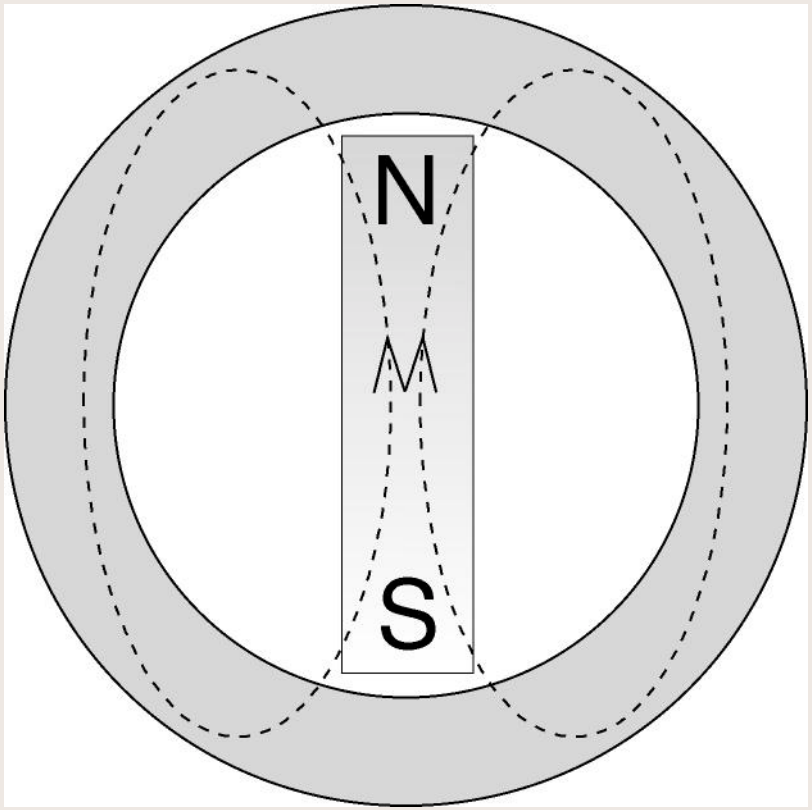
Generators

What its all about

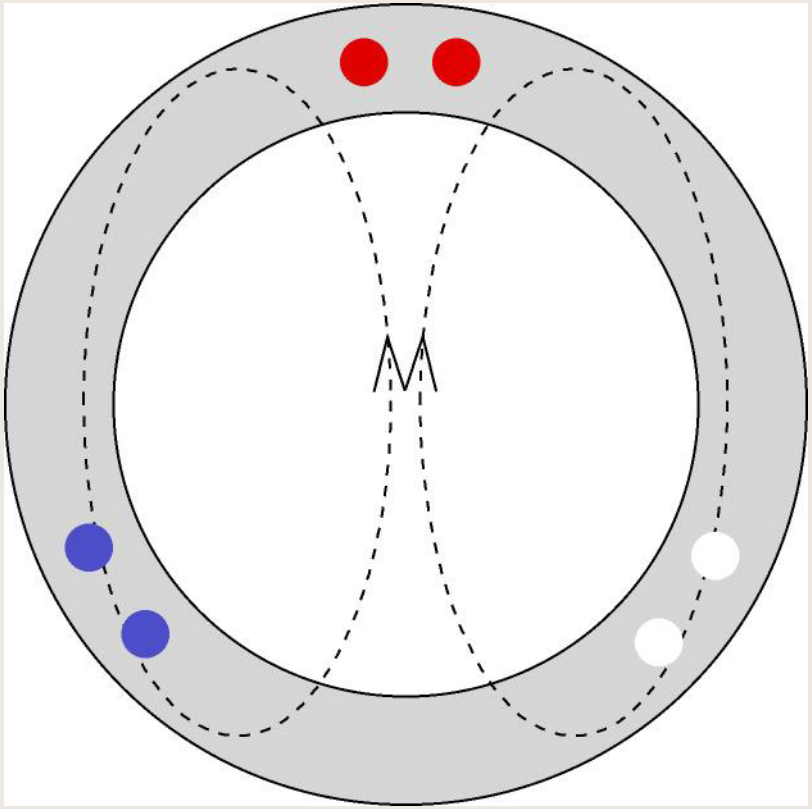
How do we make a generator?

Synchronous Operation

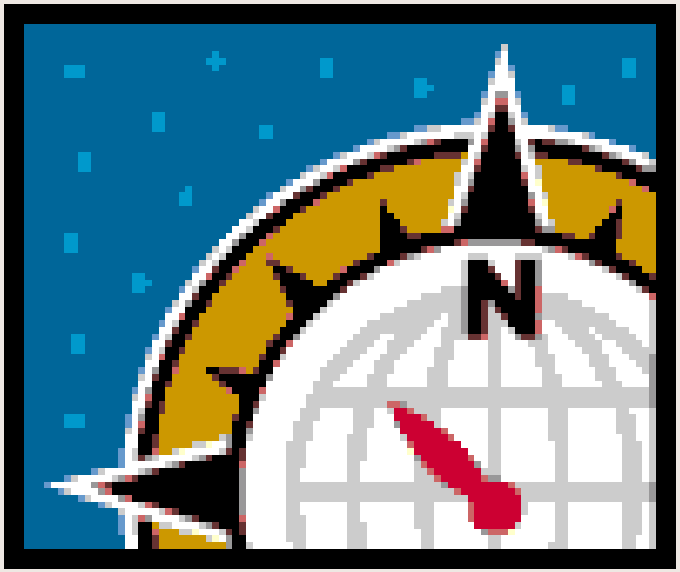
Rotor Magnetic Field



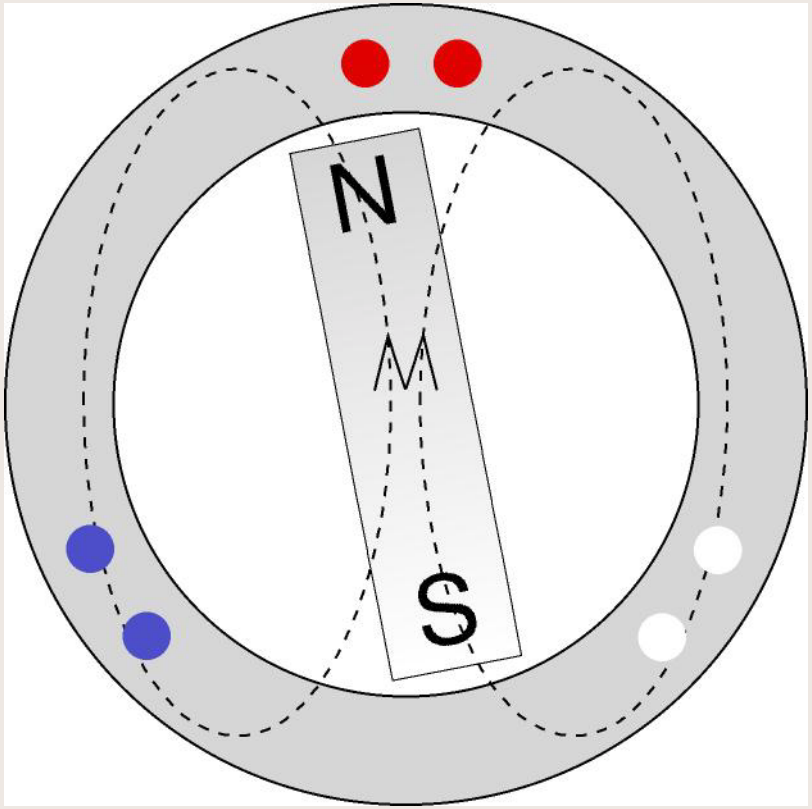
Stator Magnetic Field



Forces and Magnetic Fields



Force Between Fields



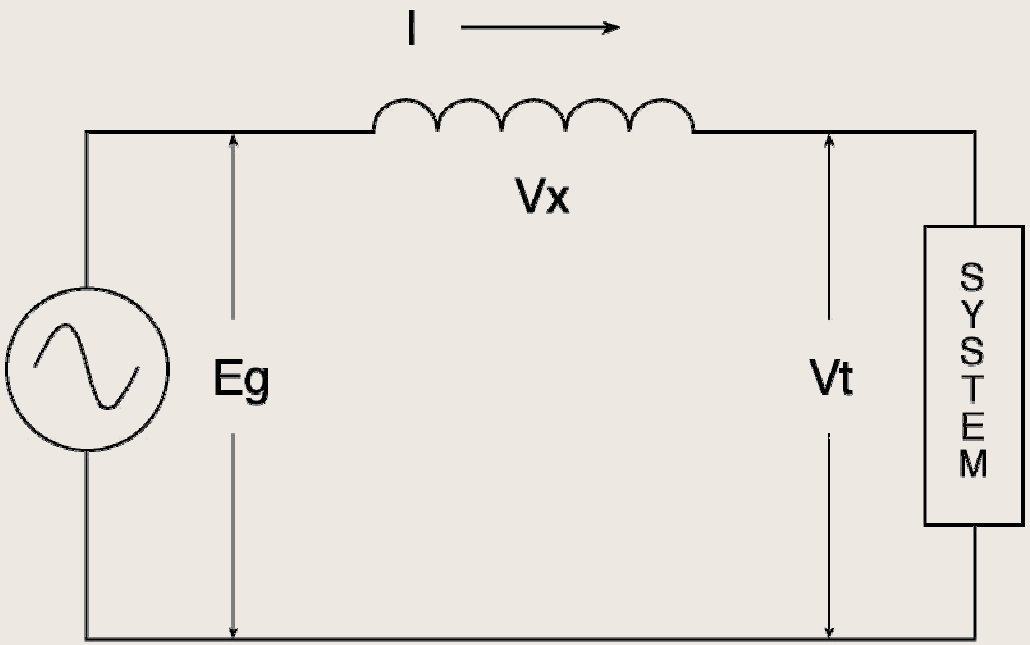
Motoring

- Generators & motors are the same thing
- Generators motor if they are synchronized and the governor is closed
- Power flows in from the grid

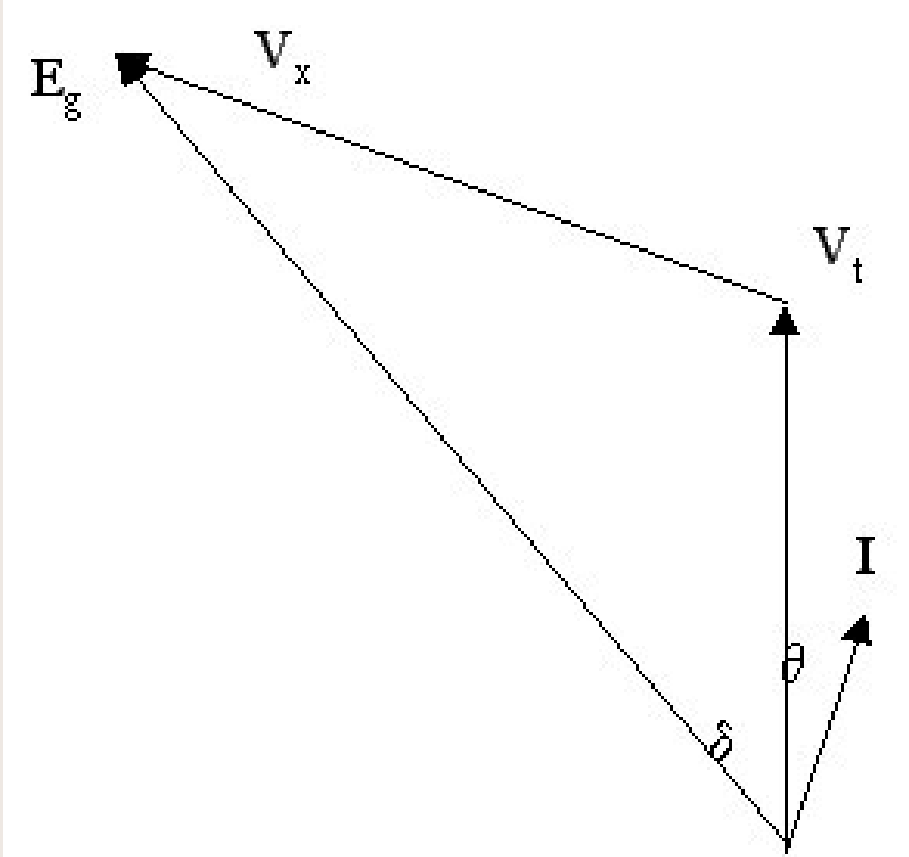
Limits

- Under steady state conditions the load angle must be less than 90°
- Exceeding 90° leads to pole slipping
  - Tremendous current and torque pulsations
  - Can lead to catastrophic failures

