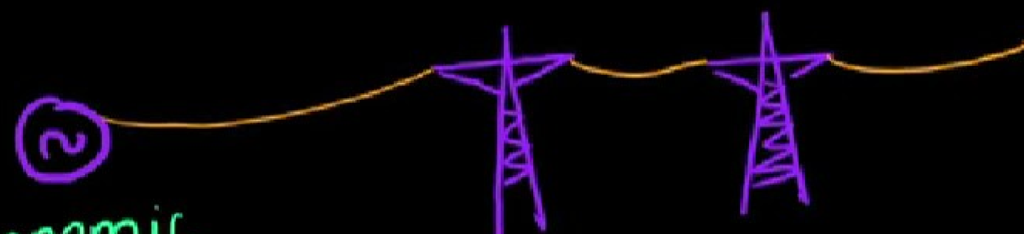
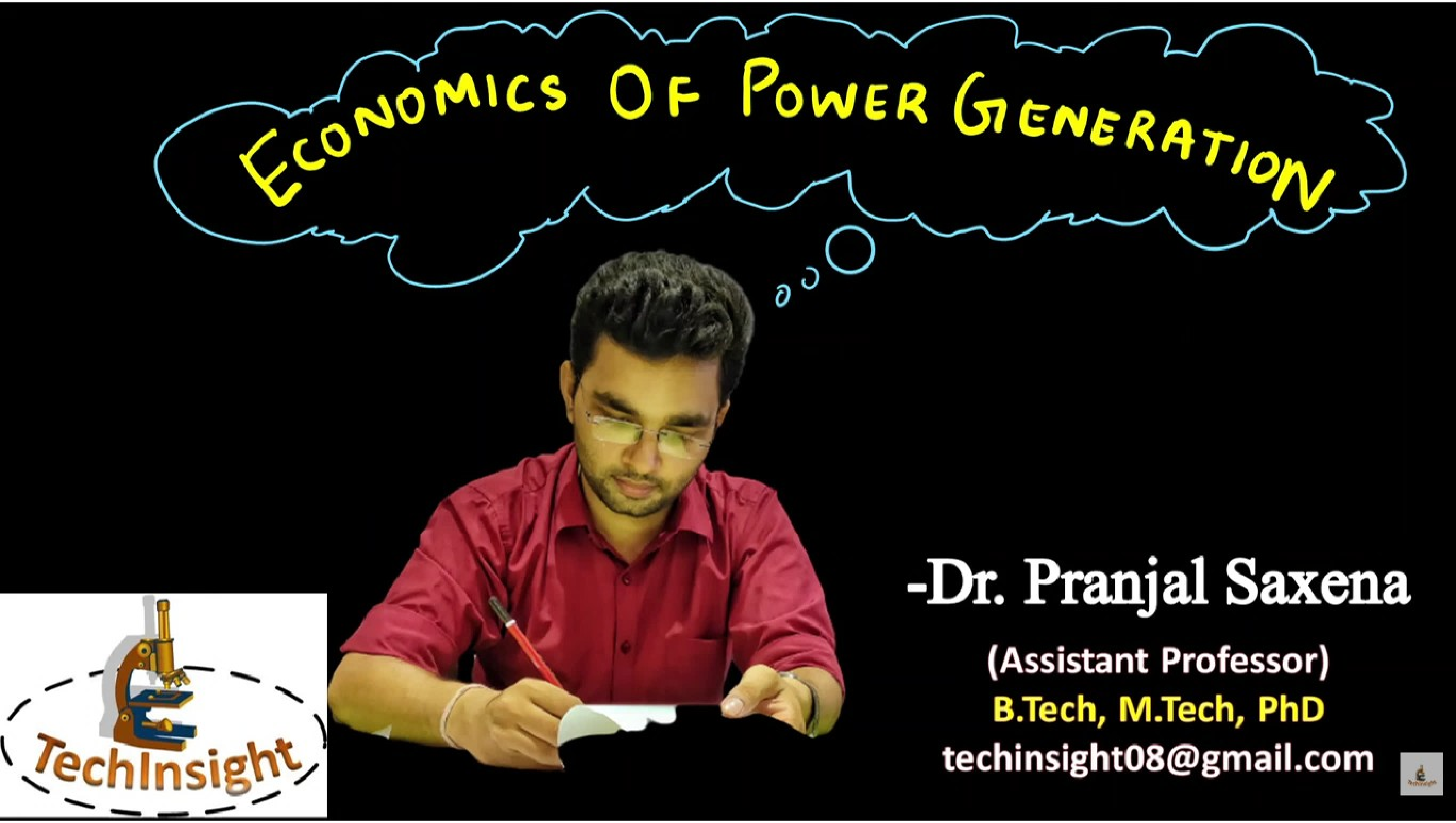
Ultimate aim

Earn Profit

Economic Transmission



Economic Generation


ECONOMICS OF POWER GENERATION
-Dr. Pranjal Saxena
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techinsight08@gmail.com
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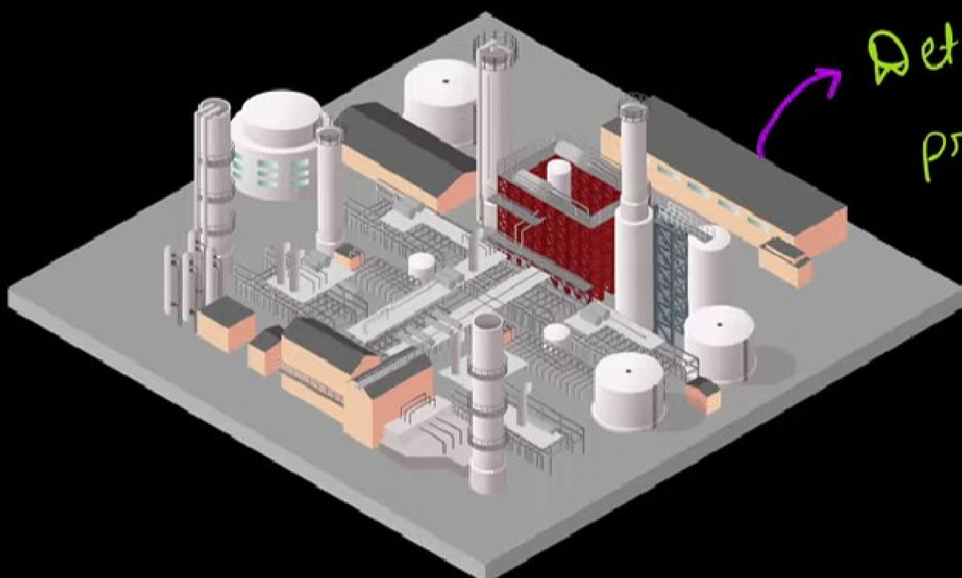
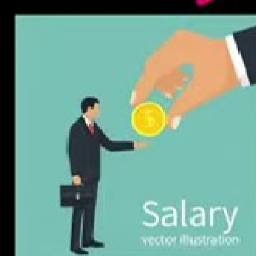
"The cost of determining the per unit (1 kWh) cost of production of electrical energy is known as Economics of power generation"



Determining the production cost is very complex

Cost of Land

Depreciation cost



Staff Salary

Interest on Capital

Cost estimation

Total cost of Electric Energy generated

- Fixed Cost
- Semi Fixed Cost
- Running or Operating cost

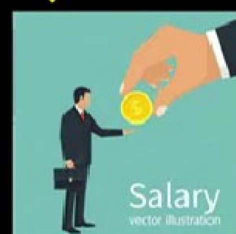
1. Fixed Cost

" Cost which is independent of max^m demand and Units generated"

Fixed Cost

Capital cost of Land

Annual cost of organization



High rank official Salaries

$\boxed{* \text{ Fixed Cost} = a}$ → constant

2. Semi - Fixed Cost

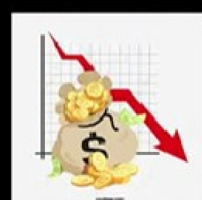
Semi → depends on max^m demand → Variable

Fixed → independent of units generated

* Semi fixed Cost $\propto$ Max^m demand on Power station

$\boxed{= b . kW}$

Interest on Capital



Depreciation Cost

Management & Clerical staff

* Higher the max^m demand $\longrightarrow$ Higher the semi-fixed cost

Max demand on Power Station $\uparrow$ $\longrightarrow$ Staff $\uparrow$ $\longrightarrow$

$\uparrow$

Max demand on Power Station $\uparrow$ $\longrightarrow$ Equipment $\uparrow$

Interest on Capital $\uparrow$

Depreciation Cost $\uparrow$

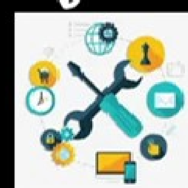
3. Running Cost

"Depends on number of units generated"

