LECTURE 2

Two Major Uses of Power Electronics: Motor Control and Modern Lighting

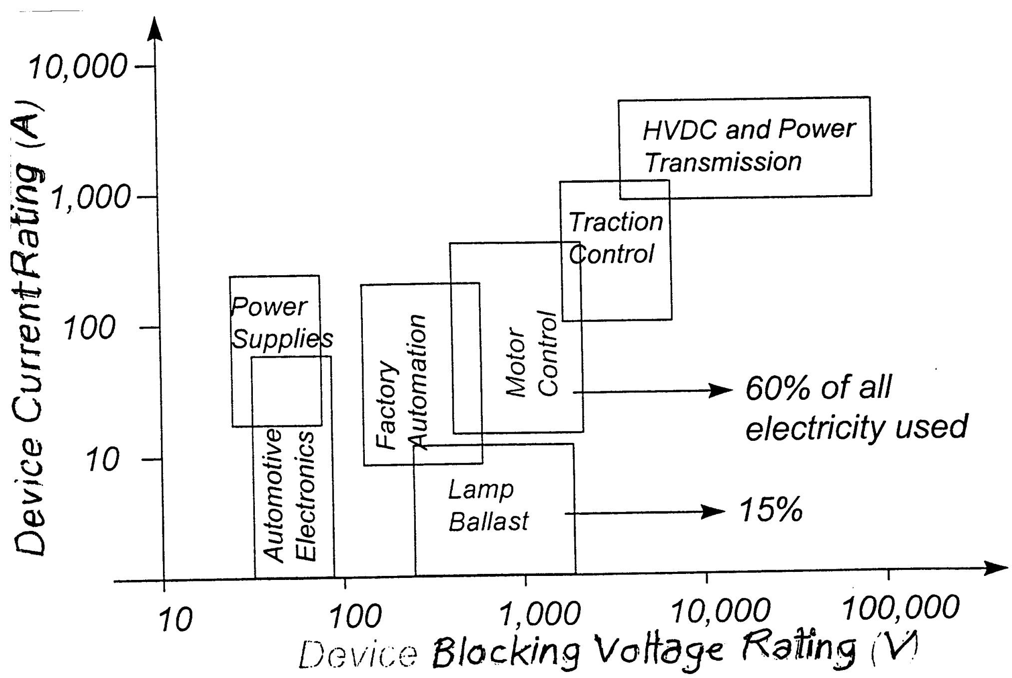
I. Overview of Applications

A. Overview
B. Improved Motor Control
C. Efficient Excitation of Gas Discharge

TWO MAJOR APPLICATIONS OF POWER ELECTRONICS: INDUSTRIAL ELECTRONICS

A. Overview

POWER ELECTRONICS USES NEW SWITCHING CIRCUIT TOPOLOGIES TO MAKE SMALLER, LOWER WEIGHT AND HIGHER EFFICIENCY POWER SUPPLIES. These supplies for the first time are available at variable frequencies need for applications in motor drive and in lighting which together constitute over 75% of electricity use.

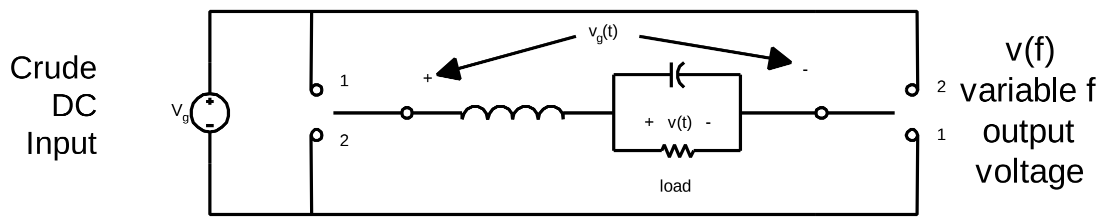


Clearly, we have different applications that place specific requirements on the solid state switches. Only as advances in solid state switches occurred could these new applications become cost effective. Switch technology is an enabling one for new applications. Two issues are enabling: electrical peformance and cost.