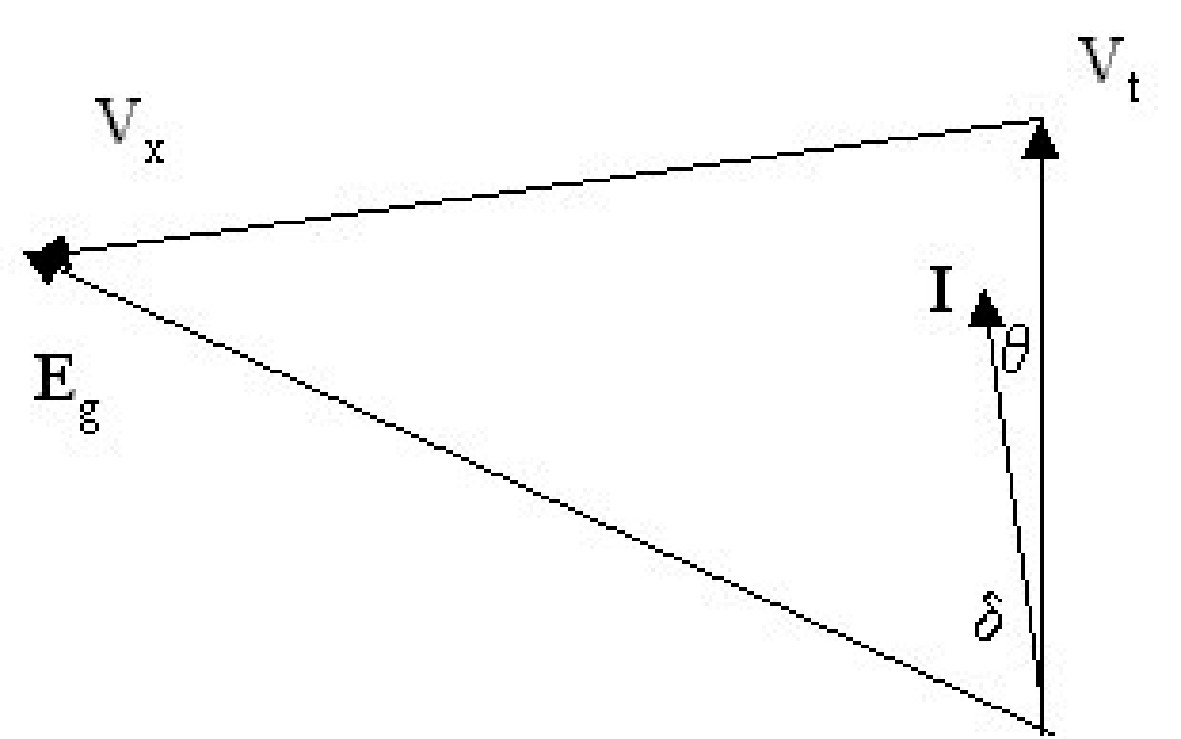
Generator Simplified Equivalent Circuit

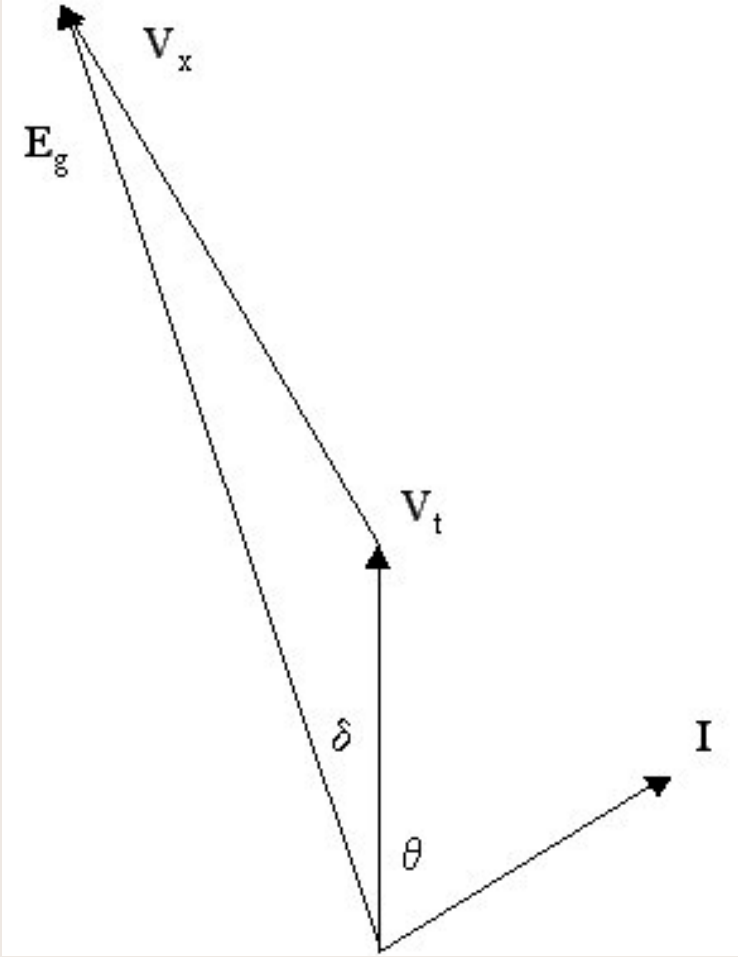


Phasor Diagram



Increasing Steam Flow

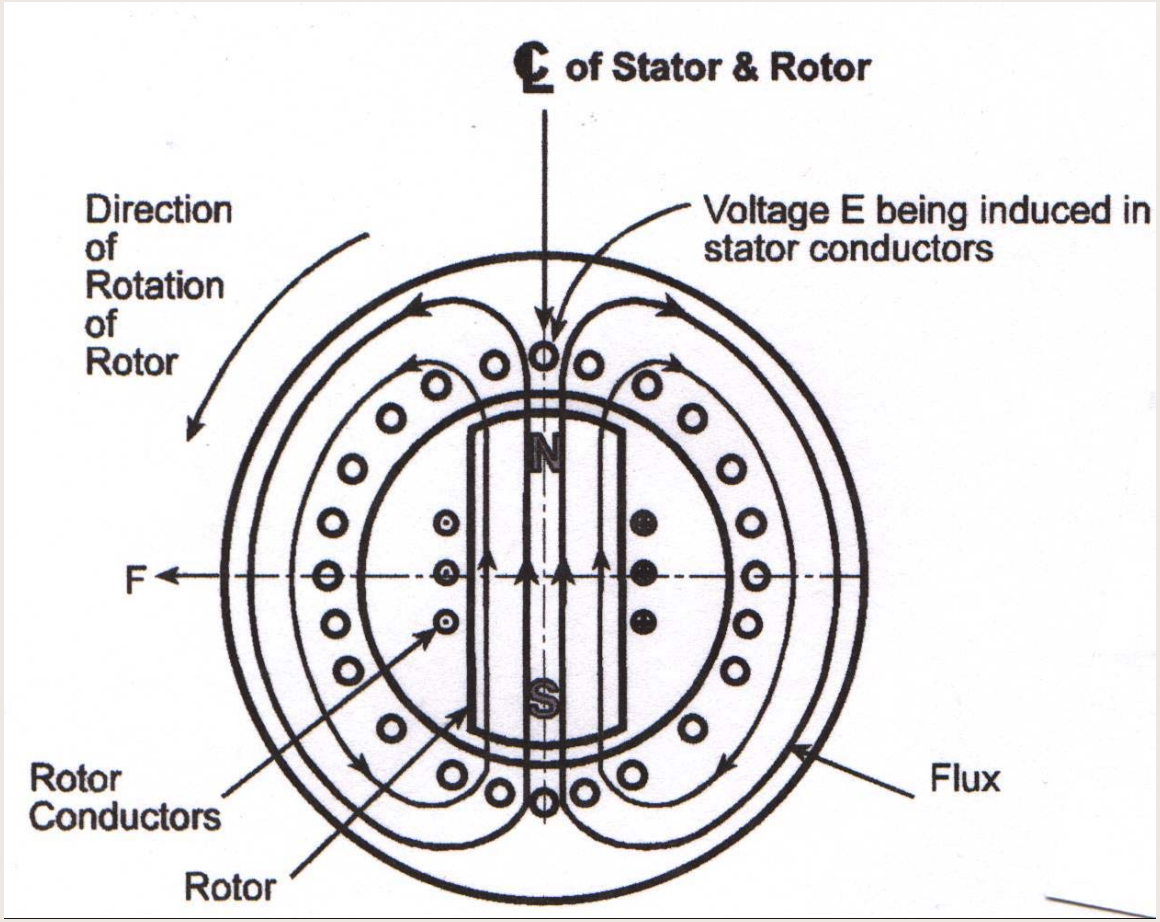



V_x
E_g
V_t
δ
I
θ

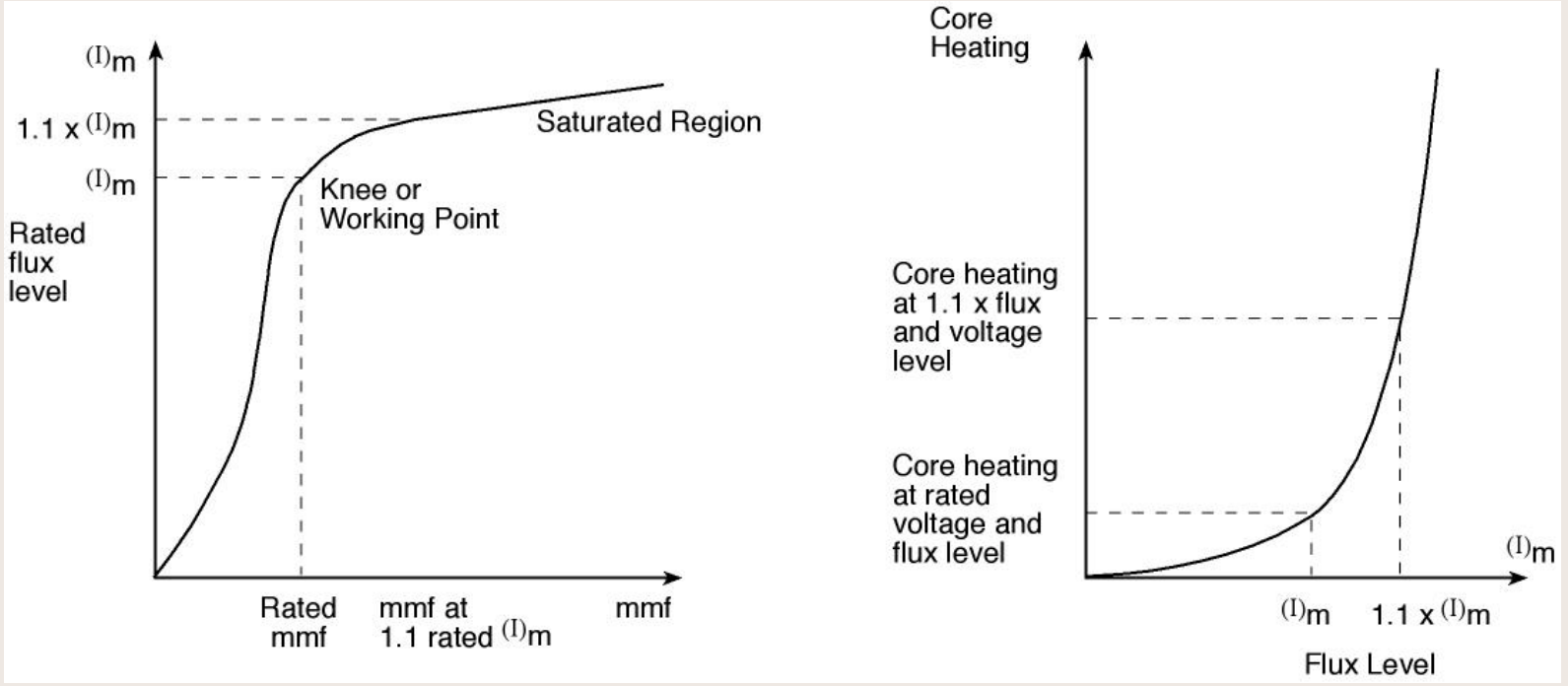
Synchronizing

- Machine is run up to speed
  - 1800 rpm (4 pole machine)
- Field is applied
- Machine is adjust so $E_g = V_t$ in magnitude and phase
- Breaker is closed to connect generator to the system

