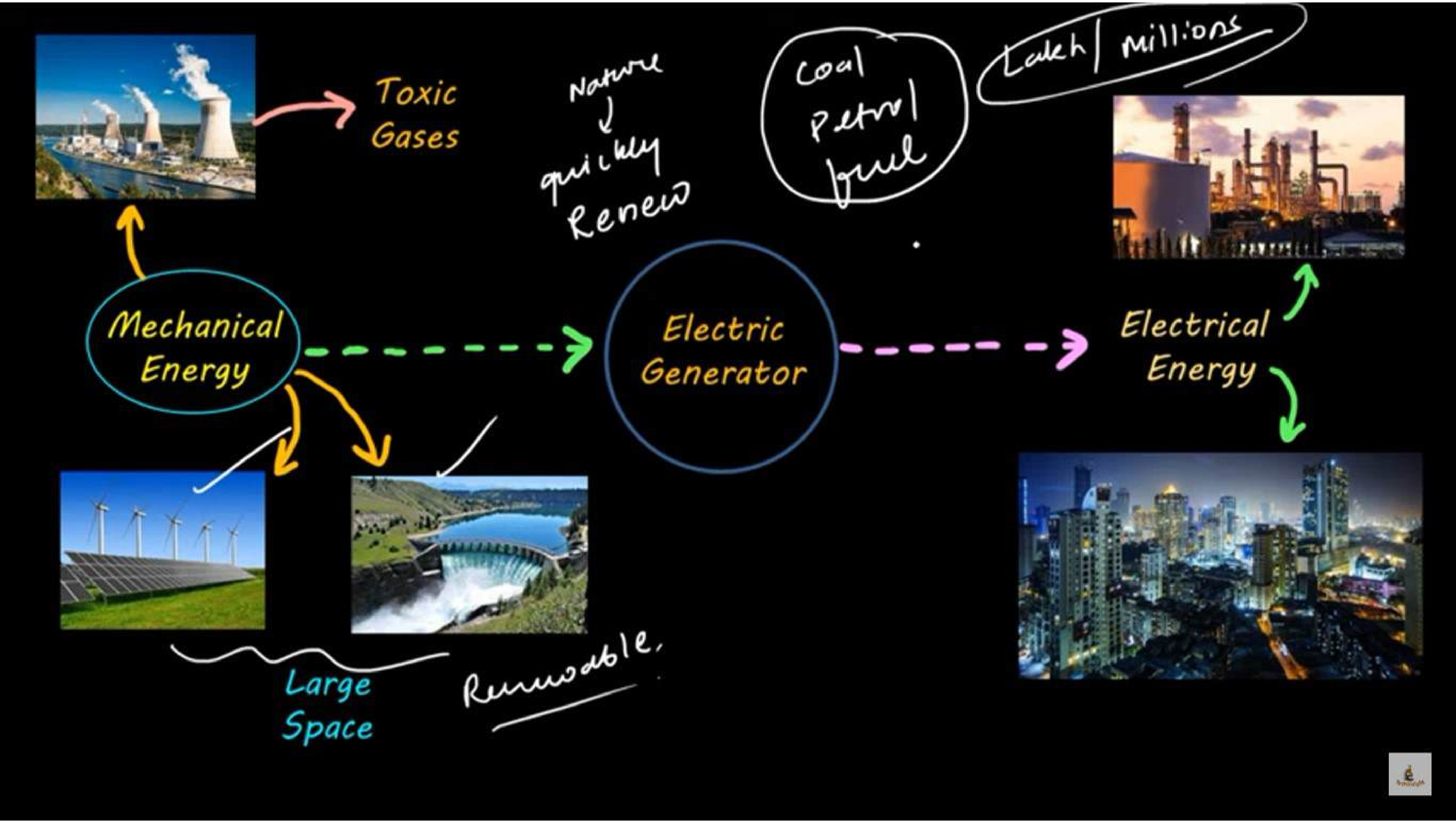
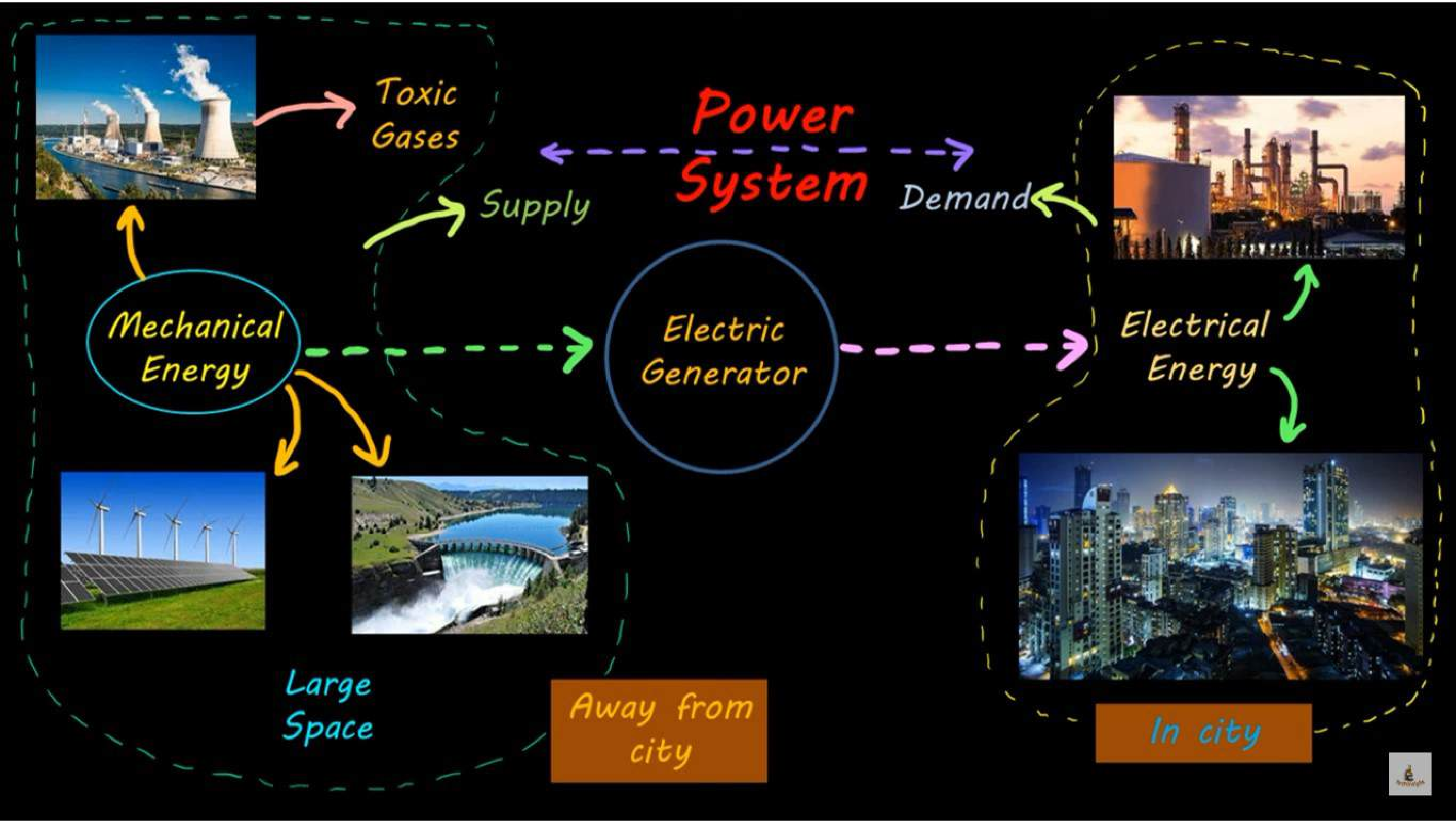
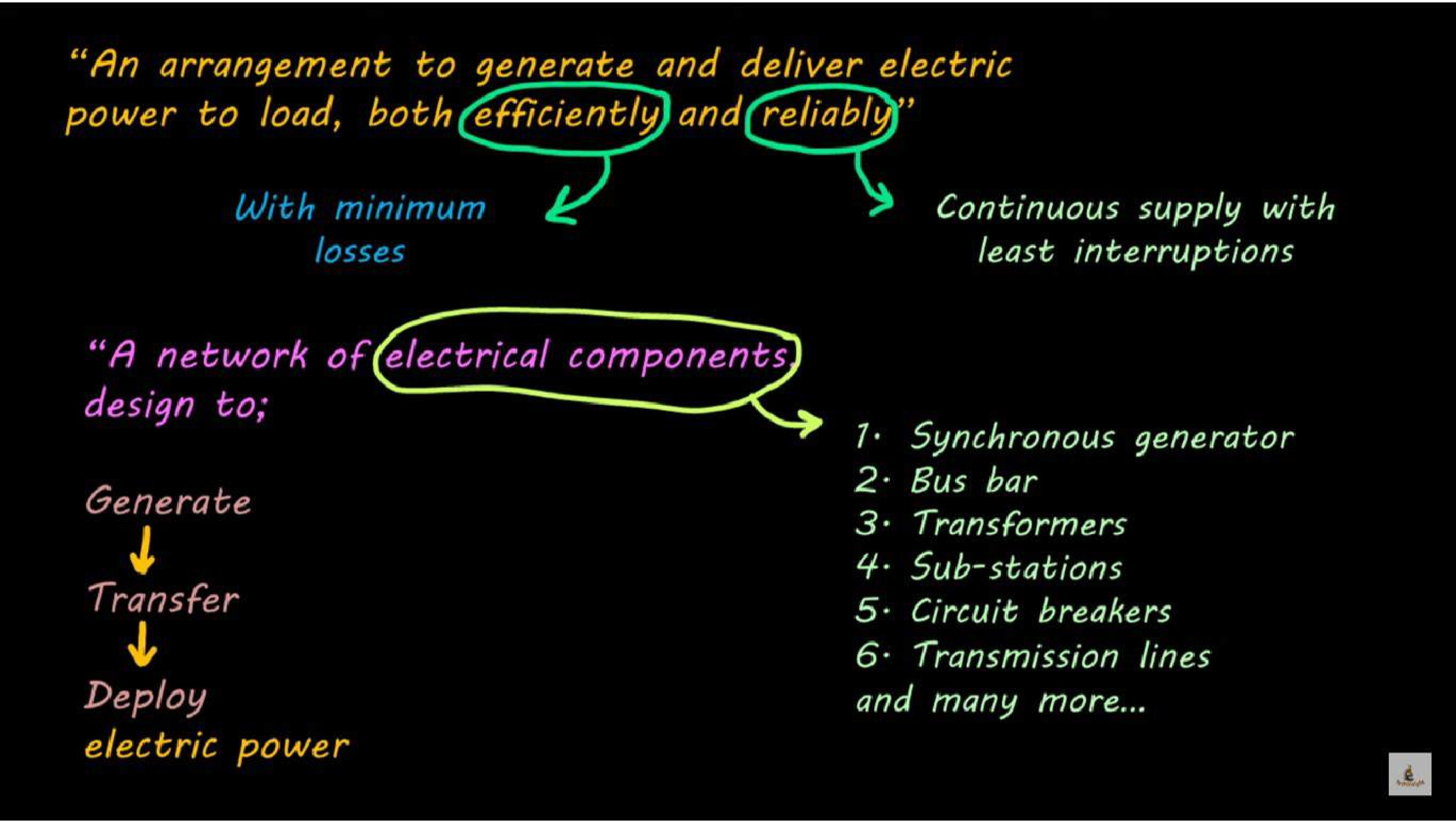

Toxic Gases
Nature
quickly
Renew
coal
petrol
fuel
Lakh / Millions
Mechanical Energy
Electric Generator
Electrical Energy
Large Space
Renewable,


Toxic Gases
Power System
Supply
Demand
Mechanical Energy
Electric Generator
Electrical Energy
Large Space
Away from city
In city

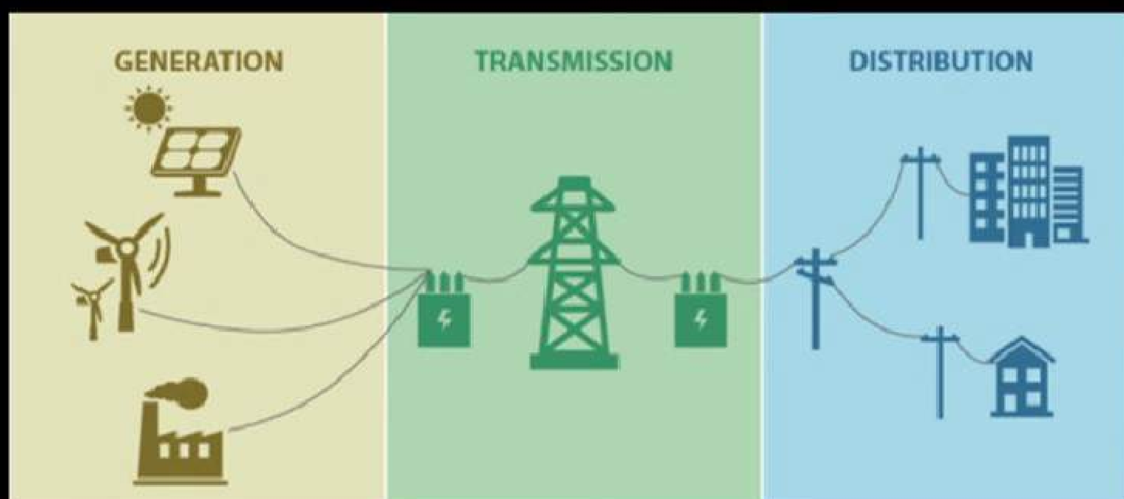

"An arrangement to generate and deliver electric power to load, both efficiently and reliably"
With minimum losses
Continuous supply with least interruptions
"A network of electrical components, design to;
Generate
Transfer
Deploy
electric power
1. Synchronous generator
2. Bus bar
3. Transformers
4. Sub-stations
5. Circuit breakers
6. Transmission lines
and many more...

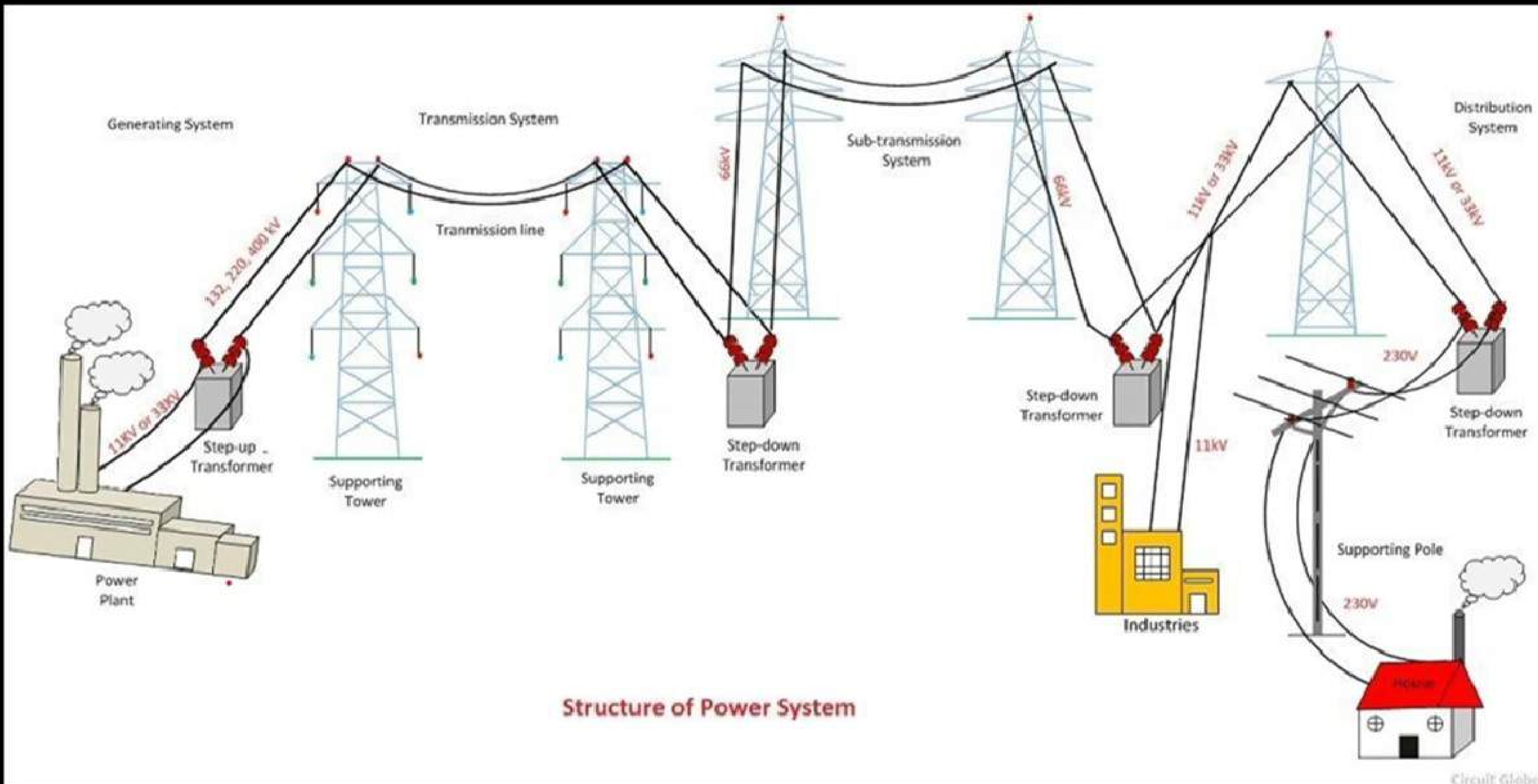
Division of Power System

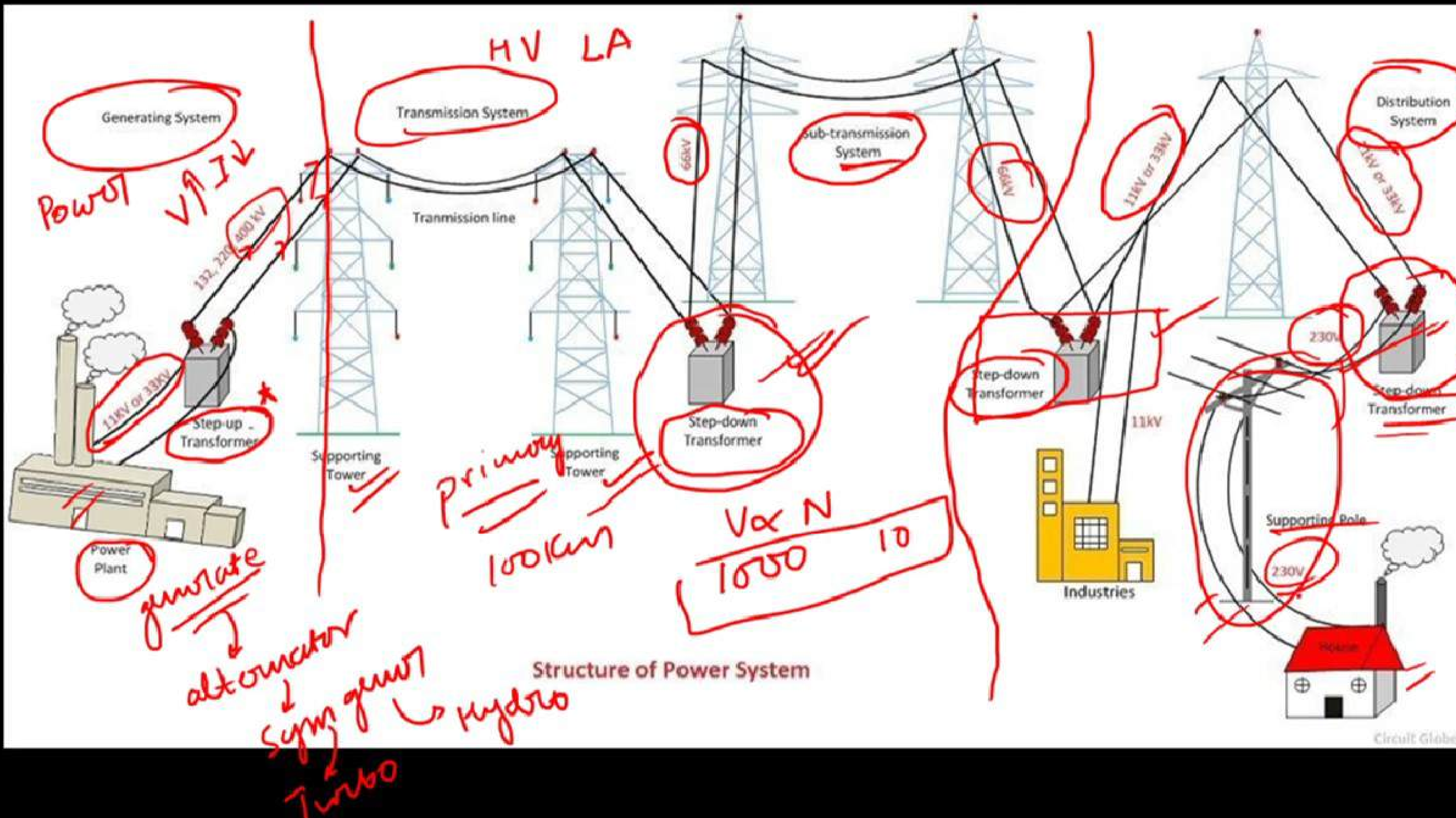
Generating System

Transmission System

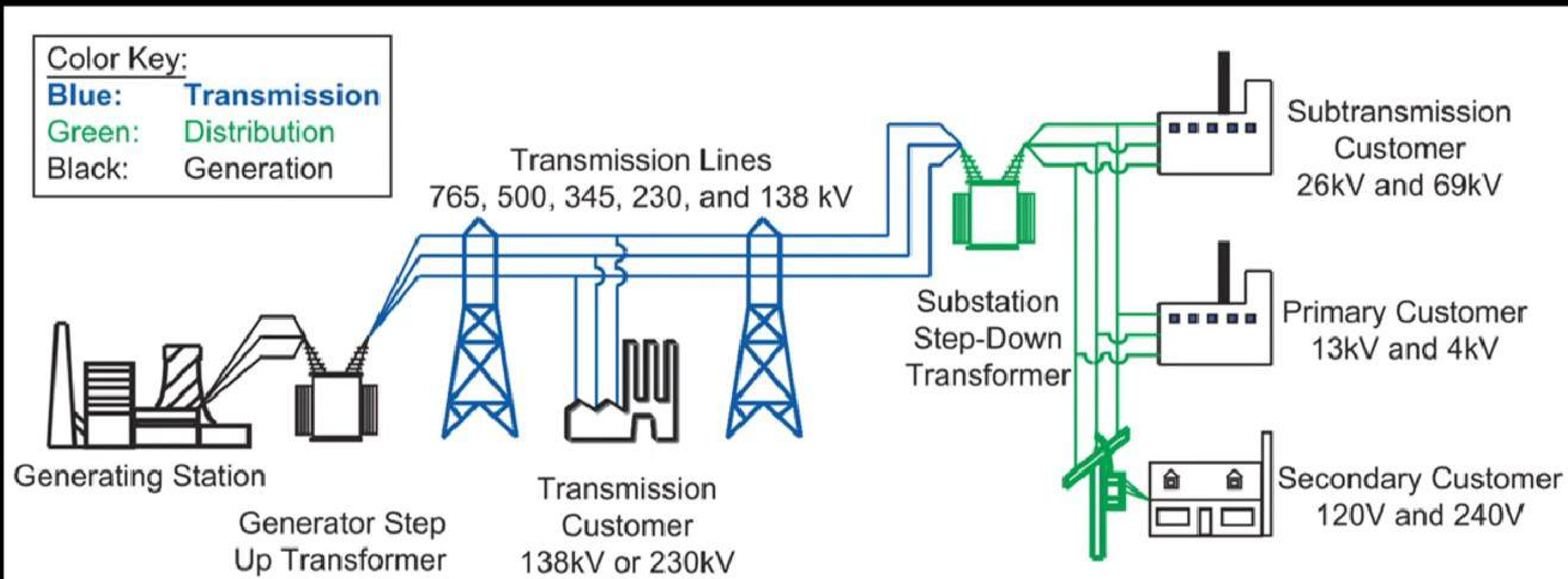
Distribution System



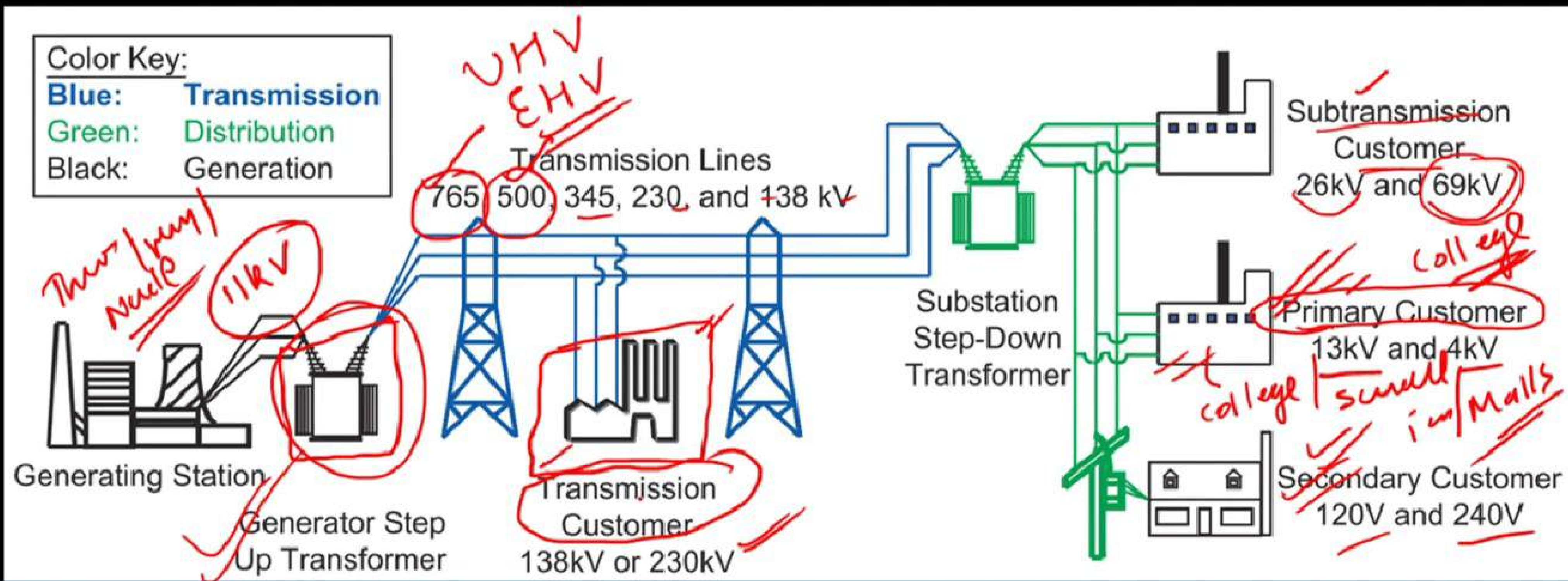

Generating System
Transmission System
Sub-transmission System
Distribution System
132, 220, 400 kV
11KV or 33KV
Tranmission line
66kV
66kV
11kV or 33kV
11kV or 33kV
230V
11kV
Step-up Transformer
Supporting Tower
Supporting Tower
Step-down Transformer
Step-down Transformer
Step-down Transformer
Power Plant
Industries
Supporting Pole
230V
House
Structure of Power System
Circuit Globe

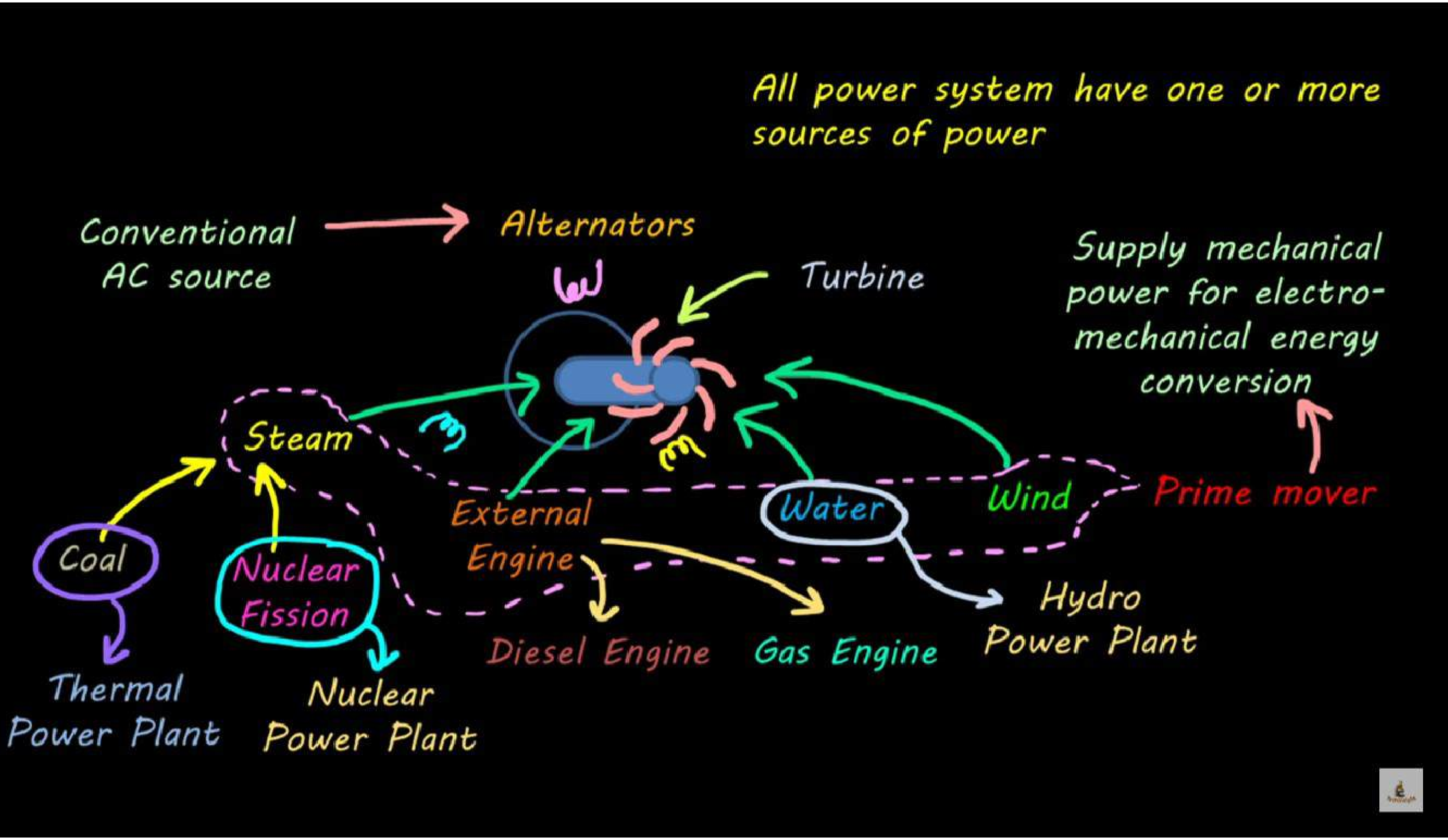


Structure of Power System



Color Key:
Blue: Transmission
Green: Distribution
Black: Generation
Transmission Lines
765, 500, 345, 230, and 138 kV
Subtransmission
Customer
26kV and 69kV
Substation
Step-Down
Transformer
Primary Customer
13kV and 4kV
Generating Station
Generator Step
Up Transformer
Transmission
Customer
138kV or 230kV
Secondary Customer
120V and 240V


Color Key:
Blue: Transmission
Green: Distribution
Black: Generation
Transmission Lines
765, 500, 345, 230, and 138 kV
UHV
EHV
11kV
Generating Station
Generator Step Up Transformer
Transmission Customer
138kV or 230kV
Substation Step-Down Transformer
Subtransmission Customer
26kV and 69kV
Primary Customer
13kV and 4kV
college
Secondary Customer
120V and 240V


All power system have one or more sources of power
Conventional AC source
Alternators
Turbine
Supply mechanical power for electro-mechanical energy conversion
Steam
External Engine
Water
Wind
Prime mover
Coal
Nuclear Fission
Diesel Engine
Gas Engine
Hydro Power Plant
Thermal Power Plant
Nuclear Power Plant

Speed of Alternator → Depends on

Depends on → No. of poles

Depends on → Frequency Required

No. of poles → Depends on prime mover

Depends on prime mover → High impact (Steam) → Turbo generator → Small number of poles

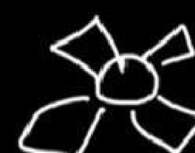
Depends on prime mover → Low impact (Water) → Hydro generator → Large number of poles

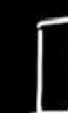
speed $N_s = \frac{120 f}{P}$ 50Hz

$$\boxed{N_s \propto \frac{1}{P}}$$

Frequency Required → Must be same for complete nation

Example: 50Hz for India





Power system $\xrightarrow{\text{Energy}}$ Loads → Perform functions →

1. Lightning
2. Wind
3. Heating
4. Weight lifting

Loads → Industrial, Households

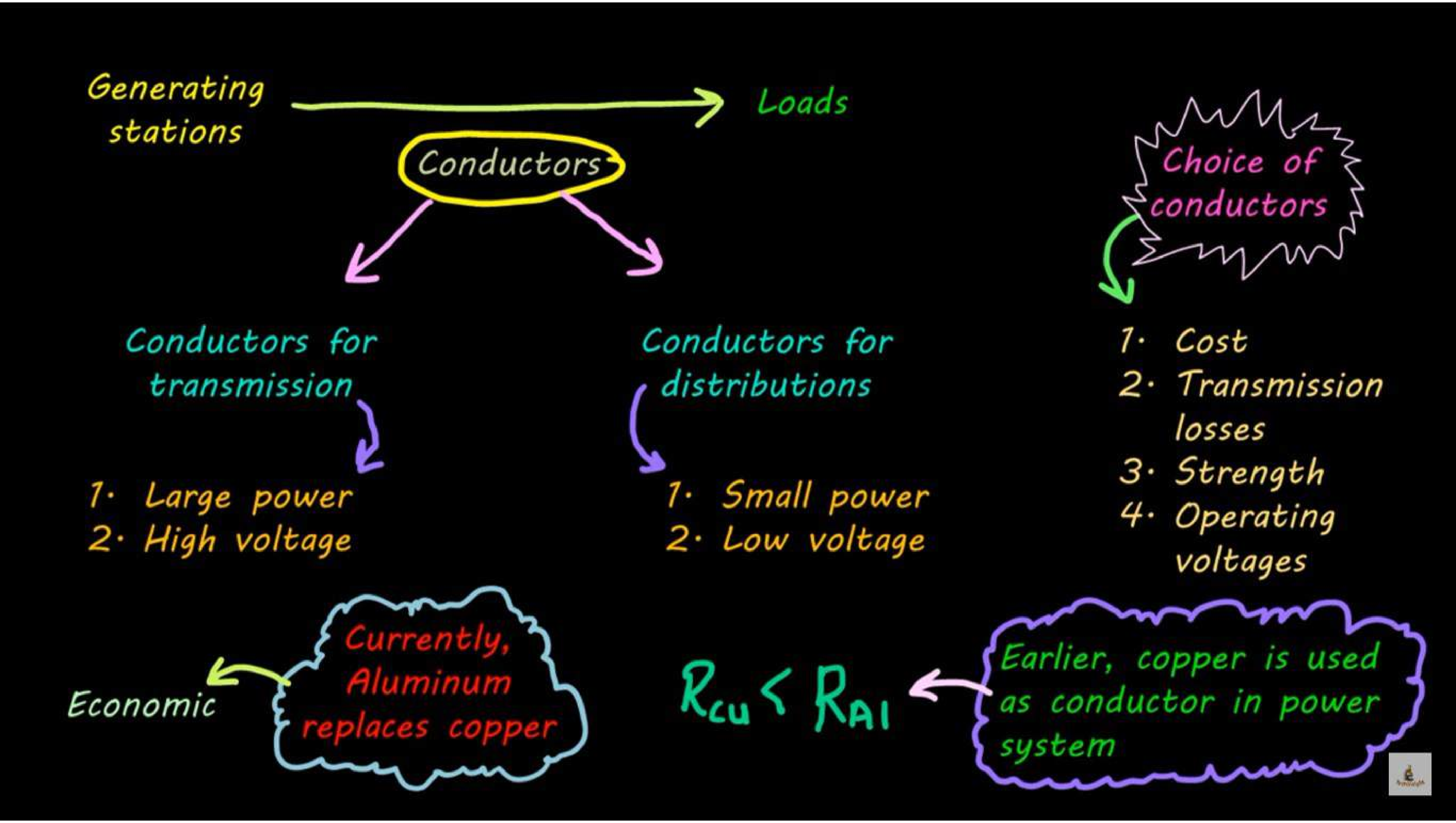
Need active & reactive power

Industrial

Need 3-phase supply → smooth oper → large power

Households

Need 1-phase supply


Generating stations
Loads
Conductors
Choice of conductors
Conductors for transmission
Conductors for distributions
1. Large power
2. High voltage
1. Small power
2. Low voltage
1. Cost
2. Transmission losses
3. Strength
4. Operating voltages
Economic
Currently, Aluminum replaces copper
$R_{Cu} < R_{Al}$
Earlier, copper is used as conductor in power system

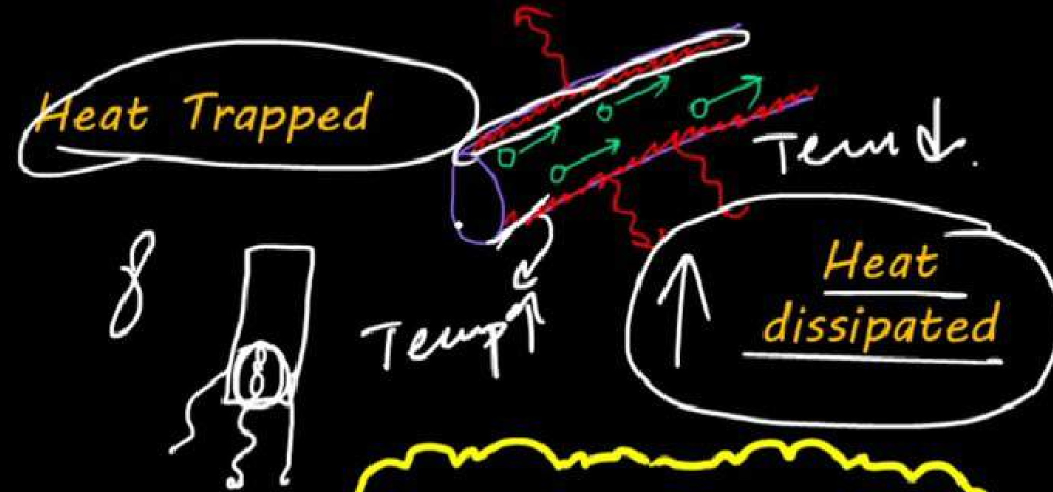
Rating

The rating of conductors is decided by

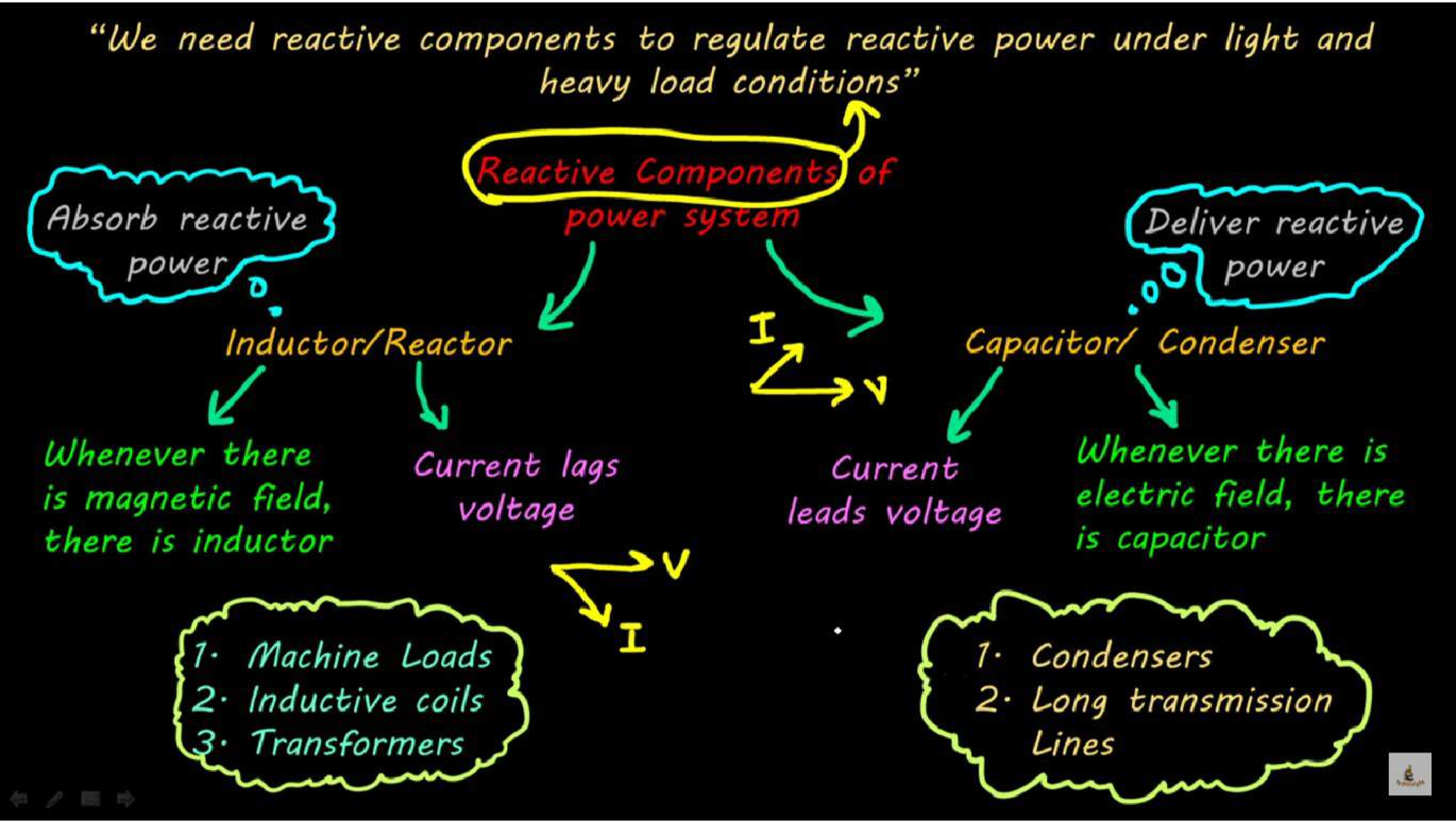
Ampacity

ampere capacity

maximum current, in amperes, that a conductor can carry continuously without exceeding its temperature rating

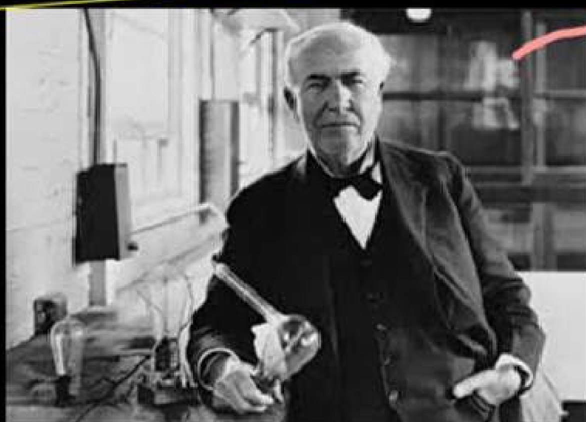


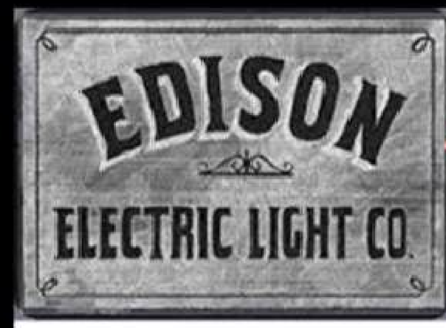
The ampacity of a conductor depends on its ability to dissipate heat without damage to the conductor or its insulation



"We need reactive components to regulate reactive power under light and heavy load conditions"
Reactive Components of power system
Absorb reactive power
Deliver reactive power
Inductor/Reactor
Capacitor/ Condenser
I
V
Whenever there is magnetic field, there is inductor
Current lags voltage
Current leads voltage
Whenever there is electric field, there is capacitor
V
I
1. Machine Loads
2. Inductive coils
3. Transformers
1. Condensers
2. Long transmission Lines

