The Radio Teleswitch: An historical perspective on the roll-out of domestic load control

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Abstract
In the mid-1990s, much like today, there was strong research interest in demand management in the built environment and its potential for mitigating electricity grid challenges. Tariffs, technologies and infrastructure required to enable it had been developed and were generally available. So what went wrong?

Since 1984 in Great Britain, the 'radio teleswitch' system had allowed for remote switching of meters and of loads such as electric heating in people's homes. Electrical engineers anticipated that this would usher in an era of improved load management and promote more even demand. But by 1996 the system was described as being 'significantly under utilised' [1] and, while hopes remained high, only a small percentage of British homes today have dynamically switched meters, heating or hot water [2].

This paper, based on historical desk research, outlines the development of the radio teleswitch system and compares it to discussions around smart grids and automation that are live today. It considers how dynamically switched systems were promoted and introduced to homes, how the landscape has now changed, and whether these changes might be enough to allow the systems being discussed now a greater chance of success. In this way it attempts to introduce a novel perspective to understanding both the deployment of load control technology in buildings and the limits on making efficient use of electricity infrastructure. It also hopes to inform current research and development by highlighting the rich track record of work in this area.

Introduction
Ever since the development of the first electricity networks, a key industry ambition has been to optimize (usually by maximizing) the use of assets such as generation and network infrastructure. In large part this has involved creating demand for electrical appliances, especially ones which operate in off-peak periods and therefore help improve the load factor of the system. [3] provides an insightful overview of the various efforts made to both build electricity demand in general and to promote shifting of demand to off-peak times, including government restrictions on use between specified times [4] and campaigns to exhort people to off-peak usage. Another key tool is the time-varying tariff, where different rates are charged for consuming electricity at different times with the aim of influencing people's usage patterns.

The ultimate ambition for generators and system operators, however, has been to exercise more direct forms control over the actual appliances whose use constitutes the load itself. While campaigns and tariff designs can be effective, they are indirect forms of influence that are mediated through householders' behaviour. This can be difficult to predict, and is almost impossible to influence reliably over the very short (i.e. seconds to minutes) intervals sometimes required by power systems. Introducing elements of automation can help, but can also exacerbate problems, such as the when timers are used to turn on appliances at the beginning of off-peak periods, creating rapid ramps in demand.

This paper is about the form of direct control that has been most widely used in Great Britain – the radio teleswitch (RTS). Introduced in the 1980s, it offered the exciting potential to reliably balance demand and supply of electricity, while working hand in hand with appliances that provided silent, smokeless comfort to consumers. In the paper I explore how the system works and track its development from the early days of optimism and growth to today, where it is largely the preserve of people disengaged with the energy market. I look at how the system was promoted and attempt to understand the reasons behind its ultimate stagnation. Finally I draw parallels with contemporary direct load control projects and consider which challenges still remain, and which may have been overcome.

System function and development

The radio teleswitch system in the UK is overseen by the Energy Networks Association, which provides basic information about its operation[1]. The system works by encoding data signals into radio broadcasts which in turn are decoded by teleswitch devices on consumer premises.

1. Distribution network operators (DNOs) have specific codes for teleswitches operating on their networks. The DNOs provide instructions to the Central Teleswitch Control Unit, which processes the instructions with the codes and passes them on to the British Broadcasting Corporation (BBC).
2. The data is sent out in the BBC Radio 4 long wave transmission (better known for its 'Test Match Special' full coverage of five-day-long cricket matches) produced at three different transmitters to cover the whole of the UK. The data streaming rate is 25 bits per second[2] (compared to the average broadband Internet speed in the UK of just under 23 million bits per second), and message are sent every two minutes.
3. The signals is received by the teleswitch (i.e. the devices installed on consumer premises).

Teleswitches have two main functions. One is to allow electricity meters to be switched between tariff rates – a function that is otherwise performed using a simple time switch. The other function is to allow the switching of electrical loads such as heaters. The teleswitch stores tariff or operating instructions until such time as a new message is received via the radio signal (with the appropriate code). In this way the radio teleswitch system can be used either to programme normal operation, or to provoke an immediate response (such as if load shedding is required). This paper focuses principally on the load control (rather than meter switching) functionality of the RTS.

Before the introduction of the RTS in the UK, tariff and load switching was accomplished by means of simple timer switches. These, however, had the problem of needing to be reset after power outages and lacking the ability to accommodate bi-annual transitions between Greenwich Mean Time (GMT) and British Summer Time (equivalent to GMT plus one hour) [1]. They also lacked the ability to respond in a dynamic way to demands on the grid or to easily accept new tariff structures. These reasons were key drivers of the development of the RTS.