Running Cost

Annual Fuel Cost

Lubricating oil cost



Repair and maintainance cost

Operating staff Salaries

$\ast$ Running Cost = c. kWh

Expression for cost of Electrical Energy

Types

3-Part

Fixed cost + Semi Fixed Cost + Running Cost

$a + b\,kW + c\,kWh$

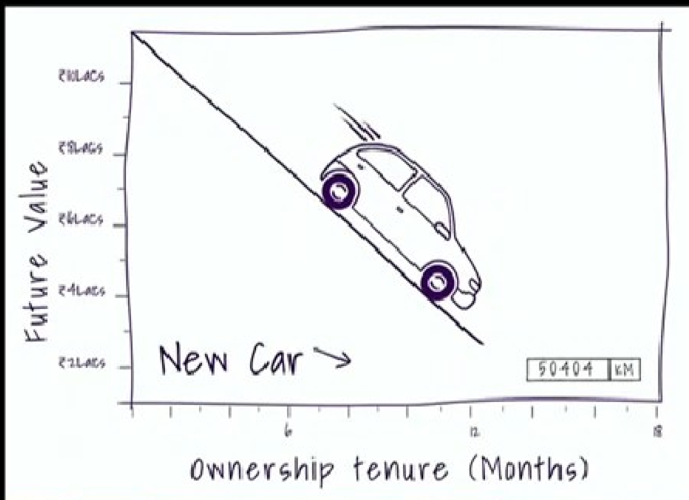
2 Part → Simplified version of 3-Part System

