



KING ETHELRED'S COLLEGE OF ENGINEERING

Established in 978 (ish)

DEPARTMENT OF IMPROBABLE SYSTEMS,
LOAD FORECASTING AND DOMESTIC THERMODYNAMICS

SYNCHRONISED BOILING: THE DOMESTIC KETTLE AS A GRID-SCALE LOAD EVENT

An investigation into television pick-up, half-time thermodynamics and the remarkable national capacity for doing one thing at once



A departmental research thesis prepared under the College Fellowship Ordinance
(Kettles and Domestic Plant) 1911

*Fortitudine.
Ingenio.
Tea and biscuits.*

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ABSTRACT

The domestic kettle is the most numerous item of heavy electrical plant in the United Kingdom and the only one routinely operated by people in dressing gowns. Individually it is a 3 kW resistive load of no consequence. Collectively, and given a penalty shoot-out, it is a scheduled emergency. This thesis treats the half-time surge as a demand-response problem in reverse: a population that cannot be persuaded to stagger its showers will, unprompted and to the second, align its boiling.

The phenomenon is known to the system operator as television pick-up. It is real, it is forecast daily, and its record remains the 2,800 MW step that followed the England v West Germany penalty shoot-out of 4 July 1990, a figure commonly expressed as roughly 933,000 kettles switched on together. The study reviews the electrical characteristics of the kettle, the physics of grid frequency, the response of pumped-storage plant, the operator's forecasting practice and the gradual decline of the pick-up in an age of streaming. A fictional but physically plausible Senior Common Room trial is used to examine the human factors, including anticipatory boiling, the Overfill Penalty and the re-boil.

The principal finding is that the British public constitutes a highly reliable synchronous load which is merely selective about the cause. The secondary finding is that the national grid has, for forty years, been engineered around the assumption that several million people will want tea at exactly the same moment, and that this assumption has never once been wrong. The thesis recommends that the kettle be formally recognised as critical national infrastructure and that the College's proposal for staggered half-times be referred to the football authorities without expectation.

Research status. This is a fictional King Ethelred's College thesis. Television pick-up, the 1990 record, the frequency limits, the pumped-storage response times and the thermodynamics of boiling water are real and referenced. The Senior Common Room trial in Chapter 6 is synthetic and constructed to be plausible rather than represented as measurements actually performed. Mrs Partridge has asked that this be made clear.

Keywords: kettle; television pick-up; grid frequency; pumped storage; Dinorwig; demand forecasting; half-time; thermodynamics; tea; national character.

ACKNOWLEDGEMENTS

The author wishes to thank the National Energy System Operator's demand forecasting team, whose published explanations of television pick-up provided the inconveniently factual portions of this work, and whose professional obligation to watch the television schedule for a living is acknowledged with something between admiration and envy.

Thanks are due to First Hydro's Dinorwig Power Station, which has spent four decades being ready for the nation's tea, and to the Department of Civil Engineering, which lent a clamp meter after being assured that no bridge work would be delayed. The Department later asked why the clamp meter had been returned with a teaspoon attached.

Mrs Enid Partridge of the Senior Common Room agreed to take part in the Chapter 6 trial on condition that nobody timed her. She was timed. The College apologises, and notes that the result was in any case remarkable.

The College Estates Office is thanked for confirming that the Senior Common Room ring main is rated for six kettles and that the seventh was, in the Office's words, 'a matter for the Bursar'. The Bursar has asked that his views on the seventh kettle be recorded as strongly held and not repeated.

Finally, the author acknowledges the several million members of the public who, on the evening of 4 July 1990, without instruction, coordination or the slightest awareness of the system operator, produced the largest synchronised demand event in British electrical history and then sat down again.

Statement on nomenclature. Throughout this thesis the term *kettle* refers to the electric jug kettle in ordinary British domestic use. Stove-top kettles are acknowledged as heritage plant. The American practice of heating water in a microwave is outside the scope of the study and, the College suggests, of civilisation.

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NOMENCLATURE

Symbol	Meaning
P	electrical power drawn by a kettle, W
E	energy required to raise water to boiling, J
m	mass of water in the kettle, kg
c	specific heat capacity of water, 4,186 J/(kg K)
ΔT	temperature rise from tap to boil, K
f	system frequency, Hz
ΔP	step change in system demand, MW
N_k	kettle-equivalent of a demand step, $\Delta P / 3 \text{ kW}$
t_b	time to boil, s
t_r	response time of reserve plant, s
KRI	Kettle Readiness Index (Chapter 7)
OP	Overfill Penalty (Section 2.3)
AB	anticipatory boiling: switching on before the whistle
SCR	Senior Common Room
TVP	television pick-up
NESO	National Energy System Operator (formerly National Grid ESO)

1 INTRODUCTION

1.1 Background

Every evening the electricity system of Great Britain is balanced, second by second, by engineers who must know in advance what the population is about to do. Most of what the population does is gradual. It gets up, it goes to work, it comes home, it cooks, it goes to bed, and the demand curve rises and falls with the polite inevitability of a tide. There is one exception. When a sufficiently large number of people are watching the same programme and the programme stops, they all stand up at once, and a measurable fraction of them put the kettle on.

The system operator calls this television pick-up. It has been forecast, managed and occasionally dreaded since the 1970s. Its record was set on 4 July 1990, when the end of the England v West Germany World Cup semi-final penalty shoot-out imposed a demand step of about 2,800 MW on the system, a figure the operator itself has expressed as roughly 933,000 kettles.[1][2] The audience is estimated at 26 million. The England team lost. The kettles did not.