Generator Prior to Synchronization

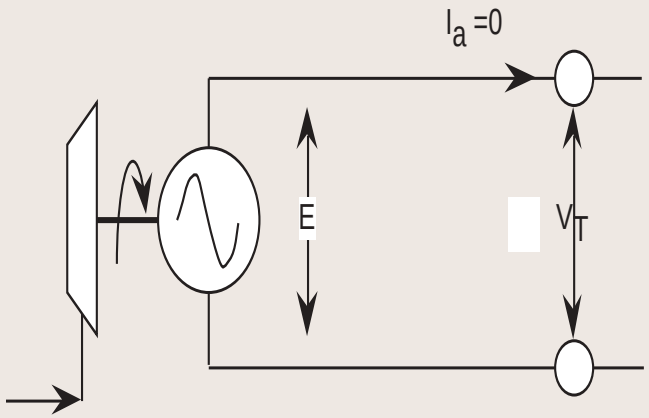


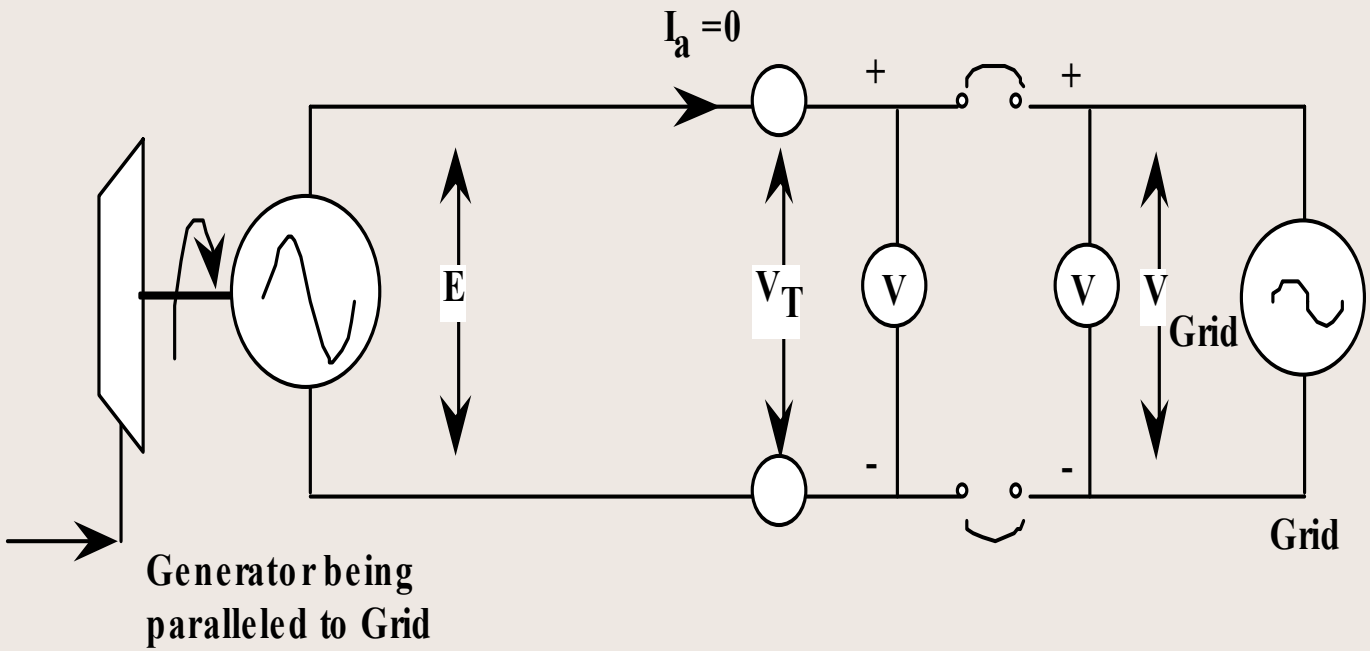
Magnetic Core Heating



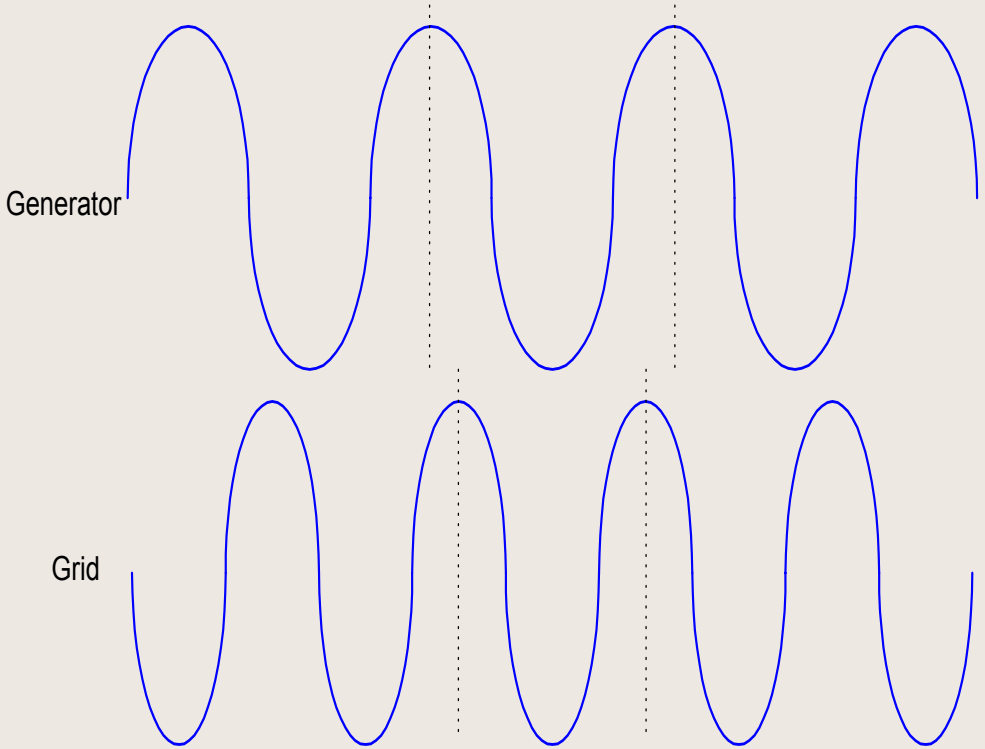
Conditions for Synchronization

- Phase sequence
- Voltage magnitude
- Frequency
- Phase angle

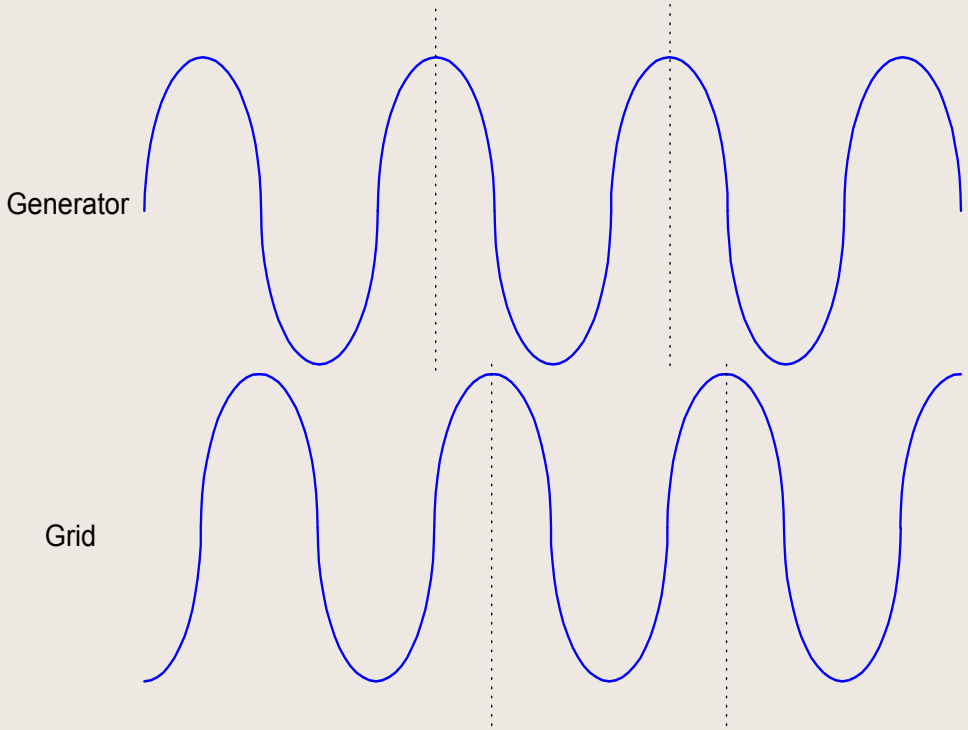



$I_a = 0$
+
+
E
V_T
V
V
V
Grid
-
-
Grid
Generator being
paralleled to Grid

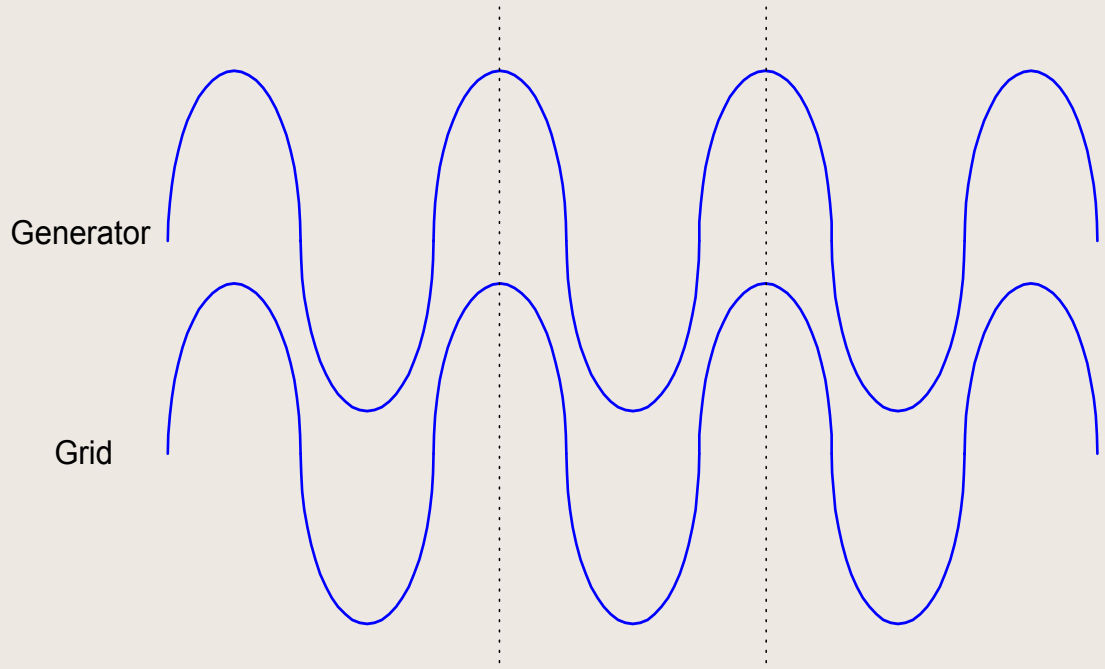
Machine slower than system



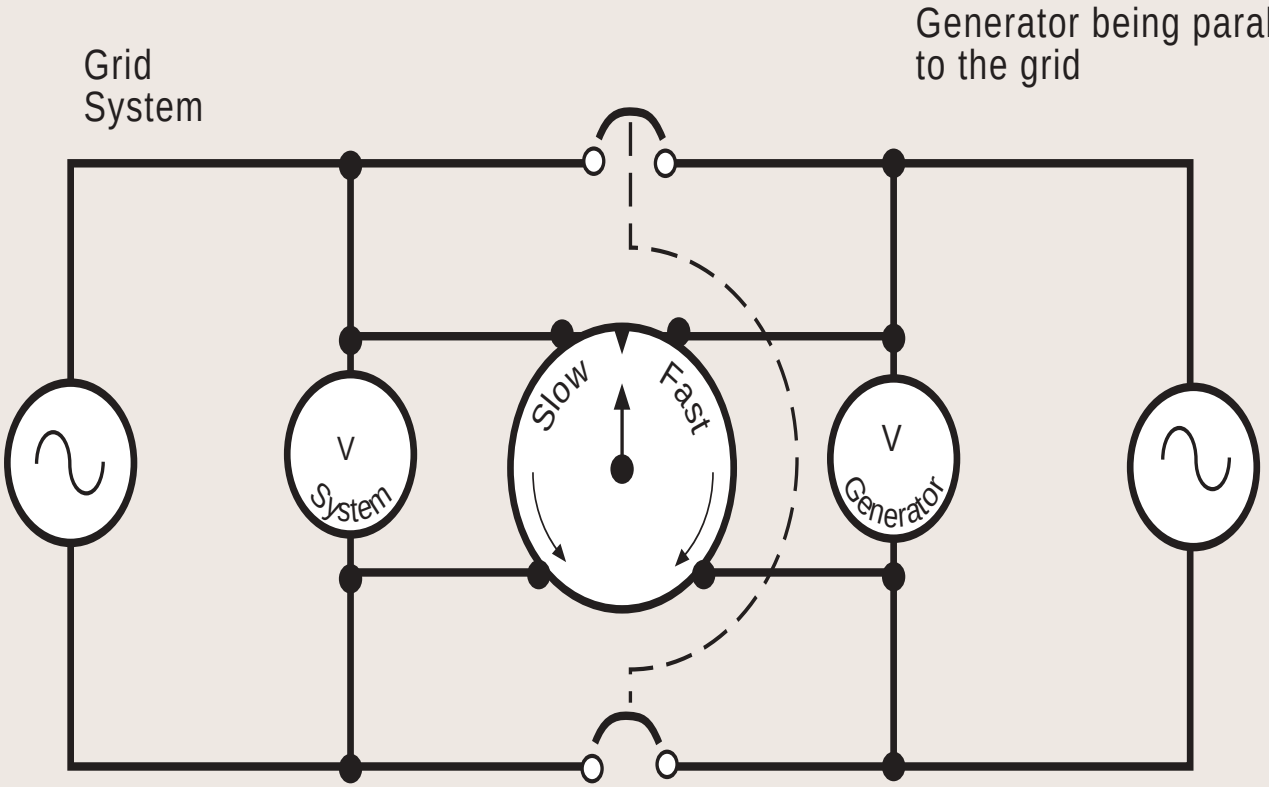
Phase Angle



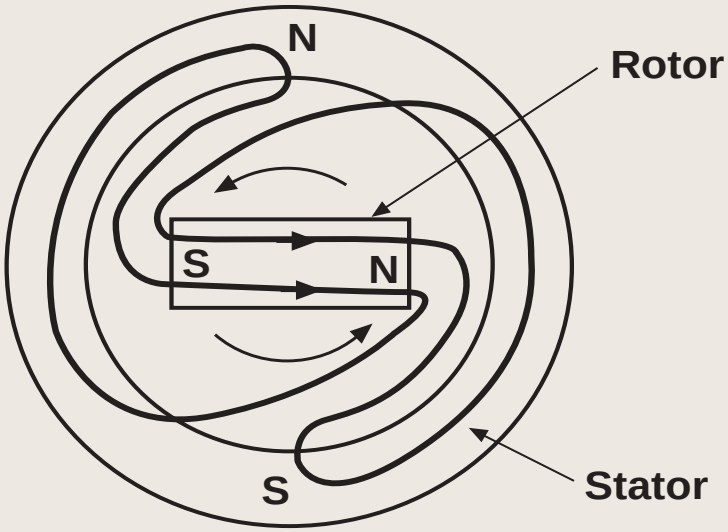
Properly Synchronized



Synchronizing Equipment



Armature Reaction



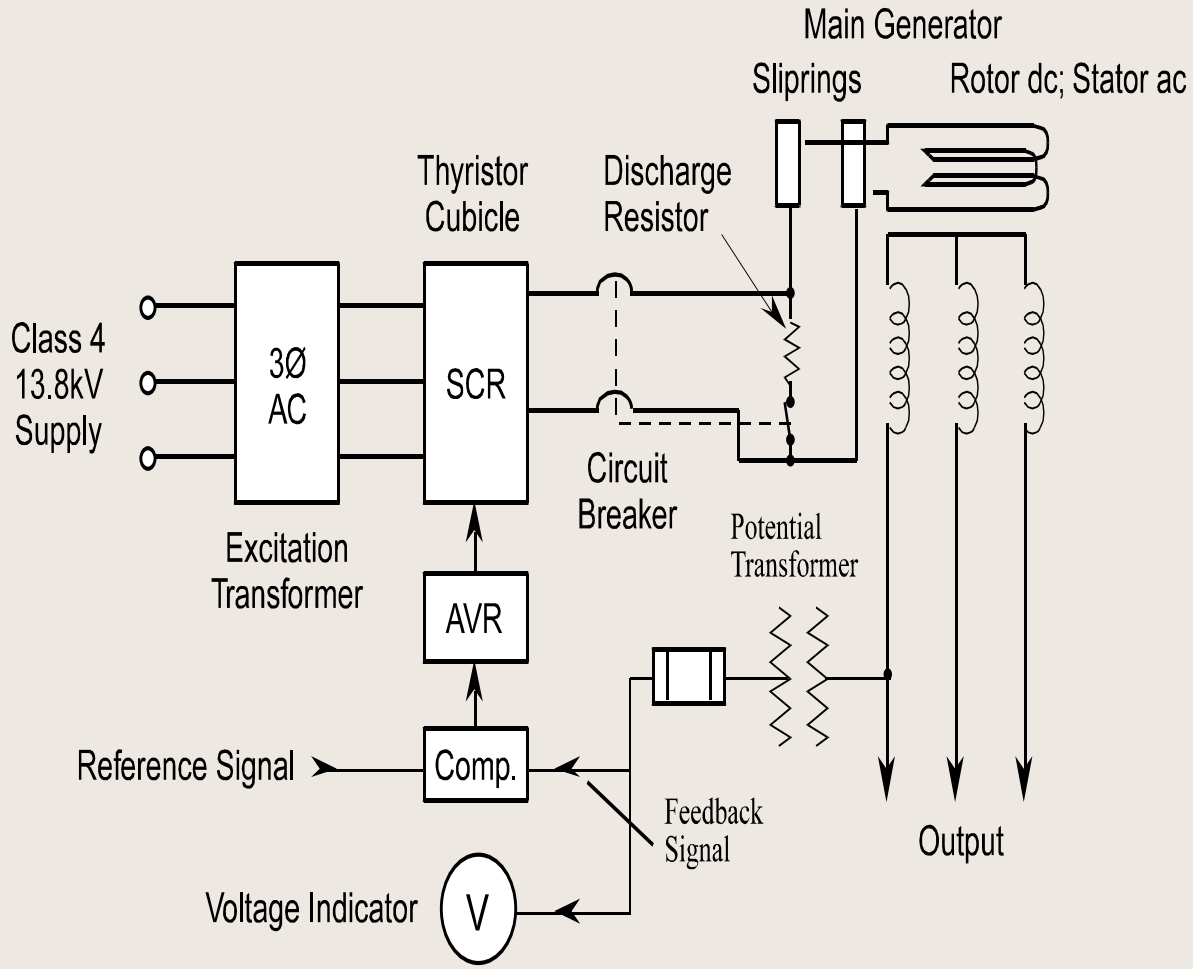
Closing onto a dead bus

- Leading PF
  - AVR will reduce excitation
- Lagging PF
  - Terminal voltage will drop AVR increases excitation
- Faulted Bus
  - High currents flow
- No load
  - Nothing happens