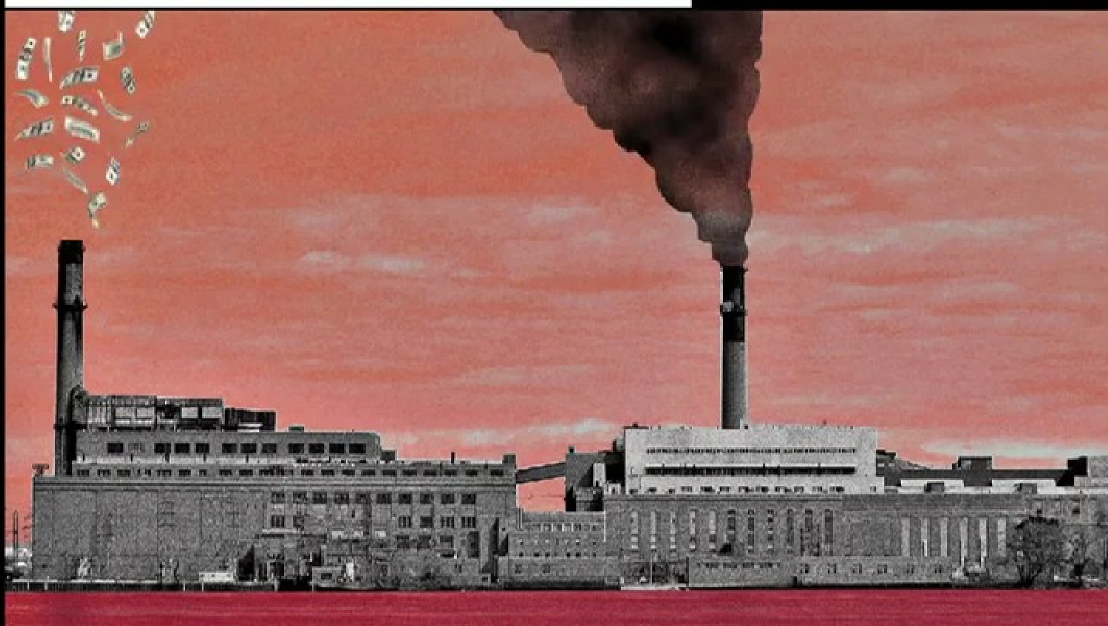
Semi Fixed + Running Cost

$A\,kW + B\,kWh$

$\boxed{* \; a + b\,kW = A\,kW}$

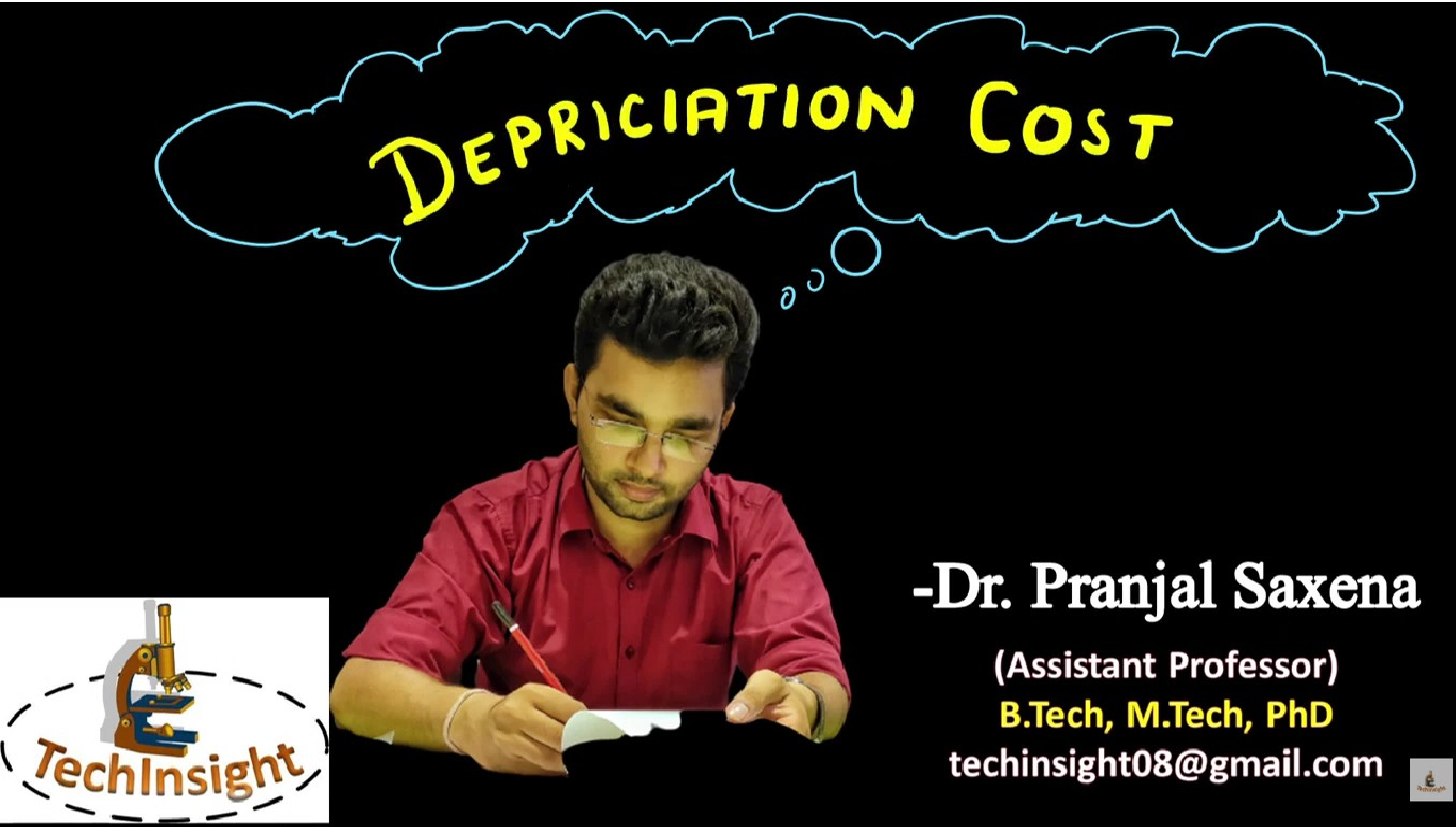
$\boxed{c\,kWh = B\,kWh}$





decrement in value

Depriciation Cost


DEPRICIATION COST
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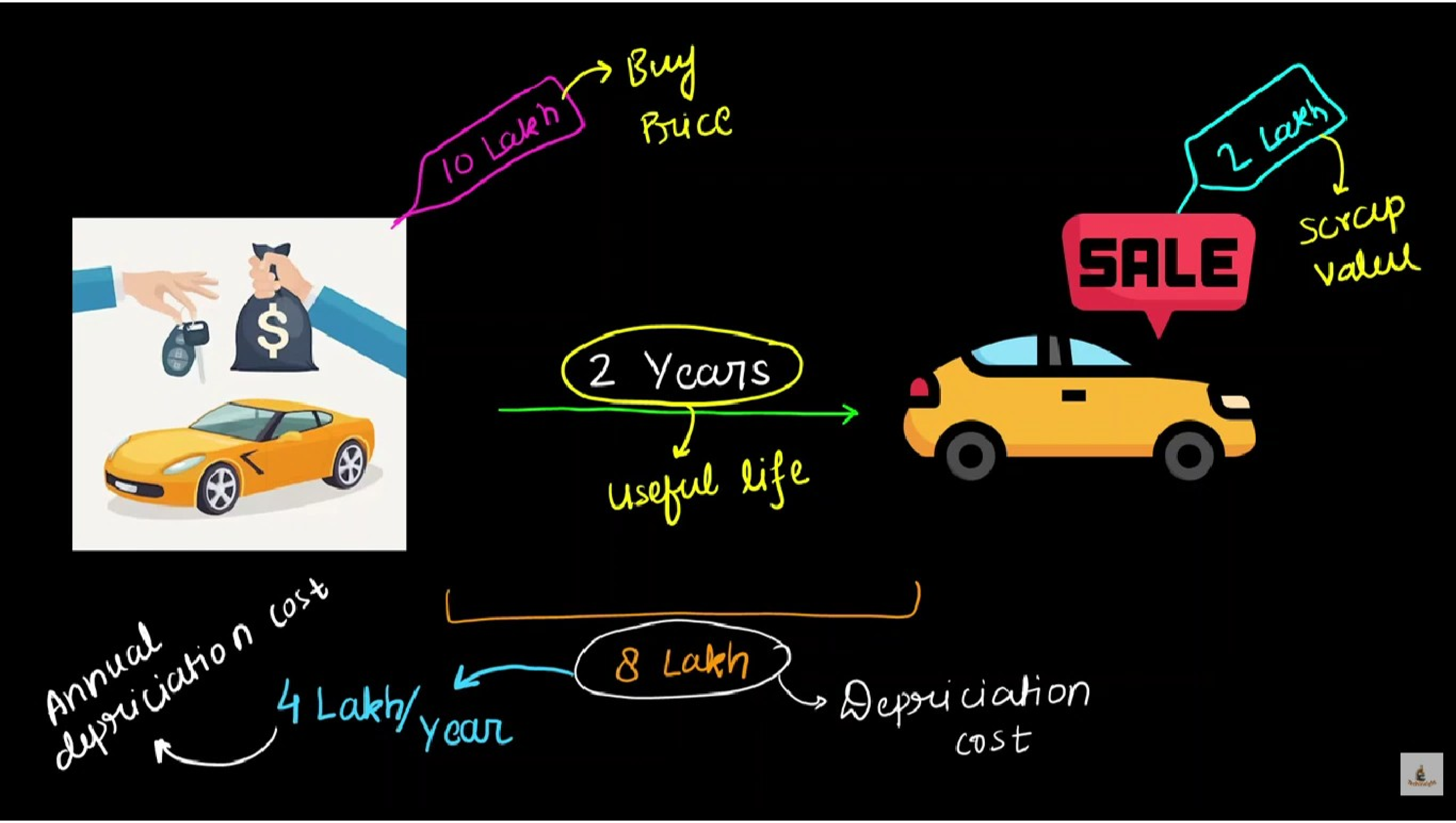

10 Lakh
Buy Price
2 Lakh
scrap value
SALE
2 Years
useful life
8 Lakh
Depriciation cost
4 Lakh/Year
Annual depriciation cost

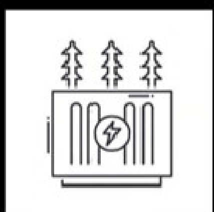
#Depriciation Cost

" The decrease in value of power plant equipment and building due to constant use is known as depriciation Cost "

useful life → 50 to 60 Years

due to wear and tear, the equipment of Power System deteriorates

* Plant has to replace the depreciated equipments via new one

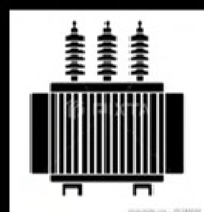


Old equipment

Buy = 9 Lakh

10 years

1 Lakh



New equipment

= 9 lakh

8 lakh more

act as huge economic burden on utility

Depreciation cost

Annual Depreciation charges

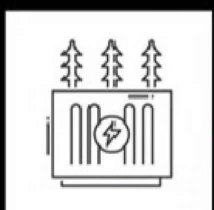
"Depreciation charges to be set aside every year to counter the depreciation of equipment"

equals to the cost of replacement of equipment

3 Methods

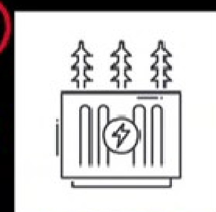
1. Straight line method
2. Diminishing value
3. Sinking fund

annual depriciation charges

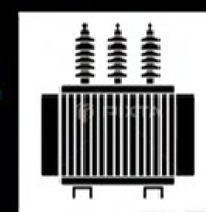


80K 80K 80K 80K

10 years



Replace



Old equipment

Buy = 9 Lakh

depreciation charge collected = 8 Lakh

1 Lakh

\+

New equipment

= 9 lakh

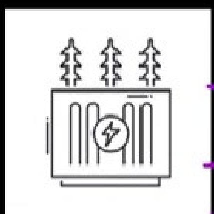
1. Straight Line method

constant depriciation every year

Scrap cost after useful life

* Annual depriciation charge = $\frac{\text{Total depriciation}}{\text{Useful life}} = \frac{\text{Buy Price} - \text{Scrap value}}{\text{Useful life}}$

equipment available for use



Old equipment

Buy = 9 Lakh

useful life = 10 years

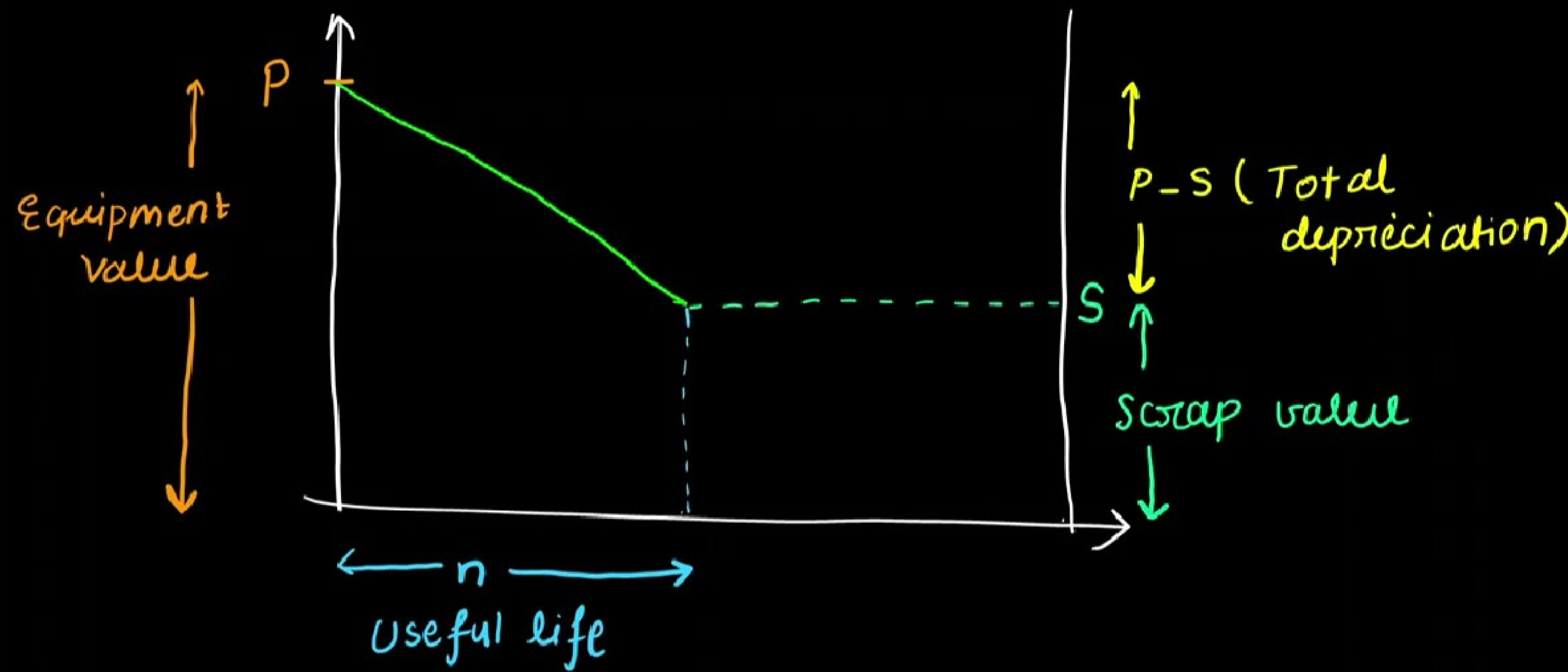
Scrap value = 1 lakh

Annual depriciation charge $= \frac{9-1}{10}$

$=$ 0.8 Lakh or 80 k

$$\boxed{ADC = \frac{P - S}{n}}$$

Curve



* Curve shows constant depriciation charges

Features

1. Extreme simple method

2. Defects → assumption of constant depriciation every year is not correct

   → Not include interest accumulated

Solution

Diminishing value

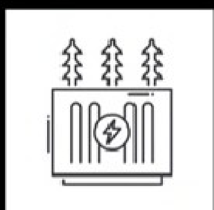
Sinking fund

Diminishing Value Method

"Diminishing charge is made at a fixed rate on the diminishing value."

assume that equipment depriciated at fixed rate

eg.