The RTS was not the only contender to achieve such functionality, however, and it was by no means the first. As early as 1897, patents were taken out for systems which augmented the mains alternating or direct current with a signal to allow varying tariffs, or to remotely switch loads such as streetlamps [5]. Such 'ripple control' systems were identified by [5] as operating in many European countries as well as Australia, New Zealand and the African continent, with the combined capacity of systems subject to this control estimated at over 120 Gigawatts. The system is still widely used in New Zealand. Telephone line based systems had also been explored [6]. According to [6], a key benefit of the RTS system compared to others was its ability to be applied on a totally random basis over a large area without having to install a large number of new local transmitters (requiring an extended installation period).

Large scale trials of the RTS system began at the start of the 1980s, which 'proved the reliability of the system and excellent nationwide coverage' [7], p38. The system became fully operational in 1984[3], when local electricity boards began to place orders for teleswitches. The electricity boards were in charge of both networks and supply of electricity, meaning they were responsible for both local load management and customer billing (roles which are separated in the UK today). Teleswitches appealed to them because they allowed more reliable switching of meters, the ability to alter tariff times without having to physically visit the meter, and the possibility of offering interruptible tariffs [6].

Such innovative tariffs included *Budget Warmth*, where customers could pay a weekly fixed charge in return for having a storage heater in one room which is set to always provide a comfortable level of warmth and which is charged by the Central Electricity Generating Board (CEGB) depending on weather conditions and demand on the grid [8]. At the same time that such tariffs were being developed, the RTS system was awarded the Queen's Award for Technological Achievement [8], and 'prospects for innovative tariff and load control developments [were] a major source of favourable comment' [6], p276.

[1] http://www.radioteleswitch.org.uk/
[2] http://alancordwell.co.uk/Legacy/radio/teleswitch1.html
[3] http://www.radioteleswitch.org.uk/history.html

Innovation continued in the years to follow, including systems which do not sound out of place even today. The CELECT heating system, for example, allowed customers to set desired temperatures for individual rooms in their house by day and time. The RTS was then used to convey outdoor temperature predictions and cost data to the system, allowing it to optimize charging and release of heat to match the temperature settings [9]. By this time the electricity industry in the UK had been privatized, with all electricity being bought and sold through the 'Pool', which was seeing substantial price fluctuation within and between days, with evidence that this was linked to domestic load [10]. Indeed, [10] (p5.27.1) state that 'The logical conclusion … is the adoption of real-time tariffs for domestic consumers that change in response to the actual cost of supplying electricity'. The RTS seemed ideally placed to help respond to this challenge.

Potential unfulfilled

By the mid-1990s, however, optimism was waning. [1] described it as having be 'significantly under utilised ever since … the widespread introduction of the system' (p20). They argue that initial technical limitations on the number of Group Codes which were available (limiting the number of tariffs) could not be blamed, since even after these were expanded there was little development. Instead, looking forward to the imminent introduction of competition in the electricity supply market (in 1998), they highlight the difficulties in financial reconciliation – what is now known as settlement – between suppliers and the Pool as the most significant challenge. Specifically, the lack of half-hourly metering or statistical demand profiles adjusted for each supplier adjusted by dynamic switching patterns meant that there was no realistic prospect of suppliers being sufficiently rewarded for influencing load. This lack of incentive to influence for suppliers to influence load profile was also recognized by [11], who state (p290):

> *Since, with Profiling, a supplier's payments to the Pool in respect of a consumer will be independent of the actual load shape of that consumer, there will be no incentive for suppliers to pick out consumers with favourable actual load patterns. But other characteristics of consumers, such as payment method, total size of consumption and payment record will be of interest to suppliers.*

The same problem was also blamed for the lack of development of the CELECT heating system described above, as well as the additional challenge of the differing aims of suppliers and network operators in managing demand. Even though a trial in 100 homes had demonstrated a 25% reduction in peak demand reduction on the local network, and average reductions of 8% per customer in overall electricity use while, it is claimed, improving comfort, it did not progress beyond the trial stage [12].

Even if half-hourly settlement had been desired, it was difficult to see how it could be achieved given the technology available at the time. As [1] suggest, offering half-hourly settlement for small consumers would likely not be feasible since 'A system that relies on recovering millions of data items … would seem doomed from the outset' (p23). Instead, they suggest that much of the job of bill calculation should be devolved to the meter itself, which would store half-hourly data on usage tagged by time and tariff band, which would allow infrequent readings to provide for retrospective settlement. At the time, they asked: 'Is such a system realistically achievable or just another pipe dream?' (p23). While they recognize the potential benefits of systems with bi-directional communication, they see the established RTS system as at least complementary and still worthy of development.

