Speed sensorless
Machine Theory

- Inter-disciplinary (PE, control system, machine design, sensors)
- Several research area
- Expanding

Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

Block Diagram of Electric drives



➢Role of Electric Drive: Efficient conversion of power from electrical to mechanical and vice versa

➢Role of PPU: Delivers appropriate form of frequency and voltage to the machine (as required by the load or the prime mover)

Power Processor

- Modulates power flow from source to motor in such a manner that motor is imparted speed-torque characteristics required by the load.
- During transient operations, it restricts source and motor currents to permissible limits.
- Selects the mode of operation of the motor.
- Converts the electrical energy of the source in the form suitable for motor.

Converter

Advantages of Electrical Drives

- Flexible Control Characteristics
  - Steady state and dynamic characteristics can be shaped to satisfy load requirements
  - Speed can be controlled in wide range
  - Electric braking can be employed
- They are available in wide range of speed, power and torque.
- Electric motors have high efficiency, low no-load losses and considerable short time overloading capacity
- They can be operated in any operating conditions
- Do not pollute the environment
- Can operate in all four quadrants of speed-torque plane
- Unlike other prime-movers, there is no need to refuel or warm-up the motor.
- They are powered by electrical energy.

Parts of Electrical Drives

- Load
- Motor
- Power Modulator
- Control Unit
- Source

Electric Motor

- DC Motor
  - Shunt
  - Series
  - Compound
  - Permanent Magnet
- AC Motor
  - Induction Motor
    - Squirrel-cage IM
    - Slip-ring (wound rotor) IM
    - Linear
  - Synchronous Motors
    - Wound field
    - Permanent Magnet
- Brushless DC Motors
- Stepper Motors
- Switched Reluctance Motors