Problem with Edison's DC system





Unable to step-up or step-down the voltage ~~levels of DC power~~

Transformer

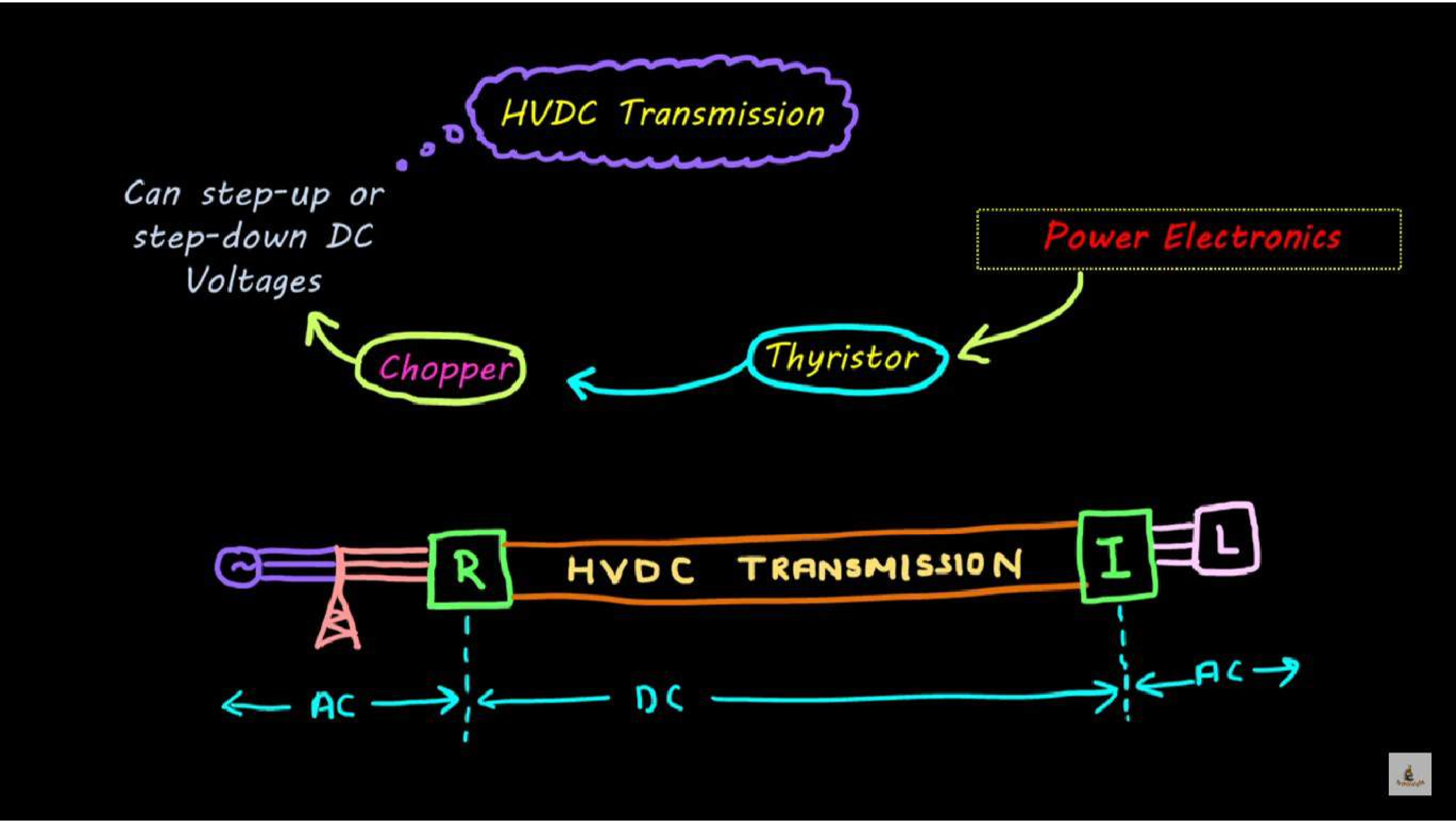
step up/down

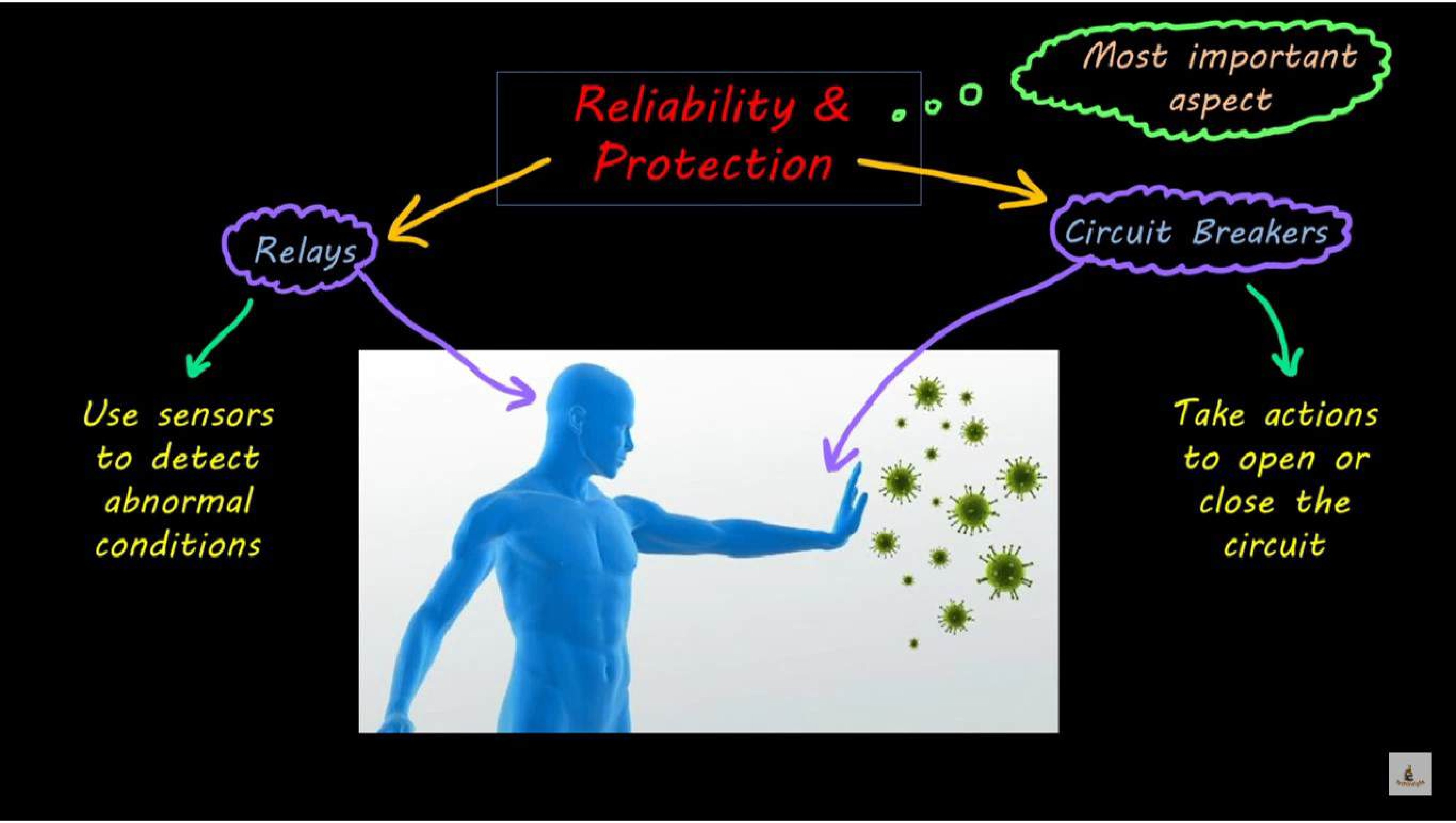
AC power

couldn't be transmitted long distances

Advantages

1. Low losses (no corona losses)
2. Economical (needs only two wires of transmission, while a 3 phase AC may need up to 4 wires)
3. No skin effect
4. No need of reactive power regulation


HVDC Transmission
Can step-up or step-down DC Voltages
Power Electronics
Chopper
Thyristor
R
HVDC TRANSMISSION
I
L
AC
DC
AC

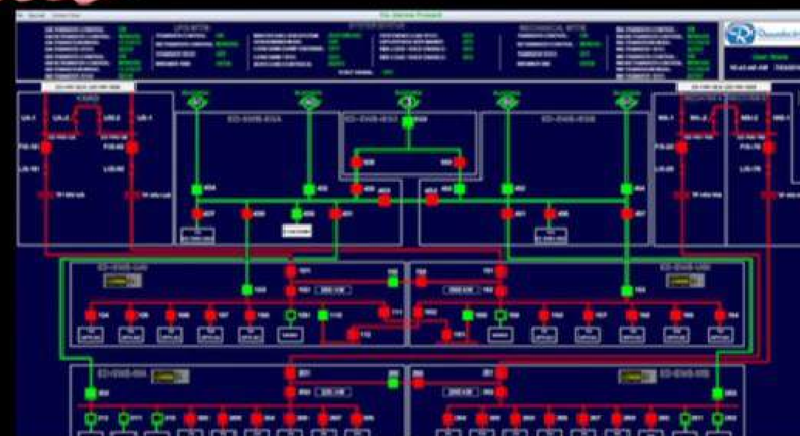

Reliability & Protection
Most important aspect
Relays
Circuit Breakers
Use sensors to detect abnormal conditions
Take actions to open or close the circuit

SCADA

Supervisory control and data acquisition

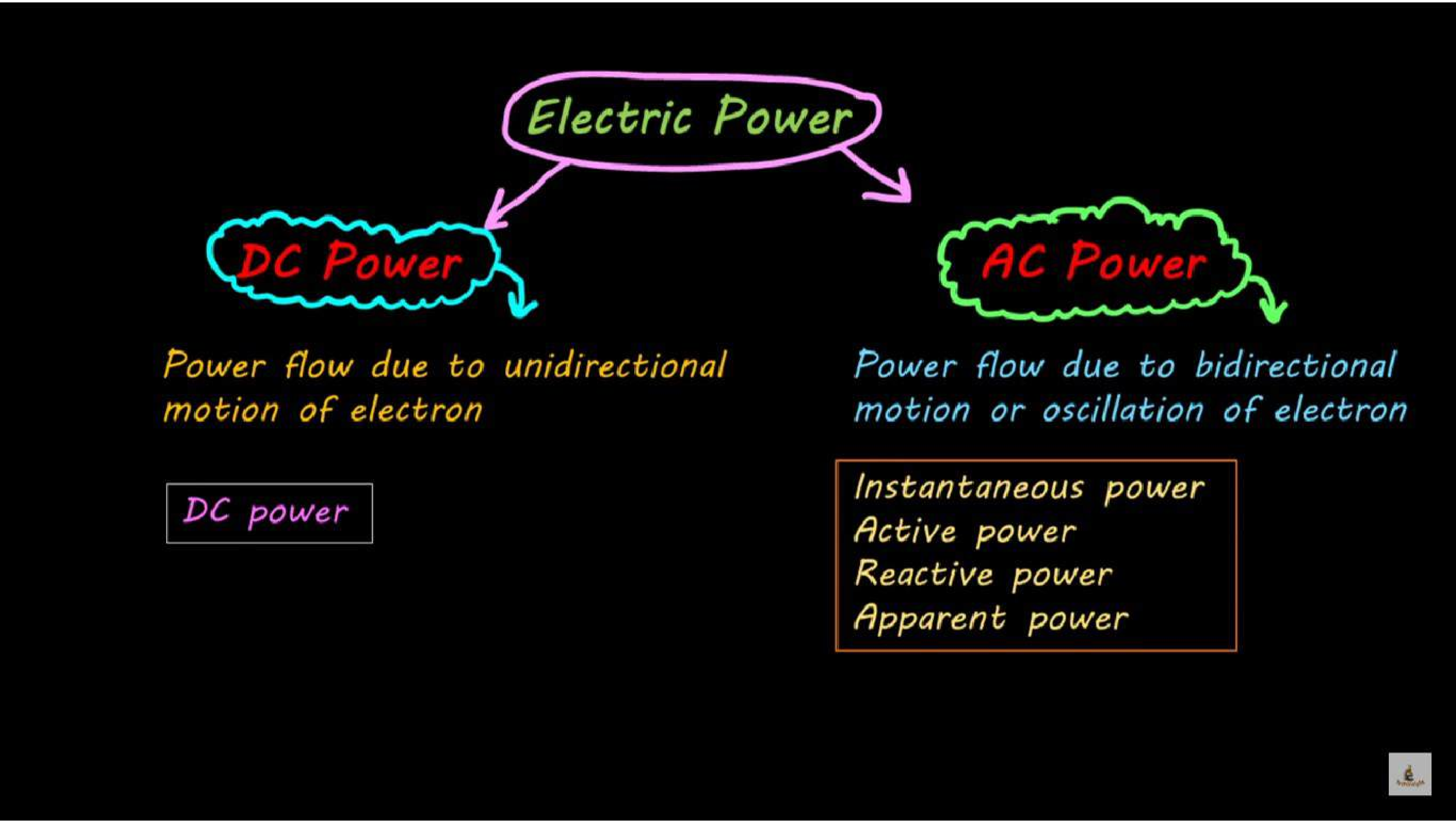
HISTORY

Lamps and switches



Used to

\# Switch on generators
\# Controlling Generation
\# switch off generators for maintenance


Electric Power
DC Power
AC Power
Power flow due to unidirectional motion of electron
Power flow due to bidirectional motion or oscillation of electron
DC power
Instantaneous power
Active power
Reactive power
Apparent power

Definition

In an electric circuit, instantaneous power is the time rate of flow of energy past a given point of the circuit.

the product of instantaneous voltage (v) across the element and instantaneous current (i) through the element

$i(t) \rightarrow$ Inst. current

$I(t) \rightarrow$ Rms value

$I_m \rightarrow$ max ~~rms~~ value

Symbol

Instantaneous power $\leftarrow$ - - - - - $p(t)$

Instantaneous Current $\leftarrow$ - - - - - $i(t)$

Instantaneous Voltage $\leftarrow$ - - - - - $v(t)$

Definition

In an electric circuit, instantaneous power is the time rate of flow of energy past a given point of the circuit.

the product of instantaneous voltage (v) across the element and instantaneous current (i) through the element

Symbol

Instantaneous power ← $p(t)$

Instantaneous Current ← $i(t)$

Instantaneous Voltage ← $v(t)$

$$p(t) = i(t) \cdot v(t)$$

Polarity

$$p(t) = v(t) \cdot i(t)$$

Opposite polarity

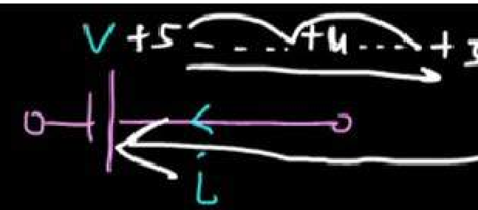
$+v(t)$ $-v(t)$

$-i(t)$ $+i(t)$

$-p(t)$

Power flow back from load to source

i flows in the direction of voltage rise



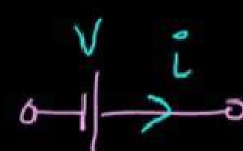
Same polarity

$+v(t)$ $-v(t)$

$+i(t)$ $-i(t)$

$+p(t)$

Power flow from source to load



Here, i flows in the direction of voltage drop

Mathematical Expression

if. $v(t) = V_m \sin \omega t$ $\quad$ $i(t) = I_m \sin(\omega t - \phi)$

↳ angle of lag

* $p(t) = V_m \sin \omega t \cdot I_m \sin(\omega t - \phi)$

using $\sin A \sin B$ formula

* $p(t) = \frac{V_m \cdot I_m}{2} [\cos \phi - \cos(2\omega t - \phi)]$ (max^m value)

using $\cos(A - B)$ formula

* $p(t) = VI \cos \phi [1 - \cos \omega t] - VI \sin \phi \sin 2\omega t$ (Rms value)

Mathematical Expression

if. $v(t) = V_m \sin \omega t$ $\quad i(t) = I_m \sin(\omega t - \phi)$

ϕ → angle of lag

* $p(t) = V_m \sin \omega t \cdot I_m \sin(\omega t - \phi)$

↓ using $\sin A \sin B$ formula

* $p(t) = \frac{V_m \cdot I_m}{2} [\cos \phi - \cos(2\omega t - \phi)]$

↓ Using $\cos(A-B)$ formula

* $p(t) = \underbrace{VI\cos\phi[1 - \cos\omega t]}_{\text{I}} - \underbrace{VI \sin\phi \sin 2\omega t}_{\text{II}}$

Inst. active power

Inst. Reactive power.

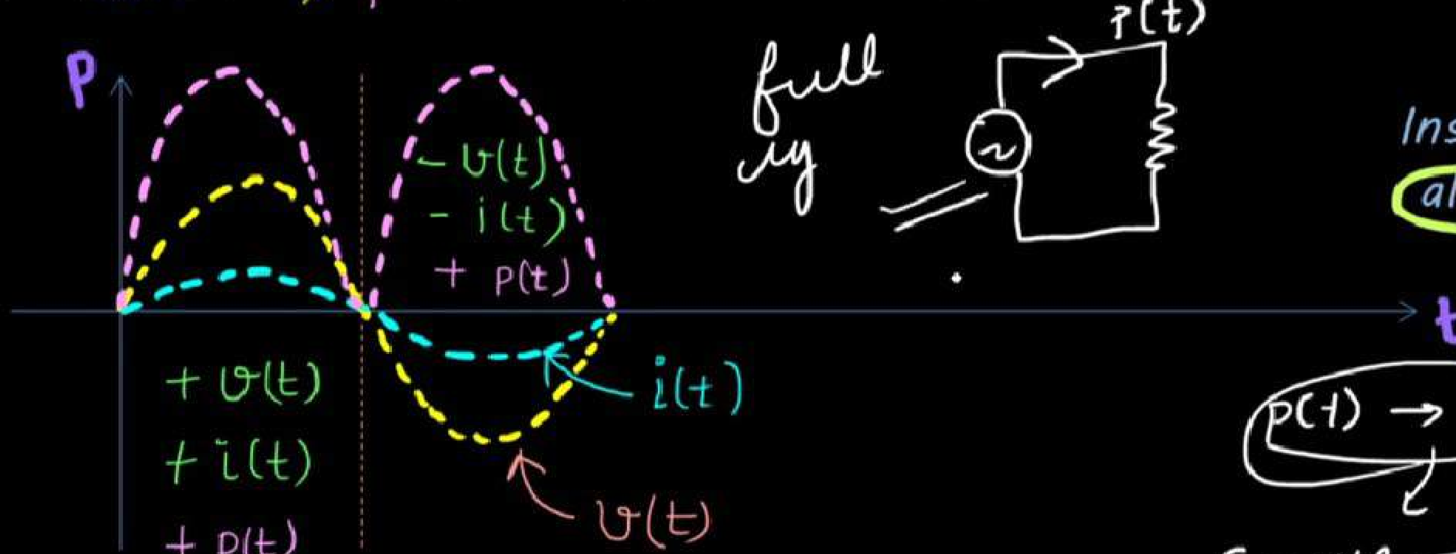
$p(t)$ = Ins. A.P + Ins. R.P

Conditions: 1. 1-Phase AC system
2. Purely Resistive Load

Instant. voltage $\Rightarrow v(t) = V_m \sin \omega t$

Instant. current $\Rightarrow i(t) = I_m \sin \omega t$

Inst. Power $\Rightarrow p(t) = V_m \sin \omega t \cdot I_m \sin \omega t$



In Purely resistive load

Where v and I are in same phase

Instant power is always positive

$p(t) \rightarrow +ve$

Source $\longrightarrow$ Load

Conditions: 1. 1-Phase AC system

2. Purely Inductive Load

In Purely Inductive load

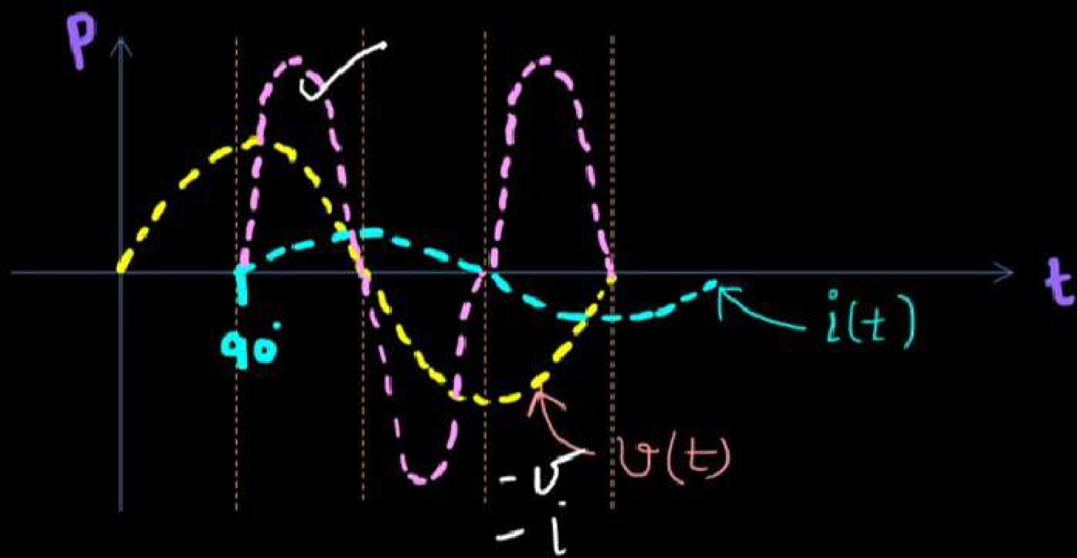
Where v and I are 90* ~~space~~ phase apart

Instant power can be positive or negative

Instant. voltage $\Rightarrow v(t) = V_m \sin \omega t$

Instant. current $\Rightarrow i(t) = I_m \sin(\omega t - 90)$

Inst. Power $\Rightarrow p(t) = V_m \sin \omega t \cdot I_m \sin(\omega t - 90)$



Conditions: 1. 1-Phase AC system

2. Purely Capacitive Load

In Purely Capacitive load

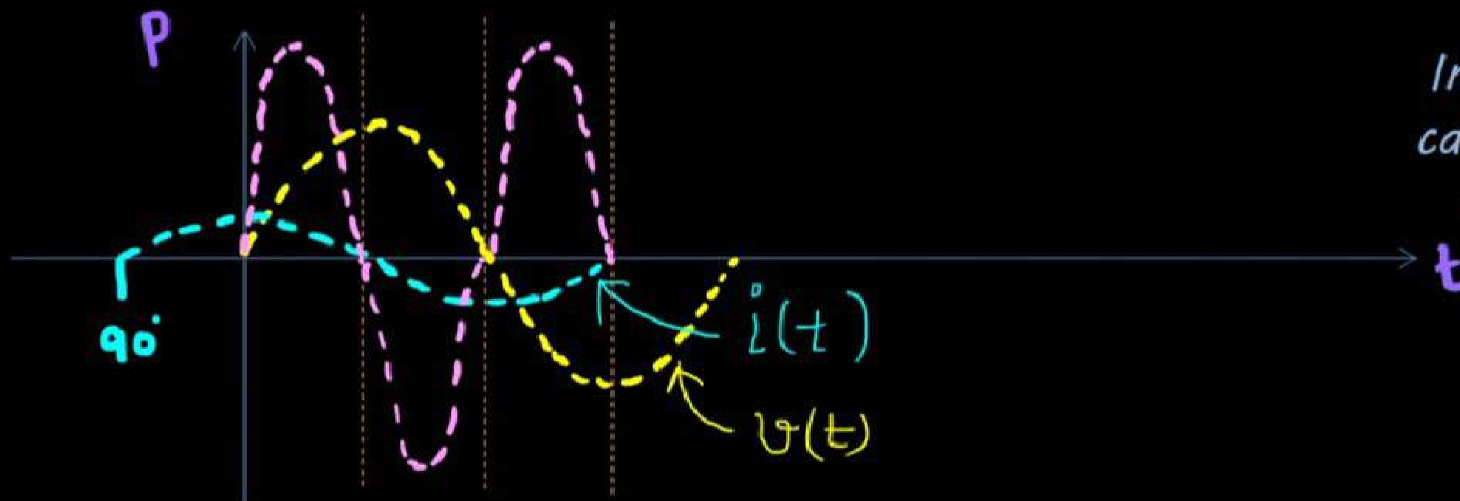
Instant. voltage $\Rightarrow v(t) = V_m \sin\omega t$

Instant. Current $\Rightarrow i(t) = I_m \sin(\omega t + 90)$

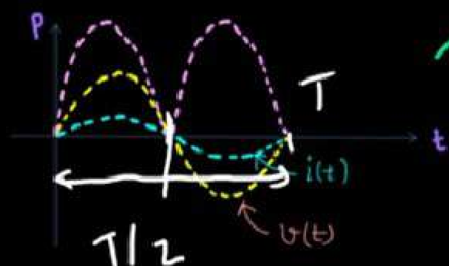
Inst. Power $\Rightarrow p(t) = V_m \sin\omega t \cdot I_m \sin(\omega t + 90)$

Where v and I are 90* ~~space~~ Phase apart

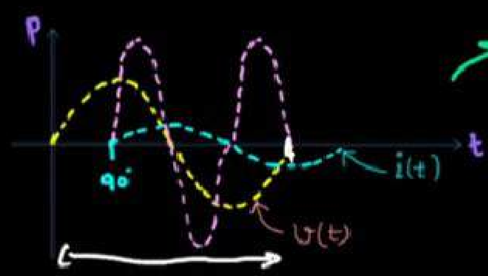
Instant power can be positive or negative



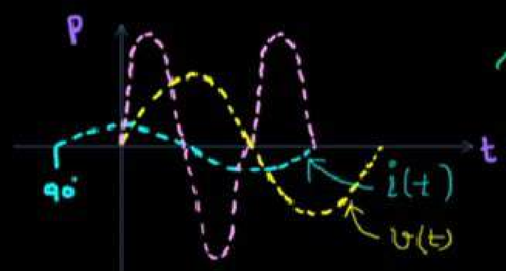
Conclusion 1



Resistive case



Inductive case



Capacitive case

Voltage and Current frequency $\longrightarrow f$

$V \rightarrow f = \frac{1}{T} = f$

$I \rightarrow f = \frac{1}{T}$

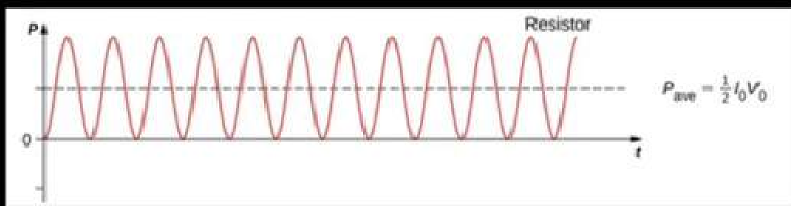
Instant. Power frequency $\longrightarrow 2f$

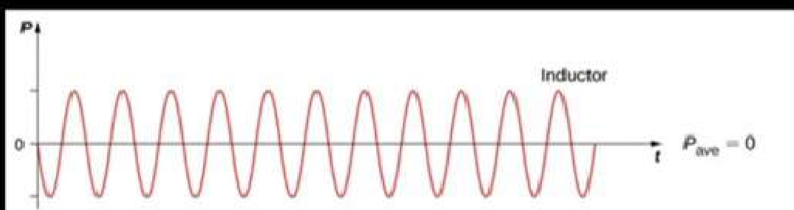
$P \rightarrow T/2$

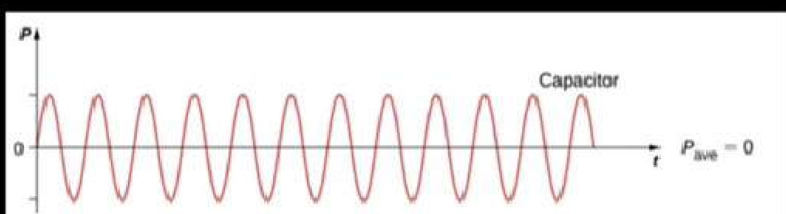
$f_P \rightarrow \frac{1}{T/2} = \frac{2}{T} = 2f$

$f_{iP} = 2f$

Conclusion 2







Avg. Power in 1 cycle

+ve → power transfer from Source to load

0 → Power oscillates between Load and source

0

Half cycle → Power flow from source to load

2nd Half cycle → from load to source

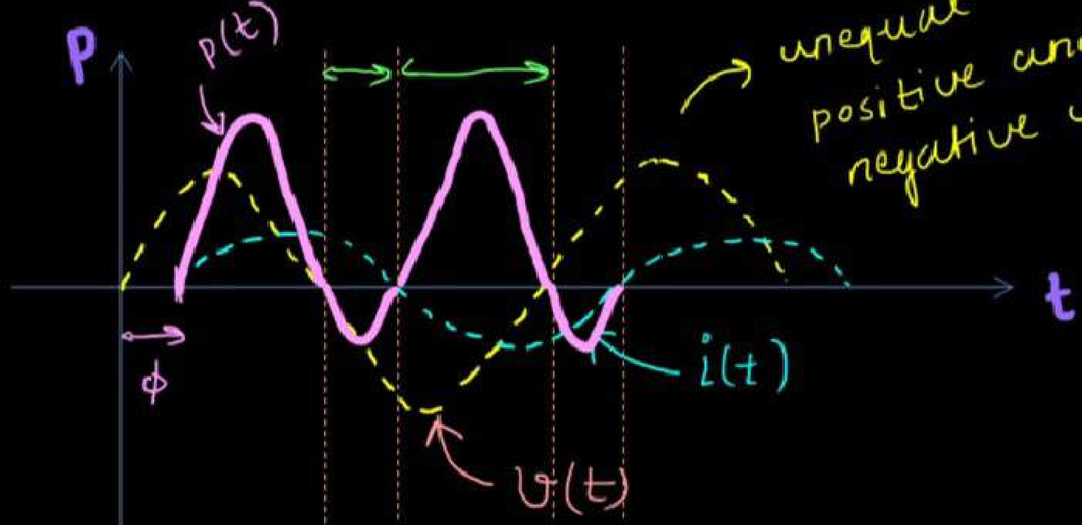
Conditions: 1. 1-Phase AC system
2. R-L Load

Instant. voltage $\Rightarrow v(t) = V_m \sin\omega t$

Instant. Current $\Rightarrow i(t) = I_m \sin(\omega t - \phi)$

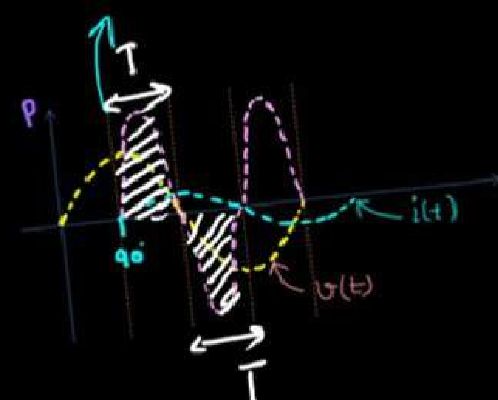
Instant. Power $\Rightarrow p(t) = V_m \sin\omega t \cdot I_m \sin(\omega t - \phi)$

equal positive and negative cycle



unequal positive and negative cycle

Purely Inductive load

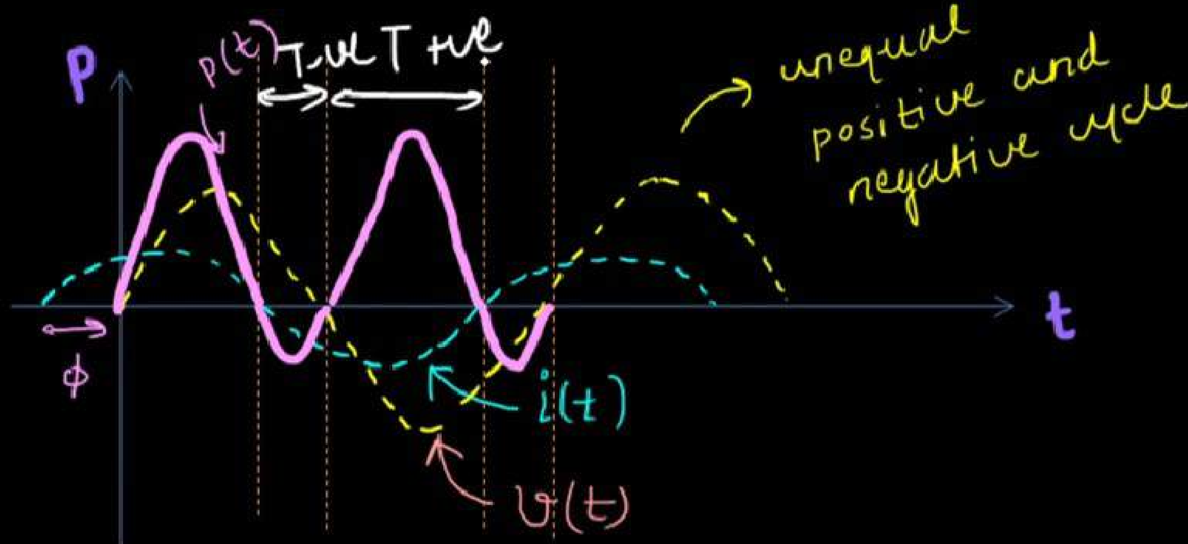


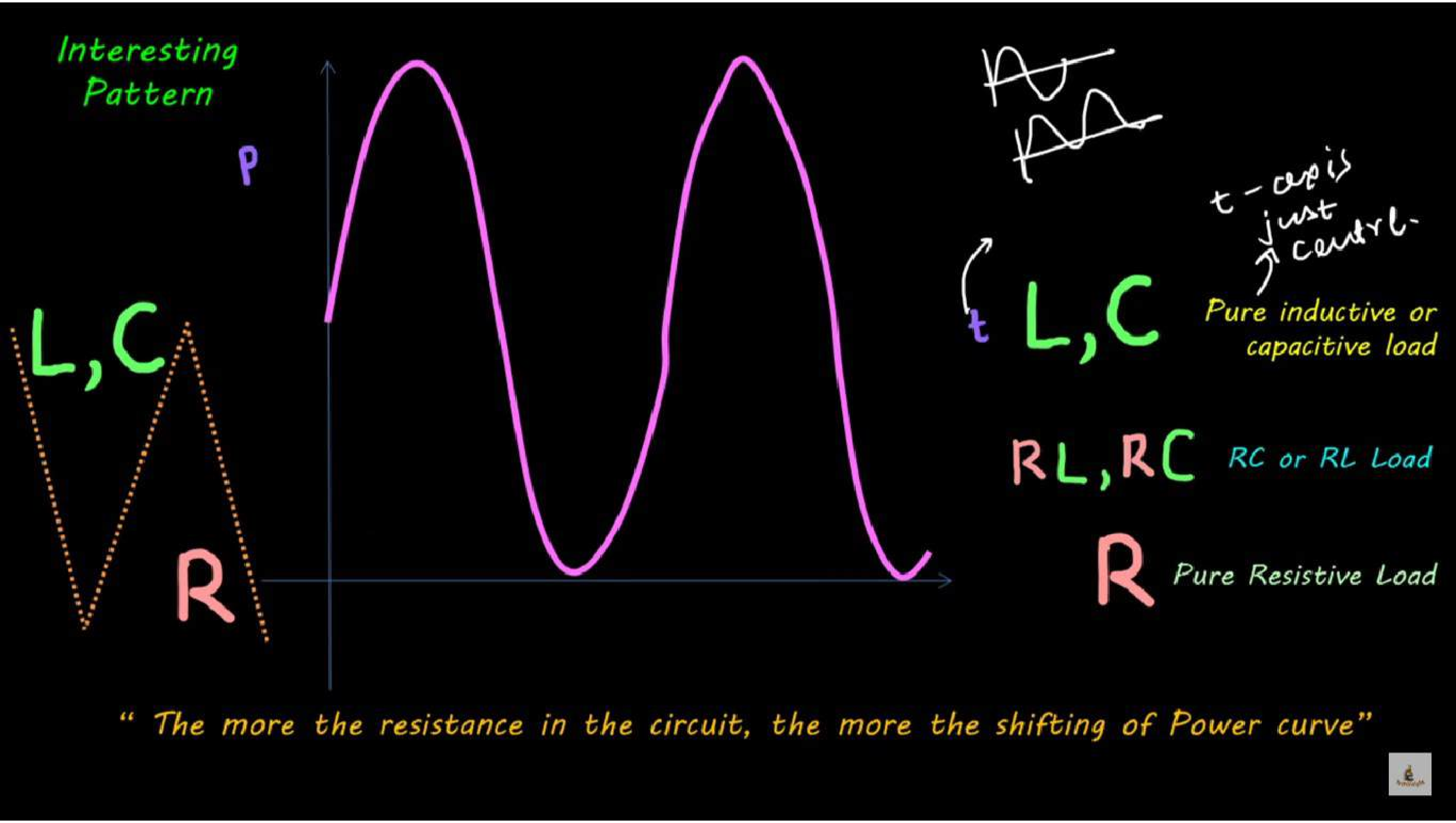
Conditions: 1. 1-Phase AC system
2. R-C Load

Instant. voltage $\Rightarrow$ $v(t) = V_m \sin \omega t$

Instant. current $\Rightarrow$ $i(t) = I_m \sin(\omega t + \phi)$

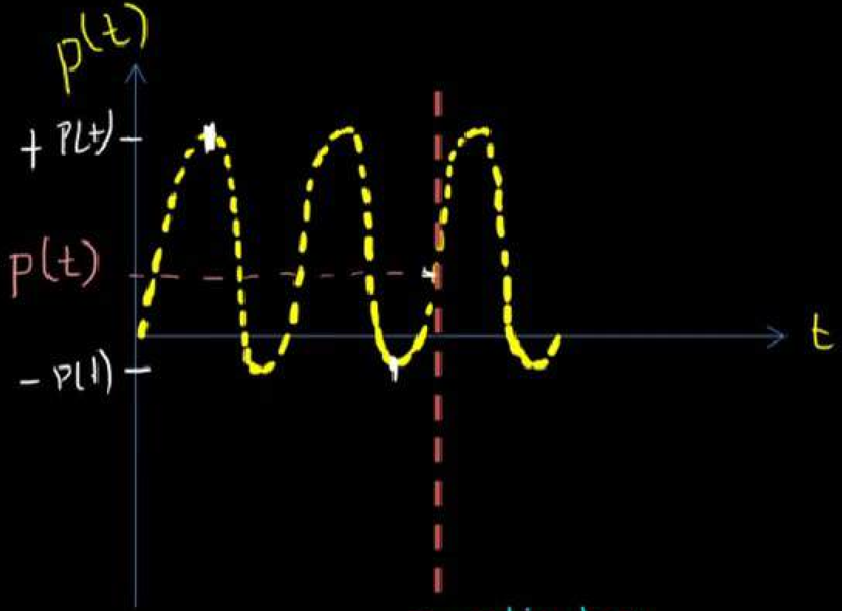
Instant. Power $\Rightarrow$ $p(t) = V_m \sin \omega t \cdot I_m \sin(\omega t + \phi)$



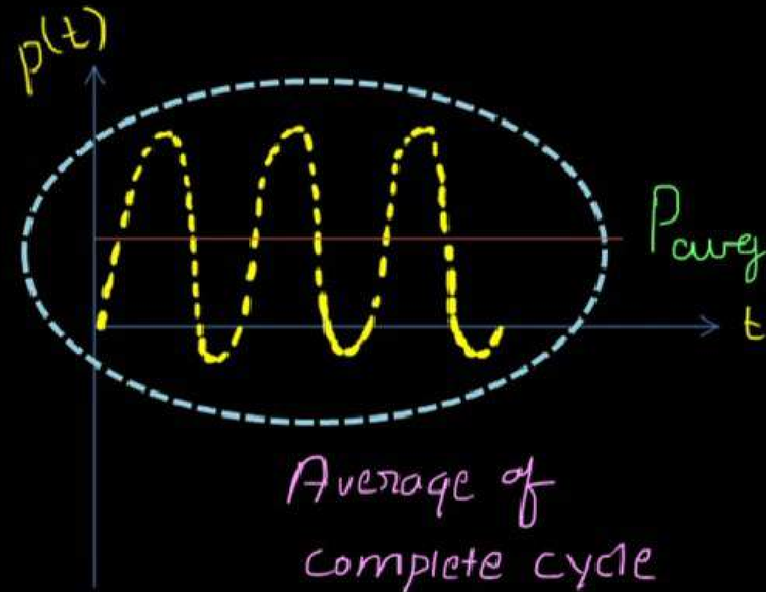


Interesting Pattern
P
L,C
R
t
L,C
Pure inductive or capacitive load
RL,RC
RC or RL Load
R
Pure Resistive Load
t - axis just centre
" The more the resistance in the circuit, the more the shifting of Power curve"

How instantaneous power differ from average power????



particular instant

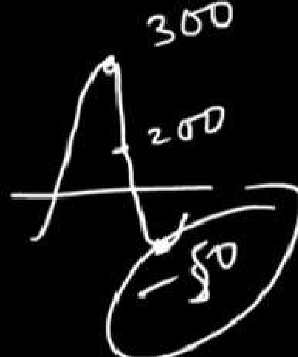


Average of complete cycle

Instantaneous Power ⟷ **Average Power**

time average of the instantaneous power over one cycle

Practical Importance



Instantaneous Power

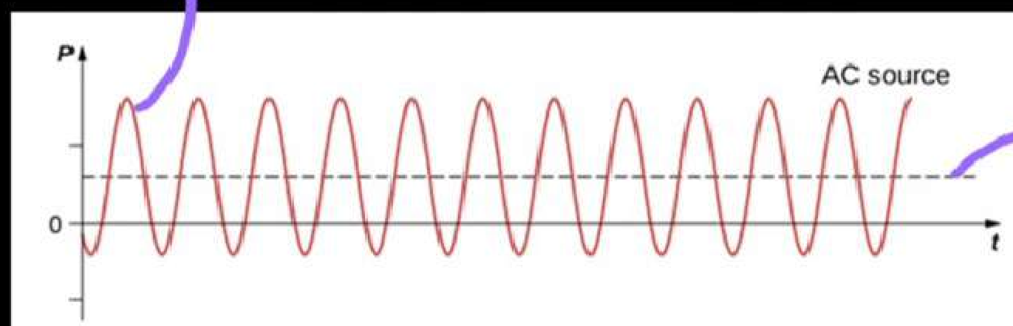
varies in both magnitude and sign over a cycle

Doesn't have any practical importance

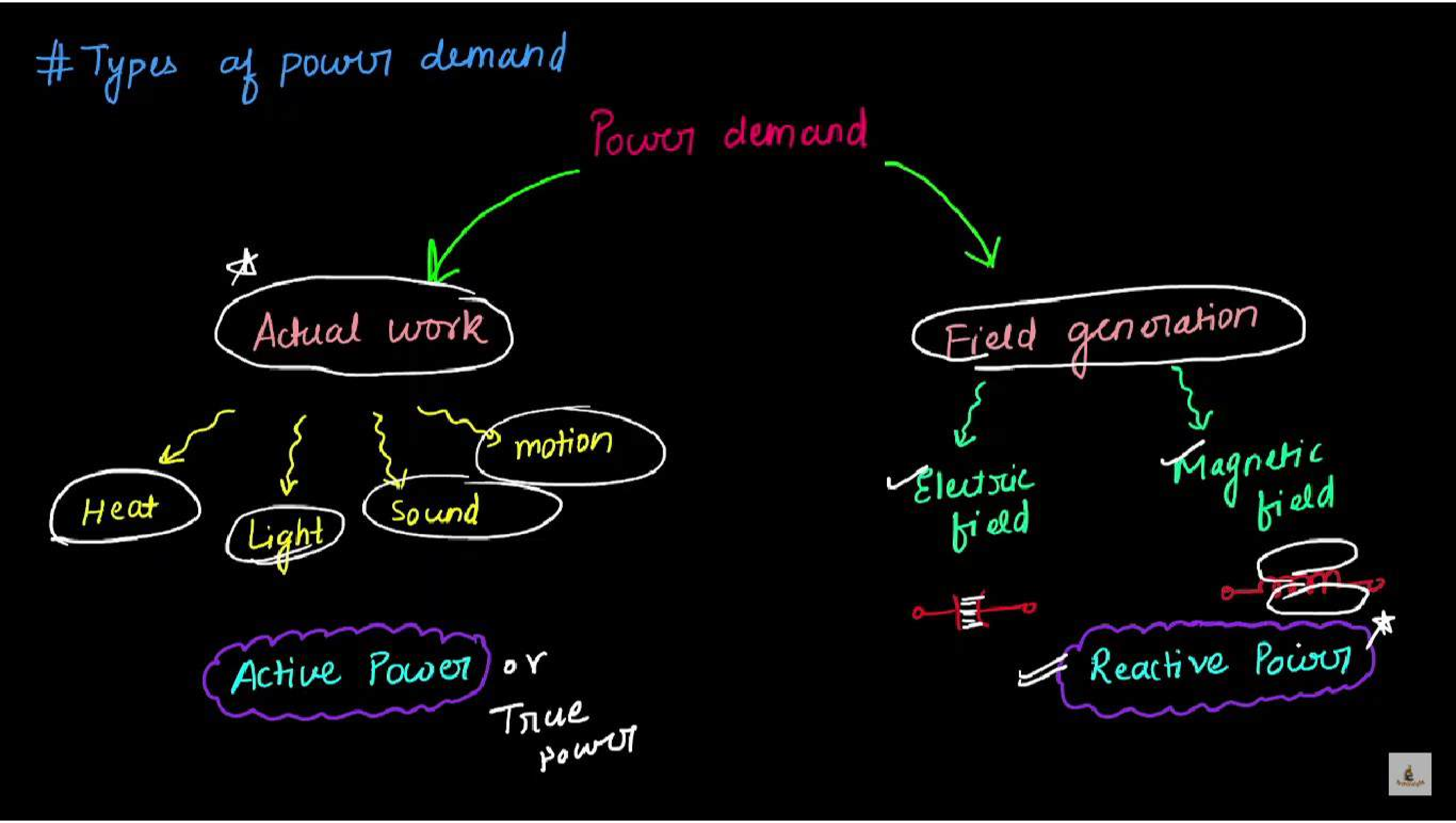
Average Power

the power averaged over time, hence fix in magnitude

Inst. Pow.