B. Improved Motor Control

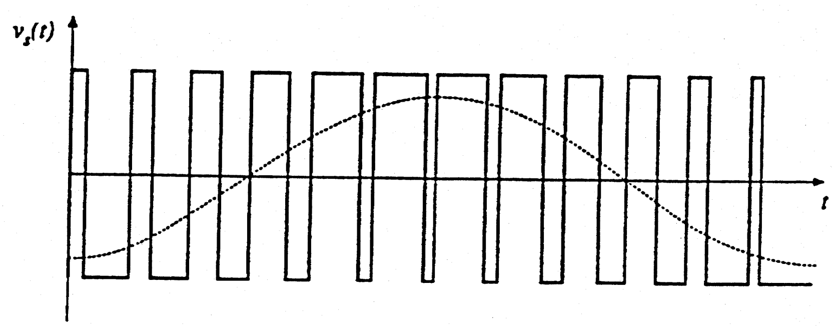
1. ILLUSTRATIVE VARIABLE AC OUTPUT: V(f)

We always assume that the AC mains has been rectified to provide a crude DC voltage. Next, we switch that voltage into a load with LC filtering to achieve an output AC at a different frequency from the original mains frequency. The later frequency is more suitable to the application and is often VARIABLE to achieve speed control on a motor.



Bridge-type dc-1ϕac inverter circuit.

We vary the switch duty cycle to achieve a variable frequency output form the DC as schematically indicated below.



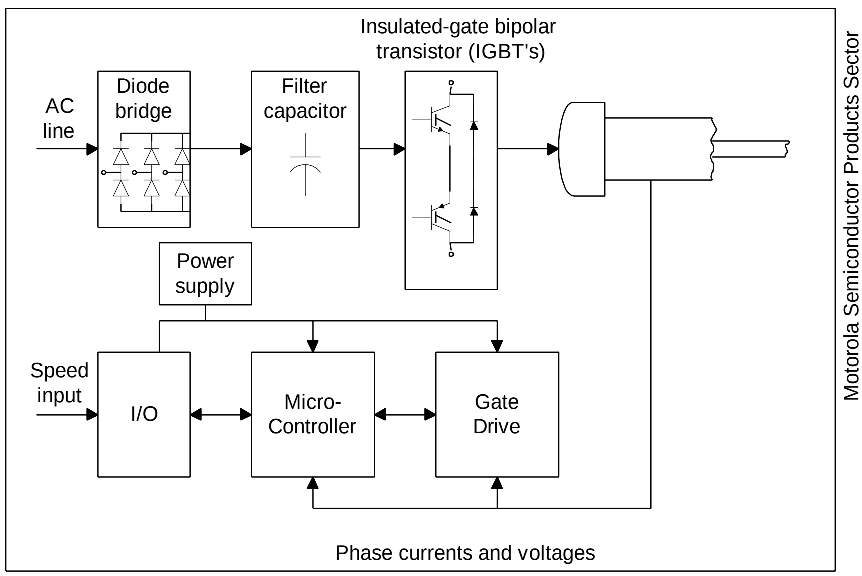
The switch fequency is f_{sw} and is chosen so that $f_{sw} >> f_{out}$. f_{out} is chosen by duty cycle of on-off of the switch. Typical pulse-width-modulated switch voltage and its low frequency component. $V \sin \omega_{out} t$, $V = f_1(D)$, $\omega_{out} = f_2(D)$

This course provides details on how we achieve this.