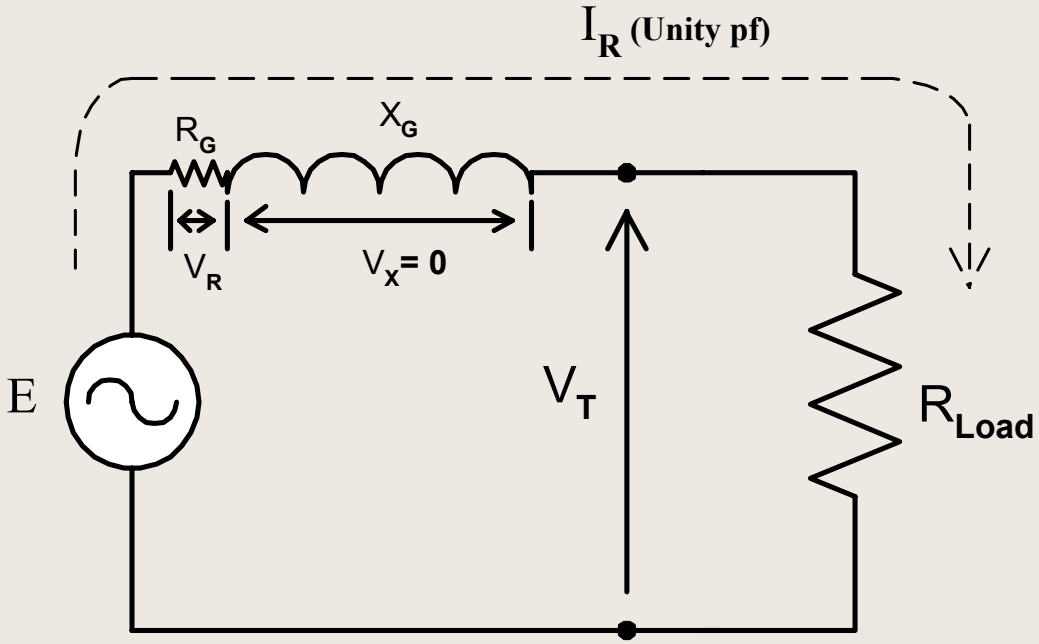
Finite or Infinite

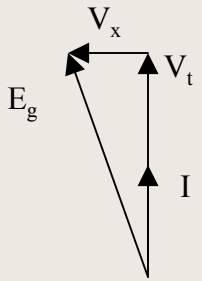
- Operation of the generator is apparently different
- Changes in steam valve position have no effect on speed (infinite)
- Changes in excitation only affect voltages locally
- Generator >5% gives finite characteristics

AVR

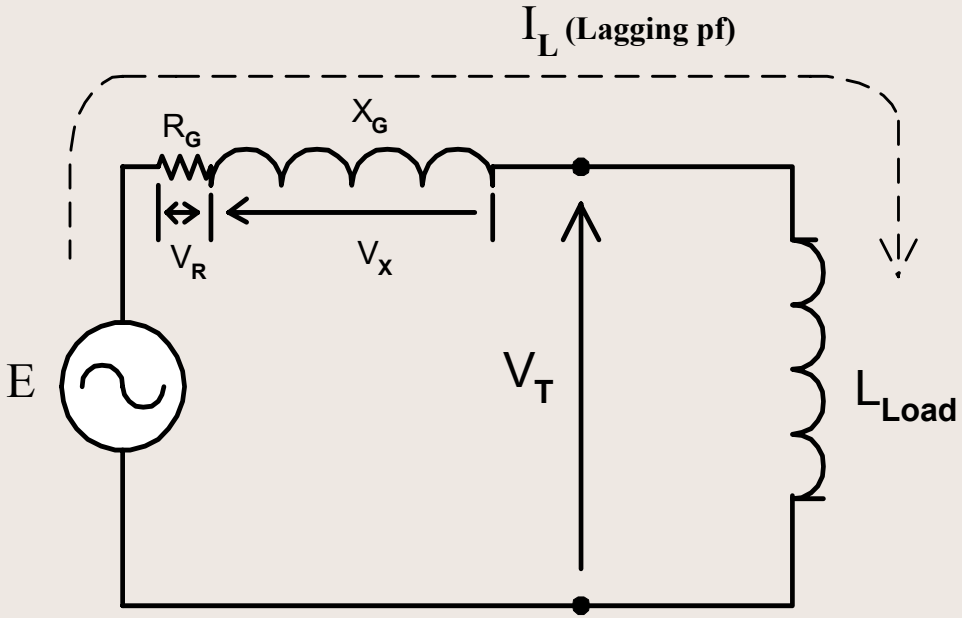

Main Generator
Sliprings
Rotor dc; Stator ac
Thyristor Cubicle
Discharge Resistor
Class 4 13.8kV Supply
3Ø AC
SCR
Circuit Breaker
Potential Transformer
Excitation Transformer
AVR
Reference Signal
Comp.
Feedback Signal
Output
Voltage Indicator
V

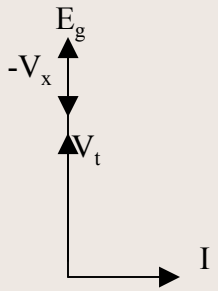
Resistive Load



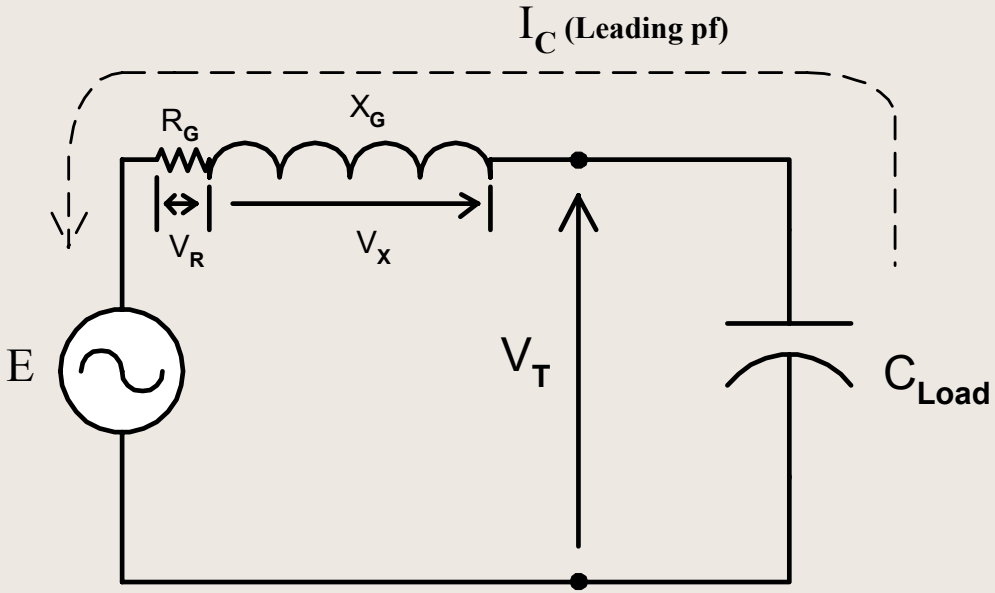


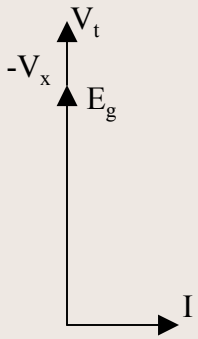
Lagging Load



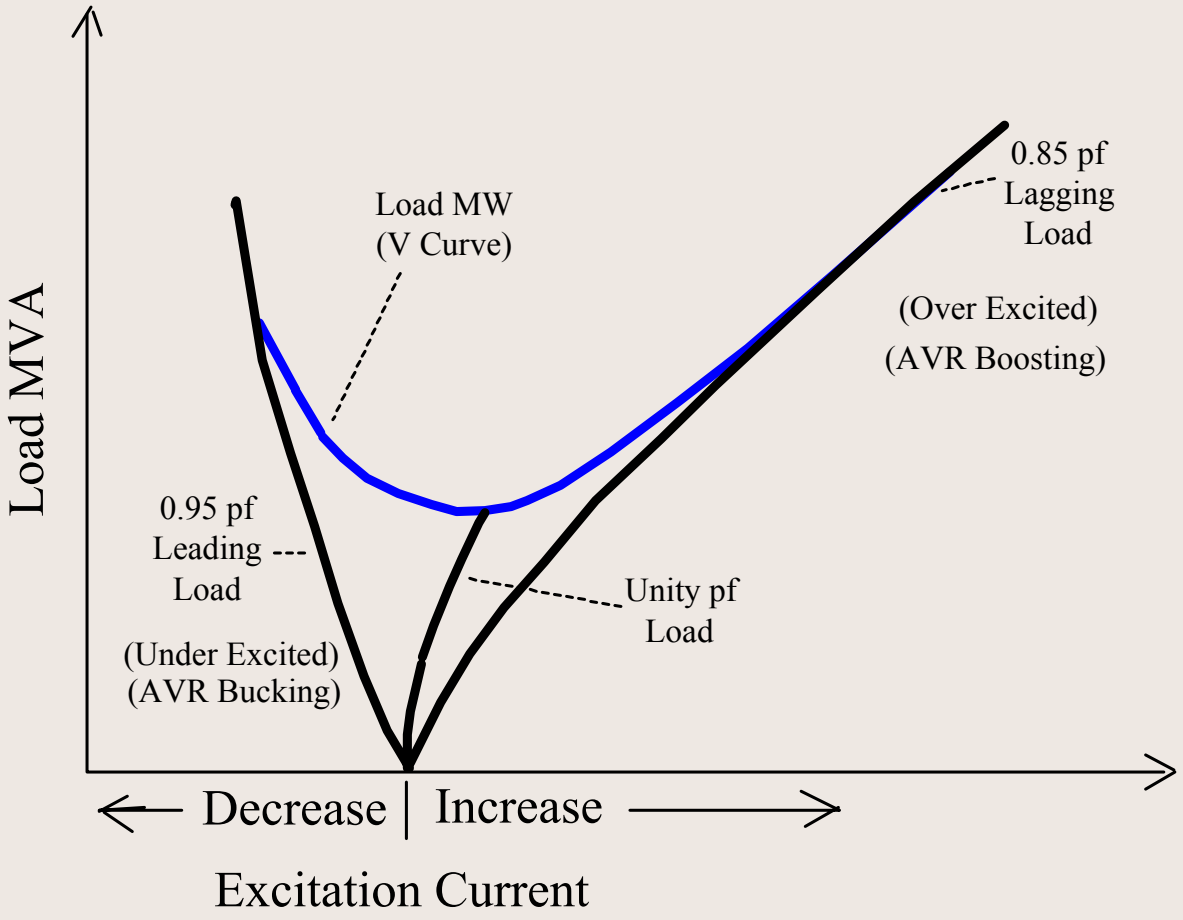


Capacitive Load

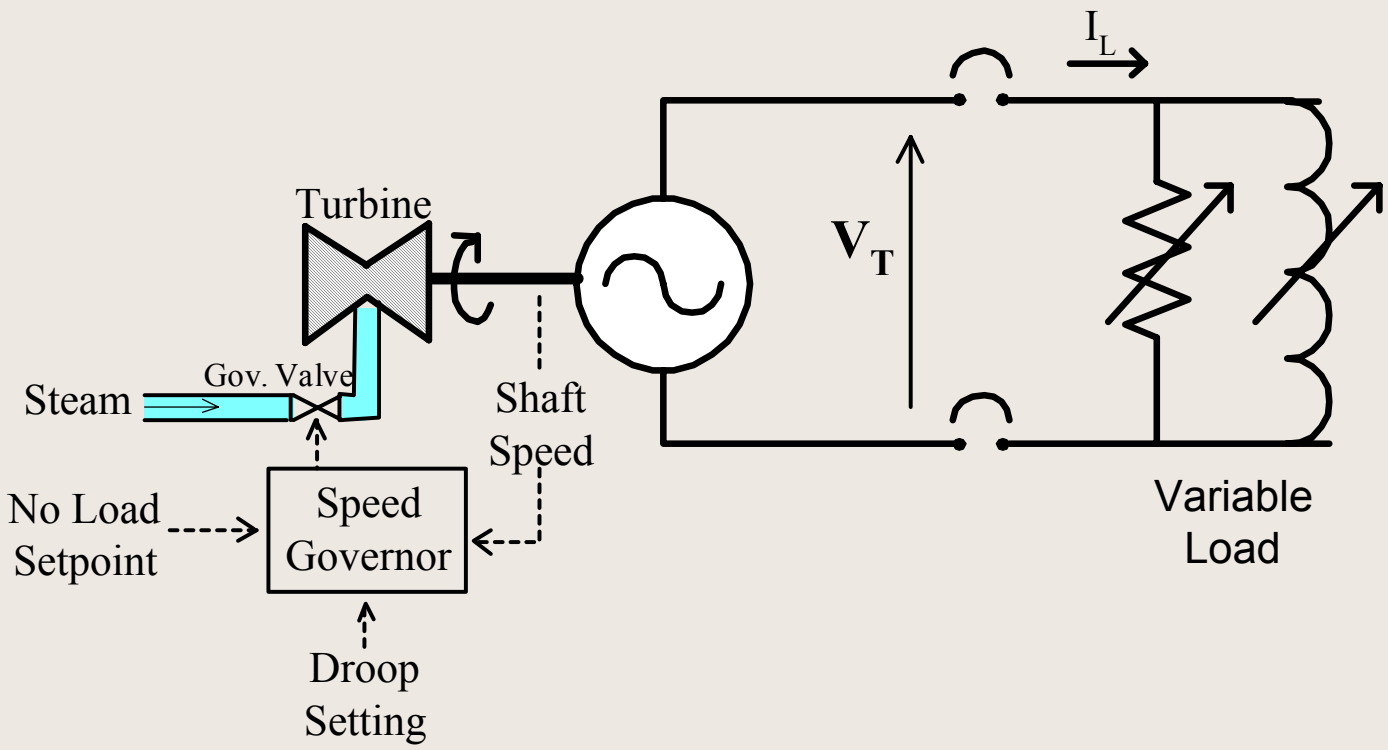




V-curves


Load MVA
Load MW
(V Curve)
0.85 pf
Lagging
Load
(Over Excited)
(AVR Boosting)
0.95 pf
Leading ---
Load
(Under Excited)
(AVR Bucking)
Unity pf
Load
Decrease
Increase
Excitation Current

