

Power Lines

Build a National Grid: pylons, transformers and cables that carry power from power stations to towns without wasting it.

UK Years 9–13

Ages 13–18

US grades 8–12

Physics · Electricity



Inside this pack

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Play it free

dowplay.com/games/power-lines

Runs in any browser on Chromebooks, iPads, laptops and phones. No accounts, no ads, nothing to install. Progress is saved only on the device being used.

A separate PDF has the worksheets on their own, ready to print for students.

1 · OVERVIEW

What students learn

Power Lines turns the National Grid into a puzzle. Students build the network that carries electricity from power stations to a village, a farm, towns, a steelworks, a city and an island: overhead lines at 11, 33, 132 and 400 kV, transformers where voltages meet, and underground or undersea cables where pylons aren't allowed. The game solves every network with real physics: the current in each line, the energy wasted heating it ($P = I^2 \times R$) and the voltage lost on the way. Its eight levels run from Year 9 to Year 13.

By the end, students can

- describe how the **National Grid** carries electricity from power stations to homes
- use $P = I \times V$ to work out the current in a power line
- use $P = I^2 \times R$ to explain why cables waste energy, and why a **higher voltage wastes less**
- explain what **step-up** and **step-down transformers** do
- explain why every cable has a **current rating**
- weigh cost against losses and the landscape when **designing a network**

You will need

- One device per pair (any browser)
- A projector for the starters
- Worksheet 1 or 2 for each student, and calculators

Timing

Each lesson plan fills 60 minutes. The levels also work as a homework or a club activity: each takes 5–15 minutes.

Curriculum links

Course	Content	Levels
KS3 Science (England)	Energy transfer by electricity; power in watts; the idea that wires and appliances transfer energy	1–2
GCSE Physics / Combined Science	The National Grid: step-up and step-down transformers, and why electricity is transmitted at high voltage; $P = I V$ and $P = I^2 R$; energy wasted heating wires	1–8
GCSE Physics (higher tier)	Transformers: for an ideal transformer $V_p \times I_p = V_s \times I_s$, and $V_p \div V_s = N_p \div N_s$	3–8
A-level Physics	Resistance of wires and power losses; potential difference along a conductor	4–8
US (NGSS)	HS-PS3-3; MS-ETS1-1, MS-ETS1-2 and HS-ETS1-3: designing solutions within criteria and constraints such as cost, efficiency and environmental impact	All

2 · TEACHER BACKGROUND

How the game works

The map is a real network:

1. Each square is 5 km. Lines join the middles of neighbouring squares: across, up, down or diagonally. Power stations, towns and factories connect at their **yard**, the grey square with a yellow ring.
2. Lines of the same voltage that meet on a square join up. Different voltages only join through a **transformer** on that square. Each power station makes power at its own voltage, and each place needs power at its own voltage, so they usually need a transformer too.
3. For every line, the game works out the current needed to deliver the power it carries ($P = I \times V$), the voltage it loses ($V = I \times R$) and the energy it wastes heating up ($P = I^2 \times R$). A place counts as **powered** when it gets at least **94%** of its voltage.

Lines and cables (per 5 km square)

Voltage	Carried on	Resistance	Safe current (rating)	Overhead cost	Cable cost
11 kV	wooden poles	2.0 Ω	300 A	£2m	£8m
33 kV	steel poles	1.5 Ω	400 A	£3m	£12m
132 kV	pylons	0.5 Ω	800 A	£5m	£20m
400 kV	large pylons	0.1 Ω	2,000 A	£10m	£40m

A diagonal step is 7.07 km, so it costs about 1.4 times as much (rounded to the nearest £1m) and has 1.4 times the resistance. Underground and undersea **cables** work in the same way as overhead lines but cost four times as much. Pylons can't stand in water or in the national park: there, only cable will do.

Transformers

A transformer joins every voltage that meets on its square. The game treats it as ideal: the power going out equals the power coming in, so stepping the voltage up steps the current down. It costs **£4m** for voltages up to 33 kV, **£8m** for 132 kV and **£15m** for 400 kV (whichever is the highest voltage on its square), plus **£10m** for a platform if it stands out at sea.