2. Motor Control Applications of variable frequency output power v(f) supplies

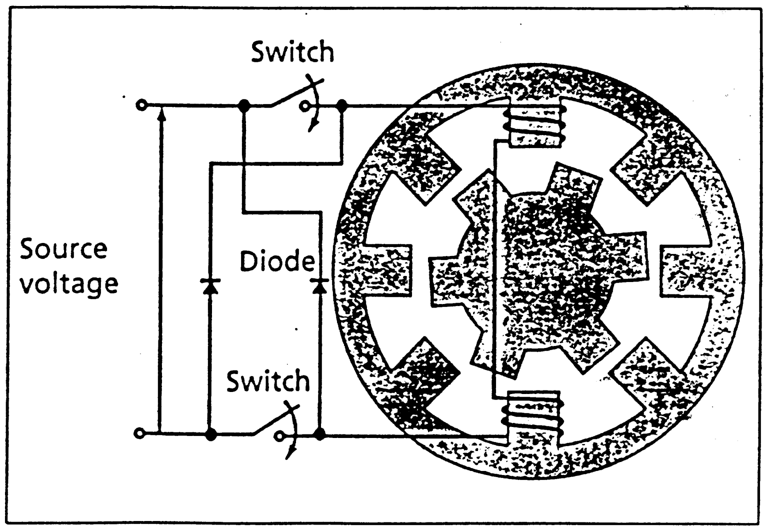
•SYNCHRONOUS MOTOR: ω_{out} IS PROPORTIONAL TO f_{in}-SPEED CONTROL of the motor via v(f)
This allows us to replace an expensive dc motor with a cheap synchronous motor provided the AC-AC conversion electonics are cheap, accurate and reliable.

[1] A typical motor drive includes a microcontroller and a gate drive that turns the insulated-gate field-effect transistors (called IGBT's) on and off to operate the motor.



MOTOROLA MOTOR CONTROL CHIP

•NEW POWER CHIPS MAKE EVEN SIMPLER TYPES OF MOTOR DESIGN FEASIBLE. COMPLEXITY IS MOVED FROM THE MOTOR TO THE POWER SUPPLY.
•EXAMPLE IS THE EMERSON SWITCHED RELUCTANCE MOTOR:
WHICH IS EVEN SIMPLER THAN A SYNCHRONOUS MOTOR. THERE ARE NO COILS ON ROTOR. STATOR HAS COIL DRIVEN POLES THAT ARE SWITCHED. COMMERCIAL PRODUCTION OF SUCH A MOTOR IS NOW BEGINNING.

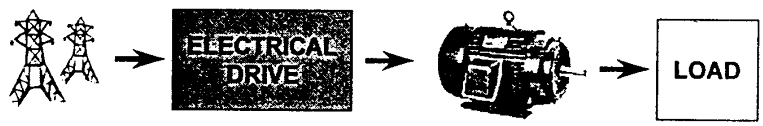


[3] The switched reluctance motor is diagrammed as a simplified eight-pole stator and a six-pole rotor machine. Torque is developed by the tendency of a magnetic circuit to adopt a configuration of minimum reluctance (to maximize the magnetic flux). This tendency translates into a rotation of the rotor so that its poles align with the stator's poles. These pole pairs are in turn energized sequentially from a dc source through electronic switches, thereby creating the rotating torque.

Below we will outline three pages of motor applications of power electronics in schematic form to allow an overview of the revolution taking place. We do so to motivate the study of power electronics by showing the rich applications that are emerging. Keep in mind in motor applications we need not exceed 20 or 30 thousand RPM and our power levels are up to MW. In general, output frequencies will usually not exceed 1-2 thousand RPM.

Motor Drives

- A Motor Powered by an Electrical Drive Converts Electrical Energy into Variable Speed Mechanical Motion



Typical Industrial Applications

- Fans (~30% of market)
- Pumps (~20% of market)
- Conveyors (~20% of market)
- Compressors (~3% of market)
- Cranes
- Hoists
- Calendar Rollers
- Winders
- Extruders

Motor Drive Markets

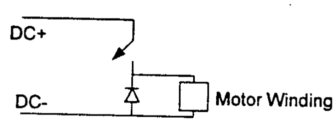
- Commercial
  - Building Heating, Ventilating, & A/C
  - Wastewater Treatment
  - Non-Industrial OEM
- Consumer
  - Heating & A/C
  - Major Appliances
  - Computers, VCR's, etc.
- Industrial
  - Manufacturing Machinery
  - Material Handling
  - Fans and Pumps

Widely Used Motor Drives

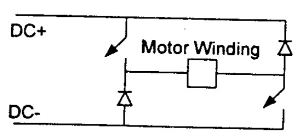
- **Low Power** (< 250 Watts, < 100 Volts)
  - Voltage Source PWM
    - DC Motors, Stepper Motors, PM AC Motors
- **Medium Power** (0.25 - 500 kW, 230 - 575 Volts)
  - 3-Phase Voltage Source PWM
  - Phase-Controlled Rectifier
  - H-Bridge PWM
- **High Power** (> 1,000 kW, > 2,000 Volts)
  - Current Source PWM
  - Load Commutated Current Source
  - Multilevel Voltage Source PWM
  - 6-Phase, 12-Phase, etc.