Governor Control



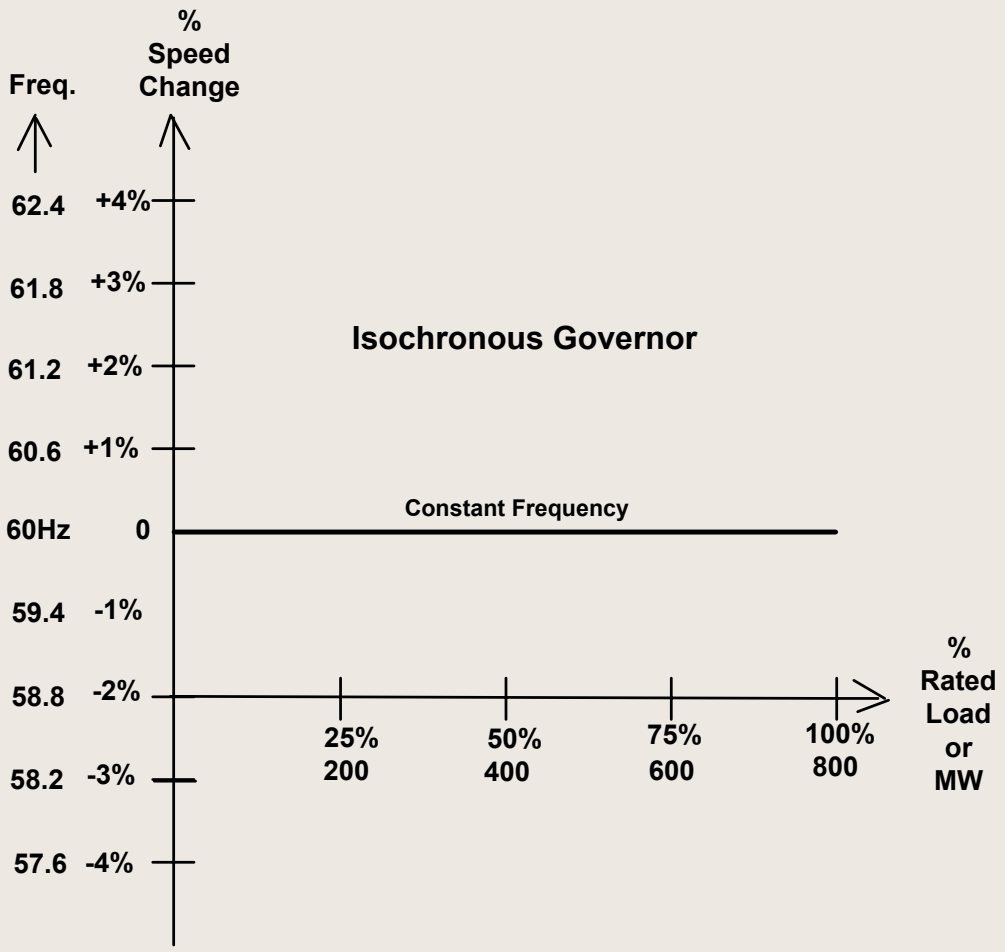
Speed Droop

- Electrical word for proportional control

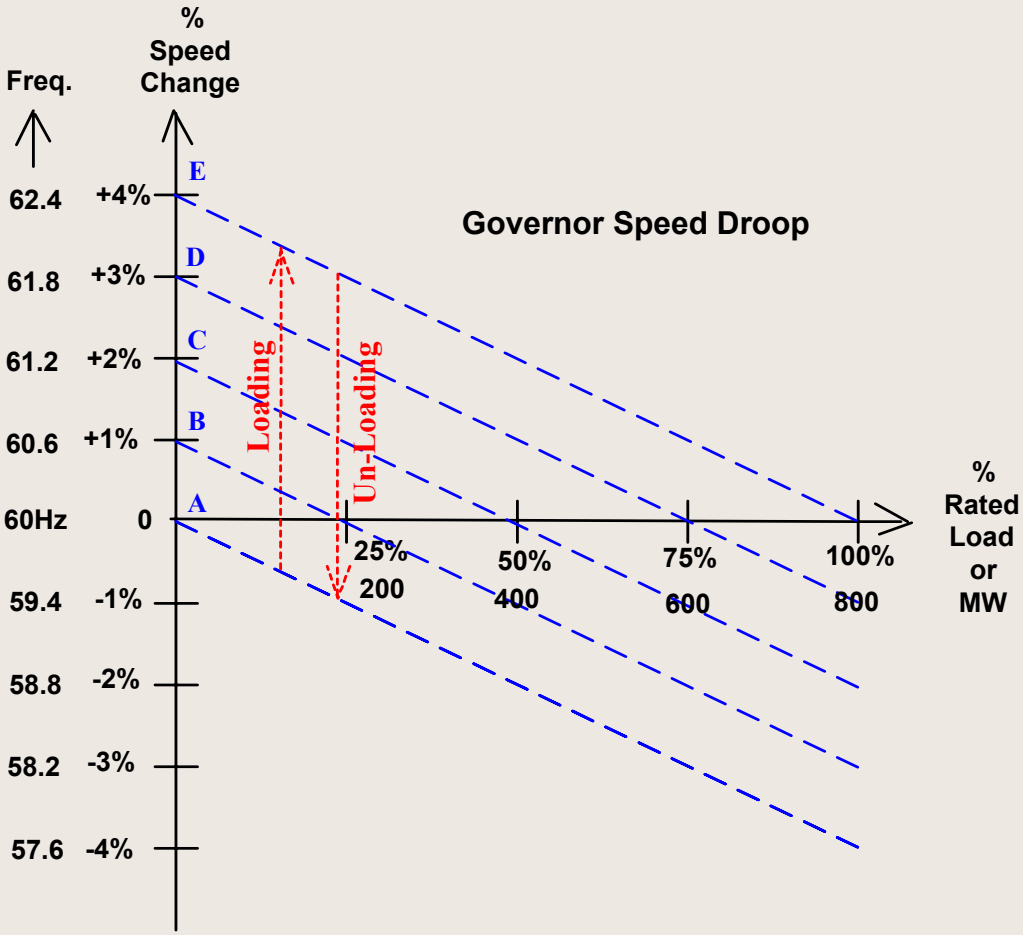
$$\text{Droop} = \frac{\text{Speed Drop NL to FL}}{\text{Rated Speed}} \times 100\%$$

- Isochronous - proportional + integral

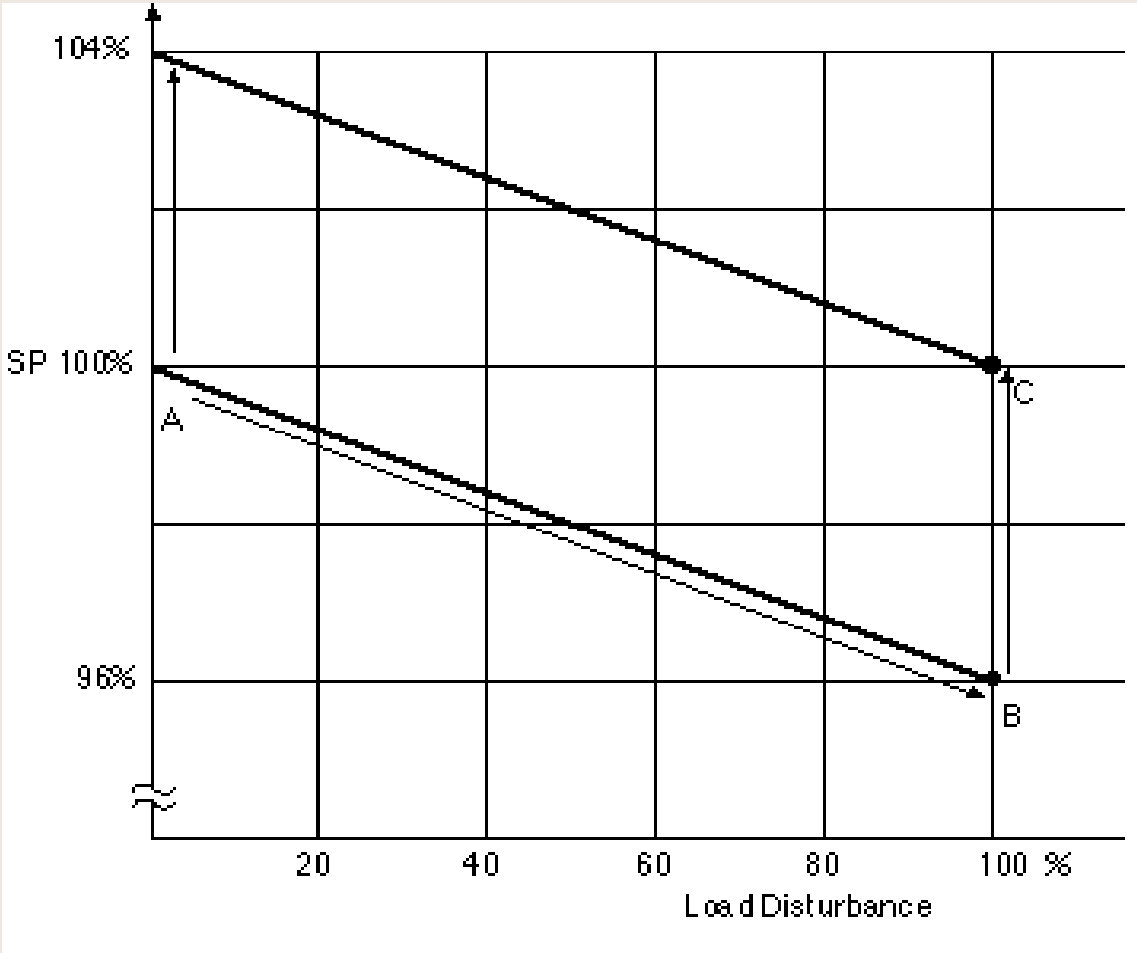
Isochronous



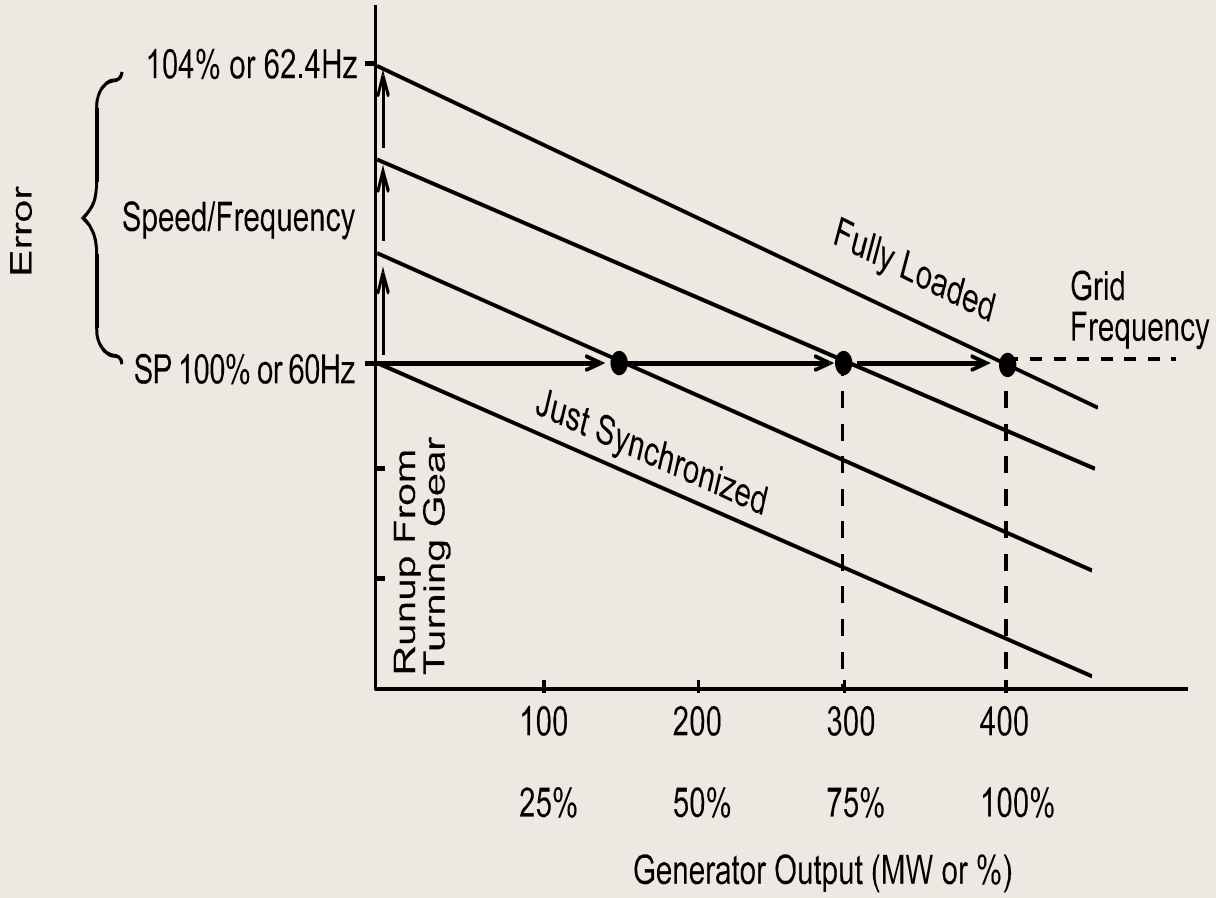
4% Droop


%
Speed
Change
Freq.
62.4
+4%
E
61.8
+3%
D
61.2
+2%
C
60.6
+1%
B
60Hz
0
A
59.4
-1%
58.8
-2%
58.2
-3%
57.6
-4%
Governor Speed Droop
Loading
Un-Loading
25%
200
50%
400
75%
600
100%
800
%
Rated
Load
or
MW