The rules

- No line may carry more than its rating: it would overheat and sag. Overloaded lines glow red.
- A power station can't make more than its capacity, including the power wasted in the lines.
- Some levels limit the share of the power that may be wasted (between 2% and 5%).
- Lines mustn't form a loop, and two power stations mustn't be joined. (Real grids do both; it keeps the maths simple.)

2 · TEACHER BACKGROUND (CONTINUED)

Reading the screen

Lines are coloured by voltage: **green 11 kV**, **blue 33 kV**, **purple 132 kV** and **red 400 kV**. Moving dots show power flowing away from the power station: the faster they move, the bigger the current. Places stay grey until they are powered, then light up. The goals at the top show which places are powered and how much power is wasted.

Turning on **Numbers** labels every line with its current and the power it wastes, every place with the voltage it receives, and each power station with the power it sends out. The figures on the worksheets are taken straight from that view.

Stars

1 star for a network that works, 2 for staying within the budget, 3 for matching the cheapest design we know. Costs are in millions of pounds and roughly in proportion to the real ones.

Key words

National Grid	The network of cables and transformers that links power stations to homes and businesses.	Transformer	Changes the voltage of an electricity supply. A step-up transformer raises it; a step-down transformer lowers it.
Transmission	Carrying electricity long distances at very high voltage (400 kV, 275 kV).	Distribution	Sharing electricity out locally at lower voltages (132 kV, 33 kV, 11 kV).
kV, MW	1 kV = 1,000 volts. 1 MW = 1,000,000 watts.	Current rating	The largest current a cable can carry safely before it overheats.
Power loss	Energy wasted heating the wires each second: $P = I^2 \times R$.	Substation	A fenced site with transformers, where lines of different voltages meet.

Safety note. Overhead power lines carry voltages that can kill without contact: electricity can jump across the air gap. Remind students never to climb pylons, fly kites or drones near power lines, or go near fallen cables, and to stay out of substations.

The real National Grid

Power station generators make electricity at around 25 kV. In Great Britain, step-up transformers raise it to **400 kV or 275 kV** for the transmission network. Near towns it's stepped down to **132 kV, 33 kV and 11 kV** for the local distribution networks, and street transformers bring it down to the **230 V** used in homes. Roughly 2% of the electricity is lost in the transmission network and around 5–6% in the distribution networks.

What the model leaves out

Real grids use alternating current (AC) on three wires at once, so transformers can work; the game uses simple DC sums, which give the same ideas. Real transformers waste 1–2% of the power, real current ratings change with the weather, and real underground cables at the highest voltages can cost far more than four times an overhead line. Good discussion points with older students.

3 · LEVEL GUIDE

Level by level

"3 stars" is the cheapest design we know. Keep it to yourself until students have had a go: the fun is in the search. All currents are the largest in the line.

1 Switch On

Year 9 · Power lines carry energy

- Watch for** A line that stops next to a yard instead of reaching it.
- 3 stars, £6m** A straight 11 kV line, 3 squares: 76 A, 4.1% wasted, Ashby gets 95.9% of its voltage.
- Ask** "Ashby takes 0.8 MW at 11 kV. What current is that?" (73 A. The line carries 76 A because the station also supplies the 35 kW wasted on the way.)

2 Far Away Farm

Year 9 · $P = I^2 \times R$

- Watch for** 11 kV all the way: so much voltage is lost that the power can't get through. 33 kV without a transformer at the farm.
- 3 stars, £32m** Transformers at the power station and the farm, and a 33 kV line, 8 squares: 62 A, 2.3% wasted.
- Ask** "Three times the voltage means a third of the current. What happens to the power wasted?" (A ninth.)

3 Step Up, Step Down

Year 10 · Transformers

- Watch for** No transformer at the power station (it makes 25 kV). 33 kV: 30 MW would need 909 A, far over the 400 A rating.
- 3 stars, £66m** Step up to 132 kV at the power station and down to 11 kV at Riverton, 10 squares: 229 A, 0.87% wasted.
- Ask** "Why not use 400 kV here?" (It works, but costs £130m: well over budget.)