Widely Used Low Power Drives

- **One Transistor Voltage Source PMW**
  - DC Motors, Split-Phase PM AC Motors



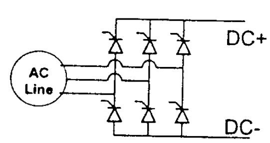
- **Two Transistor Voltage Source PWM**
  - Stepper Motors (also switched reluctance)



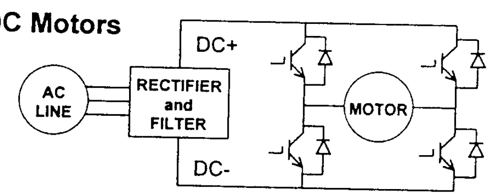
Each Motor Winding Requires a Separate Circuit

Widely Used Medium Power Drives

- **Phase Controlled Rectifiers**
  - DC Motors, Rectifier for AC Drives

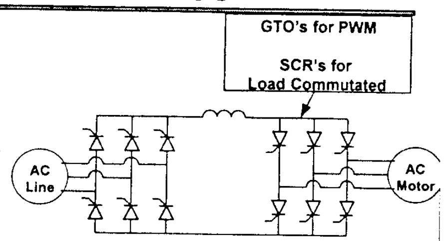


- **H-Bridge**
  - DC Motors

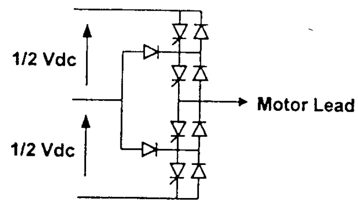


High Power AC Motor Drives

- Current Source
  - ➢Mature Technology
    - PWM for Induction Motor
    - Load Comm. For Sync. Motor

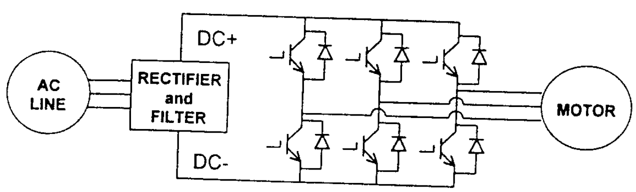


- Multilevel Voltage Source PWM
  - ➢Emerging Technology



The 'King' of Medium Power Drives

- Voltage Source PWM
  - ➢Induction Motors, Synchronous Motors
  - ➢99+% Market Share for Medium Power AC Drives



Trends in Drive Topologies

- Power Line Harmonic Reduction
  - ➢Increases demand for line-side filters
  - ➢Decreases acceptance of simple 3-phase diode and SCR rectifiers
  - ➢Increases use of 12-pulse and 18-pulse rectifiers
  - ➢Increases use of PWM rectifiers

- EMI/EMC Reduction
  - ➢Increases the use of passive filters to isolate the drive from other equipment
  - ➢Increases interest in soft switching

D. Efficient Excitation of Lighting Discharges

Modern lighting employs gas discharges rather than the old hot filament incandesent light bulbs. The former include the familiar fluoresent lights,the yellow sodium lights in highways and industrial parking lots as well as new light bulb size fluoresent lights. The latter have the potential to replace incandesent lights entirely with enormous energy savings. To do so we need to provide on board electronic ballast at low cost via power electronics.