fixed rate = 10%

Old equipment

after 1 year

Buy = 9 Lakh $\xrightarrow{10\%}$ 90,000/-

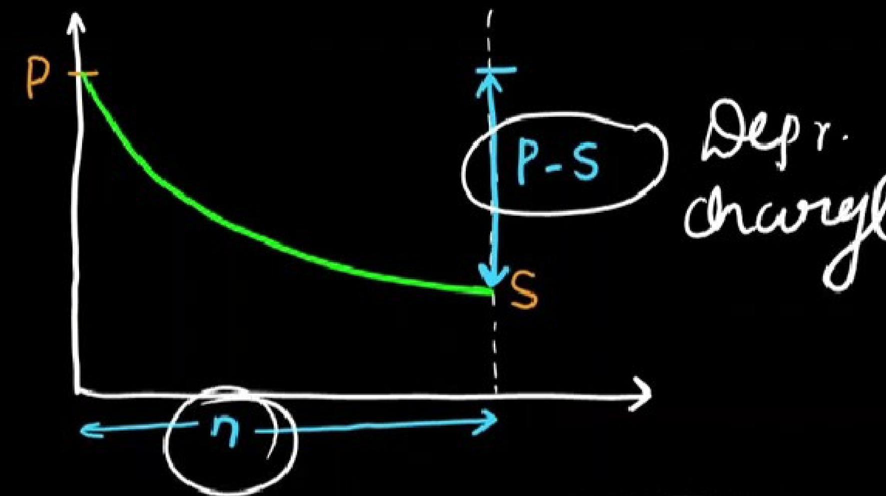
8.1 lakh $\xrightarrow{10\%}$ 81,000/-

7.29 lakh $\xrightarrow{10\%}$ 72,900/-

Depriciation charges collected

Mathematical formulation

- Initial value = P
- useful life = n
- scrap value = S



Annual depriciation unit = x

eg 10% depriciation, $x = 0.1$

∴ value of equipment

after 1 year $= P(1-x)$

after 2 years $= P(1-x)^2$

$\boxed{\text{after } n \text{ years} = P(1-x)^n}$ → Scrap value

$$\boxed{S = P(1-x)^n}$$

$$\boxed{x = 1 - \left(\frac{S}{P}\right)^{1/n}}$$

Features

- more rational than straight line method
- curve shows heavy charges in initial years and diminishing charges in later years.

Drawback

- In later years, maintainance and repair $\uparrow$ while depriciation charges $\downarrow$
- Interest on depriciation charges not included

Sinking Fund Method

Sinking Fund Method

[fixed depriciation charge
+
Compound interest on depriciation charge] + Scrap Value = Buy / Replacement cost

straight line method

for n-years

Improves the depriciation charge calculation

Formula

* Total fund collected in n-years $= \dfrac{q\left[(1+r)^n - 1\right]}{r}$

q → fixed annual depriciation charge

r → annual rate of interest

Total fund collected in n-years → $(P-S)$

$$\therefore \boxed{P - S = \frac{q\left[(1+r)^n - 1\right]}{r}}$$

$$\boxed{q = (P-S)\underbrace{\left[\frac{r}{(1+r)^n - 1}\right]}_{K_{FF}}}$$

K_{FF} → Sinking Fund Factor

$$\boxed{q = K_{FF} \cdot (P-S)}$$

Important Formulas

1. Annual Depriciation Cost

- straight line method $= \frac{P-S}{n}$
- Diminishing value $= x\%$

  $\Rightarrow x = 1 - \left(\frac{S}{P}\right)^{1/n}$
- sinking fund method $\Rightarrow q = (P-S)\left[\frac{r}{(1+r)^n - 1}\right]$

2. Fund collected after N- years

↳ straight line method = $\frac{P-S}{n} \times N$

↳ Diminishing value = $P[1-(1-x)^N]$

↳ Sinking fund method = $\frac{q(1+r)^N-1}{r}$

3. Actual value of equipment after N-years

↳ P − [fund collected in N years]

↳ straight line method = $P - \left[\text{annual depriciation} \times N\right]$

↳ Diminishing value = $P(1-x)^N$

↳ sinking fund method = $P - \left[\dfrac{q(1+r)^N - 1}{r}\right]$

Q. Equipment has cost ₹ 15,60,000/- has a salvage value of 60,000/- at the end of 25 years. Determine annual depriciation cost/ fund/unit in

scr + fixed = Repdn.

(a) straight line (b) Diminishing value (c) $\boxed{\text{Sinking fund}}$

Ans (i) Annual depriciation $= \dfrac{P-S}{n} = \boxed{60{,}000}$/-

(ii) annual depriciation unit $\Rightarrow x = 1 - \left(S/P\right)^{1/n}$

60,000

25

15,60,000

fixed + scrap = Replacem.

compound

com

$= 0.122$ or 12.2%

(iii) annual depriciation fund $\Rightarrow q = (P-S)\left[\dfrac{r}{(1+r)^{n}-1}\right] = 31{,}433$/-

Design of Power Transmission

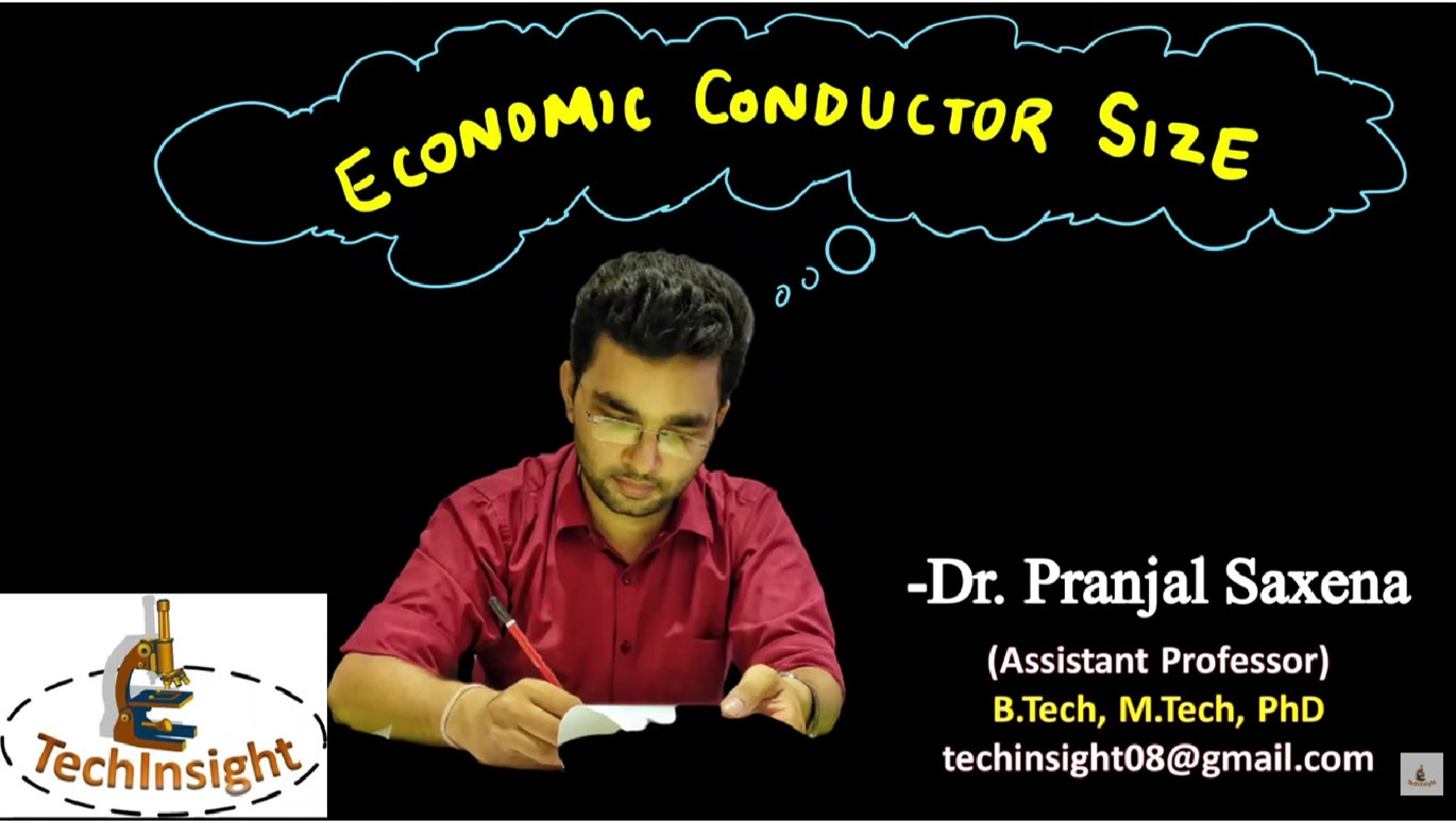
↓

Cost Efficient

↙ ↘

Economic conductor size

Economic Transmission voltage


ECONOMIC CONDUCTOR SIZE
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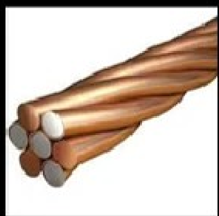
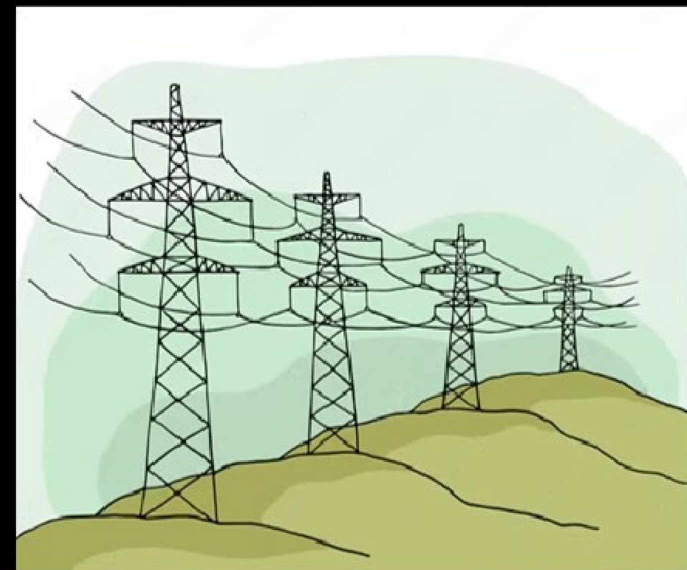
Economic Conductor size



conductor cost → considerable part of total transmission cost → Area should be economical