Avg. Pow.



Types of power demand
Power demand
Actual work
Field generation
Heat
Light
Sound
motion
Electric field
Magnetic field
Active Power
or
True power
Reactive Power

kW

kVAR

Active power + Reactive power

=

Apparent power

kVA

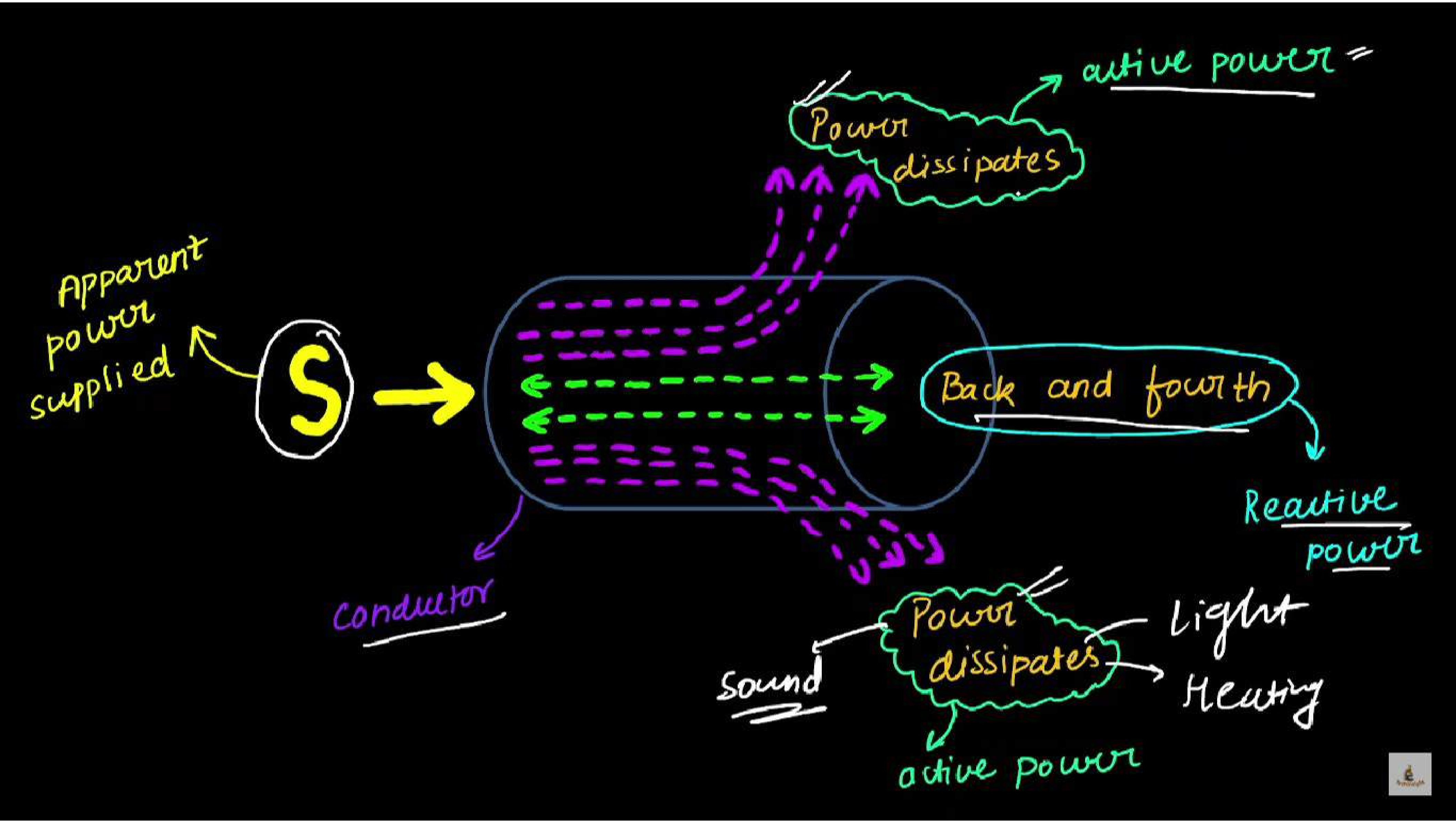
V I

"kVA"

Source

Trans.

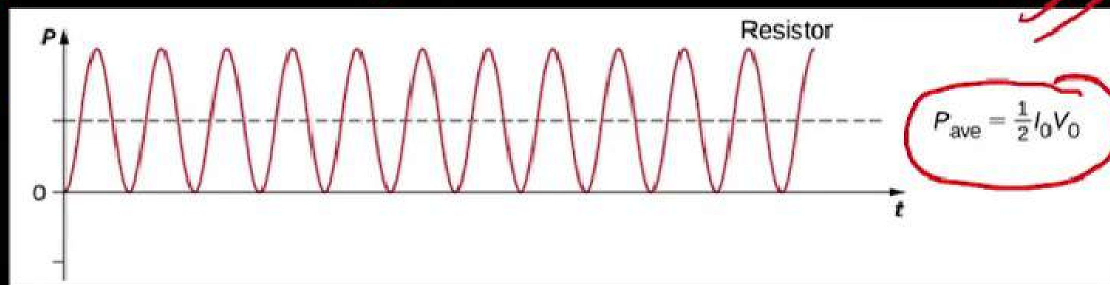
gener


Apparent power supplied
S
conductor
Power dissipates
active power =
Back and fourth
Reactive power
Power dissipates
Sound
Light
Heating
active power

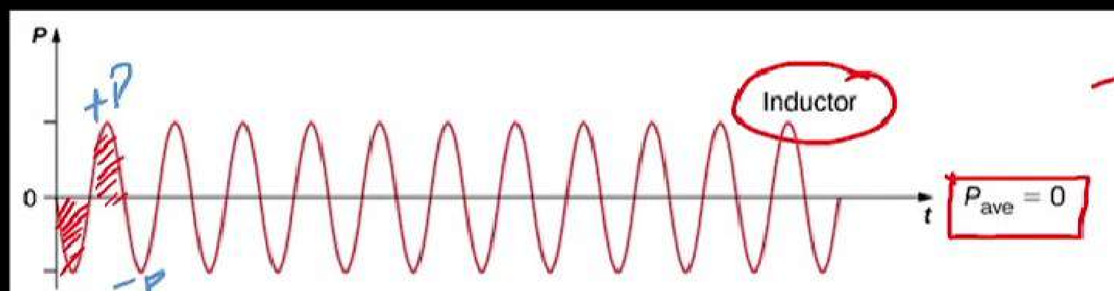
True power or Active pow or kW

$P_{avg} \neq 0$

Power dissipates



100 Hz

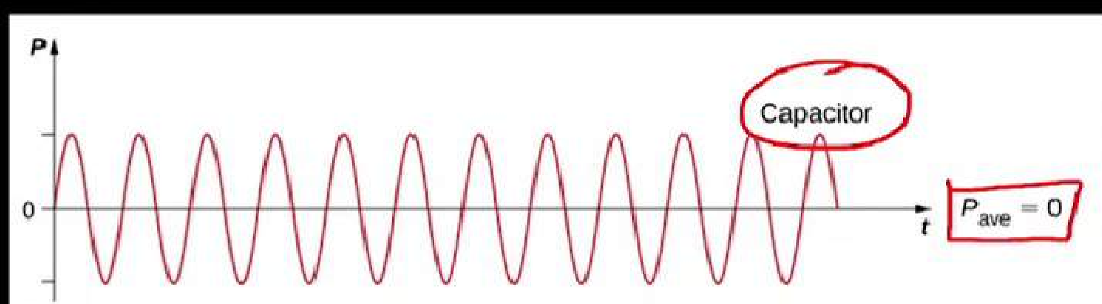


power back Forth

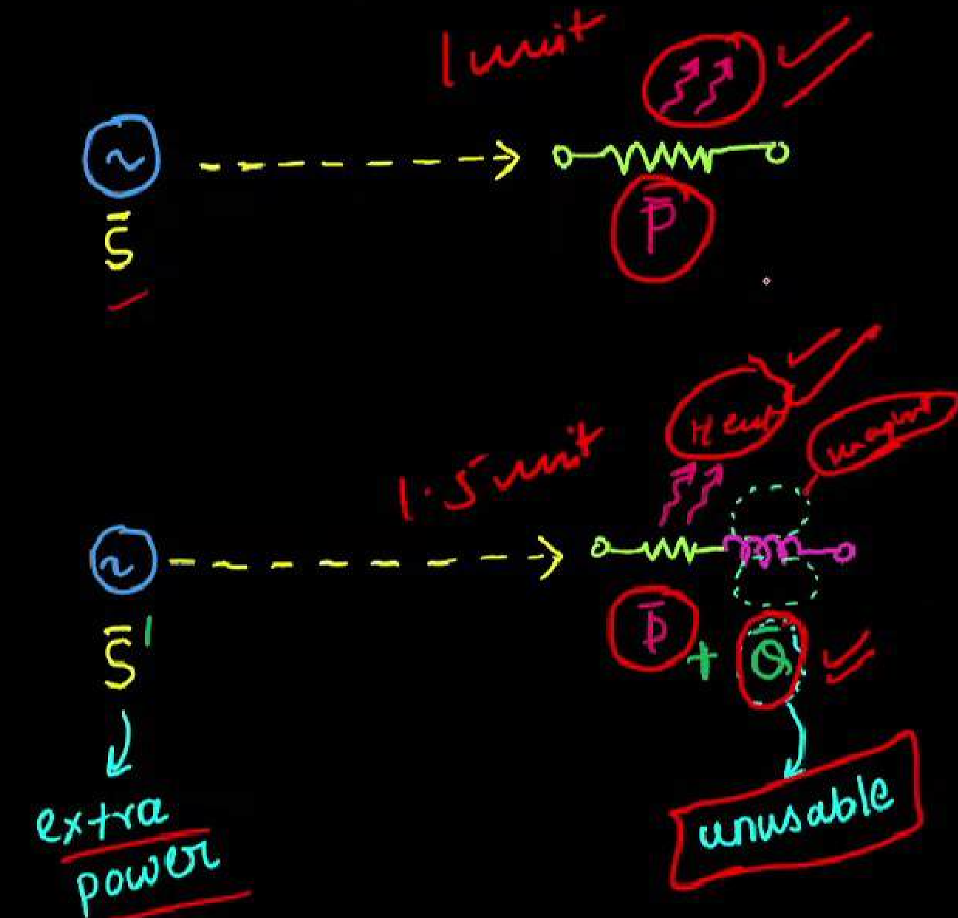
Zero average power dissipation

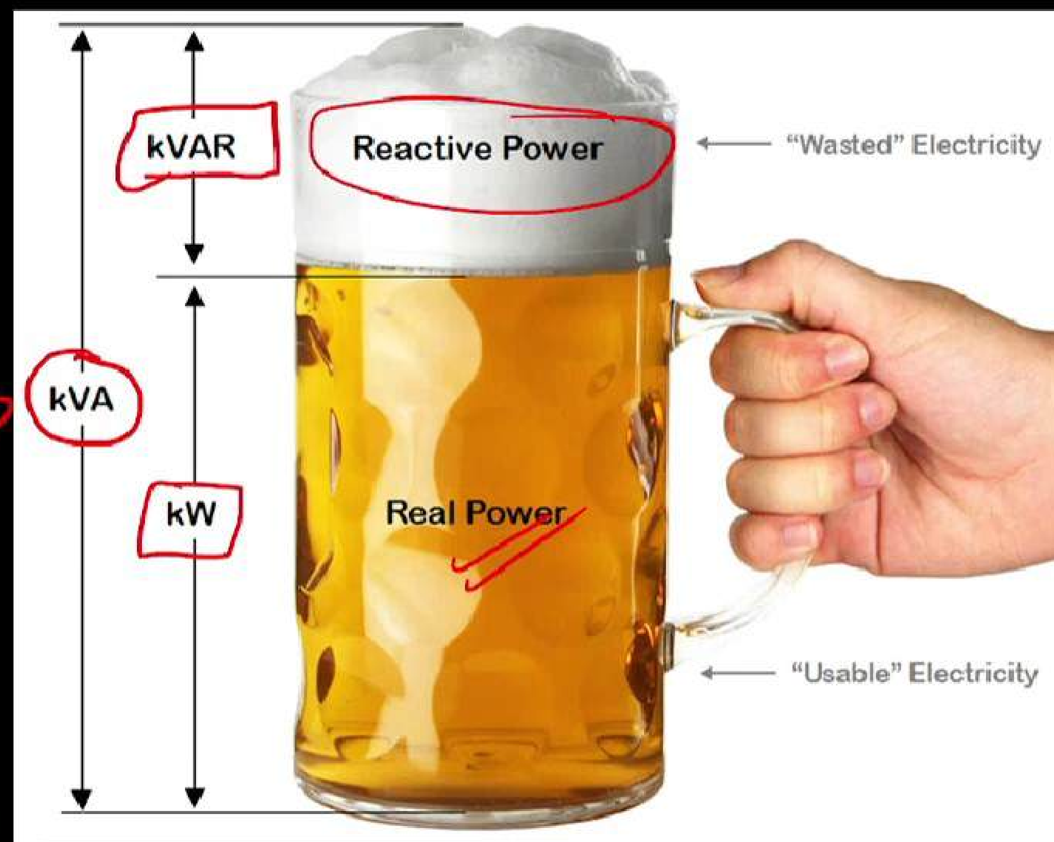
zero

2f



Effect of Reactive power





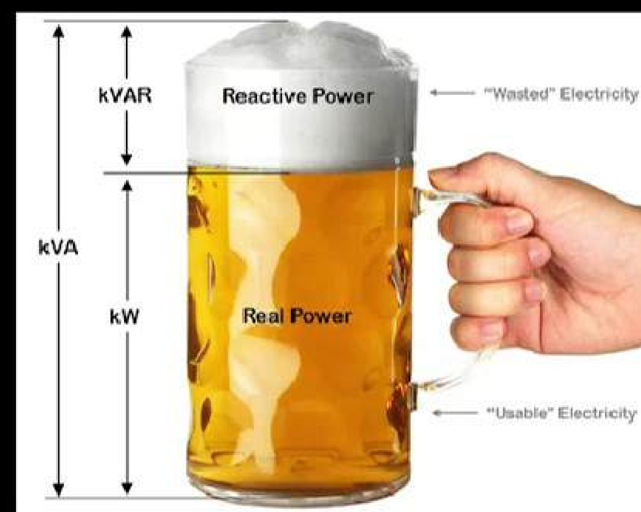
$$\bar{S} = \bar{P} + \bar{Q}$$

Total power demanded from source to perform useful work

decides the amount of power needed to perform useful work

decides the amount of extra power needed to perform useful work

Heating



$\bar{S} = \bar{P} + \bar{Q}$ ---> phasor sum ---> $S = \sqrt{P^2 + Q^2}$

extra dummy

R

10 unit   10 unit

$\bar{S}$ $\bar{P}$

R   L

15 unit

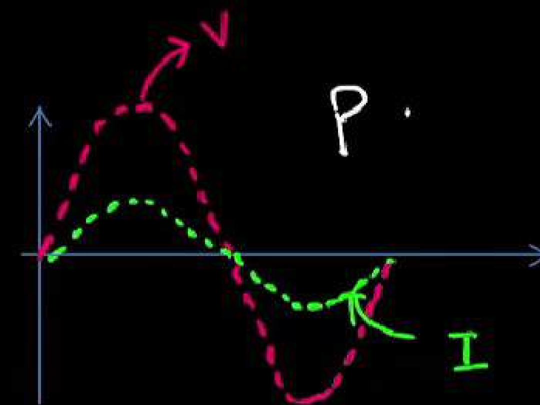
10 unit   5 unit

11·18 units

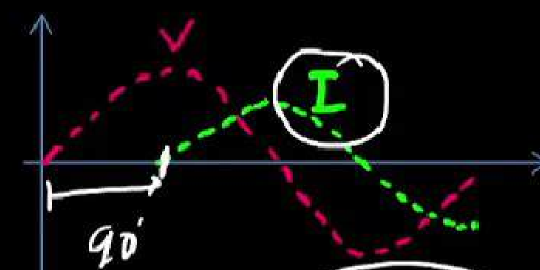
$S = \sqrt{10^2 + 5^2} = 11 \cdot 18$

Identification

P → Voltage and current same phase



Q → Voltage and current 90° out of phase



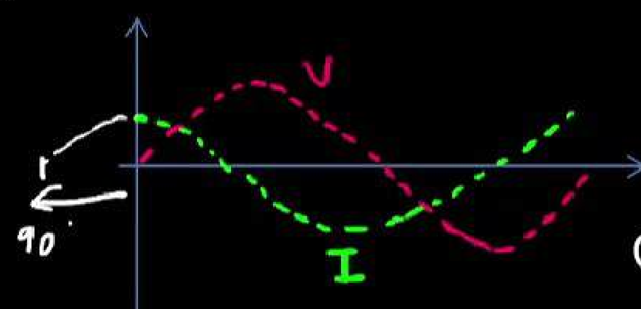
90° lag

P+Q

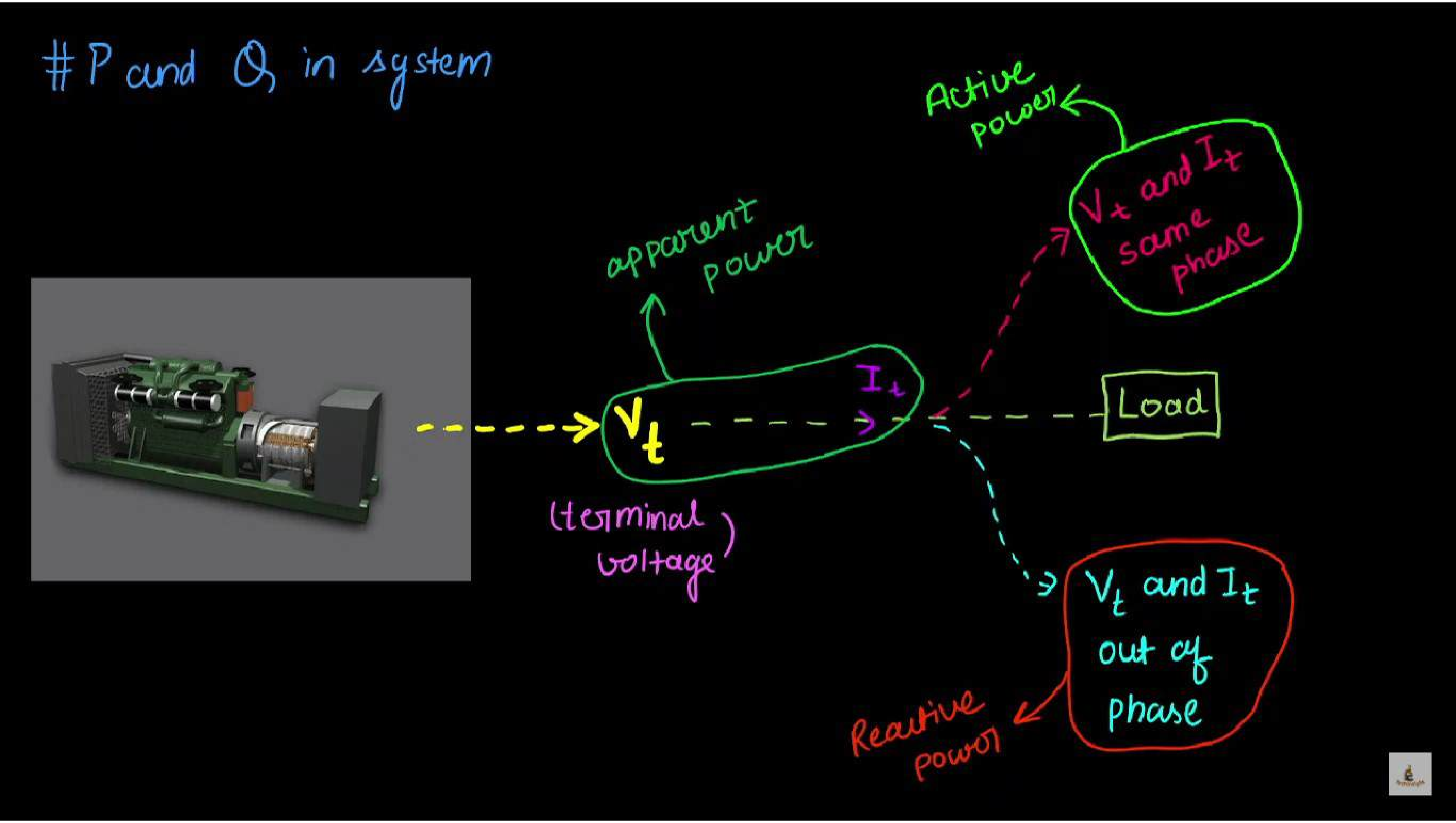
<90°

0<

0 ⟶ 90°



90° lead



P and Q in system
apparent power
V_t
(terminal voltage)
I_t
Load
Active power
V_t and I_t same phase
Reactive power
V_t and I_t out of phase

Active and Reactive power control

conventional generator

alternator

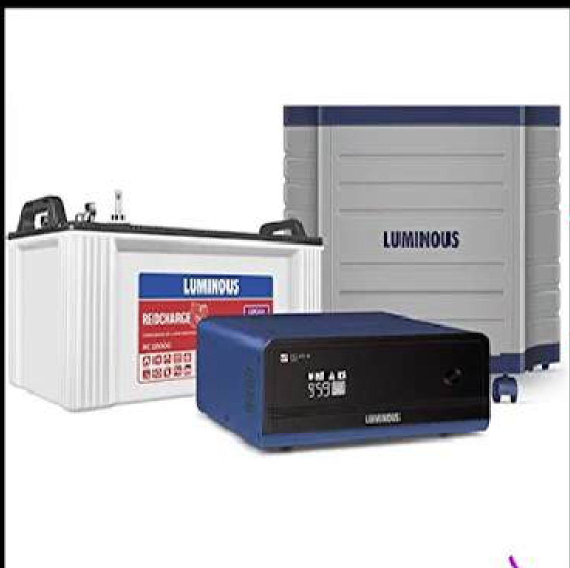
* active power demand

governor & prime mover

** Reactive power demand

field excitation

Active and Reactive power control



Inverter

active power demand → V_t and I_t same phase

Reactive power demand → V_t and I_t out of phase

90°

Types of machine

Generator

Volt. source

+P

+ 200W

- 200W

+P
-P

+20 KVAR

- 30 KVAR

+P → V supply power

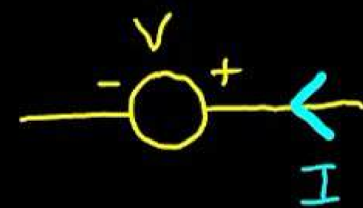
-P → V absorb power

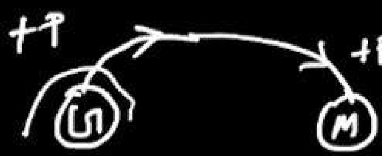
+Q → V supply reactive power

-Q → V absorb reactive power

Motor

+Q
-Q





+P → V absorb Power

-P → V supply power

+Q → V absorb reactive power

-Q → V supply reactive power

actual work or conventional work

G

P supply

+P

−P power absor

M

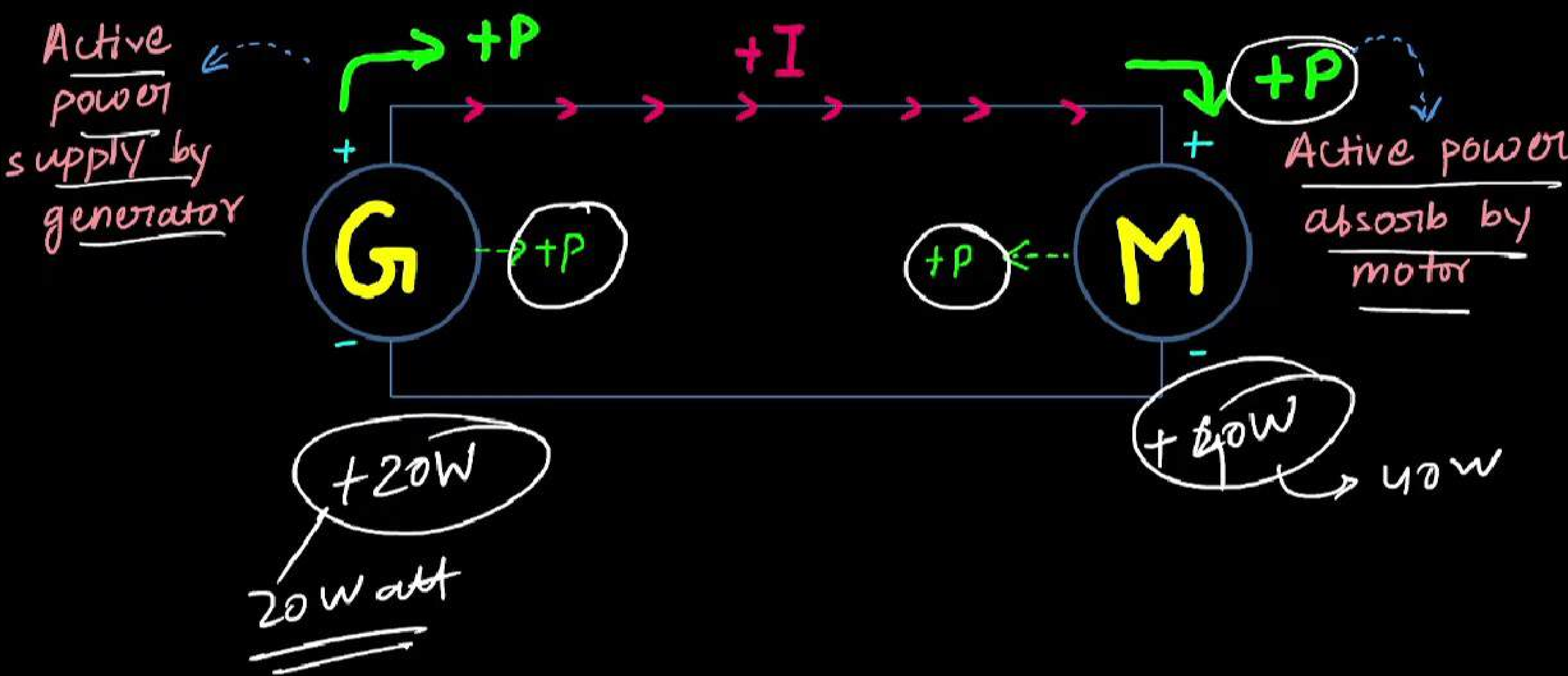
P absorb

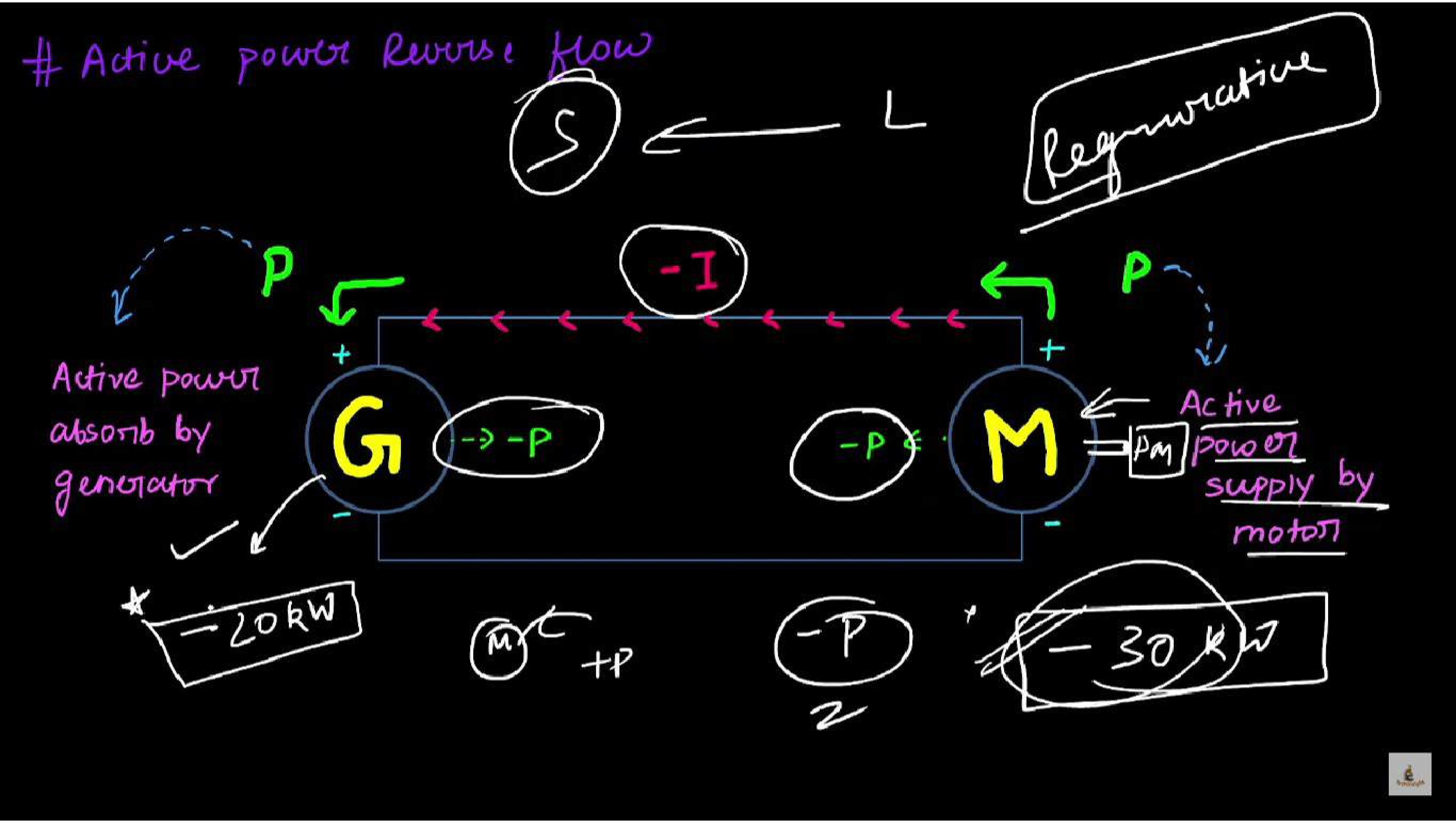
+P

−P power deliver

Active power flow

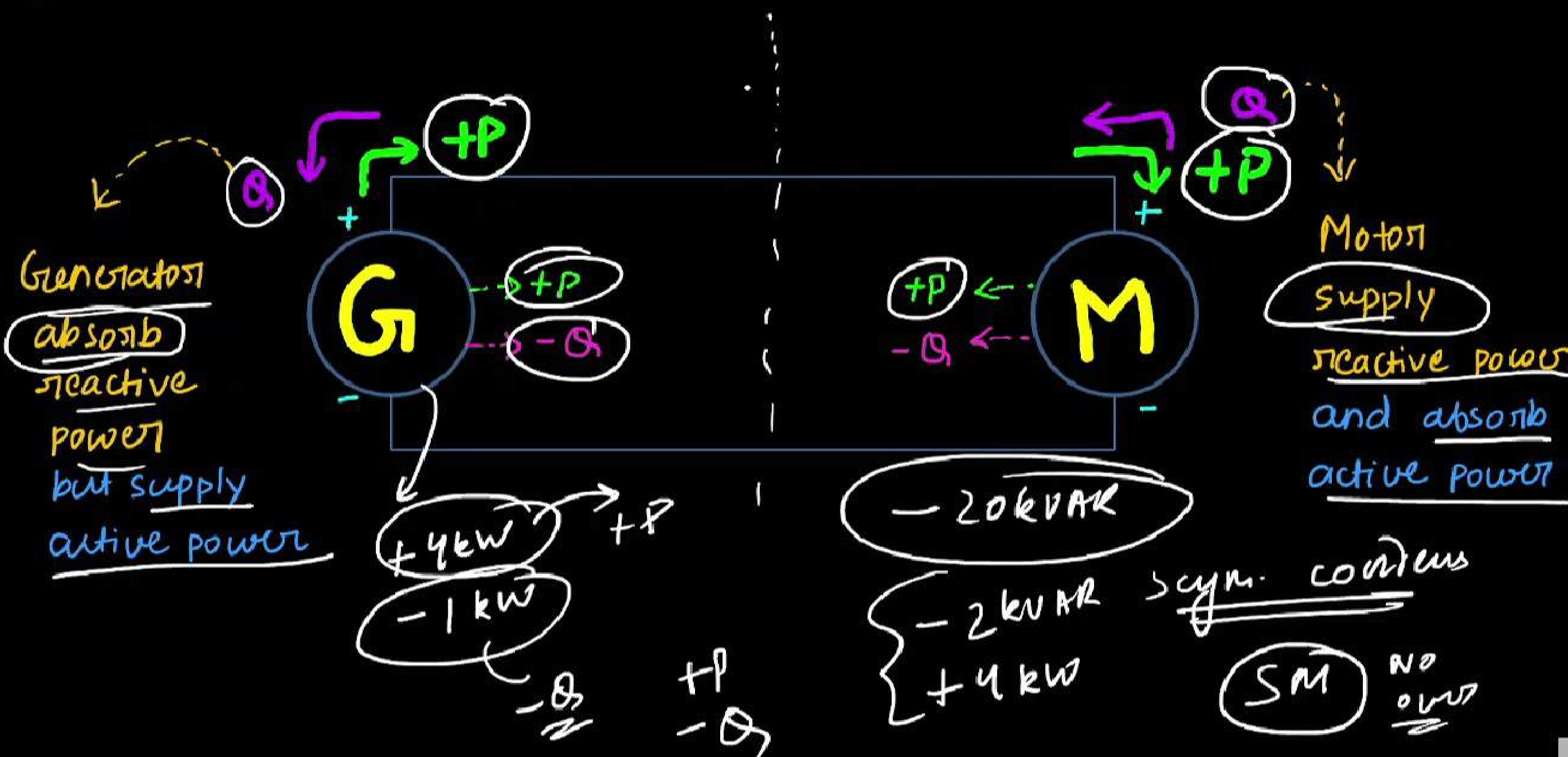
Normal scenario

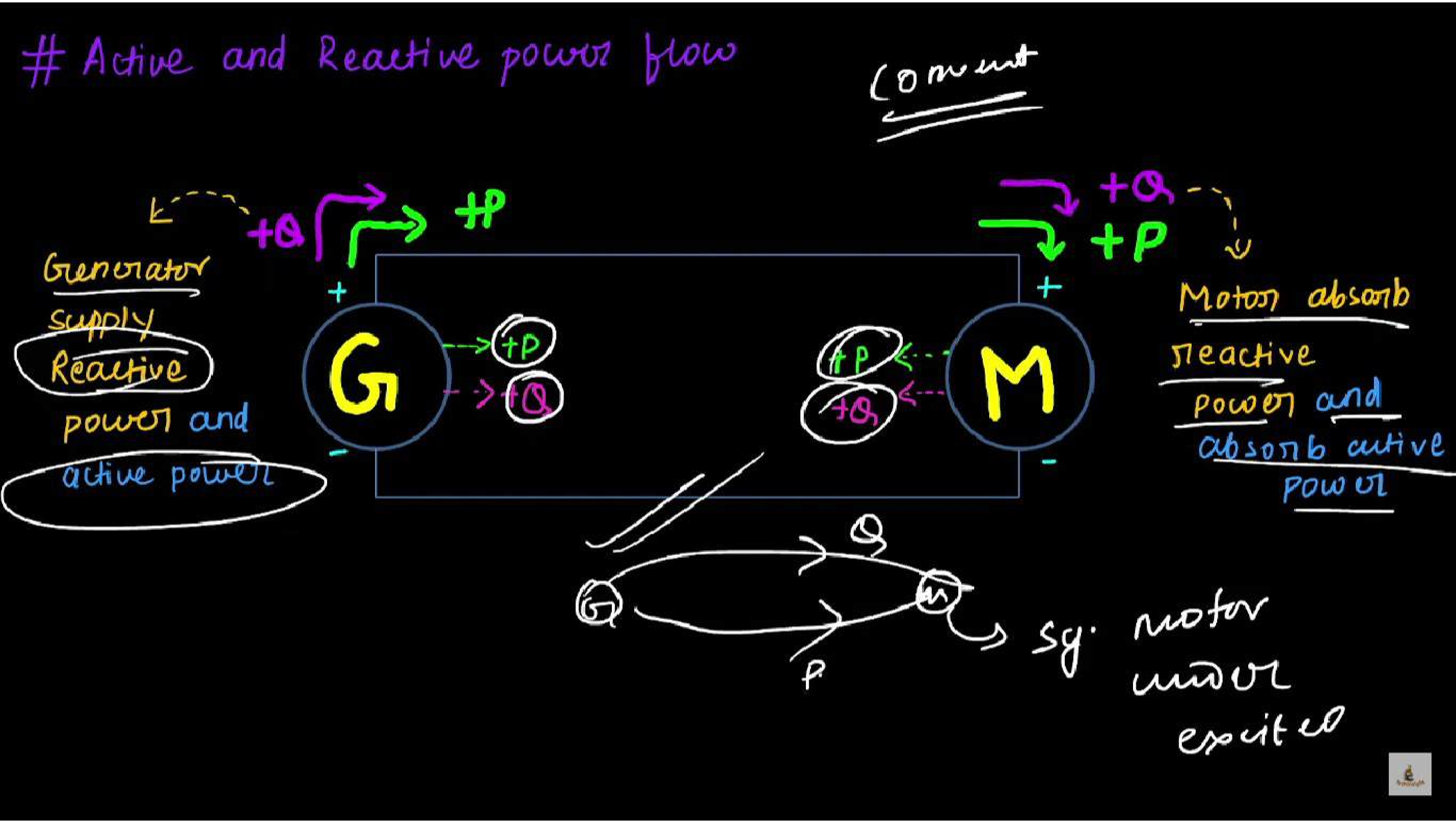




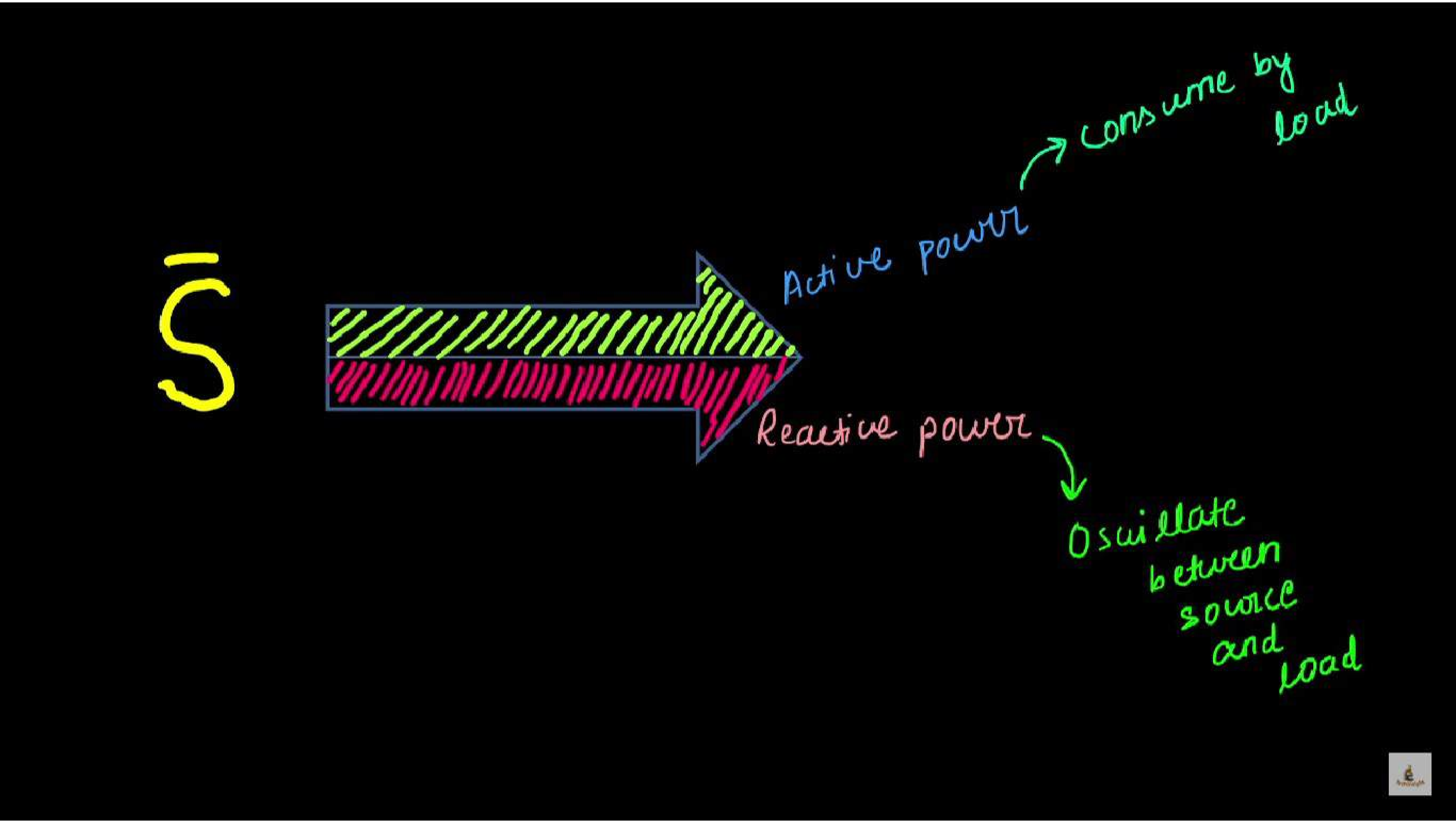
Active power Reverse flow
S
L
Regenerative
P
-I
P
+
+
Active power absorb by generator
G
-> -P
-P <-
M
PM
Active power supply by motor
-
-
-20kW
M
+P
-P
2
-30 kW

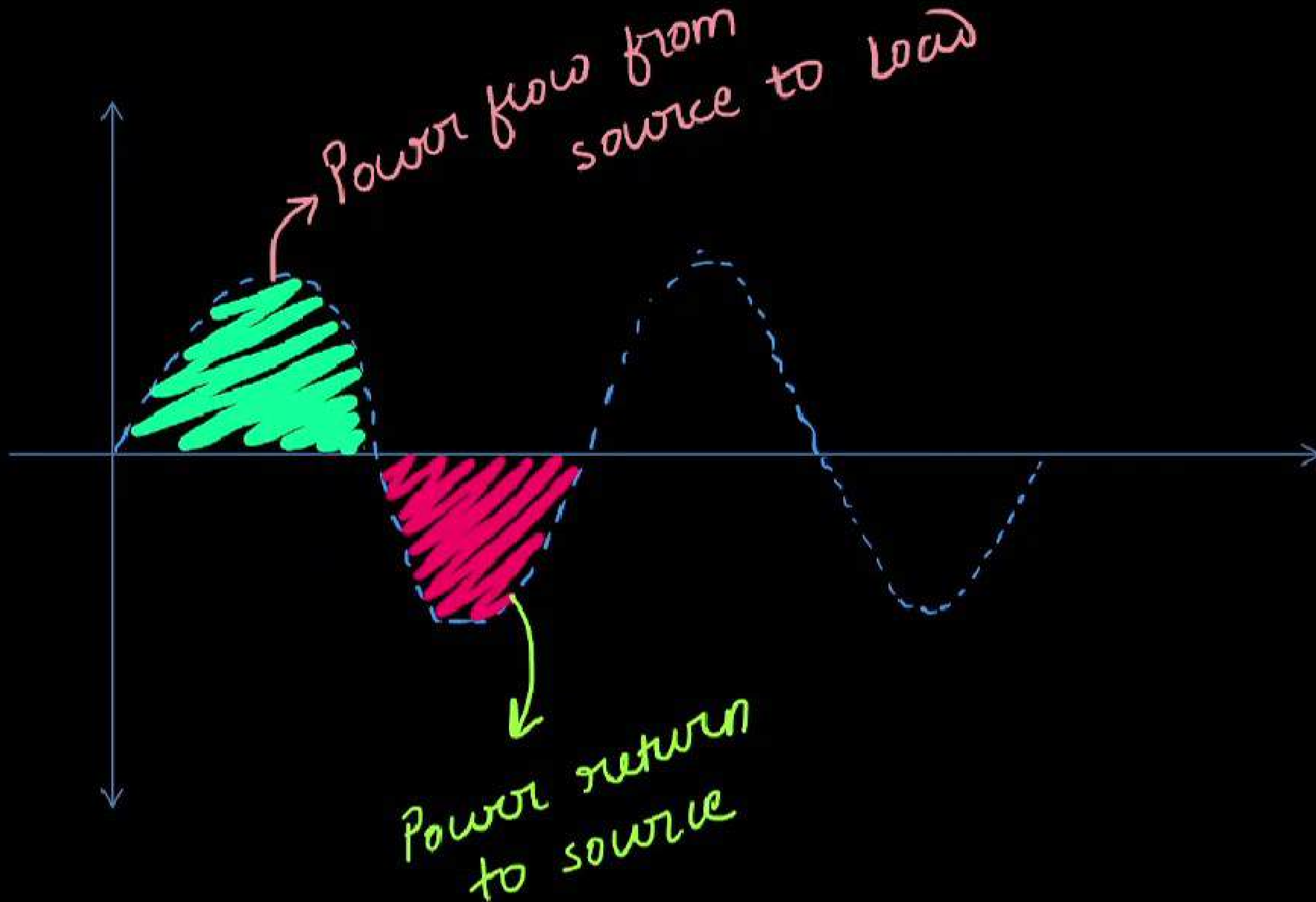
Active and Reactive power flow





Active and Reactive power flow
+Q
+P
Generator supply Reactive power and active power
+
G
−
+P
+Q
+P
+Q
M
+
−
+Q
+P
Motor absorb reactive power and absorb active power
Q
P
sy. motor under excited