By 2005 an estimated 4.5m customers had multi-rate tariffs [13], while by some counts around 1.5m had electric heating [14]. However, less than half a million meters were thought to be under contracts that permitted direct control via the RTS, and that some did not have 'double' meters which split out control of heating from other loads, meaning that remote control was likely to be unacceptable. Without the costly exercise of visiting homes to check, it was hard for suppliers to actually know what the specific contractual or metering arrangements in each home were. Compounding this, the cost for new suppliers of obtaining a new RTS Group Code and setting it up on relevant meters was high, and the inability to tie customers in to long-term contracts meant that the risk of committing to this cost was unlikely to be justified [13]. There was also the potential for conflict as certain codes were always reserved to distribution network operators to manage network constraints [13]. The combination of these factors is likely to have led to the continued lacklustre development of the RTS system.

An article in *Utility Week* in 2008 reflected on the RTS at 25 years old [15]. The experts interviewed in the piece, Geoffrey Hensman and Drew McGregor, raise a number of number of changes in the structure of the electricity industry related to the lack of take-up, including lack of vertical integration (leading to lack of shifting incentives alluded to above), and the move away from geographically defined supply regions (again, related to the split DNO/supplier incentive problem). However, they also re-emphasize some of the early promise of the scheme, such as its ability to make viable 'service' models of supply such as Budget Warmth – where heat or comfort are the product rather than energy. At that time, still preceding established plans for smart meter roll-outs, there was still some optimism for an enduring role for the RTS.

By the current decade, most thoughts had turned to how best to phase out the RTS. This was mainly driven by the anticipated transition to smart meters, which would perform the same function and more. There were also questions over the future of the Radio 4 LW transmission – as the technology required to broadcast it was no longer produced [2], leading to a shortage of spare parts[4].

Looking back over the life of the RTS, therefore, we see an initial period in the 70s and early 80s characterized by lots of research interest, leading to the introduction of the system amid high expectations. The technology was available to facilitate widespread direct load control, as was the technology which could create load worth controlling (in the form of electric heating systems). There were certainly some incentives in place to industry actors to undertake load control and flatten the load profile. However, while the system has functioned well since then, it did not have the transformative effect on the demand side that some in industry may have envisaged. Analysis at the time suggests this was mainly due to a combination of lack of incentive to shape load of individual customers and misalignment of aims between goals between different actors in the system. The next section considers the hopes alive now for the potential of smart appliances, including heating systems, to accomplish this transformation in the coming decades, and the extent to which these (and other) challenges faced by the RTS live on or have changed.

A new hope?

Prominent smart grid scenarios today envisage an electrified world with homes full of connected devices, heated electrically, and with electric vehicles in the driveway – all coordinated in harmony for the good of households and the overall network. Firstly, it is useful to consider what has changed since the time of the RTS which might bode well for the realization of this vision. Around the world, the introduction of smart meters provides a route by which price and direct load signals can be sent to smart appliances (although this is also possible simply over the Internet). Smart meters (depending on how advanced they are, which varies from country to country) or Internet-based systems afford substantial improvements over the RTS in providing features such as bidirectional communication and the ability to deal with 'millions of data items' [1]. As established above, the ability to transmit effective load control signals was not actually one of the major problems with the RTS – indeed, arguably it was a simpler system that, once it was turned on, was reliably accessible to pretty much everyone in the country using basic technology. The more advanced systems available today should permit a finer level of control, but this does not appear to have been a major barrier to the success of the RTS (although there may be indirect effects – see later paragraph).

One clear change in GB since the time of the RTS is the introduction of elective half-hourly settlement of small users. Up until recently, if suppliers wanted to settle customers on anything other than a standard profile they still had to use an agreed alternative profile – effectively introducing a new average profile for any new demand response tariff, and assuming that customers on the tariff followed that profile. With half-hourly settlement it is now possible to settle customers of the basis of when they actually use electricity. This provides a genuine incentive to suppliers to shift their customers' demand to times when the wholesale cost of electricity is cheaper, as they know that they will actually benefit from any such shift. This was highlighted above as a barrier to the success of the RTS, so does seem to be a significant positive shift for the prospect of doing domestic load control. Furthermore, it seems likely that half-hourly settlement will become mandatory, making it even more important for suppliers to consider when their customers are using power.