4 The Steelworks

Year 10 · Current ratings

- Watch for** 132 kV all the way: 1,178 A, well over the 800 A rating, and the line glows red.
- 3 stars, £110m** 400 kV, 8 squares, with transformers at both ends (the steelworks takes 132 kV): 375 A, 0.08% wasted.
- Ask** " $150 \text{ MW} \div 132 \text{ kV} = 1,136 \text{ A}$. Why does the game show 1,178 A?" (The voltage falls along the line, so more current is needed.)

3 · LEVEL GUIDE (CONTINUED)

Level by level

5 Two Towns

Years 10–11 · Branching networks

- Watch for** Splitting too early: the long 33 kV branches waste too much (7.6%). 33 kV all the way: the power can't get through.
- 3 stars, £80m** 132 kV to column 10, a transformer there, and a 33 kV branch to each town: main line 159 A, branches 318 A, 4.6% wasted.
- Ask** "Where is most of the power wasted, and why?" (In the 33 kV branches: bigger current.)

6 The National Park

Year 11 · Underground cables

- Watch for** Pylons in the park (not allowed). Cable straight through the middle: it works, but costs £176m.
- 3 stars, £124m** 132 kV overhead round to the park's narrow neck at the bottom, 3 squares of underground cable across it, then overhead again: 308 A, 1.5% wasted.
- Ask** "Underground cable costs four times as much. When is it worth it?"

7 The Big City

Years 11–12 · A hierarchy of voltages

- Watch for** 132 kV to the city (2,574 A). An 11 kV branch to Stoke Hill (its voltage falls to 92.7%).
- 3 stars, £193m** A 400 kV line to Kingsport (12 squares, 757 A); Elm Green on its own 33 kV line from the power station; Stoke Hill on a 33 kV branch tapped off the 400 kV line, with a transformer at column 10: 0.24% wasted.
- Ask** "Why is Elm Green fed from the power station, but Stoke Hill from the big line?" (Elm Green is close; tapping the 400 kV line costs a £15m transformer.)

8 Wind at Sea

Years 12–13 · Offshore wind

- Watch for** 132 kV to Seaham (1,190 A). An 11 kV cable to Gull Island (328 A, over its 300 A rating).
- 3 stars, £288m** A transformer on the wind farm's platform; 400 kV undersea cable to the coast (4 squares) and overhead to Seaham (6 squares), 375 A; a 33 kV cable to Gull Island, 92 A: 0.12% wasted.
- Ask** "Why is it worth paying for a transformer out at sea?"

4 · LESSON PLAN · YEARS 9–10 · 60 MINUTES

Lesson 1: Why the grid uses high voltages

Objectives

- Describe how electricity gets from a power station to a home.
- Use $P = I \times V$ to work out the current in a power line.
- Explain why a higher voltage wastes less energy.

Resources

- Worksheet 1 (one each), calculators
- Devices, one per pair
- Power Lines on the projector

Time	Activity
Starter 10 min	Ask: "Your phone charger uses a few volts. Why are there pylons carrying 400,000 volts across the country?" Collect ideas. Then open Level 2, Far Away Farm and build an 11 kV line straight to the farm: it glows red-hot and the power can't get through. Undo, and ask what could help.
Main 1 15 min	Worksheet 1, Part A: label the National Grid, then use $P = I \times V$ and $P = I^2 \times R$ for the farm at 11 kV and 33 kV.
Main 2 25 min	Pairs play levels 1–4 and fill in the record table (Part B). Before building, one partner predicts the current with $P = I \times V$. Circulate and ask: "Where does the voltage change? What do you need there?"
Plenary 10 min	Part C together, with the Far Away Farm figure: 62 A and 46 kW wasted, 2.3% of the power. Exit ticket: <i>why does the National Grid step the voltage up, and why does it step it down again?</i>

Support

Use the in-game hints. Give the formula triangle for $P = I \times V$, and a reminder that 33 kV = 33,000 V and 2 MW = 2,000,000 W.