$\bar{S}$
Active power
consume by load
Reactive power
Oscillate between source and load



$$Q_{avg} = 0$$

$+$ 20kVAR

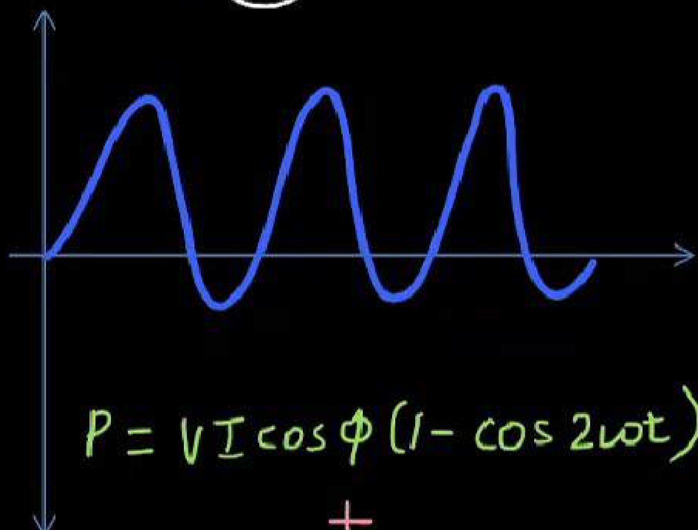
$-$ 20kVAR ?

polarity of Q

magnitude of Q

Instantaneous power

$P = ?$ avg. power



$P = VI\cos\phi(1-\cos 2\omega t)$

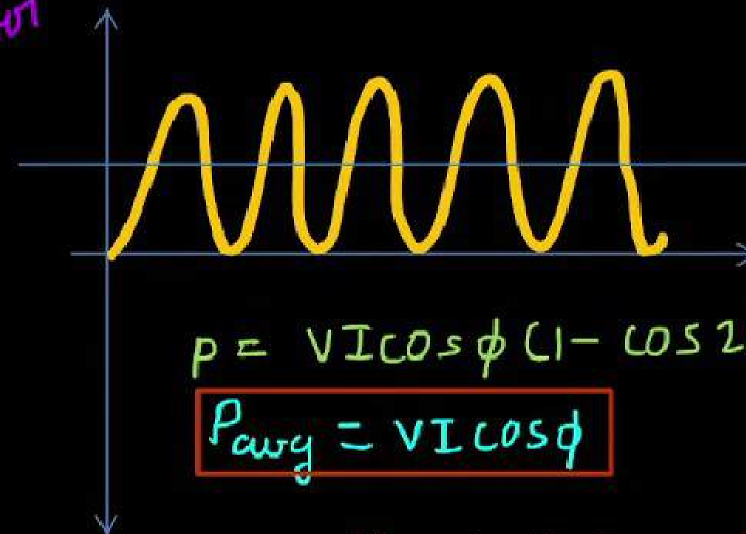
$+$

$VI\sin\phi \sin 2\omega t$

$\bar{Q}$ = max^m power

Active power

P_{avg}



$p = VI\cos\phi(1-\cos 2\omega t)$

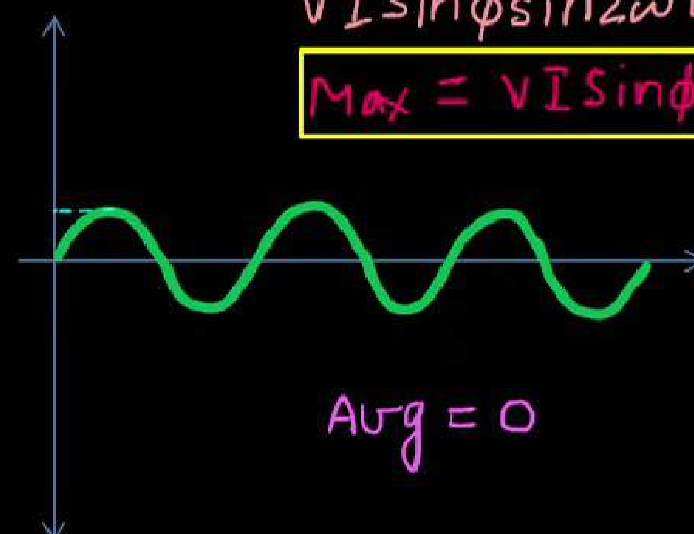
$\boxed{P_{avg} = VI\cos\phi}$

$VI\sin\phi\sin 2\omega t$

$\boxed{Max = VI\sin\phi = Q}$

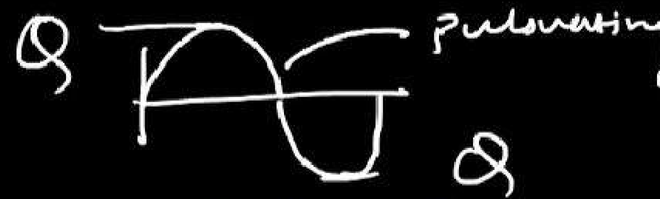
Q

Max^m power return back to source



Avg = 0

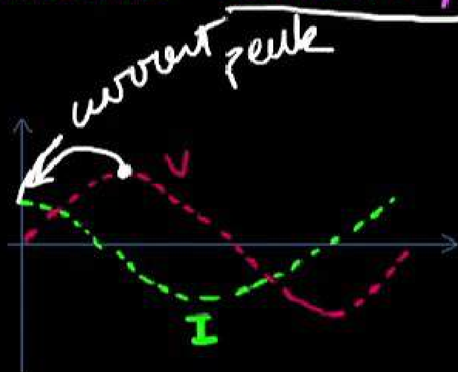
Reactive power measurement



"Reactive power is measured as the maximum of the pulsating power over a cycle"

+20kVAR
↓
I peak

Reactive power can be positive or negative, depending on whether current peaks before or after voltage.



90° lead

−Q

−20kVAR

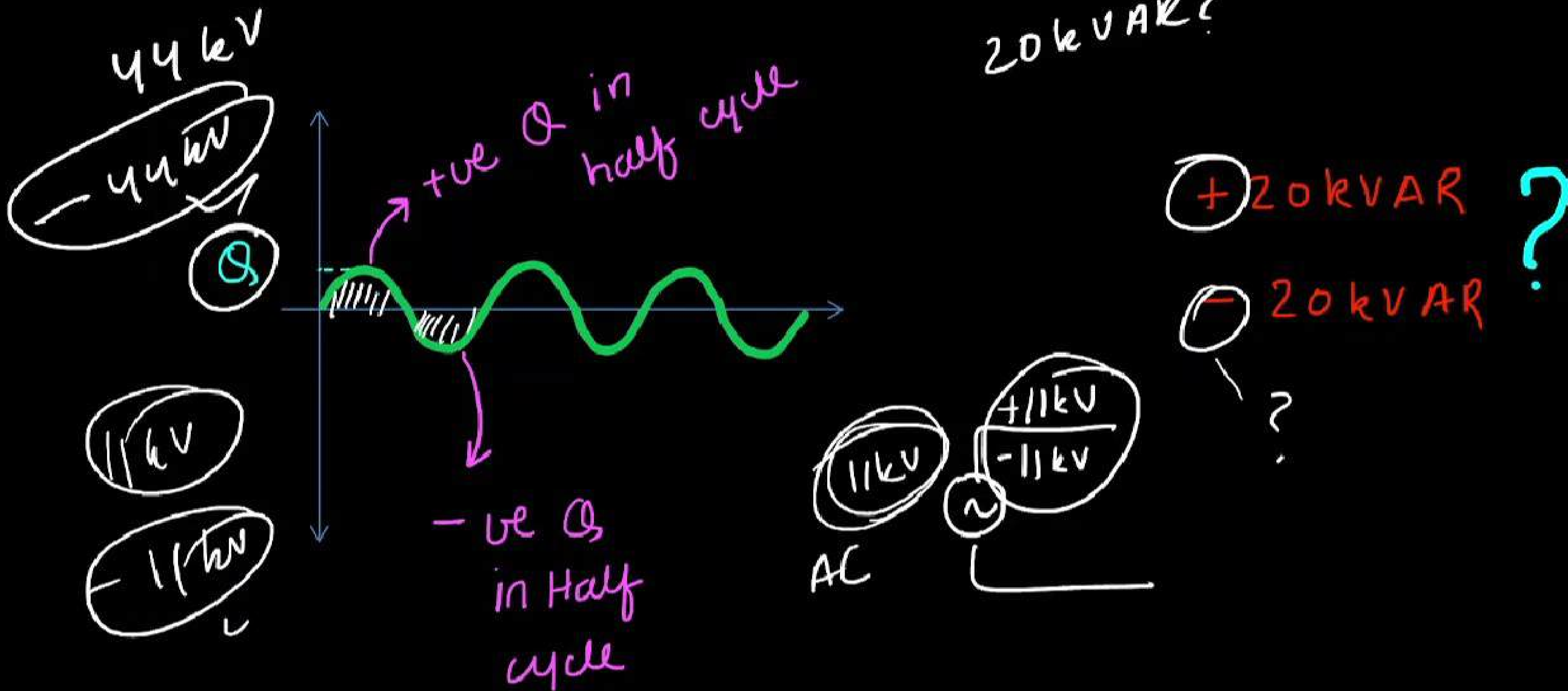
I peak before voltage peak

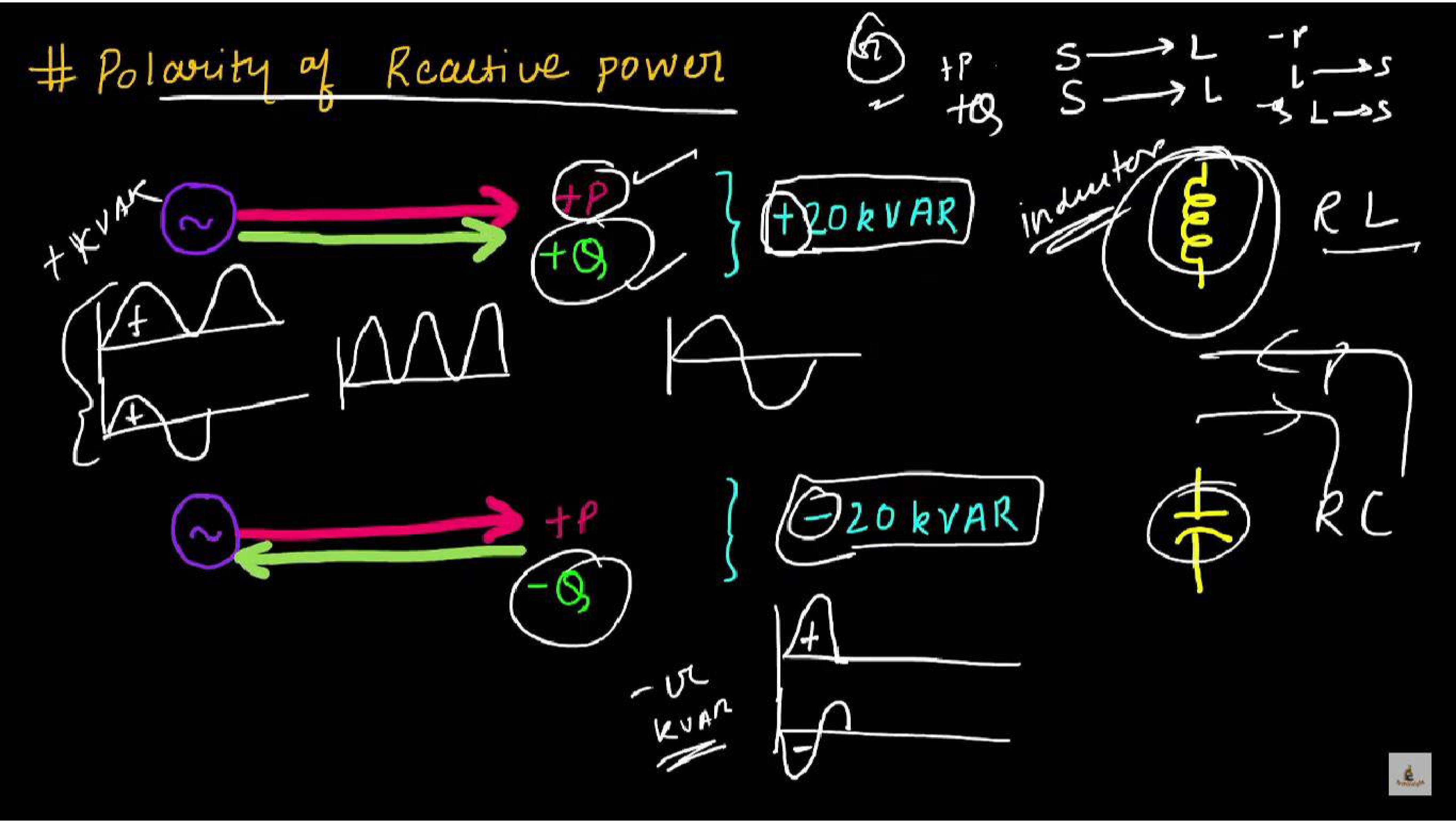
90° lag

+Q

current peak after the volt peak

What is positive and negative Reactive power ?



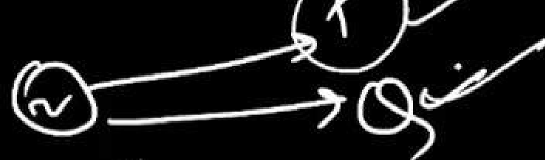


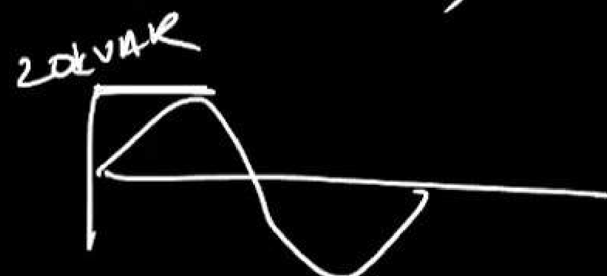
Polarity of Reactive power
+P S → L
+Q S → L
-P L → S
-Q L → S
+kVAR
+P
+Q
+20kVAR
inductor
RL
+P
-Q
-20kVAR
RC
-ve kVAR

Generator

+20kVAR

1. 

2. 

3. 

4. current <u>peak after voltage peak</u>

Space Requirement

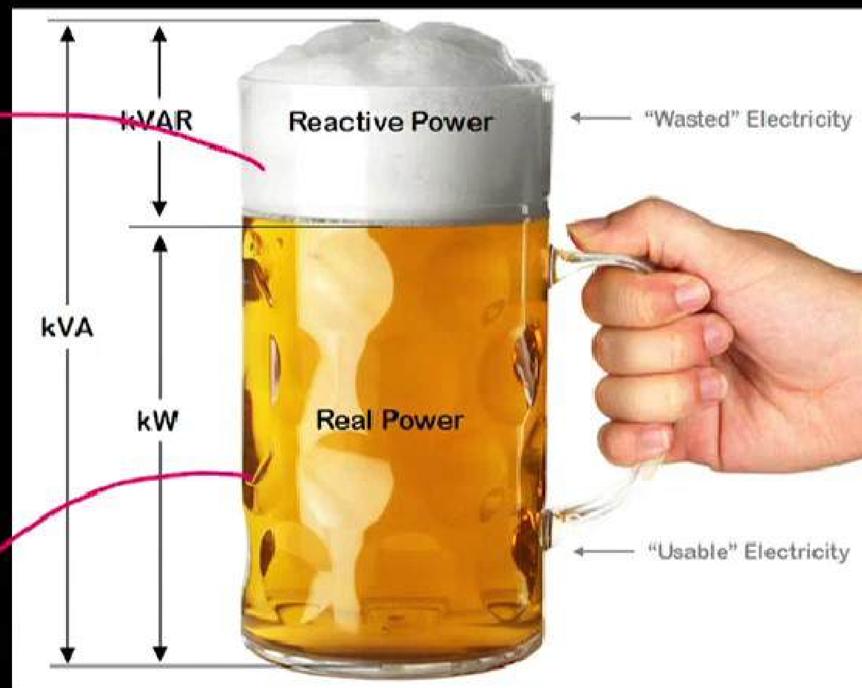
React → img

High fizz $\boxed{\text{coke}}$ Bubble $\boxed{\text{coke}}$ zero fizz

cold drink → "P"

Bubble → "Q"

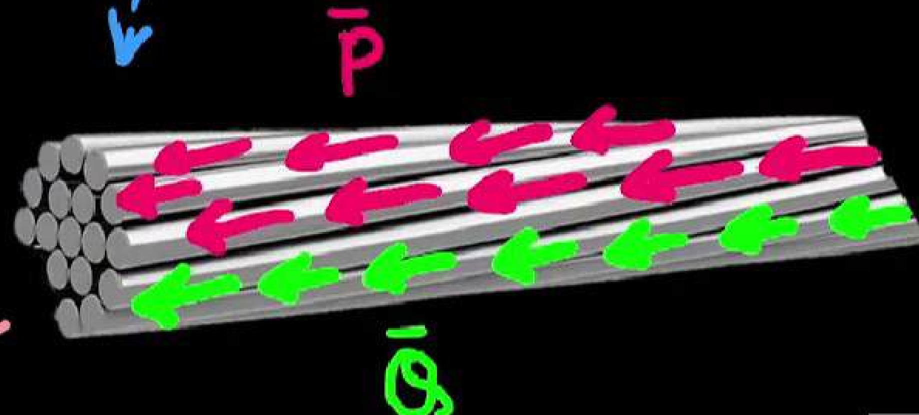
Space opt by reactive power



Space opt by active power

Conductor Selection

Thermal capacity

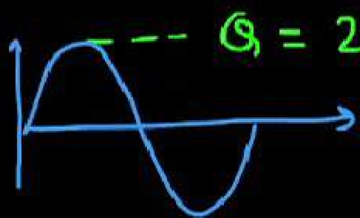


$$(\text{Thermal capacity})^2 > (P)^2 + (Q)^2$$

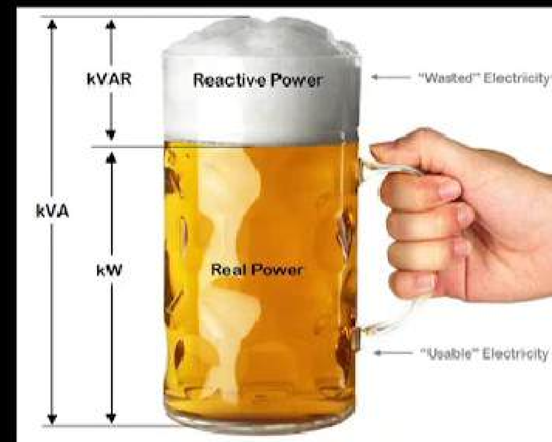
$\boxed{+20 \text{ kVAR}}$

* 

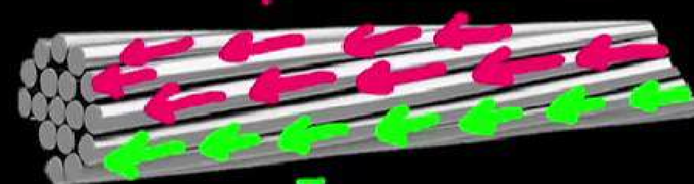
* P and Q same direction

* 

* I lag V



$\bar{P}$



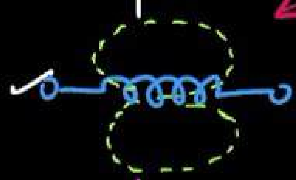
$\bar{Q}$

Ther. cap $> \sqrt{P^2 + Q^2}$


TYPES OF VAR

Q

lag VARs. magnetic field



lag reactive power

or

$\boxed{\text{lag VARs}}$

current lag voltage

© Ⓜ

electric field

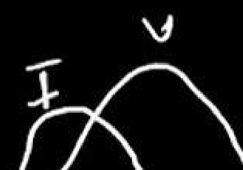
lead VARs

leading reactive power

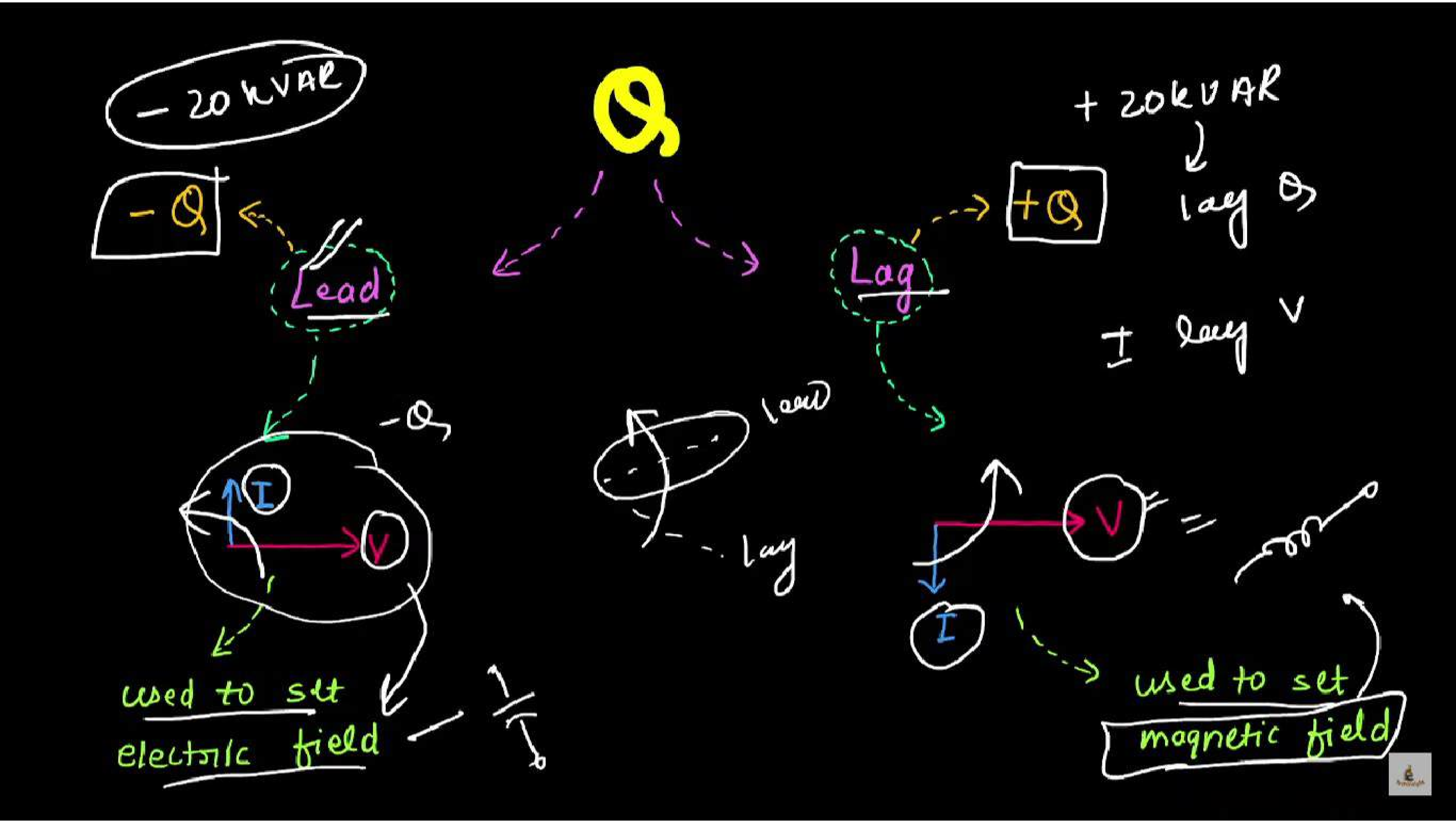
or

leading VARs

current lead voltage

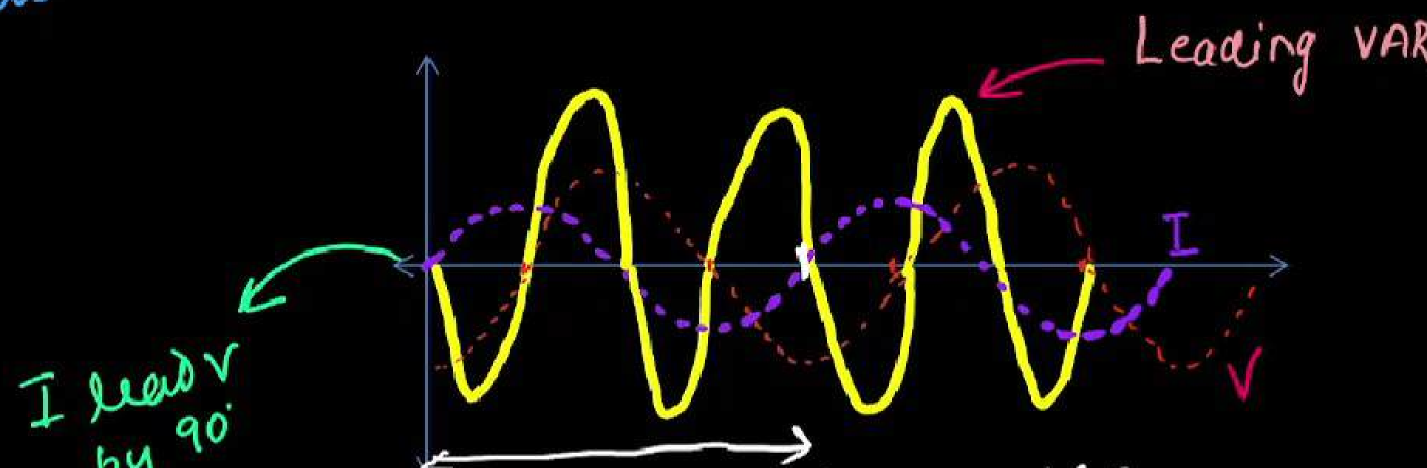


NOTE:- conventionally, Q → $\boxed{\text{lag VARs.}}$ lag.


-20 kVAR
-Q
Q
Lead
Lag
+Q
+20kVAR
lag Q
I lag V
-Q
I
V
lead
lag
V
I
used to set electric field
used to set magnetic field

Leading VARs

* Taking I as reference.

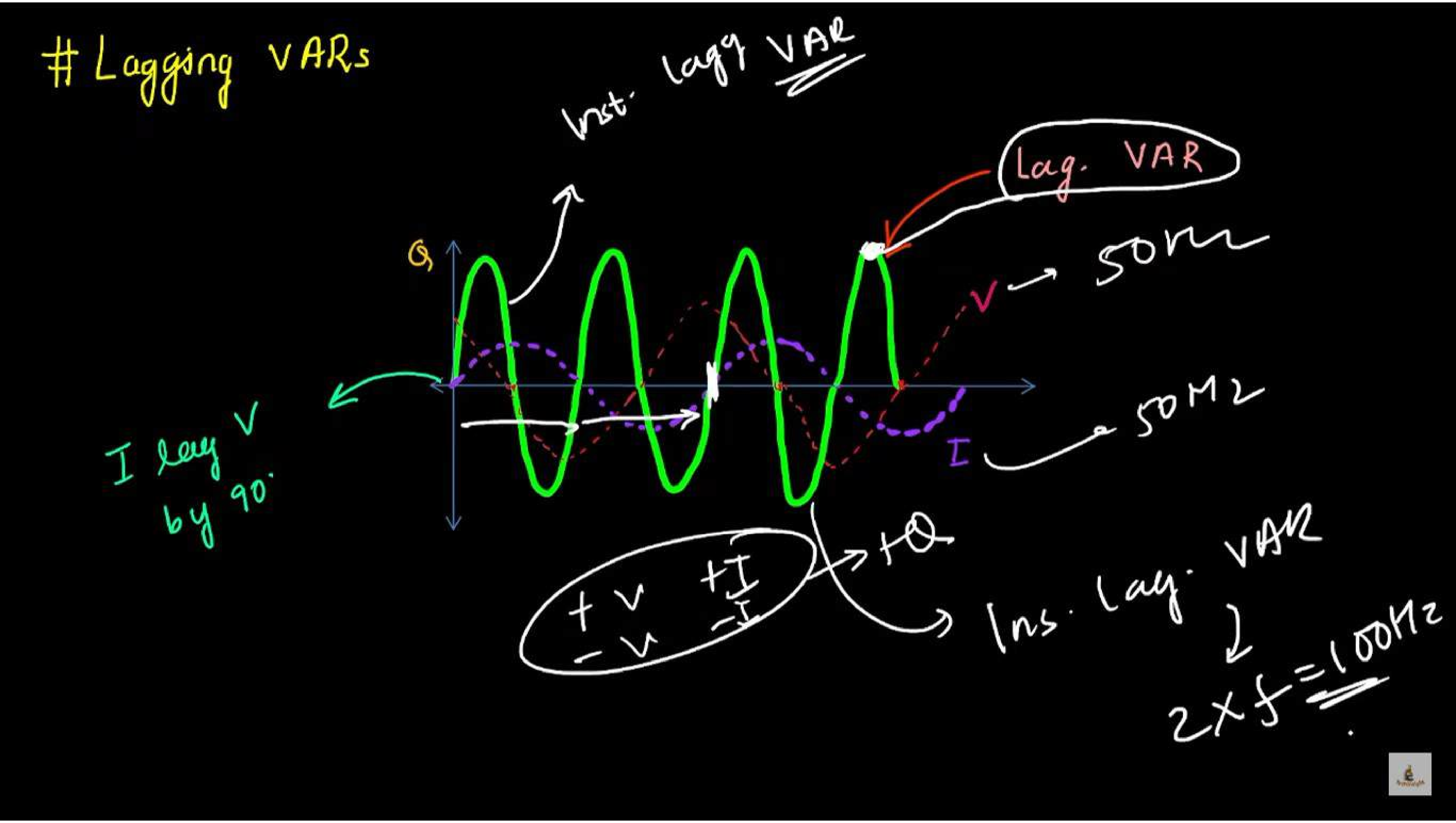


I → 1 cycle

V → 1 cycle

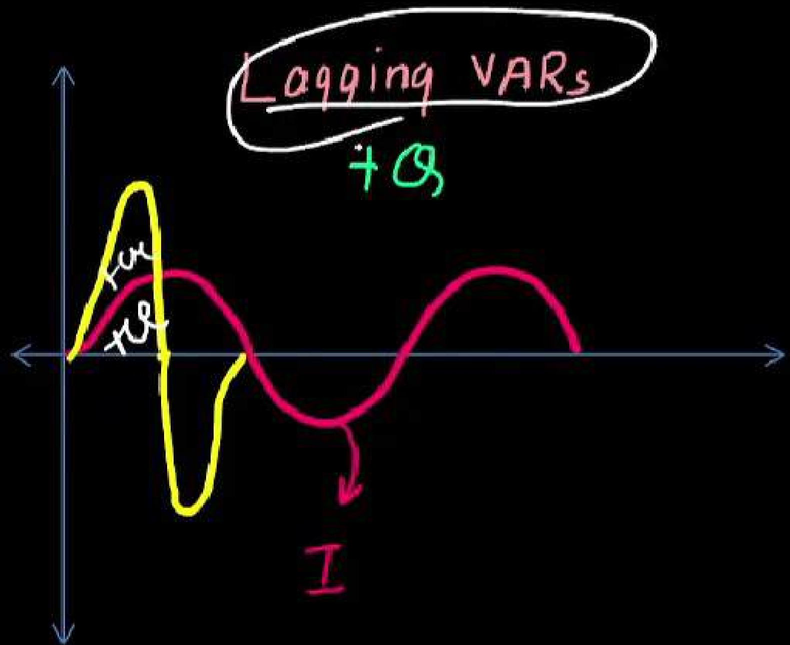
} → 50 Hz

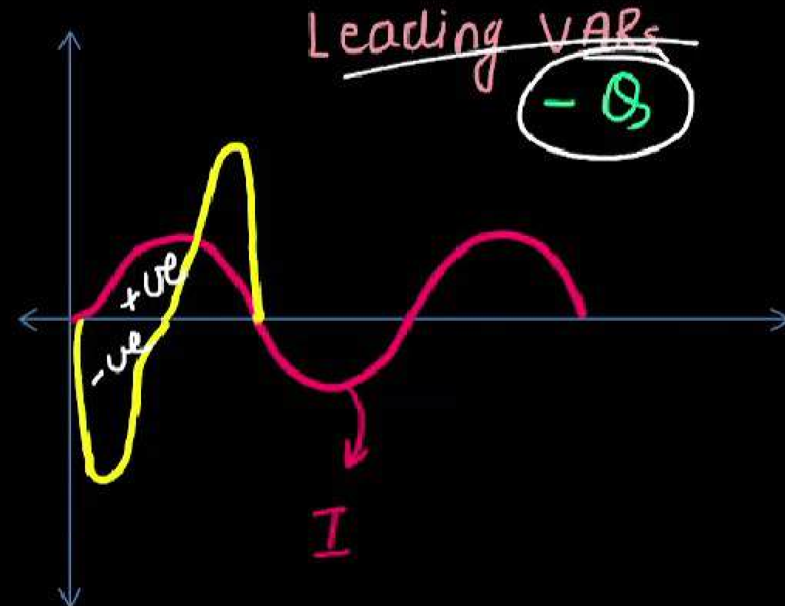
2 cycle of Ing Q → 100 Hz



Lagging VARs
Inst. lagg VAR
Lag. VAR
Q
V → 50Hz
50Hz
I
I lag V by 90°
+V +I
−V −I
+Q
Ins. lag. VAR
2×f = 100Hz

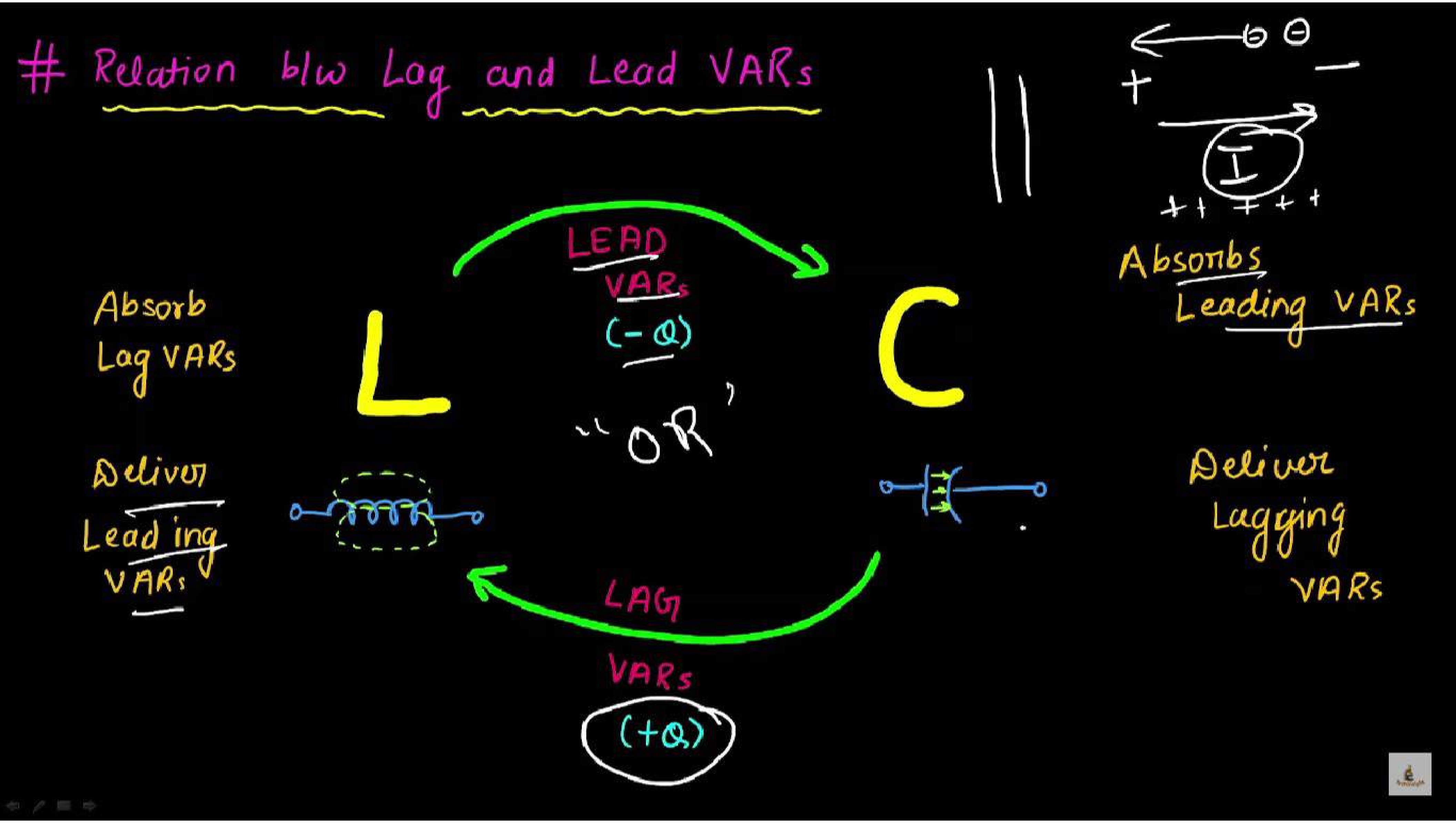
How to identify leading and lagging VARs



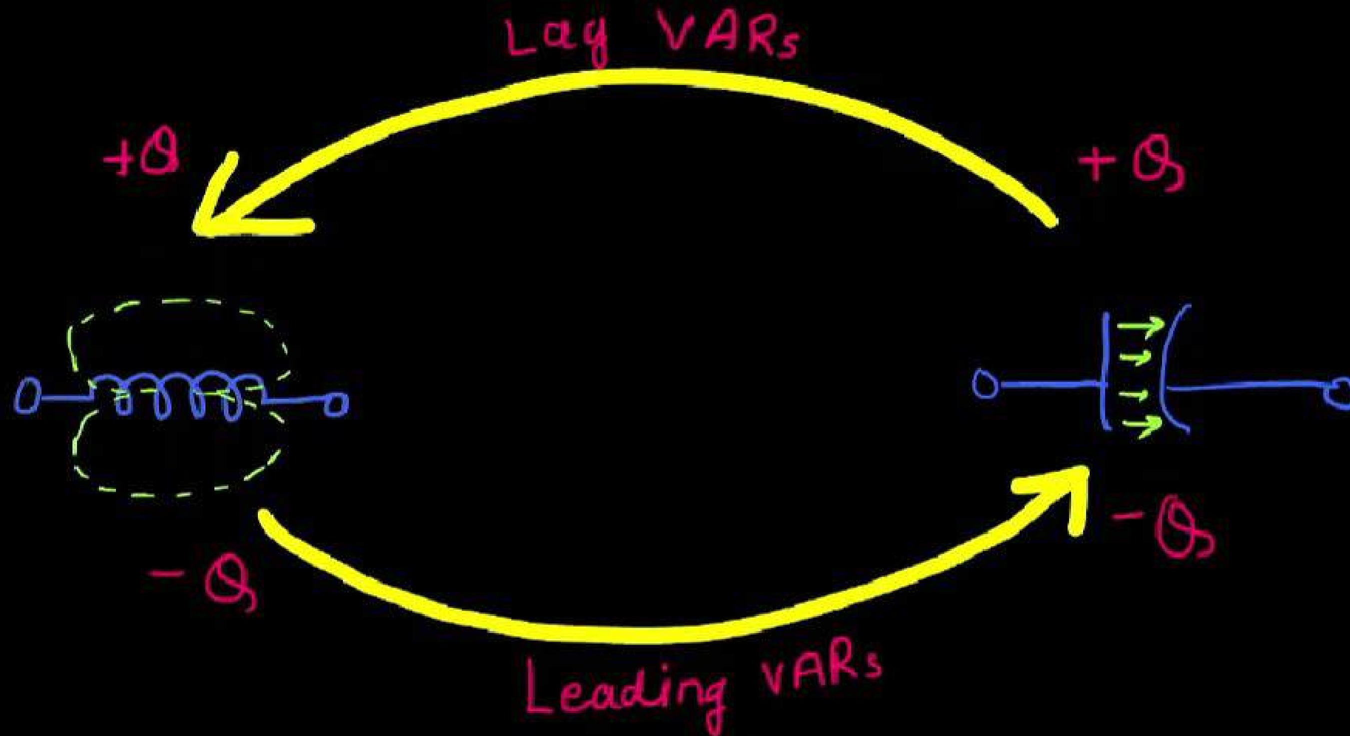


Both current and

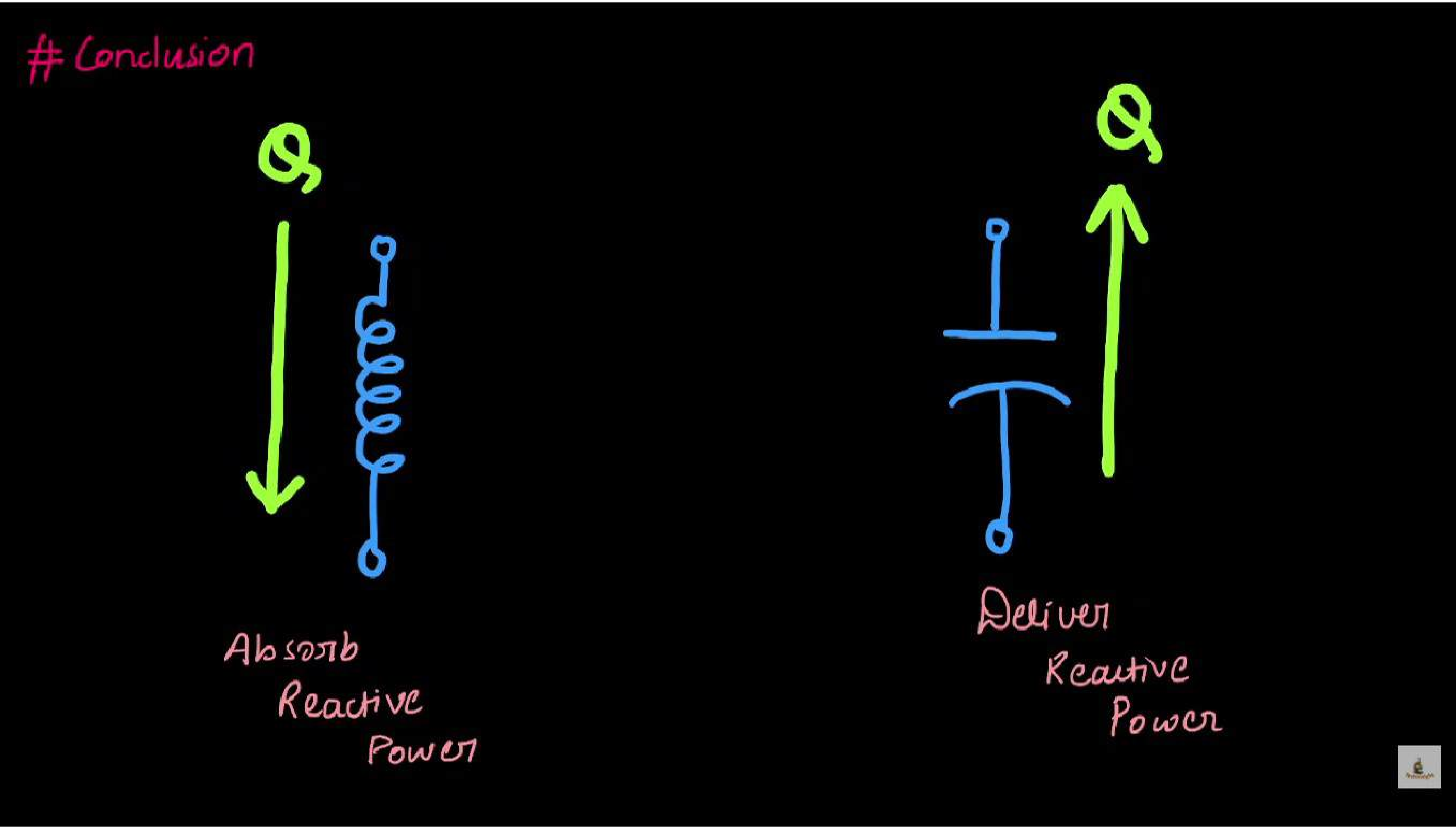
Q rise simultaneously



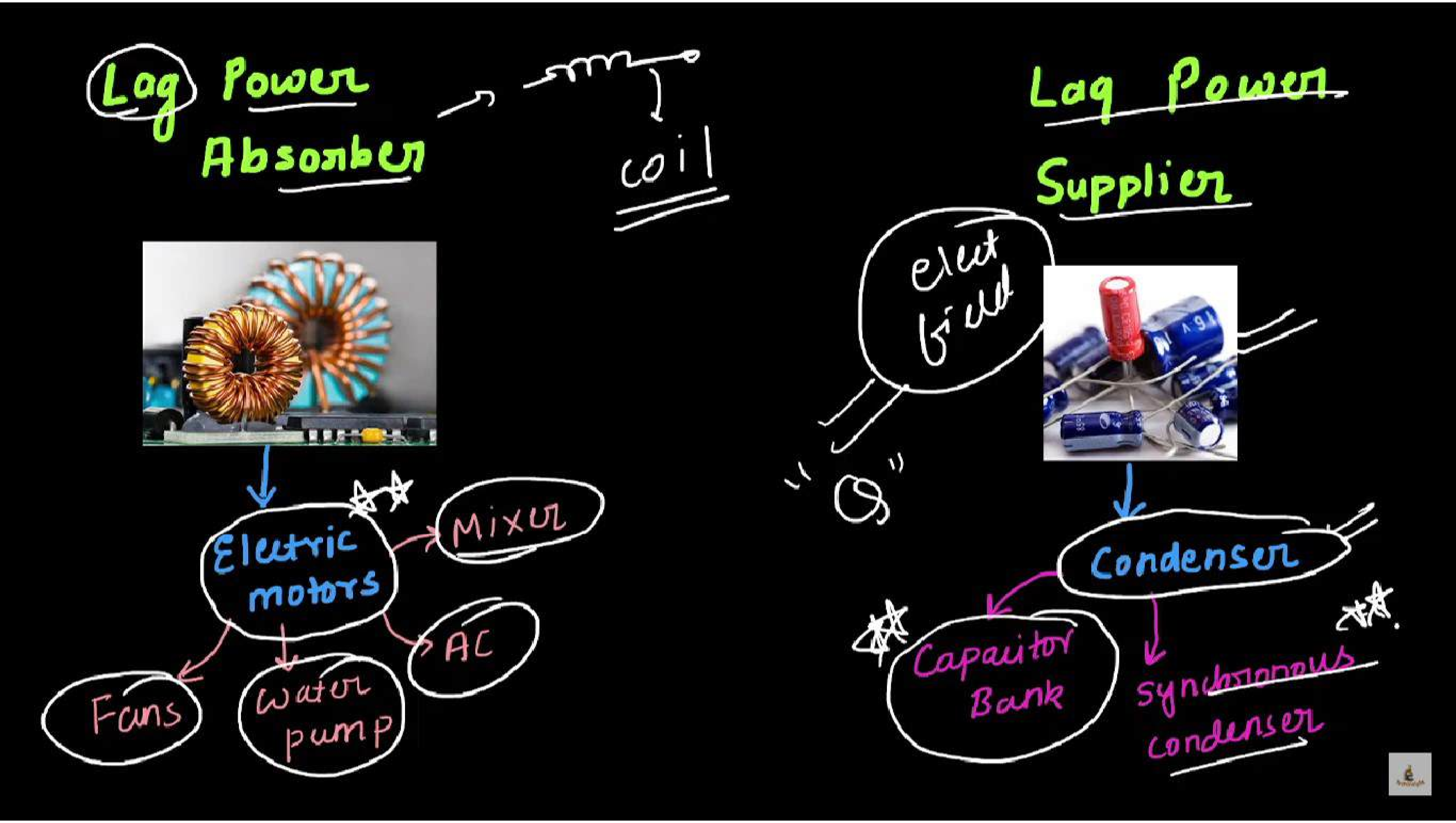
Relation b/w Lag and Lead VARs
Absorb Lag VARs
Deliver Leading VARs
L
LEAD VARs (-Q)
"OR"
LAG VARs (+Q)
C
Absorbs Leading VARs
Deliver Lagging VARs
I