The College considers this a matter of some engineering interest. A 2,800 MW step is more than the output of a large nuclear station. It arrives with no notice beyond the television schedule, it lasts a few minutes, and it must be met without allowing the frequency of the entire synchronous system to sag outside its statutory limits. That it is met, reliably and largely invisibly, is a genuine achievement. That it is caused by tea is the reason this thesis exists.

1.2 Research questions

- What does a kettle actually demand of the electricity system, and why is the British kettle so much more demanding than its overseas relations?
- How large is a television pick-up, how has it changed, and what does the operator do about it?
- What happens to system frequency in the seconds after several hundred thousand kettles switch on, and what stands between that moment and the lights going out?
- How do individual operators behave at half-time, and can their behaviour be classified, timed and gently criticised?
- Should the kettle be treated as critical national infrastructure, and if so, who should be told?

College hypothesis. The nation's electricity system is not really sized for industry, heating or transport. It is sized for the moment when Coronation Street finishes, and everything else is fitted in around it.

2 THE KETTLE AS ELECTRICAL PLANT

2.1 Ratings and the 13 A plug

The British domestic kettle owes its character to the BS 1363 plug and socket, which provide a fused 13 A supply at a nominal 230 V. The arithmetic is short. Thirteen amperes at 230 V is 2,990 W, which is why the mass-market kettle is rated at or just under 3 kW, and why the element can be heard beginning its work before the lid has quite closed. A kettle is essentially a large resistor with a handle. There is no motor, no electronics worth the name and no capacity to be reasoned with.

The comparison with North America is instructive and is developed in Chapter 8. A 120 V circuit protected at 15 A yields about 1,800 W as an absolute ceiling and about 1,500 W in practice for a portable appliance. The transatlantic kettle therefore takes roughly twice as long to do the same job, which explains a great deal about the transatlantic reputation of tea.

2.2 Energy to boil

The energy required to bring water from tap temperature to boiling is given by $E = m c \Delta T$. For one litre from 15 °C to 100 °C, with $c = 4,186 \text{ J/(kg K)}$, the figure is about 356 kJ. At 3 kW and with an effective efficiency of 90 per cent this corresponds to about 132 seconds. A single mug of 0.3 L requires about 40 seconds. Figure 2.1 shows the relationship, which is linear and therefore ought to be well understood by the public. Chapter 7 will show that it is not.

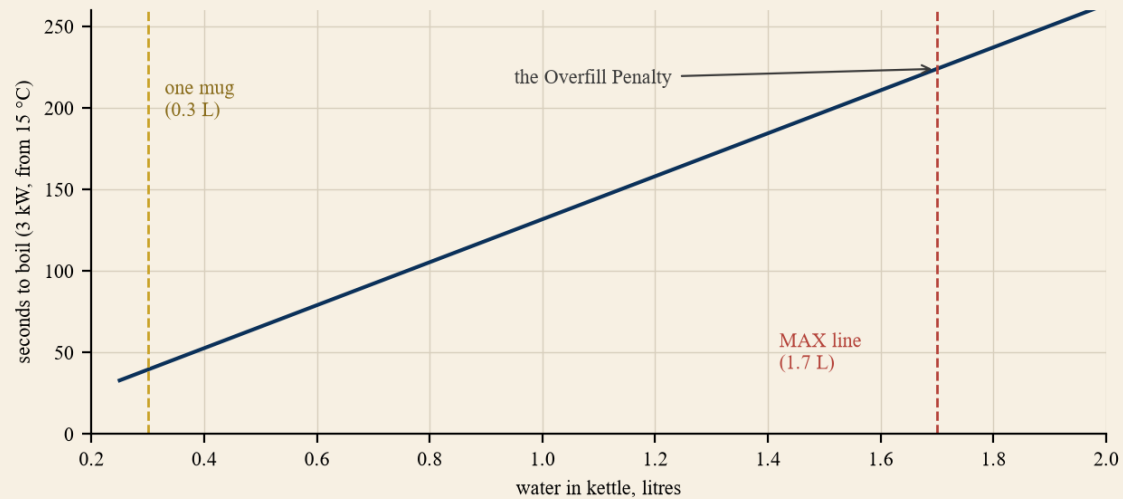


Figure 2.1 - Time to boil against fill volume for a 3 kW kettle from 15 °C, assuming 90 per cent of the electrical energy reaches the water. The Overfill Penalty is the vertical distance between what the operator wanted and what the operator filled.

2.3 The Overfill Penalty

The Overfill Penalty is defined as the additional energy, time and grid demand incurred by boiling more water than will be used. It is universal. An operator who requires one mug and fills the kettle to the MAX line demands the same 3 kW for roughly five times as long, and returns the balance of the water to room temperature in the kettle where it awaits the re-boil. The College regards the Overfill Penalty as the largest single avoidable domestic energy loss that nobody intends to do anything about.

It should be noted in fairness that the Penalty does not increase the size of a television pick-up, which is governed by the number of kettles switched on and not by their fill. It does, however, extend the duration of the event, which matters to the operator because reserve plant has to keep running until the last overfilled kettle clicks off.