Stretch

Turn on Numbers and check every current against $P = I \times V$. Try Level 5, Two Towns, and explain why the main line's current is about half the branches' total, but at a higher voltage.

Misconceptions to listen for

- "A higher voltage wastes more energy." It's the other way round: for the same power, a higher voltage means a smaller current, and the energy wasted depends on the current squared.
- "A transformer makes more power." A step-up transformer raises the voltage but lowers the current: the power stays (almost) the same.
- "The current gets used up along the line." The current is the same all along a line; it's energy that is wasted, as heat.

Homework: Worksheet 1, Part D, and get 3 stars on Level 2.

5 · LESSON PLAN · YEARS 11–13 · 60 MINUTES

Lesson 2: Designing a power network

Objectives

- Use $P = I V$, $P = I^2 R$ and the transformer equation in calculations.
- Explain why cables have current ratings.
- Evaluate network designs on cost, efficiency and environmental impact.

Resources

- Worksheet 2 (one each), calculators
- Devices, one per pair
- Power Lines on the projector

Time	Activity
Starter 10 min	Show Level 4, The Steelworks with a 132 kV line and Numbers on: 1,178 A, glowing red. "The line is rated 800 A. What are our options?" Take answers (thicker wire, two lines, a higher voltage), then build the 400 kV design: 375 A.
Main 1 15 min	Worksheet 2, questions 1–3: currents and losses at different voltages, the transformer equation, and current ratings.
Main 2 25 min	Pairs play levels 5–8 (Year 11 mainly levels 5–6; Years 12–13 levels 7–8). Use questions 4–5 to guide Two Towns and The National Park.
Plenary 10 min	Plan question 6 together: an evaluation of high-voltage transmission. Finish it as homework.

Support

Model one full calculation on the board: $P \rightarrow I \rightarrow I^2 R \rightarrow$ percentage wasted. In Two Towns, have students label each line with its current before they start building.

Stretch

The Big City: work out whether tapping the 400 kV line or running a separate 33 kV line is cheaper for each village before building. Wind at Sea: find the cheapest working design.

Misconceptions to listen for

- "Just use thicker wires." Thicker conductors help, but they're heavier and dearer, and losses still grow with the current squared. Raising the voltage cuts the current far more cheaply.
- "Higher voltage is always better." It needs bigger pylons, more expensive transformers and wider safety clearances, so it's only worth it for large amounts of power.
- "Underground cables are always better for the environment." They protect the view, but digging the trench disturbs land and wildlife, and faults are slower to find and fix.

Homework: Worksheet 2, question 6 (6 marks).

The National Grid

Name: _____ Class: _____ Date: _____

Power = current × voltage: $P = I \times V$, so $I = P \div V$. **Power wasted heating a wire:** $P = I^2 \times R$.
 1 kV = 1,000 V · 1 MW = 1,000,000 W · 1 kW = 1,000 W

Part A · From power station to home

A1 This diagram shows how electricity gets from a power station to a home.



- a) and b) Write **step-up** or **step-down** in the gaps (a) and (b). [2]
 c) What voltage do homes in the UK use? [1]

A2 In **Switch On**, the village of Ashby takes 0.8 MW at 11 kV. Work out the current it takes. [2]

A3 In **Far Away Farm**, the farm needs 2 MW.

- a) What current would an 11 kV line need to carry? [1]

- b) What current would a 33 kV line need to carry? [1]

- c) The 33 kV line is 40 km long and has a resistance of 12 Ω . Use $P = I^2 \times R$ to work out the power wasted heating it. [2]