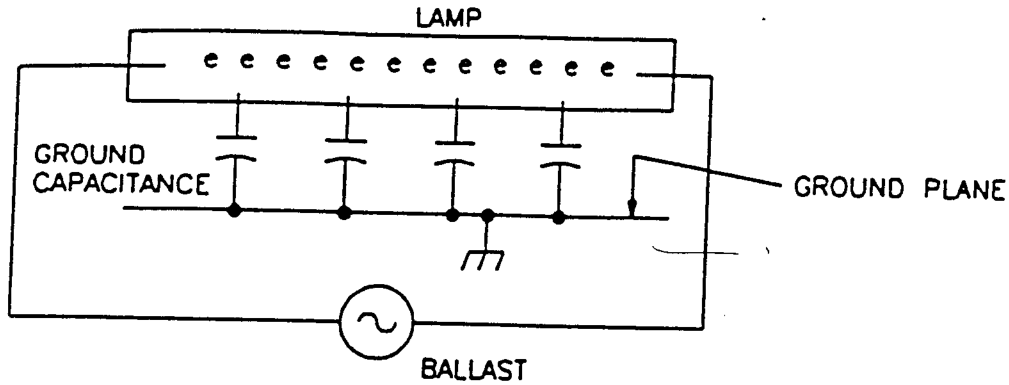
In the next three pages we will see:

- The electronic power supply for lighting is not at 60 Hz but rather at KHz to improve efficiency

- Power electronics converts the mains 60 Hz to the required KHz operating frequency and at the desired high voltage

- We will use the term BALLAST to describe the power electronics as this the term used in the lighting industry. Resonant excitation is employed but BOTH series and parallel excitation schemes find use depending on the light source

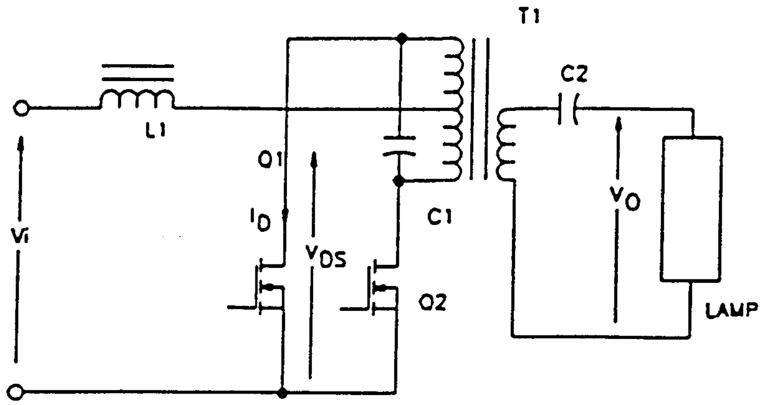
- Ballast requirements as well as tradeoffs will be outlined

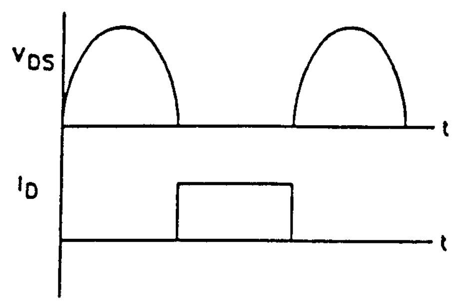


- HF lighting electronics is here, and a lot more is around the corner
- Most activities:
  - in low-cost fluorescent applications (CFL and linear)
  - high-frequency HID
  - automobile
- Frontiers:
  - electrodless
  - backlights

Ballast Circuits

- Low-frequency
  - Lag
  - Lead
  - Lead peak
  - Switched DC
- High-frequency
  - Parallel resonant
  - Series resonant
- Other
  - Power factor correction
  - Starting circuits