2.4 The kettle population

Ownership surveys have consistently placed the electric kettle in the great majority of British households, and the number of households is a little under 29 million. The system therefore contains, at a conservative estimate, more than 25 million kettles, with an aggregate connected load in the region of 75 GW. This exceeds the peak demand of the entire system by a comfortable margin. The kettle population is, in other words, a fully installed emergency which the nation has agreed not to operate all at once, and the whole of Chapter 3 concerns what happens when it comes close.

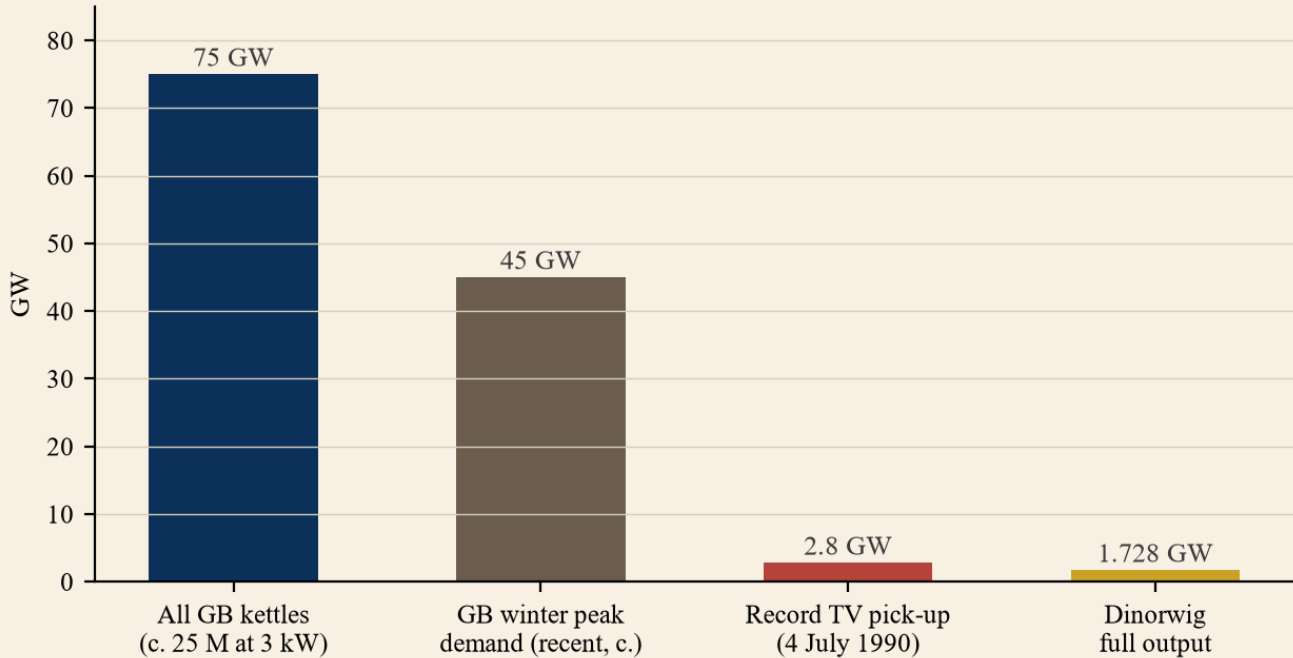


Figure 2.2 - Indicative comparison of the connected kettle fleet with the system's recent winter peak demand, the record pick-up and the output of Dinorwig. The kettle figure is an estimate from ownership and household counts; the other three are published values.[1][5][10]

3 TELEVISION PICK-UP

3.1 The phenomenon

A television pick-up is a rapid rise in demand caused by a large audience doing the same thing when a programme pauses or ends. The operator attributes it principally to kettles, with contributions from lights, refrigerators whose doors have been opened, and the water pumps that follow a synchronised visit to the lavatory.[1] The last of these is the subject of a separate and more delicate literature.

The size of a pick-up depends on the audience, on how simultaneously the programme releases it, and on how many of them were already holding a cup. Sporting fixtures are the strongest cause because their breaks are exact, shared and emotionally significant. A soap opera produces a smaller but more predictable step because it ends at the same time every week and the audience has rehearsed.

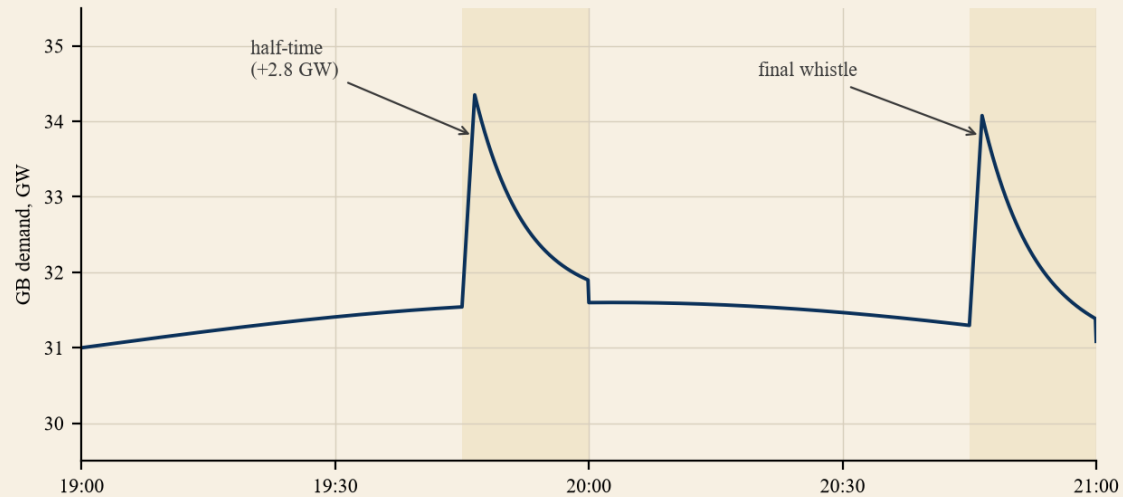


Figure 3.1 - Illustrative shape of national demand through a televised evening match, with half-time and final-whistle steps of the 1990 magnitude superimposed on a typical background. The shape is schematic; the 2.8 GW is not.

