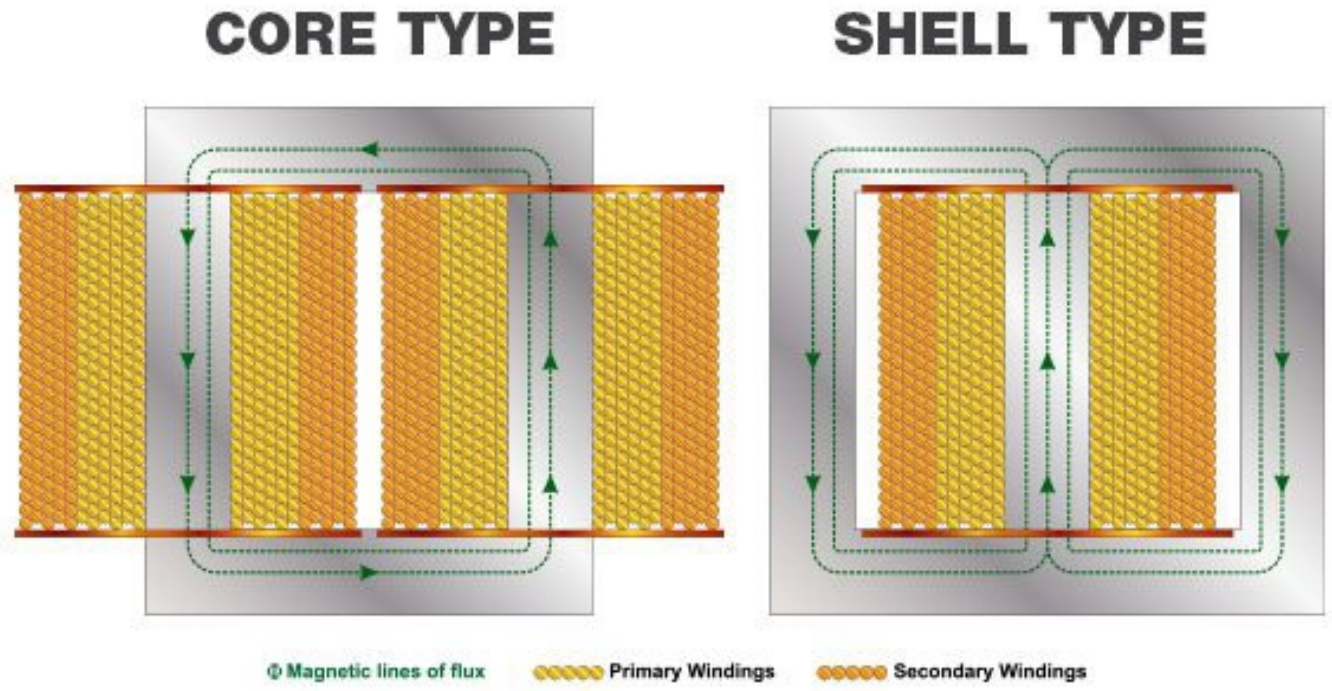
Transformers – Lesson 2



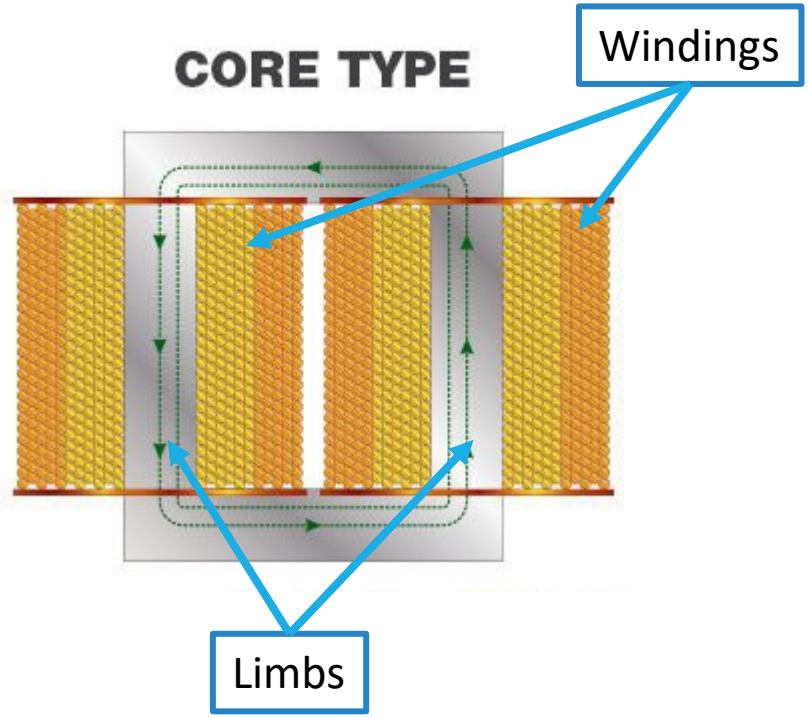
Type configurations

- There are two main transformer types (different from transformer purpose)



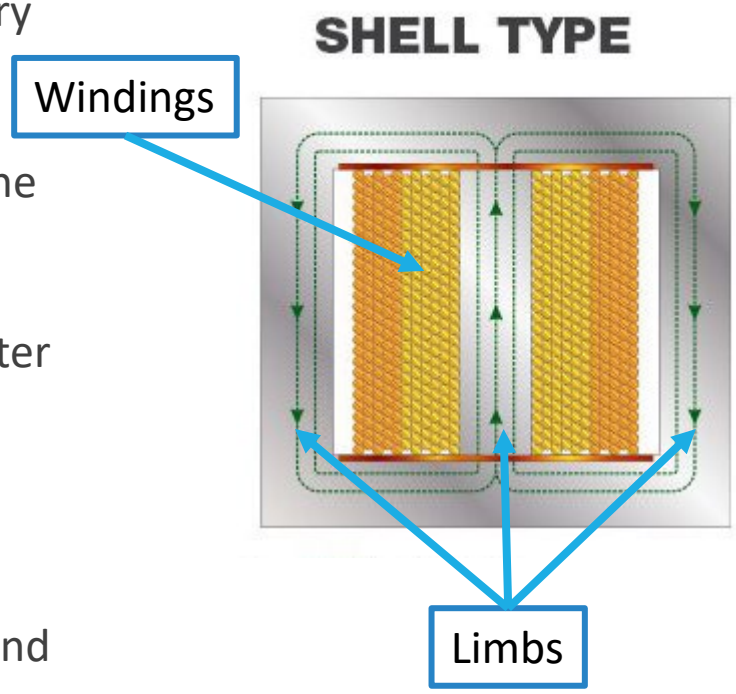
Core Type

- The primary and secondary windings surround the limbs of the magnetic core.
- In a typical single-phase design, both windings are divided between two limbs.
- The magnetic flux follows one continuous path around the core.
- The low-voltage winding is normally closest to the core, with the high-voltage winding outside it.
- The windings are relatively exposed, making cooling and maintenance easier.



Shell Type

- The magnetic core surrounds most of the primary and secondary windings.
- In a typical single-phase design, both windings are located on the central limb.
- The magnetic flux divides into two return paths through the outer limbs.
- The windings can be interleaved to improve magnetic coupling.
- The surrounding core provides additional mechanical support and protection.