Kelvin's Law :→ Most economical area of conductor → Total annual cost of Transmission line is Minimum

Total annual cost of Transmission line

C_1

Annual charge on capital cost of conductor

- ↳ Interest on capital cost of conductor
- ↳ Depriciation on capital cost of conductor

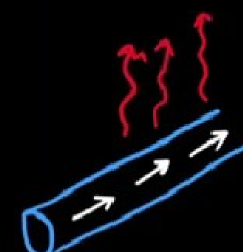
$C_1 \propto$ area of conductor (a)

$= P_1 a$

C_2

cost of energy wasted in the conductor

- ↳ mainly energy lost due to I^2R Losses



$C_2 \propto \frac{1}{\text{area (a)}}$

* Total cost $C_T = C_1 + C_2 = P_1 a + \frac{P_2}{a}$

$$\boxed{C_T = P_1 a + \frac{P_2}{a}}$$

Most economical area (a) $= \sqrt{\frac{P_2}{P_1}}$

* Its min. value is obtained by; $\frac{dC_T}{da} = 0 \Rightarrow P_1 - \frac{P_2}{a^2} = 0$

$$= \boxed{P_1 = P_2/a^2}$$

$$P_1 a = \frac{P_2}{a}$$

$$\boxed{C_1 = C_2}$$

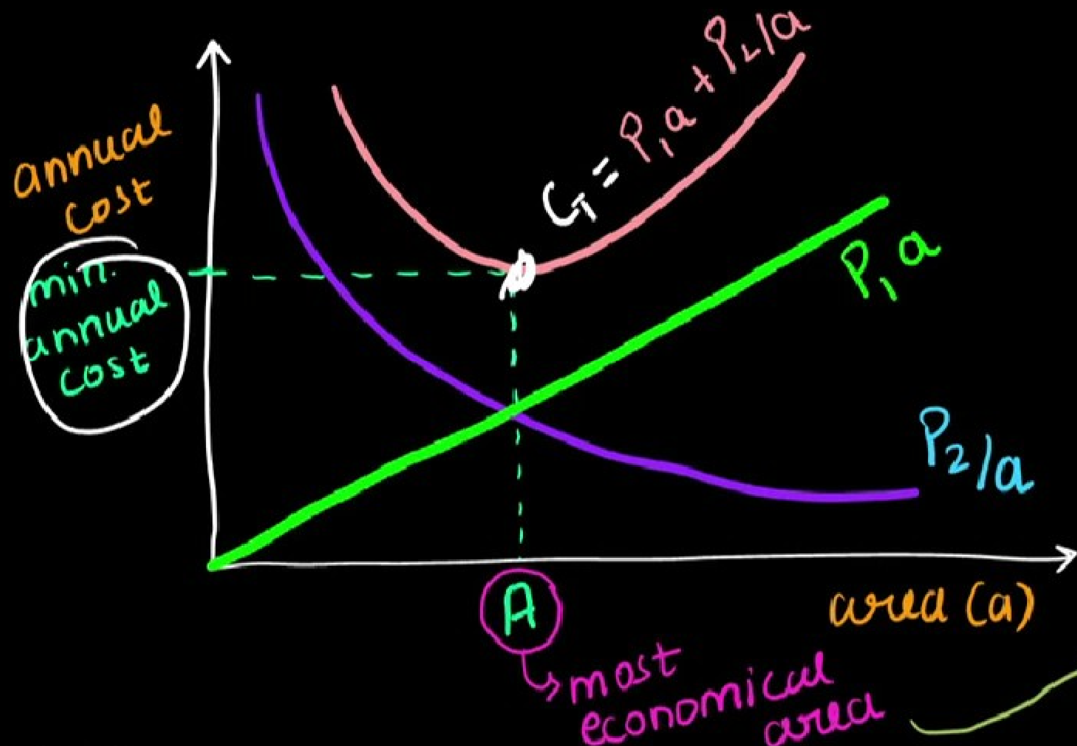
"The **Kelvin's law** states that the most economical size of a conductor is that for which annual interest and depreciation on the capital cost of the conductor is equal to the annual cost of energy loss."

Kelvin's Law

Most economical area of conductor

Annual interest and depriciation cost of conductor = annual cost of energy wasted

$P_1 a$ $\qquad$ P_2/a



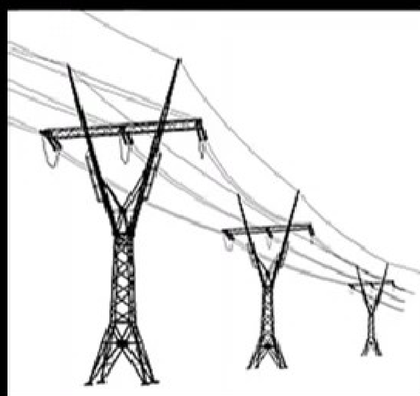
$$P_1 a = P_2/a$$

$$A = \sqrt{\frac{P_2}{P_1}}$$

#Error

Missing

C_1 → annual interest and depriciation on capital cost of Conductor

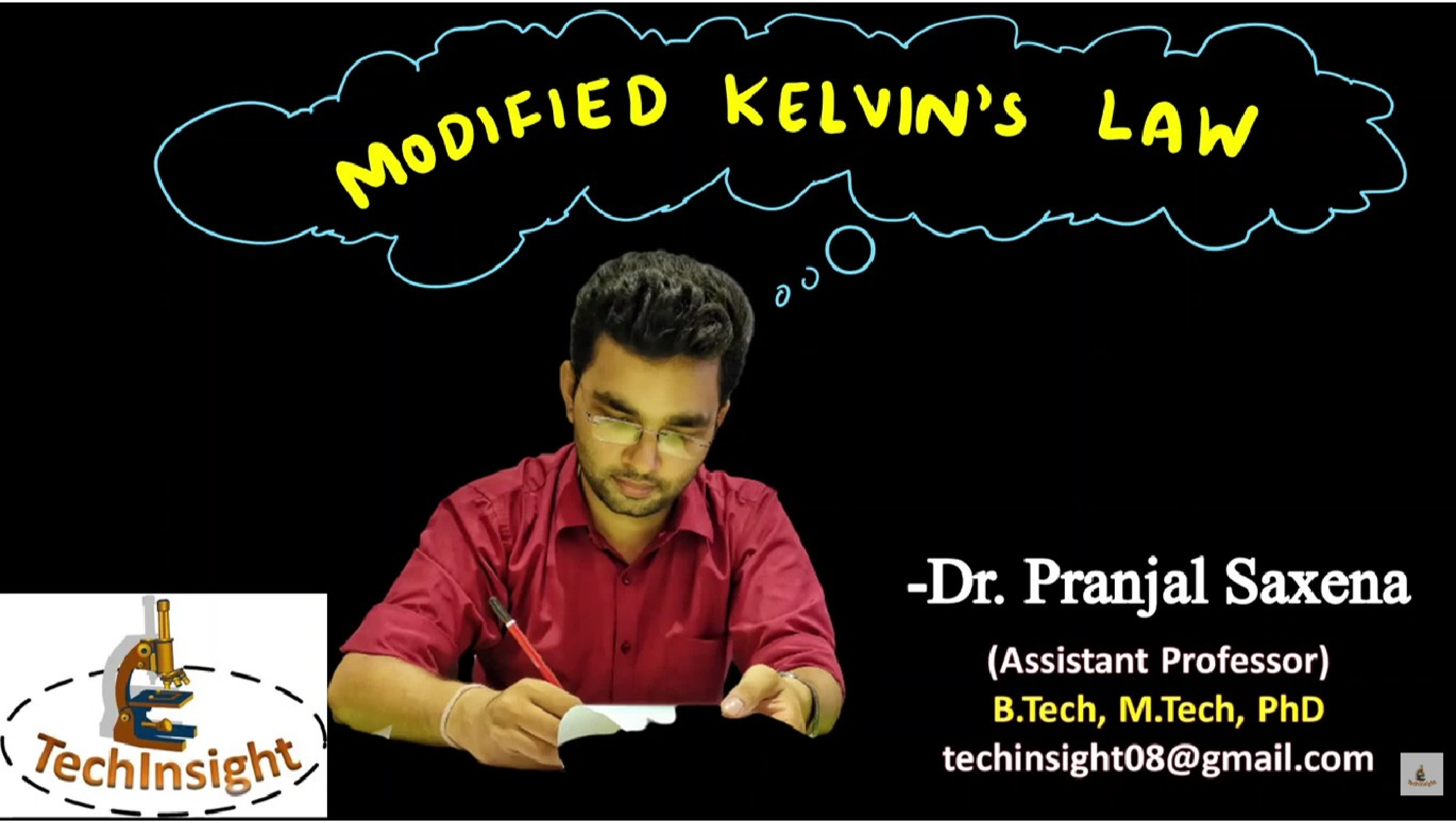


Overhead Transmission

- Insulator cost
- Labour cost
- Support structure cost

Underground cable

Modified KELVIN'S LAW → G. Kapp


MODIFIED KELVIN'S LAW
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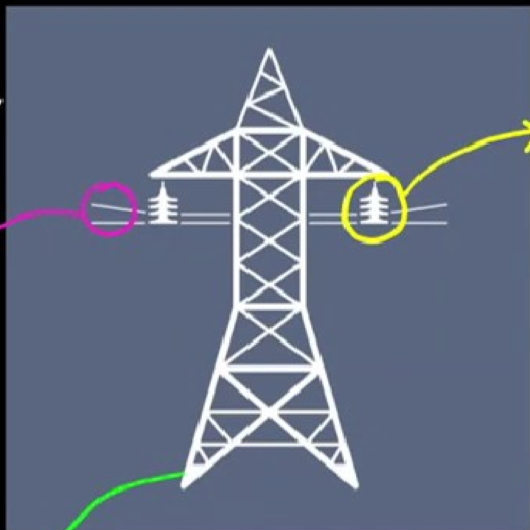
depends on cond. area