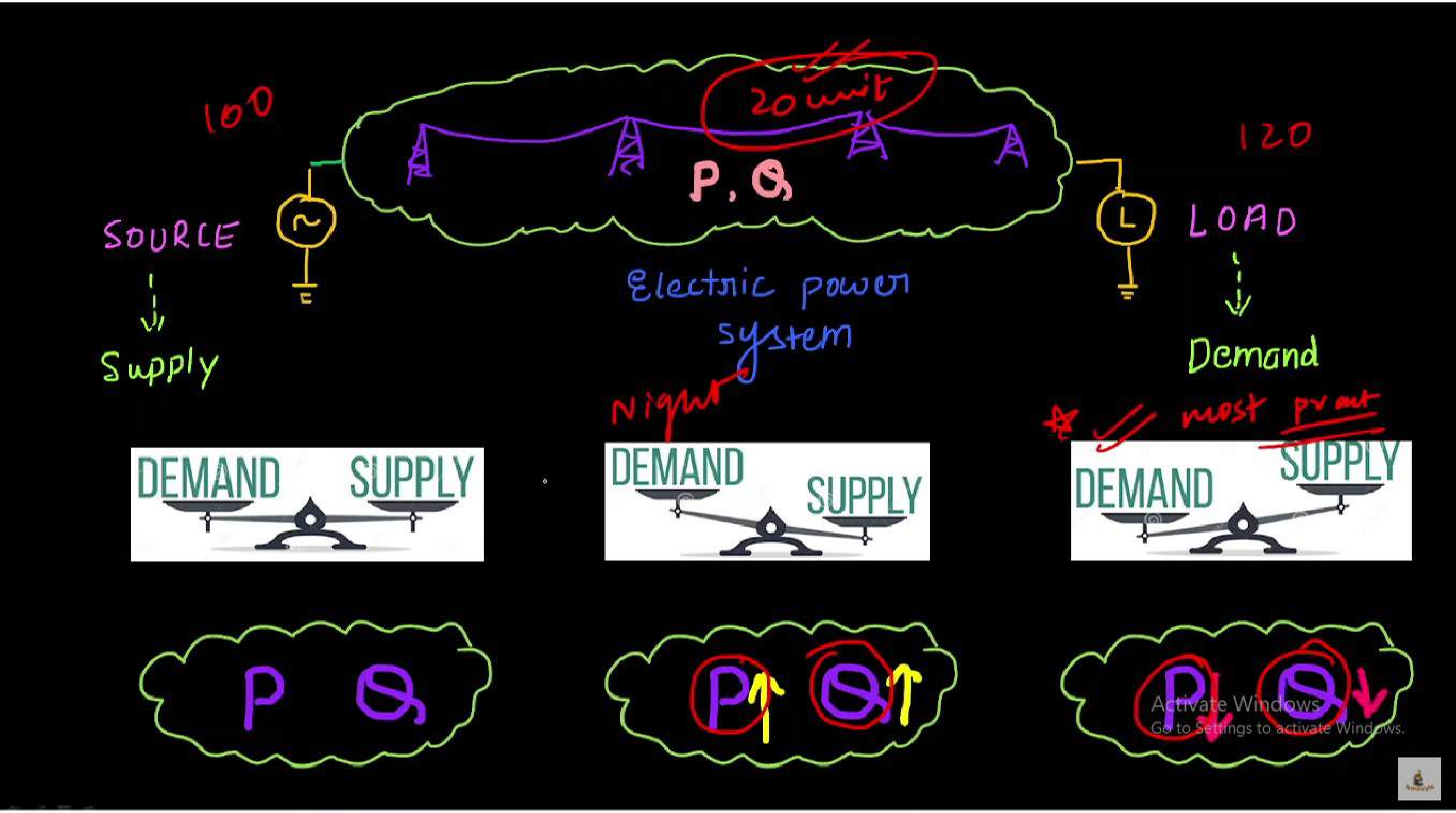
"In power system we use L and C to counter each other"



Conclusion
Q
Q
Absorb Reactive Power
Deliver Reactive Power


Lag Power Absorber
coil
Electric motors
Mixer
AC
Fans
water pump
Lag Power Supplier
elect field
"Q"
Condenser
Capacitor Bank
synchronous condenser


EFFECT OF P & Q


100
20 unit
120
P, Q
SOURCE
Supply
LOAD
Demand
Electric power system
Night
most
DEMAND
SUPPLY
DEMAND
SUPPLY
DEMAND
SUPPLY
P Q
P Q
P Q

Controlling Parameters

active $P \rightarrow f$

Reactive $Q \rightarrow V$

demand = supply

50 Hz

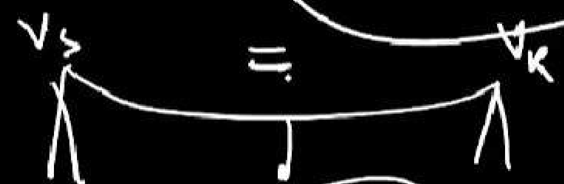
$\boxed{P_{system} = P_{rated}}$ $\boxed{f = f_{rated}}$

$Q_{system} = Q_{rated}$ $\boxed{V_s = V_R}$

दोनों

11 kV = 11 kV

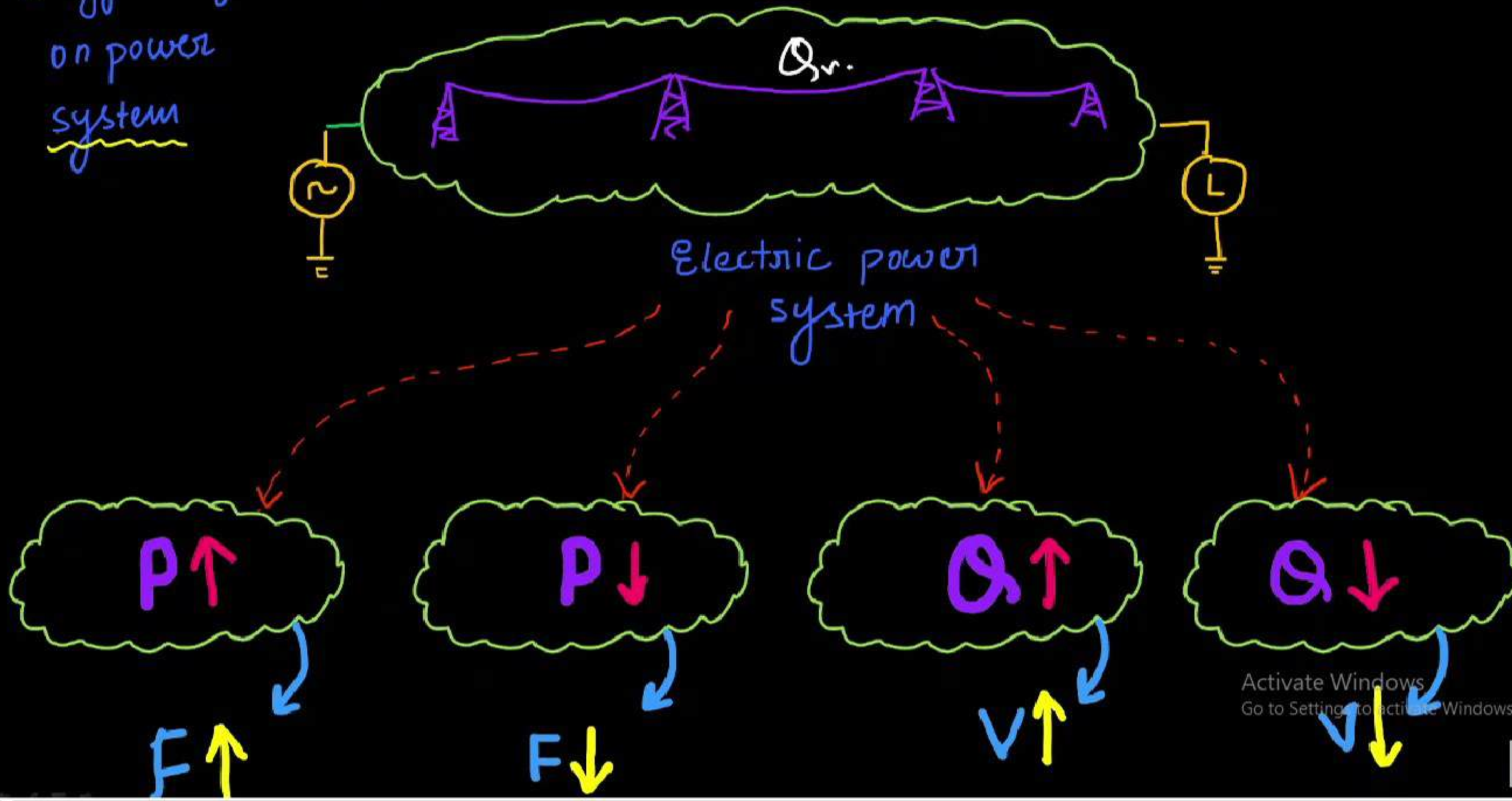
$Q_{rated} = Q_{system}$

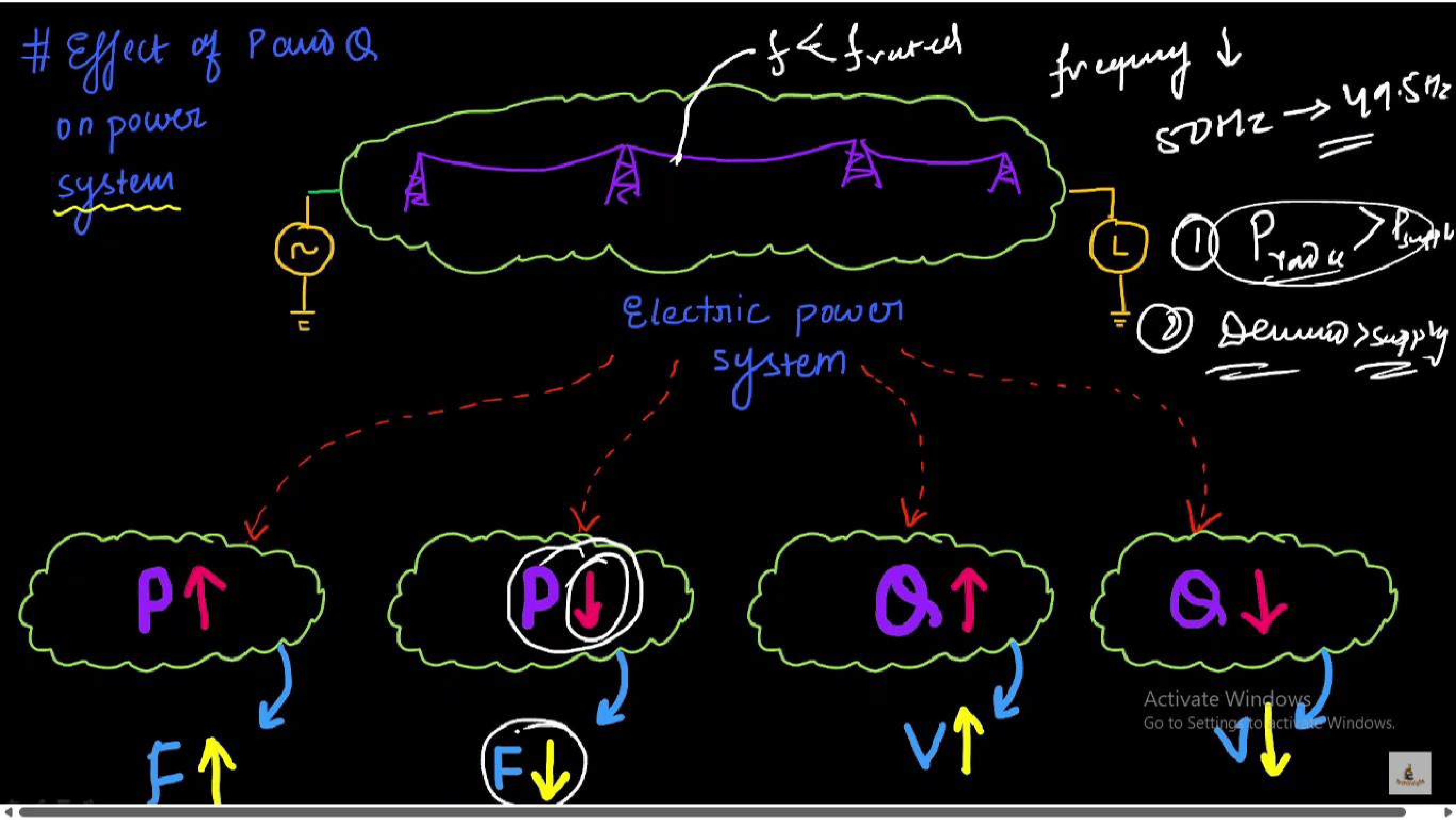


$P_{rate} = P_{system}$

frequency → 50Hz

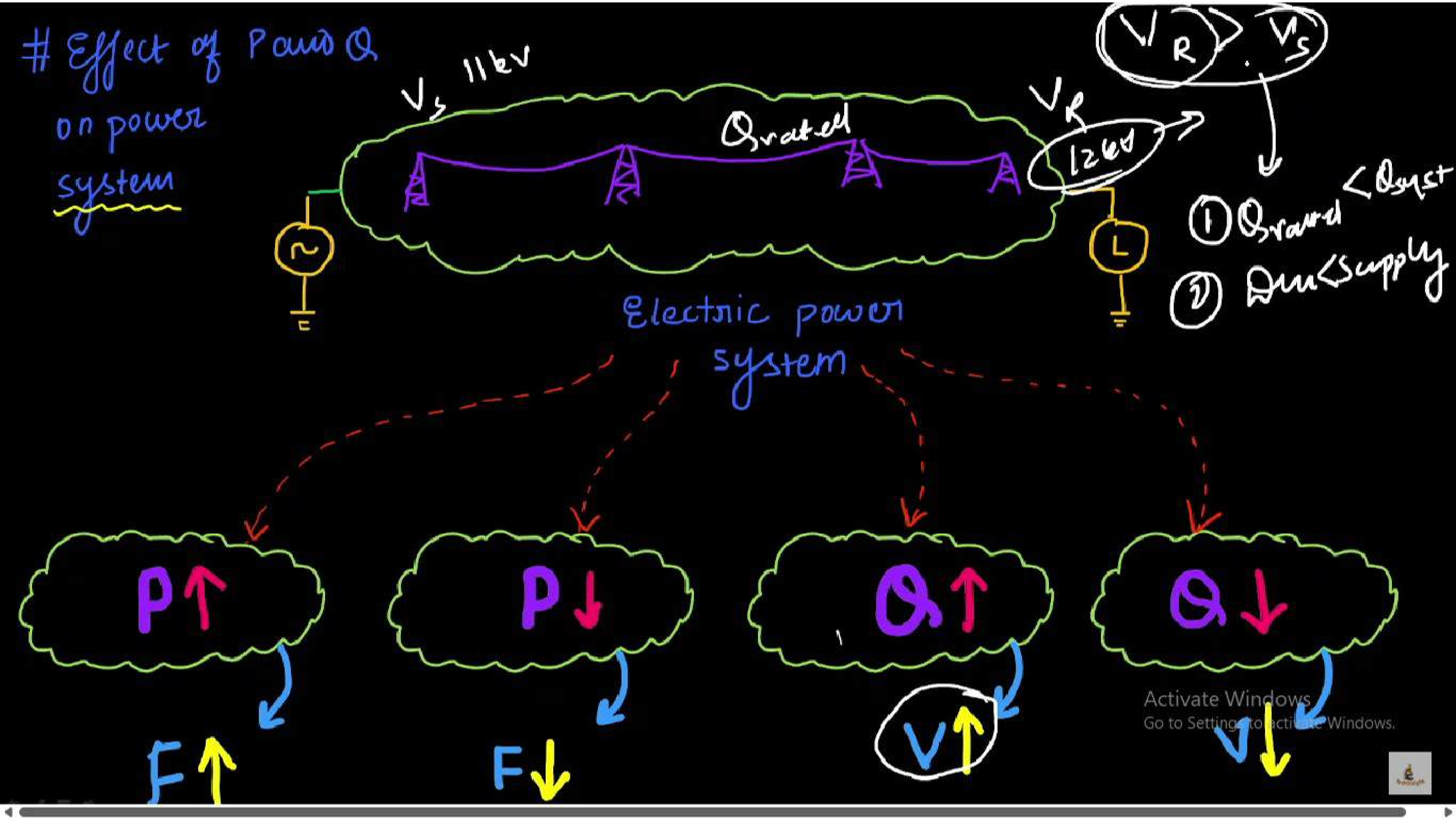
Effect of P and Q on power system

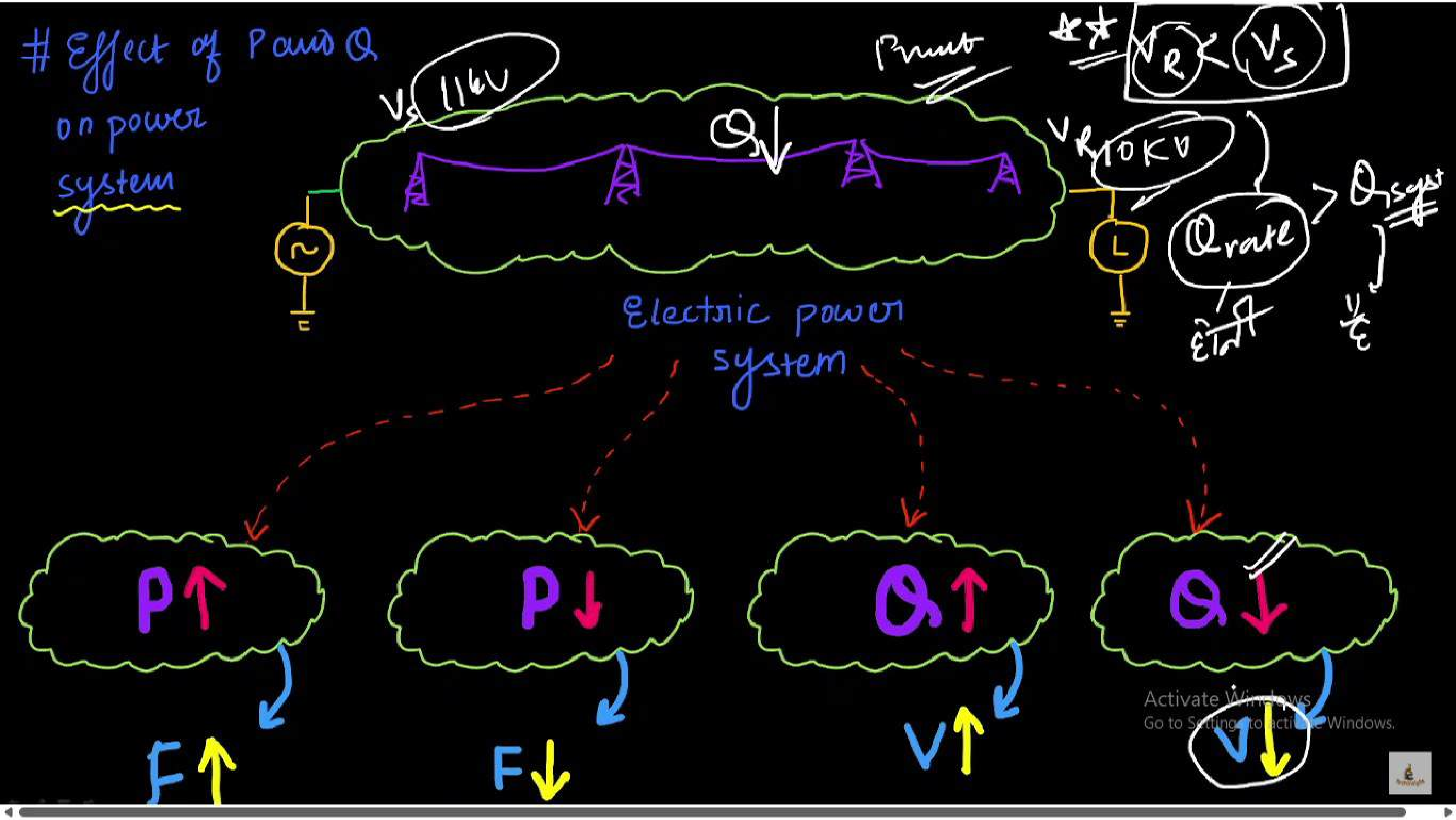




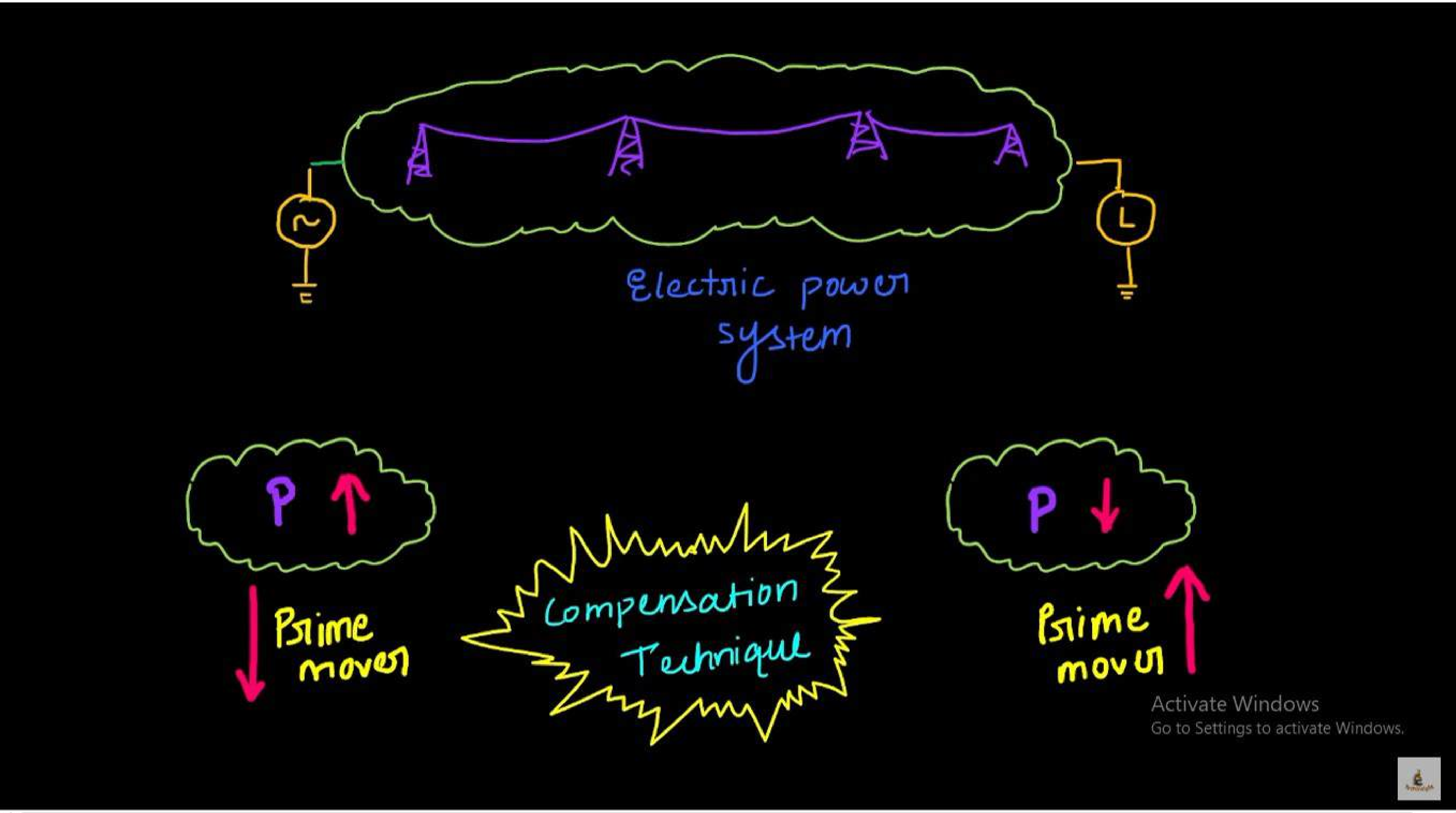
Effect of P and Q on power system
f < frated
frequency ↓
50Hz → 49.5Hz
① Prodn > Psupply
② Demand > supply
~
L
Electric power system
P ↑
P ↓
Q ↑
Q ↓
F ↑
F ↓
V ↑
V ↓
Activate Windows
Go to Settings to activate Windows.

Effect of P and Q on power system

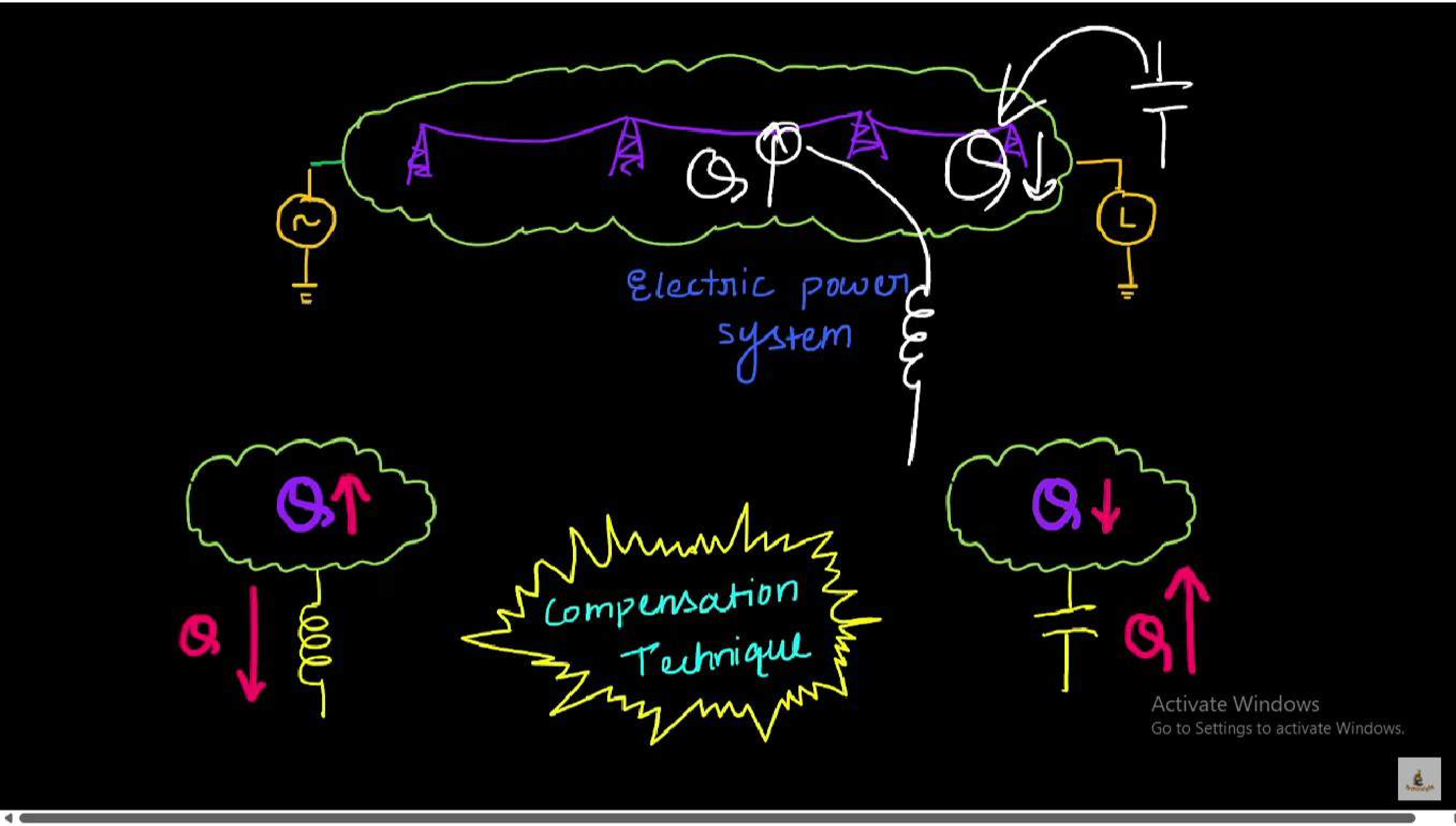


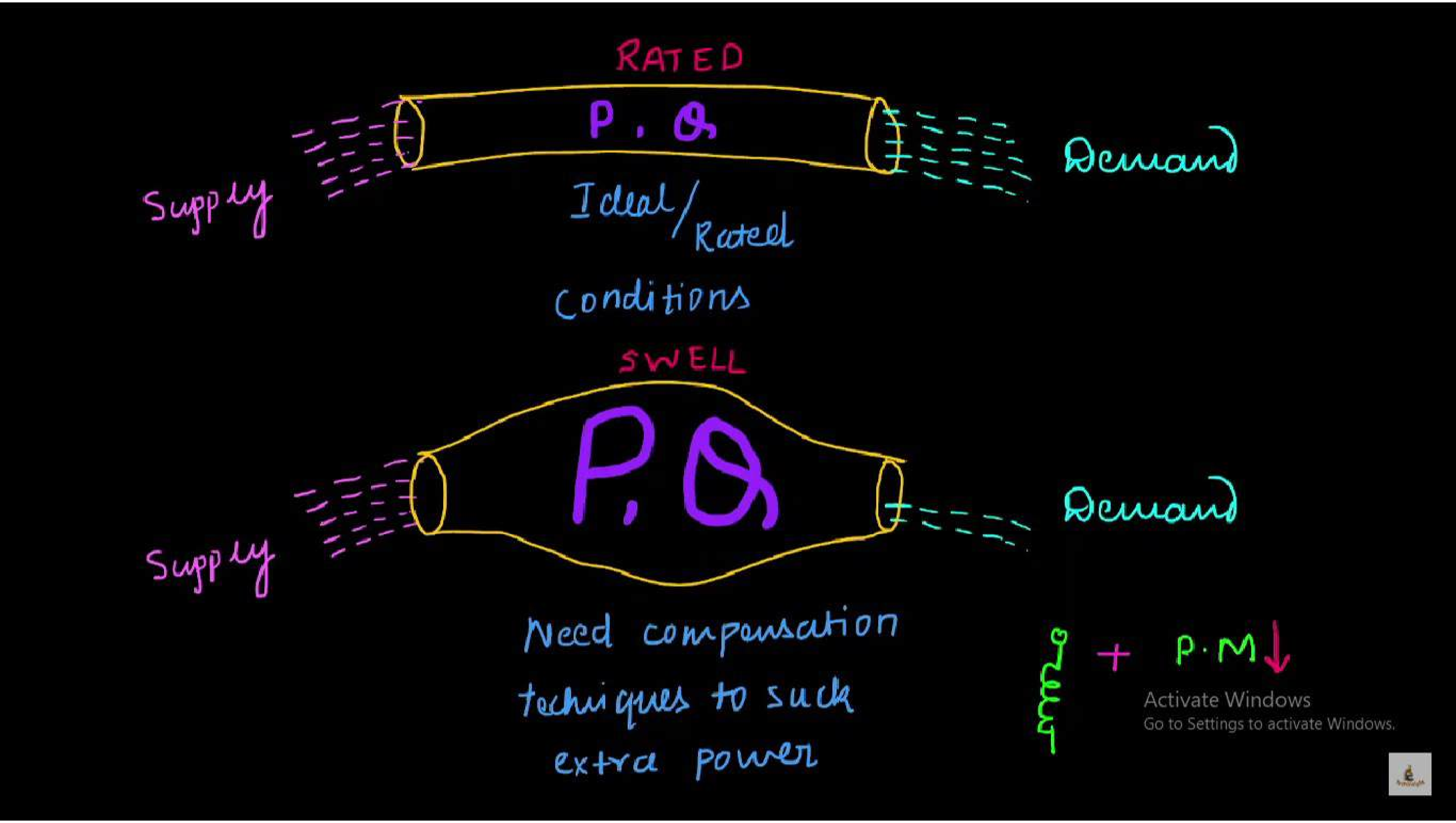


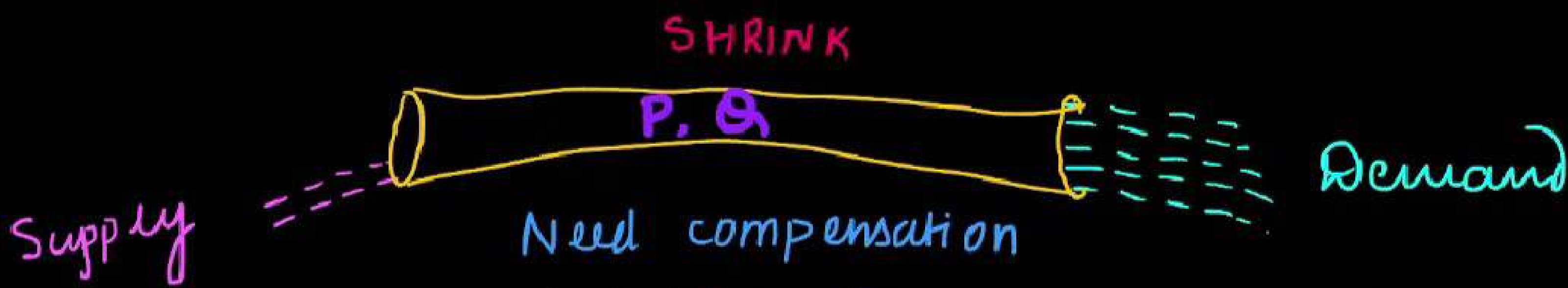
Effect of P and Q on power system
Vs 11kV
Q↓
Point
VR 10kV
VR < Vs
Qrate
Electric power system
P↑
P↓
Q↑
Q↓
F↑
F↓
V↑
V↓
Activate Windows
Go to Settings to activate Windows.



L
Electric power system
P ↑
Prime mover ↓
Compensation Technique
P ↓
Prime mover ↑
Activate Windows
Go to Settings to activate Windows.


Q↑
Q↓
Electric power system
Q↑
Q↓
Compensation Technique
Q↓
Q↑
Activate Windows
Go to Settings to activate Windows.


RATED
P, Q
Supply
Demand
Ideal/Rated
conditions
SWELL
P, Q
Supply
Demand
Need compensation
techiques to suck
extra power
+ P.M↓
Activate Windows
Go to Settings to activate Windows.



Need compensation technique to insert required power

$+$ P.M $\uparrow$

$$\Delta P \longrightarrow \Delta f$$

$$\Delta Q \longrightarrow \Delta V$$


POWER TRIANGLE

Calculations

$\cos\theta = \frac{P}{S}$

power factor

$\cos\theta = \frac{P}{VI}$

$\therefore \underbrace{P = VI\cos\theta}_{\text{active power}}$

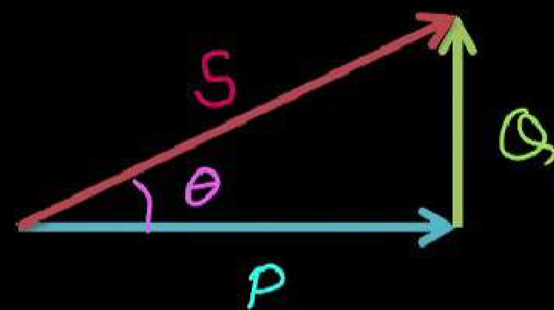
θ :- Power factor angle

θ

θ

P.f

$\sin\theta \propto \theta \quad \cos\theta$



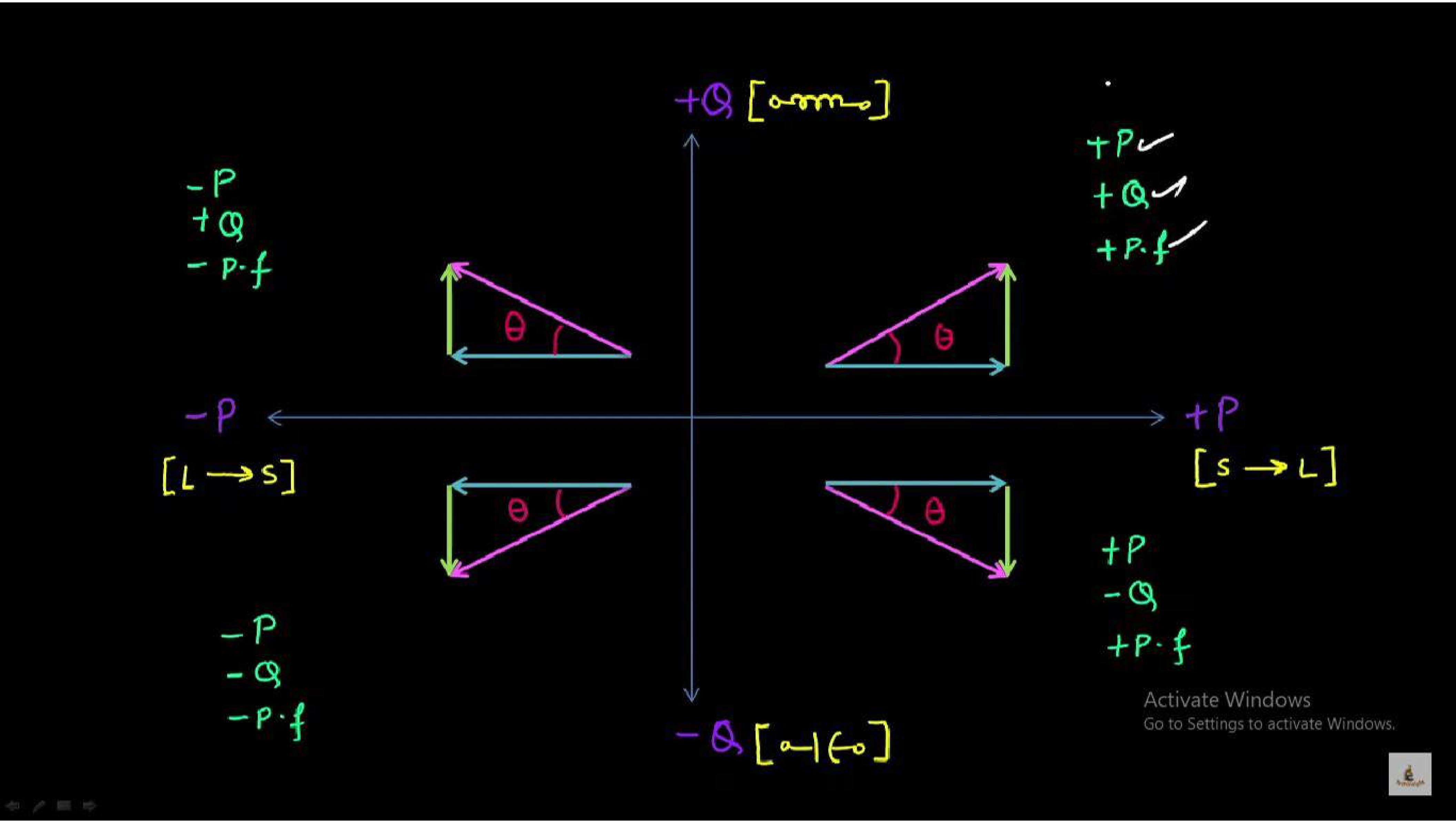
$\sin\theta = \frac{Q}{S} = \frac{Q}{VI}$

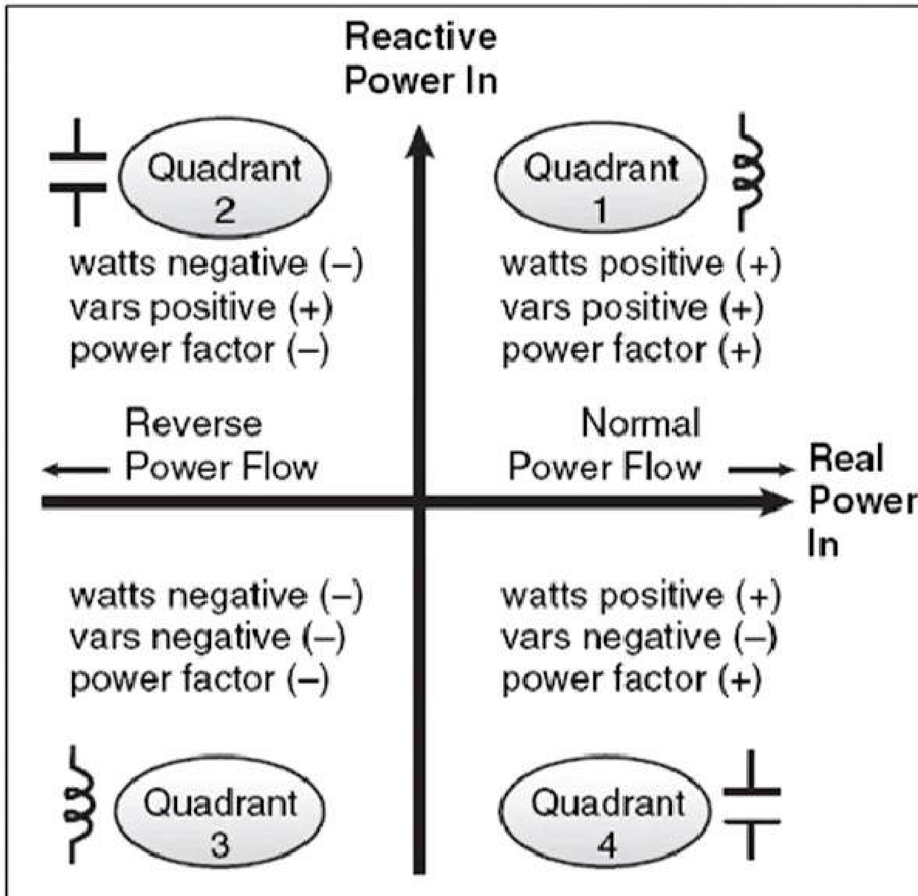
θ

P.f

cos θ

$\therefore \underbrace{Q = VI\sin\theta}_{\text{Reactive power}}$

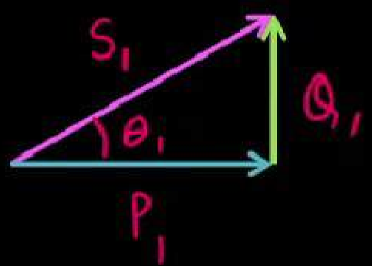

+Q
-P
+Q
-P.f
+P
+Q
+P.f
θ
θ
-P
[L → S]
+P
[S → L]
θ
θ
+P
-Q
+P.f
-P
-Q
-P.f
-Q
Activate Windows
Go to Settings to activate Windows.