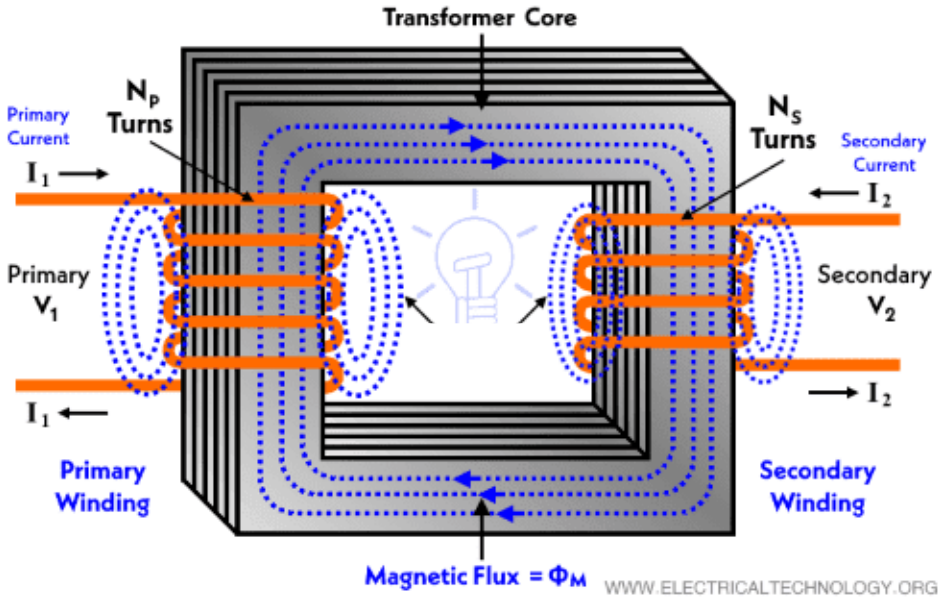


Advantages and Disadvantages

Feature	Core Type	Shell Type
Cooling	Windings are more accessible, making cooling easier	Windings are more enclosed, requiring careful cooling design
Maintenance	Generally easier to inspect and access windings	More difficult to access and repair windings
Magnetic leakage	Can have greater leakage flux, depending on winding arrangement	Typically good magnetic coupling, especially with interleaved windings
Mechanical strength	Windings are less enclosed	Windings are better supported during mechanical stresses
Construction	Relatively straightforward arrangement	More complex winding and core arrangement
Applications	Widely used in distribution and power transformers	Used in power transformers and applications requiring robust winding support

Why Transformers Aren't Ideal

- In an ideal transformer, 100% of the input power is transferred to the output.
- However, real transformers experience energy losses, meaning their efficiency is always below 100%.
- There are 4 main reasons for this energy loss which we will discuss in this lesson.



The 4 reasons for power loss

1. Copper Losses

The windings have electrical resistance, causing energy to be lost as heat ($P = I^2R$).

2. Hysteresis Losses

The magnetic core is repeatedly magnetised and demagnetised by the AC supply, causing energy to be lost as heat.

3. Eddy Current Losses

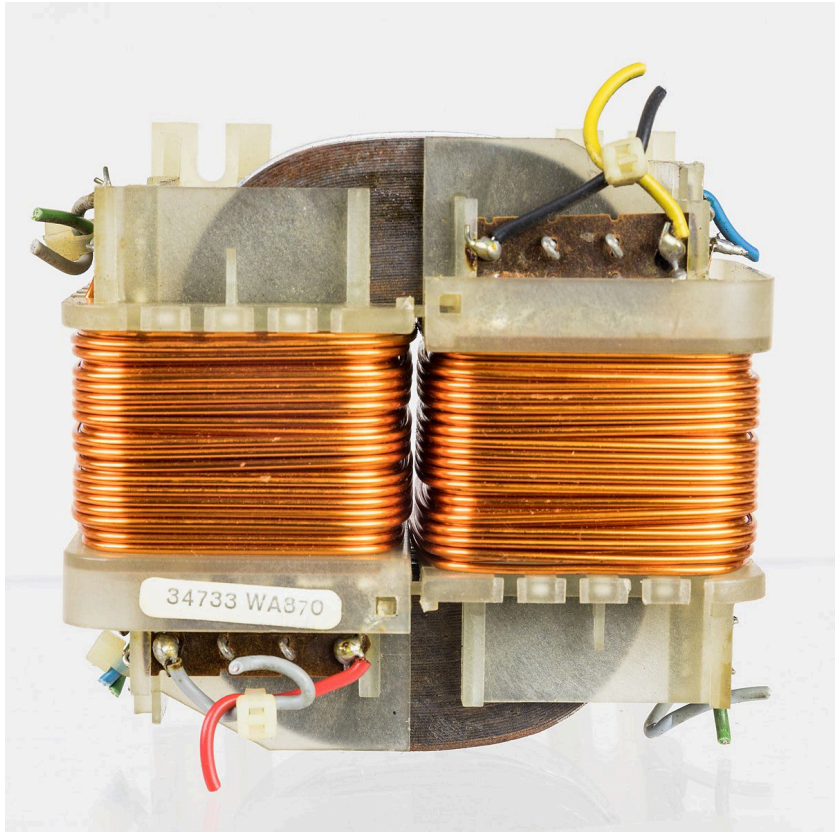
The changing magnetic field induces circulating currents within the metal core, generating unwanted heat.