Conductor cost



Insulator cost

Independent of conductor area

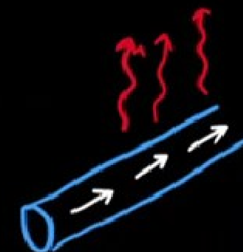
Support structure cost → Partially dependent on area

C_1

Annual charge $= P_1 + P_2 a$

cost independent of area

Cost proportional to area



C_2

Annual cost $= \dfrac{P_3}{a}$

Cost inversely proportional to area of conductor

Total annual cost

$$\boxed{C = P_1 + P_2 a + \frac{P_3}{a}} \quad \text{—— (1)}$$

* To obtain min. annual capital cost ⟶ differentiate eq (1) w.r.t area (a)

$$\frac{dC}{da}$$

$$\boxed{P_2 a = \frac{P_3}{a}}$$

variable part of annual capital cost

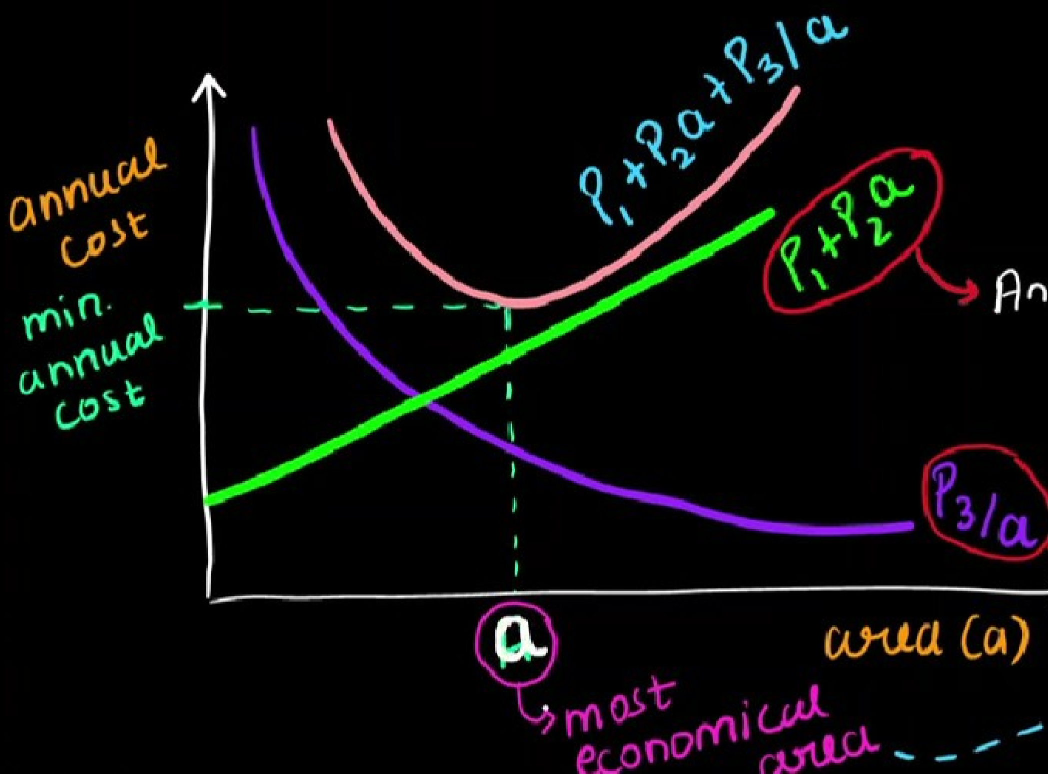
Annual cost of energy wasted

Modified Kelvin's Law

Most economical area of conductor → Variable part of annual capital cost = annual cost of energy wasted

Variable part of annual capital cost → $P_2 a$

annual cost of energy wasted → P_3/a



$P_1 + P_2 a$ → Annual charge on capital outlay

P_3/a → Annual cost of energy wasted

most economical area → $\boxed{P_2 a = P_3/a}$ → $\boxed{a = \sqrt{\frac{P_3}{P_2}}}$

Kelvin's Law

Most economical area of conductor

Annual interest and depriciation cost of conductor = annual cost of energy wasted

consider only conductor cost

$$\boxed{P_1 a = \frac{P_2}{a}}$$

Modified Kelvin's Law

Most economical area of conductor

Variable part of annual $\boxed{\text{capital cost}}$ = annual cost of energy wasted

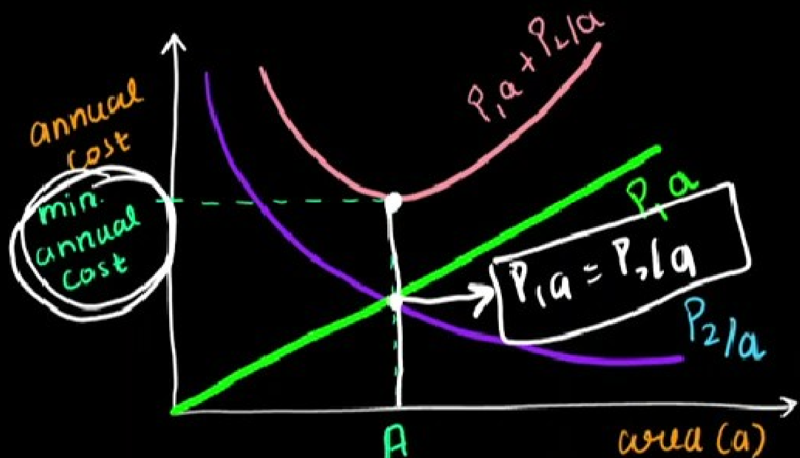
consider cost of conductor, support, Insulator, Labour

$$\boxed{P_2 a = \frac{P_3}{a}}$$

Kelvin's Law

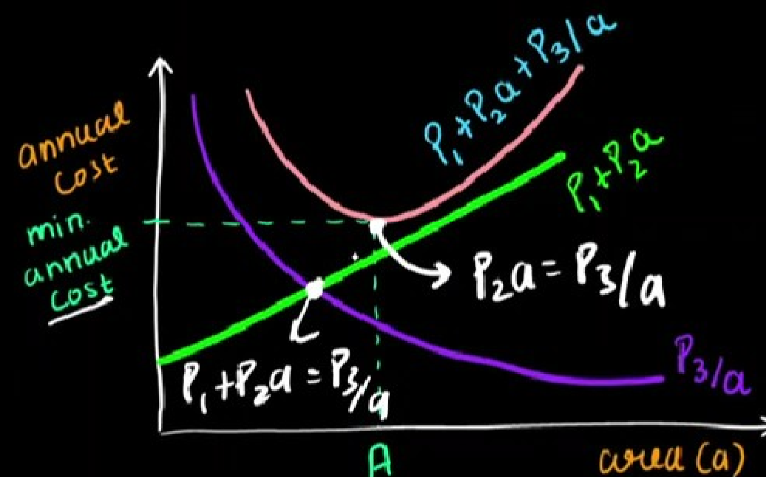
$$P_1 a = P_2 / a$$

$$\boxed{C_T = P_1 a + \frac{P_2}{a}}$$



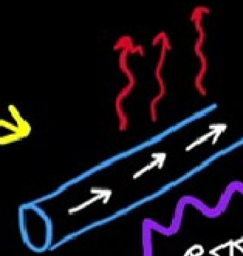
Modified Kelvin's Law

$$\boxed{C = P_1 + P_2 a + \frac{P_3}{a}}$$



Limitation

1. Variable part of annual capital cost = annual cost of energy wasted



error

actual Load curve

2. Annual capital cost = $P_1 + aP_2$

inaccurate assumption

10mm

3. Law ignores :→ Corona loss, safety factor

4. economical area of conductor

not Practical

No mechanical strength

acquire major portion of capital investment

$\downarrow$ area of conductor $\xrightarrow{\text{Selection criteria}}$ Current flow $\downarrow$

$$\boxed{\text{For economic operation}}$$
$$\downarrow$$
$$\boxed{\text{Minimum area of conductor}}$$

$S = VI$

for constant S;