3.2 The historical record

Published lists of the largest pick-ups are dominated by football and by the occasional national event.[2] The figures most often quoted are given in Table 3.1. The 1990 semi-final stands alone, partly because of the audience and partly because a penalty shoot-out ends with a single kick, after which there is nothing whatever left to watch.

Event	Date	Step	Kettle-equivalent
England v West Germany, World Cup semi-final, penalty shoot-out	4 July 1990	c. 2,800 MW	c. 933,000
The Thorn Birds, final episode	22 January 1984	c. 2,600 MW	c. 867,000
Royal wedding, Prince of Wales and Lady Diana Spencer	29 July 1981	c. 1,800 MW	c. 600,000
England v Tunisia, World Cup group match	18 June 2018	c. 600 MW	c. 200,000

Table 3.1 - The largest published television pick-ups. Kettle-equivalents assume 3 kW per kettle and nothing else switched on, which is generous to the kettle.

Two things are apparent. The first is that the nation will boil a kettle for a wedding, a war of the Roses in a television mini-series, or a football match, and does not appear to distinguish sharply between them. The second is the decline in magnitude over time, which is examined in Chapter 5 and which the College regards as the most significant cultural change in the electrical history of the country.

3.3 Why the audience is a synchronous load

Engineers spend considerable effort attempting to shift domestic demand. Off-peak tariffs, smart meters and a great many leaflets have been deployed to persuade households to run their washing machines at night. The results are modest. Yet the same households, offered no incentive at all, will align their behaviour to within a few seconds when a referee blows a whistle. The difference is not the strength of the signal but its nature: a tariff asks for cooperation, while a half-time break supplies an occasion. The College notes that the demand-side industry has not yet tried simply asking the public to boil the kettle now, all together, for the good of the system. It suspects it would work.

4 FREQUENCY, INERTIA AND THE FIRST SIXTEEN SECONDS

4.1 What frequency measures

The synchronous system of Great Britain runs at a nominal 50 Hz. The frequency is not a setting but a balance: when generation exceeds demand the rotating machines of the system speed up and the frequency rises, and when demand exceeds generation they slow and it falls. The operator is required to hold the steady-state frequency within statutory limits of 49.5 to 50.5 Hz and aims in normal operation to stay within 49.8 to 50.2 Hz.[3][4] A large pick-up is therefore a direct assault on the one number the operator is not allowed to lose.

4.2 The dynamics of a kettle step

When several hundred thousand kettles switch on within a few seconds, the additional power is at first supplied by the kinetic energy of every rotating generator on the system, which slow down together. This is inertia, and its contribution is measured in seconds. It buys time; it does not buy tea. Within those seconds, plant that has been contracted to respond to frequency must begin to increase its output, and within tens of seconds enough reserve must be delivering to arrest the fall and begin recovery. Figure 4.1 shows the shape of the event in schematic form.

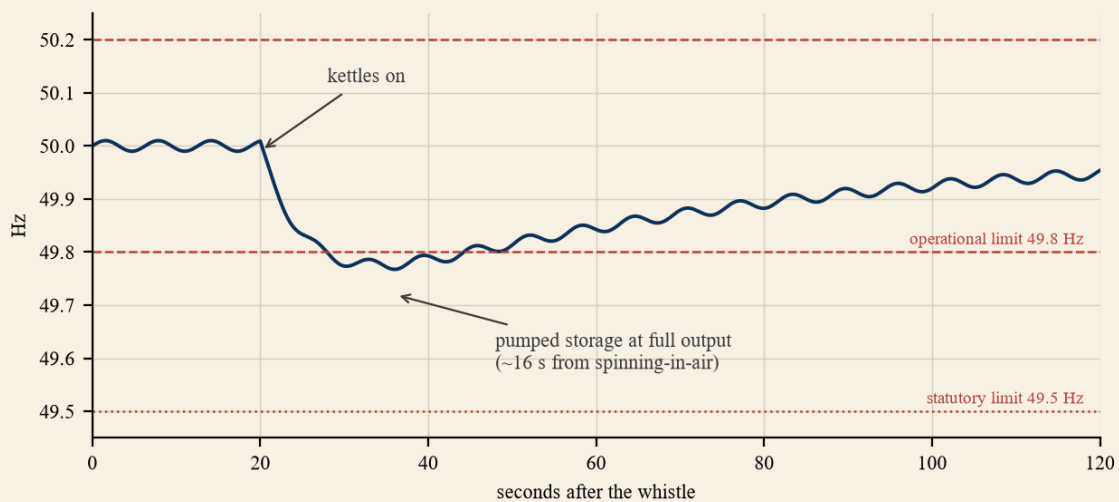


Figure 4.1 - Schematic frequency excursion following a large kettle step, with the operational and statutory lower limits. The curve is illustrative. The limits, and the response time, are real.