4. Magnetic Flux Leakage

Some magnetic flux does not link both windings, reducing magnetic coupling and contributing to voltage drops under load.

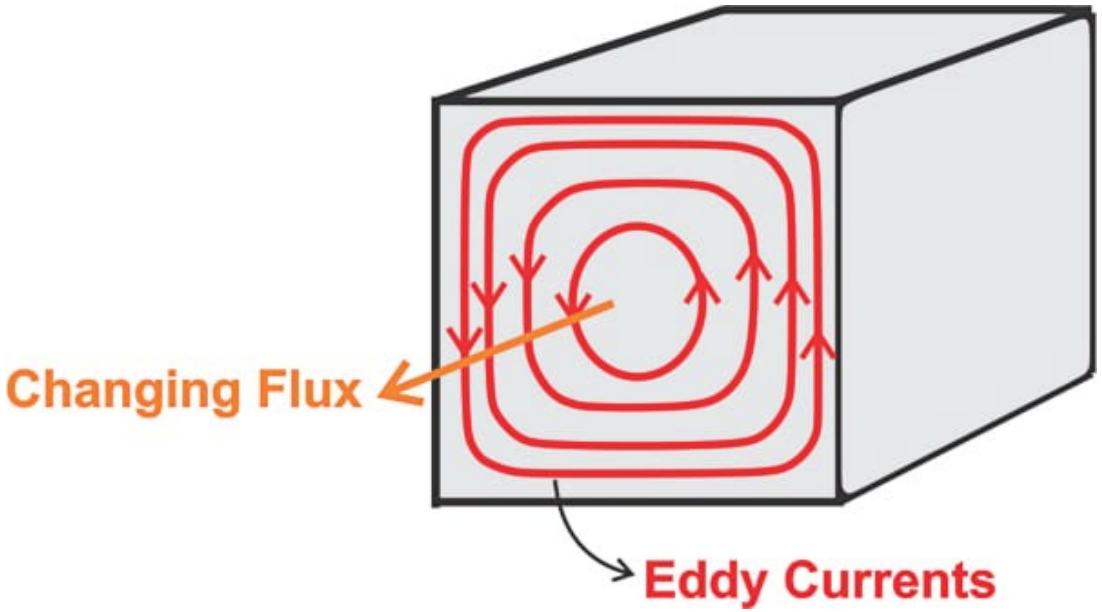
Source of Power Loss - Windings

- One of the areas power loss can come from is the resistance of the wire that makes up the windings
- The formula for this is $\boldsymbol{P = I^2 R}$ where:
  - P = Power Loss
  - I = Current
  - R = Resistance