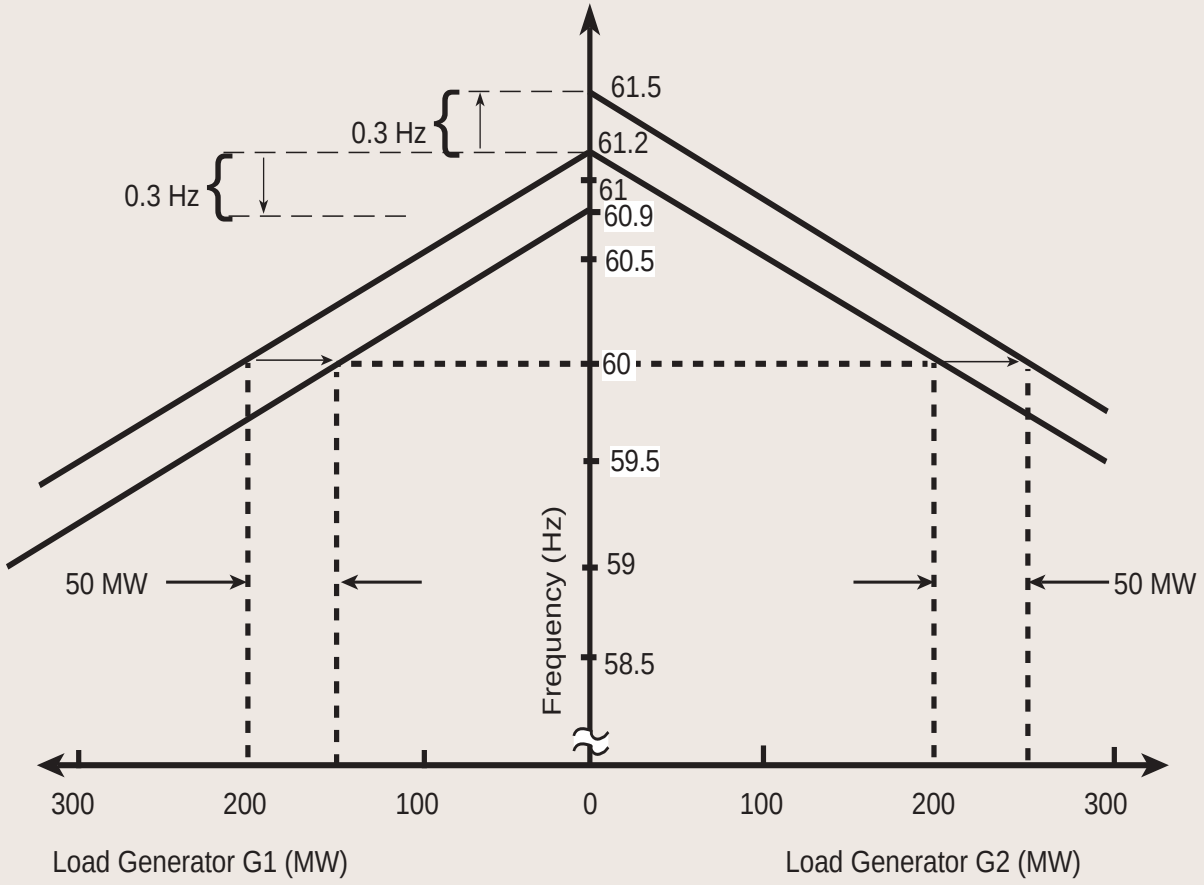
Effect of Adding Load

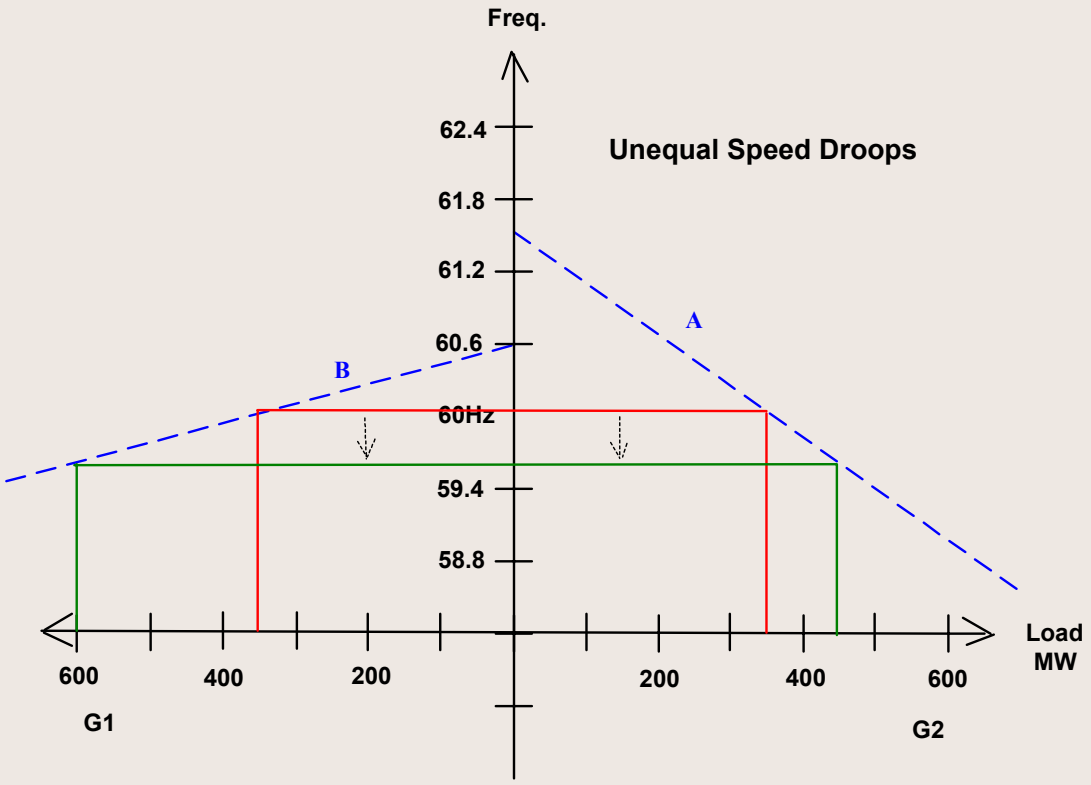


Generator Synchronized

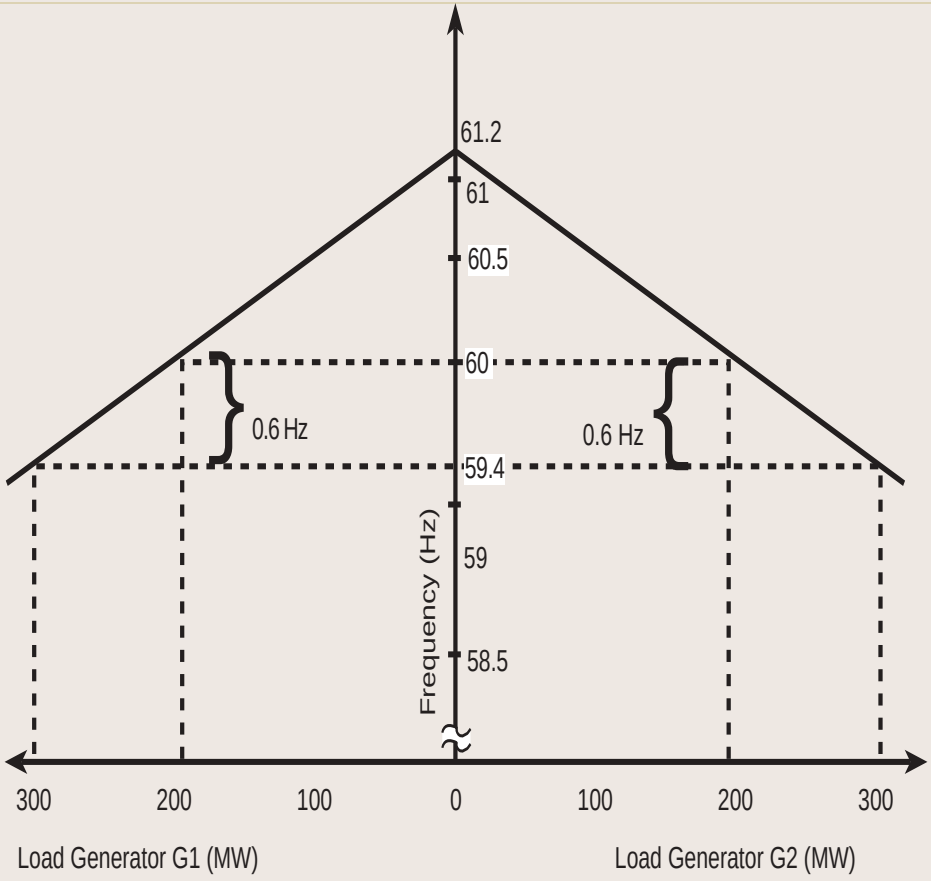


Increasing Load

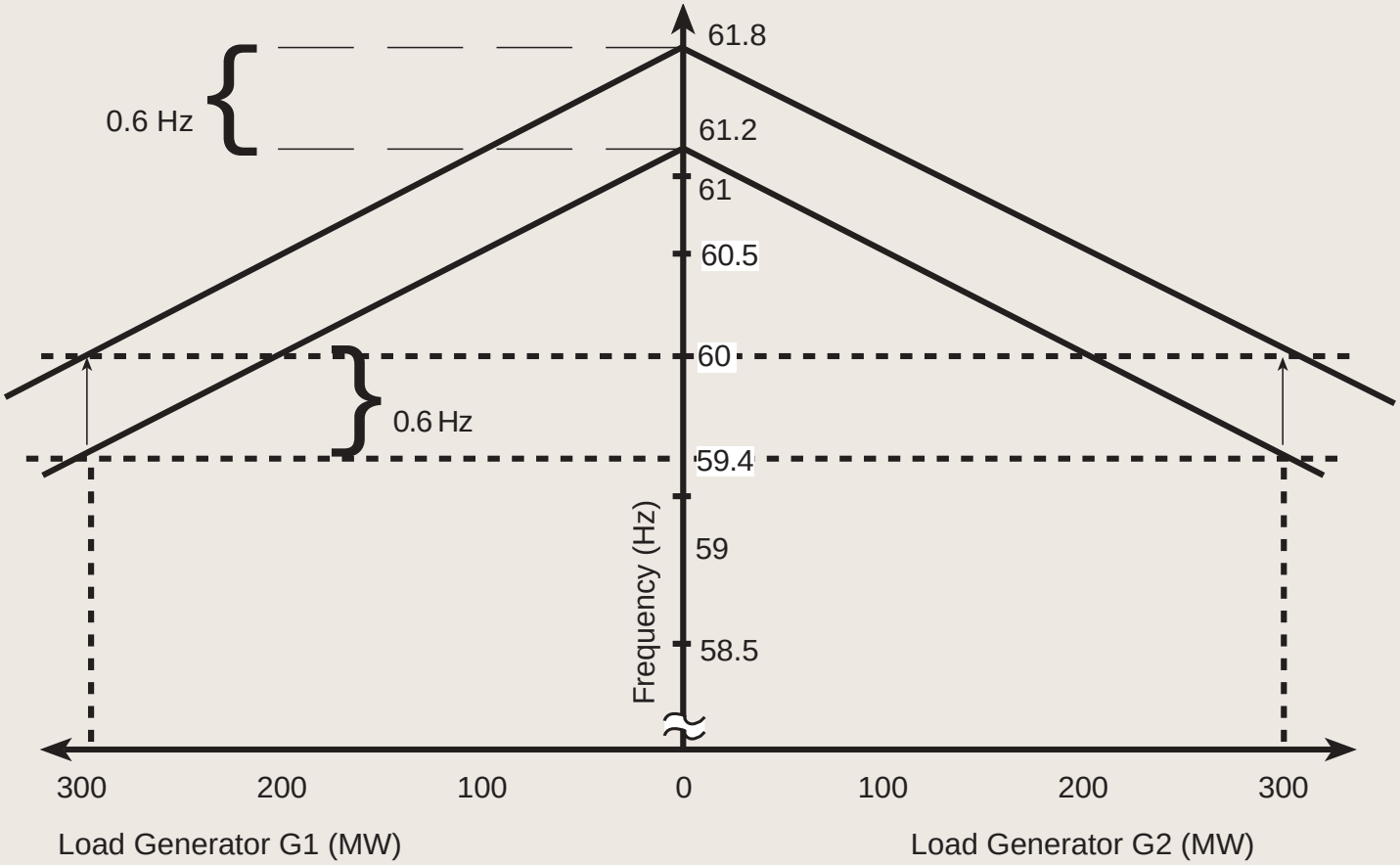



Freq.
62.4
61.8
61.2
60.6
60Hz
59.4
58.8
Unequal Speed Droops
A
B
600
400
200
200
400
600
G1
G2
Load
MW

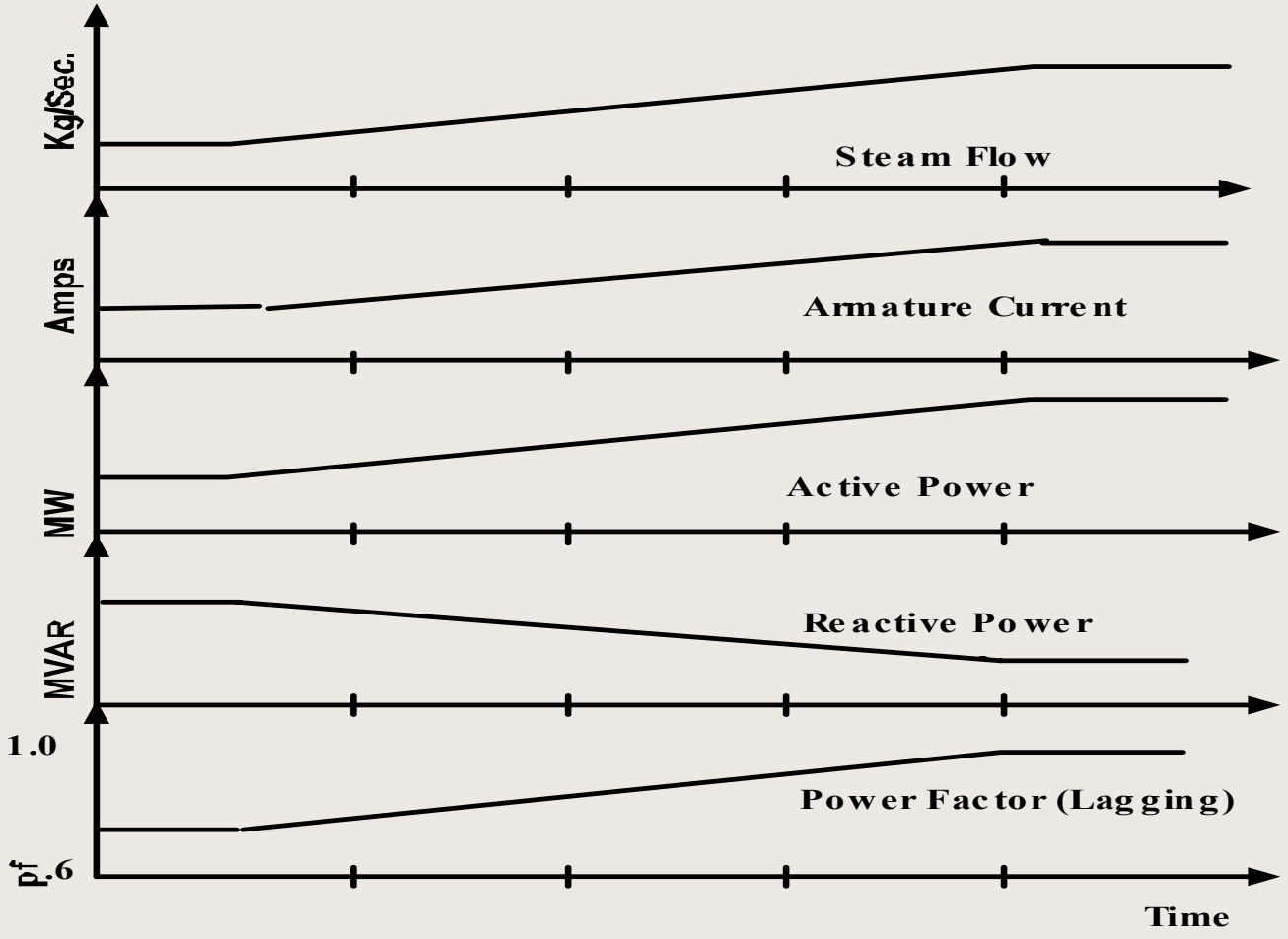
Finite Bus


61.2
61
60.5
60
59.4
59
58.5
Frequency (Hz)
0.6 Hz
0.6 Hz
300
200
100
0
100
200
300
Load Generator G1 (MW)
Load Generator G2 (MW)