4.3 Dinorwig, or the mountain that waits for half-time

The classic response to a television pick-up is pumped-storage hydroelectricity, and the classic pumped-storage station is Dinorwig in north Wales. Built inside Elidir Fawr and commissioned in 1984, it can deliver up to 1,728 MW and, with its six units synchronised and spinning in air, can reach full load in around sixteen seconds.[5][6] Water that was pumped uphill overnight, when nobody wanted anything, falls through the mountain at the precise moment that everybody wants the same thing.

The College wishes to draw attention to the scale of this arrangement. A mountain in Snowdonia was hollowed out, at considerable expense, so that a proportion of the water in Llyn Peris could be held in readiness for the end of EastEnders. The College does not say this to mock. It says it because it is one of the finest examples in existence of engineering built around an accurate understanding of human behaviour, and because it is generally described in the literature as though the human behaviour were incidental.

Departmental observation. A nuclear station cannot be asked to hurry. A gas turbine can be asked, but will take a few minutes to agree. Dinorwig simply opens a valve. It is the only major plant on the system whose operating philosophy is recognisably that of a person who has heard the front door and put the kettle on.

4.4 The newer reserves

In recent years the response services have been supplemented by batteries, which are faster still, and by contracted reductions in industrial load. Battery response is measured in fractions of a second and requires no mountain. The College acknowledges the improvement while noting that a battery, however fast, lacks the moral weight of 9 GWh of Welsh rainwater held against the possibility of a penalty shoot-out.

5 FORECASTING AND THE DECLINE OF THE PICK-UP

5.1 Watching the schedule for a living

The operator's demand forecasters study the television schedule as a matter of professional duty. Programme timings, audience predictions, the length of advertising breaks and the likelihood of extra time are all considered, and the forecast is refined during the event itself. A match that goes to penalties is the forecaster's equivalent of a storm warning: the step will be larger, later and sharper than the schedule implied, and the plant must be held ready for longer than anyone budgeted.[1]

The College observes that this may be the only job in the country in which watching the football is not merely tolerated but structurally necessary, and in which the correct professional response to a late equaliser is to telephone Wales.

5.2 The decline

The largest pick-ups belong to the 1980s and 1990s. Since then the audience has fragmented across channels, shifted in time by recording and streaming, and moved partly to devices that do not involve a living room at all. Households watching the same match on a slightly delayed stream are no longer synchronous to the second, and a step spread over a minute is a much gentler thing than a step delivered in ten seconds. The 2018 World Cup opener produced a pick-up of about 600 MW, respectable but a fraction of 1990.[7]

Domestic technology has changed too. Modern televisions draw far less than the cathode-ray sets of 1990, so the switch-off at the end of a programme no longer offsets so much of the kettle step, and lighting has moved to LED. The kettle itself, however, remains a 3 kW resistor with a handle. Of all the electrical equipment in the home it is the one that progress has declined to touch, and the College regards this as correct.

5.3 Residual synchronicity

The decline should not be overstated. Major tournaments, royal occasions and national ceremonies still produce steps in the hundreds of megawatts, and the operator still plans for them. The nation's capacity for simultaneous boiling is diminished, not lost. It is, in the College's assessment, dormant rather than extinct, and would return in full at the first sign of an England penalty shoot-out on a single free-to-air channel.

5.4 A worked forecast

To illustrate the forecaster's problem, Table 5.1 sets out a synthetic timeline for an England knock-out match on a single free-to-air channel with an audience of twenty million. The steps are the Department's estimates, scaled from the published record, and are offered to show the shape of the evening rather than to predict any particular one.

Broadcast event	Time	Expected step	Forecaster's note
Kick-off	20:00	small fall	Lights off, kettles idle, nation seated
Half-time whistle	20:47	+1,200 MW	Reliable; the referee is on our side
Second half kicks off	21:03	gradual fall	Overfillers still boiling
Full-time, level scores	21:52	+900 MW	Smaller than half-time; the anxious do not leave the room
Extra time, half-way	22:09	+500 MW	Unbudgeted; call Wales
Penalty shoot-out ends	22:31	+2,000 MW or more	Everything at once; nothing left to watch
Post-match analysis	22:35	fall	Televisions off; the studio is not compelling

Table 5.1 - Synthetic pick-up timeline for a knock-out match. The pattern is drawn from the operator's published descriptions; the numbers are the Department's own and should not be used to schedule a mountain.

The final row deserves comment. The end of a penalty shoot-out releases the whole audience in the same second and leaves it with nothing to return to. The step is therefore not only large but unusually sharp, and the forecaster's only warning is the moment, some minutes earlier, when extra time ends level. The Department suggests that this is the closest thing British engineering has to a storm cone, and that it is hoisted by a referee.

6 THE SENIOR COMMON ROOM TRIAL

6.1 Design

To examine the human factors of a pick-up at a scale the Bursar would approve, a synthetic trial was constructed in the Senior Common Room. Eight members of the College were provided with a kettle each, a mug each, a televised match and no instructions. Kettle switch-on times were recorded relative to the half-time whistle by a clamp meter on each supply. The results are presented in Figure 6.1 and are, as the abstract makes clear, plausible rather than real.