Overview of AC and DC drives

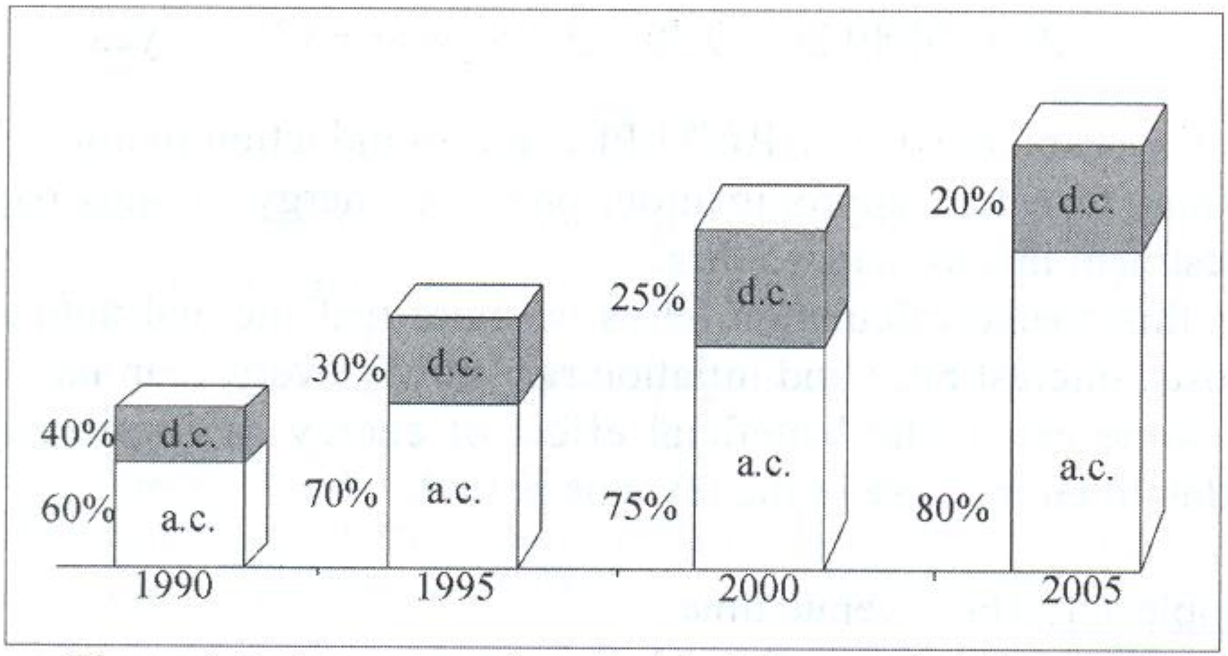
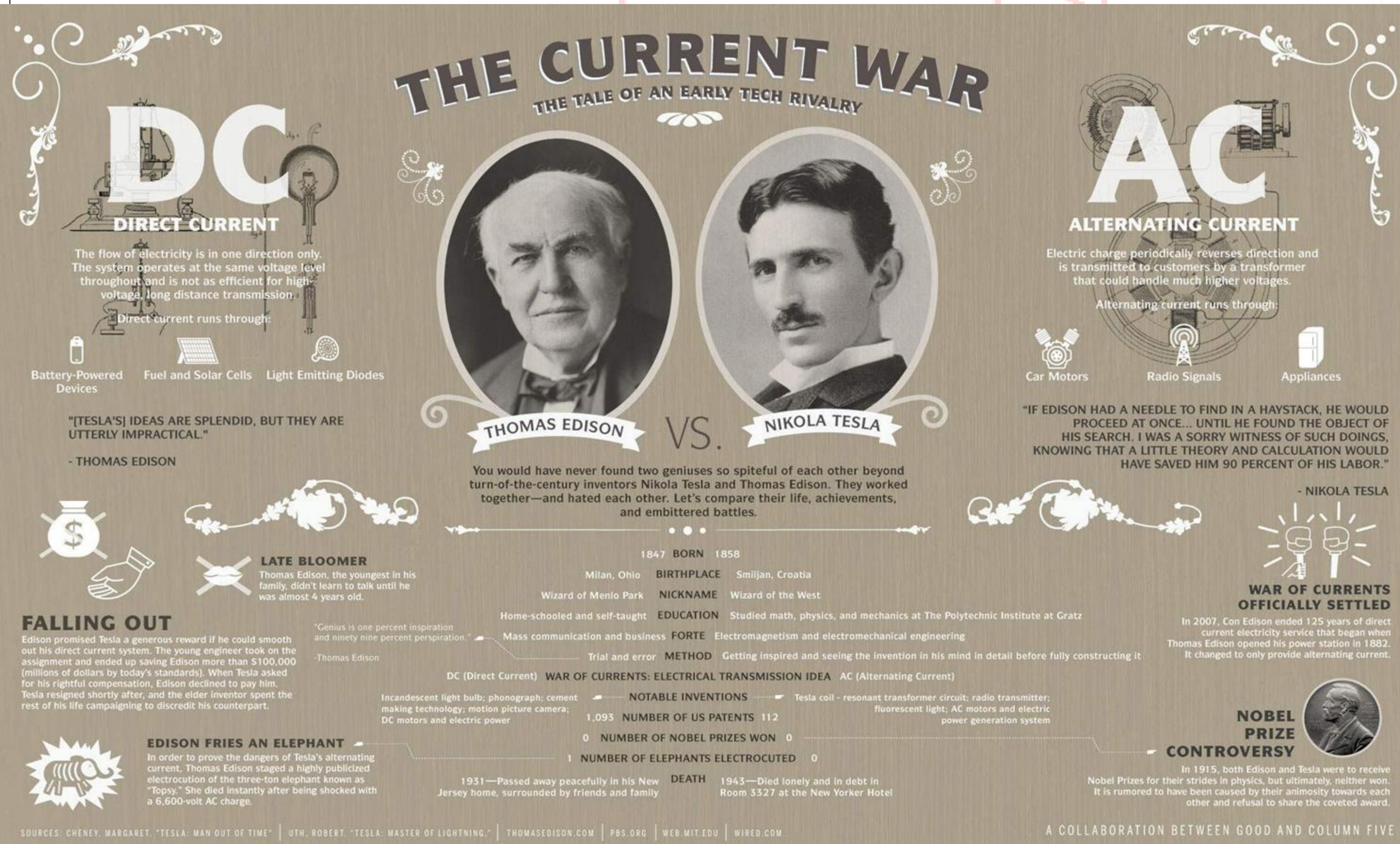