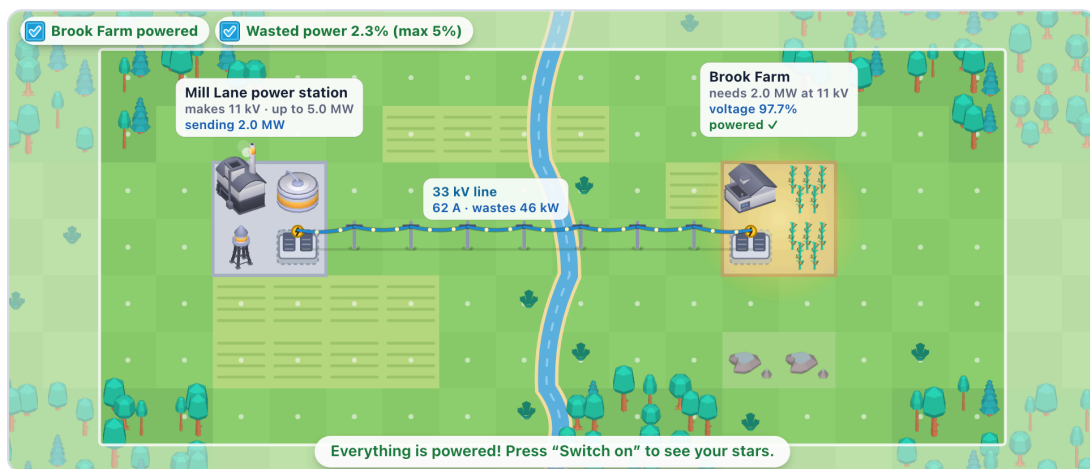
- d) Tripling the voltage cuts the current to a third. How many times smaller does that make the power wasted? [1]

Part B · Play levels 1 to 4

Before you build, use $P = I \times V$ to predict the current. Record your best design for each level.

Level	Voltages used	Transformers	Cost	Stars	What went wrong, and how I fixed it
1			£ m		
2			£ m		
3			£ m		
4			£ m		

Part C · Read the numbers



C1 This is **Far Away Farm** with a 33 kV line and **Numbers** on. Read the current in the line and the power it wastes. The station sends out 2,046 kW: what percentage is wasted? [3]

C2 Brook Farm gets 97.7% of its voltage, not 100%. Explain why. [2]

Part D · Explain

D1 Explain how the National Grid uses transformers to get electricity to homes efficiently and safely. Use the words *current*, *voltage* and *energy wasted*. [4]

Losses, ratings and network design

Name: _____

Class: _____

Date: _____

$P = I \times V$ · $P = I^2 \times R$ · $V = I \times R$ · ideal transformer: $V_p \times I_p = V_s \times I_s$ and $V_p \div V_s = N_p \div N_s$
Each map square is 5 km. Resistance per square: 33 kV line 1.5Ω · 132 kV line 0.5Ω · 400 kV line 0.1Ω

1 Step Up, Step Down. Riverton needs 30 MW. It is 10 squares (50 km) from the power station.

a) What current would a 33 kV line carry? [1]

b) A 33 kV line is only safe up to 400 A. What would happen to it? [1]

c) What current would a 132 kV line carry? [1]

d) Work out the resistance of the 132 kV line, the power wasted in it, and that power as a percentage of 30 MW. [3]

2 Transformers. The power station's step-up transformer changes 25 kV into 132 kV.

a) Its primary coil has 1,000 turns. How many turns does the secondary coil need? [2]

b) 30.3 MW goes into the transformer. Assuming it's ideal, work out the current in the primary coil and in the secondary coil. [2]