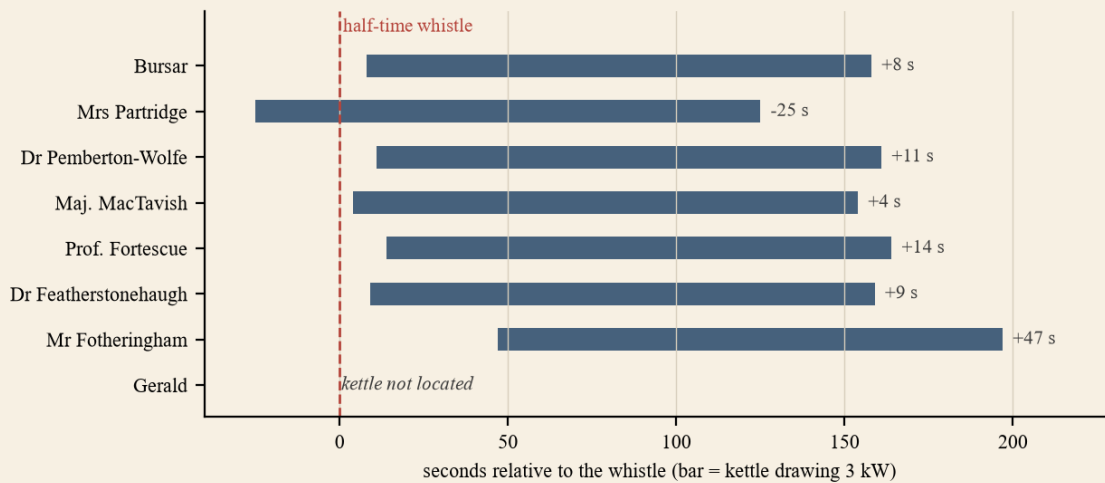


Figure 6.1 - Synthetic Senior Common Room trial. Each bar is a kettle drawing 3 kW, plotted from switch-on relative to the half-time whistle. Mrs Partridge's negative value is discussed below. Gerald's kettle was not located.

6.2 Results

Six of the eight kettles were switched on within fifteen seconds of the whistle, which reproduces the national behaviour with a fidelity the Department found faintly unsettling. Major MacTavish was fastest at four seconds, having risen during the added time on the reasonable grounds that nothing was going to happen. Professor Fortescue took fourteen seconds, most of which was spent locating his spectacles in order to find the switch.

Mr Fotheringham switched on at forty-seven seconds, having first delivered a short account of the Apollo Guidance Computer's power budget to a colleague who had not asked. His kettle was also the only one filled to the MAX line and consequently the last to finish, demonstrating the Overfill Penalty in its natural habitat.

Mrs Partridge switched on twenty-five seconds before the whistle. When asked how she had known, she said that it was obvious, and that the referee had been looking at his watch. The Department has classified this behaviour as anticipatory boiling and regards it as the single most valuable demand-management technique identified in the programme. It is not clear that it can be taught.

Gerald could not be found. His kettle could not be found either. The Department notes that a kettle which cannot be found imposes no load on the system and is in that narrow sense the most efficient kettle in the trial.

6.3 The seventh kettle

At the moment of maximum coincident demand six kettles were drawing a combined 18 kW from a ring main which Estates had rated for exactly that. Mr Fotheringham's late start was therefore the difference between a trial and an incident. The Department records that the College's own frequency-response strategy at half-time consisted of one man explaining spacecraft to another, and that it worked.

7 HUMAN FACTORS AND THE KETTLE READINESS INDEX

7.1 Operator classification

Drawing on the trial and on several decades of informal observation, the Department proposes the following classes of half-time kettle operator.

Class	Behaviour	Effect on the system
Anticipator	Switches on before the whistle on the basis of the referee's body language	Spreads the step earlier; wholly beneficial; rare
Sprinter	Rises at the whistle and reaches the kettle in under ten seconds	Forms the leading edge of the pick-up
Deliberator	Rises at the whistle, discusses the first half, then boils	Extends the event; reduces the peak
Overfiller	Fills to MAX for one mug	Doubles the duration; increases Dinorwig's working day
Re-boiler	Returns during the second half to boil water already boiled	Creates an unforecast secondary step; deplored
Absentee	Cannot be located, along with the kettle	None; efficient; suspicious

Table 7.1 - Classes of half-time kettle operator. Households commonly contain more than one class, and marriages have been tested on the point.

7.2 The Kettle Readiness Index

The Kettle Readiness Index expresses, on a scale from 0 to 1, the fraction of a household's kettles which are filled to the required level, plugged in and within reach of a person who intends to use them at the next break. A KRI of 1 indicates a household prepared for half-time as for an air raid. A KRI of 0 indicates a household in which the kettle is being used to hold pens. National KRI is not measured. The College estimates it from pick-up magnitudes and suspects it is higher than the country would care to admit.

7.3 One for the pot

The doctrine of one for the pot, under which an additional measure of tea is added beyond the number of drinkers, has an electrical analogue. The extra water boiled for a cup that nobody will drink is a small Overfill Penalty on every kettle in the country, and the College calculates that it is nationally significant while accepting that it is nationally non-negotiable. The section is included for completeness and not in the expectation of reform.

7.4 The click

The kettle announces the end of its duty cycle with a click, produced when a bimetallic thermostat in the base deflects under steam temperature and opens the supply. The click is a genuine engineering signal: it marks, to within a second, the moment at which 3 kW leaves the system. It is also, in the Department's observation, the only industrial control signal in the country to which the entire population is trained to respond, usually by standing up in another room.