Figure 1.4. A.c. versus d.c. electric drives market dynamics

Extracted from *Boldea & Nasar*


THE CURRENT WAR
THE TALE OF AN EARLY TECH RIVALRY
DC
DIRECT CURRENT
The flow of electricity is in one direction only. The system operates at the same voltage level throughout and is not as efficient for high-voltage, long distance transmission.
Direct current runs through:
Battery-Powered Devices
Fuel and Solar Cells
Light Emitting Diodes
"[TESLA'S] IDEAS ARE SPLENDID, BUT THEY ARE UTTERLY IMPRACTICAL."
- THOMAS EDISON
AC
ALTERNATING CURRENT
Electric charge periodically reverses direction and is transmitted to customers by a transformer that could handle much higher voltages.
Alternating current runs through:
Car Motors
Radio Signals
Appliances
"IF EDISON HAD A NEEDLE TO FIND IN A HAYSTACK, HE WOULD PROCEED AT ONCE... UNTIL HE FOUND THE OBJECT OF HIS SEARCH. I WAS A SORRY WITNESS OF SUCH DOINGS, KNOWING THAT A LITTLE THEORY AND CALCULATION WOULD HAVE SAVED HIM 90 PERCENT OF HIS LABOR."
- NIKOLA TESLA
THOMAS EDISON
VS.
NIKOLA TESLA
You would have never found two geniuses so spiteful of each other beyond turn-of-the-century inventors Nikola Tesla and Thomas Edison. They worked together—and hated each other. Let's compare their life, achievements, and embittered battles.
LATE BLOOMER
Thomas Edison, the youngest in his family, didn't learn to talk until he was almost 4 years old.
FALLING OUT
Edison promised Tesla a generous reward if he could smooth out his direct current system. The young engineer took on the assignment and ended up saving Edison more than $100,000 (millions of dollars by today's standards). When Tesla asked for his rightful compensation, Edison declined to pay him. Tesla resigned shortly after, and the elder inventor spent the rest of his life campaigning to discredit his counterpart.
"Genius is one percent inspiration and ninety nine percent perspiration."
-Thomas Edison
EDISON FRIES AN ELEPHANT
In order to prove the dangers of Tesla's alternating current, Thomas Edison staged a highly publicized electrocution of the three-ton elephant known as "Topsy." She died instantly after being shocked with a 6,600-volt AC charge.
1847 BORN 1858
Milan, Ohio BIRTHPLACE Smiljan, Croatia
Wizard of Menlo Park NICKNAME Wizard of the West
Home-schooled and self-taught EDUCATION Studied math, physics, and mechanics at The Polytechnic Institute at Gratz
Mass communication and business FORTE Electromagnetism and electromechanical engineering
Trial and error METHOD Getting inspired and seeing the invention in his mind in detail before fully constructing it
DC (Direct Current) WAR OF CURRENTS: ELECTRICAL TRANSMISSION IDEA AC (Alternating Current)
Incandescent light bulb; phonograph; cement making technology; motion picture camera; DC motors and electric power NOTABLE INVENTIONS Tesla coil - resonant transformer circuit; radio transmitter; fluorescent light; AC motors and electric power generation system
1,093 NUMBER OF US PATENTS 112
0 NUMBER OF NOBEL PRIZES WON 0
1 NUMBER OF ELEPHANTS ELECTROCUTED 0
1931—Passed away peacefully in his New Jersey home, surrounded by friends and family DEATH 1943—Died lonely and in debt in Room 3327 at the New Yorker Hotel
WAR OF CURRENTS OFFICIALLY SETTLED
In 2007, Con Edison ended 125 years of direct current electricity service that began when Thomas Edison opened his power station in 1882. It changed to only provide alternating current.
NOBEL PRIZE CONTROVERSY
In 1915, both Edison and Tesla were to receive Nobel Prizes for their strides in physics, but ultimately, neither won. It is rumored to have been caused by their animosity towards each other and refusal to share the coveted award.
SOURCES: CHENEY, MARGARET. "TESLA: MAN OUT OF TIME" | UTH, ROBERT. "TESLA: MASTER OF LIGHTNING." | THOMASEDISON.COM | PBS.ORG | WEB.MIT.EDU | WIRED.COM
A COLLABORATION BETWEEN GOOD AND COLUMN FIVE