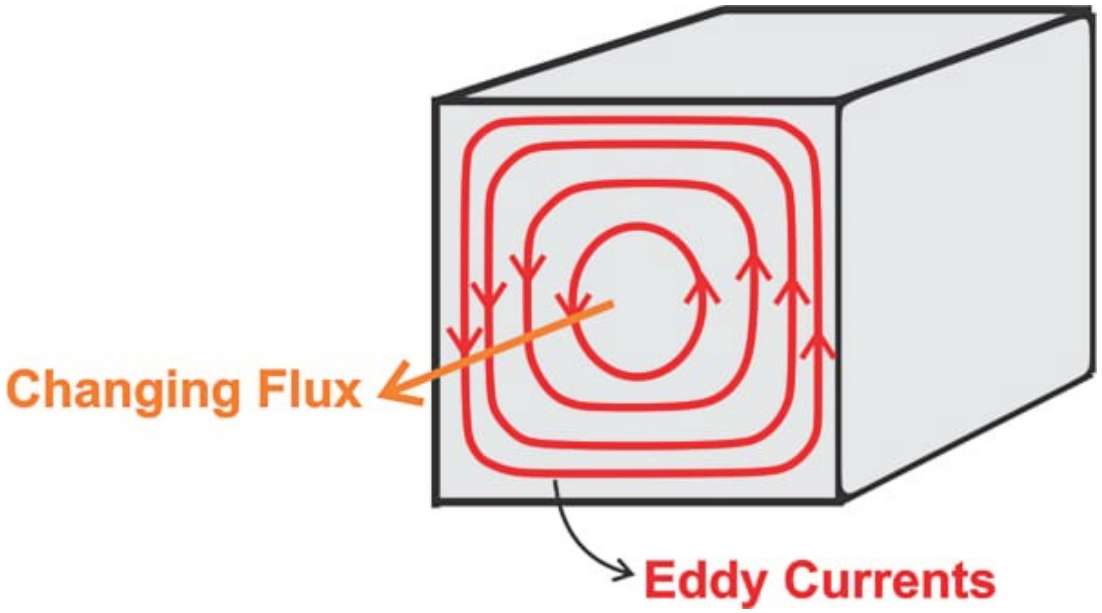
Source of Power Loss - Core

- Another area with potential for power loss is the core due to the magnetic effects it is under
- One source of power loss is **Hysteresis Loss** which happens when the magnetic field reverses with each AC cycle
- Another source is Eddy Current Loss which is when a current is induced in the core that makes energy dissipate as heat



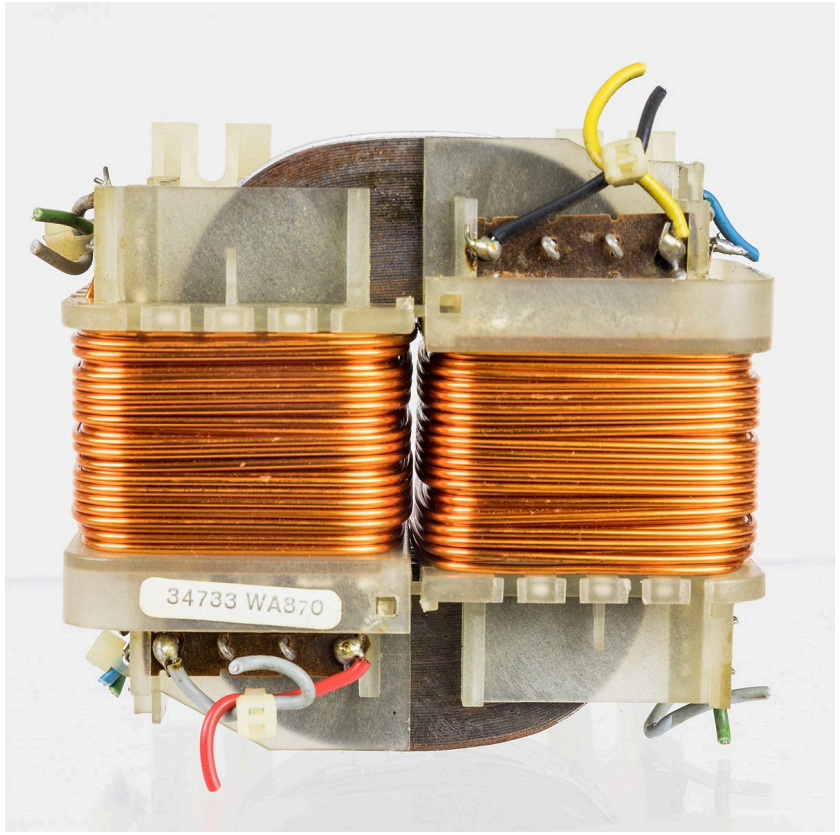
Source of Power Loss - Core

- The loss due to eddy current loss can be calculated using the equation:
- $\boldsymbol{P_{eddy} = K_e * B^2 * f^2 * t^2 * V}$
- Where:
  - P_{eddy} is the power loss
  - K_e is the constant from the core material
  - B is magnetic flux density
  - f is the frequency of the AC source
  - t is the thickness of the laminated sheets
  - V is the volume of the core material