Aggregated across a pick-up, the clicks form the trailing edge of the event. Because fill volumes vary, they are spread over a minute or more, and the demand recovers as a slope rather than a step. The operator is therefore spared a second transient, and Dinorwig is stood down gradually. The nation does not know it is doing this. It is doing it anyway.

7.5 The re-boil

The re-boil occurs when water that has already been boiled, and has cooled while the operator was distracted, is boiled again. It is common, unforecast and, from the system's point of view, entirely gratuitous: the second boil consumes almost as much energy as the first and arrives at a moment nobody planned for, typically during play. The Department has been unable to find any published estimate of national re-boil energy and suspects that this is because nobody has wanted to know.

A related and more forgivable case is the top-up boil, in which the operator adds a little water to an already hot kettle. The energy is modest. The habit of doing it during a penalty shoot-out is not.

8 ANTICIPATORY BOILING: TOWARDS A THEORY

8.1 The observation

Mrs Partridge's negative switch-on time in Chapter 6 was not an error. She had, by her own account, noticed that the referee was looking at his watch, that the fourth official was reaching for the added-time board, and that the commentator's voice had acquired the slightly valedictory tone that precedes a whistle. She acted on these signals and had a full mug before the players had left the pitch. The Department regards this as the single most important finding of the trial and has spent some time trying to understand it.

8.2 The added-time board as a demand signal

The fourth official's board, raised at the end of normal time to show the minutes to be added, is not intended as an instrument of grid management. It is nonetheless the earliest public and unambiguous notice of when the whistle will come, and it is seen by the entire audience at the same instant. An anticipator who responds to the board spreads their contribution to the pick-up by up to five minutes ahead of the sprinters, and if a large fraction of the audience did the same the half-time step would become a half-time ramp.

The Department is aware that persuading twenty million people to boil the kettle at the sight of a small illuminated number is an ambitious programme. It notes only that they already stand up at the sound of a whistle, and that the difference between a whistle and a board is one of habit rather than principle.

8.3 Limits of the technique

Anticipatory boiling fails in two circumstances. The first is the late goal, in which the anticipator has boiled and the game has not stopped, producing a cooled kettle and, in due course, a re-boil. The second is the anticipator who is wrong about the referee. Mrs Partridge reports that she has never been wrong about a referee. The Department has not been able to test this claim and is not inclined to try.

Departmental finding. The most effective demand-side technology observed in the programme was a woman of some years' experience watching a referee. It requires no capital, no tariff and no leaflet. The Department has not yet found a way to install it in twenty million households and would welcome proposals.

9 COMPARATIVE NATIONAL BEHAVIOUR

Television pick-up is not unique to Britain, but it is unusually pronounced here, and the College attributes this to three factors. The first is the 3 kW kettle, which delivers a sharper step per household than the 1.5 kW appliances of 120 V countries. The second is tea, which is brewed with freshly boiled water and cannot, as coffee can, be kept warm in a jug all evening. The third is a long national habit of watching the same programme at the same time and regarding the break as an instruction.

Continental Europe shares the voltage and lacks the tea. North America shares neither and has the refrigerator, whose door-opening surge is real but modest and whose contents do not need boiling. The College has not attempted a full international comparison, partly for want of data and partly because every draft of the section began to sound like an argument about kettles that had been going on since 1776.

Statement on the microwave. The Department has been asked to comment on the practice of heating water for tea in a microwave oven. It declines. It notes only that a microwave is a 1 kW appliance, that it produces no audible click, and that a nation which adopted it would lose both the pick-up and the point.

10 POLICY IMPLICATIONS

10.1 Critical national infrastructure

The College recommends that the domestic kettle be recognised formally as critical national infrastructure. The case is straightforward. It is the largest aggregate load on the system, it is the cause of the largest demand steps in the system's history, a mountain has been hollowed out to accommodate it, and its behaviour is more predictable than that of most generators. It is difficult to identify another item of plant that meets all four tests.

10.2 The kettle as a demand-side resource

If the public can synchronise its boiling to a whistle, it can in principle synchronise it to anything. The College proposes, without much hope, a national Kettle Signal: a short broadcast tone, issued by the operator when surplus wind generation is depressing prices, inviting the nation to boil now. The energy would be stored in the form of tea, which is the only storage medium the public has ever shown any enthusiasm for. Estates has asked to be consulted before the tone is trialled in College.

10.3 Staggered half-times

The most direct means of reducing a pick-up is to reduce its simultaneity. The College has therefore drafted a proposal to the football authorities under which the half-time whistle would be blown at slightly different moments in different regions of the country. The proposal has been reviewed by the Department of Applied Geopolitics, which described it as 'technically sound and politically the end of the College', and it has been placed in the archive with the other recommendations of that character.

11 CONCLUSIONS

- The British kettle is a 3 kW resistive load whose rating is fixed by the 13 A plug, and whose aggregate installed capacity comfortably exceeds the peak demand of the system that supplies it.
- Television pick-up is real, forecast daily, and historically capable of steps approaching 3 GW, the record being the 2,800 MW that followed the 1990 World Cup semi-final shoot-out.
- The system survives these events through inertia, contracted frequency response and pumped storage, of which Dinorwig can reach 1,728 MW in about sixteen seconds. The statutory frequency limits have been held.
- Pick-ups have declined with the fragmentation and time-shifting of audiences, but the underlying capacity for synchronised boiling is dormant rather than lost.
- The synthetic Senior Common Room trial reproduced national behaviour closely, identified anticipatory boiling as the most valuable technique available, and confirmed that Gerald cannot be found.
- The fourth official's added-time board is the earliest public notice of a pick-up and could, in principle, convert the half-time step into a ramp. In practice it would first have to be explained to the public, and then to the fourth official.
- The kettle satisfies every reasonable test for critical national infrastructure and should be recognised as such, preferably before the next penalty shoot-out.