IEC Power Factor Sign Convention

Application of power Δ

Machine-1



$\cos\theta_1$

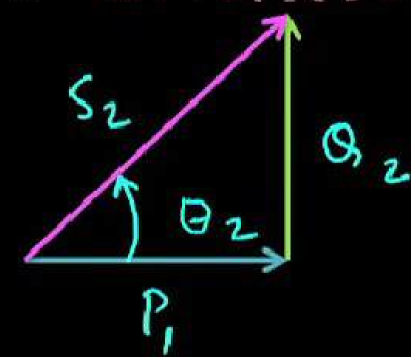
P_1

Q_1

S_1

FAIL

Machine-2 → demands more power from source for same work



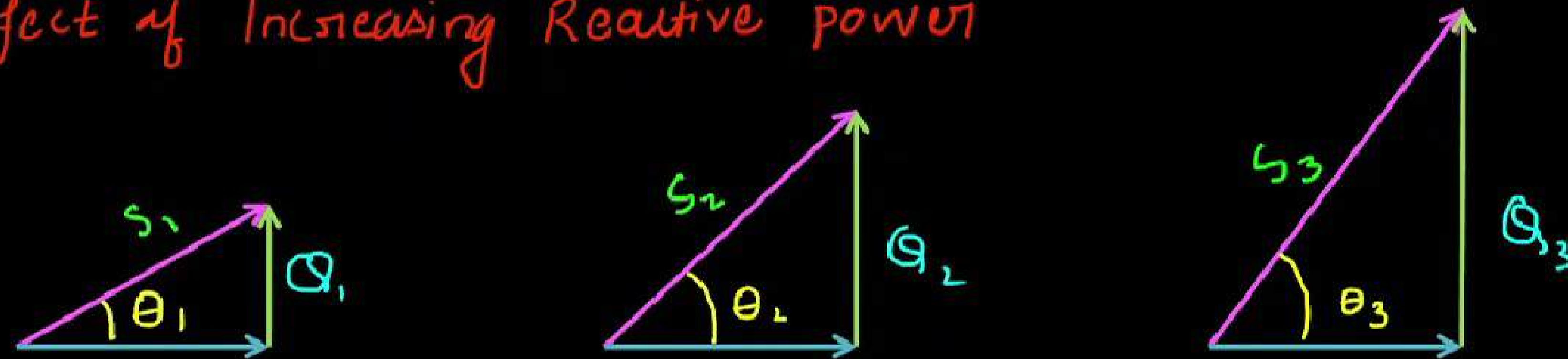
$\cos\theta_2 \downarrow$

P_1

$Q_2 \uparrow$

$S_2 \uparrow$

Effect of Increasing Reactive power



$$P_1 = P_2 = P_3$$

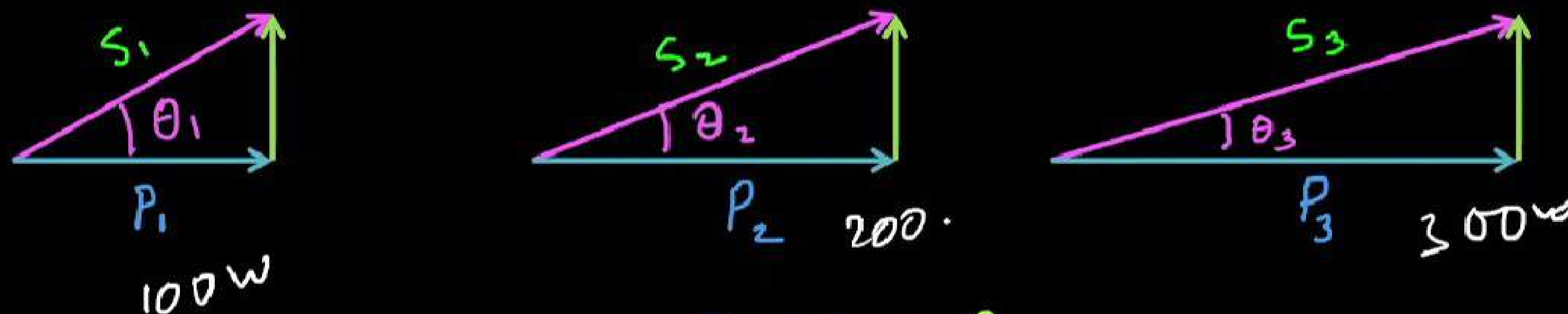
$$Q_1 < Q_2 < Q_3$$

$$\theta_1 < \theta_2 < \theta_3$$

$$P.F_1 > P.F_2 > P.F_3$$

$$S_1 < S_2 < S_3$$

Effect of increasing Active power



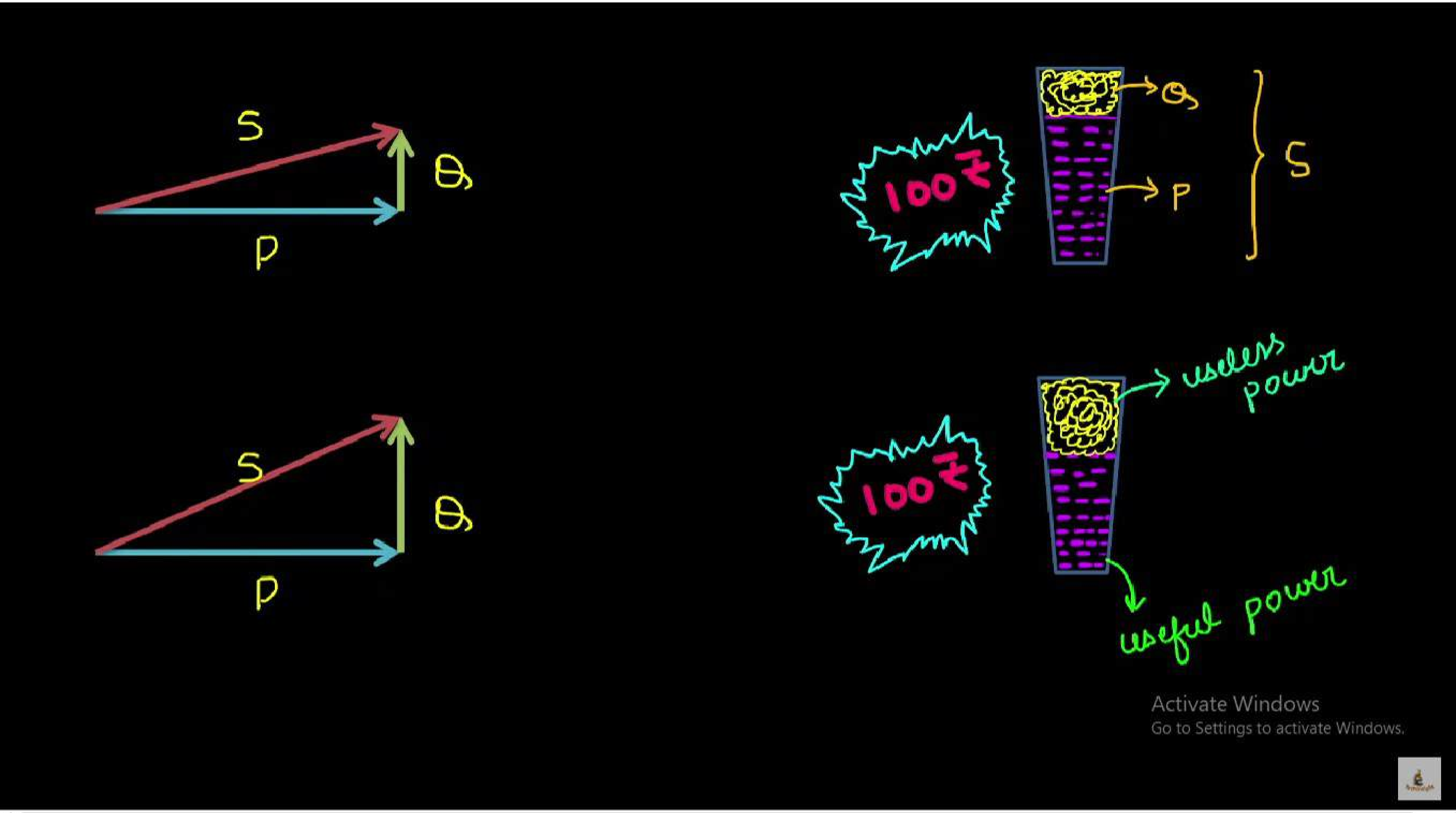
$$Q_1 = Q_2 = Q_3$$

$$P_1 < P_2 < P_3$$

$$\theta_1 > \theta_2 > \theta_3$$

$$P.F_1 < P.F_2 < P.F_3$$

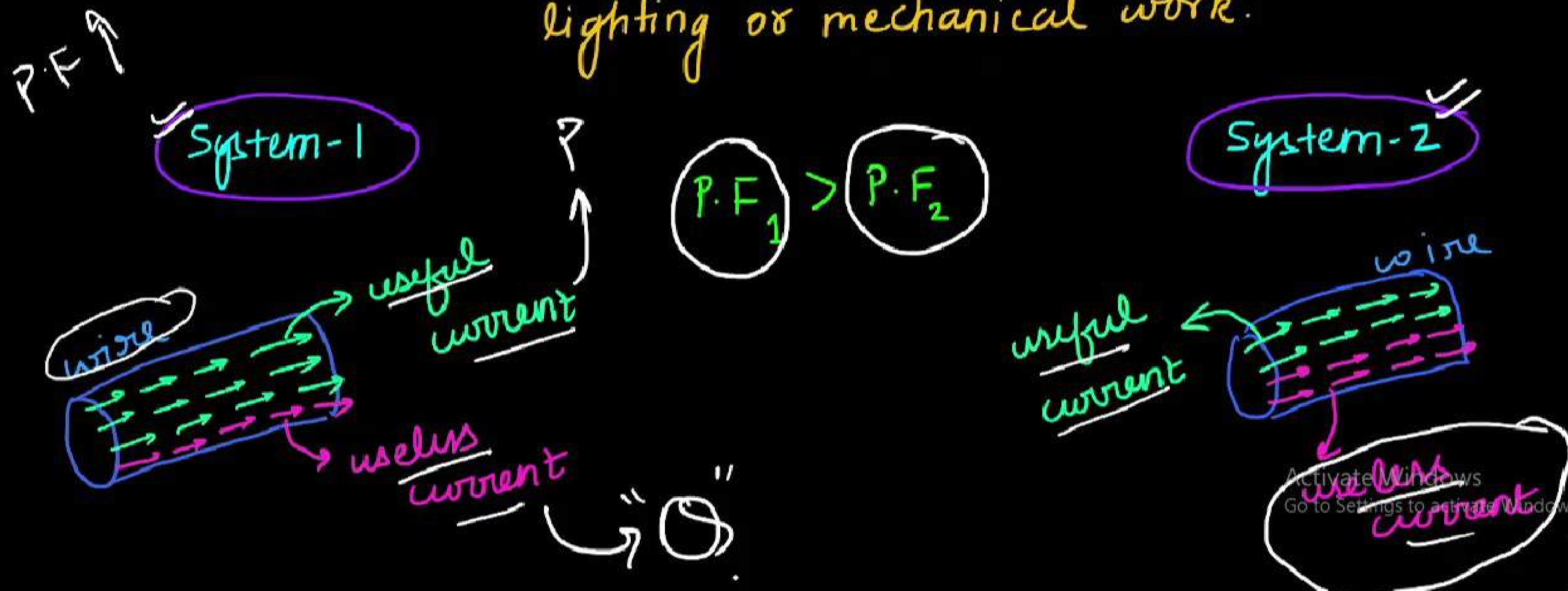
$$S_1 < S_2 < S_3$$


S
Q
P
S
Q
P
100₹
Q
P
S
100₹
useless power
useful power
Activate Windows
Go to Settings to activate Windows.


POWER FACTOR

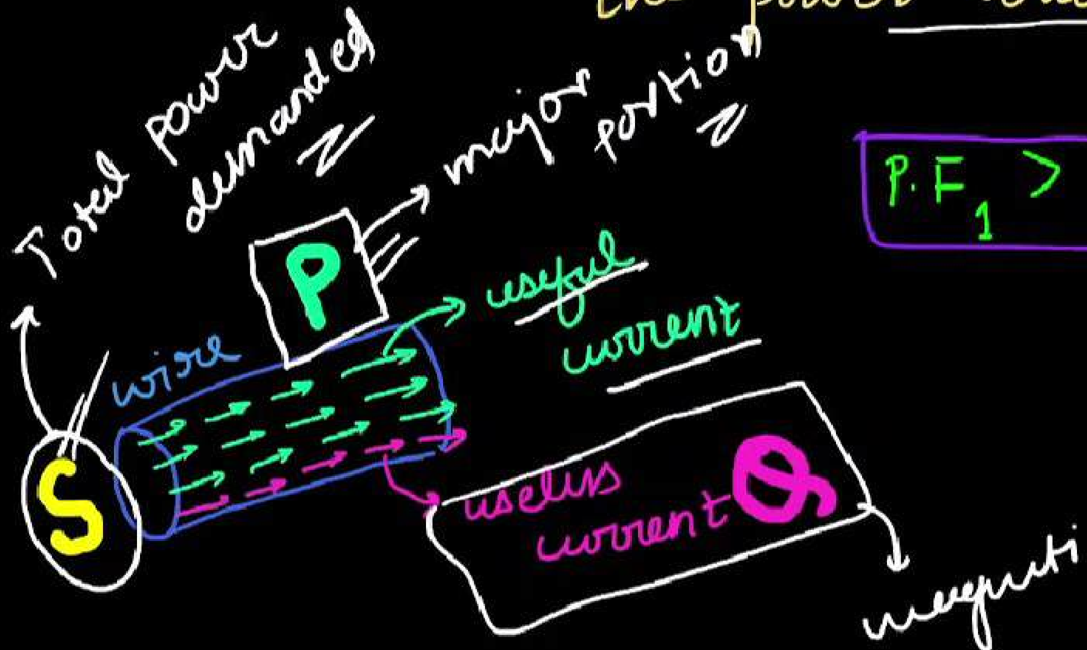
What is significance of Power factor?

Power factor ⇝ Signify the ability of system to utilize current for useful work such as heating, lighting or mechanical work.

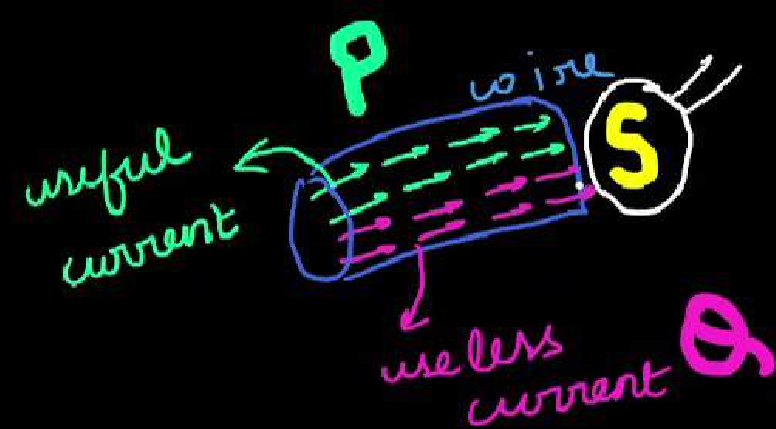


Power factor :→ Also signify how efficiently we utilize the power drawn from power system. useful

$$\boxed{P.F_1 > P.F_2}$$



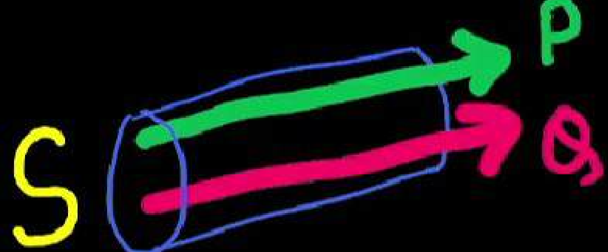
Effective utilization



Poor utilization

Technically

"P.F decides the amount of real power you derive from total power demanded."



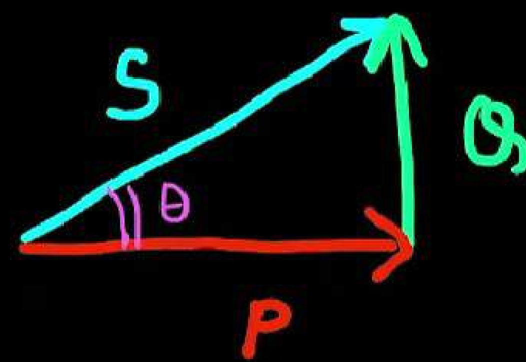
$$\boxed{\text{Power factor} = \frac{P}{S}}$$

$$P.F = \frac{\text{Real power consume}}{\text{Apparent power supplied}}$$

Formulas of P.F

* $P.F = \cos\theta$

* $P.F = \dfrac{P}{S} = \dfrac{kW}{kVA}$



* $P.F = \dfrac{R}{Z}$

* $P.F = \dfrac{kWhr}{kVAhr} = \dfrac{kWh}{\sqrt{(kWh)^2 + (kVARh)^2}}$

Values of P.F

$\boxed{S = P}$

unit

1 → R only

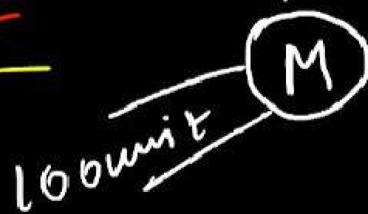
Power Factor = cos θ = { 1, 0.9, 0.8, ..., 0 }

$\boxed{S = Q}$

0 → pure Q

Values of P.F

P.F = 0.8



⇒ 80% of unit

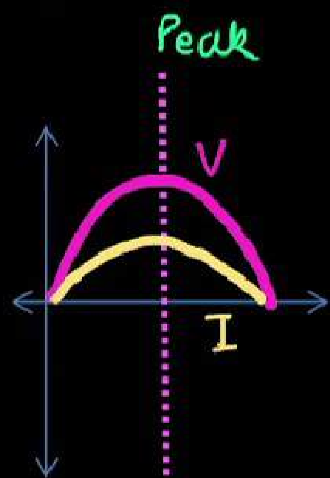
Usefull work

$$\text{Power Factor} = \cos\theta = \begin{cases} 1 \\ 0.9 \\ 0.8 \\ \vdots \\ 0 \end{cases}$$

"The value of P.F signify the % of active power present in total power demanded"

$\boxed{P.F = 0.8}$ → 80% active power present in total power demanded

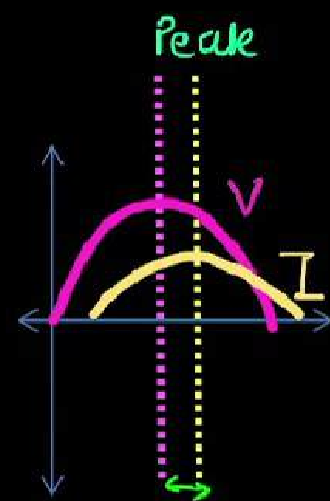
Understanding the power factor via waveform



$\theta = 0$

$\bar{S} = \bar{P}$

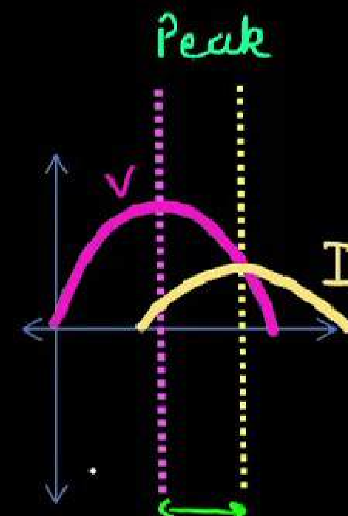
$P \cdot F = 1$



$0 < \theta < 90$

$\bar{S} = \bar{P} + \bar{Q}$

$0 < P \cdot F < 1$



$\theta = 90^\circ$

$\bar{S} = \bar{Q}$

$P \cdot F = 0$

$\theta \rightarrow$ Difference b/w peak of voltage and current


TYPES OF POWER FACTOR

Types of power factor

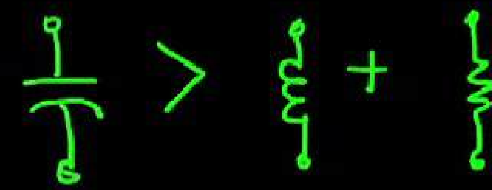
Power Factor

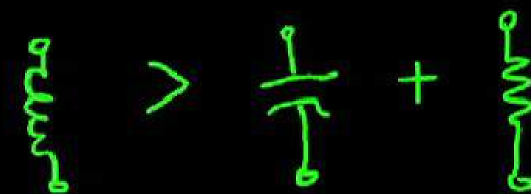
- Leading P.F
- Lagging P.F
- Unity P.F

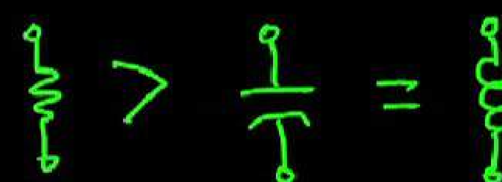
- Good P.F
- Bad P.F
- Poor P.F

- Positive P.F
- Negative P.F

Lead, Lag, and Unity P.F [in RLC Load]

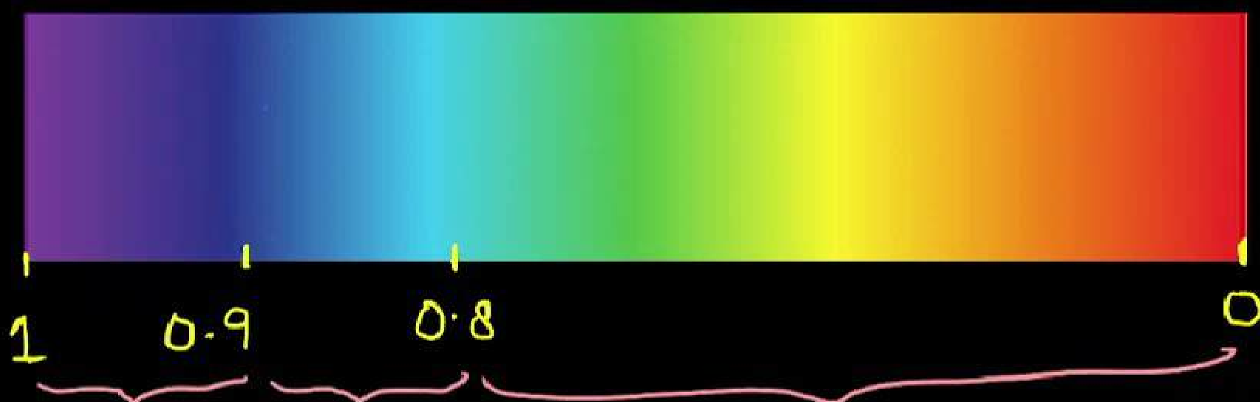
* Leading P.F $\rightarrow$ I leads V $\rightarrow$ 

* Lagging P.F $\rightarrow$ I lags V $\rightarrow$ 

* Unity P.F $\rightarrow$ I in phase V $\rightarrow$ 

Good, Bad and Poor P.F

Describe range of P.F



Good P.F — Domestic Load (0.98 – 0.9)

Bad P.F — Industrial load (0.8 to 0.7)

Poor P.F

Positive and Negative P.F

* Positive P.F

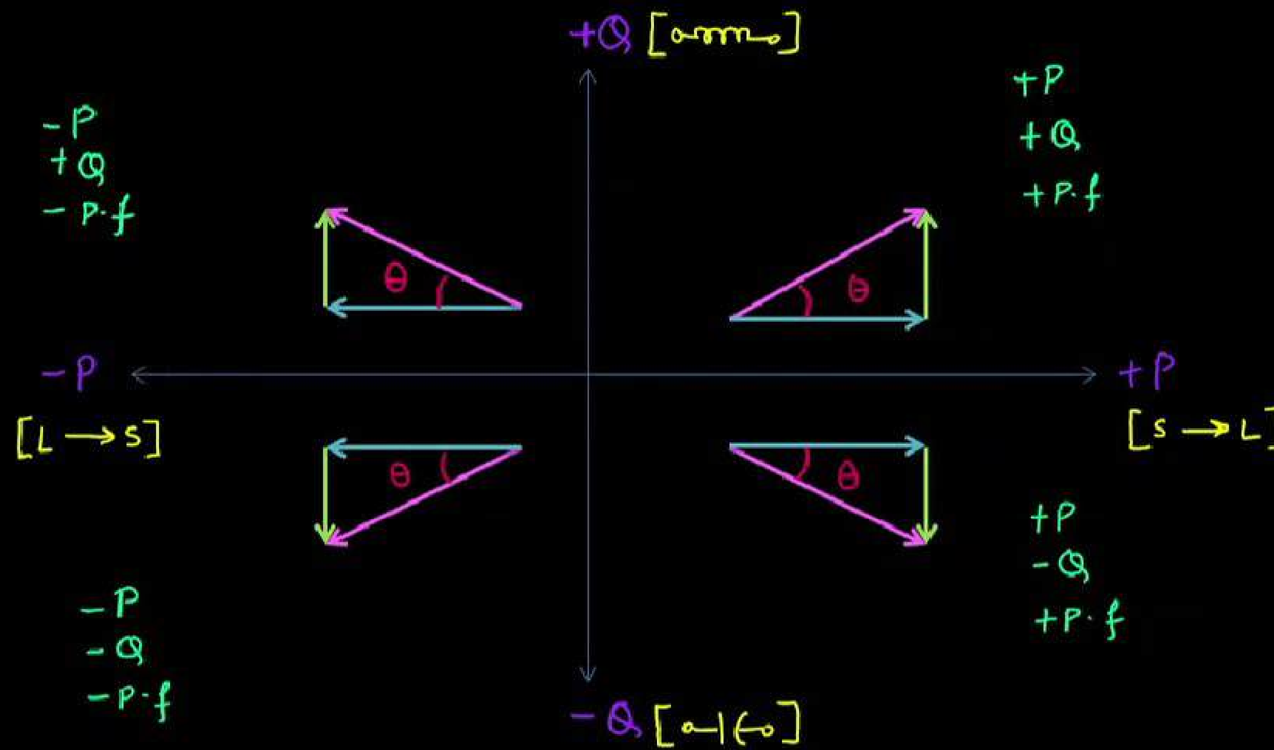
↓

Active power flow from source to Load

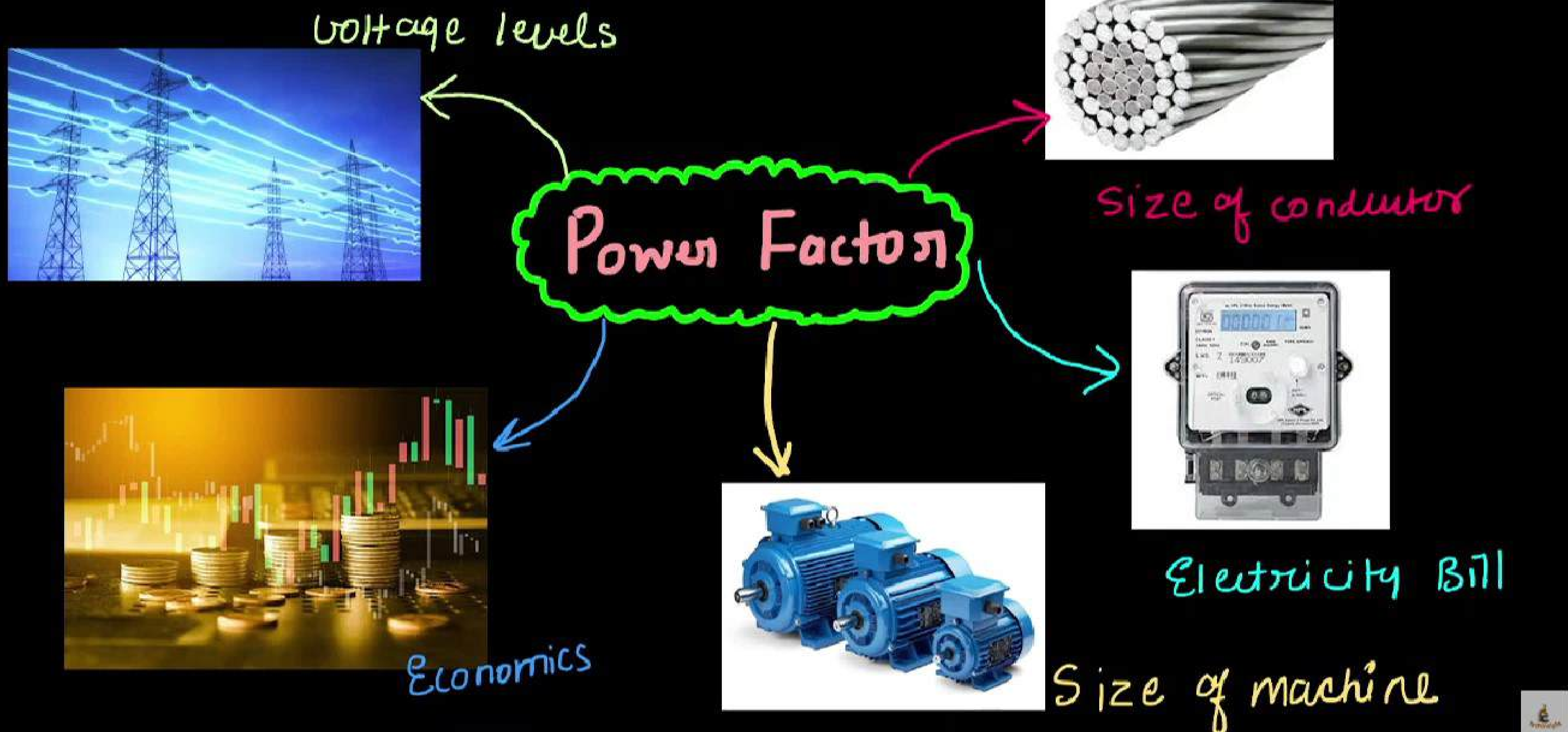
* Negative P.F

↓

Active power flow from Load to source



Importance of P.F




EFFECTS OF POWER FACTOR

Effect of P.F on size of conductor

Conductor selection or size of conductor → Current

$P = VI\cos\theta$

$I = \dfrac{P}{V\cos\theta}$

$I \propto \dfrac{1}{\cos\theta}$ for constant P and V

P.F ↓ - - - → I ↑

for same P and V

conclusion

* To deliver certain amount of power (P) at a particular voltage level (V), the amount of current requires will depends on its P.F.

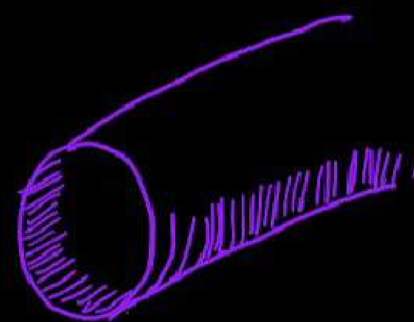
* $$\text{Amount of current needed (I) to deliver P at V} \propto \frac{1}{\text{power factor}}$$

* P.F $\downarrow$ ---> I $\uparrow$

* P.F ↓ ----> I ↑

→ conductor size ↑

conductor delivering
10 kW at 200 V,
0.9 P.F
55.5 A



conductor delivering
10 kW at 200 V
0.7 P.F.
71.4 A

#Size of machine

→ size of motor → kVA Rating

$$kVA = \frac{P}{\cos\theta}$$

$\cos\theta \downarrow$ → $\uparrow S$ → Large size motor

Conclusion

same

M1

10 kW at 200 V,

0.9 P.F

$$\boxed{S} = \frac{10,000}{0.9} = 11.1\ \text{kVA}$$

small size

M2

10 kW at 200 V

0.7 P.F.

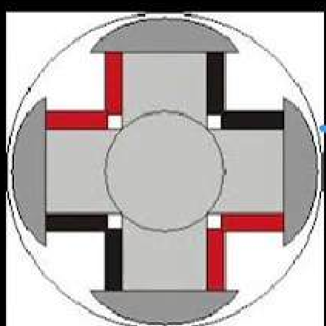
$$S = \frac{10,000}{0.7} = 14.3\ \text{kVA}$$

large size

Power factor and voltage regulation

$\downarrow$ Power factor $\longleftrightarrow$ Reactive power $\uparrow$

V $\downarrow$ V $\uparrow$



generator

* Demagnetization / Magnetization effect $\uparrow$

lead VAR

* $(V_{NL} - V_{FL}) \uparrow$

* Poor voltage regulation

Voltage Regulation

Ideal V.S → ↑ Load

V same

V.R → F.L

N.L

V.R = 0

ideal V. source

Voltage Regulation → $(V_{NL} - V_{FL})$

V

$V_R \cos\theta \pm V_x \sin\theta$

"+" Inductive load

"−" Capacitive load

$P.F \downarrow \rightarrow \theta \uparrow \rightarrow V_{drop} \uparrow$

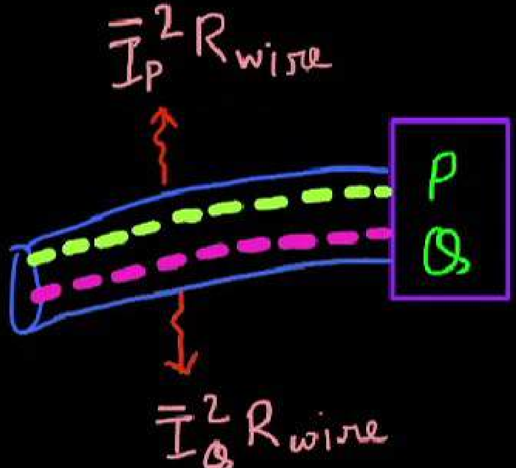
For lagging P.F. load

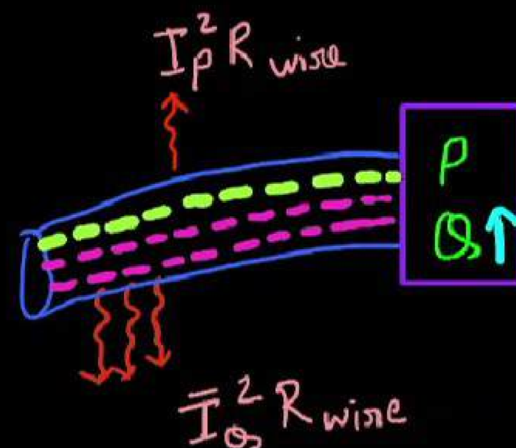
$V_{drop} = V_R \cos\theta + V_x \sin\theta$

Losses in transmission and P.F

* $P.F \downarrow \dashrightarrow I \uparrow \dashrightarrow I^2R$ losses $\uparrow$

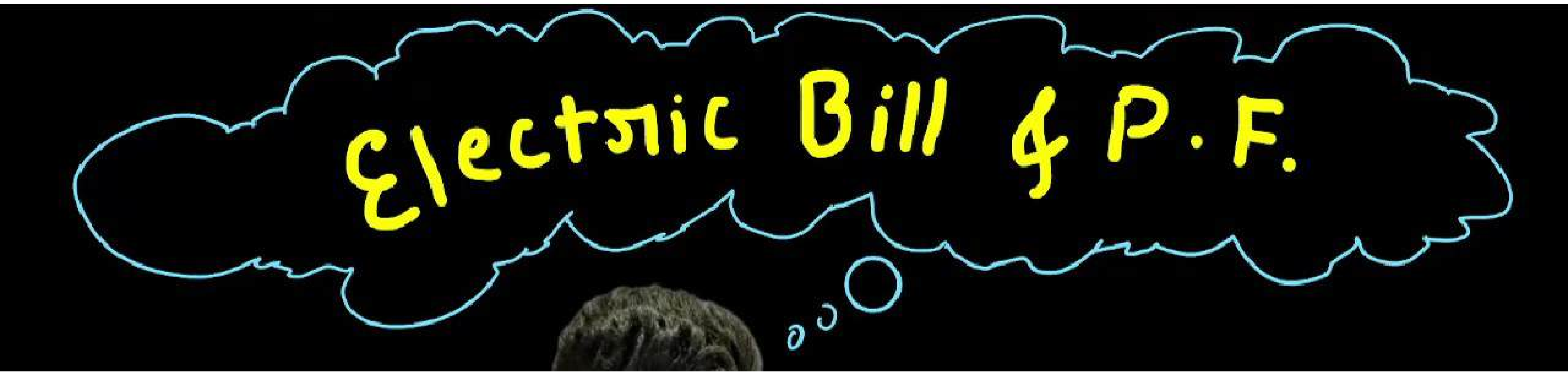
(for constant P and V)

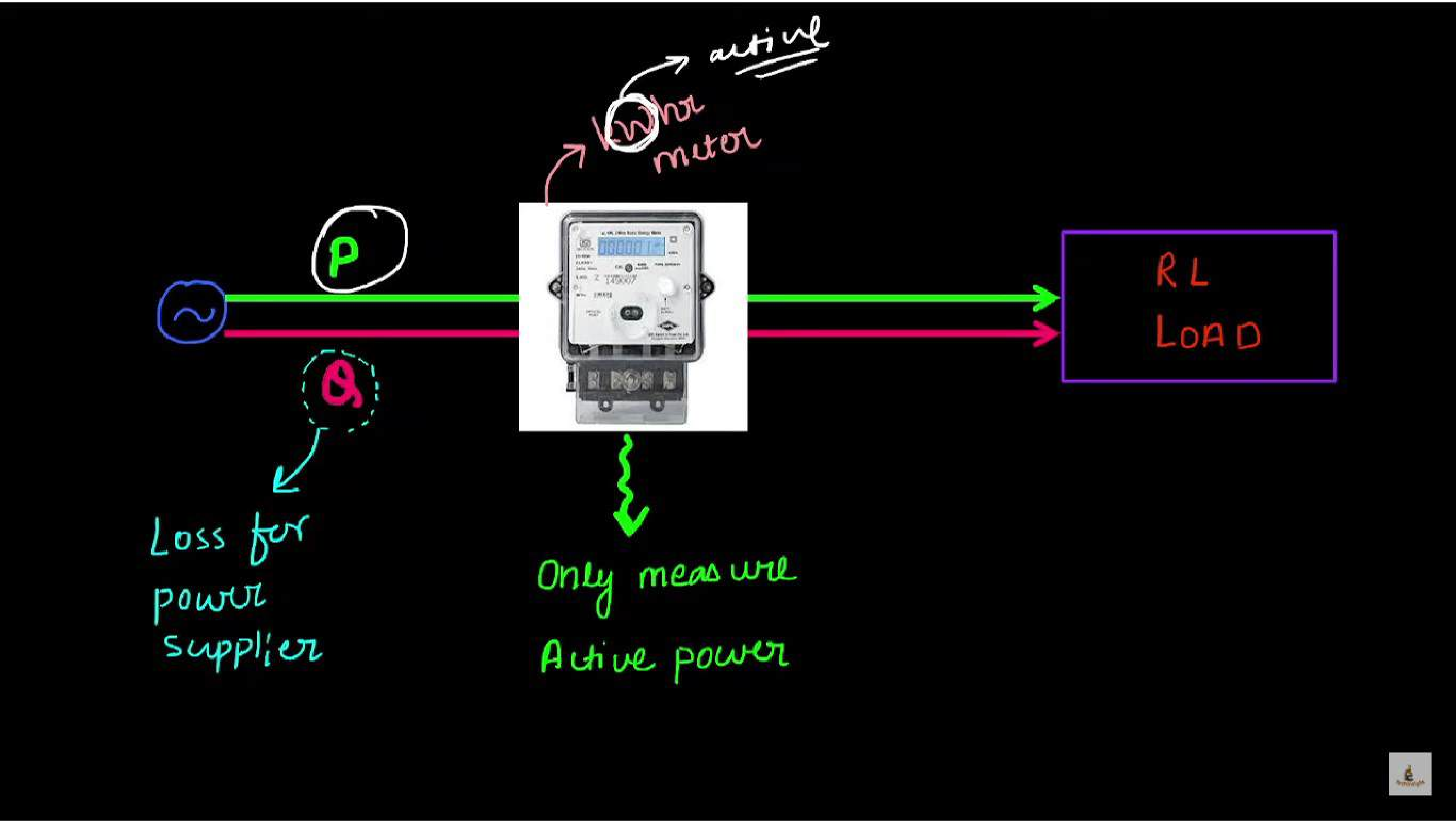
* 



P.F and your electricity Bill

& P.F


Electric Bill & P.F.


active
kWhr
meter
P
Q
Loss for
power
supplier
Only measure
Active power
RL
LOAD

2 Ways to include Reactive power in electricity Bill

kWhr meter

P

Q

Measure only P

+

Surcharge for extra Q [Low P.F]

$\bar{S}$

kVAhr meter

P

Q

Measure P + Q

Don't Need surcharges for poor P.F

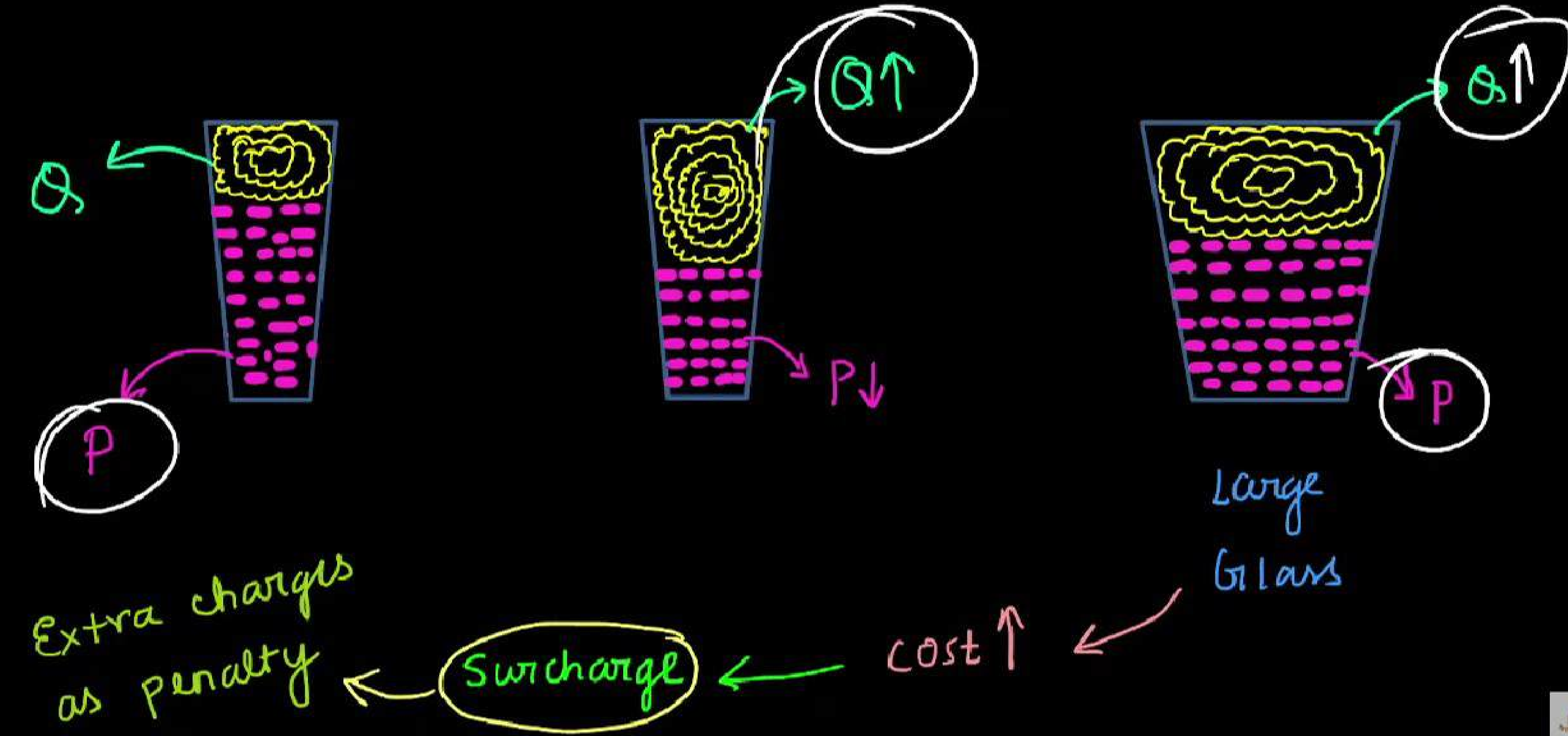
What is Power factor Surcharge

"Extra charges paid by consumer (as penalty) if their load p.f is below the desired (or preset) level"