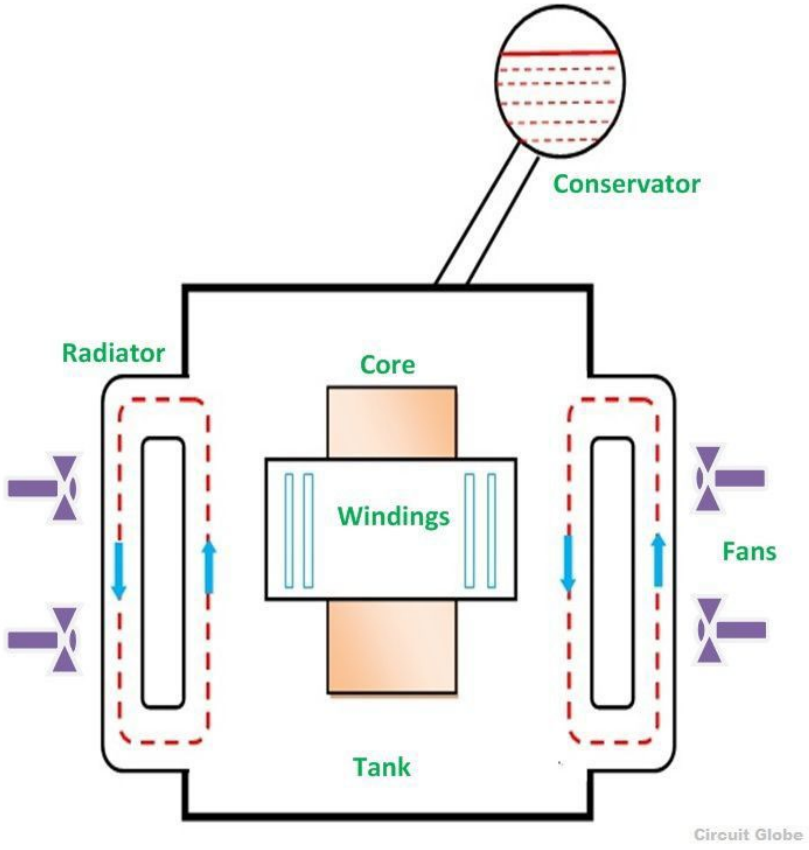
Reducing Power Loss - Windings

- We can reduce the power loss in the windings by using a low resistance material
- Though we also want a material that is easily wound, strong against heat and strong against vibration
- Copper is often used



