

2.7 The National Grid

Name: _____ Class: _____ Date: _____

Total: 25 marks**KEY WORDS** National Grid

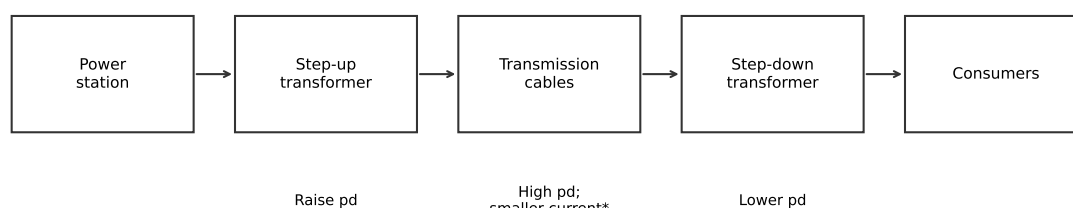
- step-up transformer
- step-down transformer

Objective

Describe the National Grid, the two transformer types, and explain – with $P = I^2R$ – why transmitting at very high potential difference is efficient. Original questions for specification 4.2.4.3.

1 Key knowledge and worked examples

The **National Grid** connects power stations to consumers through a system of cables and transformers.



*Same power entering the line; ideal transformer comparison

Higher pd for transmission; lower pd for domestic appliances.

Transformer	What it does
step-up	raises the potential difference for the transmission cables
step-down	lowers the potential difference for domestic appliances

Explain the physical chain:

1. For the same power entering the transmission line, $P = VI$: a **higher potential difference** means a **lower current** in the cables.
2. The power wasted by heating the cables is $P = I^2R$ – the cables' resistance is fixed.
3. Halving the current wastes **a quarter** of the power. So very high potential difference keeps transmission losses small – the Grid is an efficient way to transfer energy.

(How transformers themselves work is Higher Tier, physics only – see topic 4.7. Here you only need the system-level explanation.)

Worked example – teacher-written model. A simplified line receives 500 kW at its sending end. Total cable resistance is $2.0\ \Omega$. Compare sending-end pd 10 kV and 20 kV, keeping input power and resistance fixed and treating transformers as ideal. This is a simplified resistive-line calculation, not a real three-phase network model.

Convert: $P_{\text{in}} = 500\,000\ \text{W}$; $V_1 = 10\,000\ \text{V}$; $V_2 = 20\,000\ \text{V}$.

Current follows from $P = VI$, and cable heating from $P_{\text{loss}} = I^2R$.

$$\begin{aligned}I_1 &= \frac{P_{\text{in}}}{V_1} = \frac{500\,000\ \text{W}}{10\,000\ \text{V}} = 50\ \text{A} \\P_{\text{loss},1} &= I_1^2R = (50\ \text{A})^2 \times 2.0\ \Omega = 5000\ \text{W} \\I_2 &= \frac{P_{\text{in}}}{V_2} = \frac{500\,000\ \text{W}}{20\,000\ \text{V}} = 25\ \text{A} \\P_{\text{loss},2} &= I_2^2R = (25\ \text{A})^2 \times 2.0\ \Omega = 1250\ \text{W}\end{aligned}$$

Double the sending pd $\rightarrow$ half the current $\rightarrow$ one quarter of the cable loss. Input power is fixed, but useful output increases because loss is smaller. If total input is not given, a loss calculation alone cannot establish a loss percentage or efficiency.

2 Practice

2.1 Name the system that connects power stations to consumers, and the two devices that change the potential difference along it. [3]

2.2 State what a step-up transformer does and where it is placed in the system. [2]

2.3 The current in a transmission cable is halved. State what happens to the power wasted in the cable, and the equation that shows it. [2]

3 Exam-style questions

3.1 A power station generates electricity at 25 000 V for the National Grid.

- (a) Explain why a step-up transformer is used before the transmission cables. [4]
- (b) Explain why a step-down transformer is needed before electricity enters homes. [2]

3.2 A transmission cable carries 2000 A and has resistance $40\ \Omega$.

- (a) Calculate the power wasted by heating in the cable. [2]
- (b) The current is reduced to 500 A at a higher potential difference, with the same power entering the line in a simplified resistive model. Calculate the new wasted power. [2]
- (c) Use your answers to explain why the National Grid is described as an efficient way to transfer energy. [2]

3.3 Two villages argue about a new transmission line.

Village A: “Build it at 400 000 V – less energy wasted.” Village B: “Build it at 132 000 V – safer and cheaper pylons.”

(a) Use physics to support Village A’s claim, with the two equations involved. [4]

(b) Give one reason the planners still choose a lower potential difference near populated areas. [2]

Solutions

2.1 The National Grid; a step-up transformer and a step-down transformer.

2.2 It increases (steps up) the potential difference; it is placed between the power station and the transmission cables.

2.3 The wasted power falls to **one quarter**; $P = I^2R$: the resistance is unchanged, so halving I quarters I^2 and hence the wasted power.

3.1 (a) The step-up transformer raises the potential difference for transmission; for the same power entering the transmission line $P = VI$, the higher potential difference means a smaller current in the cables; the power wasted by heating the cables is $P = I^2R$; a smaller current wastes much less energy in the cables, so the transfer is more efficient. (b) Homes need a lower potential difference suitable for appliances (about 230 V, still potentially dangerous); the step-down transformer reduces the very high transmission potential difference to the domestic value.

3.2 (a)

$$P = I^2R = (2000 \text{ A})^2 \times 40 \text{ } \Omega = \mathbf{1.6 \times 10^8 \text{ W}}$$

(C1, A1 with unit.) (b)

$$P_{\text{loss}} = I^2R = (500 \text{ A})^2 \times 40 \text{ } \Omega = \mathbf{1.0 \times 10^7 \text{ W}}$$

(C1, A1.) (c) Cutting the current to a quarter (for the same sending-end power in the model, at higher pd) cut the wasted power to one sixteenth; less energy is lost to cable heating, so a greater fraction reaches consumers; no numerical efficiency or loss fraction follows without the total input.

3.3 (a) At the higher potential difference the current in the line is smaller, because the sending-end power obeys $P = VI$ – for the same power, larger V means smaller I ; the line's wasted power is $P = I^2R$ with fixed R ; so the 400 kV line wastes far less energy as heat – $(132/400)^2 \approx 11\%$ of the 132 kV line's loss at the same sending-end power in the simplified model. (b) Any one: very high potential difference needs taller pylons, wider safety clearances and more insulation – near homes that is costly and harder to make safe; lower pd reduces the danger and cost of the local section even though losses rise over a short distance.