Another set of developments has occurred on the demand side. Falls in the price and size of computer components have led to the ability to incorporate advanced sensing, processing and connectivity into many more devices. This is the basis of the Internet of Things. As suggested above, combined with more advance communication networks, this affords the possibility of finer control of appliances, whether autonomously, by users, or remotely for the purposes of load control. In theory this permits subtler forms of load control, such as frequency response by fridges which is unnoticeable to the

[4] As of today the signal is still being broadcast, and the most likely threat to its future now looks to be the shift from analogue to digital broadcasting.

customer, or within-home balancing of different appliances within boundaries set by the user. However, one basic aspect of the situation has not changed a great deal in recent decades – that is that heating is still the dominant requirement for energy consumption in British homes. No matter what can be done with other new smart appliances (setting aside electric vehicles – see later), control of electric heating systems will be the key concern. And as described above, even in the mid-90s there had been successful test of 'smart' heating systems that offer many of the functions being touted today such as the capacity to learn the properties of the building, respond to weather and provide a comfortable level of warmth even while responding to load control signals.

Lingering challenges

Since the dwindling of the RTS, therefore, we have seen significant (although not necessarily transformative) progress in the 'smartness' of control and demand technologies, as well as increased incentives to suppliers to influence customer consumption (though half-hourly settlement). Where has there been less progress? Firstly, the electricity industry in GB is still characterized by vertical disintegration. As highlighted above, this means that, while half-hourly settlement may provide an incentive for suppliers (i.e. energy retailers) to shift demand, there is no reason to believe that such shift would align with the interests of transmission and distribution network operators or some generators. Clearly the different actors in the network will have different requirements whether or not they are part of the same organization, but the current situation means that there is no coordination where interests align, or discussion and compromise where they do not. Even if (as is the aim of the regulator, Ofgem), distribution network operators begin to take on the role of distribution system operators, this does not address the interest misalignment between sectors.

Perhaps the greatest uncertainty lies in the potential uptake by customers of the technologies most needed to make domestic load control feasible and worthwhile – electric heating systems and vehicles (EVs). For EVs at least, the future seems positive. In the latest National Grid Future Energy Scenarios report [16], even the 'slow progression' scenario as EVs accounting for more than 50 per cent of vehicles by 2050. EV sales in the UK are seeing exponential growth[5]. The picture for heating is less positive. Since middle of the last century, electric heating systems have been losing out to gas. Legal decarbonisation targets in the UK are driving the push towards electric heating using heat pumps (alongside district heating, and potentially other sources such as hydrogen). However, uptake has been low, and does not seem likely to hit even the minimum level the Committee on Climate Change has determined to be necessary to meet the UK's carbon reduction targets (2.5m homes by 2030) [6]. In this respect we are in a similar position to the early days of the RTS – that is, all the technology exists, and just the demand (in the form of electric heating systems) needs to be created. Arguably, however, we are now is a worse position to achieve this.

In the 1980s, the energy organizations with whom customers had a direct relationship (the electricity boards) were also in the business of selling electrical appliances, including heating systems. They had showrooms, used television advertising, and installed and maintained systems in people's homes. In a way this represented a further layer of vertical integration, taking in the actual demand technologies in homes as well as supply and transmission/distribution infrastructure. In this way, the electricity boards could both promote the use of electric heating in general, while also promoting systems which facilitated demand management – such as those open to RTS control. For example, electricity boards were reported to have purchased 170,000 teleswitches in 1986/7 to install in homes as a replacement for timeswitches [17]. They were therefore in an influential position to encourage adoption of demand responsive technologies.

Today, this level of integration with technology retail is comparatively very small as technology retail operations were sold off following privatization. While operations such as British Gas Connected Homes are active in the technologies such as smart thermostats, there are no major marketing drives for these to apply to electric heating in particular – they are rather about gaining traction in the connected home market in general. There is also little in the way of a marketplace where domestic demand response beneficiaries (such as DNOs) and providers (aggregators such as appliance manufacturers) can work together to achieve mutually beneficial impacts. Were such a marketplace to exist it could potentially foster the best of both worlds, where network actors could express clearly their demand response

[5] http://www.nextgreencar.com/electric-cars/statistics/

[6] https://www.theccc.org.uk/wp-content/uploads/2013/12/Frontier-Economics-Element-Energy-Pathways-to-high-penetration-of-heat-pumps.pdf

needs, with competition in the market for how best to meet them. More consideration is given to this market in the final section.