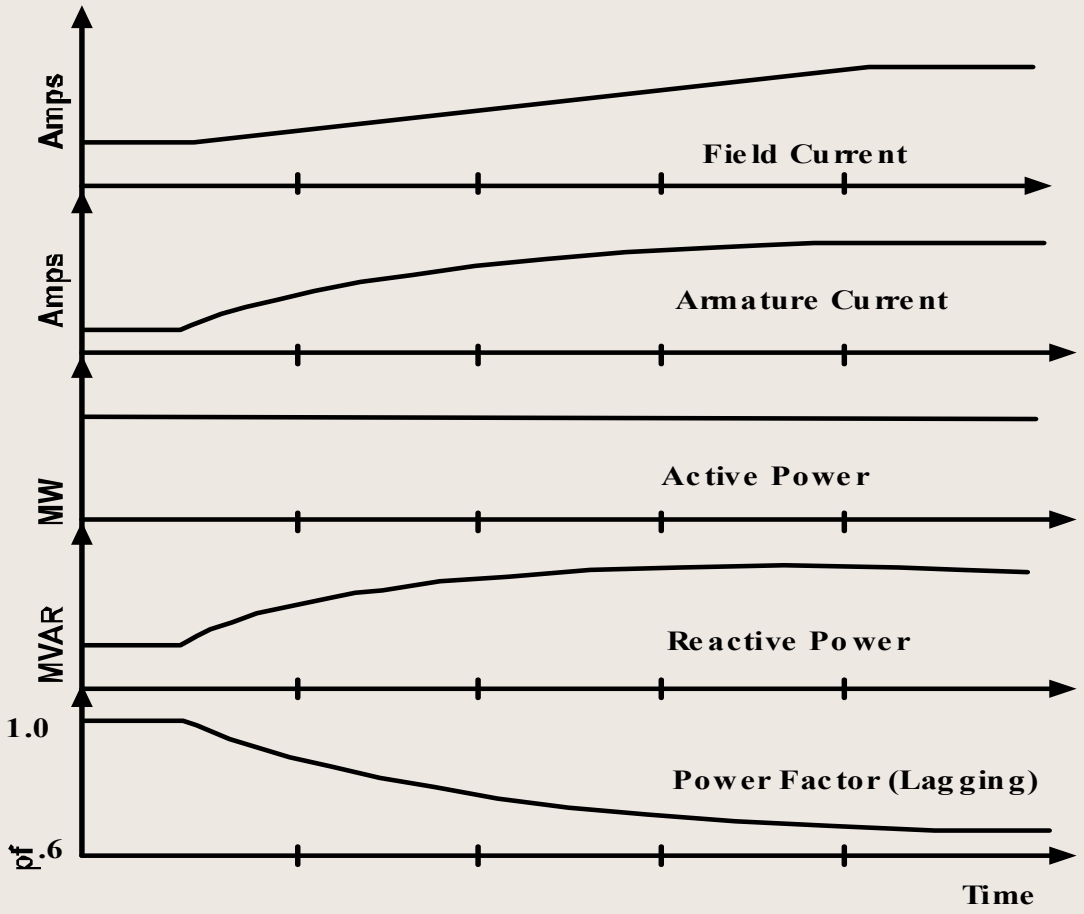
Frequency Restoration



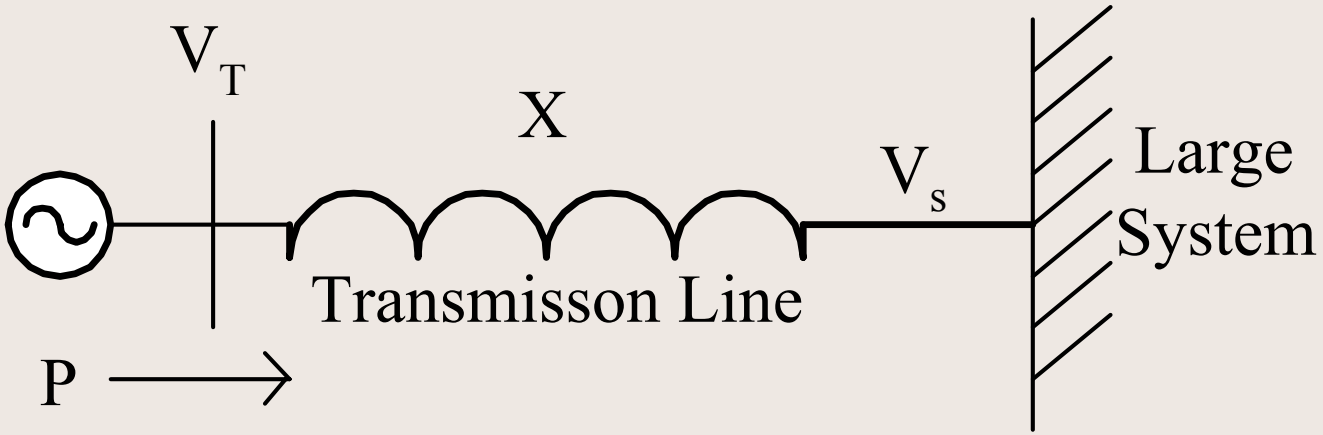
Adjusting Steam Flow



Adjusting Excitation

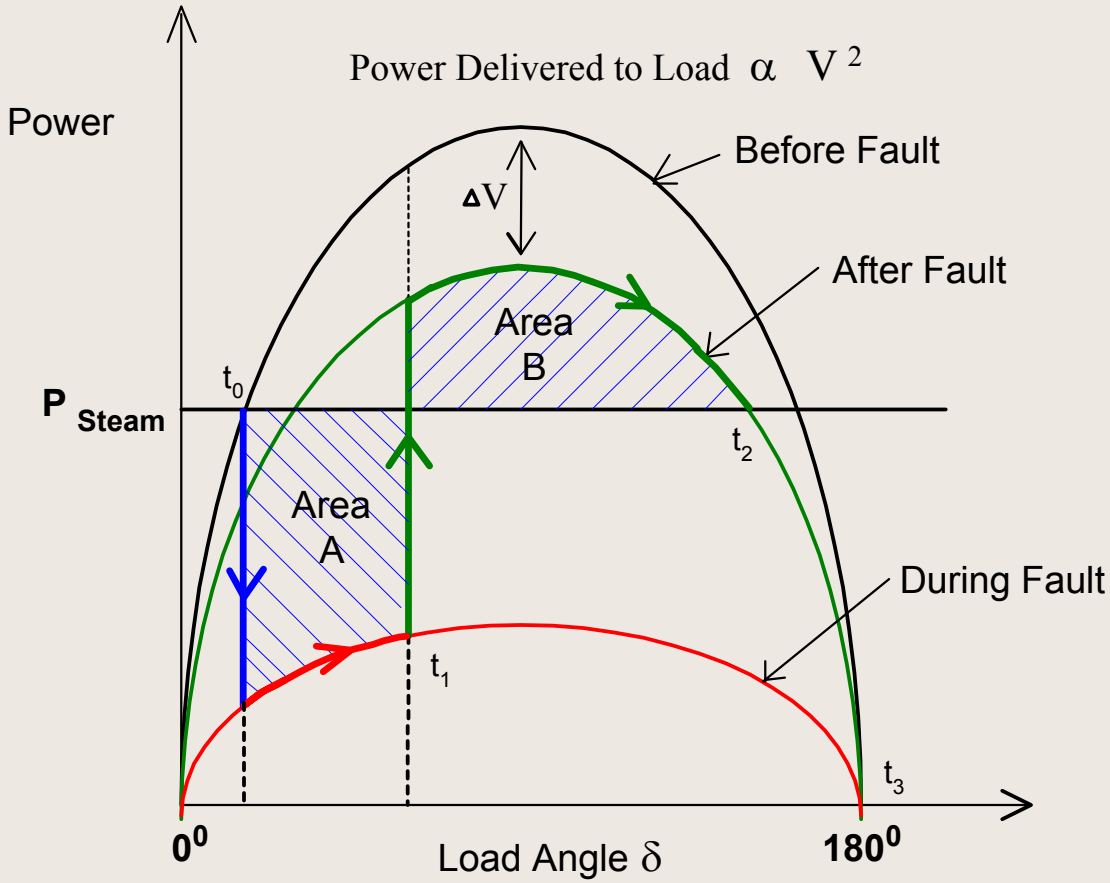


Stability

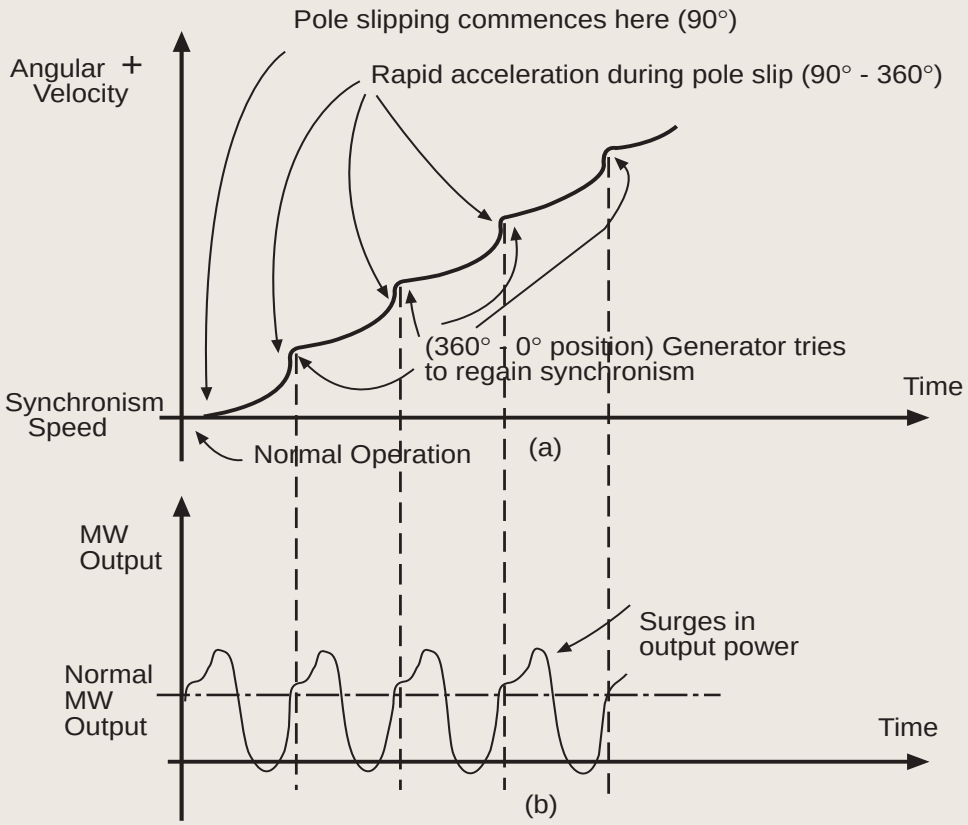


$$P = \frac{V_T V_s}{X} \sin \partial$$

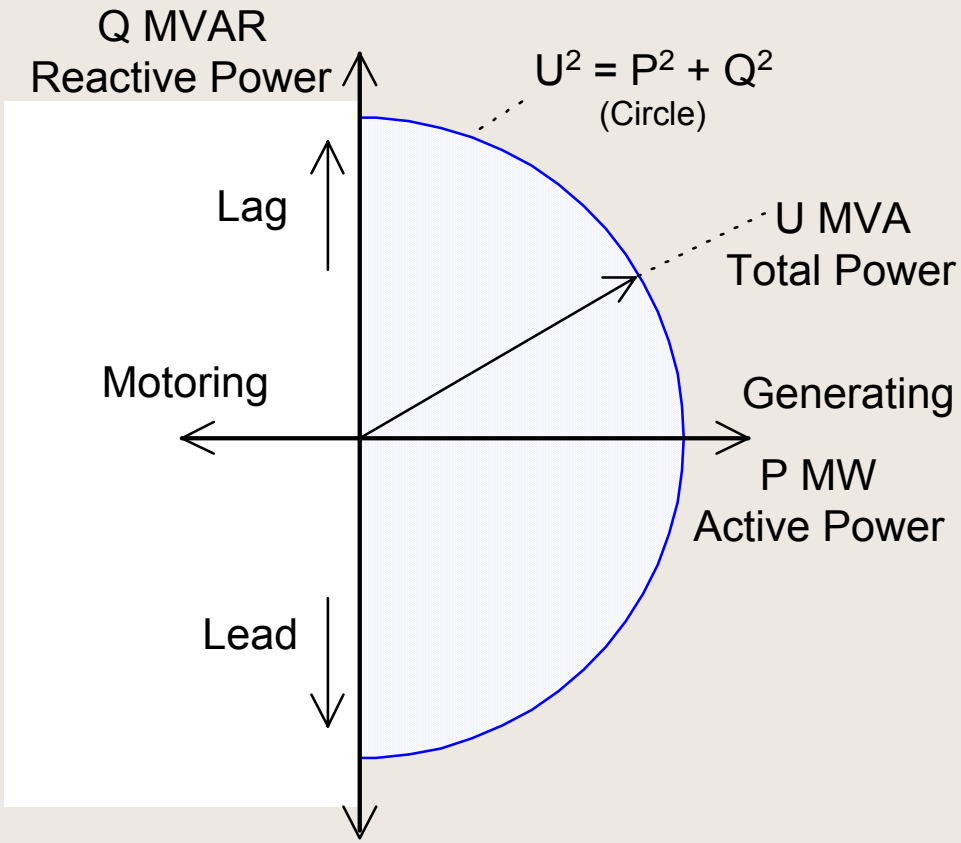
Power Transfer Curve



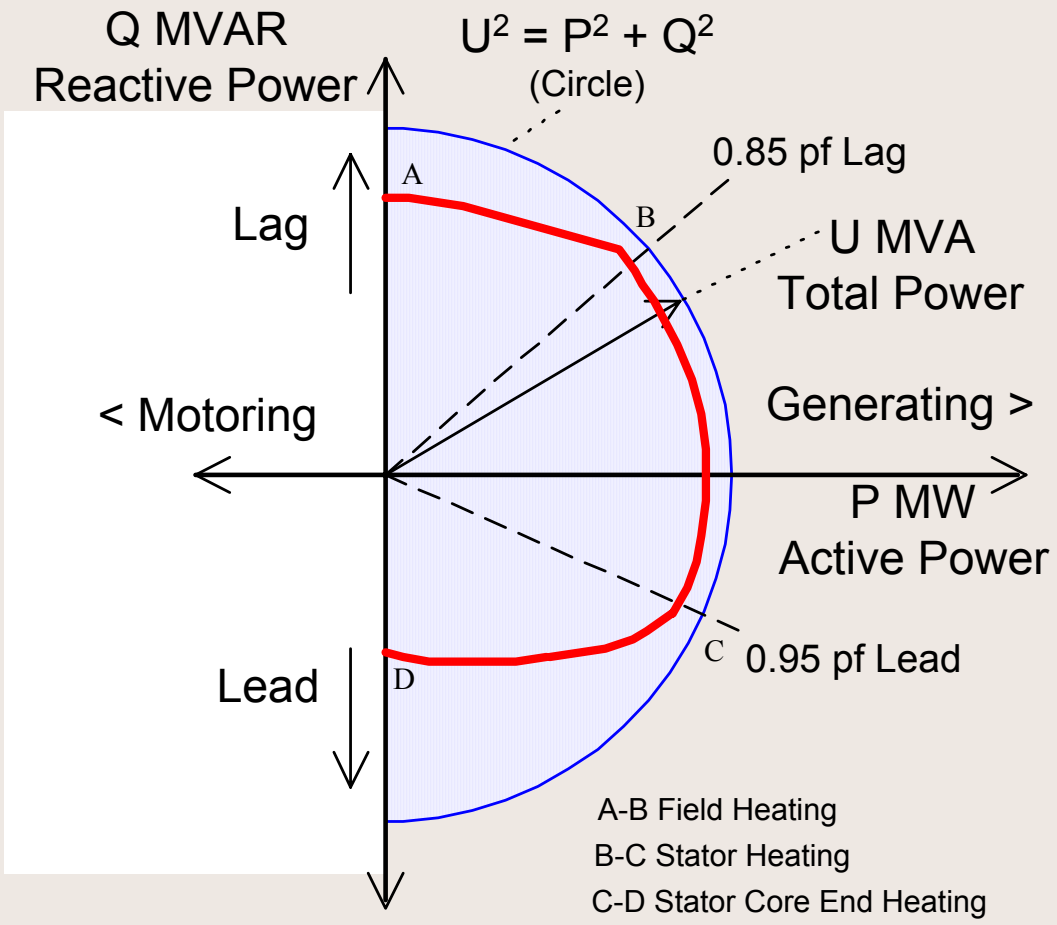
Out of Step


Pole slipping commences here (90°)
Angular + Velocity
Rapid acceleration during pole slip (90° - 360°)
(360° - 0° position) Generator tries to regain synchronism
Synchronism Speed
Time
Normal Operation
(a)
MW Output
Surges in output power
Normal MW Output
Time
(b)

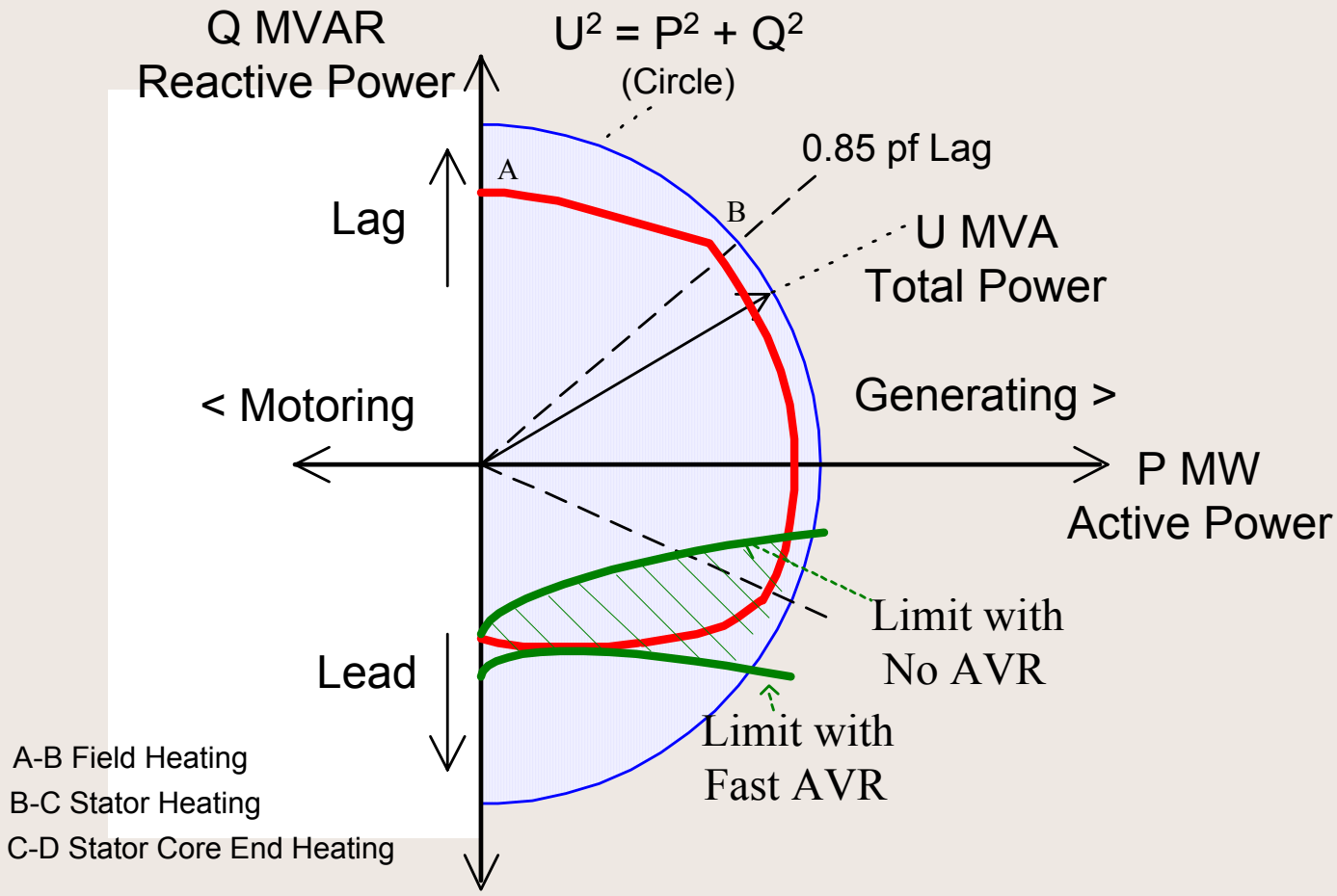
Generator Heating



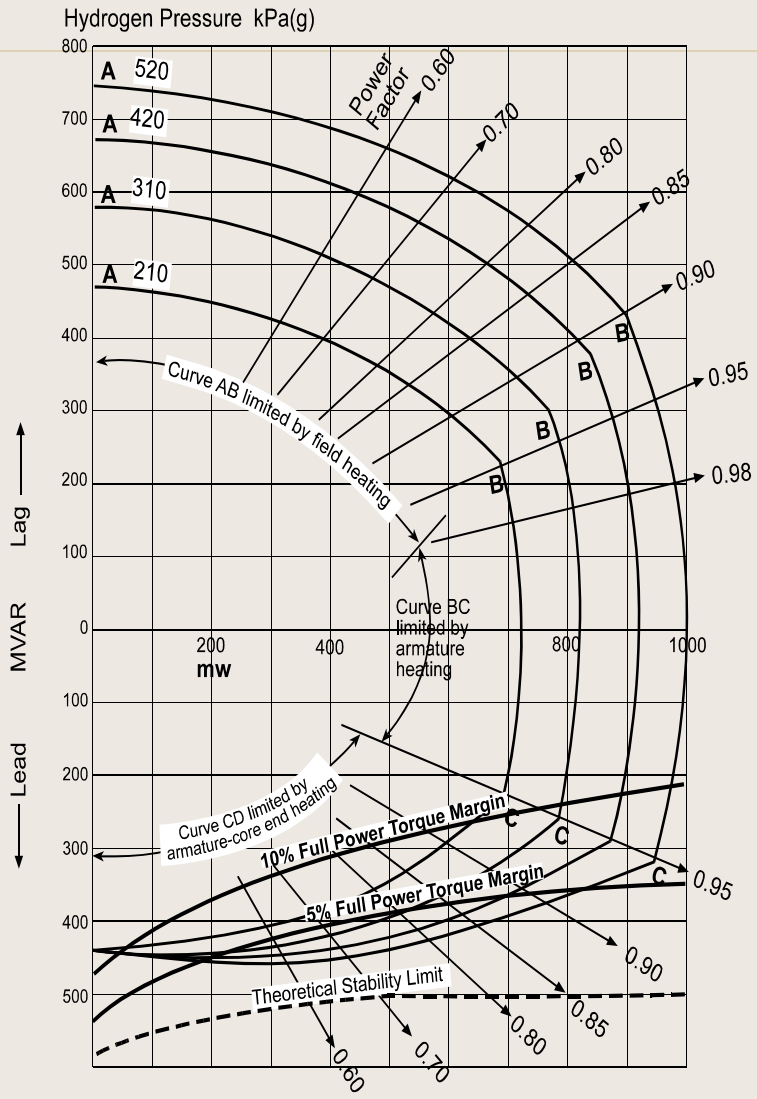