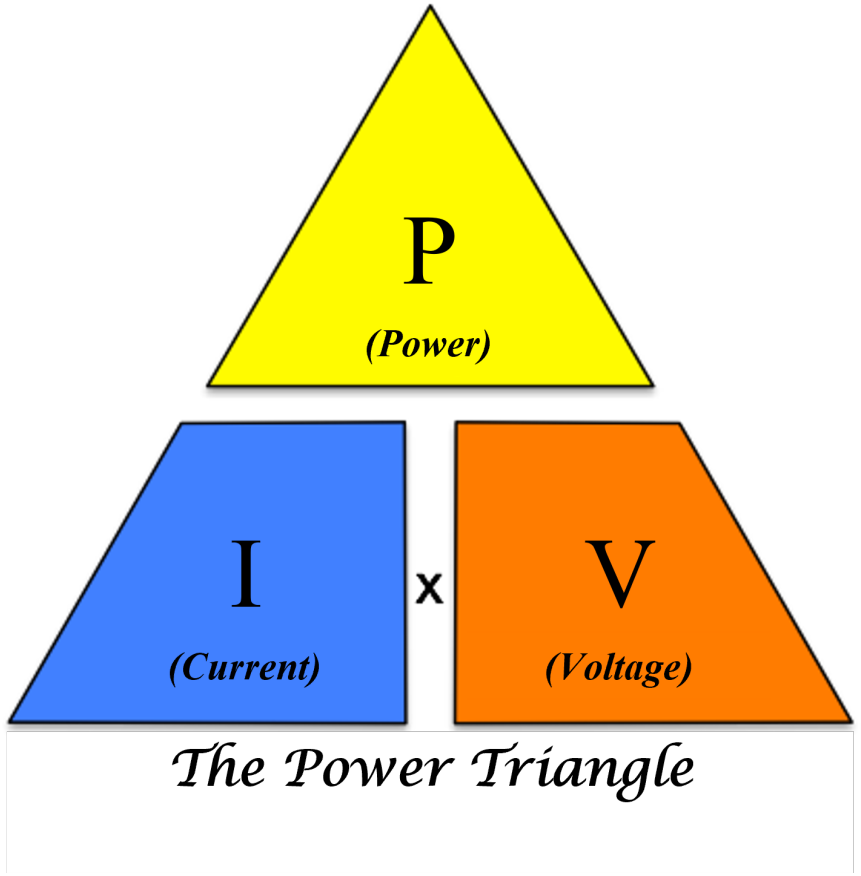
Reducing Power Loss - Core

- **Cooling:** Improve efficiency by using oil or air-cooling systems to dissipate heat.
- **Laminated Cores**: Reduce eddy current losses by using thin layers of core material (laminations) insulated from each other.



Working out power efficiency/loss

- We can work out the power efficiency of a transformer using the equation:
- $\frac{Power_P}{Power_S}$ or $\frac{V_P * I_P}{V_S * I_S}$
- The equation for power loss is:
- $Power_P - Power_s$



Calculating Change (Voltage) (Real)

- The relationship between the amount of turns and the windings voltages do not change when you factor in power inefficiencies

  - $\boldsymbol{V_S = V_P * \frac{N_S}{N_P}}$

  - Where:
    - V_P = primary (input) voltage
    - V_S = secondary (output) voltage
    - N_S = number of secondary winding turns
    - N_P = number of primary winding turns

Calculating Change (Current) (Real)

- The relationship between the amount of turns and the windings current does change when factoring in power inefficiencies

  - $\boldsymbol{I_S = I_P * \frac{N_P}{N_S} * \eta\%}$

  - Where:
    - I_P = primary (input) current
    - I_S = secondary (output) current
    - N_S = number of secondary winding turns
    - N_P = number of primary winding turns
    - η = the efficiency of the transformer

Relating Voltage and Current (Real)

- In a real scenario there will be power losses
- So, for a 2% power loss: $\boldsymbol{98\%Power_P = Power_s}$
- So, we can write it as: $\boldsymbol{98\%(V_P * I_P) = V_S * I_S}$
- Again we can rearrange this to find any of the values when we have the other 3 as well as the power loss of the transformer

$$\frac{\boldsymbol{\eta\%(V_P * I_P)}}{\boldsymbol{V_S}} = \boldsymbol{I_S}$$

Safety Considerations

- **High Voltage Hazards:** Transformers operate at high voltages, which can be dangerous. Always ensure transformers are properly insulated and grounded to prevent electrical shock.
- **Proper Grounding:** Ensure that the transformer is grounded correctly to prevent potential electric shock hazards and ensure safe operation. Faults in grounding systems can lead to electrical fires or system failures.
- **Overload Protection:** Use fuses or circuit breakers to prevent transformers from being overloaded, which could cause overheating and potential damage or fire. Overcurrent protection is essential for the safety of both the transformer and the connected circuit.

Safety Considerations

- **Transformer Ventilation:** Ensure that transformers have adequate ventilation or cooling systems (such as oil or air cooling) to prevent overheating. Excessive heat can degrade transformer insulation and increase the risk of fire.

- **Inspection and Maintenance:** Regularly inspect the transformer for any signs of wear, leaks, or damaged insulation. Perform routine maintenance to ensure efficient operation and detect any potential issues before they become safety hazards.

- **Environmental Considerations:** Be aware of any environmental hazards, such as temperature extremes or moisture, which can affect transformer operation and safety. In case of a transformer malfunction or failure, be prepared to handle toxic fumes or fire risks.