↓ Ohmic losses

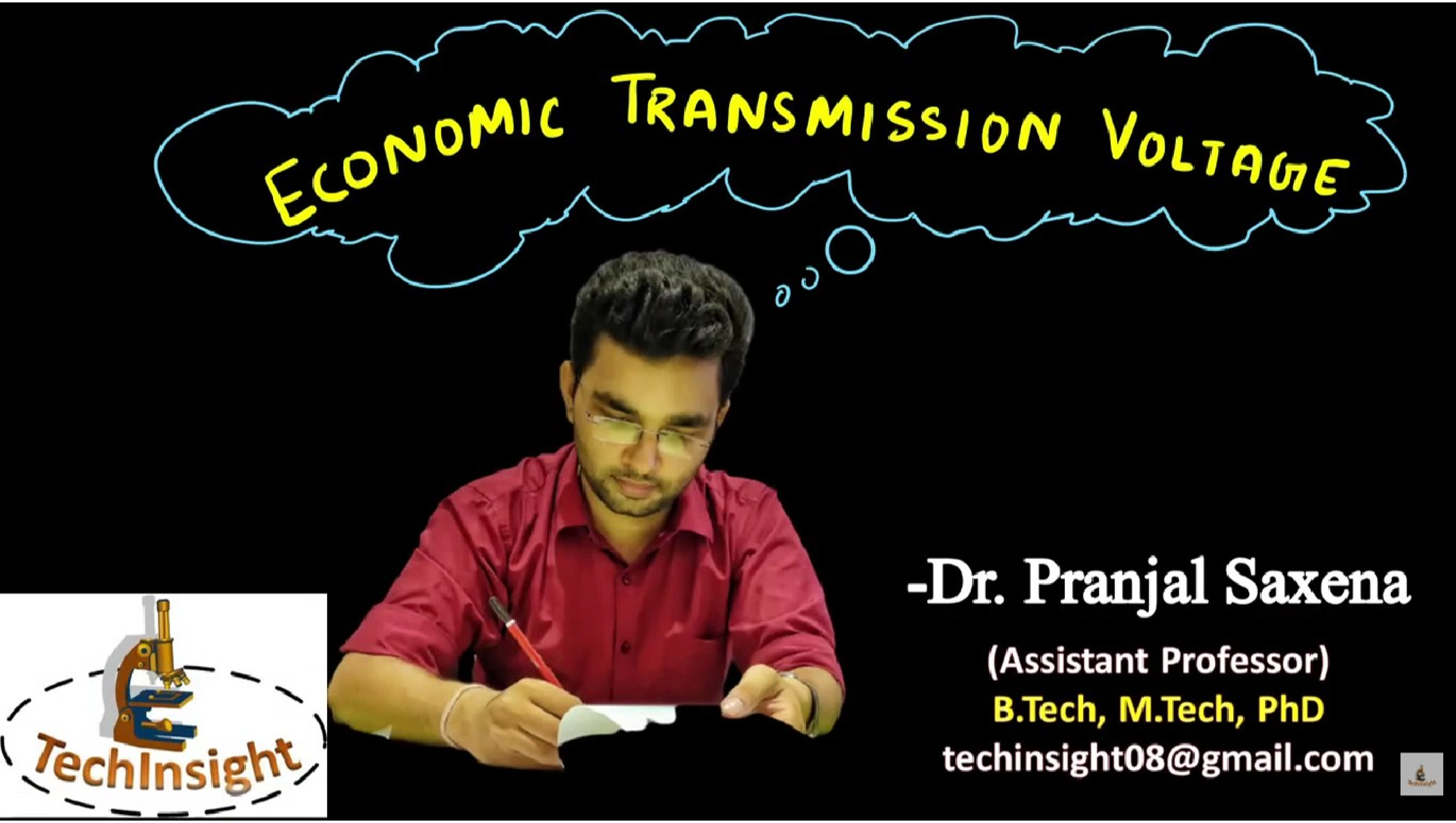
↓ conductor required

$$\downarrow \text{Current} \propto \frac{1}{\uparrow \text{Voltage}}$$

High voltage Transmission

Important Question

Most Economical voltage?


ECONOMIC TRANSMISSION VOLTAGE
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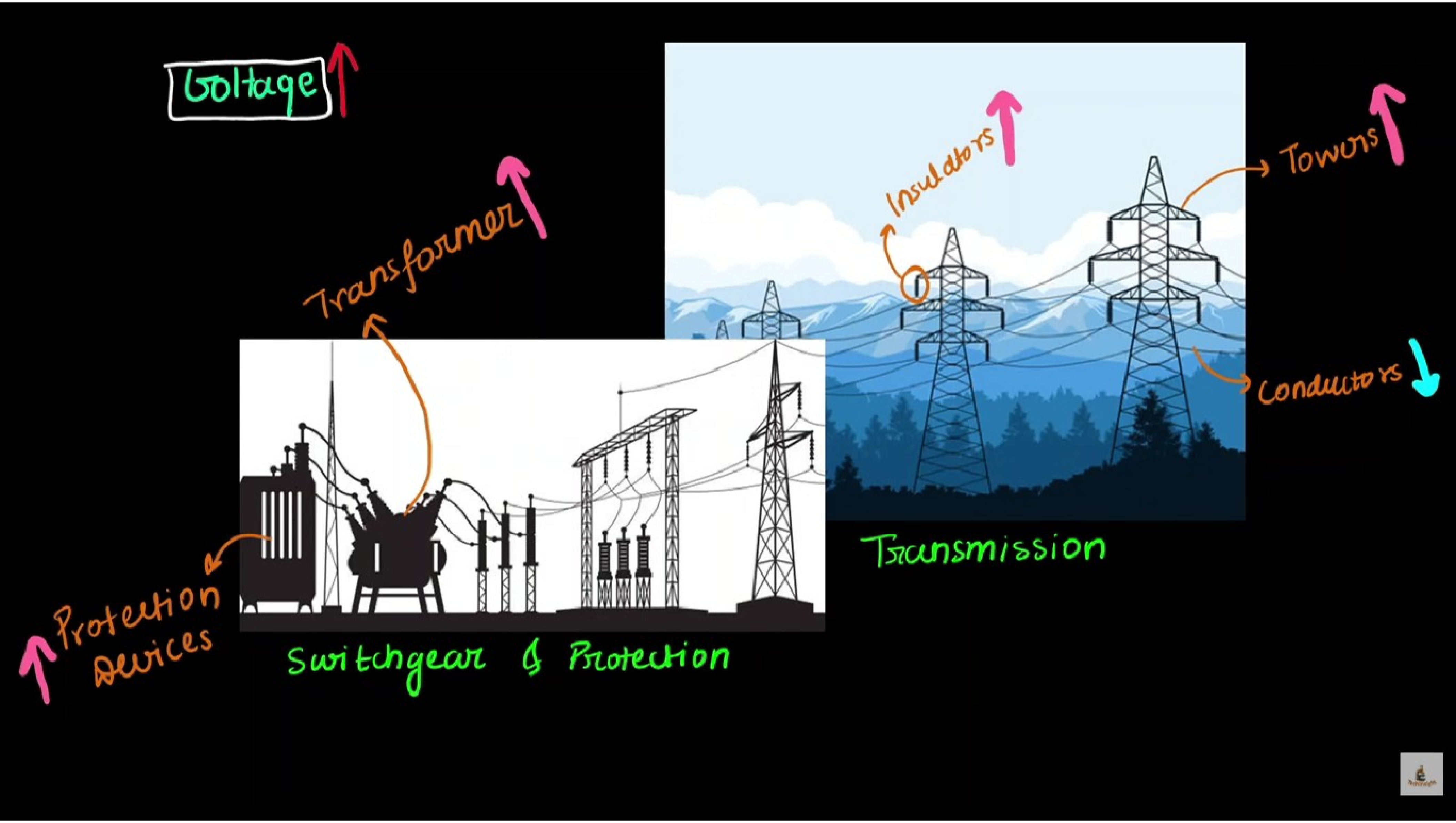
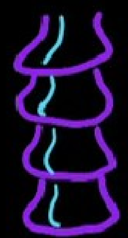


Voltage
Transformer
Insulators
Towers
Conductors
Transmission
Protection devices
Switchgear & Protection