Principal finding. The British public is a highly reliable synchronous load. It is merely selective about the cause.

Secondary finding. For forty years the electricity system has been engineered on the assumption that several million people will want tea at the same moment. The assumption has never failed. The College can think of no other assumption about the public of which this is true, and suggests that policy-makers in unrelated fields might usefully begin from it.

REFERENCES

- [1] National Grid ESO / NESO, 'Demand forecasting and TV pick-up', system operator explanatory material on the effect of television audiences on electricity demand, including the 1990 record and the role of kettles.
- [2] Drax Group, '7 of the biggest TV moments in UK electricity history', published list of the largest television pick-ups including the 1990 semi-final (2,800 MW), The Thorn Birds (1984) and the 1981 royal wedding.
- [3] NESO, 'Frequency Response Obligations: statutory, code and licence requirements', setting out the statutory limits of 49.5 to 50.5 Hz and the operational range of 49.8 to 50.2 Hz.
- [4] NESO, 'Security and Quality of Supply Standard: Frequency Risk and Control Policy'.
- [5] Engie / First Hydro, 'Dinorwig Power Station', operator description: 1,728 MW, full output in around sixteen seconds, commissioned 1984.
- [6] Institution of Civil Engineers, 'Dinorwig Power Station: harnessing hydroelectric power', project description including the Elidir Fawr caverns and pumped-storage operation.
- [7] Network magazine, 'National Grid experience 600 MW pick-up during England's World Cup opener', June 2018.
- [8] BS 1363, '13 A plugs, socket-outlets, adaptors and connection units', British Standards Institution.
- [9] Utilitywise, 'World Cup impact on TV pick-up and the National Grid', 2018, quoting the 933,000-kettle equivalent.
- [10] NESO, system demand data and Future Energy Scenarios, for recent winter peak transmission demand of roughly 45 GW.

Sources were consulted in September 2026. King Ethelred's College is fictional; the sources are not. Where a figure is prefixed 'c.' it is the commonly published value and the College has not attempted to improve upon it.

APPENDIX A - SAMPLE CALCULATIONS

A.1 Kettle-equivalent of the 1990 pick-up

$N_k = \Delta P / P = 2,800,000,000 \text{ W} / 3,000 \text{ W} = 933,333$ kettles. The operator's rounded figure of 933,000 is adopted throughout. The College notes that the calculation assumes every kettle was a 3 kW kettle and every switch-on was a kettle, neither of which is true, and that the answer is nonetheless the one everybody uses.

A.2 Energy and time to boil one mug

For 0.3 kg of water from 15 °C to 100 °C: $E = 0.3 \times 4,186 \times 85 = 106,743 \text{ J}$. At 3,000 W and 90 per cent effective delivery, $t_b = 106,743 / 2,700 = 39.5 \text{ s}$. For a kettle filled to 1.7 L the same calculation gives 224 s, of which 184 s constitute the Overfill Penalty.

A.3 Aggregate connected kettle load

Taking 25 million kettles at 3 kW: $25,000,000 \times 3,000 \text{ W} = 75 \text{ GW}$. This is presented for scale only. The College does not recommend that it be tested.

APPENDIX B - OPERATOR CARD

Observed condition	Action
Fourth official raises the board	Fill kettle to required level; stand by
Referee looking at watch	Hand on switch; do not yet commit
Whistle	Switch on; do not discuss the first half until the click
Kettle filled to MAX for one mug	Accept the Overfill Penalty; resolve to do better
Water already boiled once	Do not re-boil during play; the operator was not warned
Six kettles on one ring main	Delay the seventh; explain spacecraft to someone
Kettle cannot be found	Ask Gerald; if Gerald cannot be found, this is normal
Penalty shoot-out	Telephone Wales

Approved by the College Domestic Plant Committee, subject to the usual disclaimer that the referee remains the responsibility of the football authorities.

APPENDIX C - FUTURE WORK

A full experimental campaign should instrument a representative sample of households through a major tournament, recording kettle switch-on to the second against the broadcast timeline. The College recognises that the ethics application would need to explain why it wished to know exactly when people make tea, and that the honest answer is unlikely to help.

The relationship between streaming delay and pick-up dispersion deserves proper measurement, as does the effect of second-screen behaviour on whether the viewer stands up at all. The re-boil remains entirely unstudied and the Department suspects it is larger than anyone thinks.

Finally, anticipatory boiling should be examined as a trainable skill. Mrs Partridge has declined to run a course.

APPENDIX D - DEPARTMENTAL NOTE

The Department of Improbable Systems, Load Forecasting and Domestic Thermodynamics traces its lineage to the College's Crown Works responsibilities for stores, water and the provisioning of garrisons, in which the reliable supply of hot water to large numbers of people at short notice was a matter of practical defence. Modern television pick-up is therefore regarded as a direct continuation of the founding mandate, with the garrison replaced by the audience and the enemy by the schedule.

The College records that the present work required no defence expenditure, no overseas deployment, one clamp meter and seven kettles, of which six were returned. By departmental standards this represents a satisfactory programme, and the Bursar has been assured that the seventh is a matter for Gerald.

Persevera Etelred