Set by utilities

POWER FACTOR		SURCHARGE
100%	but 90% or more	None
90%	but 88% or more	2%
88%	but 85% or more	4%
85%	but 80% or more	9%
80%	but 75% or more	16%

Why power system charge "surcharge" for Q

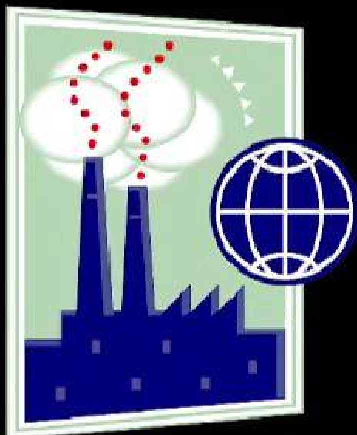


Difference b/w electricity Bill of Domestic and Industrial Consumer

* Very low VAR requirement
* Not a major concern
* kWhr meter

* Very high VAR requirement
* Major concern
* kWhr meter with surcharge or kVAhr meter is used

Why Industries have poor power factor



* Heating furnaces
* Arc Lamps

↓

extremely Low P.F

mainly use → **Induction Motors** (1-ϕ or 3-ϕ)

↓

Low and Lagging power factor

at No-Load

P.F = 0.2 to 0.3

at Full load

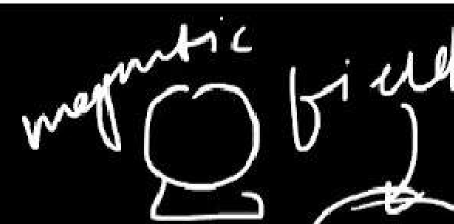
P.F = 0.8 to 0.9

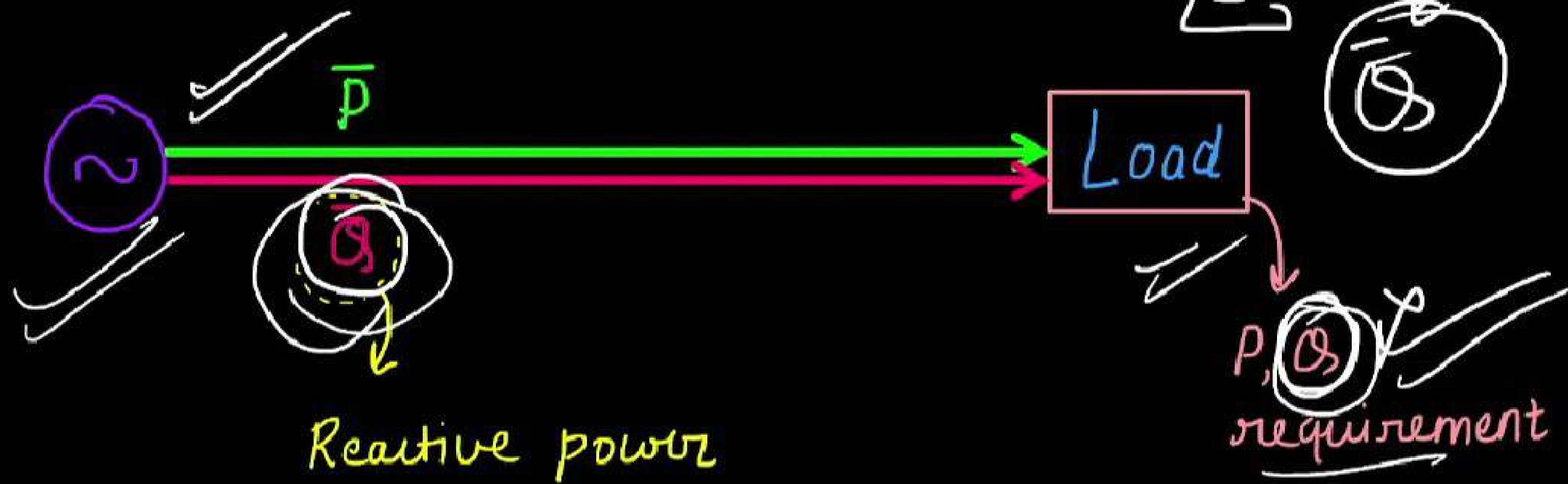

POWER FACTOR CORRECTION

Benefits of P.F. correction

* Electricity Bill ↓
* No surcharge
* Energy utilization η ↑
* Economical Benefit for both consumer and utilities

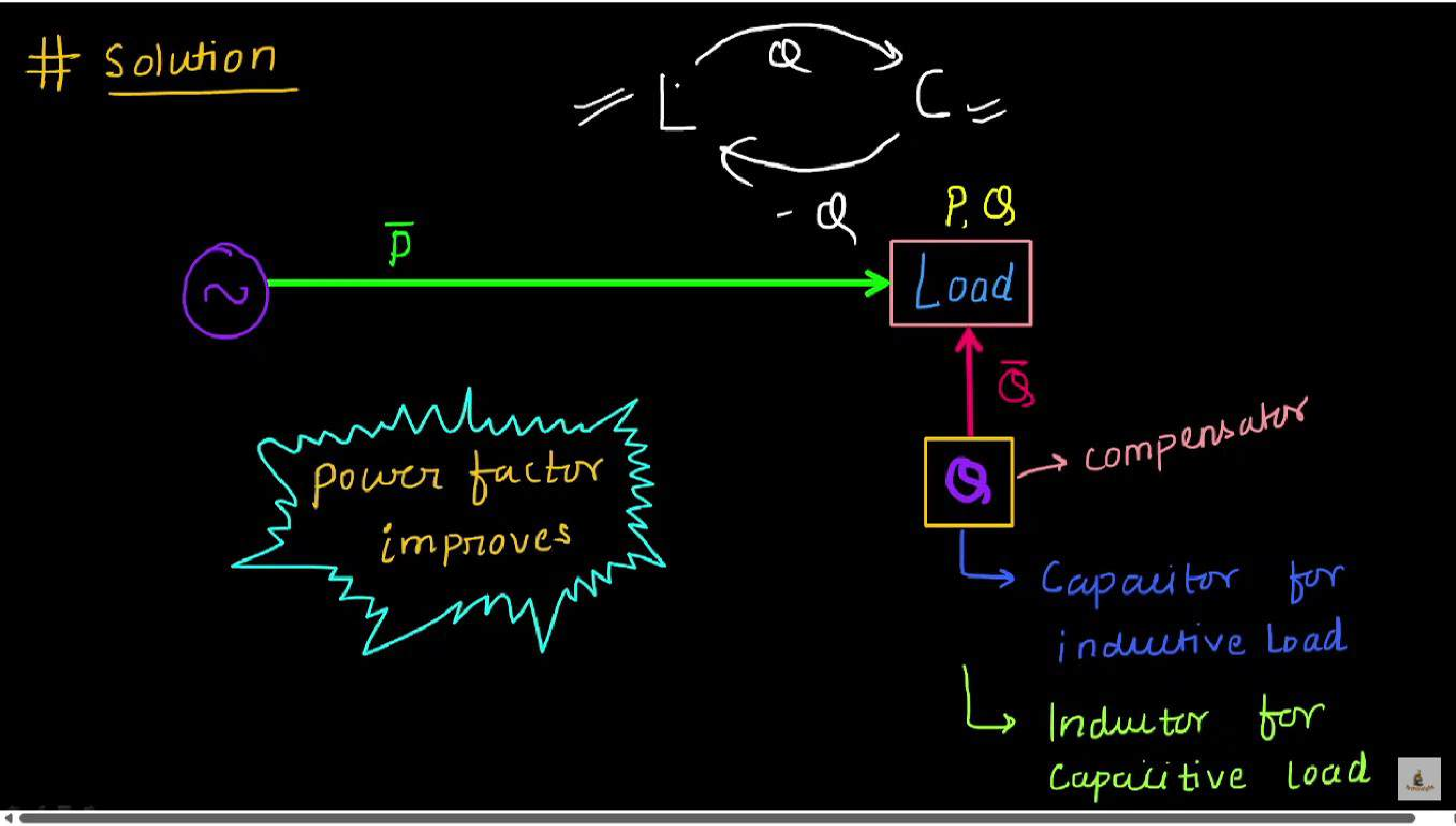
Cause of poor Power factor





Reactive power demanded from utility

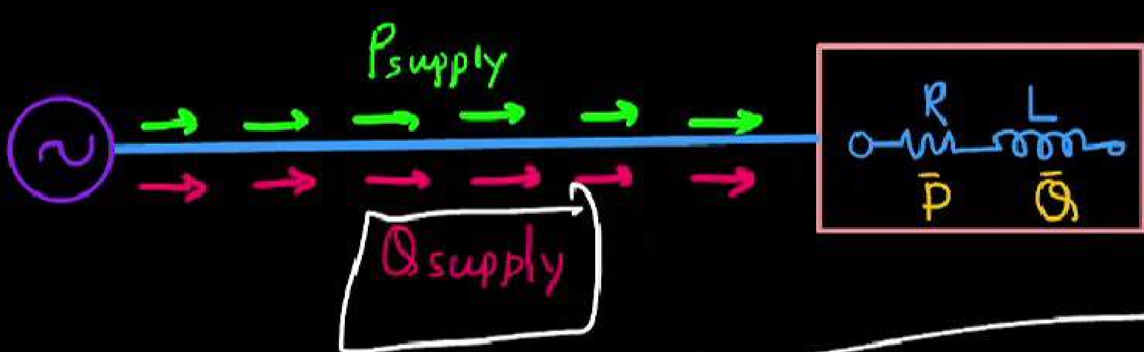
Main cause of P.F decrement



Solution
Q
L
C
-Q
P, Q
$\bar{P}$
Load
$\bar{Q}$
Q
compensator
Capacitor for inductive load
Inductor for capacitive load
power factor improves

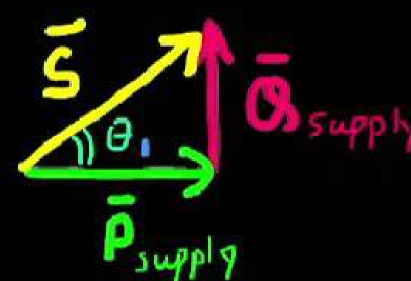
P.F correction using capacitor

Case: 1 Reactive power supplied by utility



$Q_{supply} = Q$

$P_{supply} = P$

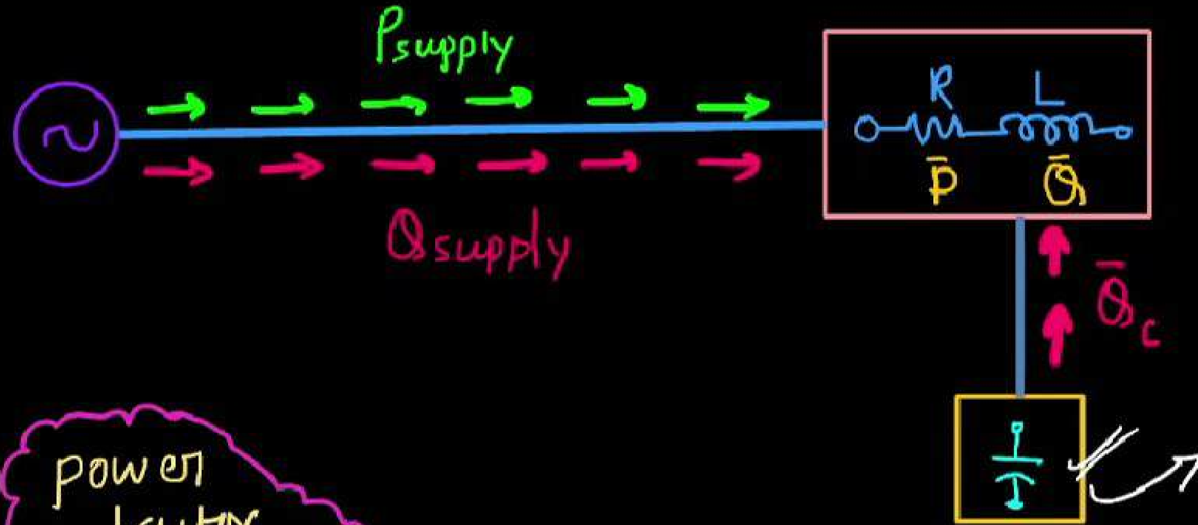


$$Q_{demand} = \boxed{Q = Q_{supply}}$$

poor P.f

$P.F = \cos\theta_1$

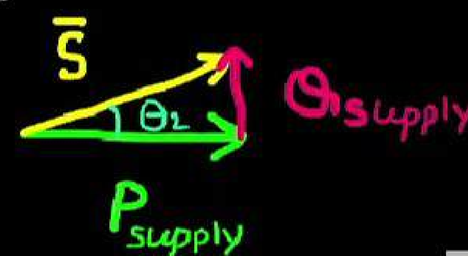
Case 2: Reactive power supplied by both Utility and Capacitor



Reactive power compensator

$$\bar{Q} = \bar{Q}_{supply} + \bar{Q}_c$$

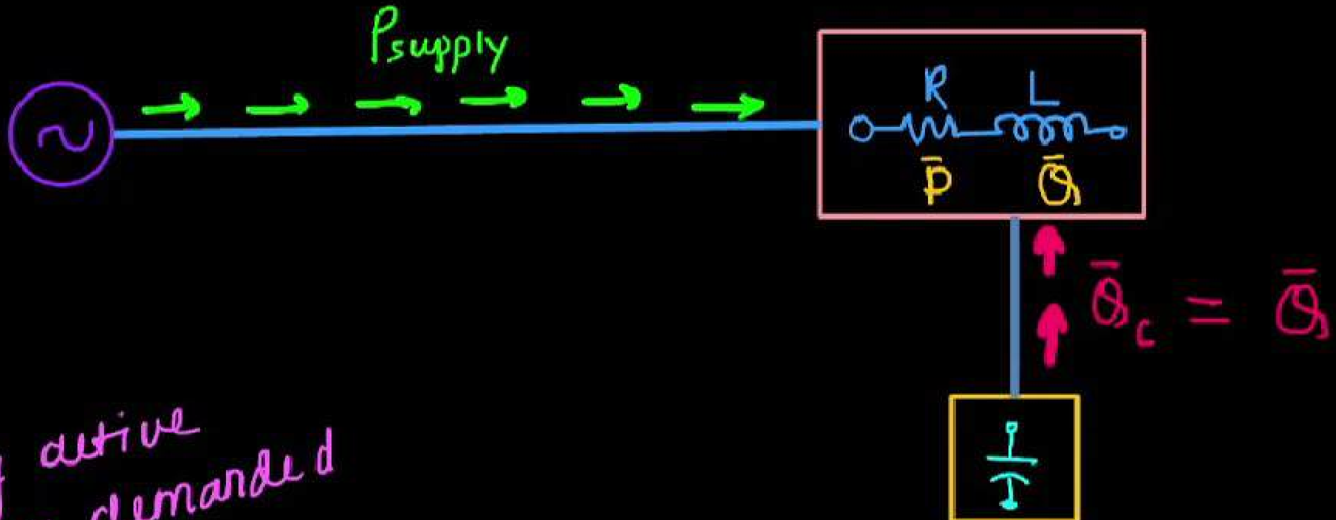
$$\boxed{\bar{Q}_{supply} = \bar{Q} - \bar{Q}_c}$$



power factor Improve

$$P.F = \cos\theta_2 > \cos\theta_1$$

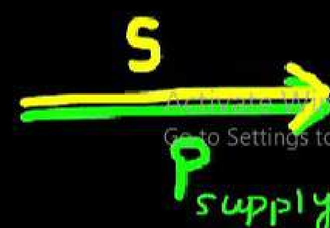
Case-3: Reactive power completely supplied by Capacitor



$$\bar{Q} = \bar{Q}_c$$

$$\bar{Q}_{supply} = 0$$

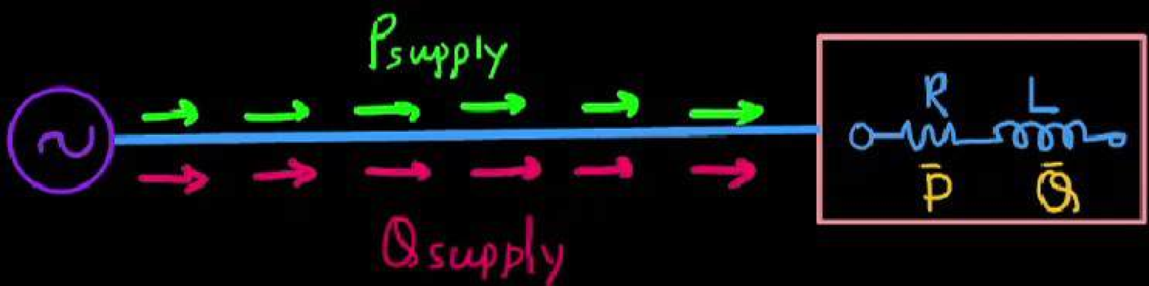
only active power demanded from utility ← Unity power factor ← $\cos\theta_3 = 1$

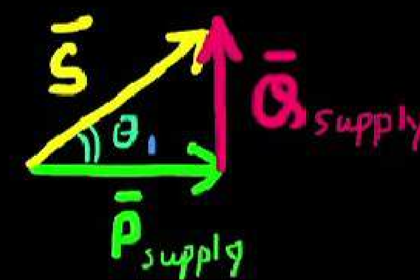



RATING OF CAPACITOR

Rating of capacitor

Case → I: Without capacitor





$P.F = \cos\theta_1$

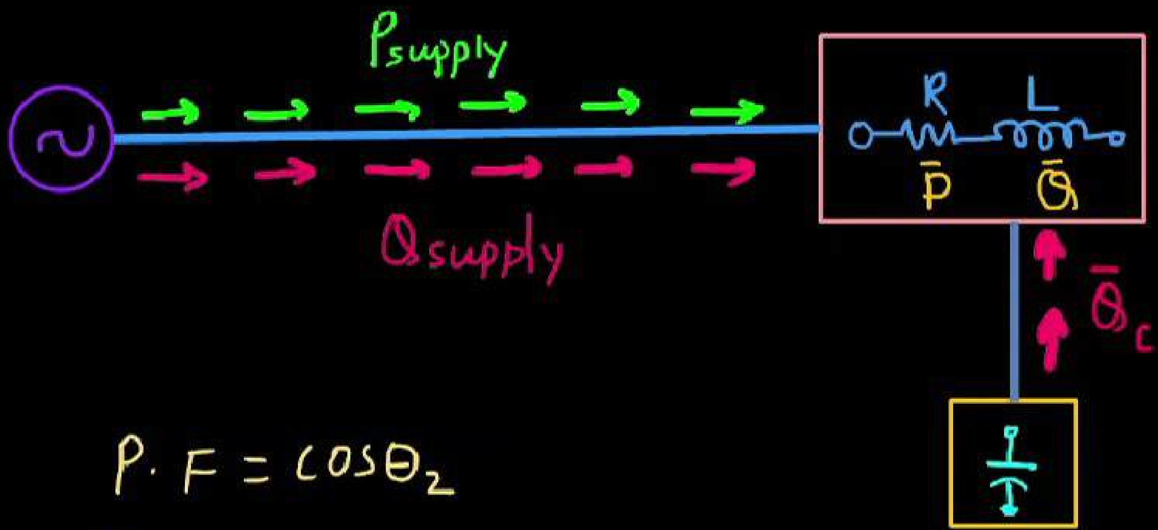
$Q_{supply} = Q$

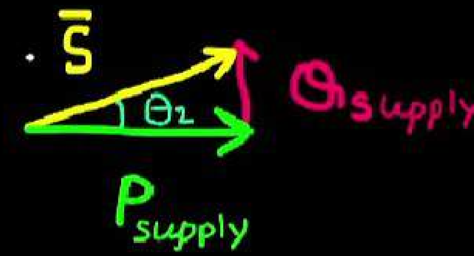
$P_{supply} = P$

$$\tan\theta_1 = \frac{Q_{supply}}{P_{supply}} = \frac{Q}{P}$$

$$\therefore \boxed{Q = P\tan\theta_1}$$

Case-2: With capacitor





$$P.F = \cos\theta_2$$

$$\bar{Q}_{supply} = \bar{Q} - \bar{Q}_c$$

$$\bar{P}_{supply} = \bar{P}$$

$$Q_{supply} = P_{supply} \cdot \tan\theta_2$$

$$\boxed{Q_{supply} = P \tan\theta_2}$$

$$Q_c = Q - Q_{supply}$$

$$= P \,Tan\theta_1 - P \,Tan\theta_2$$

$$\boxed{Q_c = P(Tan\theta_1 - Tan\theta_2)}$$

Reactive Power (VARs) Supplied by capacitor

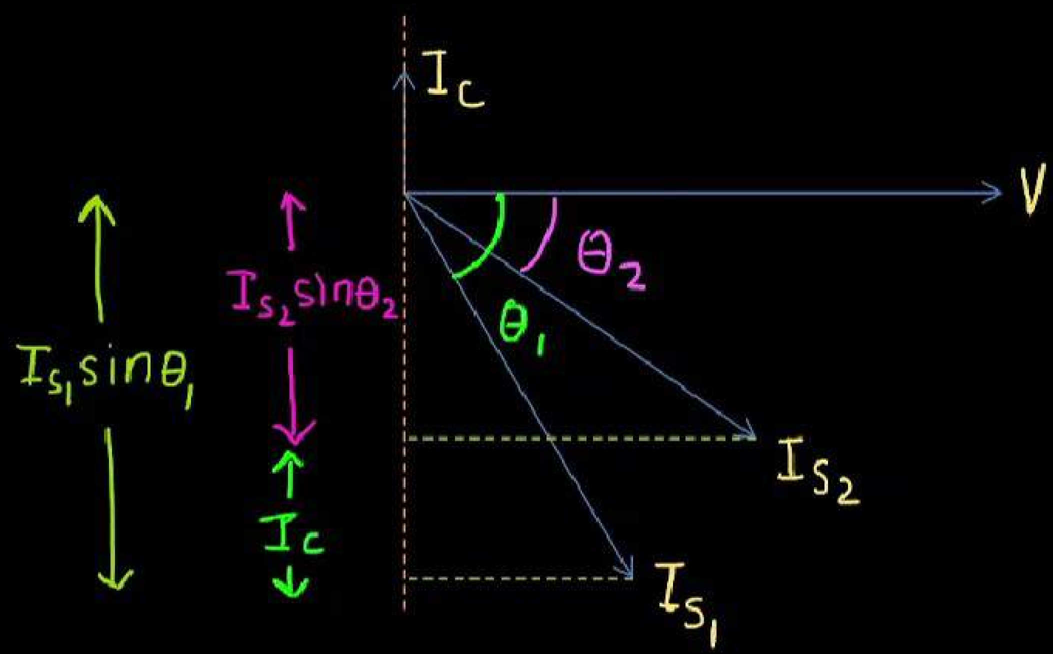
$$Q_c = \frac{V}{X_c}$$

$$Q_c = V . \omega C$$

$$\boxed{C = \frac{Q_c}{V\omega}}$$

Please Note: Here Q = V*V / X [V square divide by X capacitance] and C= Q/V*V*w [reactive power divided by V square and angular frequency]

Through phasor diagram



$$I_{s_1}\sin\theta_1 = I_C + I_{s_2}\sin\theta_2$$

$$\boxed{I_C = I_{s_1}\sin\theta_1 - I_{s_2}\sin\theta_2}$$

Capacitance require to improve P.F from $\cos\theta_1 \rightarrow \cos\theta_2$ is

$$C = \frac{I_c}{\omega V}, \quad \boxed{X_C = \frac{V}{I_c}}$$


P.F. CORRECTION DEVICE

When utilities need P.F correction devices

POWER FACTOR		SURCHARGE
100%	but 90% or more	None
90%	but 88% or more	2%
88%	but 85% or more	4%
85%	but 80% or more	9%
80%	but 75% or more	16%

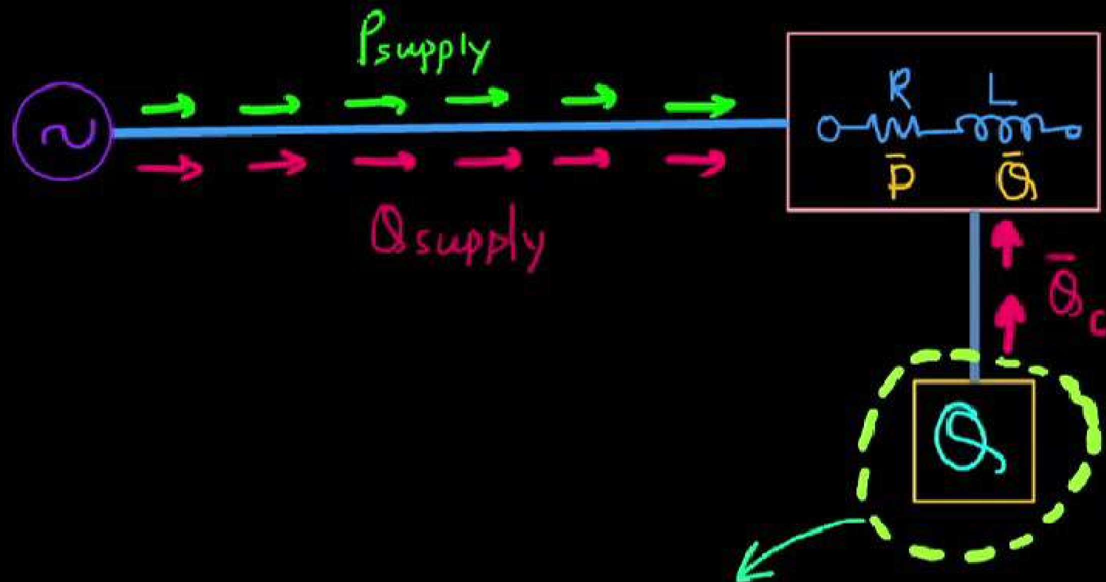
→ Domestic load

→ Surcharge will take care of extra Q

Below 0.8 p.f

Utilities needs to take essential steps to improve power factor

Essential steps



Install
power factor correction
devices

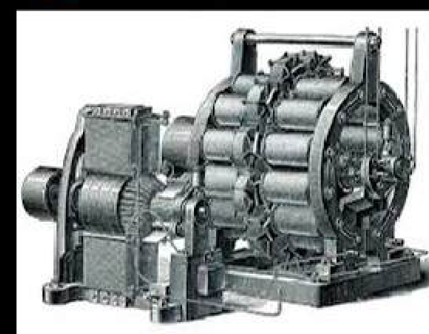
Essential steps

Power Factor correction devices

Static VAR compensator

Static Capacitors

Synchronous condenser



Phase Advancer

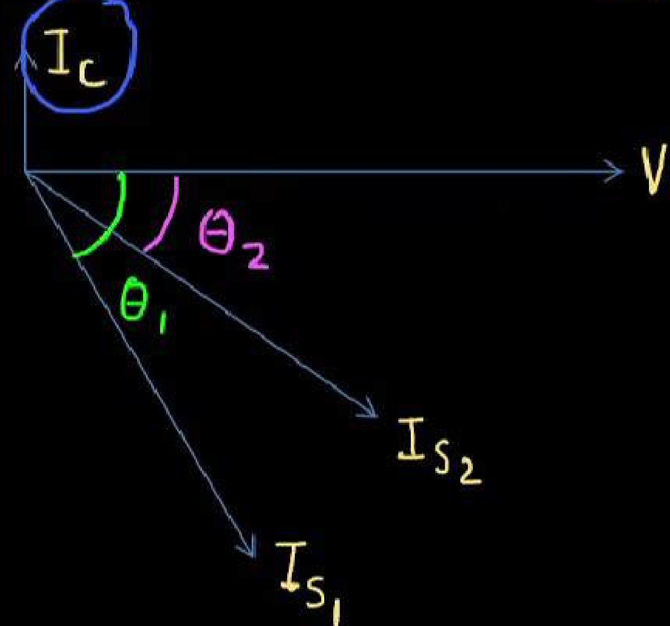
Static Capacitor

Unchangable Capacitor

or

fixed value capacitor

Leading current



$\theta \downarrow$

$\uparrow$ Power factor

" Used in factories "

* Advantages

* Low losses
* Little maintainance, as they don't have any rotating parts.
* Easily installed as they have light weight
* Works good under any atmospheric conditions

* Disadvantages

* Short service

* Easily damaged if voltage exceed rated value

* Difficult to repair

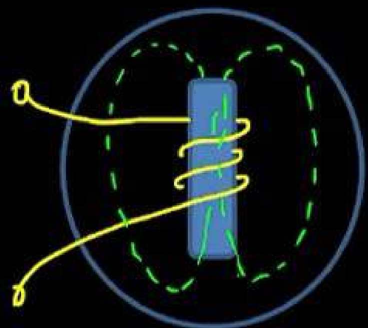
* Fixed capacitance

Synchronous Condenser

+

DC

−



"Excitation"

3 types

Rated = Actual

Rated Excitation

Rated > Actual

Under Excitation

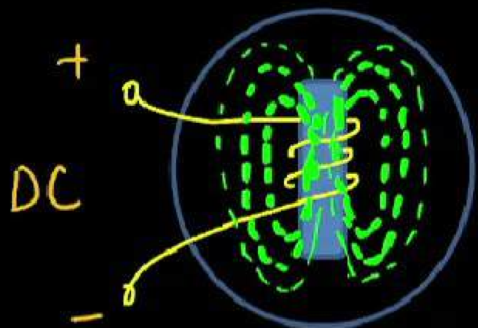
Rated < Actual

Over Excitation

Motor has more reactive power than required

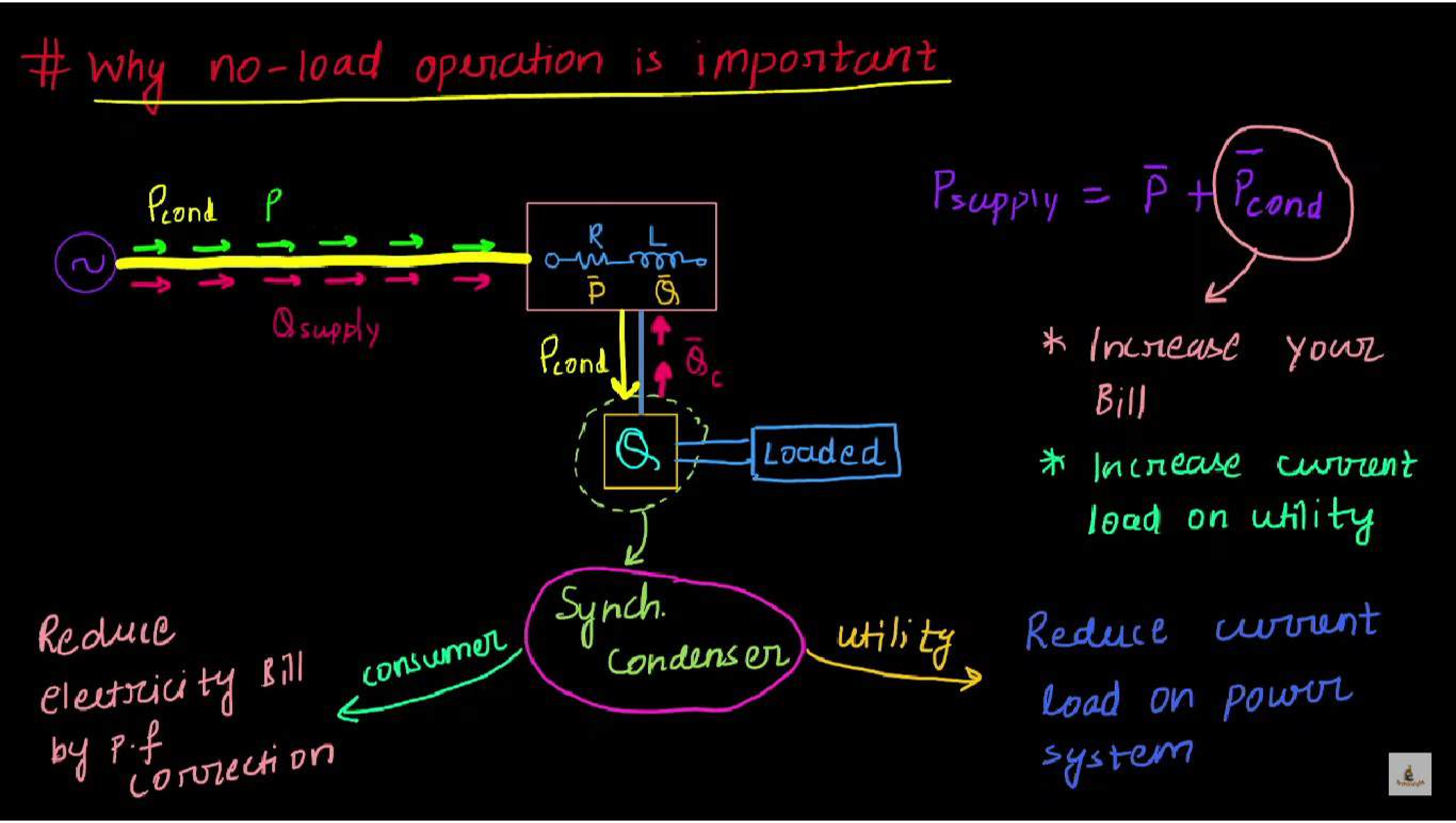
supply extra Q back to utility and act as condenser.

Essential conditions



Over-excited Synchronous motors + No load operation = Synchronous Condenser

Why no-load operation?



Why no-load operation is important
Pcond
P
Qsupply
R
L
P̄
Q̄
Pcond
Q̄c
Q
Loaded
Psupply = P̄ + P̄cond
* Increase your Bill
* Increase current load on utility
Synch. condenser
consumer
utility
Reduce electricity Bill by p.f correction
Reduce current load on power system

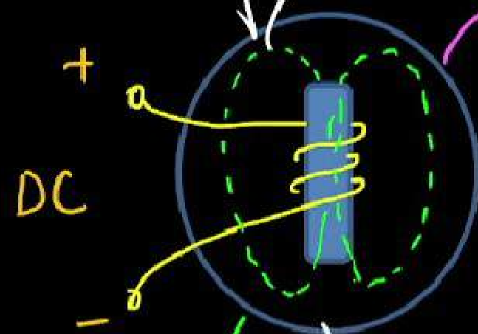
Advantages

Source

under excita

$\boxed{Q_{rate} > Q}$

Capacitor



Easy to vary capacitance

By controlling the levels of d.c excitation

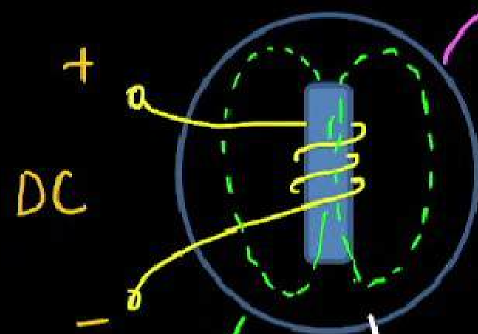
Can supply or absorb Q depending on situation

sy:

$Q > Q_{rated}$

source

Advantages



Easy to vary capacitance

By controlling the levels of d.c excitation

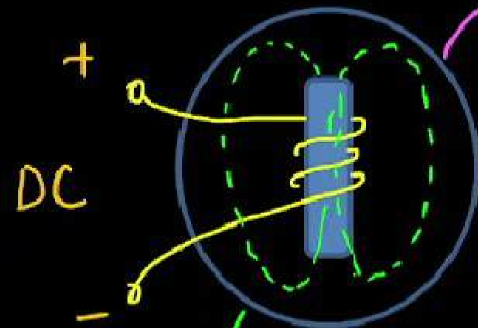
Can supply or absorb Q depending on situation

over ex →

under exc →

rated exci →

Advantages



Easy to vary capacitance

By controlling the levels of d.c excitation

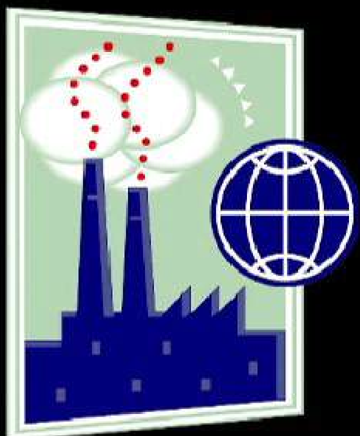
Can supply or absorb Q depending on situation

Disadvantages

* Losses in syn. condenser > losses in static capacitor
* Maintainance cost ↑
* Noise ↑
* Cost ↑ → Needs extra starter to start synch. condenser


PHASE Advancers

Why Industries have poor power factor



mainly use → Induction Motors

(1-ϕ or 3-ϕ)

↓

Low and Lagging power factor

at No-Load

P.F = 0.2 to 0.3

Bad P.F

at Full load

P.F = 0.8 to 0.9

Phase advancers

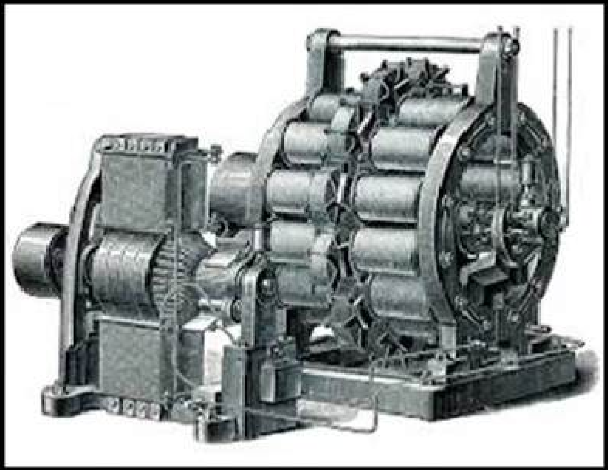
↓

A.C. Exciter

↓

Used to improve the power factor of Induction Motor

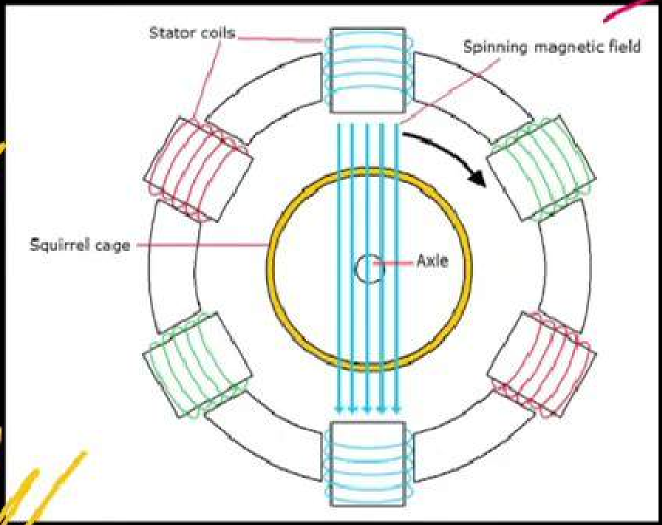
"Only Induction Motor"



Why IM have poor power factor

Short ckt

Huge current



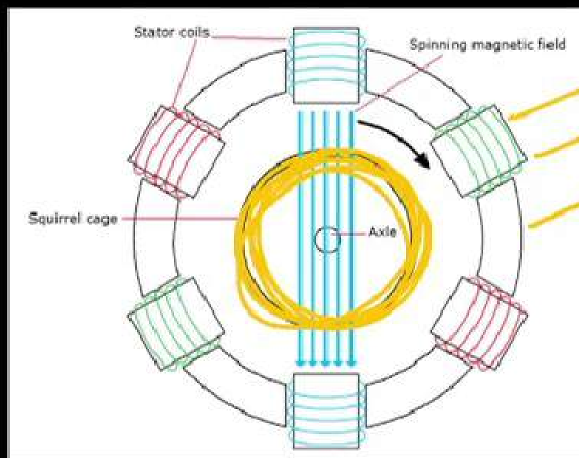
Stator try to energize short circuited rotor via Induction

0.2 - 0.3 p.f.

Stator draws huge lagging reactive current from utility

Power factor degrades

How phase advancer solves the problem



I lagging.

IM — poor p.f

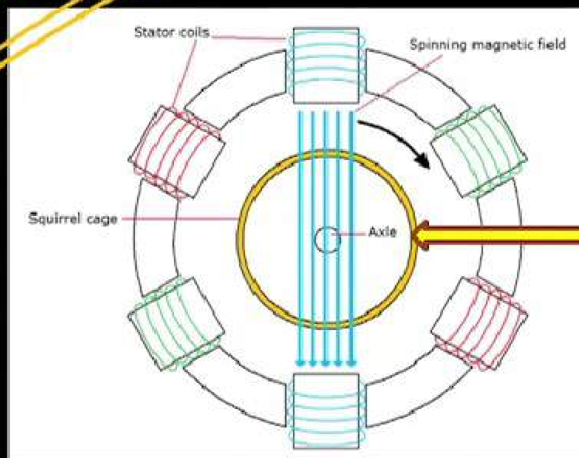
Huge lagging current

To energize rotor.