$$V_{OC}(\omega t) = \frac{\pi}{2\sqrt{2}} V_{IDC} \sin(\omega t$$

$$\omega_{OC} = \frac{1}{\sqrt{Lm\ C1}}$$

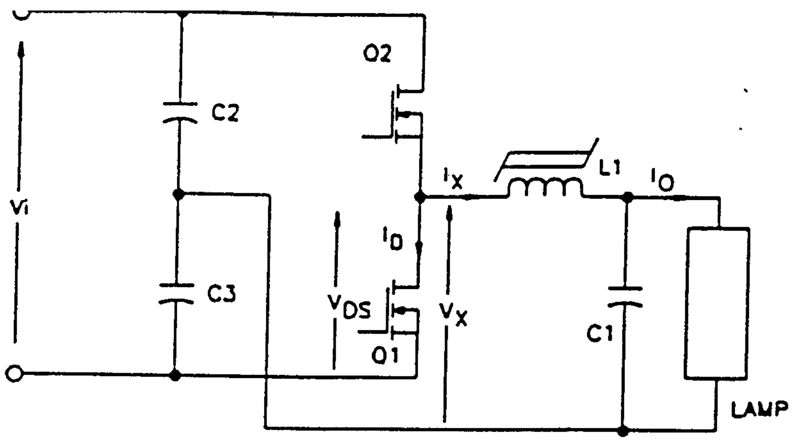
$$\omega_{SC} = \frac{1}{\sqrt{Lm\ (C1+C2)}}$$

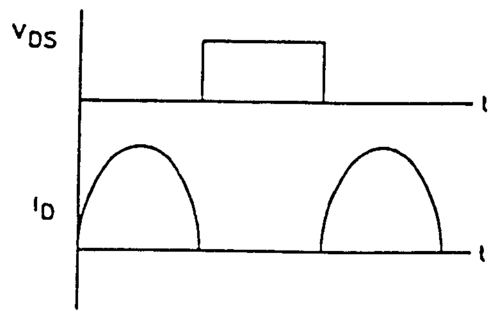
$$I_{OSC}(\omega t) = j\omega_{SC} C2\, V_{OC}(\omega t)$$

vhere:

Lm: Magnetizing inductance of transformer T1
Q1,Q2: Switched at resonance
N: Turns ratio of transformer T1 is assumed to be 1
L1 > > Lm

PARALLEL RESONANT BALLASTS





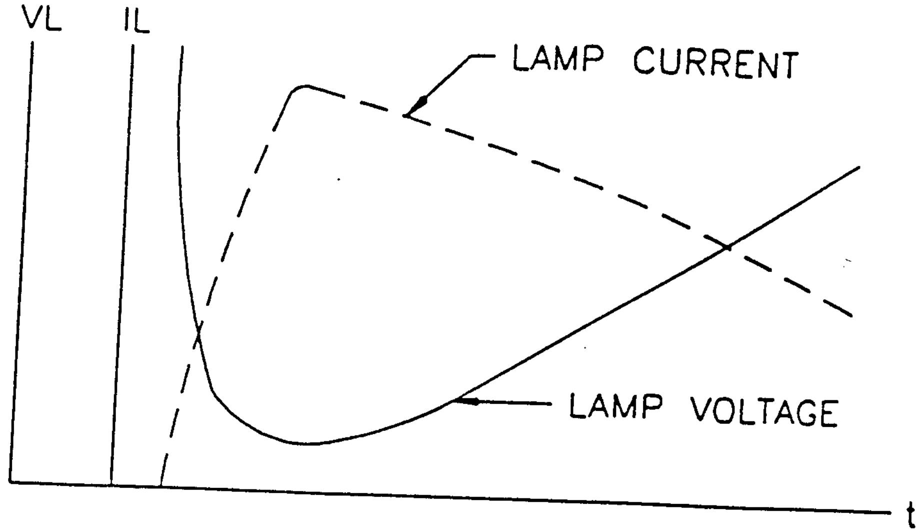
$$V_X(\omega t) = \frac{2\sqrt{2}}{\pi} V_{IDC} \sin(\omega t)$$

$$I_O(\omega t) = \frac{V_X(\omega t)}{j\omega L1} \quad if \quad \omega = \frac{1}{\sqrt{L1\,C1}}$$