Limits


Q MVAR
Reactive Power
$U^2 = P^2 + Q^2$
(Circle)
0.85 pf Lag
A
B
Lag
U MVA
Total Power
< Motoring
Generating >
P MW
Active Power
C
0.95 pf Lead
Lead
D
A-B Field Heating
B-C Stator Heating
C-D Stator Core End Heating

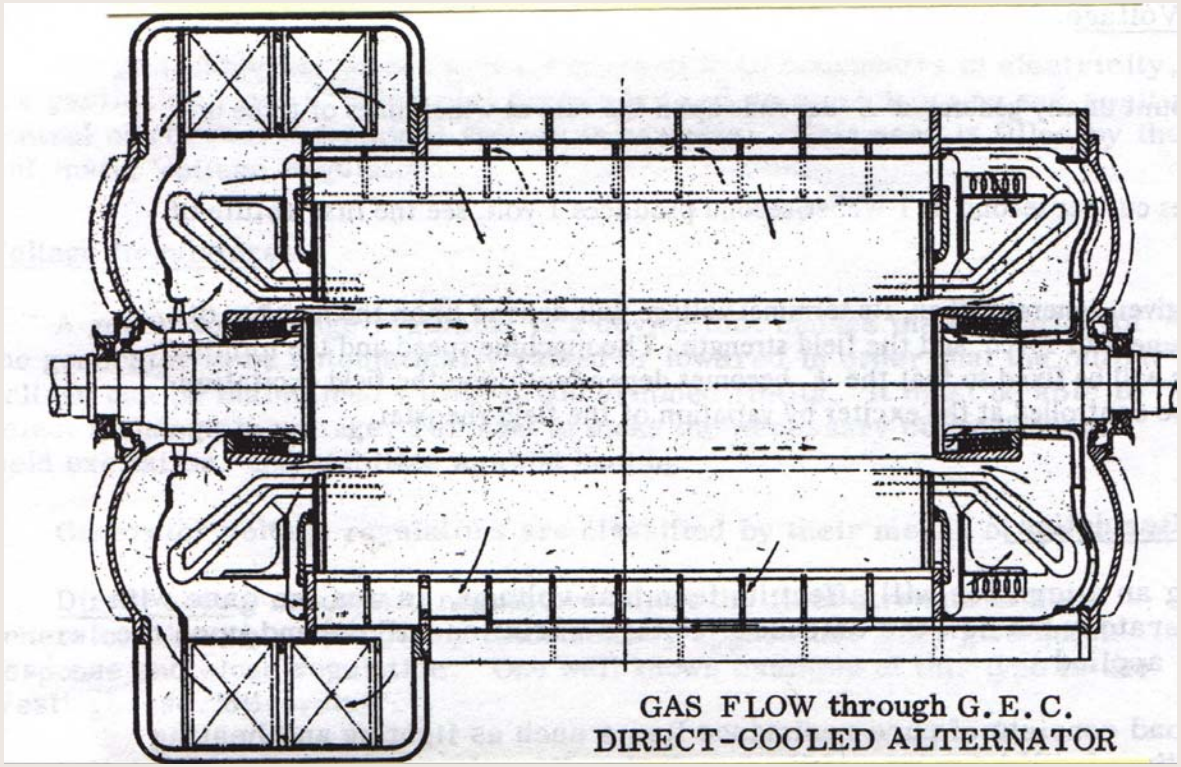
Stability Limits



H_2 Pressure


Hydrogen Pressure kPa(g)
800
700
600
500
400
300
200
100
0
100
200
300
400
500
A 520
A 420
A 310
A 210
Power Factor
0.60
0.70
0.80
0.85
0.90
0.95
0.98
B
B
B
B
Curve AB limited by field heating
Curve BC limited by armature heating
200
400
800
1000
mw
MVAR
Lag
Lead
Curve CD limited by armature-core end heating
10% Full Power Torque Margin
5% Full Power Torque Margin
C
C
C
0.95
0.90
0.85
0.80
0.70
0.60
Theoretical Stability Limit

Cooling



For You To Do