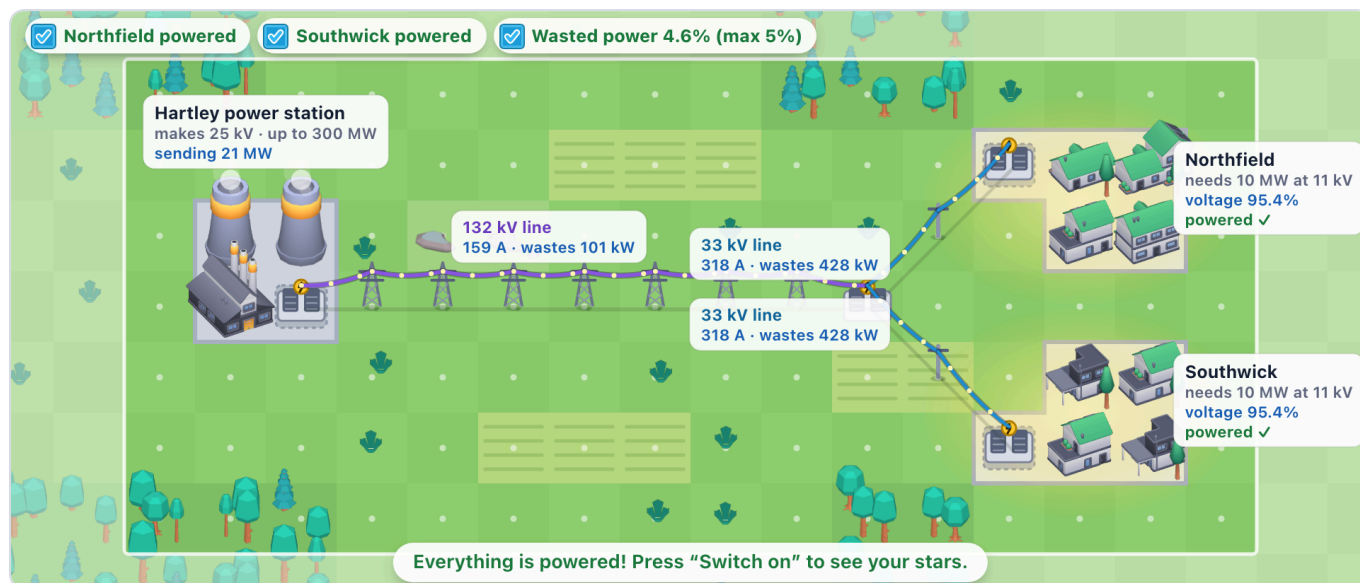
3 The Steelworks needs 150 MW. A 132 kV line is rated at 800 A.

a) Work out the current in a 132 kV line. Can it be used? [2]

b) The game shows 1,178 A in the 132 kV line, a bit more than your answer. Suggest why. [2]

c) What current would a 400 kV line carry? [1]

4 Two Towns. One 132 kV line runs from the power station to a substation, where a transformer feeds a 33 kV branch to each town. Each town needs 10 MW.



a) Use the figure to show that the power going into the substation is about the same as the power coming out. [2]

b) Which lines waste the most power? Explain why. [2]

c) An engineer suggests 132 kV lines all the way to both towns: £92m and 0.5% wasted, instead of £80m and 4.6% wasted. Give one argument for and one against. [2]

5 The National Park. 132 kV costs £5m per square overhead, and £20m per square as underground cable. Each transformer costs £8m.

a) One design goes straight through the park: 4 squares overhead and 7 squares of underground cable, with two transformers. Work out its cost. [2]

b) The 3-star design costs £124m by crossing the park where it's narrowest. Give two reasons why engineers sometimes pay for underground cables anyway. [2]

[6]

Plan your answer first. For each idea, note the evidence from the game and whether it's an advantage or a disadvantage.

Idea	Evidence from Power Lines (numbers or levels)	Advantage or disadvantage?
Current		
Energy losses		
Cost		
Safety and environment		

Now write your answer, finishing with a conclusion.

7 · ANSWERS

Worksheet 1 answers

Part A

A1 a) **Step-up**. b) **Step-down**. c) **230 V**.

A2 $I = P \div V = 800,000 \div 11,000$ (1) = **73 A** (1).

A3 a) $2,000,000 \div 11,000 =$ **182 A**.

b) $2,000,000 \div 33,000 =$ **61 A**.

c) $P = 60.6^2 \times 12$ (1) = **44,000 W**, or 44 kW (1).

(Rounding to 61 A gives 45 kW: also correct.)

d) **9 times** smaller (3²).

Part C

C1 **62 A** and **46 kW** (1); $46 \div 2,046 \times 100$ (1) = **2.2%** (1). (The game shows 2.3%, from unrounded numbers.)

C2 The line has resistance (1), so some voltage is lost along it: $V = I \times R = 62 \times 12 \approx 740$ V, about 2.3% of 33 kV (1).