Focus on the user

A final important question for both the RTS and future smart heating systems is that of public demand and acceptability. While a number of the documents located as part of this work do touch on consumer perceptions, it tends to be blandly positive but with little detail. For example:

- 'There has been virtually no customer reaction to the use of radio teleswitches … where the Budget Warmth scheme is in operation, both customers and boards are pleased' [6]: 276.
- On the CELECT heating system: 'Initial feedback from these trials has been very good, with users experiencing enhanced levels of comfort and controllability' [9]: 6
- 'A survey of customers in Aberystwyth showed they viewed electricity more positively after moving to Menter [an RTS-based tariff]' [18] [Manweb's staff newspaper]

Set against this are reports of consumers being dissatisfied with electric and night storage heating technologies in general. For example, research previously conducted by me [19] (pp90-91) included some participants on a Cyclocontrol scheme, a now discontinued method of remotely controlling the floor heating in blocks of flats based on weather forecasts (conveyed through signals encoded in the network frequency, rather than the RTS). It found substantial dissatisfaction with the lack of control available to residents, with no option to affect the temperature other than opening the windows (p95). [20] reports the results of (now unavailable online) research by Consumer Focus showing 68% of people with storage heaters are happy with the system, compared to 91% of those with gas heating. [20] goes on to say that while 'storage heating is not wildly unpopular … it does have the reputation of being difficult to control' (p3).

As well as experience of the heating system, there is also the question of the extent to which people were aware, or had positive/negative views on, the external influence over RTS-controlled heating systems. A report for Ofgem on customers with dynamically switched meters found that, 'For the majority of customers, the idea of dynamically switching meters (and therefore the associated heating system) to control their electricity was … completely foreign' [21]: 11. Instances of people mentioning external control were described as 'relatively rare' (p13). The work found that most people had inherited their heating systems and learned to use them by trial and error, without having any 'official' guidance. If customers do want to discover details of the kind of external control they may be subject to, they have to dig into dense terms and conditions documents. For example, Scottish Power's T&Cs document 'Fixed Price Energy June 2016'[7] runs to 24 pages, and uses the following language (p11): 'The Controlled Circuit is energised for periods having an aggregate daily duration between 0 and 14 hours chosen by ScottishPower on the basis of forecast weather conditions', or 'The Controlled Circuit is energised for two or more periods with an aggregate daily duration of 8.5 hours'.

New smart control systems have been developed for both legacy storage heating systems [22] and heat pumps (e.g. [19], chapter 6) which place great emphasis on consumer controllability while also permitting external control for the purposes of demand response. Research such as [23] suggests that a substantial proportion of energy bill-payers are happy to accept some level of external control of heating. The indications from past experience and ongoing research is that external control of appliances is in principle acceptable to many people, and that it is the execution (such as the extent to which control impacts on comfort or performance) that will be critical.

Conclusions and future prospects for flexibility

In this article I have traced the rise and fall of the radio teleswitch system for directly controlling domestic heating in Great Britain. The system was born to an integrated, state-organized energy system with incentives to maximize overall electricity use while minimizing peaks. It soon found itself operating in a situation of misaligned incentives between privatised operators with domestic consumers who were deserting electric heating. I argue that despite great advances in technological capabilities, the structural issues which led to the aborted growth and slow demise of the radio teleswitch still largely exist today. Unless something changes, this has implications for the potential role of demand flexibility in the energy system.

[7] https://www.scottishpower.co.uk/pdf/o201606_FixedPriceEnergy.pdf

There is one final significant trend not yet discussed that could be the salvation of flexibility in the future: decentralization. Distributed generation capacity in many countries has been growing rapidly for years, which together with falling battery costs for electric vehicles, home storage and grid-level storage promises to both increase the need for demand flexibility and make it easier to accomplish. However, the most important development may well be in the decentralization of markets for power. As [24] describes, the combination of distributed generation and storage with blockchain technology may herald a situation where transaction costs are low enough that individual households can deal directly with each other (peer-to-peer trading), form microgrids, or have direct relationships with a range of actors in the existing power industry [25]. Each actor can then offer a cost-reflective price directly to customers on an open market, helping to address the problem of misaligned incentives. More of the appliances people buy[8] have the innate ability to communicate with each other, and while energy trading is likely low in the list of priorities behind such purchases, this ability does permit market participation if the incentive (and cost, in effort and other ways) is right. It remains to be seen if these developments – which currently match the optimism seen in the early days of the radio teleswitch – can ultimately exceed it in delivery.

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