Overview of AC and DC drives

DC motors: Regular maintenance, heavy, expensive, speed limit

Easy control, decouple control of torque and flux

AC motors: Less maintenance, light, less expensive, high speed

Coupling between torque and flux – variable spatial angle between rotor and stator flux

Overview of AC and DC drives

Before semiconductor devices were introduced (<1950)

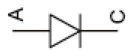
- AC motors for fixed speed applications
- DC motors for variable speed applications

After semiconductor devices were introduced (1950s)

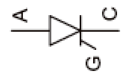
- Variable frequency sources available – AC motors in variable speed applications
    - Coupling between flux and torque control
    - Application limited to medium performance applications – fans, blowers, compressors – scalar control
- High performance applications dominated by DC motors – tractions, elevators, servos, etc.

After semiconductor devices were introduced (1950s)

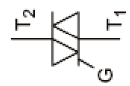
- DIODE (1955)



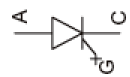
- THYRISTOR (1958)



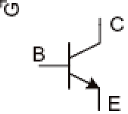
- TRIAC (1958)



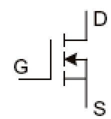
- GATE TURN-OFF THYRISTOR (GTO) (1980)



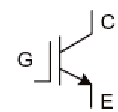
- BIPOLAR POWER TRANSISTOR (BPT or BJT) (1975)



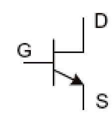
- POWER MOSFET (1975)



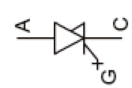
- INSULATED GATE BIPOLAR TRANSISTOR (IGBT) (1985)



- STATIC INDUCTION TRANSISTOR (SIT) (1985)



- INTEGRATED GATE-COMMUTATED THYRISTOR (IGCT) (1996)



- SILICON CARBIDE DEVICES

Overview of AC and DC drives

After vector control drives were introduced (1980s)

- AC motors used in high performance applications – elevators, tractions, servos
- AC motors favorable than DC motors – however control is complex hence expensive
- Cost of microprocessor/semiconductors decreasing – predicted 30 years ago AC motors would take over DC motors

Power processor (Converter)

- AC – DC Converter (Rectifier)
  - Uncontrolled Rectifier
  - Controlled Rectifier
- AC – AC Converter
  - AC Voltage Regulator
  - Cyclo-converter
- DC – DC Converter
  - Buck
  - Boost
  - Buck-boost
- DC – AC Converter (Inverter)

Sources

<u>Power sources</u>

- DC – batteries, fuel cell, photovoltaic – unregulated
- AC – Single- three- phase utility, wind generator - unregulated

Feed back (Sensing) unit

<u>Sensors</u>

- Sensors (voltage, current, speed or torque) is normally required for closed-loop operation or protection
- Electrical isolation between sensors and control circuit is needed for the reasons previously explained
- The term 'sensorless drives' is normally referred to the drive system where the speed is estimated rather than measured.

Control unit

- Complexity depends on performance requirement
- analog- noisy, inflexible, ideally has infinite bandwidth.
- digital – immune to noise, configurable, bandwidth is smaller than the analog controller's
- DSP/microprocessor – flexible, lower bandwidth - DSPs perform faster operation than microprocessors (multiplication in single cycle), can perform complex estimations
- Electrical isolation between control circuit and power circuit is needed:
  - Malfuction in power circuit may damage control circuit
  - Safety for the operator
  - Avoid conduction of harmonic to control circuit

MULTI-DISCIPLINARY NATURE OF DRIVE SYSTEMS

- Theory of Electric Machines
- Power Electronics
- Control Theory
- Real-Time Control Using DSPs
- Mechanical System Modeling
- Sensors
- Interactions of Drives with the Utility Grid

Choice of Electrical Drives

- Steady state operating requirements
  - Speed-torque characteristics
  - Speed regulation
  - Speed range
  - Efficiency
  - Duty cycle
  - Quadrants of operation
  - Speed fluctuations
- Transient operation requirements
- Requirements related to the source
- Capital and running cost, maintenance needs, life
- Space and weight restrictions if any.
- Environment and location
- Reliability