Part D

D1 Any four: a step-up transformer at the power station raises the voltage (1); this lowers the current for the same power (1); a smaller current wastes less energy heating the cables, as $P = I^2 R$ (1); a step-down transformer lowers the voltage again near homes (1); to a safe 230 V for homes (1). Also credit: lower currents need thinner, cheaper cables.

More from DowPlay

Free engineering games for ages 12–18: **Light It Up** (circuits), **Grid Manager** (renewable energy), **Logic Lab** (logic gates), **Gear Garage** (gears and machines) and **Bridge Builder** (structures), each with a free teacher pack. Ideas for new games? Get in touch at dowplay.com/about#contact.

Worksheet 2 answers

- 1 a) $30,000,000 \div 33,000 = \mathbf{909\text{ A}}$.
 b) It would **overheat** and sag, and could fail (more than twice its rating).
 c) $30,000,000 \div 132,000 = \mathbf{227\text{ A}}$.
 d) $R = 10 \times 0.5 = \mathbf{5\ \Omega}$ (1); $P = 227^2 \times 5 = \mathbf{258\text{ kW}}$ (1); $258 \div 30,000 \times 100 = \mathbf{0.86\%}$ (1). (The game shows 0.87%.)
- 2 a) $N_s = 1,000 \times 132 \div 25$ (1) = **5,280 turns** (1).
 b) Primary: $30,300,000 \div 25,000 = \mathbf{1,212\text{ A}}$ (1); secondary: $30,300,000 \div 132,000 = \mathbf{230\text{ A}}$ (1).
- 3 a) $150,000,000 \div 132,000 = \mathbf{1,136\text{ A}}$ (1): more than the 800 A rating, so **no** (1).
 b) The line has resistance, so the voltage falls along it (1); at a lower voltage, more current is needed to deliver the same power (1).
 c) $150,000,000 \div 400,000 = \mathbf{375\text{ A}}$.

- 4 a) In: $132,000 \times 159 \approx \mathbf{21.0\text{ MW}}$ (1). Out: $2 \times 33,000 \times 318 \approx \mathbf{21.0\text{ MW}}$ (1). (Each town gets 10 MW; the rest is wasted in the 33 kV branches.)
 b) The **33 kV branches**, 428 kW each (1): their current, 318 A, is twice the main line's, and the power wasted depends on I^2 , with more resistance per square too (1).
 c) For: it wastes far less energy, so it costs less to run (1). Against: it costs £12m more to build, and the 3-star design is within the 5% limit (1).
- 5 a) $4 \times \text{£}5\text{m} + 7 \times \text{£}20\text{m} + 2 \times \text{£}8\text{m}$ (1) = **£176m** (1).
 b) Any two: to protect beautiful landscapes such as national parks; near homes, towns or airports where pylons aren't wanted or can't go; across water; cables are safer from storms, ice and wind.

Question 6 mark scheme (6 marks)

Level	Description
3 (5–6 marks)	A detailed evaluation of current, energy losses, cost and safety, explaining how they are linked and using evidence from the game (numbers or levels). Reaches a justified conclusion.
2 (3–4 marks)	Explains at least two factors with some evidence. The conclusion is partial or not fully justified.
1 (1–2 marks)	Simple statements about one or two factors, with little explanation.
0	Nothing worthy of credit.

Indicative content

Current and losses

- $P = I V$: a higher voltage needs a smaller current
- Losses are $I^2 R$, so they fall with the square of the current
- Step Up, Step Down: 909 A at 33 kV; 0.87% wasted at 132 kV

Ratings and cost

- Smaller currents stay within cable ratings (The Steelworks: 1,178 A vs 375 A)
- Thinner, cheaper cables can be used
- But high-voltage pylons and transformers cost more, so lower voltages suit small loads

Safety and environment

- Very high voltages are dangerous: tall pylons, clearances, substations fenced off
- Step-down transformers give a safe 230 V for homes
- Pylons spoil views; cables cost more (The National Park)

Credit references to alternating current (needed for transformers), the efficiency of transformers, and the UK grid's 400 kV and 275 kV transmission lines.