Suppy

How phase advancer solves the problem

sync ind. machine



p.f

cos 90°

pure inductive

Zero lagging Current

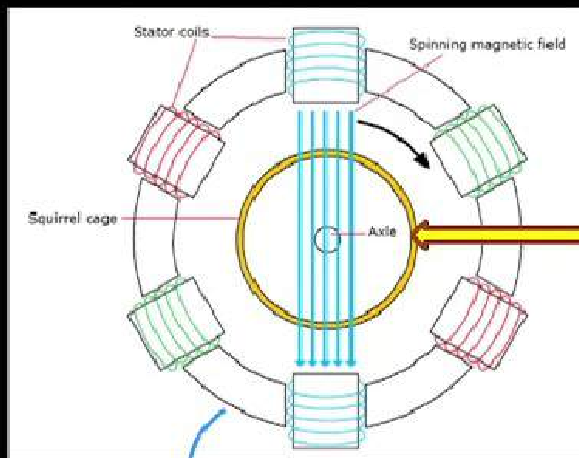
Phase Advancer

V

I

cos 90° lagging

How phase advancer solves the problem



Zero lagging current

Phase Advancer

Excites the rotor of IM

Stator don't demand lagging current from utility → p.f improves

How to connect phase advancer with IM

Split

commu

Slip ring

complete ring

AC gen

AC motor

DC

commutator

DC

Slip - Ring

Split

AC

complete ring

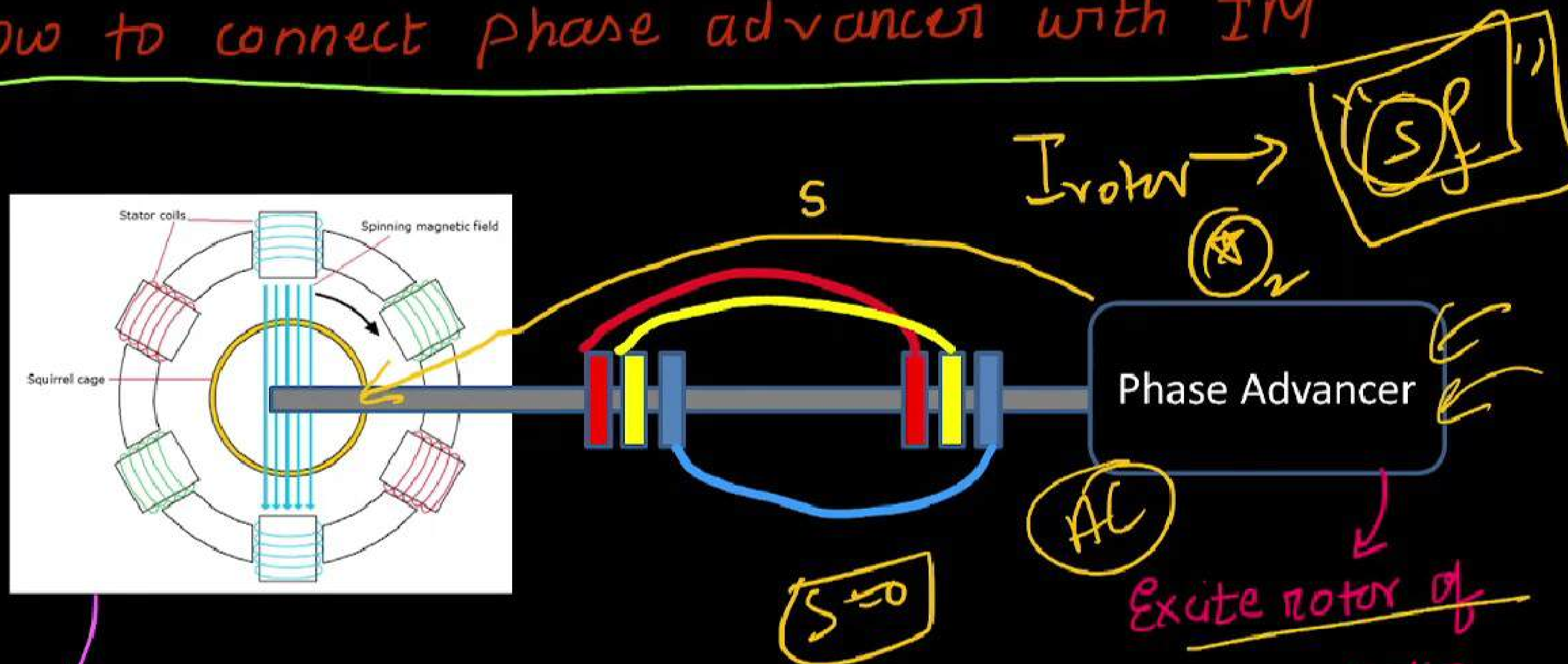
AC

Stator & rotor

polarity

AC

How to connect phase advancer with IM



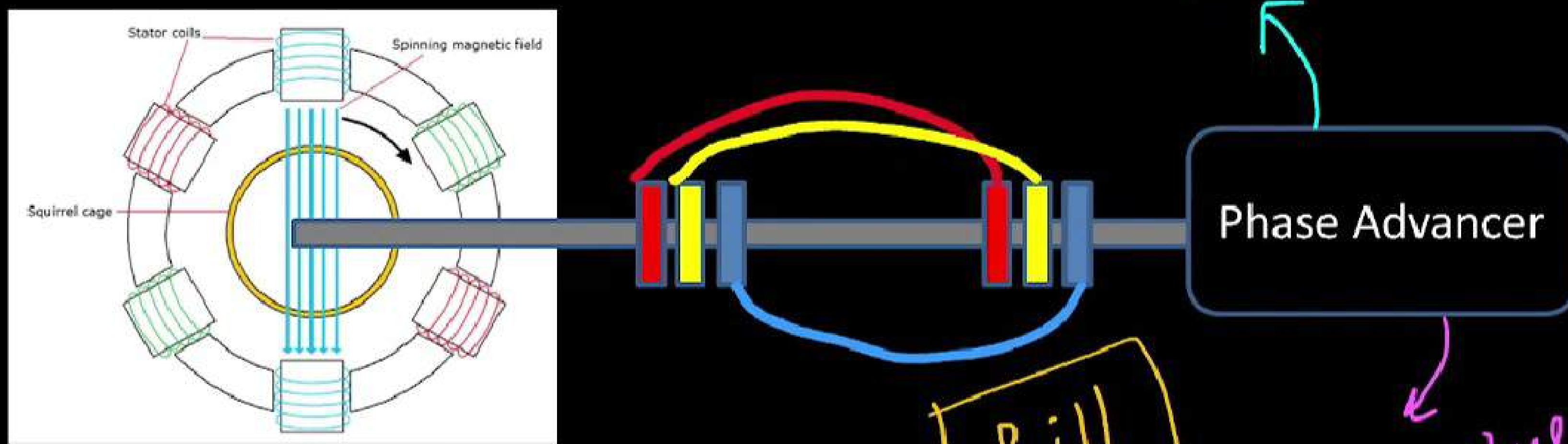
Excite rotor of IM at slip frequency

2 Important things to run IM

1. Rotor excitation
2. slip

Disadvantage

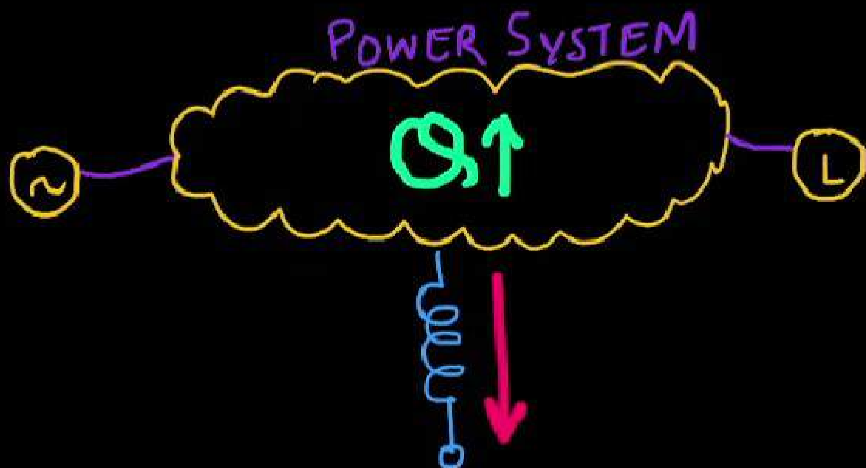
Uneconomical for IM below 200 HP.

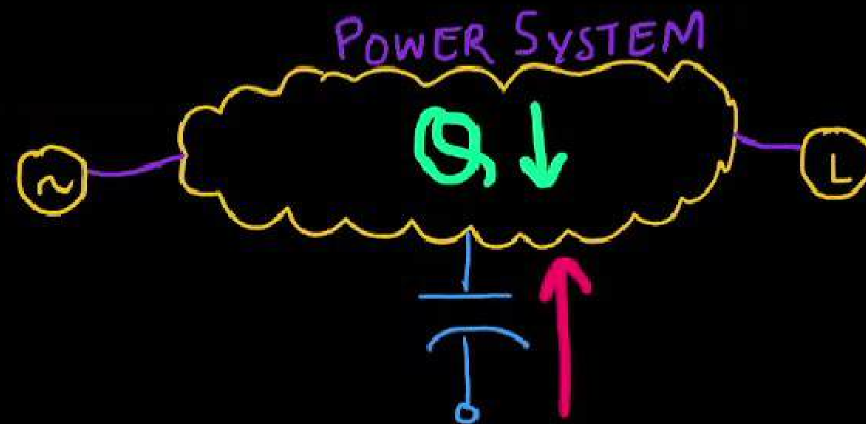


Bill

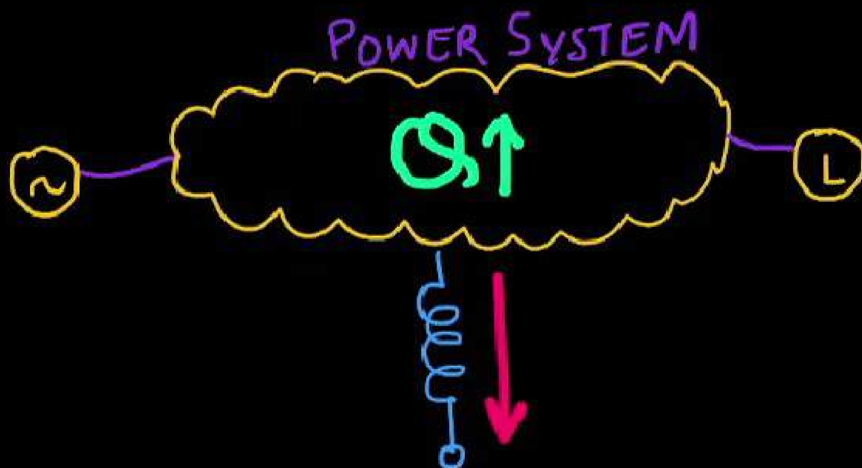
only useful for IM

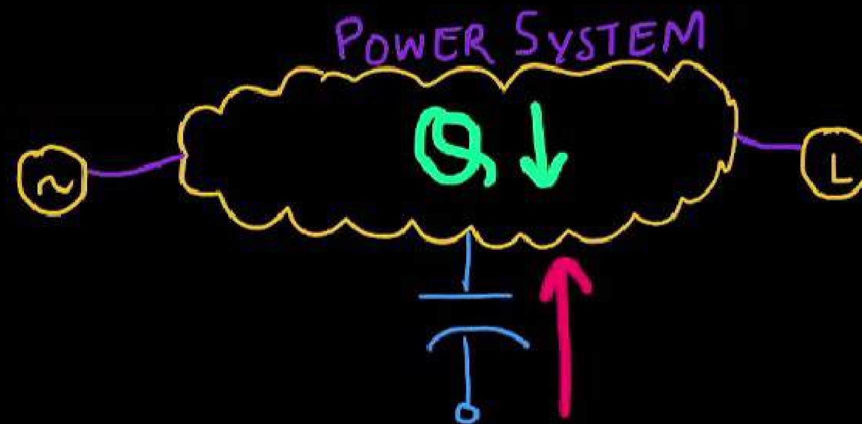
100. Phase avcer loss < cost of "poor p.f"





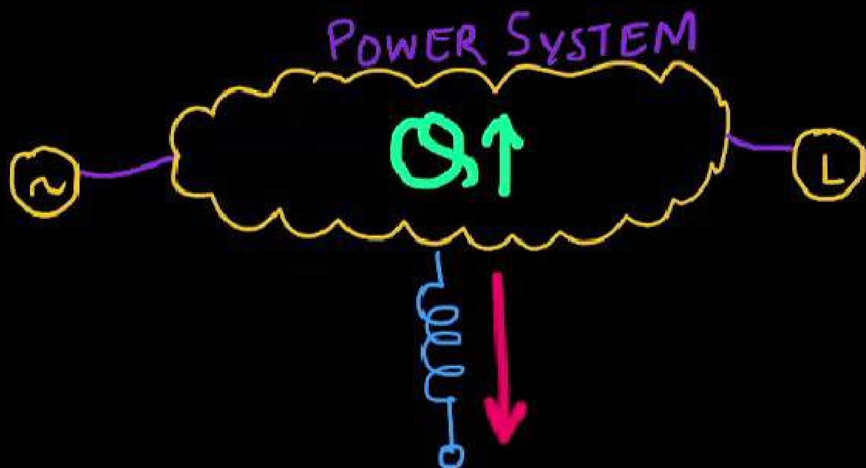
Connect
Disconnect } Switching Transients

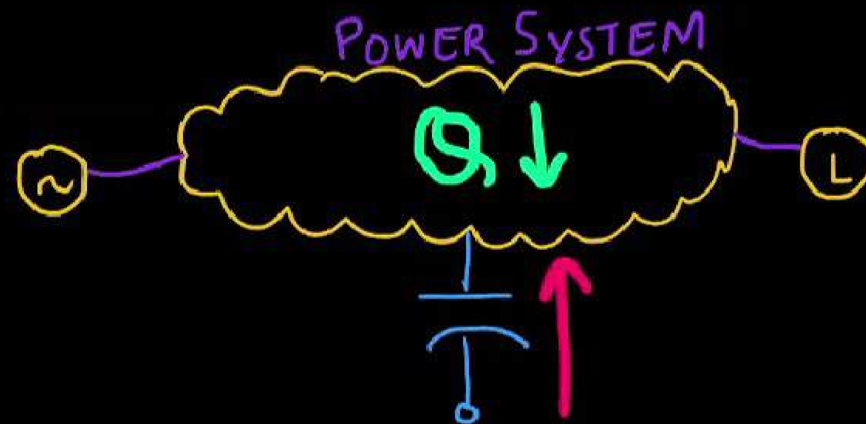




Connect
Disconnect } Switching Transients

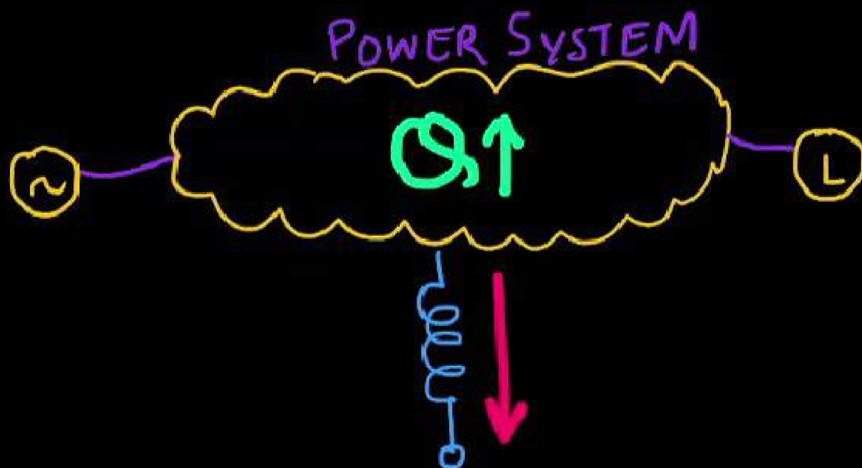
$Q > Q_{rated}$

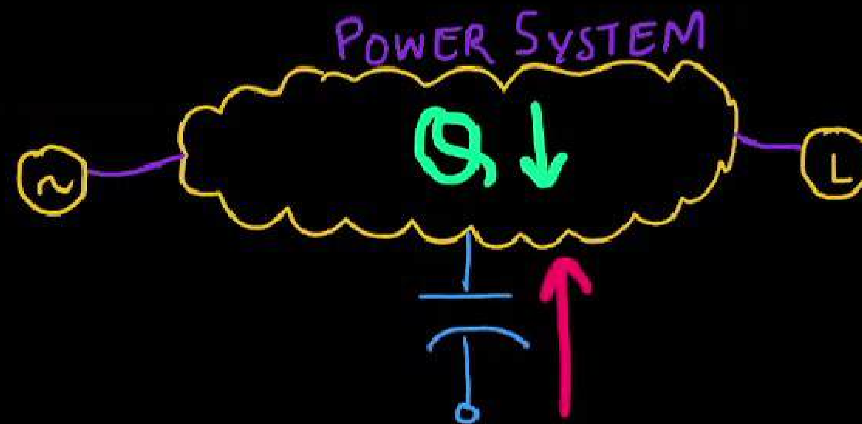




Connect
Disconnect
} Switching Transients

$Q < Q_{rated}$





Connect
Disconnect
Switching Transients

Static VAR compensator or

$Q < Q_{rated}$


Static VAR Compensator

static VAR compensator

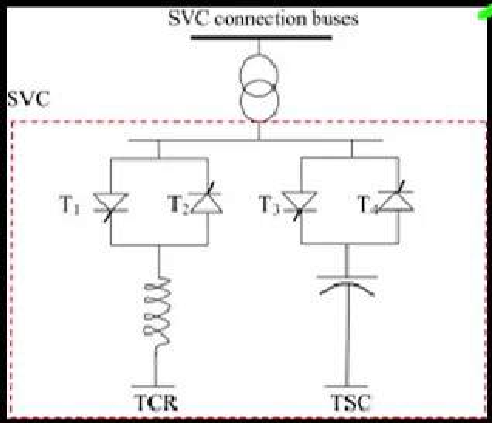
SVC

No rotating part

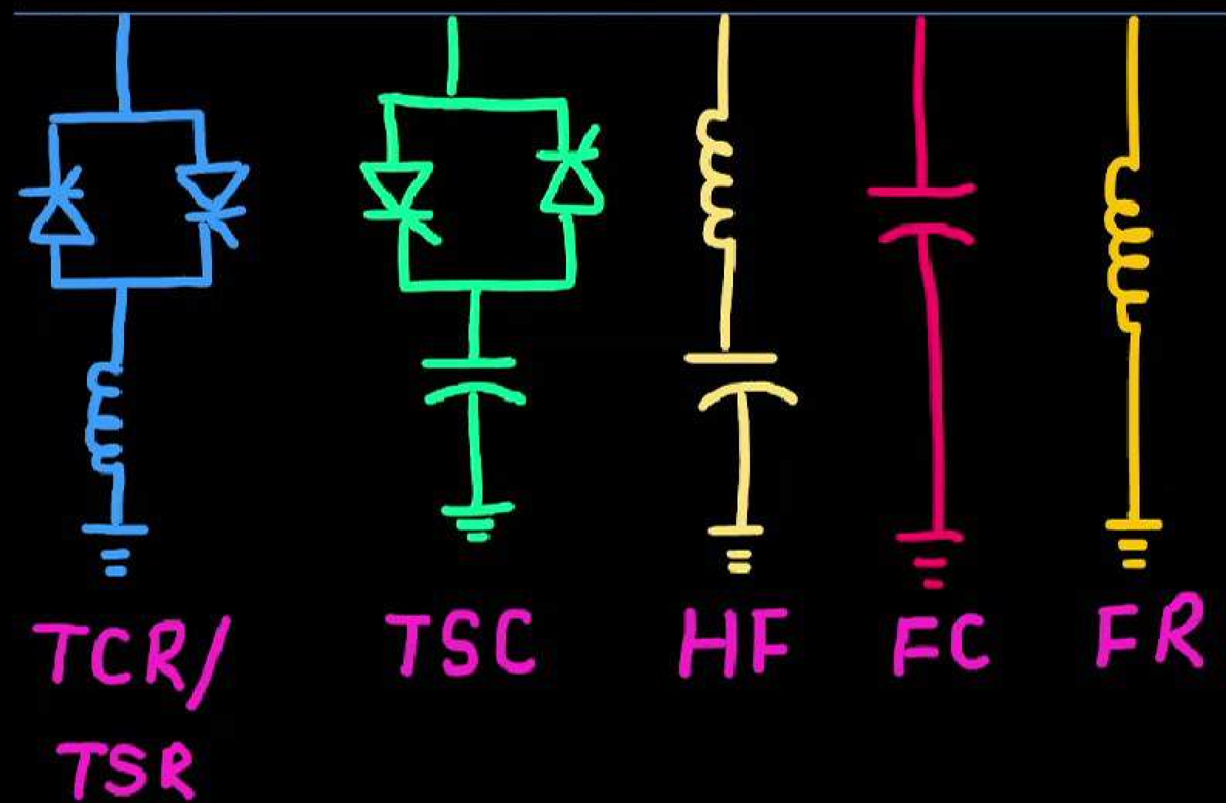
flexible compensation

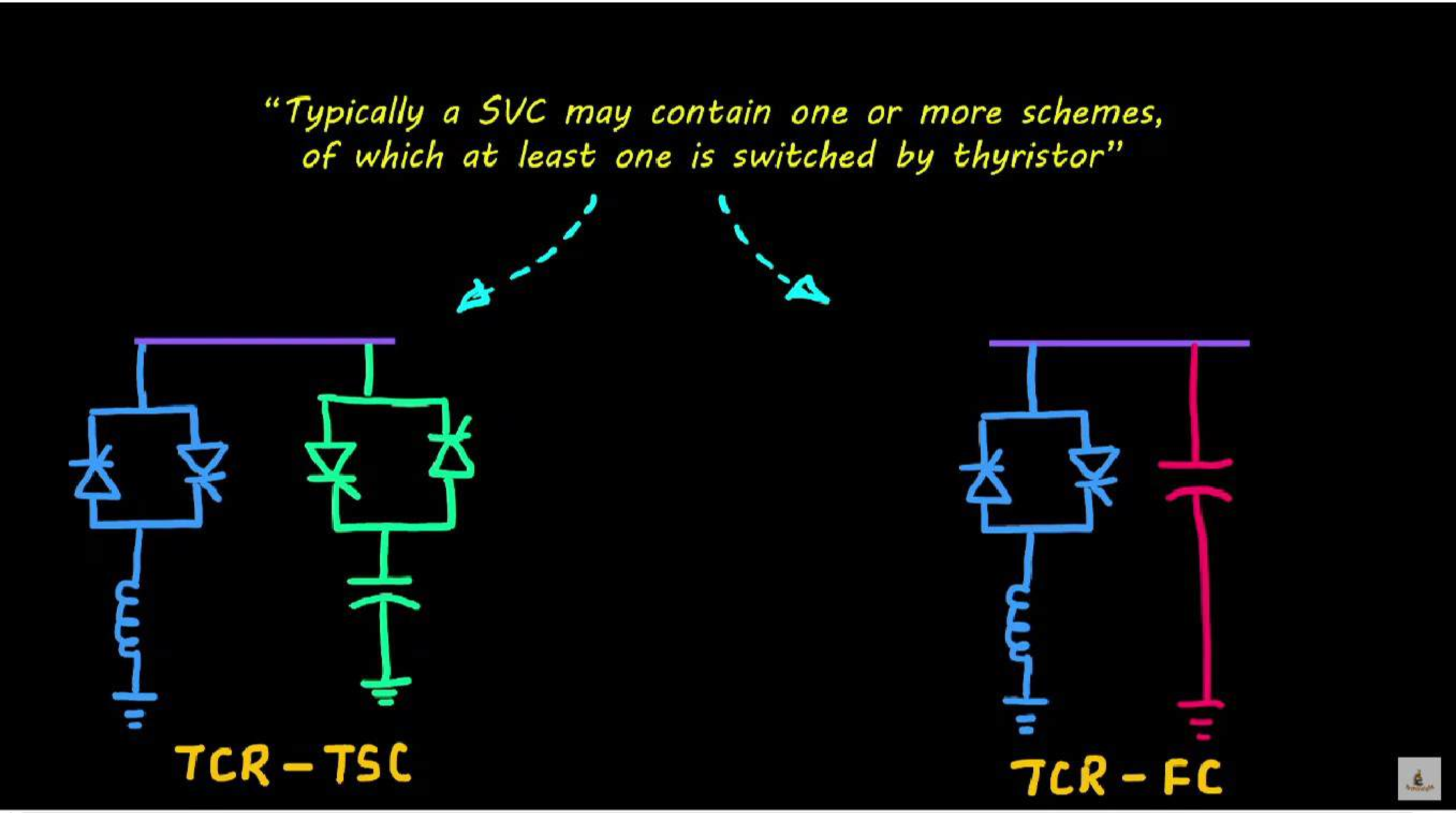
Designed to bring the system closer to unity power factor

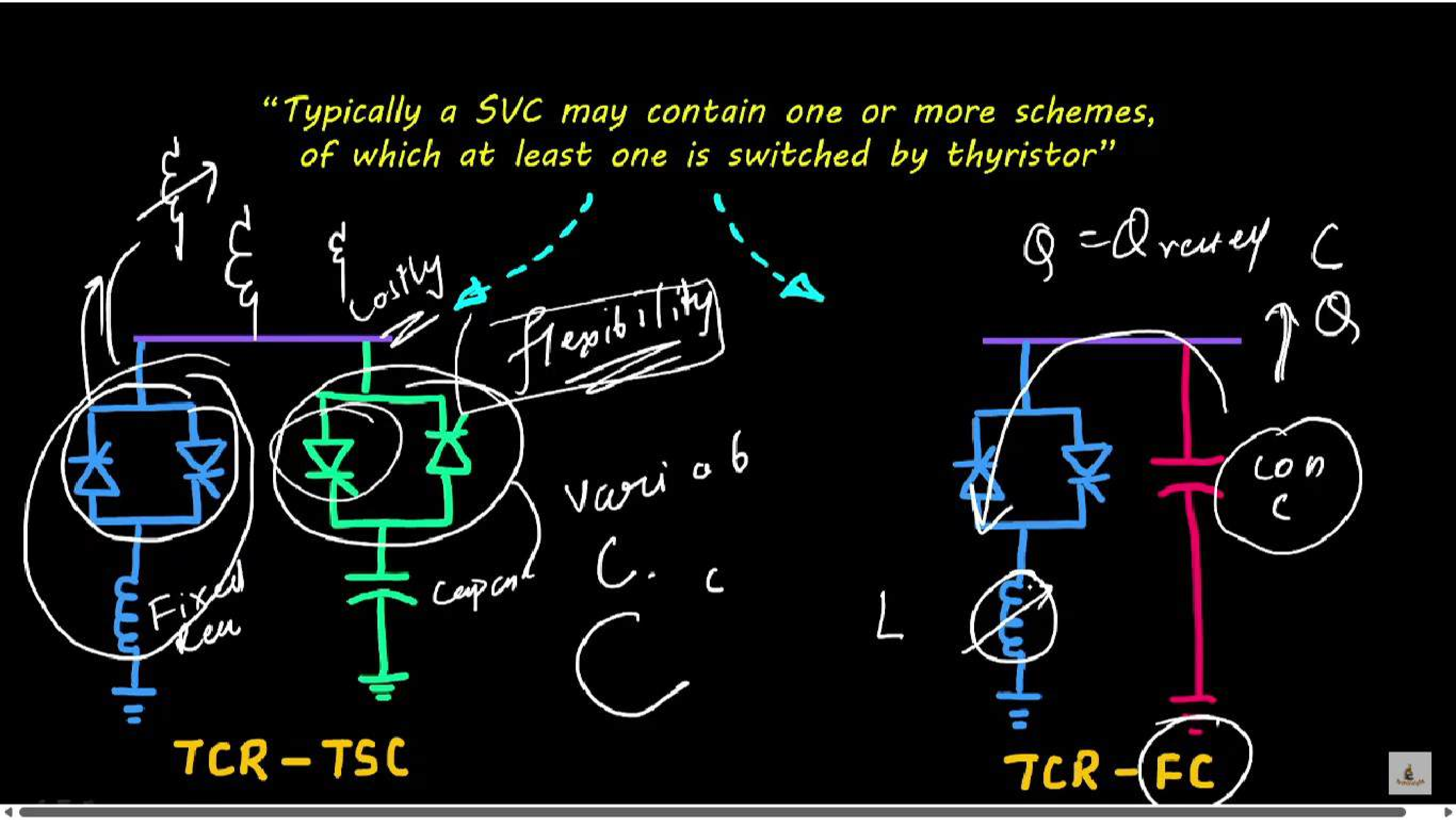
"It is a flexible VAR compensation device that can supply or absorb reactive power by using thyristor controlled capacitor and reactor"

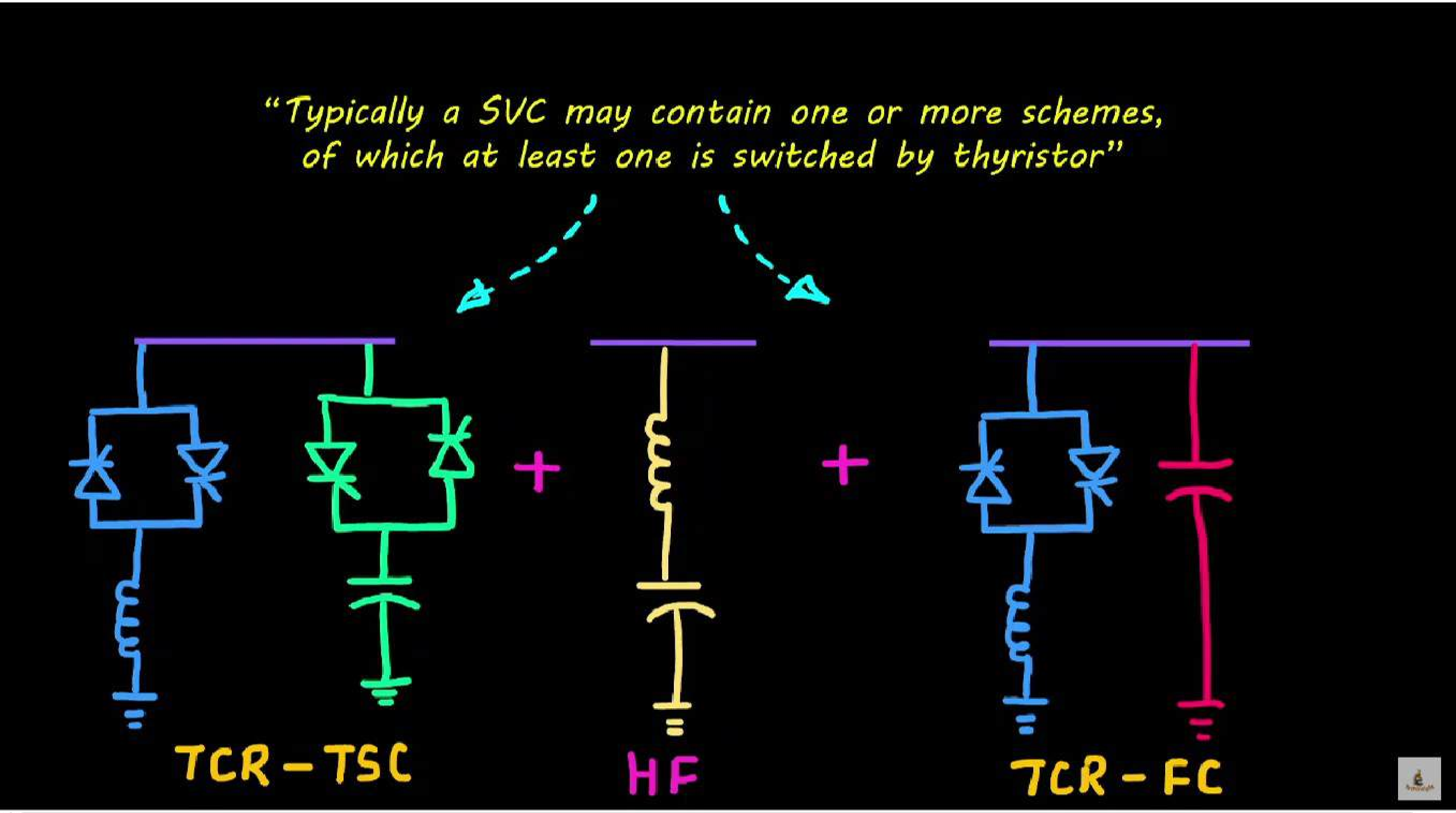


Schemes of SVC

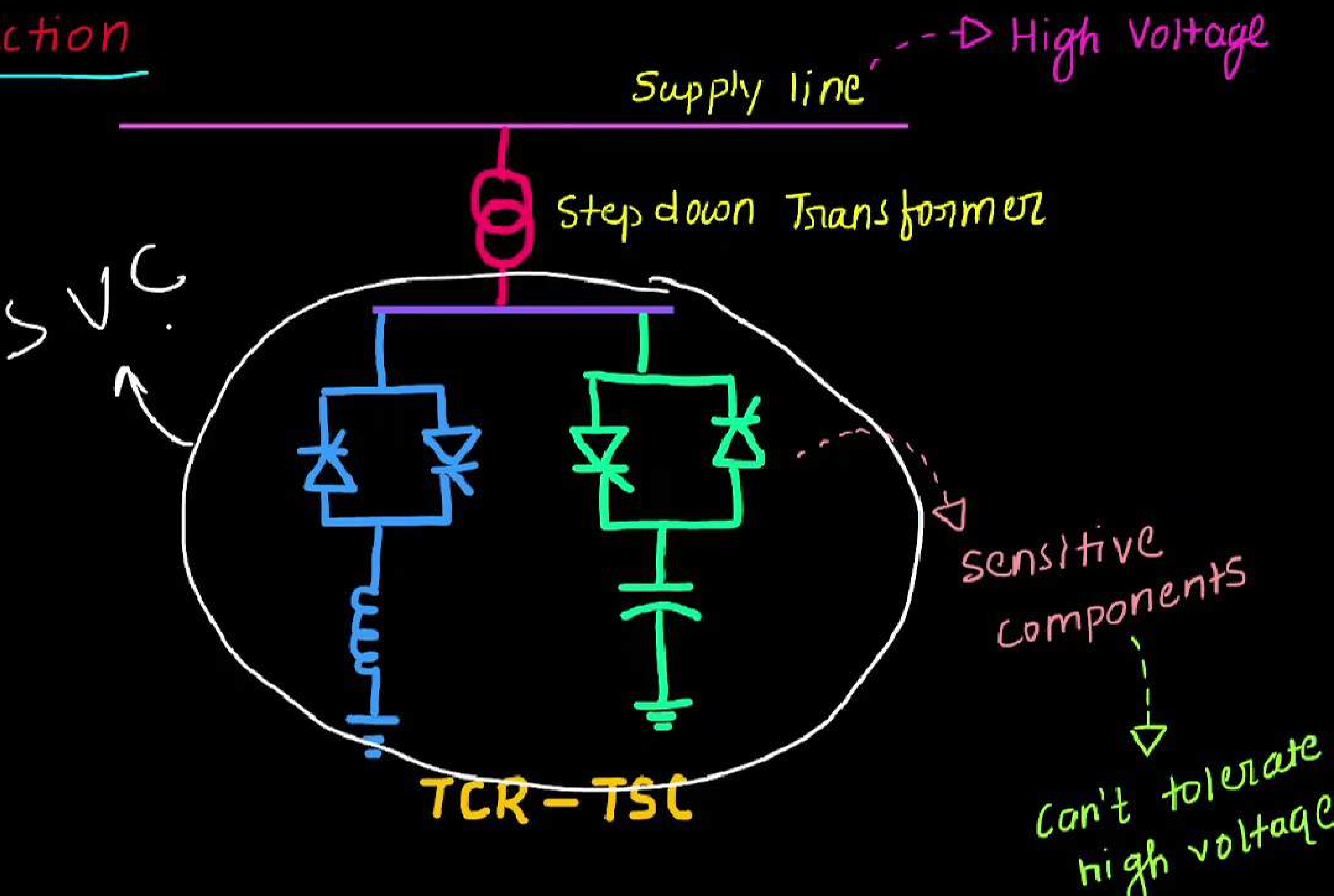



"Typically a SVC may contain one or more schemes,
of which at least one is switched by thyristor"
TCR – TSC
TCR – FC


"Typically a SVC may contain one or more schemes,
of which at least one is switched by thyristor"
Costly
Flexibility
Fixed
L
TCR – TSC
TCR – FC

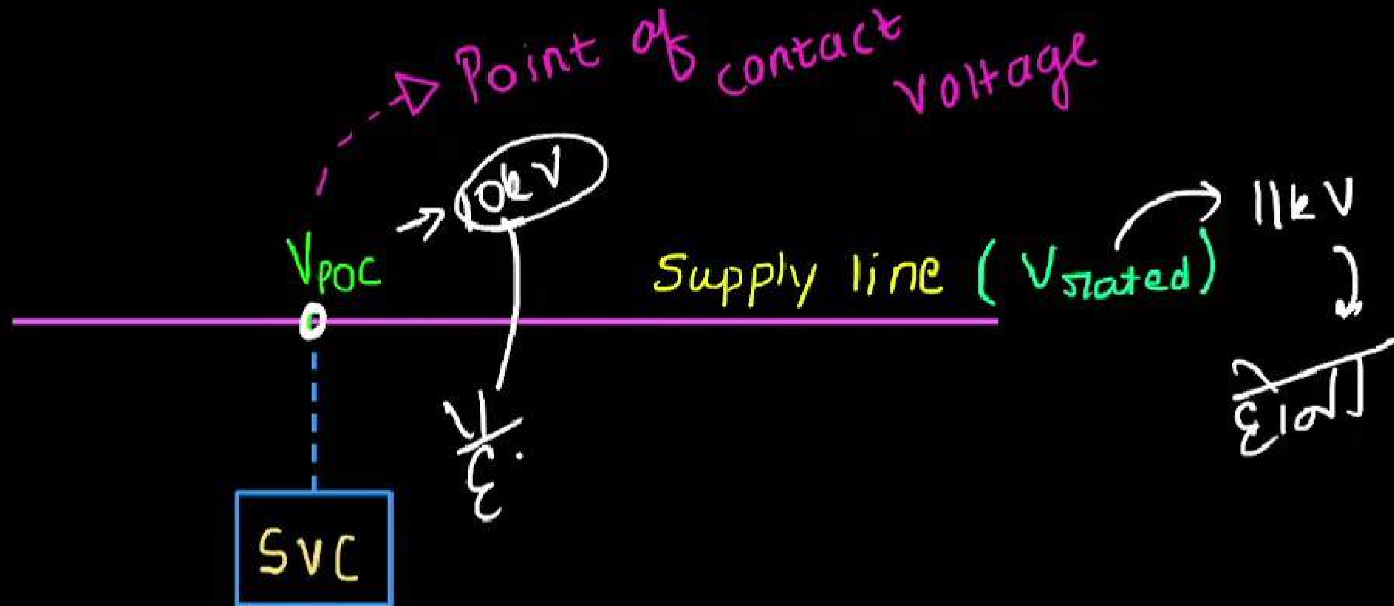

"Typically a SVC may contain one or more schemes, of which at least one is switched by thyristor"
+
+
TCR – TSC
HF
TCR – FC

Connection

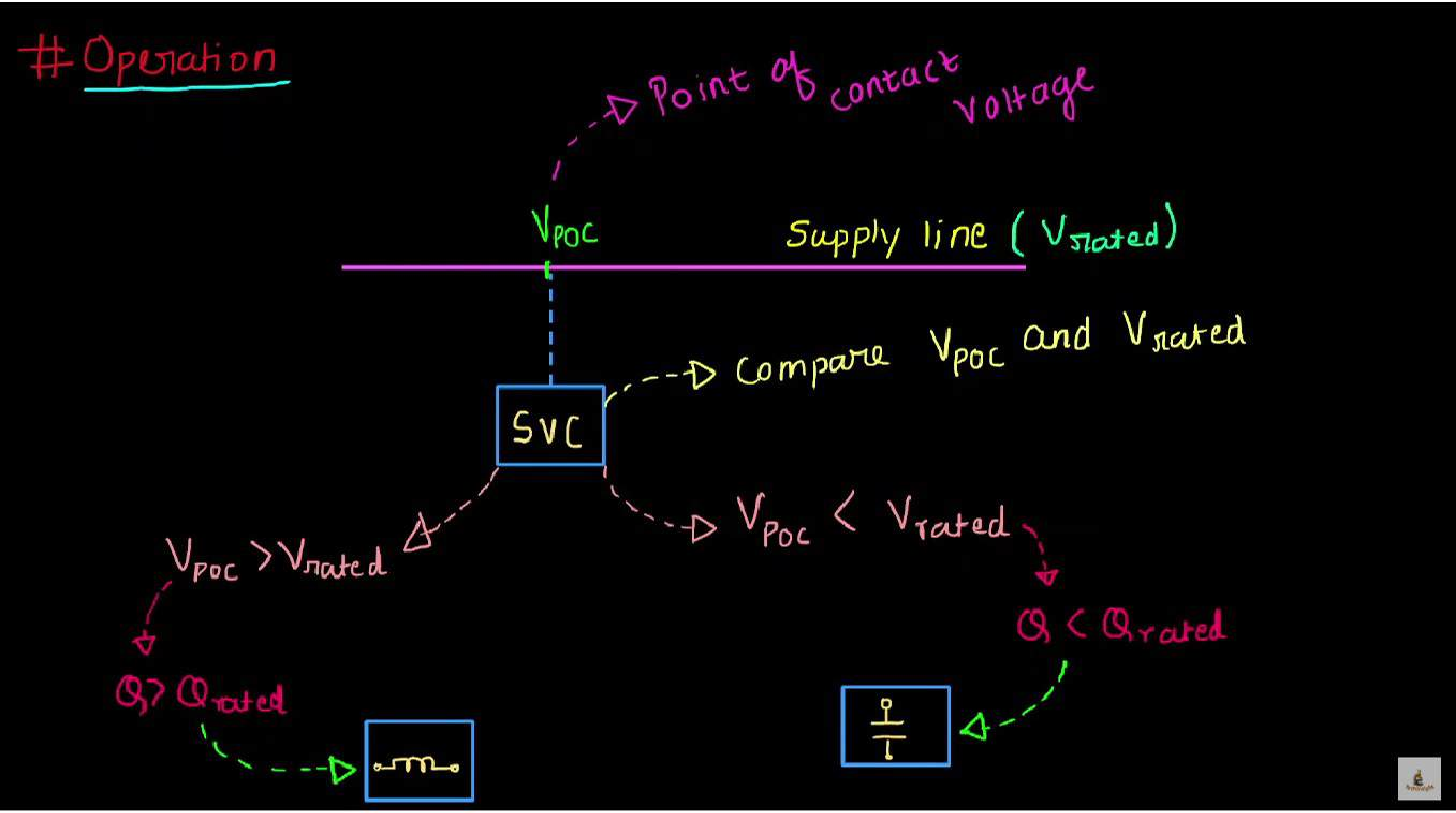


Supply line
High Voltage
Step down Transformer
SVC
sensitive components
Can't tolerate high voltage
TCR – TSC

Operation



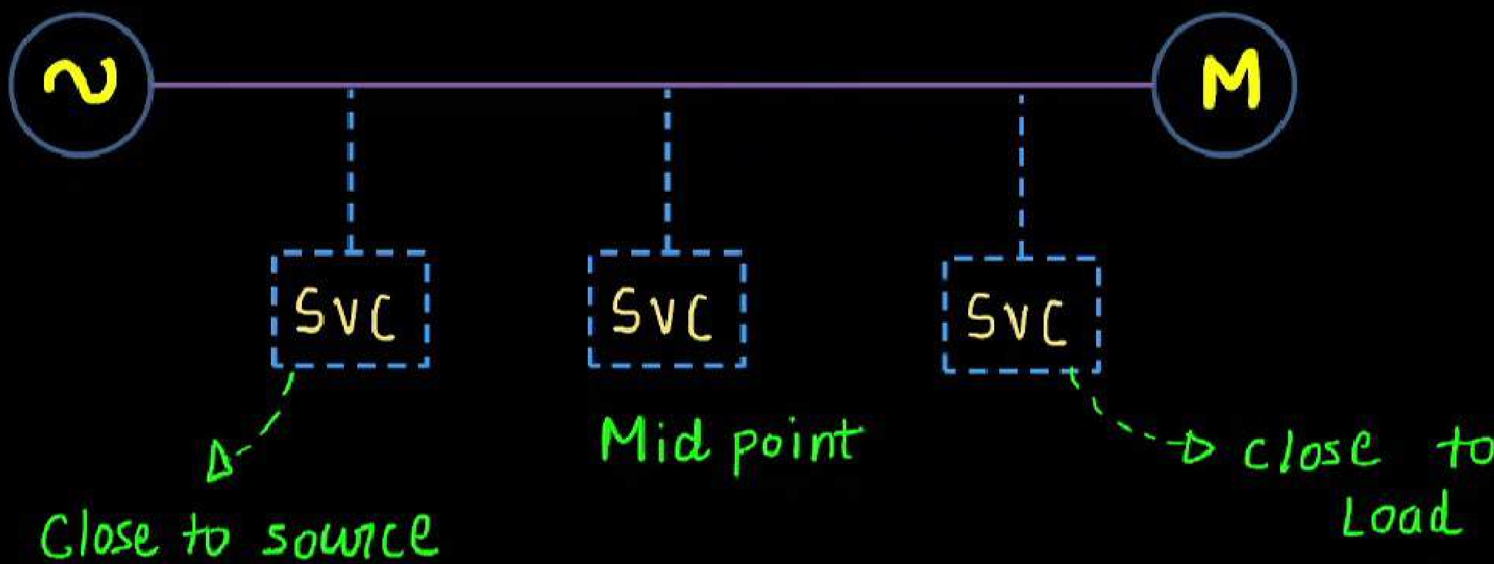
Point of contact voltage
10kV
V_{POC}
Supply line (V_{stated})
11kV
SVC



Operation
Point of contact voltage
V_{POC}
Supply line (V_{rated})
SVC
Compare V_{POC} and V_{rated}
$V_{POC} > V_{rated}$
$Q > Q_{rated}$
$V_{POC} < V_{rated}$
$Q < Q_{rated}$

Location of SVC

"Location of SVC is very important in determining its effectiveness"



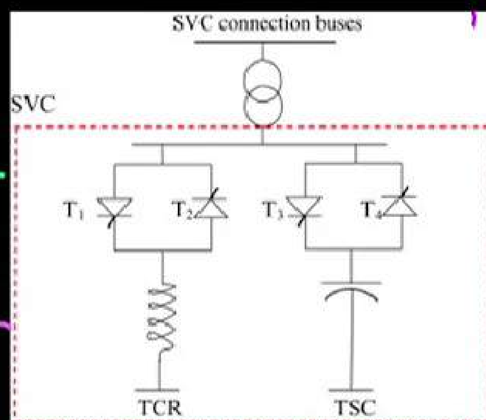
They should be connected at either near loads or at mid points of transmission line

Features

Continuous and fast regulation

belongs to FACTS devices family

Flexible Alternating Current Transmission System (FACTS)



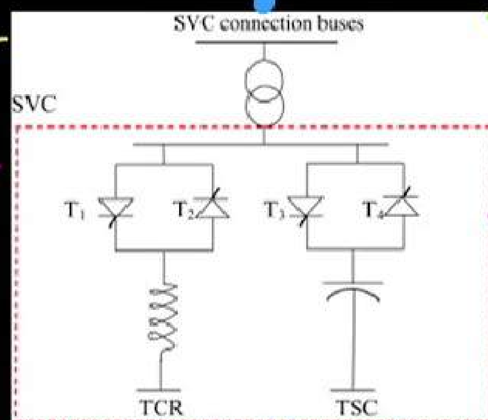
flexible in control

Applications

↑ Transmission capacity

↑ Stability during large and small disturbances

Smoothly Improves voltage profile



Disadvantages

Limited overloading capability

More expensive

Sensitive components