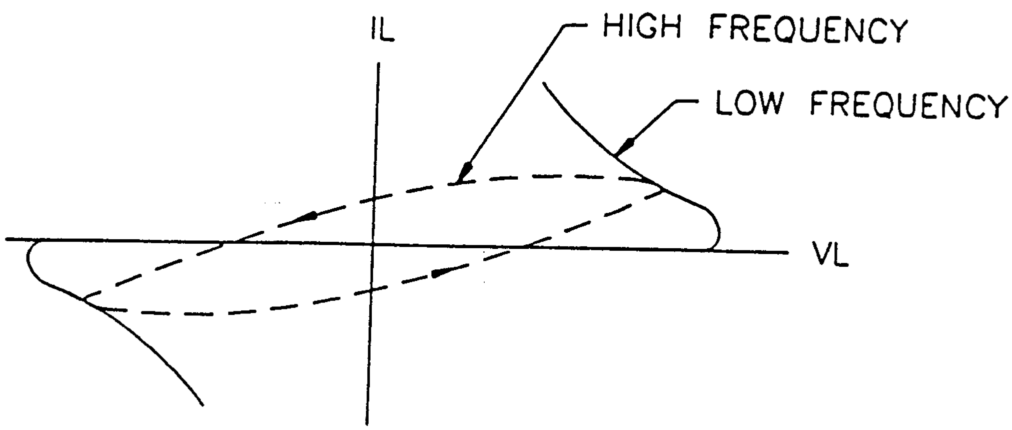
$$I_O(\omega t) = \frac{2\sqrt{2}}{j\pi\omega L1} V_{IDC} \sin(\omega t)$$

vhere devices Q1 and Q2 are switched at resonance.

SERIES RESONANT BALLASTS



LAMP WARM UP CHARACTERISTICS



LAMP LOAD LINE TRAJECTORY

Ballast Parameters

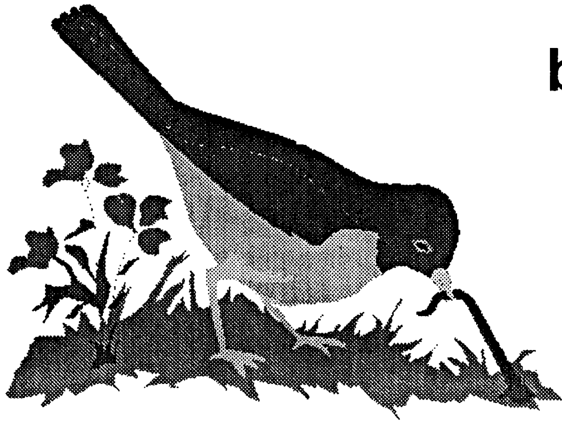
- Voltage parameters:
  - Open circuit voltage
  - Starting voltage
  - Reignition voltage
  - Lamp voltage (cold, hot)
  - Instant restrike voltage
  - Cathode voltage
- Current parameters:
  - Lamp current (hot)
  - Starting current (cold)
  - Current crest factor
  - Preheat current

BALLAST TRADEOFFS

A. POWER FACTOR
B. CURRENT CREST FACTOR
C. LAMP LIFE
D. COST
E. EFFICIENCY
D. FLICKER
E. POWER REGULATION

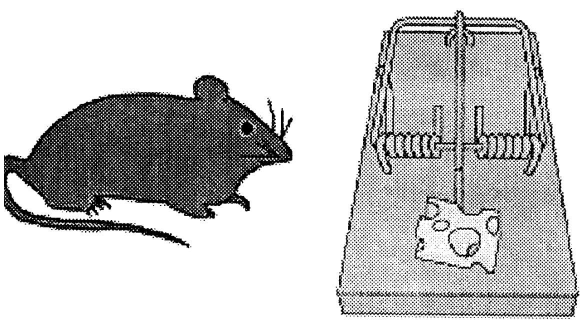
The above discussion of power electronics growing role in the lighting industry gives further motivation to learn more about this field. Progress in any new field is slow because of the well known problems with early utilization of any technology and the abandonment of an old technology.

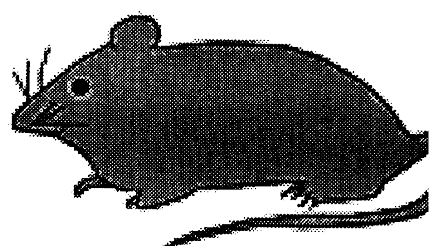
The early bird gets the worm



but

The second mouse gets the cheese.





Illustrative AC output from DC input via controlled Switching: HOW IS IT DONE?

We will cover this next time