Effect of voltage



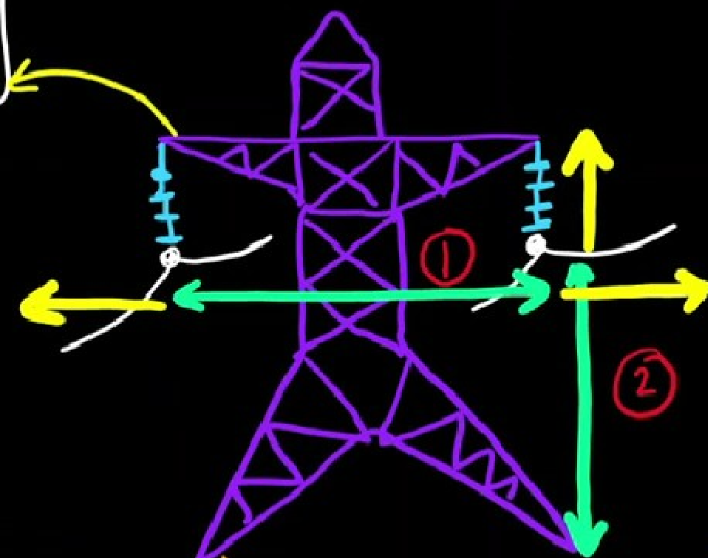
Insulators

↑ No. of discs required $\propto$ voltage ↑

$\boxed{\text{Cost of Insulator} \uparrow}$

$\boxed{\text{voltage} \uparrow}$

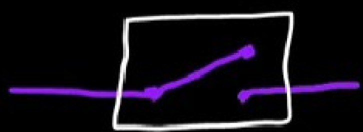
$\boxed{\text{cost of Tower} \uparrow}$



$\boxed{\text{Insulate}}$ ↑ conductors → air → gap ↑

1 from other conductors

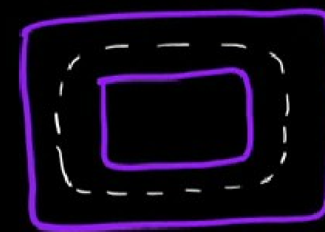
2 from ground → ground clearance



Circuit Breakers

$\uparrow$ Rating of CB $\propto$ voltage $\uparrow$

Cost of CB $\uparrow$



Transformers

flux density > Rated

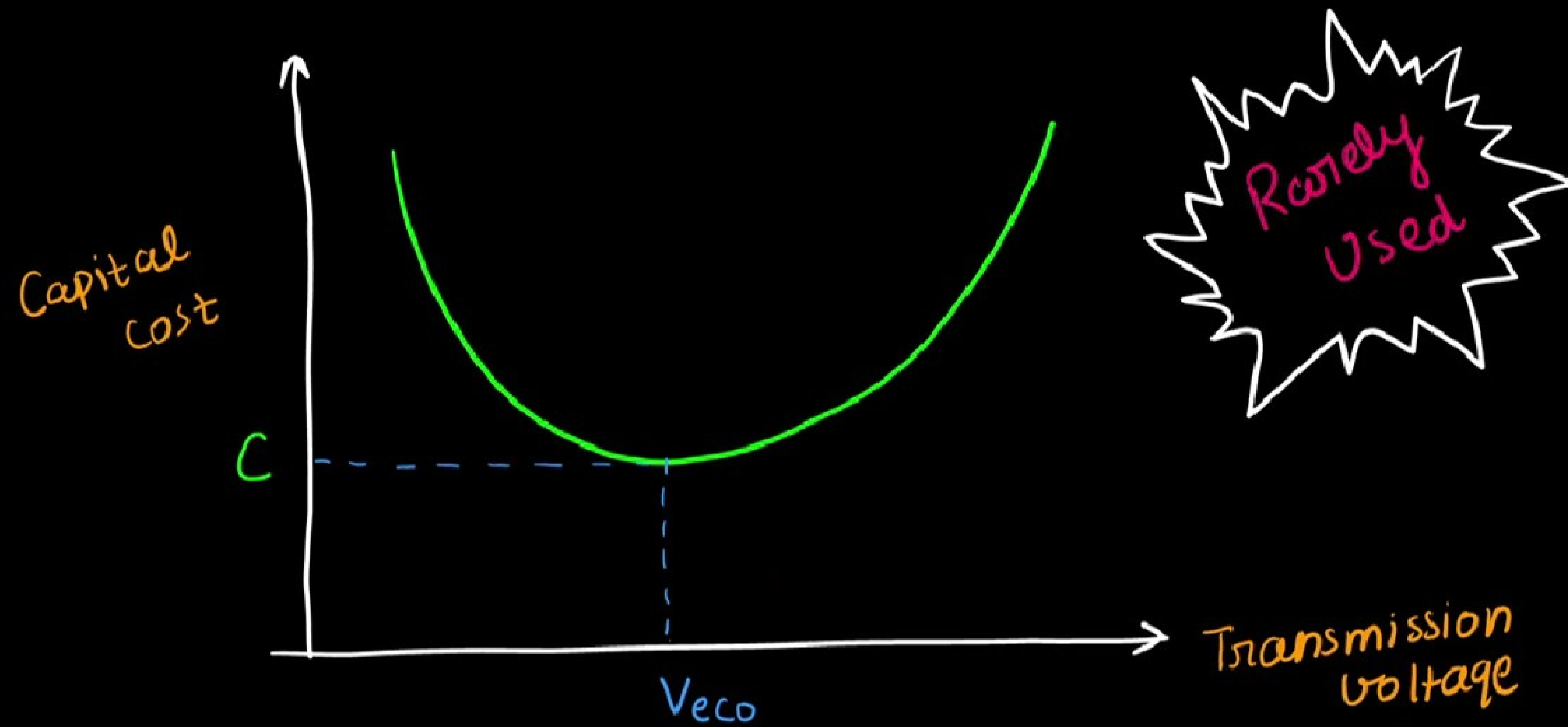
$\uparrow \frac{V}{f}$

f constant

$\uparrow$ Size of Transformer

Core saturate

Cost of Transformer $\uparrow$


Rarely Used
Capital cost
C
Transmission voltage
Veco

Empirical formula for Economical Voltage

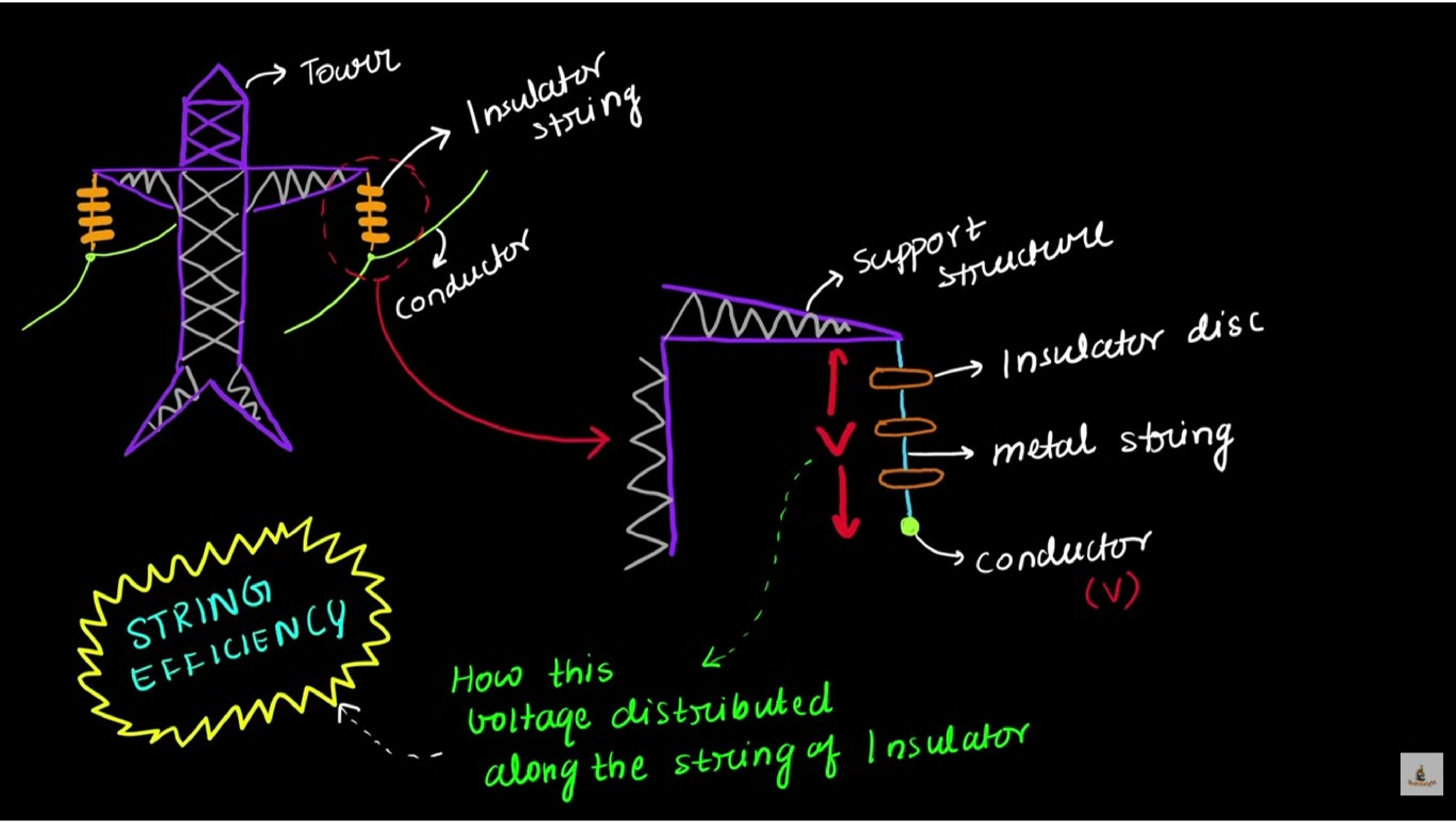
$$\boxed{V_{eco} = 5.5\sqrt{0.62\,l + \frac{3P}{150}}}$$

These 2 includes all factors

V_{eco} → line voltage in kV

l → distance of transmission line in km

P → max^m kW/phase to be delivered


Tower
Insulator string
conductor
support structure
Insulator disc
V
metal string
conductor
(V)
STRING EFFICIENCY
How this voltage distributed along the string of Insulator